



OELs 6

Study on collecting the most recent information on substances to analyse health, socio-economic and environmental impacts in connection with possible amendments of Directive 2004/37/EC on the protection of workers from the risks related to exposure to carcinogens, mutagens or reprotoxic substances at work

Final report V3

Poly aromatic hydrocarbons (PAH)

November 2024



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LIST OF ABBREVIATIONS AND ACRONYMS

ACSH	Advisory Committee of Safety and Health at Work
AhR	Aryl hydrocarbon receptor
AGS	Ausschuss für Gefahrstoffe
AM	Arithmetic mean
APF	Assigned Protection Factor
BAT	Best Available Technique
BaP	Benzo[a]pyrene
BF	Blast Furnace
BGV	Biological guidance value
BLV	Biological Limit Value
BOF	basic oxygen furnaces
BOEL	Binding OEL
BPC	Biocidal Product Committee
BPR	Biocidal Product Regulation
BR	Better Regulation
BREF	Best available techniques reference document
BTX	Benzene, toluene and xylene
BW	Body weight
C&L	Classification & Labelling (inventory)
CAEF	European Foundry Association
CAN	Climate Action Network
CAREX	Carcinogen Exposure (inventory)
CAS	Chemicals Abstracts Service
CBA	Cost Benefit Analysis
CDB	Current disease burden
CEA	Cost Effectiveness Analysis
CEN	European Committee of Standardization
CLP	Classification, Labelling and Packaging of substances Regulation
CMRD	Carcinogens, Mutagens and Reproductive substances Directive
CSR	Chemical Safety Report
CSR	Chemical Safety Report
CRM	Critical Raw Material
CTPhT	Coal Tar Pitch high temperature
DA	DNA adducts
DALY	Disability Adjusted Life Years
DECOS	Dutch Expert Committee on Occupational Standards
DEEE	Diesel Engine Exhaust fumes
DEFRA	Department for Environment, Food & Rural Affairs
DG	Directorate General
DRR	Dose Response Relationship
EAF	Electric Arc Furnaces
EC	Elemental Carbon
ECHA	European Chemicals Agency
EEA	European Economic Area
EMEP	European Monitoring and Evaluation Programme
E-PRTR	European Pollutant Releases and Transfer Register
ERR	Exposure Risk Relationship
ES	Exposure Scenario
ETS	European Trading Scheme
EV	Electric Vehicles
FoBiG	Forschungs und Beratungsinstitut Gefahrstoffe

FDB	Future disease burden
GBD	Global Burden of Disease
GESTIS	Internationale Grenzwerte für chemische Substanzenm (International limits for chemical substances)
GHG	Green House Gas
GM	Geometric mean
GOS	Gross Operating Surplus
HDS	High Demand Scenario
HFO	Heavy Fuel Oil
HMA	Hot Mix Asphalt
IA	Impact Assessment
IARC	International Agency for Research of Cancer
ICE	Internal combustion engines
ISO	The International Organization for Standardization
LDS	High Demand Scenario
LEV	Local Exhaust Ventilation
LH	Luteinizing Hormone
LOAEL	Lowest observed adverse effect level
LOD	Limit of Detection
LOQ	Limit of quantification
MCA	Multi-criteria analysis
N/A	Not available or Not applicable
NACE	"Nomenclature statistique des activités économiques dans la Communauté européenne" or the Statistical Classification of Economic Activities in the European Community
NOEL	No observed effect level
OEL	Occupational Exposure Limit
3-OHBP	3-Hydroxybenzoapyrene
1-OHP	1-Hydroxypyrene
OSH	Occupational Safety and Health
PAH	Polycyclic Aromatic Hydrocarbons
PBT	Persistent, Bioaccumulative and Toxic
PER	Preliminary Exposure Reduction
PM	Particulate Matter
PNEC	Predicted No Effect Concentrations
POP	Persistent Organic Pollutant
PPE	Personal Protection Equipment
PROC	The process categories
PV	Photovoltaic (solar panel)
QALY	Quality-Adjusted Life Year
R&D	Research & Development
RAC	Committee for Risk Assessment
REACH	Registration, Evaluation, Authorisation and Restriction of Chemi- cals
RMM	Risk Management Measure
RPA	Risk & Policy Analysts
RPE	Respiratory Protective Equipment
SCBA	Self Contained Breathing Apparatus
SCOEL	Scientific Committee on Occupational Exposure Limits
SEAC	Committee for Socio-Economic Analysis
SIREP	Italian carcinogen exposure database
SME	Small and Medium-sized Enterprise
STEL	Short term exposure limit
SRM	Strategic raw materials
SRMO	Severely Refined Mineral Oils

SU	Sectors of use
SWD	Staff Working Document
TWA	Time Weighted Average
UDS	Unscheduled DNA synthesis
URR	Unit relative risk
UVCB	Coal-derived products that are of unknown or variable composition, complex reaction products or of biological materials
VCM	Value for cancer morbidity
VSL	Value of statistical life
YLD	Years Lived with Disease/Disability
WCS	Worker Contributing Scenario
WMA	Warm Mix Asphalt
WPC	Working Party on Chemicals
WTP	Willingness to pay

ABSTRACT EN-FR-DE

EN: This study supports the European Commission's Impact Assessment of a potential Occupational Exposure Limit (OEL) value for polycyclic aromatic hydrocarbons (PAH) under the scope of Carcinogens, Mutagens and Reprotoxic substances Directive (CMRD, Directive 2004/37/EC). This report estimates costs and benefits for a range of potential OELs for PAH. The monetised impacts relate primarily to the compliance costs of achieving the OEL and the avoided costs of ill health for conditions including lung cancer and two non-cancer endpoints (developmental toxicity (spontaneous abortion) and male infertility (sperm motility)). Exposure to PAH occurs during the use of PAH containing products and as a byproduct of the heating/combustion of materials. The study team estimate approximately 440,000 workers may experience airborne exposure in the workplace across the EU, and approximately 4,000,000 when factoring in dermal exposure. Four reference OEL policy options are assessed against the baseline: 7, 70, 700, 2000 ng/m³. The cost benefit ratios for all policy options indicate higher costs than benefits, with no benefits estimated at the highest policy options as current exposure levels are not high enough to result in a case of ill health. All other policy options result in health benefits.

FR: Cette étude soutient l'analyse d'impact de la Commission européenne concernant une éventuelle valeur limite d'exposition professionnelle (LEP) pour les hydrocarbures aromatiques polycycliques (HAP) dans le cadre de la directive sur les agents cancérigènes, mutagènes et toxiques pour la reproduction (CMRD, directive 2004/37/CE). Ce rapport estime les coûts et les avantages d'une série de LEP potentielles pour les HAP. Les impacts monétisés concernent principalement les coûts de mise en conformité pour atteindre la LEP et les coûts évités des problèmes de santé pour des pathologies telles que le cancer du poumon et deux paramètres non cancéreux (toxicité pour le développement (avortement spontané) et infertilité masculine (motilité des spermatozoïdes)). L'exposition aux HAP se produit lors de l'utilisation de produits contenant des HAP et en tant que sous-produit du chauffage/de la combustion de matériaux. L'équipe chargée de l'étude estime qu'environ 440 000 travailleurs peuvent être exposés par voie aérienne sur leur lieu de travail dans l'UE, et environ 4 000 000 si l'on tient compte de l'exposition par voie cutanée. Quatre options politiques de LEP de référence sont évaluées par rapport à la ligne de base : 7, 70, 700, 2000 ng/m³. Les ratios coûts-avantages de toutes les options politiques indiquent des coûts plus élevés que les avantages, aucun avantage n'étant estimé pour les options politiques les plus élevées car les niveaux d'exposition actuels ne sont pas suffisamment élevés pour entraîner un cas de mauvaise santé. Toutes les autres options politiques sont bénéfiques pour la santé.

DE: Diese Studie unterstützt die Folgenabschätzung der Europäischen Kommission für einen möglichen Arbeitsplatzgrenzwert für polyzyklische aromatische Kohlenwasserstoffe (PAK) im Rahmen der Richtlinie über krebserzeugende, erbgutverändernde und fortpflanzungsgefährdende Stoffe (CMRD, Richtlinie 2004/37/EG). In diesem Bericht werden Kosten und Nutzen für eine Reihe potenzieller Arbeitsplatzgrenzwerte für PAK geschätzt. Die monetarisierten Auswirkungen beziehen sich in erster Linie auf die Kosten für die Einhaltung des Arbeitsplatzgrenzwerts und die vermiedenen Kosten für Erkrankungen wie Lungenkrebs und zwei nicht krebsbedingte Endpunkte (Entwicklungstoxizität (Spontanabort) und männliche Unfruchtbarkeit (Spermienmotilität)). Die Exposition gegenüber PAK erfolgt bei der Verwendung von PAK-haltigen Produkten und als Nebenprodukt bei der Erhitzung/Verbrennung von Materialien. Das Studienteam schätzt, dass etwa 440.000 Arbeitnehmer in der EU am Arbeitsplatz einer Exposition über die Luft ausgesetzt sind, und etwa 4.000.000, wenn man die Exposition über die Haut berücksichtigt. Vier Optionen für Referenzgrenzwerte werden im Vergleich zur Ausgangslage bewertet: 7, 70, 700 und 2000 ng/m³. Die Kosten-Nutzen-Verhältnisse für alle Optionen zeigen, dass die Kosten höher sind als der Nutzen, wobei für die

höchste Option kein Nutzen veranschlagt wird, da die derzeitige Exposition nicht hoch genug ist, um einen Krankheitsfall zu verursachen. Alle anderen Optionen führen zu gesundheitlichen Vorteilen.

EXECUTIVE SUMMARY

The Carcinogens, Mutagens and Reprotoxic substances Directive (Directive 2004/37/EC), hereinafter the CMRD, protects workers from exposure to carcinogens, mutagens or reprotoxic substances at work. The aim of this study is to support the European Commission's Impact Assessment (IA) of a potential Occupational Exposure Limit (OEL) and Biological Limit Value (BLV) for Polycyclic Aromatic Hydrocarbons (PAH).

The Exposure Risk Relationship (ERR) uses benzo[a]pyrene (BaP) (inhalable fraction) as indicator substance to characterise exposure to the PAH mixture, it is a very potent (non-threshold) carcinogen and a large amount of exposure data is available for this substance. No single metabolite/ biomarker can adequately represent the variability of PAH exposure mixtures and the 2022 RAC opinion considers that BaP is the most appropriate available marker. The OEL policy options are based on BaP. However, RAC did not propose a limit value due to BaP being a non-threshold carcinogen. RAC further proposes to establish a BLV with 3-hydroxybenzo[a]pyrene (3-OHBaP, the metabolite of BaP) in urine as the marker substance, based on a correlation equation between air concentration and metabolite in urine.

The endpoints assessed are: lung cancer, reproductive toxicity to men (sperm motility), developmental toxicity in females (stillborn, and spontaneous abortion). Costs and benefit calculations do not consider skin cancer and bladder cancer. Skin cancer is a recognised ill health impact of exposure to PAH but it cannot be quantified as there is insufficient information to develop an ERR. There is also an indication of elevated risk of bladder cancer, but there was inconclusive evidence due to confounding factors such as the presence alongside PAH of other substances known or suspected to increase the risk of bladder cancer. Sensitivity analysis assessed the hypothetical avoided cases of bladder cancer (although the ERR is not robust), which reduced the overall cost-benefit ratios. Due to the lack of data about skin cancer, it is not possible to perform a sensitivity analysis.

Twenty-two sectors are analysed. The main factors considered in their selection were whether they have been mentioned in multiple sources and whether the exposure to PAH can be quantified. There were several further complex issues relating to the selection of sectors and these are explained in section 3.2.9. A key point is whether the available data indicates that the 95th percentile of the exposure concentrations is below the lowest assessed OEL as the assessment would indicate no impact, when using BaP as indicator for PAH mixtures.

The costs and benefits (relative to the baseline) estimated in this report for the different target OELs (ng/m³) and BLVs (nmol/mol creatinine urine concentration) are summarised in Table 0-1. The benefits are shown for both Method 1 and Method 2. The costs are for the present value (PV) over 40 years with a static discount rate of 3%. They assume a 5% turnover in staff.

There are significant differences between the costs and benefits for all policy options, with the most stringent (E.g., 7 ng/m³ & 0.2 nmol/mol creatinine) policy option having the least effective cost-benefit ratio (where costs are 330-960 times the benefits) and the least stringent (2000 ng/m³ & 3.8 nmol/mol creatinine) policy option having no ratio due to no benefits.

Table 0-1 Summary of monetised costs and benefits (static discount rate, additional to the baseline) (€ millions)

Policy option	7 ng/m ³ & 0.2 nmol/mol creatinine	70 ng/m ³ & 0.3 nmol/mol creatinine	Transitional period option	700 ng/m ³ & 1.5 nmol/mol creatinine	2000 ng/m ³ & 3.8 nmol/mol creatinine
Total benefits M1	€ 190	€ 100	€ 100	€ 16	€ 0
Total benefits M2	€ 64	€ 20	€ 20	€ 2	€ 0
Total costs (OEL)	€ 44,000	€ 3,100	€ 3,100	€ 230	€ 150
Cost benefit ratio M1 (OEL)	232	31	31	14	-
Cost benefit ratio M2 (OEL)	675	154	154	115	-
Total costs (OEL & BLV)	€ 55,000	€ 5,700	€ 5,700	€ 1,400	€ 780
Cost benefit ratio M1 (OEL & BLV)	293	56	56	87	-
Cost benefit ratio M2 (OEL & BLV)	850	284	284	701	-

Source: Study team.

Notes: Transitional period: 140 ng/m³ & 0.3 nmol/mol creatinine for six years and then 70 ng/m³ & 0.3 nmol/mol creatinine. Costs for transitioning sectors are not expected to increase or decrease as a result of changes to adjustments or complying with the OEL. However, the period in which costs are incurred will be delayed by 6 years and requires costs for transitional sectors to be reduced by 8% to more accurately reflect the present value. These reduced costs have been summed with totals for non-transitional sectors at 70ng/m³ to illustrate the impacts of the transitional period on the overall costs.

The multi-criteria analysis summarising both the monetised and qualitative impacts is shown in Table 0-2.

Table 0-2 Multi-criteria analysis (all impacts over 40 years and additional to the baseline) per OEL/BLV option (€ millions)

Impact	Stakeholders affected	7 ng/m ³ & 0.2 nmol/mol creatinine	70 ng/m ³ & 0.3 nmol/mol creatinine	Transitional period option **	700 ng/m ³ & 1.5 nmol/mol creatinine	2000 ng/m ³ & 3.8 nmol/mol creatinine
Direct costs – adjustment						
Risk management measures - first year	Companies	€ 1,700	€ 220	Cannot be monetised	€ 5	€ 0
Risk management measures – recurrent	Companies	€ 2,900	€ 200	Cannot be monetised	-€ 1	€ 0
Risk management measures - discontinuation	Companies	€ 32,000	€ 2,200	Cannot be monetised	€ 0	€ 0
Risk management measures total	Companies	€ 37,000	€ 2,700	€ 2,500	€ 3	€ 0

Impact	Stakeholders affected	7 ng/m ³ & 0.2 nmol/mol creatinine	70 ng/m ³ & 0.3 nmol/mol creatinine	Transitional period option **	700 ng/m ³ & 1.5 nmol/mol creatinine	2000 ng/m ³ & 3.8 nmol/mol creatinine
Risk management measures total per company	Companies	€ 0	€ 0	€ 0	€ 0	€ 0
Monitoring (sampling and analysis)	Companies	€ 550	€ 290	€ 290	€ 180	€ 120
Risk management measures - first year	Public sector	€ 540	€ 16	€ 16	€ 0	€ 0
Risk management measures – recurrent	Public sector	€ 5,300	€ 47	€ 47	€ 0	€ 0
Risk management measures - discontinuation	Public sector	€ 0	€ 0	€ 0	€ 0	€ 0
Risk management measures total	Public sector	€ 5,900	€ 63	€ 63	€ 0	€ 0
Risk management measures total per public authority	Public sector	€ 8	€ 0	€ 0	€ 0	€ 0
Monitoring (sampling and analysis)	Public sector	€ 1	€ 0	€ 0	€ 0	€ 0
Transposition costs	Public sector	€ 1	€ 1	€ 1	€ 1	€ 1
Direct costs - administrative						
Monitoring administrative burden	Companies	€ 120	€ 66	€ 65	€ 41	€ 27
Monitoring administrative burden	Public sector	€ 0	€ 0	€ 0	€ 0	€ 0
Direct costs – total compliance						
Adjustment, monitoring and administration burden costs	Companies	€ 38,000	€ 3,000	€ 2,900	€ 230	€ 150
Adjustment, monitoring and administration burden costs per company	Companies	€ 0	€ 0	€ 0	€ 0	€ 0
Adjustment, monitoring and administration burden costs	Public sector	€ 5,900	€ 63	€ 63	€ 0	€ 0
Adjustment, monitoring and administration burden costs per public authority	Public sector	€ 8	€ 0	€ 0	€ 0	€ 0
Total compliance costs	Companies Public authorities	€ 44,000	€ 3,100	€ 2,900	€ 230	€ 150
Direct costs - enforcement costs						

Impact	Stakeholders affected	7 ng/m ³ & 0.2 nmol/mol creatinine	70 ng/m ³ & 0.3 nmol/mol creatinine	Transitional period option **	700 ng/m ³ & 1.5 nmol/mol creatinine	2000 ng/m ³ & 3.8 nmol/mol creatinine
Enforcement costs except transposition	Public sector	Enforcement costs may arise as a result of ensuring compliance with new OELs however these costs are not estimated as they are specific to Member States individual inspection regime.				
Indirect costs - other						
Firms discontinuing at least a part of their business - No. of company closures	Companies	3,462	146	The number is likely to be lower than 146	-	-
Firms discontinuing at least a part of their business - %	Companies	0.79%*	0.03%*	The number is likely to be lower than 0.03%	-	-
Total compliance costs as % of turnover over 40 years (including discontinuations)	Companies	Up to 6.3% (C19.1 Coking plants – small & medium enterprises)	Up to 2.9% (C19.1 Coking plants – small & medium enterprises)	Cannot be estimated	Up to 0.01% (several sectors and company sizes)	Up to 0.01% (several sectors and company sizes)
First year compliance costs as % of annual turnover (excluding discontinuations)	Companies	Up to 19% (C16.1 wood preservation – small enterprises)	Up to 3% (C24.45 other non-ferrous metallurgy – small enterprises)	Cannot be estimated	0.7% (several sectors – small enterprises)	0.7% (D35.11 coal fired power plants – small enterprises)
Employment – Jobs lost	Workers & families	47,758	2,725	Cannot be estimated – may be a reduction jobs lost due to fewer discontinuations	-	-
Employment – Social cost	Workers & families	€ 4,000	€ 230	Cannot be estimated – may be a reduction jobs lost due to fewer discontinuations	€ 0	€ 0
International competitiveness	Companies	Significantly negative impacts	Negative impacts	Negative impacts	No significant impacts	No significant impacts
Consumers	Consumers	Costs for enterprises at 7 ng/m ³ and 70 ng/m ³ make up a significant			Costs at 700 ng/m ³ and 2000 ng/m ³ are less	

Impact	Stakeholders affected	7 ng/m³ & 0.2 nmol/mol creatinine	70 ng/m³ & 0.3 nmol/mol creatinine	Transitional period option **	700 ng/m³ & 1.5 nmol/mol creatinine	2000 ng/m³ & 3.8 nmol/mol creatinine
		proportion of turnover/GOS and the study team expects costs to be passed onto consumers through increased prices; including C20.13 carbon black manufacturers, C19.1 coking, C24.45 other metallurgy, C10.13 and C10.2 smokehouses, G45.2 automotive repair, N81.22 chimney sweeps, C16.1 wood preservation, E38.2 soil remediation, F42.11 road paving, and F42.12 welding of railroad tracks. The impact of the second lowest policy option is likely to be more limited than under the lowest policy option. The transitional period will delay the increase in consumer prices, or allow for a gradual increase over 6 years, although the impact will be the same as 70 ng/m³.			substantial and may not result in as significant price increases for consumers.	
Internal market Lowest to highest OEL	Companies	1 : 1	1 : 1	1 : 1	1 : 10	1 : 28.6
Specific MSs/regions - MSs that would have to change OELs	Public sector	27 Member States: AU, BE, BG, CY, CZ, DE, DK, EE, EL, ES, FI, FR, HR, HU, IE, IT, LT, LU, LV, MT, NL, PL, PT, RO, SE, SI, SK	26 Member States: AU, BE, BG, CY, CZ, DK, EE, EL, ES, FI, FR, HR, HU, IE, IT, LT, LU, LV, MT, NL, PL, PT, RO, SE, SI, SK	26 Member States: AU, BE, BG, CY, CZ, DK, EE, EL, ES, FI, FR, HR, HU, IE, IT, LT, LU, LV, MT, NL, PL, PT, RO, SE, SI, SK	23 Member States: AU, BE, CY, CZ, DK, EE, EL, ES, FI, FR, HR, HU, IE, IT, LT, LU, MT, PL, PT, RO, SE, SI, SK	15 Member States: BE, CY, CZ, DK, EL, ES, FI, FR, HR, IE, IT, LU, MT, PT, RO
Regulation	Companies	A REACH Restriction on PAH in articles may be proposed by ECHA in future. EU Emissions Trading System (EU ETS) is driving steel plants to move to hydrogen as a reducing agent and the carbon border adjustment mechanism should help prevent cheaper imports.				
Direct benefits – improved well-being - health						
Reduced cases of ill health (lung cancer)	Workers & families	141	35	35	2	0
Reduced cases of ill health (developmental toxicity)	Workers & families	38	38	38	7	0
Reduced cases of ill health (male infertility)	Workers & families	3,157	3,157	3,157	608	0
Ill health avoided, incl. intangible costs (M1 to M2)	Workers & families	€ 180 - 59	€ 97 - 16	€ 89 - 15	€ 15 - 1	€ 0

Impact	Stakeholders affected	7 ng/m³ & 0.2 nmol/mol creatinine	70 ng/m³ & 0.3 nmol/mol creatinine	Transitional period option **	700 ng/m³ & 1.5 nmol/mol creatinine	2000 ng/m³ & 3.8 nmol/mol creatinine
Direct benefits – improved well-being - safety						
Avoided costs	Companies	€ 1	€ 0	€ 0	€ 0	€ 0
Avoided costs	Public sector	€ 5	€ 34	€ 4	€ 1	€ 0
EU policy agenda	All	Improvements in workers fundamental rights and contribution towards Green Deal: Chemical Strategy towards a toxic-free environment				
Direct benefits – improved well-being - environmental						
Environmental releases	All	Increased reduction in PAH emissions at all levels except 2000 ng/m³ where no RMM adjustments are anticipated. In some sectors environmental emissions are expected to reduce as OELs become more stringent. This is due to RMMs resulting in greater containment/abatement of emissions (e.g. through increased use of closed systems or novel cleaner processes as they become available). It is unclear whether the use of alternatives would produce different levels of emissions and the extent to which this may occur, although as outlined in this report alternatives are not viable for most sectors. In the example of road paving where alternatives may be available, it is unknown whether emissions would be affected.				
European climate law	All	Discontinuations in three sectors steel and iron foundries (C24.1), manufacture of aluminium (C24.42), and other non-ferrous metallurgy (C24.45)) key for the green transition will be affected by the lowest two policy options. For C24.1, discontinuations are approximately 10 times higher, for C24.42 discontinuations are approximately five times higher, and for C24.45 discontinuations are approximately three times higher at 7 ng/m³ than at 70 ng/m³. Overall, the large extent of discontinuations at 7 ng/m³ may result in fewer products or materials essential for the green transition to be available in the EU, increase dependency on third country sources for supply. Transitional periods do not affect the production of relevant materials in these sectors.			No impacts	
Direct benefits – market efficiency						
Level playing field	Companies	A harmonised OEL at EU level would help to ensure a level playing field between companies operating in different EU Member States. As shown above ('Specific MSs/regions - MS that would have to change OELs'), at all policy option levels the introduction of an EU wide OEL would result in greater alignment of Member States.				
Indirect benefits						
Administrative simplification	Companies	Should all Member States have a harmonised OEL/BLV this would reduce the administrative burden for enterprises with operations across multiple Member States. However, the majority of				

Impact	Stakeholders affected	7 ng/m ³ & 0.2 nmol/mol creatinine	70 ng/m ³ & 0.3 nmol/mol creatinine	Transitional period option **	700 ng/m ³ & 1.5 nmol/mol creatinine	2000 ng/m ³ & 3.8 nmol/mol creatinine
		enterprises under review are small and are unlikely to have multi-national operations and be unaffected by this simplification. Sectors with the highest costs (in section 8) are typically medium and large enterprises which may benefit from such an administrative simplification.				
Synergy	Companies	Synergies in terms of exposure reduction for other chemical substances used in production sectors may occur. The specific substances will vary between the sectors. The level of synergy to be harnessed will also depend on the RMMs applied in each enterprise.				
Corporate Social Responsibility	Companies	Work with PAHs may be less perceived as a risky line of work associated with health issues. As a result of such an improvement in the public image, companies may find it easier to recruit and retain staff, reducing the cost of recruitment and increasing the productivity of workers.				
Avoided cost of setting an OEL	Public sector	€ 2	€ 2	No change	€ 2	€ 1
Other impacts						
Recycling – loss of business	Recycling companies	Metallurgical sectors may result in discontinuations at the lowest policy option levels, which in turn would result in less production of materials within the EU. However, the study team anticipate companies would continue to source materials from outside the EU to meet demand and subsequently materials available for recycling would be unaffected. However, metallurgical sectors also undertake secondary production (recycling) of metals which would also be subject to costs related to OELs/BLVs. At 7ng/m³ metallurgical sectors are expected to have significant discontinuations resulting in loss of EU capacity to recycle metals. At 70 ng/m³ the impacts to metallurgical sectors are less significant in terms of discontinuations, thereby assuming capacity to recycle metals is maintained. Recycling is not considered to be impacted in other areas.				
Impacts on fundamental rights	All	Positive impact on health and safety. Increased monitoring will help to ensure that future exposures remain controlled and worker risk remains low.				
Impacts on digitalisation	Companies	Digitalisation may be impacted by high costs to silicon metal and graphite manufacturers (used in semiconductor manufacturing, fuel cells, PV solar panels and EV batteries). Costs and discontinuations related to silicon (C24.45) are estimated to be significantly negative at 7 ng/m ³ , negative at 70ng/m ³ , and negligible at 700 ng/m ³ and 2,000 ng/m ³ suggesting impacts on digitalisation would mainly be experienced at the most stringent policy option level. Regarding graphite production (C23.99b) modelling estimates significantly negative costs at 7 ng/m ³ and negative costs at 70 ng/m ³ indicating cost impacts on digitalisation at these levels (no impacts at 700 ng/m ³ and 2,000 ng/m ³). Synthetic graphite production is reliant upon C19.1 coking which also experiences significant costs at the lowest two policy options. Collectively the difficulties of silicon and graphite production sector to meet costs at the two lowest policy options may result in negative impacts on digitalisation through increased material costs or greater reliance upon imports from third countries (primarily China).				
Contributions to the UN sustainable development goals	All	Goal 3 – positive Goal 7 – positive Goal 8 – positive				

Impact	Stakeholders affected	7 ng/m ³ & 0.2 nmol/mol creatinine	70 ng/m ³ & 0.3 nmol/mol creatinine	Transitional period option **	700 ng/m ³ & 1.5 nmol/mol creatinine	2000 ng/m ³ & 3.8 nmol/mol creatinine
		Goal 14 and 15 – positive				

Source: Study team.

Notes: May not sum to total due to rounding.

Totals have been presented as two scenarios, '(OEL)' including first year and recurring adjustment costs, air monitoring, and administrative burden.

* Please note the percentage of all companies discontinuing presented in these rows are significantly lower than the sectoral percentages presented in Table 8-13. This is due to D35.11 and G45.2 sectors with a significantly higher number of companies resulting in skewed total percentages.

** Transitional period: 140 ng/m³ & 0.3 nmol/mol creatinine for six years and then 70 ng/m³ & 0.3 nmol/mol creatinine. Costs for transitioning sectors are not expected to increase or decrease as a result of changes to adjustments or complying with the OEL. However, the period in which costs are incurred will be delayed by 6 years and requires costs for transitional sectors to be reduced by 8% to more accurately reflect the present value. These reduced costs have been summed with totals for non-transitional sectors at 70ng/m³ to illustrate the impacts of the transitional period on the overall costs.

Other issues to be considered in the decision-making process include:

Benzo[a]pyrene (BaP) as a marker. BaP is used as the sole indicator for exposure to a mixture. BaP is a very potent carcinogen and it is generally accepted that it is a good proxy for measuring exposure to total PAH. BaP is not always present and exposure to other carcinogenic PAH can occur. However, it is not possible to quantify their benefits due to a lack of ERR. However, protection from BaP in the PAH mixture is likely to result in protection from other PAH in the mixture. Of the sectors under the scope of this study, most have data that identify exposure to one or more carcinogenic PAH Cat. 1 that are under the scope of the CMRD (other than BaP) or are expected to, due to similarity in processes and/or products used (e.g., handling heated coal and petroleum derived products). Therefore, there is the possibility that occupational exposure to other carcinogenic PAH takes place and is not monitored. As noted by RAC *"In such settings it would be preferable to monitor exposure to a wider variety of PAH, e.g., the 16 EPA PAH, even if they were less carcinogenic than BaP. [...] Nevertheless, the exposure minimisation principle of CMRD should apply to any carcinogenic PAH."*

Other cancers and effects. The ERR is derived for lung cancer, and there is conclusive evidence that PAH cause skin cancer, but there are insufficient data to quantify effects. There is also indication of elevated risk of bladder cancer, but inconclusive evidence due to confounding factors. Sensitivity calculations done by RAC indicate that, the risk of bladder cancer could influence the ERR by up to a factor of 1.7. Other bodies have identified the possibility of other illnesses, but conclusions cannot be drawn. Finally, BaP is a non-threshold carcinogen, meaning that exposure to any amount of BaP has the potential to cause effects.

Future trends. The study team has identified future trends for a number of sectors, but it was not possible to model some sectors:

- Steel and iron foundries may be subject to trends similar to aluminium, since steel is needed for many infrastructures critical to achieve net zero emissions, e.g. wind turbines.

- The manufacture of synthetic graphite is also expected to increase since is used in Li-ion batteries (electric vehicles), fuel cells and other articles and processes needed to achieve net zero emissions. The demand trends available however do not take into account imports vs manufacture, natural vs synthetic and future potential for recycling.
- Coking coal sites are generally integrated with steel plants where coke is used as a reducing agent in basic oxygen furnaces (BOF) in the manufacture of primary steel. It is anticipated that these will largely shift to hydrogen as a reducing agent and to generate electricity. A major by-product of coking is coal tar, the raw material for coal tar pitch. The latter is currently needed in the manufacture of graphite and carbon electrodes, that are essential in almost all metallurgical processes and, as indicated above, graphite is needed in other processes and articles. Therefore, the future of coking is uncertain.

Dose response relationships (DRRs) based on animal studies and duration of effects.

The DRR data are based on experimental studies with animals rather than epidemiological studies. Although there is supportive information from human studies, quantifying effects in humans from animal experimental data. A further uncertainty regarding the effects on fertility (sperm motility in males) is that from the animal studies it cannot be concluded whether the effects on fertility are reversible or not. To avoid overestimating the effects in humans, for the modelling it was assumed that they are permanent.

Résumé Exécutif

La directive sur les agents cancérigènes, mutagènes et toxiques pour la reproduction (directive 2004/37/CE), ci-après dénommée CMRD, protège les travailleurs contre l'exposition à des agents cancérigènes, mutagènes ou toxiques pour la reproduction sur le lieu de travail. L'objectif de cette étude est de soutenir l'analyse d'impact (IA) de la Commission européenne concernant une éventuelle limite d'exposition professionnelle (LEP) et une valeur limite biologique pour les hydrocarbures aromatiques polycycliques (HAP).

La relation exposition-risque (RER) utilise le benzo[a]pyrène (BaP) (fraction inhalable) comme substance indicatrice pour caractériser l'exposition au mélange de HAP, car il s'agit d'un cancérigène très puissant (sans seuil) et de nombreuses données d'exposition sont disponibles pour cette substance. Aucun métabolite ou biomarqueur unique ne peut représenter de manière adéquate la variabilité des mélanges d'exposition aux HAP et l'avis du CER 2022 considère que le BaP est le marqueur disponible le plus approprié. Les options politiques en matière de VLEP sont basées sur le BaP. Cependant, le CER n'a pas proposé de valeur limite car le BaP est un cancérigène sans seuil. Le CER propose en outre d'établir une VLB avec le 3-hydroxybenzoapyrène (3-OHBaP, le métabolite du BaP) dans l'urine comme substance marqueur, sur la base d'une équation de corrélation entre la concentration dans l'air et le métabolite dans l'urine.

Les critères d'évaluation sont les suivants : cancer du poumon, toxicité pour la reproduction chez les hommes (motilité des spermatozoïdes), toxicité pour le développement chez les femmes (enfants mort-nés et avortements spontanés). Les calculs des coûts et des bénéfices ne tiennent pas compte du cancer de la peau et du cancer de la vessie. Le cancer de la peau est un effet nocif reconnu de l'exposition aux HAP, mais il ne peut être quantifié car les informations sont insuffisantes pour établir un RER. Il existe également des indications d'un risque élevé de cancer de la vessie, mais les preuves ne sont pas concluantes en raison de facteurs de confusion tels que la présence, aux côtés des HAP, d'autres substances connues ou suspectées d'augmenter le risque de cancer de la vessie. L'analyse de sensibilité a évalué les cas hypothétiques de cancer de la vessie évités (bien que le RER le soit pas robuste), ce qui a réduit les ratios coûts-avantages globaux. En raison du manque de données sur le cancer de la peau, il n'est pas possible d'effectuer une analyse de sensibilité.

Vingt-deux secteurs sont analysés. Les principaux facteurs pris en compte pour leur sélection étaient de savoir s'ils étaient mentionnés dans plusieurs sources et si l'exposition aux HAP pouvait être quantifiée. La sélection des secteurs a soulevé plusieurs autres questions complexes, qui sont expliquées au point 3.2.9. Il est essentiel de savoir si les données disponibles indiquent que le 95e percentile des concentrations d'exposition est inférieur à la LEP la plus basse, car l'évaluation indiquerait qu'il n'y a pas d'impact si l'on utilise le BaP comme indicateur pour les mélanges de HAP.

Les coûts et les bénéfices (par rapport à la situation de référence) estimés dans le présent rapport pour les différentes LEP cibles sont résumés dans le tableau 1. Les bénéfices sont indiqués pour la méthode 1 et la méthode 2. Les coûts correspondent à la valeur actuelle (VA) sur 40 ans avec un taux d'actualisation statique de 3%. Ils reposent sur l'hypothèse d'une rotation du personnel de 5%.

Il existe des différences significatives entre les coûts et les bénéfices pour toutes les options politiques, l'option politique la plus basse ayant le rapport coût-bénéfice le moins efficace (où les

coûts sont de 330 à 960 fois supérieurs aux bénéfices) et l'option politique la plus élevée n'ayant pas de rapport en raison de l'absence de bénéfices.

Table 0-1 Résumé des coûts et bénéfices monétisés (taux d'actualisation statique, en plus du scénario de référence) (en millions d'euros)

Option politique	7 ng/m ³ & 0,2 nmol/mol créatinine	70 ng/m ³ & 0,3 nmol/mol créatinine	Option de période transitoire	700 ng/m ³ & 1,5 nmol/mol créatinine	2000 ng/m ³ & 3,8 nmol/mol créatinine
Total des bénéfices M1	€ 190	€ 100	€ 100	€ 16	€ 0
Total des bénéfices M2	€ 64	€ 20	€ 20	€ 2	€ 0
Total des coûts (LEP)	€ 44.000	€ 3.100	€ 3.100	€ 230	€ 150
Rapport coût-bénéfice M1 (LEP)	232	31	31	14	-
Rapport coût-bénéfice M2 (LEP)	675	154	154	115	-
Total des coûts (LEP & VLB)	€ 55.000	€ 5.700	€ 5.700	€ 1.400	€ 780
Rapport coût-bénéfice (LEP & VLB)	293	56	56	87	-
Rapport coût-bénéfice M2 (LEP & VLB)	850	284	284	701	-

Source : équipe d'étude

Notes : Période de transition : 140 ng/m³ et 0,3 nmol/mol de créatinine pendant six ans, puis 70 ng/m³ et 0,3 nmol/mol de créatinine. Les coûts pour les secteurs en transition ne devraient pas augmenter ou diminuer en raison des modifications apportées aux ajustements ou au respect de la VLEP. Toutefois, la période au cours de laquelle les coûts sont encourus sera retardée de 6 ans et les coûts pour les secteurs en transition devront être réduits de 8 % afin de refléter plus précisément la valeur actuelle. Ces coûts réduits ont été additionnés aux totaux pour les secteurs non transitoires à 70 ng/m³ afin d'illustrer les impacts de la période transitoire sur les coûts globaux.

L'analyse multicritère résumant les impacts monétaires et qualitatifs est présentée dans le tableau 0-2.

Table 0-2 Analyse multicritères (tous les impacts sur 40 ans et supplémentaires par rapport à la ligne de base) par option LEP (en millions d'euros)

Impact	Acteurs concernés	7 ng/m ³ & 0,2 nmol/mol créatinine	70 ng/m ³ & 0,3 nmol/mol créatinine	Option période transitoire **	700 ng/m ³ & 1,5 nmol/mol créatinine	2000 ng/m ³ & 3,8 nmol/mol créatinine
Coûts directs - ajustement						
Mesures de gestion des risques - première année	Entreprises	€ 1.700	€ 220	Ne peut pas être monétisé	€ 5	€ 0

Impact	Acteurs concernés	7 ng/m ³ & 0,2 nmol/mol créatinine	70 ng/m ³ & 0,3 nmol/mol créatinine	Option période transitoire **	700 ng/m ³ & 1,5 nmol/mol créatinine	2000 ng/m ³ & 3,8 nmol/mol créatinine
Mesures de gestion des risques - récurrent	Entreprises	€ 2.900	€ 200	Ne peut pas être monétisé	-€ 1	€ 0
Mesures de gestion des risques - cessations d'activité	Entreprises	€ 32.000	€ 2.200	Ne peut pas être monétisé	€ 0	€ 0
Mesures de gestion des risques - total	Entreprises	€ 37.000	€ 2.700	€ 2.500	€ 3	€ 0
Mesures de gestion des risques - total par entreprise	Entreprises	€ 0	€ 0	€ 0	€ 0	€ 0
Surveillance (échantillonnage et analyse)	Entreprises	€ 550	€ 290	€ 290	€ 180	€ 120
Mesures de gestion des risques - première année	Secteur public	€ 540	€ 16	€ 16	€ 0	€ 0
Mesures de gestion des risques - récurrent	Secteur public	€ 5.300	€ 47	€ 47	€ 0	€ 0
Mesures de gestion des risques - cessations d'activité	Secteur public	€ 0	€ 0	€ 0	€ 0	€ 0
Total des mesures de gestion des risques	Secteur public	€ 5.900	€ 63	€ 63	€ 0	€ 0
Total des mesures de gestion des risques par autorité publique	Secteur public	€ 8	€ 0	€ 0	€ 0	€ 0
Surveillance de l'air (échantillonnage et analyse)	Secteur public	€ 1	€ 0	€ 0	€ 0	€ 0
Coûts de transposition	Secteur public	€ 1	€ 1	€ 1	€ 1	€ 1
Coûts directs - administratifs						
Charge administrative liée à la surveillance de l'air	Entreprises	€ 120	€ 66	€ 65	€ 41	€ 27
Charge administrative liée à la surveillance de l'air	Secteur public	€ 0	€ 0	€ 0	€ 0	€ 0
Coûts directs - conformité totale						
Adjustment, monitoring and	Entreprises	€ 38.000	€ 3.000	€ 2.900	€ 230	€ 150

Impact	Acteurs concernés	7 ng/m³ & 0,2 nmol/mol créatinine	70 ng/m³ & 0,3 nmol/mol créatinine	Option période transitoire **	700 ng/m³ & 1,5 nmol/mol créatinine	2000 ng/m³ & 3,8 nmol/mol créatinine
Coûts de la charge d'ajuste- ment, de contrôle et d'administra- tion (LEP unique- ment)						
Coûts d'ajuste- ment, de contrôle et de gestion par entreprise (LEP uniquement)	Entreprises	€ 0	€ 0	€ 0	€ 0	€ 0
Coûts de l'ajuste- ment, du contrôle et de la charge administrative (LEP uniquement)	Secteur public	€ 5.900	€ 63	€ 63	€ 0	€ 0
Coûts d'ajuste- ment, de contrôle et de gestion par autorité publique (LEP uniquement)	Secteur public	€ 8	€ 0	€ 0	€ 0	€ 0
Total des coûts de mise en con- formité (LEP uniquement)	Entre- prises Autorités publiques	€ 44.000	€ 3.100	€ 2.900	€ 230	€ 150
Coûts directs - coûts d'exécution						
Coûts d'applica- tion hors transpo- sition	Secteur public			Des coûts de mise en œuvre peuvent ré- sulter de la mise en conformité avec les nouvelles LEP, mais ces coûts ne sont pas estimés car ils sont spécifiques au régime d'inspection de chaque État membre.		
Coûts indirects - autres						
Entreprises ces- sant au moins une partie de leurs activités - Nombre de fer- metures d'entre- prises	Entreprises	3.462	146	Il est pro- bable que ce chiffre soit infé- rieur à 146	0	0
Entreprises ces- sant au moins une partie de leurs activités - %	Entreprises	0,79%*	0,03%*	Il est pro- bable que ce chiffre soit infé- rieur à 0,03 %.	0	0
Coûts totaux de mise en confor- mité en % du chiffre d'affaires sur 40 ans (y compris les ces- sations d'activité)	Entreprises	Jusqu'à 6,3 % (C19.1 Cokeries - petites et moyennes entre- prises)	Jusqu'à 2,9 % (C19.1 Cokeries - petites et moyennes entre- prises)	Ne peut pas être estimé	Jusqu'à 0,01 % (plusieurs secteurs et tailles d'en- treprises)	Jusqu'à 0,01% (plusieurs secteurs et tailles d'en- treprises)

Impact	Acteurs concernés	7 ng/m ³ & 0,2 nmol/mol créatinine	70 ng/m ³ & 0,3 nmol/mol créatinine	Option période transitoire **	700 ng/m ³ & 1,5 nmol/mol créatinine	2000 ng/m ³ & 3,8 nmol/mol créatinine
Coûts de mise en conformité pour la première année en % du chiffre d'affaires annuel (à l'exclusion des cessations d'activité)	Entreprises	Jusqu'à 19 % (C16.1 Préservation du bois - petites entreprises)	Jusqu'à 3 % (C24.45 autres métallurgies non ferreuses - petites entreprises)	Ne peut pas être estimé	0,7 % (plusieurs secteurs - petites entreprises)	0,7 % (D35.11 centrales électriques au charbon - petites entreprises)
Emploi - Emplois perdus	Travailleurs et familles	47,758	2,725	Ne peut pas être estimé - il peut s'agir d'une réduction du nombre d'emplois perdus en raison de la diminution du nombre d'abandons	-	-
Emploi - Coût social	Travailleurs et familles	€ 4.000	€ 230	Ne peut pas être estimé - il peut s'agir d'une réduction du nombre d'emplois perdus en raison de la diminution du nombre d'abandons	€ 0	€ 0
Compétitivité internationale	Entreprises	Impacts négatifs importants	Impacts négatifs	Impacts négatifs	Pas d'impact significatif	Pas d'impact significatif
Consommateurs	Consommateurs	Les coûts pour les entreprises à 7 ng/m³ et 70 ng/m³ représentent une part importante du chiffre d'affaires/SIG et l'équipe chargée de l'étude s'attend à ce que les coûts soient répercutés sur les consommateurs par le biais d'une augmentation des prix ; y compris C20.13 fabricants de noir de carbone, C19. 1 co-kéfaction, C24.45 autre métallurgie, C10.13 et C10.2 fumoirs, G45.2 réparation automobile, N81.22 ramoneurs, C16.1 préservation du bois, E38.2 assainissement des sols, F42.11 revêtement des routes et F42.12 soudage des voies ferrées. La période de transition retardera l'augmentation des prix à la consommation ou permettra une augmentation progressive sur 6 ans, bien que l'impact soit le même qu'à 70 ng/m³.			Les coûts à 700 ng/m ³ et 2000 ng/m ³ sont moins importants et peuvent ne pas entraîner des augmentations de prix aussi significatives pour les consommateurs.	
Marché intérieur	Entreprises	1 : 1	1 : 1	1 : 1	1 : 10	1 : 28.6
De la plus basse à la plus haute LIEP	Secteur public	27 États membres :	26 États membres:	26 États membres:	23 États membres:	15 États membres:

Impact	Acteurs concernés	7 ng/m³ & 0,2 nmol/mol créatinine	70 ng/m³ & 0,3 nmol/mol créatinine	Option période transitoire **	700 ng/m³ & 1,5 nmol/mol créatinine	2000 ng/m³ & 3,8 nmol/mol créatinine
		AU, BE, BG, CY, CZ, DE, DK, EE, EL, ES, FI, FR, HR, HU, IE, IT, LT, LU, LV, MT, NL, PL, PT, RO, SE, SI, SK	AU, BE, BG, CY, CZ, DK, EE, EL, ES, FI, FR, HR, HU, IE, IT, LT, LU, LV, MT, NL, PL, PT, RO, SE, SI, SK	AU, BE, BG, CY, CZ, DK, EE, EL, ES, FI, FR, HR, HU, IE, IT, LT, LU, LV, MT, NL, PL, PT, RO, SE, SI, SK	AU, BE, CY, CZ, DK, EE, EL, ES, FI, FR, HR, HU, IE, IT, LT, LU, MT, PL, PT, RO, SE, SI, SK	BE, CY, CZ, DK, EL, ES, FI, FR, HR, IE, IT, LU, MT, PT, RO
Règlement	Entreprises	Une restriction REACH sur les HAP dans les articles pourrait être proposée par l'ECHA à l'avenir. Le système communautaire d'échange de quotas d'émission (SCEQE) incite les aciéries à utiliser l'hydrogène comme agent réducteur et le mécanisme d'ajustement frontalier du carbone devrait permettre d'éviter les importations à moindre coût.				
Avantages directs - amélioration du bien-être et de la santé						
Réduction des cas de mauvaise santé (Cancer du poumon)	Travailleurs et familles	141	35	35	2	-
Réduction des cas de mauvaise santé (Toxicité pour le développement)	Travailleurs et familles	38	38	38	7	-
Réduction des cas de mauvaise santé (Infertilité masculine)	Travailleurs et familles	3.157	3.157	3.157	608	-
Maladies évitées, y compris les coûts intangibles (M1 à M2)	Travailleurs et familles	€ 180 - 59	€ 97 - 16	€ 89 - 15	€ 15 - 1	-
Avantages directs - amélioration du bien-être - sécurité						
Coûts évités	Entreprises	€ 1	€ 0	€ 0	€ 0	€ 0
Coûts évités	Secteur public	€ 5	€ 4	€ 4	€ 1	€ 0
Agenda politique de l'UE	Tous les secteurs	Amélioration des droits fondamentaux des travailleurs et contribution au Green Deal : stratégie chimique pour un environnement sans toxicité				
Avantages directs - amélioration du bien-être - environnement						
Rejets dans l'environnement	Tous	Réduction accrue des émissions de HAP à tous les niveaux, sauf à 2000 ng/m3, où aucun ajustement des mesures de gestion des risques n'est prévu. Dans certains secteurs, les émissions dans l'environnement devraient diminuer à mesure que une LEP deviennent plus strictes. Cela est dû au fait que les mesures de gestion des risques entraînent un meilleur confinement/réduction des émissions (par exemple, grâce à l'utilisation accrue de systèmes fermés ou de nouveaux procédés plus propres au fur et à mesure qu'ils deviennent disponibles). Il est difficile de savoir si l'utilisation d'alternatives produirait des niveaux d'émissions différents et dans quelle mesure cela pourrait se produire, bien que, comme le souligne le présent rapport, les alternatives ne soient pas viables pour la plupart des secteurs. Dans l'exemple du revêtement des routes, où des solutions de				

Impact	Acteurs concernés	7 ng/m ³ & 0,2 nmol/mol créatinine	70 ng/m ³ & 0,3 nmol/mol créatinine	Option période transitoire **	700 ng/m ³ & 1,5 nmol/mol créatinine	2000 ng/m ³ & 3,8 nmol/mol créatinine
		remplacement pourraient être disponibles, on ne sait pas si les émissions seraient affectées.				
Loi européenne sur le climat	Tous	Les arrêts d'activité dans trois secteurs (fonderies d'acier et de fer (C24.1), fabrication d'aluminium (C24.42) et autres métallurgies non ferreuses (C24.45)), essentiels pour la transition verte, seront affectés par les deux options politiques les plus basses. Pour C24.1, les abandons sont environ 10 fois plus élevés, pour C24.42 les abandons sont environ cinq fois plus élevés, et pour C24.45 les abandons sont environ trois fois plus élevés à 7 ng/m3 qu'à 70 ng/m3. Dans l'ensemble, l'ampleur des abandons à 7 ng/m3 peut se traduire par une diminution du nombre de produits ou de matériaux essentiels à la transition écologique disponibles dans l'UE et par une dépendance accrue à l'égard des sources d'approvisionnement des pays tiers. Les périodes de transition n'affectent pas la production des matériaux concernés dans ces secteurs.			Pas d'impact	
Avantages directs - efficacité du marché						
Des conditions de concurrence équitables	Entreprises	Une LIE harmonisée au niveau de l'UE contribuerait à garantir des conditions de concurrence équitables entre les entreprises opérant dans différents États membres de l'UE. Comme indiqué ci-dessus (« États membres/régions spécifiques - États membres qui devraient modifier leur LEP »), l'introduction d'une LEP à l'échelle de l'UE entraînerait un plus grand alignement des États membres, quel que soit le niveau de l'option politique retenue.				
Avantages indirects						
Simplification administrative	Entreprises	Si tous les États membres disposaient d'une LEP/VLB harmonisée, cela réduirait la charge administrative pour les entreprises qui exercent leurs activités dans plusieurs États membres. Toutefois, la majorité des entreprises examinées sont petites et il est peu probable qu'elles aient des activités multinationales et qu'elles ne soient pas affectées par cette simplification. Les secteurs où les coûts sont les plus élevés (voir section 8) sont généralement des moyennes et grandes entreprises qui pourraient bénéficier d'une telle simplification administrative.				
Synergie	Entreprises	Des synergies en termes de réduction de l'exposition à d'autres substances chimiques utilisées dans les secteurs de production peuvent se produire. Les substances spécifiques varieront d'un secteur à l'autre. Le niveau de synergie à exploiter dépendra également des RMM appliquées dans chaque entreprise.				
Responsabilité sociale des entreprises	Entreprises	Le travail avec les HAP peut être moins perçu comme une activité à risque associée à des problèmes de santé. Grâce à cette amélioration de l'image publique, les entreprises pourront plus facilement recruter et conserver leur personnel, ce qui réduira les coûts de recrutement et augmentera la productivité des travailleurs.				

Impact	Acteurs concernés	7 ng/m ³ & 0,2 nmol/mol créatinine	70 ng/m ³ & 0,3 nmol/mol créatinine	Option pé-riode transitoire **	700 ng/m ³ & 1,5 nmol/mol créatinine	2000 ng/m ³ & 3,8 nmol/mol créatinine
Coût évité de la mise en place d'une LEP	Secteur public	€ 2	€ 2	Pas de change-ment	€ 2	€ 1
Autre impacts						
Recyclage - perte d'activité	Entreprises de recy-clage	Les secteurs métallurgiques pourraient être amenés à cesser leurs ac-tivités dans le cadre des options stratégiques les plus basses, ce qui entraînerait une diminution de la production de matériaux dans l'UE. Toutefois, l'équipe chargée de l'étude prévoit que les entreprises con-tinueront à s'approvisionner en matériaux en dehors de l'UE pour ré-pondre à la demande et que, par conséquent, les matériaux dispo-nibles pour le recyclage ne seront pas affectés. Cependant, les secteurs métallurgiques entreprennent également une production secondaire (recyclage) de métaux qui serait également soumise à des coûts liés aux VLEP/VLB. À 7 ng/m³, on s'attend à ce que les secteurs métallurgiques subissent d'importantes interruptions, ce qui entraînerait une perte de la capacité de l'UE à recycler les mé-taux. À 70 ng/m³, les incidences sur les secteurs métallurgiques sont moins importantes en termes d'abandon, ce qui suppose que la capa-cité de recyclage des métaux est maintenue. Le recyclage n'est pas considéré comme étant affecté dans d'autres domaines.				
Impacts sur les droits fondamen-taux	Tous	Impact positif sur la santé et la sécurité. Le renforcement de la sur-veillance permettra de garantir que les expositions futures restent contrôlées et que le risque pour les travailleurs reste faible.				
Impacts sur la numérisation	Entreprises	La numérisation peut être affectée par des coûts élevés pour les fabri-cants de silicium métallique et de graphite (utilisés dans la fabrication de semi-conducteurs, de piles à combustible, de panneaux solaires photovoltaïques et de batteries pour véhicules électriques). Les coûts et les interruptions liés au silicium (C24.45) sont estimés être significativement négatifs à 7 ng/m³, négatifs à 70 ng/m³ et négli-geables à 700 ng/m³ et 2 000 ng/m³, ce qui suggère que les effets sur la numérisation se feraient principalement sentir au niveau de l'option politique la plus stricte. En ce qui concerne la production de graphite (C23.99b), la modélisation estime des coûts significative-ment négatifs à 7 ng/m³ et des coûts négatifs à 70 ng/m³, ce qui in-dique des incidences sur les coûts de numérisation à ces niveaux (au-cune incidence à 700 ng/m³ et 2 000 ng/m³). La production de gra-phite synthétique dépend de la cokéfaction C19.1, qui entraîne égale-ment des coûts importants pour les deux options stratégiques les plus basses. Collectivement, les difficultés du secteur de la production de silicium et de graphite à faire face aux coûts dans le cadre des deux options stratégiques les plus basses peuvent avoir des incidences né-gatives sur la numérisation en raison de l'augmentation des coûts des matériaux ou d'une plus grande dépendance à l'égard des importa-tions en provenance de pays tiers (principalement la Chine).				
Contributions aux objectifs de déve-loppement du-rable des Nations unies	Tous les	Objectif 3 – positif Objectif 7 – positif Objectif 8 – positif Objectif 14 and 15 – positif				

Source : équipe d'étude

Notes : Les chiffres ayant été arrondis, il est possible que leur somme ne corresponde pas exactement au total indiqué. Les totaux ont été présentés sous forme de deux scénarios, « (LEP) » incluant les coûts d'ajus-tement de la première année et les coûts récurrents, la surveillance de l'air et la charge administrative.

* Veuillez noter que le pourcentage de toutes les entreprises qui cessent leurs activités présenté dans ces lignes est nettement inférieur aux pourcentages sectoriels présentés dans le tableau 8-13. Cela est dû au fait que les secteurs D35.11 et G45.2 comptent un nombre significativement plus élevé d'entreprises, ce qui fausse les pourcentages totaux.

*** Période transitoire : 140 ng/m³ et 0,3 nmol/mol de créatinine pendant six ans, puis 70 ng/m³ et 0,3 nmol/mol de créatinine. Les coûts pour les secteurs en transition ne devraient pas augmenter ou diminuer en raison des modifications apportées aux ajustements ou au respect de la LEP. Toutefois, la période au cours de laquelle les coûts sont encourus sera retardée de 6 ans et les coûts pour les secteurs en transition devront être réduits de 8 % afin de refléter plus précisément la valeur antérieure à l'envoi. Ces coûts réduits ont été additionnés aux totaux pour les secteurs non transitoires à 70 ng/m³ afin d'illustrer les impacts de la période transitoire sur les coûts globaux.*

D'autres questions doivent être prises en compte dans le processus de décision :

Le benzo[a]pyrène (BaP) comme marqueur. Le benzo[a]pyrène est utilisé comme seul indicateur de l'exposition à un mélange. Le BaP est un cancérigène très puissant et il est généralement admis qu'il constitue un bon indicateur de l'exposition aux HAP. Le BaP n'est pas toujours présent et l'exposition à d'autres HAP cancérigènes peut se produire. Cependant, il n'est pas possible de quantifier leurs avantages en raison de l'absence d'une relation exposition-risque. Toutefois, la protection contre le BaP dans le mélange de HAP est susceptible d'entraîner une protection contre d'autres HAP dans le mélange. Parmi les secteurs couverts par cette étude, la plupart disposent de données identifiant l'exposition à un ou plusieurs HAP cancérigènes Cat. 1 cancérigènes entrant dans le champ d'application du CMRD (autres que le BaP) ou sont susceptibles de l'être en raison de la similitude des procédés et/ou des produits utilisés (par exemple, la manipulation de charbon chauffé et de produits dérivés du pétrole). Il est donc possible que l'exposition professionnelle à d'autres HAP cancérigènes ait lieu et ne soit pas surveillée. Comme le note le CER, *"dans de tels contextes, il serait préférable de surveiller l'exposition à une plus grande variété de HAP, par exemple les 16 HAP de l'EPA, même s'ils sont moins cancérigènes que le BaP. [Néanmoins, le principe de minimisation de l'exposition du CMRD devrait s'appliquer à tous les HAP cancérigènes]"*.

Le 3-hydroxybenzo[a]pyrène (3-OHBP) comme biomarqueur. Les mêmes remarques concernant l'utilisation du BaP comme marqueur pour le mélange s'appliquent à l'utilisation du 3-OHBP comme biomarqueur pour le mélange de HAP. En outre, l'équipe chargée de l'étude note ce qui suit :

- On manque de données sur les niveaux de 3-OHBP dans l'urine dans de nombreux secteurs. Cela signifie qu'il n'a pas été possible de faire des comparaisons significatives entre les concentrations actuelles de métabolites et les options proposées pour les VLEP;
- La relation entre le BaP et le 3-OHBP ne serait pas précise dans les faibles niveaux d'exposition et en dessous de 0,1729 nmol/mol de créatinine (0,41 µg/g de créatinine), la concentration correspondante dans l'air serait négative;
- Les échantillons d'urine ne doivent pas être conservés à l'état congelé ou doivent être analysés dès que possible après décongélation - les experts ont des avis divergents à ce sujet;
- Les variables confusionnelles telles que le tabagisme, la consommation d'aliments fumés ou grillés (en particulier les viandes), et la proximité de feux brûlant des combustibles solides (c'est-à-dire des activités non liées à l'exposition sur le lieu de travail) sont connues pour augmenter l'exposition aux HAP en suspension dans l'air et les concentrations de métabolites.

- Le DFG (2013, cité par le CER, 2022) indique que le meilleur moment pour l'échantillonnage est 16 heures après la dernière exposition, c'est-à-dire avant le poste suivant, en raison des délais d'excrétion. DFG ainsi que le CIRC (2023) indiquent que le 3-OHBaP (mais pas le 1-OHP) est de préférence métabolisé et excrété dans les fèces.
- - Certains répondants, ainsi que des experts, ont indiqué qu'il y a actuellement un manque de laboratoires accrédités pour analyser le 3-OHBaP en Europe, en particulier avec la nouvelle méthode d'analyse plus sensible. On s'attend à ce que, si une BLV contenant du 3-OHBaP entre en vigueur, les laboratoires adoptent les méthodes existantes et proposent l'analyse requise du 3-OHBaP. Bien qu'il puisse y avoir une capacité à court terme, cette question devrait se résoudre d'elle-même.

Autres cancers et effets. La relation exposition-risque est dérivée pour le cancer du poumon, et il existe des preuves concluantes que les HAP provoquent le cancer de la peau, mais les données sont insuffisantes pour quantifier les effets. Il existe également des indications d'un risque élevé de cancer de la vessie, mais les preuves ne sont pas concluantes en raison de facteurs de confusion. Les calculs de sensibilité effectués par le RAC indiquent que le risque de cancer de la vessie pourrait influencer le TRE d'un facteur allant jusqu'à 1,7. D'autres organismes ont identifié la possibilité d'autres maladies, mais aucune conclusion ne peut être tirée. Enfin, le BaP est un cancérogène sans seuil, ce qui signifie que l'exposition à n'importe quelle quantité de BaP peut avoir des effets.

Tendances futures. L'équipe chargée de l'étude a identifié les tendances futures pour un certain nombre de secteurs, mais il n'a pas été possible de modéliser certains secteurs:

- Les fonderies d'acier et de fer pourraient connaître des tendances similaires à celles de l'aluminium, car l'acier est nécessaire pour de nombreuses infrastructures essentielles pour parvenir à des émissions nettes nulles, par exemple les turbines éoliennes.
- La fabrication de graphite synthétique devrait également augmenter, car il est utilisé dans les batteries Li-ion (véhicules électriques), les piles à combustible et d'autres articles et processus nécessaires pour parvenir à des émissions nettes nulles. Les tendances de la demande disponibles ne tiennent toutefois pas compte des importations par rapport à la fabrication, du naturel par rapport au synthétique et du potentiel futur de recyclage.
- Les sites de charbon à coke sont généralement intégrés à des aciéries où le coke est utilisé comme agent réducteur dans les fours à oxygène de base pour la fabrication de l'acier primaire. On s'attend à ce que ces sites passent en grande partie à l'hydrogène comme agent réducteur et pour produire de l'électricité. Un sous-produit important de la cokéfaction est le goudron de houille, matière première du brai de goudron de houille. Ce dernier est actuellement nécessaire à la fabrication d'électrodes en graphite et en carbone, qui sont essentielles dans presque tous les processus métallurgiques et, comme indiqué ci-dessus, le graphite est nécessaire dans d'autres processus et articles. L'avenir de la cokéfaction est donc incertain.

La relation dose-effet basés sur des études animales et durée des effets. Les données de la relation dose-effet sont basées sur des études expérimentales sur des animaux plutôt que sur des études épidémiologiques. Bien qu'il existe des informations complémentaires provenant d'études humaines, il n'est pas possible de quantifier les effets sur l'homme à partir de données

expérimentales sur les animaux. Une autre incertitude concernant les effets sur la fertilité (motilité des spermatozoïdes chez les mâles) réside dans le fait que les études animales ne permettent pas de conclure si les effets sur la fertilité sont réversibles ou non. Pour éviter de surestimer les effets chez l'homme, on a supposé qu'ils étaient permanents pour la modélisation.

KURZFASSUNG

Die Richtlinie über krebserzeugende, erbgutverändernde und fortpflanzungsgefährdende Stoffe (Richtlinie 2004/37/EG), im Folgenden CMRD genannt, schützt Arbeitnehmer vor der Exposition gegenüber krebserzeugenden, erbgutverändernden oder fortpflanzungsgefährdenden Stoffen bei der Arbeit. Ziel dieser Studie ist es, die Folgenabschätzung der Europäischen Kommission für einen potenziellen Arbeitsplatzgrenzwert (AGW) und einen biologischen Grenzwert für polyzyklische aromatische Kohlenwasserstoffe (PAK) zu unterstützen.

Bei der Expositions-Risiko-Relation (ERR) wird Benzo[a]pyren (BaP) (einatembare Fraktion) als Indikatorsubstanz verwendet, um die Exposition gegenüber dem PAK-Gemisch zu charakterisieren, da es sich um ein sehr starkes Karzinogen (ohne Schwellenwert) handelt und eine große Menge an Expositionsdaten für diesen Stoff verfügbar sind. Kein einzelner Metabolit/Biomarker kann die Variabilität der PAK-Expositionsmischung angemessen darstellen, und in der Stellungnahme des RAC von 2022 wird BaP als der am besten geeignete verfügbare Marker angesehen. Die AGW-Optionen beruhen auf BaP. Der RAC hat jedoch keinen Grenzwert vorgeschlagen, da BaP ein Karzinogen ohne Schwellenwert ist. RAC schlägt weiterhin vor, einen biologischen Grenzwert (BGW) mit 3-Hydroxybenzoapyren (3-OHBaP, dem Metaboliten von BaP) im Urin als Markersubstanz festzulegen, basierend auf einer Korrelationsgleichung zwischen der Luftkonzentration und dem Metaboliten im Urin.

Die bewerteten Endpunkte sind: Lungenkrebs, Reproduktionstoxizität bei Männern (Spermienmotilität), Entwicklungstoxizität bei Frauen (Totgeburten und Fehlgeburten). Kosten- und Nutzenberechnungen berücksichtigen Haut- und Blasenkrebs nicht. Hautkrebs ist eine anerkannte gesundheitliche Auswirkung der Exposition gegenüber PAK, kann aber nicht quantifiziert werden, da nicht genügend Informationen vorliegen, um eine ERR zu entwickeln. Es gibt auch Hinweise auf ein erhöhtes Risiko für Blasenkrebs, aber aufgrund von Störfaktoren wie dem Vorhandensein anderer Stoffe neben PAK, von denen bekannt ist oder vermutet wird, dass sie das Risiko für Blasenkrebs erhöhen, gab es keine schlüssigen Beweise. In einer Sensitivitätsanalyse wurden die hypothetischen vermiedenen Fälle von Blasenkrebs bewertet (obwohl die ERR nicht robust ist), was das Gesamtkosten-Nutzen-Verhältnis reduzierte. Aufgrund des Mangels an Daten über Hautkrebs ist es nicht möglich, eine Sensitivitätsanalyse durchzuführen.

Es wurden zweiundzwanzig Sektoren analysiert. Bei ihrer Auswahl wurde vor allem berücksichtigt, ob sie in mehreren Quellen erwähnt wurden und ob die PAK-Exposition quantifiziert werden kann. Bei der Auswahl der Sektoren gab es mehrere weitere komplexe Aspekte, die in Abschnitt 3.2.9 erläutert werden. Ein zentraler Punkt ist die Frage, ob aus den verfügbaren Daten hervorgeht, dass das 95. Perzentil der Expositionskonzentrationen unter dem niedrigsten bewerteten Arbeitsplatzgrenzwert liegt, da die Bewertung bei Verwendung von BaP als Indikator für PAK-Gemische keine Auswirkungen zeigen würde.

Die in diesem Bericht für die verschiedenen Ziel-Arbeitsplatzgrenzwerte geschätzten Kosten und Nutzen (im Vergleich zum Ausgangswert) sind in Tabelle 0 1 zusammengefasst. Der Nutzen wird sowohl für Methode 1 als auch für Methode 2 angegeben. Die Kosten beziehen sich auf den Gegenwartswert über 40 Jahre mit einem statischen Abzinsungssatz von 3 %. Sie gehen von einer Personalfuktuation von 5 % aus.

Bei allen Optionen gibt es erhebliche Unterschiede zwischen den Kosten und dem Nutzen, wobei die niedrigste Option das schlechteste Kosten-Nutzen-Verhältnis aufweist (bei der die Kosten

das 330- bis 960-fache des Nutzens betragen) und die höchste Option kein Verhältnis aufweist, da sie keinen Nutzen bringt.

Tabelle 0-1 Zusammenfassung der monetarisierten Kosten und des Nutzens (statischer Abzinsungssatz, zusätzlich zum Basisszenario) (in Millionen €)

Option	7 ng/m ³ & 0,2 nmol/mol Kreatinin	70 ng/m ³ & 0,3 nmol/mol Kreatinin	Option Übergangsfrist	700 ng/m ³ & 1,5 nmol/mol Kreatinin	2000 ng/m ³ & 3,8 nmol/mol Kreatinin
Gesamtnutzen M1	€ 190	€ 100	€100	€ 16	€ 0
Gesamtnutzen M2	€ 64	€ 20	€20	€ 2	€ 0
Gesamtkosten (AGW)	€ 44.000	€ 3.100	€3.100	€ 230	€ 150
Kosten-Nutzen-Verhältnis M1 (AGW)	232	31	31	14	-
Kosten-Nutzen-Verhältnis M2 (AGW)	675	154	154	115	-
Gesamtkosten (AGW & BGW)	€ 55.000	€ 5.700	€5.700	€ 1.400	€ 780
Kosten-Nutzen-Verhältnis M1 (AGW & BGW)	293	56	56	87	-
Kosten-Nutzen-Verhältnis M2 (AGW & BGW)	850	284	284	701	-

Quelle: Studenteam.

Anmerkungen: Übergangsfrist: 140 ng/m³ & 0,3 nmol/mol Kreatinin für sechs Jahre und dann 70 ng/m³ & 0,3 nmol/mol Kreatinin. Es wird nicht erwartet, dass die Kosten für die Übergangssektoren aufgrund von Änderungen bei den Anpassungen oder der Einhaltung des AGW steigen oder sinken werden. Der Zeitraum, in dem die Kosten anfallen, verschiebt sich jedoch um 6 Jahre, so dass die Kosten für die Übergangssektoren um 8 % reduziert werden müssen, um den Gegenwartswert genauer widerzuspiegeln. Diese reduzierten Kosten wurden mit den Gesamtwerten für nicht-Übergangssektoren bei 70ng/m³ addiert, um die Auswirkungen des Übergangszeitraums auf die Gesamtkosten zu veranschaulichen.

Die Multikriterienanalyse, die sowohl die monetären als auch die qualitativen Auswirkungen zusammenfasst, ist in Tabelle 0-2 dargestellt.

Tabelle 0-2 Multikriterienanalyse (alle Auswirkungen über 40 Jahre und zusätzlich zum Ausgangswert) per AGW/BGW-Option (in Millionen €)

Auswirkungen	Betroffene Stakeholders	7 ng/m ³ & 0,2 nmol/mol Kreatinin	70 ng/m ³ & 0,3 nmol/mol Kreatinin	Option Übergangsfrist **	700 ng/m ³ & 1,5 nmol/mol Kreatinin	2000 ng/m ³ & 3,8 nmol/mol Kreatinin
Direkte Kosten – Anpassung						
Risikomanagementmaßnahmen - erstes Jahr	Unternehmen	€ 1.700	€ 220	Kann nicht monetarisiert werden	€ 5	€ 0
Risikomanagementmaßnahmen – wiederkehrend	Unternehmen	€ 2.900	€ 200	Kann nicht	-€ 1	€ 0

Auswirkungen	Betroffene Stakeholders	7 ng/m ³ & 0,2 nmol/mol Kreatinin	70 ng/m ³ & 0,3 nmol/mol Kreatinin	Option Übergangsfrist **	700 ng/m ³ & 1,5 nmol/mol Kreatinin	2000 ng/m ³ & 3,8 nmol/mol Kreatinin
				monetarisiert werden		
Risikomanagementmaßnahmen - Unterbrechung	Unternehmen	€ 32.000	€ 2.200	Kann nicht monetarisiert werden	€ 0	€ 0
Risikomanagementmaßnahmen - gesamt	Unternehmen	€ 37.000	€ 2.700	€ 2.500	€ 3	€ 0
Risikomanagementmaßnahmen gesamt pro Unternehmen	Unternehmen	€ 0	€ 0	€ 0	€ 0	€ 0
Luftüberwachung (Probenahme und Analyse)	Unternehmen	€ 550	€ 290	€ 290	€ 180	€ 120
Risikomanagementmaßnahmen - erstes Jahr	Öffentlicher Sektor	€ 540	€ 16	€ 16	€ 0	€ 0
Risikomanagementmaßnahmen - wiederkehrend	Öffentlicher Sektor	€ 5300	€ 47	€ 47	€ 0	€ 0
Risikomanagementmaßnahmen - Unterbrechung	Öffentlicher Sektor	€ 0	€ 0	€ 0	€ 0	€ 0
Risikomanagementmaßnahmen gesamt	Öffentlicher Sektor	€ 5900	€ 63	€ 63	€ 0	€ 0
Risikomanagementmaßnahmen gesamt pro Behörde	Öffentlicher Sektor	€ 8	€ 0	€ 0	€ 0	€ 0
Luftüberwachung (Probenahme und Analyse)	Öffentlicher Sektor	€ 1	€ 0	€ 0	€ 0	€ 0
Umsetzungskosten	Öffentlicher Sektor	€ 1	€ 1	€ 1	€ 1	€ 1
Direkte Kosten - Verwaltung						
Verwaltungsaufwand für die Luftüberwachung	Unternehmen	€ 120	€ 66	€ 65	€ 41	€ 27
Verwaltungsaufwand für Luftüberwachung	Öffentlicher Sektor	€ 0	€ 0	€ 0	€ 0	€ 0
Direkte Kosten – Einhaltung der Vorschriften (Compliance) gesamt						
Kosten für Anpassung, Überwachung und Verwaltungsaufwand (nur AGW)	Unternehmen	€ 38000	€ 3000	€ 2900	€ 230	€ 150

Auswirkungen	Betroffene Stakeholders	7 ng/m³ & 0,2 nmol/mol Kreatinin	70 ng/m³ & 0,3 nmol/mol Kreatinin	Option Übergangsfrist **	700 ng/m³ & 1,5 nmol/mol Kreatinin	2000 ng/m³ & 3,8 nmol/mol Kreatinin
Kosten für Anpassung, Überwachung und Verwaltungsaufwand pro Unternehmen (nur AGW)	Unternehmen	€ 0	€ 0	€ 0	€ 0	€ 0
Kosten für Anpassung, Überwachung und Verwaltungsaufwand (nur AGW)	Öffentlicher Sektor	€ 5900	€ 63	€ 63	€ 0	€ 0
Kosten für Anpassung, Überwachung und Verwaltungsaufwand pro Behörde (nur AGW)	Öffentlicher Sektor	€ 8	€ 0	€ 0	€ 0	€ 0
Gesamtkosten für die Einhaltung der Vorschriften (nur AGW)	Unternehmen Öffentliche Behörden	€ 44000	€ 3100	€ 2900	€ 230	€ 150
Direkte Kosten - Durchsetzungskosten (enforcement)						
Durchsetzungskosten außer Umsetzung	Öffentlicher Sektor	Durchsetzungskosten können durch die Einhaltung der neuen AGW entstehen. Diese Kosten werden jedoch nicht geschätzt, da sie von den individuellen Kontrollsystemen der Mitgliedstaaten abhängen.				
Indirekte Kosten - Sonstige						
Unternehmen, die zumindest einen Teil ihrer Geschäftsfähigkeit aufgeben – Anzahl der Unternehmensschließungen	Unternehmen	3462	146	Die Zahl ist wahrscheinlich niedriger als 146	0	0
Unternehmen, die zumindest einen Teil ihrer Geschäftsfähigkeit aufgeben - %	Unternehmen	0,79%*	0,03%*	Die Zahl ist wahrscheinlich niedriger als 0,03 %	0	0
Gesamtkosten für die Einhaltung der Vorschriften in % des Umsatzes über 40 Jahre (einschließlich Einstellung des Betriebs)	Unternehmen	Bis zu 6,3% (C19.1 Kokereien – kleine und mittlere Unternehmen)	Bis zu 2,9% (C19.1 Kokereien – kleine und mittlere Unternehmen)	Kann nicht geschätzt werden	Bis zu 0,01% (verschiedene Branchen und Unternehmen sgrößen)	Bis zu 0,01% (verschiedene Branchen und Unternehmen sgrößen)

Auswirkungen	Betroffene Stakeholders	7 ng/m ³ & 0,2 nmol/mol Kreatinin	70 ng/m ³ & 0,3 nmol/mol Kreatinin	Option Übergangsfrist **	700 ng/m ³ & 1,5 nmol/mol Kreatinin	2000 ng/m ³ & 3,8 nmol/mol Kreatinin
Kosten für die Einhaltung der Vorschriften im ersten Jahr in % des Jahresumsatzes (ohne Einstellung des Betriebs)	Unternehmen	Bis zu 19% (C16.1 Holzschutz – kleine Unternehmen)	Bis zu 3% (C24.45 Sonstige Nichteisenmetallurgie – kleine Unternehmen)	Kann nicht geschätzt werden	0,7% (verschiedene Branchen – kleine Unternehmen)	0,7% (D35.11 Kohlekraftwerke – kleine Unternehmen)
Beschäftigung - verlorene Arbeitsplätze	Arbeitnehmer & Familien	47758	2725	Kann nicht geschätzt werden - möglicherweise eine Verringerung der Zahl der verlorenen Arbeitsplätze aufgrund von weniger Betrieben, die die Arbeit einstellen müssen	-	-
Beschäftigung - Soziale Kosten	Arbeitnehmer & Familien	€ 4000	€ 230	Kann nicht geschätzt werden - möglicherweise eine Verringerung der Zahl der verlorenen Arbeitsplätze von weniger Betrieben, die die Arbeit einstellen müssen	€ 0	€ 0
Internationale Wettbewerbsfähigkeit	Unternehmen	Erheblich negative Auswirkungen	Negative Auswirkungen	Negative Auswirkungen	Keine wesentlichen Auswirkungen	Keine wesentlichen Auswirkungen
Verbraucher	Verbraucher	Die Kosten für Unternehmen mit 7 ng/m ³ und 70 ng/m ³ machen einen beträchtlichen Teil des Umsatzes/der Umsatzerlöse aus, und das Studienteam erwartet, dass die Kosten über höhere Preise an die Verbraucher weitergegeben werden; darunter C20.13 Rußhersteller, C19. 1 Kokerei, C24.45 Sonstige Metallurgie,			Die Kosten bei 700 ng/m ³ und 2000 ng/m ³ sind weniger erheblich und führen möglicherweise nicht zu so starken Preissteigerungen für die Verbraucher.	

Auswirkungen	Betroffene Stakeholders	7 ng/m³ & 0,2 nmol/mol Kreatinin	70 ng/m³ & 0,3 nmol/mol Kreatinin	Option Übergangsfri st **	700 ng/m³ & 1,5 nmol/mol Kreatinin	2000 ng/m³ & 3,8 nmol/mol Kreatinin
		C10.13 und C10.2 Räumereien, G45.2 Kfz-Reparatur, N81.22 Schornsteinfeger, C16.1 Holzschutz, E38.2 Bodensanierung, F42.11 Straßenbau und F42.12 Schweißen von Eisenbahnschienen. Die Auswirkungen der zweitniedrigsten Option sind wahrscheinlich geringer als bei der niedrigsten Option. Die Übergangsfrist wird den Anstieg der Verbraucherpreise verzögern oder einen schrittweisen Anstieg über 6 Jahre ermöglichen, obwohl die Auswirkungen dieselben sind wie bei 70 ng/m³.				
Binnenmarkt Niedrigster bis höchster AGW	Unternehmen	1 : 1	1 : 1	1 : 1	1 : 10	1 : 28,6
Spezifische Mitgliedstaaten/Regionen – Mitgliedstaaten, die AGWs ändern müssten	Öffentlicher Sektor	27 Mitgliedstaaten: AU, BE, BG, CY, CZ, DE, DK, EE, EL, ES, FI, FR, HR, HU, IE, IT, LT, LU, LV, MT, NL, PL, PT, RO, SE, SI, SK	26 Mitgliedstaaten: AU, BE, BG, CY, CZ, DK, EE, EL, ES, FI, FR, HR, HU, IE, IT, LT, LU, LV, MT, NL, PL, PT, RO, SE, SI, SK	26 Mitgliedstaaten: AU, BE, BG, CY, CZ, DK, EE, EL, ES, FI, FR, HR, HU, IE, IT, LT, LU, LV, MT, NL, PL, PT, RO, SE, SI, SK	23 Mitgliedstaaten: AU, BE, CY, CZ, DK, EE, EL, ES, FI, FR, HR, HU, IE, IT, LT, LU, MT, PL, PT, RO, SE, SI, SK	15 Mitgliedstaaten: BE, CY, CZ, DK, EL, ES, FI, FR, HR, IE, IT, LU, MT, PT, RO
Verordnung	Unternehmen	Eine REACH-Beschränkung für PAK in Erzeugnissen könnte von der ECHA in Zukunft vorgeschlagen werden. Das EU-Emissionshandelssystem (EU ETS) veranlasst die Stahlwerke, auf Wasserstoff als Reduktionsmittel umzusteigen, und das CO ₂ -Grenzausgleichssystem dürfte dazu beitragen, billigere Importe zu verhindern.				
Direkte Nutzen – verbessertes Wohlbefinden - Gesundheit						
Geringere Krankheitsfälle (Lungenkrebs)	Arbeitnehmer & Familien	141	35	35	2	0
Geringere Krankheitsfälle (Entwicklungstoxizität)	Arbeitnehmer & Familien	38	38	38	7	0
Geringere Krankheitsfälle (Männliche Unfruchtbarkeit)	Arbeitnehmer & Familien	3157	3157	3157	608	0
Krankheitsfälle vermieden, einschließlich immaterieller Kosten (M1 bis M2)	Arbeitnehmer & Familien	€ 180 - 59	€ 97 - 16	€ 89 - 15	€ 15 - 1	€ 0

Auswirkungen	Betroffene Stakeholders	7 ng/m³ & 0,2 nmol/mol Kreatinin	70 ng/m³ & 0,3 nmol/mol Kreatinin	Option Übergangsfrist **	700 ng/m³ & 1,5 nmol/mol Kreatinin	2000 ng/m³ & 3,8 nmol/mol Kreatinin
Direkte Nutzen – verbessertes Wohlbefinden - Sicherheit						
Vermiedene Kosten	Unternehmen	€ 1	€ 0	€ 0	€ 0	€ 0
Vermiedene Kosten	Öffentlicher Sektor	€ 5	€ 4	€ 4	€ 1	€ 0
Politische Agenda der EU	Alle	Verbesserung der Grundrechte der Arbeitnehmer und Beitrag zum Green Deal: Chemiestrategie für eine giftfreie Umwelt				
Direkte Vorteile - verbessertes Wohlbefinden - Umwelt						
Freisetzungen in die Umwelt	Alle	Verstärkte Verringerung der PAK-Emissionen auf allen Ebenen mit Ausnahme von 2000 ng/m³, wo keine Anpassungen von Risikomanagementmaßnahmen zu erwarten sind. In einigen Sektoren werden die Umweltemissionen voraussichtlich zurückgehen, wenn die AGW strenger werden. Dies ist darauf zurückzuführen, dass die Risikomanagementmaßnahmen zu einer stärkeren Eindämmung/Vermeidung von Emissionen führen (z. B. durch den verstärkten Einsatz geschlossener Systeme oder neuartiger sauberer Verfahren, sobald diese verfügbar sind). Es ist unklar, ob die Verwendung von Alternativen zu anderen Emissionswerten führen würde und in welchem Umfang dies der Fall sein könnte, obwohl, wie in diesem Bericht dargelegt, Alternativen für die meisten Sektoren nicht praktikabel sind. Im Beispiel des Straßenbelags, für den es möglicherweise Alternativen gibt, ist nicht bekannt, ob die Emissionen davon beeinflusst wären.				
Europäisches Klimagesetz	Alle	In drei für den Ökologischen Wandel (Green Transition) wichtigen Sektoren - Stahl- und Eisengießereien (C24.1), Aluminiumherstellung (C24.42) und sonstige Nichteisenmetallurgie (C24.45) - wird die Einstellung des Betriebs durch die beiden niedrigsten politischen Optionen beeinflusst. Bei C24.1 sind die Einstellungen des Betriebs etwa zehnmal höher, bei C24.42 etwa fünfmal höher und bei C24.45 bei 7 ng/m³ etwa dreimal höher als bei 70 ng/m³. Insgesamt kann das große Ausmaß der Einstellungen des Betriebs bei 7 ng/m³ dazu führen, dass weniger Produkte oder Materialien, die für den Ökologischen Wandel wichtig sind, in der EU verfügbar sind und die Abhängigkeit von Drittländern für die Versorgung zunimmt. Die Übergangsfristen haben keine Auswirkungen auf die Produktion relevanter Materialien in diesen Sektoren.			Keine Auswirkungen	
Direkte Vorteile - Markteffizienz						
Gleiche Übergangsbedingungen	Unternehmen	Ein harmonisierter AGW auf EU-Ebene würde dazu beitragen, gleiche Wettbewerbsbedingungen für die in verschiedenen EU-Mitgliedstaaten tätigen Unternehmen zu gewährleisten. Wie oben dargelegt („Spezifische MS/Regionen - MS, die die AGW ändern müssten“), würde die Einführung eines EU-weiten AGW auf allen Ebenen der				

Auswirkungen	Betroffene Stakeholders	7 ng/m³ & 0,2 nmol/mol Kreatinin	70 ng/m³ & 0,3 nmol/mol Kreatinin	Option Übergangsfreist **	700 ng/m³ & 1,5 nmol/mol Kreatinin	2000 ng/m³ & 3,8 nmol/mol Kreatinin
		politischen Optionen zu einer stärkeren Angleichung der Mitgliedstaaten führen.				
Indirekte Nutzen						
Vereinfachung der Verwaltung	Unternehmen	Sollten alle Mitgliedstaaten über einen harmonisierten AGW/BLW verfügen, würde dies den Verwaltungsaufwand für Unternehmen mit Tätigkeiten in mehreren Mitgliedstaaten verringern. Die Mehrheit der untersuchten Unternehmen ist jedoch klein und wird wahrscheinlich nicht multinational tätig sein und von dieser Vereinfachung nicht betroffen sein. Bei den Sektoren mit den höchsten Kosten (in Abschnitt 8) handelt es sich in der Regel um mittlere und große Unternehmen, die von einer solchen Verwaltungsvereinfachung profitieren könnten.				
Synergie	Unternehmen	Bei anderen chemischen Stoffen, die in den Produktionssektoren verwendet werden, kann es zu Synergieeffekten in Bezug auf die Verringerung der Exposition kommen. Die spezifischen Stoffe werden von Sektor zu Sektor unterschiedlich sein. Das Ausmaß der zu nutzenden Synergie hängt auch von den in den einzelnen Unternehmen angewandten Risikomanagementmaßnahmen ab.				
Soziale Verantwortung der Unternehmen	Unternehmen	Die Arbeit mit PAK wird möglicherweise weniger als riskanter und gesundheitsgefährdender Arbeitsbereich wahrgenommen. Infolge einer solchen Verbesserung des Images in der Öffentlichkeit kann es für die Unternehmen einfacher sein, Personal einzustellen und zu halten, was die Kosten für die Einstellung senkt und die Produktivität der Arbeitnehmer erhöht.				
Vermeidete Kosten der Festlegung eines AGW	Öffentlicher Sektor	€ 2	€ 2	Keine Änderung	€ 2	€ 1
Andere Auswirkungen						
Recycling - Verlust von Geschäftsmöglichkeiten	Recycling-Unternehmen	In den metallurgischen Sektoren könnte es bei der niedrigsten Option zu einer Einstellung der Produktion kommen, was wiederum zu einer geringeren Produktion von Materialien innerhalb der EU führen würde. Das Studienteam geht jedoch davon aus, dass die Unternehmen weiterhin Materialien von außerhalb der EU beziehen würden, um die Nachfrage zu befriedigen, so dass die für das Recycling verfügbaren Materialien nicht beeinträchtigt würden. Der Metallurgiesektor führt jedoch auch die Sekundärproduktion (Recycling) von Metallen durch, für die ebenfalls Kosten im Zusammenhang mit den AGW/BGW anfallen würden. Bei 7 ng/m³ wird erwartet, dass die Metallurgiebranche in erheblichem Umfang ihre Tätigkeit einstellen muss, was zu einem Verlust der EU-Kapazitäten für das Recycling von Metallen führen würde. Bei 70 ng/m³ sind die Auswirkungen auf die metallurgischen Sektoren im Hinblick auf die Einstellung der Produktion weniger signifikant, womit davon ausgegangen wird, dass die Kapazitäten für das Recycling von Metallen erhalten bleiben. In anderen Bereichen werden keine Auswirkungen auf das Recycling gesehen.				
Auswirkungen auf die Grundrechte	Alle	Positive Auswirkungen auf Gesundheit und Sicherheit. Eine verstärkte Überwachung wird dazu beitragen, dass die Exposition in Zukunft unter Kontrolle und das Risiko für die Arbeitnehmer niedrig bleibt.				
Auswirkungen auf die Digitalisierung	Unternehmen	Die Digitalisierung kann durch hohe Kosten für Hersteller von Siliziummetall und Graphit (die in der Halbleiterherstellung, in Brennstoffzellen, PV-Solarzellen und EV-Batterien verwendet werden) beeinträchtigt werden. Die Kosten und die Einstellung der Produktion von Silizium (C24.45) werden bei 7 ng/m³ als signifikant negativ, bei 70ng/m³ als negativ und bei 700 ng/m³ und 2000 ng/m³ als vernachlässigbar eingeschätzt, was darauf hindeutet, dass die Auswirkungen auf die Digitalisierung hauptsächlich auf der Ebene der strengsten politischen Option auftreten würden. Für die Graphitproduktion (C23.99b) werden in der Modellierung signifikant				

Auswirkungen	Betroffene Stakeholders	7 ng/m ³ & 0,2 nmol/mol Kreatinin	70 ng/m ³ & 0,3 nmol/mol Kreatinin	Option Übergangsfri st **	700 ng/m ³ & 1,5 nmol/mol Kreatinin	2000 ng/m ³ & 3,8 nmol/mol Kreatinin
		negative Kosten bei 7 ng/m ³ und negative Kosten bei 70 ng/m ³ geschätzt, was auf Kostenauswirkungen auf die Digitalisierung bei diesen Werten hindeutet (keine Auswirkungen bei 700 ng/m ³ und 2000 ng/m ³). Die Herstellung von synthetischem Graphit hängt von der C19.1-Verkokung ab, die bei den beiden niedrigsten Optionen ebenfalls mit erheblichen Kosten verbunden ist. Die Schwierigkeiten des Silizium- und des Graphitproduktionssektors, die Kosten bei den beiden niedrigsten Optionen zu decken, können insgesamt zu negativen Auswirkungen auf die Digitalisierung führen, da die Materialkosten steigen oder die Abhängigkeit von Einfuhren aus Drittländern (vor allem China) zunimmt.				
Beiträge zu den UN-Zielen für nachhaltige Entwicklung	Alle	Ziel 3 – positiv Ziel 7 – positiv Ziel 8 – positiv Ziel 14 and 15 – positiv				

Quelle: Studienteam

Anmerkungen: Die Summe kann sich aufgrund von Auf- bzw. Abrunden von der Gesamtsumme unterscheiden. Die Gesamtsummen wurden als zwei Szenarien dargestellt, „(AGW)“, einschließlich der Kosten für das erste Jahr und für wiederkehrende Anpassungen, Luftüberwachung und Verwaltungsaufwand.

* Bitte beachten Sie, dass der in diesen Zeilen angegebene Prozentsatz aller Unternehmen, die ihre Tätigkeit einstellen, deutlich niedriger ist als die in Tabelle 8.13 angegebenen sektoralen Prozentsätze. Dies ist darauf zurückzuführen, dass die Sektoren D35.11 und G45.2 eine deutlich höhere Anzahl von Unternehmen aufweisen, was zu verzerrten Gesamtprozentsätzen führt.

** Übergangszeitraum: 140 ng/m³ & 0,3 nmol/mol Kreatinin für sechs Jahre und dann 70 ng/m³ & 0,3 nmol/mol Kreatinin. Es wird nicht erwartet, dass die Kosten für die Übergangssektoren aufgrund von Änderungen bei den Anpassungen oder der Einhaltung des AGW steigen oder sinken werden. Der Zeitraum, in dem die Kosten anfallen, wird sich jedoch um 6 Jahre verzögern, so dass die Kosten für die Übergangssektoren um 8 % gesenkt werden müssen, um den Gegenwartswert genauer widerzuspiegeln. Diese reduzierten Kosten wurden mit den Gesamtwerten für nicht-Übergangssektoren bei 70ng/m³ addiert, um die Auswirkungen des Übergangszeitraums auf die Gesamtkosten zu veranschaulichen.

Weitere Aspekte, die bei der Entscheidungsfindung zu berücksichtigen sind:

Benzo[a]pyren (BaP) als Marker. Benzo[a]pyren wird als einziger Indikator für die Exposition gegenüber einem Gemisch verwendet. BaP ist ein sehr starkes Karzinogen, und es wird allgemein anerkannt, dass es ein guter Indikator für die Exposition gegenüber PAK ist. BaP ist nicht immer vorhanden, und es kann zu einer Exposition gegenüber anderen karzinogenen PAK kommen. Deren Nutzen lässt sich jedoch nicht quantifizieren, da es keine ERR gibt. Der Schutz vor BaP im PAK-Gemisch wird jedoch wahrscheinlich zu einem Schutz vor anderen PAK im Gemisch führen. Für die meisten der in dieser Studie untersuchten Sektoren liegen Daten vor, die eine Exposition gegenüber einem oder mehreren krebserregenden PAK der Kat. 1, die in den Anwendungsbereich der CMRD fallen (außer BaP), oder es wird erwartet, dass dies aufgrund der Ähnlichkeit der verwendeten Verfahren und/oder Produkte der Fall ist (z. B. Umgang mit erhitzter Kohle und Erdölprodukten). Daher besteht die Möglichkeit, dass eine berufsbedingte Exposition gegenüber anderen karzinogenen PAK stattfindet, die nicht überwacht wird. Wie der RAC feststellte, "wäre es in solchen Fällen besser, die Exposition gegenüber einer breiteren Palette von PAK zu überwachen, z. B. den 16 EPA-PAK, selbst wenn diese weniger krebserregend wären als BaP. [...] Dennoch sollte der Grundsatz der Expositionsminimierung der CMRD für alle karzinogenen PAK gelten."

3-Hydroxybenzo[a]pyren (3-OHBaP) als Biomarker. Ähnliche Bemerkungen zur Verwendung von BaP als Marker für das Gemisch gelten auch für die Verwendung von 3-OHBaP als Biomarker für das PAK-Gemisch. Darüber hinaus stellt das Studienteam fest:

- In vielen Sektoren fehlt es an Daten über die Konzentration von 3-OHBaP im Urin. Dies bedeutet, dass es nicht möglich war, aussagekräftige Vergleiche zwischen den derzeitigen Metaboliten-Konzentrationen und den vorgeschlagenen BGW-Optionen anzustellen;
- Die Beziehung zwischen BaP und 3-OHBaP soll im niedrigen Expositionsbereich nicht genau sein, und unter 0,1729 nmol/mol Kreatinin (0,41 µg/g Kreatinin) wäre die entsprechende Luftkonzentration negativ;
- Urinproben sollten nicht eingefroren aufbewahrt werden, oder sie sollten so schnell wie möglich nach dem Auftauen analysiert werden - die Experten sind hier unterschiedlicher Meinung;
- Es ist bekannt, dass Störvariablen wie Rauchen, der Verzehr von geräucherten oder gegrillten Lebensmitteln (insbesondere Fleisch) und die Nähe zu Feuern, in denen feste Brennstoffe verbrannt werden (d. h. Aktivitäten, die nicht mit der Exposition am Arbeitsplatz zusammenhängen), die PAK-Exposition in der Luft und die Metaboliten-Konzentrationen erhöhen.
- Die DFG (2013, zitiert nach RAC, 2022) gibt an, dass der beste Zeitpunkt für die Probenahme aufgrund der Ausscheidungszeiten 16 Stunden nach der letzten Exposition, d. h. vor der nächsten Schicht, ist. Sowohl die DFG als auch die IARC (2023) weisen darauf hin, dass 3-OHBaP (nicht aber 1-OHP) bevorzugt metabolisiert und mit den Fäkalien ausgeschieden wird.
- Einige Befragte sowie Experten haben darauf hingewiesen, dass es derzeit an akkreditierten Laboratorien für die Analyse von 3-OHBaP in Europa mangelt, insbesondere mit der neuen und empfindlicheren Analysemethode. Es ist zu erwarten, dass bei Inkrafttreten eines BGW mit 3-OHBaP die Laboratorien die bestehenden Methoden übernehmen und die erforderliche Analyse von 3-OHBaP anbieten werden. Obwohl es kurzfristig zu Kapazitätsengpässen kommen kann, sollte sich dieses Problem von selbst lösen.

Andere Krebsarten und Auswirkungen. Die ERR wurde für Lungenkrebs abgeleitet, und es gibt schlüssige Beweise dafür, dass PAK Hautkrebs verursachen, aber es gibt nicht genügend Daten, um die Auswirkungen zu quantifizieren. Es gibt auch Hinweise auf ein erhöhtes Risiko für Blasenkrebs, aber keine schlüssigen Beweise aufgrund von Störfaktoren.

Sensitivitätsberechnungen des RAC deuten darauf hin, dass das Blasenkrebsrisiko die ERR um bis zu einem Faktor 1,7 beeinflussen könnte. Andere Gremien haben die Möglichkeit anderer Erkrankungen festgestellt, aber es können keine Schlussfolgerungen gezogen werden.

Schließlich ist BaP ein Karzinogen ohne Schwellenwert, was bedeutet, dass die Exposition gegenüber jeder Menge BaP das Potenzial hat, Auswirkungen zu verursachen.

Künftige Trends. Das Studienteam hat für eine Reihe von Sektoren Zukunftstrends ermittelt, aber es war nicht möglich, einige Sektoren zu modellieren:

- Stahl- und Eisengießereien könnten ähnlichen Trends unterliegen wie Aluminium, da Stahl für viele Infrastrukturen benötigt wird, die für die Erreichung von "Netto-Null"-Emissionen entscheidend sind, z. B. Windturbinen.

- Auch die Herstellung von synthetischem Graphit wird voraussichtlich zunehmen, da er in Li-Ionen-Batterien (Elektrofahrzeuge), Brennstoffzellen und anderen Artikeln und Verfahren verwendet wird, die zur Erreichung von "Netto-Null"-Emissionen erforderlich sind. Die verfügbaren Nachfragetrends berücksichtigen jedoch nicht Einfuhren gegenüber Herstellung, natürlich gegenüber synthetisch, und das künftige Potenzial für Recycling.
- Kokskohlenstandorte sind in der Regel in Stahlwerke integriert, in denen Koks als Reduktionsmittel in Sauerstoffblasöfen zur Herstellung von Primärstahl verwendet wird. Es ist zu erwarten, dass diese Anlagen weitgehend auf Wasserstoff als Reduktionsmittel und zur Stromerzeugung umgestellt werden. Ein wichtiges Nebenprodukt der Verkokung ist Kohlenteer, der Rohstoff für Kohlenteerpech. Letzteres wird derzeit für die Herstellung von Graphit- und Kohlenstoffelektroden benötigt, die in fast allen metallurgischen Prozessen unverzichtbar sind, und, wie bereits erwähnt, wird Graphit auch in anderen Prozessen und Artikeln benötigt. Die Zukunft der Kokerei ist daher ungewiss.

Dosis-Wirkungs-Beziehung auf der Grundlage von Tierversuchen und Dauer der Auswirkungen. Die DWB-Daten beruhen eher auf experimentellen Studien mit Tieren als auf epidemiologischen Studien. Obwohl es unterstützende Informationen aus Humanstudien gibt, lassen sich die Auswirkungen auf den Menschen anhand tierexperimenteller Daten quantifizieren. Eine weitere Unsicherheit hinsichtlich der Auswirkungen auf die Fruchtbarkeit (Spermienmotilität bei Männern) besteht darin, dass aus den Tierstudien nicht geschlossen werden kann, ob die Auswirkungen auf die Fruchtbarkeit reversibel sind oder nicht. Um eine Überschätzung der Auswirkungen beim Menschen zu vermeiden, wurde bei der Modellierung davon ausgegangen, dass sie dauerhaft sind.

1 INTRODUCTION

This chapter comprises the following sections:

- Section 1.1: Political and legal context;
- Section 1.2: Background; and
- Section 1.3: The study.

1.1 *Political and legal context*

1.1.1 The Carcinogens, Mutagens and Reprotoxic substances Directive

The Carcinogens, Mutagens and Reprotoxic substances Directive (Directive 2004/37/EC), hereinafter the CMRD, protects workers from exposure to carcinogens, mutagens or reprotoxic substances at work.

Substances within the scope of the Directive are substances that meet the criteria for classification as category 1A or 1B carcinogen, mutagen or reproductive toxicant as set out in set out in Annex I to Regulation (EC) No 1272/2008 of the European Parliament and of the Council (the CLP).

Polycyclic aromatic hydrocarbons (PAH: the abbreviation is used as both plural and singular) are today within the scope of the CMRD although no OEL has been established as they meet the criteria for classification as category 1A or 1B carcinogen, mutagen or reproductive toxicant.

PAH appear in the CMRD either directly or indirectly in the CMRD as follows (indirectly where process generated PAH can be formed)¹ in Annex I:

- **Polycyclic aromatic hydrocarbons mixtures:** work involving exposure to polycyclic aromatic hydrocarbons present in coal soot, coal tar or coal pitch. PAH, particularly those containing benzo[a]pyrene, which are carcinogens within the meaning of this Directive, currently hold a skin notation;
- **Diesel engine exhaust emissions (DEEE):** work involving exposure to diesel engine exhaust emissions. The OEL is 0.05 mg/m³ 8-h Time-Weighted Average (TWA), measured as elemental carbon; and
- **Mineral oils:** work involving dermal exposure to mineral oils that have been used before in internal combustion engines to lubricate and cool the moving parts within the engine. Mineral oils currently hold a skin notation.

As a consequence, employers' have today a number of obligations related to PAH within the scope of the Directive which include:

- The employer shall reduce the use of the substance and/or process generating exposure to PAH at the place of work by replacing them, in so far as is technically possible, with

¹ The definition of PAH in the CRMD was expanded in 2019, and DEEE and used mineral oils were also added in the same year.

substances, mixtures or process(es) which, under their conditions of use, are not dangerous or are less dangerous to workers' health or safety, as the case may be;

- Where it is not technically possible to replace the substances, the employer shall ensure that the substances are, in so far as is technically possible, manufactured and used in a closed system;
- Where a closed system is not technically possible, the employer shall ensure that the level of exposure of workers to the substances is reduced to as low a level as is technically possible; and
- Where it is not technically possible to use or manufacture a threshold reprotoxic substance in a closed system, the employer shall ensure that the risk related to the exposure of workers to that threshold reprotoxic substance is reduced to a minimum.

The requirements for minimisation of the exposure apply today to PAH within the scope of the Directive irrespective of establishing an OEL.

The minimum requirements for protecting workers that are exposed to carcinogens and mutagens are — for some substances — expressed by an Occupational Exposure Limit (OELs). For each OEL, Member States (MS) are required to establish a corresponding national limit value (OEL), from which they can only deviate to a lower but not to a higher value. An OEL expresses the concentration of the relevant substance in the air within the breathing zone of a worker in relation to a specified reference period as set out in Annex III to the CMRD.

Of importance for the current assessment, in the case of any activity likely to involve a risk of exposure to CMR substances that are within the scope of the Directive, the nature, degree and duration of workers' exposure shall be determined in order to make it possible to assess any risk to the workers' health or safety and to lay down the measures to be taken. The assessment shall be renewed regularly and, in any event, when any change occurs in the conditions which may affect workers' exposure to the substances.

To determine the degree of exposure it would typically be necessary to measure the workplace concentrations. Measurements of workplace concentrations are not specifically linked to the assessment of compliance with an OEL. The assessment shall be renewed regularly, but the CMRD does not require regular monitoring if changed in the conditions which may affect workers' exposure to the substances does not occur.

1.1.2 REACH

The substances within the scope of the study are not subject to the requirements for registrations under REACH. Some PAH are manufactured industrial chemicals, but many are process generated and are not subject to REACH registration.

PAH occur almost always in mixtures of several PAH and are formed during incomplete pyrolysis or combustion and pyrolysis processes of organic materials, such as coal and wood (see section 2.1.1). The composition of the mixture is varied and depends on the process that generates them as well as the materials involved (RAC, 2022a).

Some substances contain PAH that are released upon use. For example, anthracene oil (EC 292-602-7) and pitch, coal tar, high temp. (CTPHT) (EC number 266-028-2). These may be subject to REACH registrations and other REACH processes.

Chemical Safety Reports (CSRs). None of the substances are registered, however some substances known to contain PAH are registered. As part of the registration processes for these substances, companies have prepared CSRs which among others include an assessment of occupational exposure and environmental exposure. The CSRs that have been a source for the current assessment are presented in Table 1-1.

Table 1-1 List of substances containing PAH for which CSR have been obtained and used in the assessment

Substance	EC number
Pitch, coal tar, high-temp.	266-082-8

Classification and Labelling Inventory (C&L Inventory). This database contains classification and labelling information on notified and registered substances received from manufacturers and importers (self-classification) as well as harmonised classifications as listed in the CLP. The carcinogenic PAH have a harmonised C&L and therefore the inventory was not consulted for self-classifications.

1.1.2.1 Restrictions

The table below presents the current REACH restriction of PAH.

Table 1-2 REACH restrictions on PAH

Entry	Substance	EC number	Restriction
50	Benzo[a]pyrene (BaP)	200-028-5	The restrictions concern the use of certain products that may contain one or more of the PAH substances mentioned. These include, amongst others: 1) Extender oils shall not be placed on the market, or used for the production of tyres or parts of tyres if they contain: - more than 1 mg/kg (0,0001% by weight) BaP, or - more than 10 mg/kg (0,001% by weight) of the sum of all listed PAH; 2) Articles shall not be placed on the market for supply to the general public, if any of their rubber or plastic components that come into direct as well as prolonged or short-term repetitive contact with the human skin or the oral cavity, under normal or reasonably foreseeable conditions of use, contain more than 1 mg/kg (0,0001% by weight of this component) of any of the listed PAH; 3) Toys, including activity toys, and childcare articles, shall not be placed on the market, if any of their rubber or plastic components that come into direct as well as prolonged or short-term repetitive contact with the human skin or the oral cavity, under normal or reasonably foreseeable conditions of use, contain more than 0,5 mg/kg (0,00005% by weight of this component) of any of the listed PAH; 4) Granules or mulches shall not be placed on the market for use as infill material in synthetic turf pitches or in loose form on playgrounds or in sport applications, if they contain more than 20 mg/kg (0,002 % by weight) of the sum of all listed PAH.
	Benzo[e]pyrene (BeP)	205-883-8	
	Benzo[j]fluoranthene (BjFA)	205-910-3	
	Benzo[a]anthracene (BaA)	200-280-6	
	Chrysene (Chr)	205-923-4	
	Dibenzo[a,h]anthracene (DBAhA)	200-181-8	
	Benzo[k]fluoranthene (BkFA)	205-916-6	
	Benzo[b]fluoranthene (BbFA)	205-911-9	

Source: REACH Annex XVII

A Restriction proposal as well as related opinions by the Committee for Risk Assessment (RAC) and the Committee for Socio-Economic Analysis (SEAC) have been published in 2022 that limit the amount of PAH in clay shooting targets (ECHA, 2023a). The restriction is likely to be adopted this year.

In addition, creosote and creosote containing substances are included in REACH Annex XVII entry 31. The restrictions concern the use of these substances in wood treatment and specify that these substances shall not be placed on the market, or used, as substances or in mixtures where the substance or mixture is intended for the treatment of wood. Furthermore, wood so treated shall not be placed on the market. A further restriction is being considered on the placing on the market, re-use and secondary use of wood treated with creosote or related substances (ECHA, 2022a).

1.1.2.2 Authorisation

None of the substances within the scope of this study are listed in Annex XIV of REACH. Substances containing PAH which are released during use, may be subject to REACH authorisations, these are anthracene oil (EC 292-602-7) and pitch, coal tar, high temp. (CTPht) (EC 266-028-2).

1.1.2.3 Other relevant legislation

CLP Regulation (EC) 1272/2008. A harmonised classification of PAH has been established under the CLP. The harmonised classification of the substances within the scope of the study is indicated in Table 1-5.

Plant Protection Products Regulation (EC) 1107/2009. PAH are used in pesticides. For further details check the EFSA website under plant protection products and the specific PAH.

Human and Veterinary Medicinal Products Directives 2001/83/EC and 2004/28/EC. PAH are used in some medicines based on coal tar (skin exposure only), for further details check the EMA website and the specific PAH.

Cosmetic products Regulation (EC) No 1223/2009. A number of PAH or PAH containing substances are prohibited in cosmetic products. These include:

- E.g. benzo[a]pyrene, dibenz[a,h]anthracene, benz[a]anthracene, benzo[e]pyrene, benzo[j]fluoranthene, benz(e)acephenanthrylene, benzo(k)fluoranthene, chrysene, anthracene oil; and
- An important number of PAH mixtures with benzo[a]pyrene >0,005% w/w (e.g., entries 613-636, 1123, 1205-1211, 1540-1541 of Annex II of Regulation (EC) No 1223/2009.

Biocidal Product Regulation (BPR, EU) No 528/2012. In the BPR creosote, a PAH containing substance, is approved as an active substance for Product Type 8 for the treatment by vacuum pressure impregnation of wood in industrial installations to make railway sleepers, or utility poles for electricity or telecommunications.

Persistent Organic Pollutants Regulation (POPs, EU) 2019/2021. PAH² are listed in Annex III part B of the POPs regulation – substances subject to release reduction provisions. This entails that Member States need to draw up inventories of releases to air, water and land; communicate actions plans to identify, characterise and minimise releases with a view of eliminating releases; and when constructing new or significantly modifying old facilities with the potential

² The regulation indicates that "For the purpose of emission inventories, the following four compound indicators shall be used: benzo(a)pyrene, benzo(b) fluoranthene, benzo(k)fluoranthene and indeno(1,2,3-cd)pyrene".

for releases MS need to give priority to alternative processes or techniques that avoid the formation and release of PAH.

1.2 Background

1.2.1 Initiatives by European Commission

As stated in the Tender Specifications, in February 2021, the Commission presented its Europe's Beating Cancer Plan 6, with the aim of tackling the entire disease pathway, from prevention to quality of life of cancer patients and survivors. Actions to fight cancer at the workplace, in particular through the continuous revision of the CMRD, are key components of the Cancer Plan.

The Commission has asked the advice of RAC to assess the scientific relevance of occupational exposure limits for some carcinogenic chemical substances. In support of the Commission's request, the European Chemicals Agency (ECHA) has prepared a scientific report concerning occupational limit values for PAH at the workplace (ECHA, 2022) used as background documentation for the RAC opinion.

In the preparatory phase of making the scientific report, a call for evidence was started on 20 August 2021 to invite interested parties to submit comments and evidence on the subject. The Scientific Report and its later revision as Annex to the RAC opinion (RAC, 2022a) as well as the responses to the stakeholder consultation have been used as an offspring for the current study.

In addition, PAH are part of the 'EU roadmap on carcinogens' initiative. A simple factsheet on PAH has been developed to summarise the risk of exposure from PAH (Roadmap on Carcinogens, 2021).

1.2.2 Opinion of the Committee of Risk Assessment (RAC)

On the 1 December 2022, the Committee for Risk Assessment (RAC) published its opinion on the scientific evaluation of occupational exposure limits for PAH, which is summarised in Table 1-3.

Table 1-3 The outcome of the RAC evaluation to derive limit values for PAH and the evaluation for dermal exposure and suggested notations

Derived limit value	Concentration / notation
Occupational exposure limit value (OEL) - 8-hour time weighted average (TWA)	None
Short term exposure limit (STEL)	None
Biological limit value (BLV)	To be confirmed
Biological guidance value (BGV)	To be confirmed
Notations	
Notations	Skin

Source: RAC, 2022b

RAC recommends reviewing the entry to Annex I of the CMRD so that it covers the diverse range of carcinogenic PAH exposures.

Furthermore, RAC indicated that: "It is not possible to derive a safe level for a BLV for non-threshold carcinogens such as PAH. However, after a Binding OEL (BOEL) has been recommended by the Working Party on Chemicals (WPC) of the Commission's Advisory Committee on Safety and Health (ACSH), the level of 3-hydroxybenzo-a-pyrene (3-OHBaP) in urine corresponding to the air level of BaP should be selected as a BLV. "[...] BaP and PAH are considered

non-threshold carcinogens and the Binding OEL will be set later in the legislative process taking into account the ERR and socio-economic aspects.”

The key conclusions of the evaluation are used as starting points for the health assessment and further described in Chapter 2.

Selected key conclusions of the evaluation are (RAC, 2022b):

- Benzo[a]pyrene (BaP) is considered as indicator for PAH mixtures. BaP and carcinogenic PAH act as non-threshold carcinogens;
- There is sufficient evidence to demonstrate the carcinogenicity of BaP in experimental animals. BaP produced tumours in all species tested for which data were reported following exposure by many different routes;
- PAH are readily absorbed through inhalation, dermal and gastrointestinal routes. Although there are no human data for distribution of PAH in the body following dermal exposure, from the limited animal data that are available, it is reasonable to conclude that PAH are distributed after dermal exposure through various internal organs, including the lungs;
- In relation to occupational exposure to PAH, cancer in the lungs and skin present the main risks. However, there is no quantitative data on skin cancer to conclude on an exposure risk relationship. Therefore, the exposure risk relationship derived is explicitly restricted to excess lung cancer risk;
- To biomonitor human exposures to PAH the biomarkers most commonly applied are 1-Hydroxypyrene (1-OHP) and hydroxyphenanthrenes. Due to their low toxicity, neither of these markers represent adequately the internal exposure to carcinogenic PAH in quantitative terms. Furthermore, no single metabolite/ biomarker can adequately represent the variability of PAH exposure mixtures. To tackle these drawbacks, metabolites of the toxicologically more relevant 3-OHBaP as a metabolite of the carcinogenic BaP, and metabolites of other PAH are taken into consideration. BaP is classified as Mutagen 1B and Carcinogen 1B and is the most potent single PAH together with dibenz[a,h]anthracene;
- Animal studies demonstrated various effects in gestationally and/or early postnatally treated animals. Effects on sperm quality and male fertility have been demonstrated in human populations highly exposed to PAH mixtures. Animal studies demonstrate decreases in sperm quality, changes in testicular histology, and hormone alterations following BaP exposure in adult male animals, and decreased fertility and ovotoxic effects in adult females following exposure to BaP; and
- BaP is classified as Repro. 1B for effects on fertility and developmental toxicity, according to Regulation (EC) No 1272/2008. Observed effects reported in inhalation studies on reproductive toxicity have thresholds. These study results are not appropriate to derive definite OELs. A worst case estimate for an OEL referring to reproductive toxicity would be slightly above 200 ng BaP/m³ which would be associated with an excess lung cancer risk of more than 110 cases per 100,000 exposed workers. Consequently, an OEL below this value would cover reproductive toxicity.

1.2.3 Scientific Committee on Occupational Exposure Limits (SCOEL)

In 2016, the Scientific Committee on Occupational Exposure Limits (SCOEL) published its recommendation on occupational exposure limits for PAH, which is summarised in Table 1-4 (SCOEL, 2016).

Table 1-4 The outcome of the SCOEL evaluation to derive limit values for PAH and the evaluation for dermal exposure and suggested notations

Derived limit value	Concentration / notation
8-hour time weighted average (TWA)	No health-based OEL applicable
Short term exposure limit (STEL)	Not applicable
Biological limit value (BLV)	No health-based limit value applicable
Biological guidance value (BGV)	0.5 µg 1-hydroxypyrene in urine, determined after conjugate hydrolysis [per g creatinine]
Notations	
Notations	Skin

SCOEL notes that in general the urinary excretion of 1-OHP does not exceed 0.5 µg 1-OHP per g creatinine (determined after conjugate hydrolysis) in urine of people not occupationally exposed to PAH (equivalent to 1-OHP 0.26 µmol/mol creatinine). This value also includes smokers, who are not occupationally exposed. Exceeding this value points to occupational PAH exposure, by any route of entrance into the body. As the BGV is derived from the background of the general population, the sampling time is not critical as such. For instance, sampling may be performed before the following shift (SCOEL, 2016).

The above Recommendation was adopted by SCOEL on the 13 December 2016.

1.2.4 Advisory Committee on Safety and Health at Work (ACSH)

The ACSH in its opinion on priority chemicals for new or revised occupational exposure limit values under EU OSH legislation from 2021 listed PAH as a priority carcinogen under the CMRD (immediate priorities) (ACSH, 2021).

The 2023 ACSH opinion states that BaP is considered the relevant marker for PAH and OEL setting (ACSH, 2023). It recognised the RAC derived and ERR and consideration that a STEL is not to be relevant and agreed on the need to establish a time weighted average OEL with no STEL. Whilst RAC recommended a BLV based on the OEL, and the ACSH recognises it's usefulness, a BLV is not included in the ACSH opinion. Although specific biomonitoring considerations for fire-fighters or workers exposed to PAH during accidents should be considered in future guidance. Furthermore PAH, particularly BaP were recommended should be added to the priority list of chemical agents to be followed by the European Partnership for the Assessment of Risk from Chemicals (PARC). The opinion continues to state that should workers become exposed to PAH not containing BaP, all provisions of the CMRD will have to be complied with. In addition, existing entry in Annex III should be updated to take into account the extension of the scope of the CMRD as substances toxic to reproduction, that BaP is classified as Mutagen 1B, and skin notation should be maintained. The ACSH recommends an OEL of 70 ng/m³ should be applied, with a transitional period for the following sectors:

- Steel and iron foundries (including ferroalloy manufacturers);
- Aluminium manufacturers;
- Carbon and graphite electrode manufacturers;

- Coking plants;
- Coal tar distillation;
- Manufacture of refractory products; and
- Welding of train tracks.

For these sectors a transitionary period are recommended:

- 2 years after entry into force of the Directive at an OEL of 140 ng/m³; and
- 6 years after entry into force of the Directive, an OEL of 70 ng/m³.

1.3 The study

This report is one of six reports elaborated within the framework of a study undertaken for the European Commission by a consortium comprising Risk & Policy Analysts Ltd. (RPA) (United Kingdom), COWI A/S (Denmark), FoBiG Forschungs- und Beratungsinstitut Gefahrstoffe (Germany) (FoBiG), and the Office for Economic Policy and Regional Development (EPRD) (Poland). The four six reports are:

- Methodological note;
- Report for 1,4-dioxane;
- Report for isoprene;
- Report for polycyclic aromatic hydrocarbons (PAH);
- Report for welding fumes; and
- Report for cobalt and inorganic cobalt compounds.

One of the key aims of the study is to provide the Commission with the most recent, updated and robust information on a number of substances with the view to support the European Commission in the preparation of an Impact Assessment report to accompany a potential proposal to amend Directive 2004/37/EC.

Details on the methodology used across all substances are included in the Methodological note. The note also includes an initial screening of potential impacts for all impact categories.

1.3.1 Study objectives

One of the key aims of the study is to provide the Commission with the most recent, updated and robust information on a number of carcinogenic substances with the view to support the European Commission in the preparation of an Impact Assessment Report to accompany a potential proposal to amend Directive 2004/37/EC.

The general objectives with regard to these substances (except for welding fumes) include a detailed assessment of the baseline scenario (past, current, and future), as well as the assessment of the impacts of introducing a new OEL and, where appropriate, BLV, a STEL, and a skin notation and a respiratory notation.

The specific objective of this report is to assess the impacts of introducing a binding OEL, a BLV and a skin notation for PAH under the scope of the CMRD.

1.3.2 Limit values assessed

Throughout this document the term 'Limit Values' is used to refer to the group of measures being proposed. This includes OEL, BLV and skin notation.

OELs are 8-hour TWA exposures and define a threshold beyond which workers must not be exposed. OELs are set by the European Commission. For each OEL, Member States are required to establish a corresponding national limit value, from which they can only deviate to a lower but not a higher value.

In addition to setting/reviewing OELs, the European Chemicals Agency (ECHA) has also been mandated to adopt, as appropriate, scientific opinions on the establishment of:

- Biological limit values; and
- Skin notation.

A BLV is 'the limit of the concentration in the appropriate biological medium of the relevant agent, its metabolite, or an indicator of effect'.

A 'notation' is a means of alerting employers that air sampling alone is insufficient to accurately quantitate exposure and that other measures may need to be taken. For example, a 'skin notation' would indicate that measures need to be taken to prevent significant absorption through the skin.

1.3.3 Existing limit values at EU level

No OEL or other limit values at EU level have been established for PAH.

1.3.4 Substances within the scope of the study

Substances within the scope of the Directive are substances that meet the criteria for classification as category 1A or 1B carcinogen, mutagen or reproductive toxicant as set out in Annex I to Regulation (EC) No 1272/2008 of the European Parliament and of the Council (the CLP). Substances that meet the criteria may either have a harmonised classification and listed in Annex VI to the CLP or they may have been classified by the manufacturer or importers' self-classification.

PAH occur almost always in mixtures of several PAH and are formed during incomplete pyrolysis processes of organic materials. Therefore, PAH are process-generated and/or are released unintentionally during use. The whole mixture is within the scope of the Directive.

1.3.4.1 Harmonised classification

Ten PAH have a harmonised classification under the CLP that indicates they are carcinogenic (Carc. 1B); of these, one is further classified reprotoxic (Repr. 1B).

Table 1-5 Harmonised classification of ten PAH classified as carcinogenic according to Annex VI to the CLP

EC No	Chemical name	CAS No	Hazard class and category	Hazard statement code
205-916-6	Benzo[k]fluoranthene	207-08-9	Carc. 1B Aquatic Acute 1	H350 H400

EC No	Chemical name	CAS No	Hazard class and category	Hazard statement code
			Aquatic Chronic 1	H410
205-923-4	Chrysene	218-01-9	Muta. 2 Carc. 1B Aquatic Acute 1 Aquatic Chronic 1	H431 H350 H400 H410
200-028-5	Benzo[a]pyrene	50-32-8	Skin Sens. 1 Muta. 1B Carc. 1B* Repro. 1B Aquatic Acute 1 Aquatic Chronic 1	H317 H340 H350 H360FD H400 H410
205-911-9	Benzo[e]acephenanthrylene	205-99-2	Carc. 1B Aquatic Acute 1 Aquatic Chronic 1	H350 H400 H410
200-280-6	Benz[a]anthracene	56-55-3	Carc. 1B Aquatic Acute 1** Aquatic Chronic 1	H350 H400 H410
205-892-7	Benzo[e]pyrene	192-97-2	Carc. 1B (H350) Aquatic Acute 1 Aquatic Chronic 1	H350 H400 H410
205-910-3	Benzo[j]fluoranthene	205-82-3	Carc. 1B Aquatic Acute 1 Aquatic Chronic 1	H350 H400 H410
200-181-8	Dibenz[a,h]anthracene	53-70-3	Carc. 1B* Aquatic Acute 1** Aquatic Chronic 1	H350 H400 H410
205-878-0	Dibenzo[b,def]chrysene; dibenzo[a,h]pyrene	189-64-0	Muta. 2 Carc. 1B	H341 H350
205-877-5	Benzo[r,s,t]pentaphene	189-55-9	Muta. 2 Carc. 1B	H341 H350

Source: ECHA (2008)

* Specific Concentration Limit: $C \geq 0.01\%$

** M-factor: $M=100$

Notes: in bold are the harmonised classification endpoints that make the substances within scope of the CMRD.

2 BACKGROUND FOR ANALYSING THE HEALTH IMPACTS

This chapter comprises the following sections:

- Section 2.1: Summary of epidemiological and experimental data;
- Section 2.2: Deriving an Exposure Risk Relationship (carcinogenic effects) and a Dose Response Relationship (non-carcinogenic effects);
- Section 2.3: Groups at extra risk; and
- Section 2.4: Summary of background for analysing health impacts.

2.1 Summary of epidemiological and experimental data

2.1.1 Identity and classification

2.1.1.1 Identity

Polycyclic aromatic hydrocarbons constitute a large class of organic compounds consisting of two or more fused aromatic rings. PAH form by incomplete combustion of organic material and therefore under most circumstances do not exist isolated but as components of complex mixtures, which contain many different PAH as well as related compounds (e.g. substances with hydrogen atoms substituted by heteroatoms). Hundreds of individual substances may be released during incomplete combustion or pyrolysis (thermal degradation) of organic matter, an important source of human exposure. There are more than 100 single PAH identified (ASTDR, 1995; SCOEL, 2016; WHO, 1998). In line with the scope of the RAC opinion (RAC, 2022a) substituted (PAH with functional groups) and heterocyclic PAH are not in the scope of this report.

Ten individual PAH have harmonised EU-classifications for carcinogenicity (Carc 1B) (Table 1-5). Substance names, molecular formulae, molecular mass, and selected physicochemical properties of those constituents are listed in Table 2-1.

Table 2-1 Physicochemical properties of the ten PAH with harmonised EU-classification for carcinogenicity (Carc 1B)

Substance name	Molecular formula	Molecular mass (g/mol)	Melting point [°C]	Boiling point [°C]	Vapour pressure [Pa at 25°C]	Log K _{ow}
Benz[a]anthracene	C ₁₈ H ₁₂	228.3	160.7	400	2.8*10 ⁻⁵	5.61
Dibenz[a,h]anthracene	C ₂₂ H ₁₄	278.4	266.6	524	1.3*10 ⁻⁸	6.50
Benzo[a]pyrene	C ₂₀ H ₁₂	252.3	178.1	496	7.3*10 ⁻⁷	6.50
Chrysene	C ₁₈ H ₁₂	228.3	253.8	448	8.4*10 ⁻⁵	5.91
Benzo[k]fluoranthene	C ₂₀ H ₁₂	252.3	215.7	480	1.3*10 ⁻⁸	6.84
Benzo[e]acephenanthrylene	C ₂₀ H ₁₂	252.3	168.3	481	6.7*10 ⁻⁵	6.12
Benzo[j]fluoranthene	C ₂₀ H ₁₂	252.3	165.4	480	2.0*10 ⁻⁶	6.12
Benzo[e]pyrene	C ₂₀ H ₁₂	252.3	179	311	5.7*10 ⁻⁹	6.44
Dibenzo[b,def]chrysene	C ₂₄ H ₁₄	302.4	317	596	6.4*10 ⁻¹²	7.28
Benzo[rs]t]pentaphene	C ₂₄ H ₁₄	302.4	282	594	3.2*10 ⁻¹⁰	7.3

Source: Study team, (ECHA C&L Inventory, 2022, NLM, 2022, RAC, 2022b)

Overall, PAH are solids (at room temperature) with relatively high melting (66-439 °C) and boiling (218–596 °C) points (HCN, 2006). The two-ringed naphthalene shows the lowest melting point (80.5 °C) and highest volatility (0.087 mmHg, approx. 11.6 Pa) at room temperature (ATSDR, 2005). Naphthalene and (to a lesser degree) three-ringed PAH occur in air in the vapour phase whereas higher molecular PAH are very little to moderately volatile. All PAH in Table 2-1 have 4 or more rings. In the air they are mainly absorbed to particles. The water solubility of PAH is low (due to their lipophilic character) and tends to decrease with increasing molecular mass. However, PAH are soluble in many organic solvents (ATSDR, 1995; WHO, 1998).

2.1.2 General toxicity profile, critical endpoints and mode of action

2.1.2.1 Toxicokinetic

The toxicokinetic characteristics of PAH is summarised for human, animal and/or in vitro data below.

Inhalation is the most relevant exposure pathway for PAH for workers. However, also dermal exposure plays an important role in the occupational scenario. For the dermal exposure route absorption rates widely differ, depending on PAH components and model species (RAC, 2022b). BaP as single PAH is readily absorbed via inhalation, the oral and dermal route (Greim, 2008, RAC, 2022b).

Independently from the route of exposure PAH are rapidly distributed via blood and lymph in the whole body and reach various tissues (especially those with high lipid content) (RAC, 2022b, WHO, 2000).

Biotransformation of PAH takes place predominantly in the liver, lung, intestinal mucosa, skin, and kidneys (RAC, 2022b). PAH are mainly metabolized via CYP enzymes in the liver and initially transformed to epoxides, which are converted to dihydrodiol derivatives and phenols (RAC,

2022b). Induction of the oxidative metabolising enzymes (CYP1A1 and A2) occurs via binding to the aryl hydrocarbon receptor AhR (RAC, 2022b; WHO, 2000).

Glucuronide and sulphate conjugates of PAH metabolites are excreted in the bile and urine. Glutathione conjugates are further metabolized to mercapturic acids in the kidney and are excreted in the urine (Greim, 2008). The hydroxylated metabolites of the PAH are excreted in human urine both as free hydroxylated metabolites and as hydroxylated metabolites conjugated to glucuronic acid and sulfate (Greim, 2008). A commonly measured urinary metabolite is 1-OHP (see section 2.1.5). Renal PAH elimination was reported with a half-life range between 6 to 35 hours for workers of a coking plant, which were occupationally exposed (HCN, 2006) and for workers of an aluminium plant, the half-life for PAH elimination of 9.8 hours was measured (Greim, 2008). Metabolism is a prerequisite for hepatobiliary excretion and elimination through the faeces, regardless of route of entry. Excretion half-lives in faeces and urine have been reported in animal studies as 22 hours and 28 hours, respectively (Becher and Björseth, 1983).

2.1.2.2 Critical endpoints

There are numerous publications describing various health effects of PAH. The major health effect of PAH is an increased risk of carcinogenicity, most prominently lung cancer but also in the bladder, and skin (see Section 2.1.3). The International Agency for Research on Cancer (IARC/WHO) classified the substance benzo[a]pyrene (BaP) and certain occupational activities (e.g. coal tar distillation) as carcinogenic to humans (group 1) (IARC, 2012). There is sufficient evidence for the carcinogenicity of BaP and some other PAH in experimental animal studies (Table 2-1). The current understanding of the mechanisms underlying BaP induced carcinogenesis in experimental animal studies is almost solely based on two complementary pathways: those of the diolepoxides and the radical cations (IARC, 2012).

The most relevant non-cancer endpoint of PAH is reproductive toxicity (RAC, 2022b). BaP is classified in the EU as Repro. 1B for effects on fertility and developmental toxicity (ECHA C&L Inventory, 2022).

2.1.2.3 Mode of action

In a recent evaluation RAC concluded that the primary mode of action of BaP's carcinogenicity is genotoxicity and the mechanism of BaP and many other PAH is via "metabolic activation to electrophilic dihydrodiol epoxides and/or quinones which are capable of covalent binding to DNA" (ECHA, 2018b). The non-threshold mode of action of PAH, as assumed in all recent evaluations (see Section 2.2.3) is corroborated in RAC (2022b).

For mixtures (binary or complex) a paradox dose level relationship is described, with more-than-additive effects at low doses and less than additive effects at high doses compared to individual PAH exposure regarding DNA adduct formation (Jarvis et al., 2014).

Multiple animal studies are cited by RAC (2022b), which describe the carcinogenic potential of BaP or PAH mixtures. BaP can act either as initiator and/or promotor of carcinogenicity. The underlying mode of action is primarily genotoxicity of BaP after metabolic activation, which is universal for the different tumour types and route of exposures (see Section 2.1.3.2). Key elements of BaP metabolism to DNA-reactive metabolites are found via diolepoxide pathway, the radical cation pathway, and an *o*-quinone pathway. These DNA-reactive metabolites damage the DNA, via the formation of DNA adducts and ROS-mediated damage and can therefore cause mutations, if not adequately repaired. Depending on the site of mutation e.g. in tumour suppressor or oncogenes, tumour initiation is triggered. Clonal expansion due to tumour promotion

and progression of this mutations can also be influenced by BaP via binding to the aryl hydrocarbon receptor (AhR) (RAC, 2022b).

Next to genotoxic effects also interactions with the proteome are described (Verma et al., 2012). It has been shown that BaP and its metabolites are implicated in oxidative stress pathways, immunosuppression via AhR, as well as epigenetic mechanisms involving cell proliferation, PAH-induced apoptosis, and DNA methylation (IARC, 2012).

2.1.3 Cancer endpoints – toxicological and epidemiological key studies (existing assessments)

2.1.3.1 Human evidence

Exposure to PAH mixtures in various occupational settings has been extensively linked to increase risk of cancer. Major tumour localisation after inhalation is the lung (with some additional evidence for bladder tumours) and after dermal exposure the skin.

2.1.3.1.1 Lung cancer

Armstrong et al. (2003; 2004) performed a meta-analysis to estimate the relationship between cumulative PAH exposure via different occupational settings (including: coke oven, coal gas production, aluminium smelting, carbon anode plants, asphalt work, tar distillation, chimney sweeping, thermoelectric plant, and carbon black industry) and the risk of lung cancer. The overall mean unit relative risk (URR) for lung cancer was 1.20 (95% CI, 1.11-1.29, $p < 0.001$) for cumulative exposure of $100 \mu\text{g}/\text{m}^3$ BaP * years. IARC (2012) updated its carcinogenicity assessment of PAH for lung cancer according to specific processes and concluded that “Coal-tar pitch as encountered in paving and roofing, Coke production, Soot, as found in occupational exposure of chimney sweeps, Exposures during aluminium, production, coal gasification” cause lung cancer.

2.1.3.1.2 Bladder cancer

The outcome of the meta-analysis performed by Armstrong et al. (2003; 2004) indicated that the overall mean was strongly dependent on results for the aluminium production industry, in particular on two large studies (Romundstad et al. (2000) in Norway and especially Tremblay et al. (1995) in Canada). Although the relative risks from other industries were statistically compatible with those for the aluminium production industry, there was little independent evidence for an association of bladder cancer with PAH in coke ovens or in other industries. However, small numbers of cases, especially for mortality studies, limited the power. Another key meta-analysis from Rota et al. (2014) concluded that although the data suggest a possible relationship between PAH exposure and bladder cancer, data are still too limited to draw any definite conclusion.

IARC (2012) concluded that the following causes bladder cancer: “Exposures during aluminium production. In addition, IARC noted that a positive association has been observed between exposure to coal-tar pitch as encountered in paving and roofing and risk of bladder cancer”. However, co-exposure to asbestos, silica, amines, arsenic, cadmium, lead, nickel, vanadium, hydrocarbons (non PAH), sulphur dioxide, sulfuric acid and aldehydes cannot be excluded. Therefore, it is unclear if there is an increased risk of bladder cancer from PAH exposure.

2.1.3.1.3 Skin cancer

In settings with substantial dermal exposure with PAH mixtures an increased risk of skin cancer has been identified (Boffetta et al., 1997). IARC (2012) concluded with regard to the evidence

for skin cancer that the following specific processes cause skin cancer: "Exposures during coal-tar distillation, Soot, as found in occupational exposure of chimney sweeps".

2.1.3.2 Experimental animal evidence

Numerous experimental studies in animal models on carcinogenic effects of PAH are available. Those studies mostly investigated single PAH, mainly BaP. The main route of administration tested was dermal application of BaP. However, studies were also performed with inhalation, intratracheal installation, oral and parenteral application. Extensive summaries are described in WHO (1998), IARC (1973), and DFG (2012). This section focuses on key studies regarding inhalation and dermal exposure, since at workplaces cancerogenic effects of the lung after inhalation and skin after dermal exposure are of main concern (RAC, 2022b, Zhu et al., 2022).

To investigate the real-world exposure scenario of humans, multiple PAH containing mixtures were investigated in animal models. Animals were mainly dermally exposed to extracts, tars, or condensates. However, exposure via inhalation and oral or intratracheal administration was additionally studied.

Three key animal studies all conducted in mice, which evaluate the risk to develop lung cancer after inhalation to PAH/BaP exposure are cited by RAC (2022b). The three studies have in common, that animals were exposed to PAH mixtures including coal oven exhaust gas (containing 0.3 µg/m³ BaP) (Heinrich et al., 1986), a combination of pyrolyzed pitch and coal oven exhaust gas (containing 0.3, 60, or 90 µg/m³ BaP) (Heinrich et al., 1986), coal tar pitch volatile aerosols (50 or 90 µg/m³) (Schulte et al., 1994), and coal tar/pitch condensation aerosols (20 or 46 µg/m³ BaP) (Heinrich et al., 1994). In all studies the exposure time was either 16 h/day with 5 days/week and approx. 2 years of exposure (Heinrich et al., 1986, Schulte et al., 1994), or 17 h/day with 5 days/week and between 10 or 20 months of exposure followed by 10 months without exposure (Heinrich et al., 1994). An increased lung tumour incidence was observed after exposure with PAH mixtures in those studies (Heinrich, 1996, Heinrich et al., 1994, Schulte et al., 1994), which was shown to be dose-dependent (Heinrich et al., 1994, Schulte et al., 1994).

2.1.3.3 Genotoxicity

International assessments of genotoxicity of single PAH are summarised by RAC (2022b). It was concluded that metabolic activation to genotoxic metabolites is seen as a prerequisite for the carcinogenic potential of PAH. BaP is classified as Muta. 1B (H340) and chrysene is classified as Muta. 2 (H341) (ECHA, 2019).

Some human evidence for genotoxic effects of PAH was concluded from studies with patients topically treated with coal-tar for psoriasis. Increased concentrations of genotoxic metabolites compared to the controls were found in urine samples (Wheeler et al., 1981). Moreover, several studies showed an increase in aromatic DNA adducts after 32P-postlabelling in eczema and psoriasis patients in skin and/or blood cells (Godschalk et al., 1998, Schoket et al., 1990), and in coal tar-based paint workers (Lee et al., 2003). However, benzo[a]pyrene-7,8-diol-9,10-oxide-DNA adducts were not found to be significantly increased by Pavanello and Levis (1994) in peripheral blood cells of psoriasis patients after coal tar treatment.

Genotoxicity of PAH was intensively studied in vitro (Table 2-2) and in vivo (Table 2-3), as summarized by DFG (2012). In vitro assays include bacterial DNA repair and mutation tests; DNA damage detection in eukaryotes (including DNA repair (R), DNA adducts (DA), and unscheduled DNA synthesis (UDS)). In vivo assays were applied to test for chromosomal effects of PAH in mammalian cells (e.g. DNA binding, DNA adducts as well as sperm abnormalities). In addition, mutations after PAH exposure in *Drosophila melanogaster* were investigated as well.

Taken together it can be concluded that several PAH cause DNA damage and mutagenicity in vitro and in vivo.

Table 2-2: Summary of in vitro assays testing genotoxicity of PAH adapted from DFG (2012)

Substance Name	Mutagenicity of PAH in <i>Salmonella typhimurium</i> *	DNA damage in eukaryotes
Dibenzo[def,mno]chrysene	+/-	n.a.
Benzo[a]anthracene	+/-	UDS (+), R (+), DS (±)
Benz[e]acephenanthrylene	+/-	DA (+)
Benzo[j]fluoranthene	+	DA (+)
Benzo[k]fluoranthene	+	DA (+)
Benzo[a]pyrene	+	UDS (+), R (+), DA (+)
Chrysene	+/-	R (-), DA (-)
Cyclopenta[cd]pyrene	+	DA (+)
Dibenz[a,h]anthracene	+/-	UDS (+), R (-), DA (+), B (+)
Naphtho[1,2,3,4-def]chrysene	+/-±	n.a.
Dibenzo[b,def]chrysene	+/-±	n.a.
Dibenzo[def,p]chrysene	+/-±	n.a.
Indeno[1,2,3-cd]pyrene	+	n.a.
Naphthalene	-	n.a.
Phenanthrene	+/-	R (-), UDS (+/-)
Pyrene	+/-	R (-), UDS (+/-), DA (-)

Source: Study team, DFG (2012)

*With metabolic activation, R: DNA repair, DA: DNA adducts, UDS: unscheduled DNA synthesis, n.a.: not applicable, R: DNA repair, Results_ + positive, - negative, ± inconclusive, n.a.: not applicable.

Table 2-3: Summary of in vivo mammalian cell systems testing genotoxicity of PAH adapted from DFG (2012)

Substance Name	Effects in <i>Drosophila melanogaster</i>	Chromosomal effects in mammalian cells	Morphological transformation in mammalian cells
Dibenzo[def,mno]chrysene	n.a.	n.a.	n.a.
Benzo[a]anthracene	SLRL (+/-), somatic mutation (-), SMART (+), R (+)	SCE (+), CA (-/+), MN (+), DNA binding (+), nuclear anomalies (-), DNA adducts (+)	n.a.
Benz[e]acephenanthrylene	n.a.	SCE (+), CA (-), DNA binding (+), DNA adducts (+), MN (+), UDS (+), nuclear anomalies (-)	n.a.
Benzo[j]fluoranthene	n.a.	DNA adducts (+)	n.a.
Benzo[k]fluoranthene	n.a.	DNA adducts (+), DNA binding (+)	n.a.
11-thiabenz[a]fluorene	n.a.	MN (+), DNA adducts (+)	n.a.
Benzo[a]pyrene	SLRL (-/±), somatic mutation (+), R (+)	UDS (-), DNA binding (+), CA (+/-), SCE (+), MN (+/-), sperm anomalies (+), DNA adducts	+

Substance Name	Effects in <i>Drosophila melanogaster</i>	Chromosomal effects in mammalian cells	Morphological transformation in mammalian cells
		(+), nuclear anomalies (+), DNA binding (+), DNA adducts (+)	
Chrysene	n.a.	SCE (+), CA (-), MN (+), DNA binding (+), meta-phase oocytes (+)	n.a.
Cyclopenta[cd]pyrene	n.a.	n.a.	n.a.
Dibenz[a,h]anthracene	n.a.	SCE (+/-), CA (-), MN (+/-), DNA binding (+), DNA adducts (+), UDS (+)	n.a.
Naphtho[1,2,3,4-def]chrysene	n.a.	DNA binding (+)	n.a.
Dibenzo[b,def]chrysene	n.a.	n.a.	n.a.
Dibenzo[def,p]chrysene	n.a.	n.a.	n.a.
Indeno[1,2,3-cd]pyrene	n.a.	DNA binding (+)	n.a.
Naphthalene	n.a.	MN (-)	n.a.
Phenanthrene	n.a.	CA (-), SCE (+), MN (-)	-
Pyrene	R (±)	SCE (-), MN (-), nuclear anomalies (-), sperm abnormalities (-), DNA binding (-)	n.a.

Source: Study team, DFG (2012)

Notes:

CA: chromosomal aberration, SCE: sister chromatid exchange, MN: micronucleus assay, UDS: unscheduled DNA synthesis, somatic mutation: spontaneous change of eye pigmentation by effects on a locus in the stem cell line; SLRL: sex-linked recessive lethal mutation, SMART: somatic mutation and recommendation test. Results: + positive, - negative, ± inconclusive, n.a.: not applicable.

2.1.4 Non-cancer endpoints – toxicological and epidemiological key studies (existing assessments)

The acute toxicity of PAH is low. The key non-cancer endpoints discussed by RAC are related to reproductive toxicity (RAC, 2022b). BaP is classified in the EU as Repro. 1B for effects on fertility and developmental toxicity (ECHA C&L Inventory, 2022).

However, human evidence is scarce and experimental animal studies were mostly performed with oral or parenteral administration, leading to high observed effect levels. In the following sections, the evidence is summarised.

2.1.4.1 Human evidence

For humans, only limited epidemiological data is available for non-cancer endpoints. A recent systematic review analysed the available epidemiological data for effects on male fertility (Kakavandi et al., 2023). The authors analysed 17 studies (8 of them being case-control studies), the majority of which was conducted in China (n=10). The studies investigated correlations between various parameters linked to infertility (sperm parameters such as sperm count, motility, morphology, but also DNA damage and other effects) and PAH exposure, quantified by biomonitoring. Most studies focussed on environmental exposure and no correlation with inhalation exposure can be derived from the data. Although there were inconsistencies and methodological limitations noted, the authors concluded that their results show a significant negative relationship of PAH exposure to sperm quality.

2.1.4.2 Experimental animal evidence

Animal experiments investigating the reproductive and developmental toxicity of PAH (here focusing on BaP) showed that in general the induction of the cytochrome P450 monooxygenase receptor is crucial for the effects (differences of reprotoxic and embryotoxic effects occurred depending on the genotypes of mice). Additionally, the route of exposure might also affect the magnitude of effect (RAC, 2022b).

The mode of action relevant for reproductive and developmental toxicity effects are under investigation and not fully understood yet. BaP can bind to AhR and result in either direct transcriptional activation of different target genes or activation of second messenger system (Ramesh et al., 2022). Via these pathways interaction with the steroidogenic pathway and oestrogen signalling pathway might be crucial (Booc et al., 2014). RAC (2022b) lists six oral developmental toxicity studies (2 diet studies in mice and 4 gavage studies in mice and rats) and three reproductive toxicity studies (2 diet in mice and 1 gavage in mice), which tested dose levels ≥ 50 mg/kg/d BaP (WHO, 1998).

Five of the developmental toxicity studies detected effects including increased intrauterine toxicity and malformation, and neurodevelopmental alterations. Furthermore, two of the three reproductive toxicity studies were used to derive a no observed effect level (NOEL) of 150 mg/kg bw per day due to effects on sperm in lumen of testes, number of offspring, and malformations. In addition, an oral gavage study with BaP resulted in F1 in total sterility in 97% of exposed female and male mice. Three further gavage studies with rats with administered doses ≤ 1.2 mg/kg bw did not reveal developmental toxicity.

One subacute inhalation (via nose only) study in pregnant rats (F-344/Day 11-20 of gestation) resulted in a significant decrease in plasma progesterone, estradiol, and prolactin at concentrations of 75 and 100 $\mu\text{g}/\text{m}^3$ on day 17 of gestation (Archibong et al., 2012). In addition, a dose dependent decrease in pups per litter and in foetal survival compared to unexposed controls (survival: 78.3%, 38 % and 33.8% per litter in the dosage groups 25, 75 and 100 $\mu\text{g}/\text{m}^3$) and a decrease in main pup weight in the 75 and 100 $\mu\text{g}/\text{m}^3$ dose group was observed (Archibong et al., 2012).

Moreover, two subcutaneous studies with BaP were conducted in rats. The first study tested 5 mg/animal/day between day 1-11 or day 1-16 of gestation. At day 10 and 12 profuse vaginal haemorrhage, and at days 14 intraplacental haemorrhage was detected in the maternal animals, whereas in F1 animals, foetal death and resorption up to day 18 was observed (Wolfe and Bryan, 1939). In another subcutaneous study, conducted in Sprague-Dawley rats with 50 mg/kg bw/day at day 6-8 or 6-11 of gestation a significant increase in the number of resorptions and foetal wastage (dead fetuses plus resorption) and foetal weight reduction was detected (Bui et al., 1986).

SCOEL (2016) and DFG (2012) summarized key studies for BaP adverse effects on the fertility of female mice and on postnatal development. There are three key studies with rats (F-344) with route of application being inhalation (RAC, 2022b). For male rats two studies were conducted (Archibong et al., 2008, Inyang et al., 2003). Inyang et al. (2003) identified reduced stored sperm progressive motility in rats in the mid and high dose groups (75 and 100 μg BaP/ m^3), compared to low dose (25 μg BaP/ m^3) and controls, when treated 4 h/day for 10 days. Additionally, at 75 μg BaP/ m^3 a significant decline in serum testosterone was detected up to 48 h post cessation, followed by compensatory increase at 72 h. Moreover, luteinizing hormone (LH) levels were altered at 24, 48 and 72 h post exposure (Inyang et al., 2003). Archibong et al. (2008) made similar observations with significantly reduction in sperm production

and intra-testicular testosterone concentrations, and concurrent increase in LH levels. In addition, a significant decrease in mean testis weight (33%), total weight of tubules (27%) and total tubular length (39%) was detected in exposed rats (Archibong et al., 2008). Moreover, there is one oral gavage study in male rats, which showed a significant reduction in testicular daily sperm production, sperm counts at PND 90 and serum testosterone at PND 8,35, 90 at ≥ 10 mg/kg bw compared to controls (Liang et al., 2012).

In female rats, inhalation of BaP (50, 75, 100 $\mu\text{g BaP/m}^3$ for 4 h/day for 14 days) resulted in the high dose group in an extended estrous cycle, significant reduction of ovulation rates, foetal survival, and foetal losses. This was accompanied by a reduction in plasma estradiol and progesterone at proestrous and diestrous I. FSH levels were increased, LH was reduced in proestrous animals and AHH was induced via AhR in ovaries (Archibong et al., 2012).

Other postnatal effects mainly concern neurodevelopmental adverse effects and key studies indicate transplacental deposition of BaP to the foetus after acute maternal exposure via inhalation (BaP:carbon black aerosol (100 $\mu\text{g/m}^3$) 4 h exposure, on gestation day 15 of a 21-day gestation period). When rats were exposed in utero via mothers prenatally, DNA binding alteration of the transcription factor Sp1 in the developing cortex and cerebellum were detected postnatally. According to the authors this results hint towards a possible dysregulation of crucial gene expression during brain development and might be associated with neural (neuronal and glial) development alterations (Hood et al., 2000).

Furthermore, exposure via the oral route of exposure of up to 2 mg/kg/day BaP from postnatal exposure resulted in Sprague-Dawley rats in behavioural impairment including locomotor activity and spatial learning function (Chen et al., 2012). When parental Long Evans rats were exposed to BaP with 300 $\mu\text{g/kg/bw}$ a significant deficit in cortical neuronal response of off-spring was identified, mediated via changes in the gene expression levels of NMDA receptor unit (NR2B) (McCallister et al., 2008). Next to the neurodevelopmental toxicity effects, there is also first evidence for adverse effects during cardiovascular development, associated with postnatal increased systolic blood pressure in the offspring of BaP orally treated pregnant LEH rats in middle and high dosage group (600 and 1200 $\mu\text{g/kg/BW}$) (Jules et al., 2012).

2.1.5 Biological monitoring – toxicological and epidemiological key studies (existing assessments)

Biomonitoring of PAH exposure is performed in tissue and matrices like urine and/or blood by detecting PAH metabolites, DNA- and protein adducts (Angerer et al., 1997). In diagnostics mainly urine samples are taken and analysed for the universal PAH marker 1-OHP (1-hydroxypyrene, a major metabolite of pyrene) due to high stability and occurrence after exposure to any PAH mixture (Jongeneelen et al., 1988). Analytically 1-OHP can be detected via high performance liquid chromatography/fluorescence detector (HPLC/FLD) (limit of quantification, LOQ 20 ng/l); LC-MS/MS (limit of detection, LOD 5ng/l), and GC-MS (Barbeau et al., 2014, Heudorf and Angerer, 2001).

However, pyrene is not carcinogenic and therefore for risk assessment purposes, the ratio of pyrene to a carcinogenic PAH, such as BaP should be known (Boogaard, 2008). Since BaP is one of the most potent carcinogenic substance in PAH mixtures, biological monitoring of 3-OHBaP metabolite detection is more closely related to the genotoxic entity than 1-OHP (RAC, 2022). Relatively new methods using GC-APLI-MS have been developed to detect 3-OHBaP in urine at very low levels (LOD of 0.6 pg/l and LOQ 1.8 pg/l) (Richter-Brockmann et al., 2019). Recently an alternative to 3-OHBaP has been established with urinary trans-anti-7,8,9,10-tetrahydroxy-7,8,9,10-tetrahydrobenzo[a]pyrene (7,8,9,10-OHBaP, tetraol-BaP) (Barbeau et al., 2018). This

metabolite serves as biomarker to detect the carcinogenic mechanism of BaP with a limit of determination of 0.05 ng tetraol-BaP/L of urine (Weiss et al., 2019). In general, detection of a broad spectrum ranging from low-molecular PAH (e.g. naphthalene) and high-molecular PAH (e.g. BaP and dibenzopyrenes) would be desirable (SCOEL, 2016). Nevertheless, the proportion of PAH metabolites excreted in the urine generally decreases with an increasing molecular weight due to increasing biliary excretion (SCOEL, 2016).

PAH are ubiquitously present in the surrounding environment (e.g. tobacco smoke, smoked and grilled food, traffic exhaust, mineral oil products, domestic combustion and industrial emissions contain PAH). Those background levels have been monitored and assessed in many EU-countries for smokers and non-smokers (RAC, 2022b). The recent EU project HBM4EU reported a range of 95th percentiles for the non-smoking general population in 8 EU and 2 non-EU countries from 0.085 to 0.74 µg 1-OHP/g creatinine (RAC, 2022b). Smoking elevates 1-OHP levels about 2 to 3 times (DFG, 2013). For the assessment of occupational exposure, detecting 3-OHBaP, smoking falsifies the biomonitoring measurements (Lafontaine et al., 2006). Initial tests of urine samples from the general population show internal BaP exposures with tetraol-BaP in the range up to 0.1 ng/L. Occupational exposures were generally above 0.1 and up to about 4 ng/L of urine (Weiss et al., 2019).

It has been shown that correlations between external and internal exposure of PAH can be made. For example, post-shift urinary 1-OHP and airborne BaP levels correlated reasonably well ($r^2 = 0.768$) (Unwin et al., 2006). The relationship between BaP (=x) and 1-OHP (=y) was determined to be $y = 11.1x + 1.13$, at sites without use of respiratory protection or significant dermal exposure (RAC, 2022). ECHA (2018) further noted that "...airborne BaP correlated well ($r^2 = 0.971$) with levels of carcinogenic 4–6 ring PAH and was an effective indicator of exposure for all industries where significant particle bound PAH levels were found and, in particular, for CTPV exposure." Urinary biomonitoring data may be expressed as µg 1-OHP/g creatinine. To convert µg 1-OHP/g creatinine into µmol 1-OHP/mol creatinine, a factor of 1.93 can be used (ECHA, 2018b).

Furthermore, the relationship between airborne BaP (=x) and urinary 3-OHBaP (=y) was determined to be $y = 0.001835x + 0.1729$ ($r = 0.89$) (Lafontaine et al., 2004). ECHA (2018b) noted "[...] one limitation of this relationship is that it is also not accurate in the low exposure range and is not able to estimate exposure levels below urinary 3-OHBaP values below 0.1729 nmol/mol creatinine (below this level, the corresponding air concentration would be negative)."

In its opinion RAC propose to establish a biological guidance value (BGV) for 1-OHP, based on the levels found in the non-smoking general population (RAC, 2022b). This BGV would represent the background level of non-smoking, not occupationally exposed people.

Although the committee confirmed that it is not possible to derive a safe level, it recommended to establish a biological limit value (BLV) for 3-OHBaP in urine. This BLV should correspond to the air concentration of the BOEL once established.

2.2 Deriving an Exposure Risk Relationship (carcinogenic effects) and a Dose Response Relationship (non-carcinogenic effects)

2.2.1 Starting point

The starting point of the following quantitative considerations is the recent evaluation performed by RAC (2022a, b).

In their opinion published in December 2022 RAC considered PAH as non-threshold carcinogens and therefore did not propose a health-based OEL. Instead, an exposure-risk relationship was derived. This ERR is based on epidemiological data as analysed in the meta-analysis by (Armstrong et al., 2003, 2004), which covers many different industrial settings and jobs. The ERR uses BaP (inhalable fraction) as indicator substance to characterise exposure to the PAH mixture. RAC considered BaP to be the “most robust marker of PAH-related cancer risk via the inhalation route” (RAC, 2022a), as it is a very potent carcinogen and a large amount of exposure data is available for this substance. The ERR describes the excess risk for lung cancer from PAH exposure only. The evidence for bladder cancer was not considered sufficient by RAC for inclusion in the ERR.

BaP is classified for reproductive toxicity (Cat 1B). Therefore, any BOEL set for PAH should be protective against reprotoxic effects, according to RAC. Based on experimental animal studies with inhalation exposure to BaP as single substance (respirable fraction), RAC concluded on a putative OEL of 223 ng BaP/m³ for reproductive toxicity. Considering the expected excess cancer risk at such exposure levels RAC concluded that “there is no need to establish a separate OEL for respirable dust connected to reproductive toxicity” as an OEL based on carcinogenic effects will likely be below that concentration (RAC, 2022a).

RAC further proposed to establish a BLV with 3-OHBaP in urine as the marker substance. RAC acknowledged that a safe level for PAH as non-threshold carcinogens cannot be set. This BLV should correspond to the air concentration of the BOEL once established.

2.2.2 ERR for carcinogenic effects

2.2.2.1 Approach

In the past, various national organisations, the former Scientific Committee on Occupational Exposure Limits (SCOEL) and RAC (for different regulatory purposes: in relation to a restriction proposal for PAH in rubber crumb material used as in-fill material for synthetic turf pitches; as a recommendation of an ERR to be used for authorisation dossiers on coal tar pitch, high temperature) derived exposure-risk relationships for workers exposed to PAH by the inhalation route (Table 2-4).

All these evaluations used the information provided in the meta-analysis by (Armstrong et al., 2003, 2004) as a starting point. These authors evaluated 39 cohort studies from various industrial sectors (coke ovens, gasworks, aluminium production works, asphalt works, chimney sweeps) and calculated a unit relative risk (URR) of 1.2 for lung cancer from these studies for a cumulative exposure to 100 (µg BaP/m³) * years.

All evaluations used BaP as the indicator substance for predicting the cancer risks from the whole PAH mixture. Alternatives to the use of BaP as indicator substance as discussed by RAC (RAC,) would be

- Use of the toxic equivalency factor approach for a selection of PAH; and
- Quantifying total PAH exposure as benzene soluble matter.

Petry et al. (1996) analysed profiles of individual PAH at various workplaces and environments and calculated the relative potency of PAH mixtures with that of BaP by using toxic equivalency factors. With this approach they concluded that BaP is responsible for 27 to 67% of the potency of the mixtures.

Schneider et al. (2002) investigated the relative potency of BaP versus PAH mixtures by comparing the results of bioassay with rodents for both pure BaP and various types of PAH mixtures. They found a strong dependence on the target organ: forestomach tumours seem to be caused mainly by BaP (ratios 0.7 to 1.2 for the concentration of pure BaP versus equipotent BaP concentration in PAH mixture), whereas for lung cancer (after oral exposure, inhalation or implantation) the ratios were much higher (13 – 60) and for skin cancer after dermal exposure the ratios were 2 to 11 (with one outlier with ratio 28). They concluded that the toxic equivalency factors do not adequately reflect the potencies of mixtures as they do not take into account this exposure route and target organ specific differences. Nevertheless, using BaP as an indicator substance for the potency of PAH mixtures is also supported by these authors.

RAC concluded that based on the abundance of data for BaP and due to the fact that this substance is one of the most potent genotoxic carcinogens its use as indicator substance is a “adequate and toxicologically relevant surrogate for the overall PAH risk” (RAC, 2022a).

In the following reports, these existing ERRs are presented in some detail.

Health Council of the Netherlands – DECOS (HCN, 2006)

The Dutch Expert Committee on Occupational Standards (DECOS) of the Health Council of the Netherlands used the meta-analysis data of (Armstrong et al., 2003, 2004) (see above) for deriving an ERR for the Netherlands (HCN, 2006). Only lung cancer was considered. With the background lung cancer rate for the male Dutch population a concentration of 5.7 ng/m³ corresponding to a cancer risk of 4 per 100,000 and a concentration of 550 ng/m³ corresponding to a cancer risk of 4 per 1000 was calculated.

Ausschuss für Gefahrstoffe (Germany) (AGS, 2010)

A similar approach was chosen in Germany. Again, only lung cancer risks were quantified by deriving an ERR. With the national lung cancer rate for males the following risks were calculated.

- 700 ng/m³ corresponding to an excess cancer risk of 4 per 1000 (tolerance risk level);
- 70 ng/m³ corresponding to an excess cancer risk of 4 per 10,000 (acceptable risk level I); and
- 7 ng/m³ corresponding to an excess cancer risk of 4 per 100,000 (acceptable risk level II).

Scientific Committee on Occupational Exposure Limits (SCOEL, 2016)

SCOEL took into consideration the two evaluations of DECOS (HCN, 2006) and AGS (2010) and concluded that their outcome was very similar: “Taking both assessments together, a mean 8h-TWA PAH exposure over 40 working years of about 6 ng benzo[a]pyrene per m³ would lead to an excess lung cancer mortality rate $4 \cdot 10^{-5}$.”

RAC recommendation for ERR for PAH in coal tar pitch (high temperature) for authorisation (ECHA, 2018b)

For quantifying risks from PAH exposures due to use of high temperature coal tar pitch RAC developed an exposure-risk relationship and recommended its use in authorisation dossiers. Again, this evaluation started from the URR of 1.2 for lung cancer in the meta-analysis of

Armstrong et al. (2003). Although Armstrong et al. (2004) used a log-linear model, the linear model was considered precise enough in the low concentration range. With a background lung cancer rate for the male population in the EU-28 of 7% a risk of 5.6 per 1000 for a work life exposure (40 years) at 1 µg/m³ was calculated. This corresponds to a risk of 4 per 10,000 at a concentration of 7.1 ng/m³.

In the same way the excess bladder cancer was calculated from the URR of 1.33 reported by (Armstrong et al., 2003) and the background bladder cancer rate (EU-28, male population) of 3%. The excess bladder cancer risk was 4 per 1000 at a concentration of 1 µg/m³, or 4 per 10,000 at 4 ng/m³.

RAC/SEAC Opinion on Restriction Proposal for PAH (ECHA, 2018a)

The same ERR for bladder cancer was also used by RAC for calculating cancer risks from inhalation of PAH from use of rubber crumb as in-fill material in synthetic turf pitches. However, bladder cancer risk estimates were not included in the assessment.

RAC Opinion on Scientific Evaluation of OELs for PAH (RAC, 2022b)

In the opinion on OELs RAC considered the relationship of PAH exposure at workplaces and lung cancer consistent. However, the evidence for bladder cancer was considered less consistent: not in all studies or processes an increased risk was observed and confounding by the presence of established bladder carcinogens (aromatic amines) could not be excluded in all cases. RAC calculated the maximum influence from not considering possible bladder cancer risks to be a factor of 1.7.

The following tables provides an overview on the linear ERRs resulting from these various previous evaluations and RAC's new opinion on PAH (RAC, 2022a) by comparing the exposure concentration leading to an excess cancer risk of 4 per 100,000 exposed workers.

Table 2-4 Overview on exposure-risk relationships for workers exposed to PAH by inhalation

Organisation	Concentration BaP for excess cancer risk 4 per 100,000	
Health Council of the Netherlands, DECOS (HCN, 2006)	5.7 ng/m ³	Lung cancer, Dutch male population rates
Ausschuss für Gefahrstoffe (Germany) AGS (2010)	7 ng/m ³	Lung cancer, German male population rates
SCOEL (2016)	About 6 ng/m ³	By consideration of both DECOS and AGS
RAC recommendation for ERR for PAH in coal tar pitch (high temperature) for authorisation (ECHA, 2018b)	7.1 ng/m ³ 10 ng/m ³ 4.2 ng/m ³	Lung cancer Bladder cancer combined
Background document to RAC/SEAC opinion on Restriction proposal for PAH in crumb rubber (ECHA, 2018a)	7.1 ng/m ³	Lung cancer
RAC (2022b)	7.1 ng/m ³	Lung cancer

Source: Study team

2.2.2.2 Conclusion

The ERR used for calculating excess cancer risks at the various policy options is the one proposed by RAC (RAC, 2022b). It uses BaP as the indicator substance to estimate lung risk from exposure to PAH mixtures.

Table 2-5 Exposure-risk relationship for excess lung cancer risk of workers exposed to PAH mixtures, as proposed by RAC, with BaP concentration (inhalable fraction) as exposure indicator

Concentration of BaP (ng/m ³) as indicator for PAH mixtures	Excess (lifetime) lung cancer risk (cases per 100,000 exposed)
1	0.56
7	3.92
10	5.6
70	39.2
100	56
700	392
2000	1120

Source: RAC, 2022b

PAH are considered non-threshold carcinogens by RAC, with a linear exposure-risk relationship, which can also be expressed by the following equation:

Equation 1

$$ER_{\text{conc}} = 5.6\text{E-}06 * \text{conc.}, \quad \text{conc} > 0$$

where

- ER_{conc} refers to the excess lung cancer risk from PAH mixtures at a given concentration;

and

- Conc. is the exposure concentration given as ng BaP/m³ (inhalable fraction) (under the assumption of continuous exposure over a work life, i.e. 40 years, 8 h/d, 5 d/w, 48 w/a).

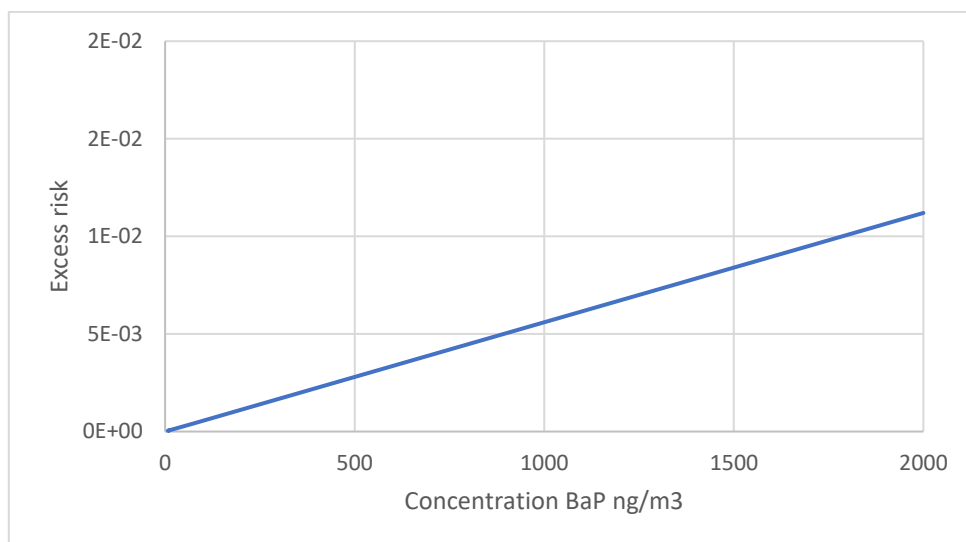


Figure 2-1: ERR for the lung cancer after PAH exposure (with exposure expressed by concentration of indicator substance BaP)

Source: Study team

2.2.2.3 Discussion

The ERR developed by RAC is based on epidemiological data (the extensive meta-analysis of (Armstrong et al., 2003) covering 39 cohort studies from various industrial sectors) on lung tumours caused by PAH mixtures and avoids uncertainties resulting from the use of experimental animal studies. However, uncertainty results from the limited evidence for further tumour locations, especially bladder tumours. There is some, but according to RAC not convincing evidence for these tumours being caused by PAH. In several of the studies showing increased incidences for these tumours, parallel exposure to aromatic amines (known carcinogens causing bladder tumours) cannot be ruled out. RAC concluded that the possible underestimation of risks due to the exclusion of bladder tumours is lower than a factor of 2.

2.2.3 DRR for non-carcinogenic effects

2.2.3.1 Approach

The most relevant non-cancer endpoint is reproductive toxicity. Other endpoints are not considered relevant by RAC in the exposure range given by the policy options of this study.

Developmental toxicity

RAC provided the following tentative quantitative consideration for this endpoint, based on the inhalation study on reproductive toxicity of Archibong et al. (2002), with inhalation exposure of pregnant female rats (exposure from gestational days 11 to 20) to respirable BaP:

- LOAEC for foetal survival: 25 µg BaP/m³
- Human NOAEC respirable BaP:
 - LOAEC foetal survival;
 - divided by 2 (4h/d in experimental study versus 8 h/d at workplace);
 - by 1.49 (respiratory volume 6.7 m³ at rest versus 10 m³ during work (light activity));

- by factor 2.5 (interspecies extrapolation);
- by factor 5 (intraspecies extrapolation);
- by factor 3 (LOAEC to NOAEC extrapolation); and
- Putative OEL inhalable BaP (respirable fraction): 223 ng BaP/m³.

With a conversion factor of 5 (assuming 20% respirable fraction in the inhalable dust) as discussed in the Annex to the RAC opinion (RAC, 2022), RAC's putative OEL would be converted to approx. 1 µg BaP (inhal)/m³.

Apart from pup survival (i.e. percentage of live foetuses at the day of birth compared to implantation sites determined at day 8 of gestation) further endpoints were investigated by Archibong et al. (2002). The number of live pups per litter and hormonal changes were also found to be affected by BaP exposure. In other publications of this group effects on male fertility after BaP inhalation were observed (reduced sperm motility at 75 µg BaP/m³ and higher, Inyang et al. (2003), changed hormone concentrations (testosterone and luteinizing hormone, at 75 µg BaP/m³ (Archibong et al., 2008, Inyang et al., 2003) and testis weights, at 75 µg BaP/m³ (Ramesh et al., 2008)) (see below: "Male reproductive toxicity (infertility)").

For deriving a DRR for developmental toxicity the same study (Archibong et al., 2002) and endpoint (foetal survival) as used by RAC for deriving the putative OEL is used. In order to derive a DRR the dose-response data from Archibong et al. (2002) are modelled with EFSA PROAST version v 70.0 at the EFSA R4EU portal³.

Table 2-6 Dose-response data from Archibong et al. (2002), used for dose-response modelling

Conc (µg BaP/m ³)	Survival (litter %)	SEM
0	98.90	1.1
25	78.30	4.1
75	38.00	2.1
100	33.80	1.3

Source: Study team

Dose-response modelling with EFSA PROAST results in a BMDL₁₀ of 9.29 µg/m³ (BMDU 20.9 µg/m³). The details and the protocol of the benchmark dose modelling are documented in 16.8.

Considering the same adjustments as performed by RAC for differences in the exposure scenario (8 hours exposure at the workplace instead of 4 hours in the experimental study, difference in respiratory volume due to light activity at the workplace), but without applying other assessment factors (i.e., for inter- and intraspecies variability), the concentration assumed to affect 10% of the exposed population (with 5% probability) is 3.12 µg BaP (respirable)/m³ (the benchmark response of 10% affected foetuses is translated into 10% affected pregnancies = female workers).

³ Available at [EFSA statistical models \(europa.eu\)](https://efsa.europa.eu/efsa-statistical-models)

RAC, in the Annex to the RAC opinion (RAC, 2022b), discussed a factor of 5 to estimate the inhalable BaP concentration from the respirable fraction. Applying the same extrapolation from the respirable to the inhalable fraction results in BMDL₁₀ (inhal) of 15.6 µg BaP (inhal)/m³.

RAC did not consider the difference in potency between single substance exposures to BaP (as performed by Archibong et al. (2002)) versus exposures to PAH mixtures. No relative potency considerations are available for reproductive toxicity of PAH. However, it is assumed that for both carcinogenicity and reproductive toxicity oxidative metabolic pathways are relevant, as at least the first steps leading to critical metabolites are shared. Therefore, in absence of specific relative potency data for reproductive toxicity, relative potencies for carcinogenicity are used to provide some guidance. However, the emphasis is on the large degree of uncertainty in this step (see below).

As discussed in the Annex to the RAC opinion (RAC, 2022b), Petry et al. (1996) calculated the relative potency of BaP versus PAH mixtures with toxic equivalency factors for carcinogenicity and concluded that BaP is responsible for 27 to 67% of the potency of the mixtures. However, equivalency factors include all kind of information, predominantly also in vitro data, which do not reflect the target organ and administration route dependency detected by Schneider et al. (2002). These authors found that in oral and inhalation experiments the carcinogenic potency of PAH mixtures for causing lung tumours was 13 to 60-fold higher when compared to their BaP concentration. In contrast, forestomach tumours after oral exposure seem to be caused mainly by the BaP content of mixtures (factor for difference in potency 1) and for skin tumours after dermal exposure a 2 to 11 fold difference was observed.

The difference in potency between BaP and typical PAH mixtures for reproductive toxicity is unknown. To account for this expected but unknown difference in the light of the observations for the endpoint carcinogenicity the factor of 5 is applied. It is emphasized that this is a poorly founded assumption which can err to both sides and it is used to allow assessing reproductive toxicity effects at high exposure concentrations as part of the cost-benefit discussions only. The assumption is supported by the observation of Ramesh et al. (2008) that the BaP-7,8-dihydrodiol (which is a precursor for the toxic metabolite 7,8-diol 9,10-epoxide and other metabolites, was observed in the testes of rats exposed to BaP by inhalation. This confirms that carcinogenicity and reproductive toxicity at least partly have common activation pathways.

- BMDL₁₀: 9 290 ng/m³;
- Exposure scenario adjustment (factors 2 and 1.49): 3 120 ng/m³;
- BMDL₁₀ inhalable fraction BaP: 15 600 ng/m³; and
- BMDL₁₀ inhalable fraction BaP for PAH mixture: 3 120 ng/m³.

Male reproductive toxicity (infertility)

In other publications of this group of researchers, effects on male fertility after BaP inhalation were investigated. After 10 days of exposure (4 h/d) of male rats to 75 and 100 µg BaP/m³ Inyang et al. (2003) observed reduced sperm motility. Further, exposure to 75 µg BaP/m³ caused reduced plasma testosterone concentrations and increased concentrations of luteinizing hormone. It is to be noticed that a full cycle of spermatogenesis in rats takes about 56-58 days. Therefore, the exposure time of 10 days is not sufficient to capture all potential effects.

The same group also studied effects of inhalative exposure to 75 µg BaP/m³ for 60 days (4 h/d, daily). Ramesh et al. (2008) reported reduced testis weights and reduced progressive motility. Further, mean density of stored spermatozoa was reduced as well as plasma testosterone concentrations and components of the steroidogenic and spermatogenic compartments of the testis. For the same experimental conditions Archibong et al. (2008) reported significantly reduction in sperm production and intra-testicular testosterone concentrations, and concurrent increase in LH levels. Further, a significant decrease in mean testis weight (33%), total weight of tubules (27%) and total tubular length (39%) was detected in exposed rats (Archibong et al., 2008).

Reduced progressive motility (ability of sperm to traverse a certain distance) was consistently observed in these studies. This is an endpoint which can be linked to respective observations in humans. WHO (2021) provides information on the distribution of this parameter in the human male general population. In the past, the 5th percentile was considered as a limit to judge on abnormal low cases of sperm motility (WHO, 2010). Although this strict criterion was not maintained by WHO (2021) for the sake of a case-by-case evaluation of infertility cases, it is applied here to assess the relevance of the observed decrease in progressive sperm motility as observed by Inyang et al. (2003) and Ramesh et al. (2008). Following WHO (2021) the criterion for a relevant effect on progressive sperm motility is 25% reduction of motile sperms.

Table 2-7 Distribution in human males for the parameter progressive sperm motility (in %)

5 th percentile	50 th percentile	95 th percentile
30%	55%	77%

Source: WHO, 2021

This criterion can be applied to the subacute study of Inyang et al. (2003):

Table 2-8 Dose-response data for progressive sperm motility (in %)

Concentration BaP (µg/m ³)	Sperm showing progressive motility (%)	Standard error
0	59	3.8
25	57	3.8
75	32	2.2
100	34	2.5

Source: Inyang et al. (2003)

The criterion of progressive sperm motility reduced by 25% would result in a critical effect size of 34% sperm motility (control minus 25%). Dose-response modelling with the EFSA online tool⁴ resulted in a benchmark dose (BMDL, lower confidence limit of the BMD, model averaging) of 43.2 µg/m³ for this criterion (details not shown). The interpretation of this BMDL for a continuous endpoint is that with a high probability 50% of the group are above and 50% are below this chosen criterion.

Ramesh et al. (2008) provided similar information from a subchronic inhalation study with BaP. Although only one concentration was investigated and therefore no dose-response information can be obtained from this study, it is advantageous compared to Inyang et al. (2003) as 60 days of exposure covers the full sperm cycle and therefore does not require any time extrapolation for considering the insufficient exposure duration.

⁴ Available at [EFSA statistical models \(europa.eu\)](https://efsa.europa.eu/EFSA_statistical_models)

Table 2-9 Dose-response data for progressive sperm motility (in %) in male rats

Concentration BaP ($\mu\text{g}/\text{m}^3$)	Sperm showing progressive motility (%)	Standard error
0	85	5.0
75	23	2.0

Source: Ramesh et al. (2008)

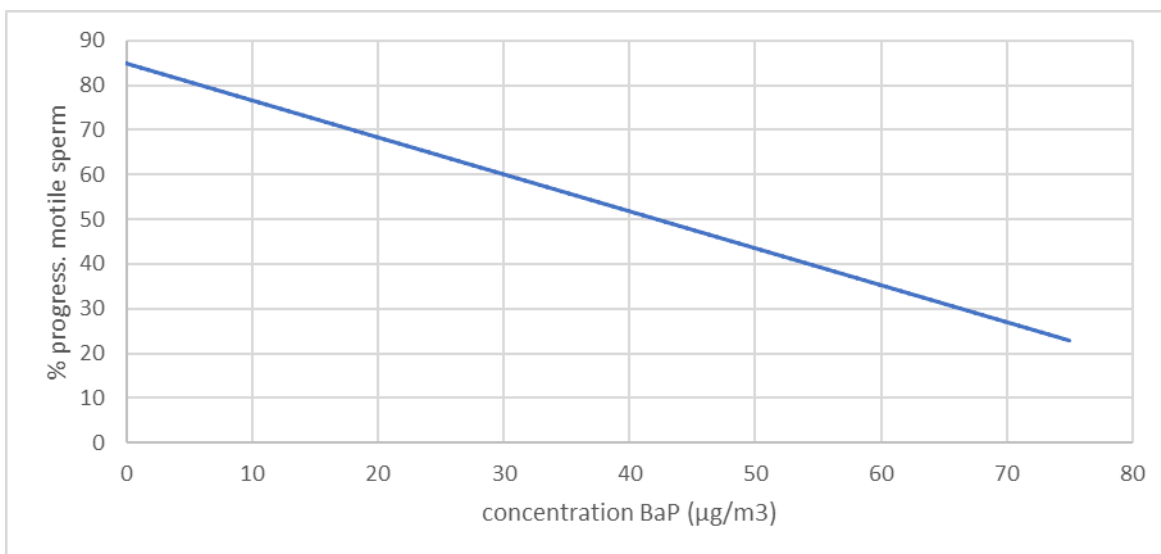


Figure 2-2: Reduction in progressive sperm motility as observed by Ramesh et al. (2008)

Source: Study team, Ramesh et al. (2008)

When applying the same criterion of 25% reduction of progressive sperm motility, then an individual animal with <60% motile sperms (starting from 85% motile sperms in the control group) would fulfil this critical effect size criterion.

The number of affected animals (male rats fulfilling this criterion) can be calculated by assuming a normal distribution of these data from means and standard deviations (see Table 2-10).

Table 2-10 Dose-response data for progressive sperm motility (in %) in male rats

Concentration BaP ($\mu\text{g}/\text{m}^3$)	Sperm showing progressive motility (%)	Standard error (SE)	Standard deviation (calculated from SE)	5 th percentile	95 th percentile	% animals below 60% progressive motility
0	85	5.0	1.58	82.4	87.6	0
75	23	2.0	0.63	22.0	24.0	100

Source: Ramesh et al. (2008)

The interpretation of these data is as follows:

- After subacute exposure of male rats with $43.2 \mu\text{g}/\text{m}^3$ 50% of animals have their progressive sperm motility reduced by 25%; and
- After subchronic exposure at $75 \mu\text{g}/\text{m}^3$ all male rats (100%) have their sperm motility reduced by at least 25%.

The dose applied by Ramesh et al. (2008) ($75 \mu\text{g}/\text{m}^3$) was too high to obtain an effect size which would better allow to assess the onset of these effects. On the other side, the subacute study does not allow to fully assess effects after exposure over a full sperm cycle. Therefore, the respective exposure concentration leading to 50% incidence is expected to be below $43.2 \mu\text{g}/\text{m}^3$.

For deriving the upper concentration of a linear DRR for male infertility the concentration of $75 \mu\text{g}/\text{m}^3$, associated with an incidence of 100% for reduced sperm motility, is used.

With the same adaptations for the exposure scenario, inhalable versus respirable particles and consideration of the potency of the PAH mixture, a concentration of $10 \mu\text{g}/\text{m}^3$ is obtained. This concentration indicates a level, at which 50% of the exposed group would experience such a reduction in sperm motility.

- Concentration (25% reduction progr. sperm motil.) $75,000 \text{ ng}/\text{m}^3$;
- Exposure scenario adjustment (factors 2 and 1.49): $25\,167 \text{ ng}/\text{m}^3$;
- Concentration inhalable fraction BaP: $125\,839 \text{ ng}/\text{m}^3$; and
- Concentration inhalable fraction BaP for PAH mixture: $25\,167 \text{ ng}/\text{m}^3$.

RAC did not derive an OEL-like concentration for male reproductive effects. However, such a concentration can be estimated using the same approach as used by RAC for developmental toxicity.

- NOAEC for male reproductive toxicity (Inyang et al., 2003) : $25 \mu\text{g BaP}/\text{m}^3$;
- Human NOAEC respirable BaP: NOAEC;
- divided by 2 (4h/d in experimental study versus 8 h/d at workplace);
- by 1.49 (respiratory volume 6.7 m^3 at rest versus 10 m^3 during work (light activity));
- by factor 2.5 (interspecies extrapolation);
- by factor 5 (intraspecies extrapolation);
- by factor 2 (time extrapolation) $336 \text{ ng BaP}/\text{m}^3$; and
- Conversion respirable to inhalable fraction by factor 5): $1.67 \mu\text{g BaP (inhal)}/\text{m}^3$.

This value needs to be adjusted again for considering the higher potency of a mixture of PAH (factor 5), leading to a concentration of $336 \text{ ng BaP}/\text{m}^3$ with BaP as indicator substance for the mixture potency. This value is very close to RAC's putative OEL.

2.2.3.2 Conclusion

DRR for developmental toxicity

The DRR for developmental toxicity is created from the points in the following table.

Table 2-11 DRR for developmental toxicity, derived from Archibong et al. (2002)

	Concentration ($\mu\text{g BaP}/\text{m}^3$) (inhalable fraction)	Percentage reduced survival (%) (5% probability)
RAC putative OEL for developmental toxicity ($0.223 \mu\text{g BaP}/\text{m}^3$), converted to inhalable dust (factor 5), divided by mixture factor 5	0.2	0
Adjusted BMLD ₁₀ (inhal) of $15.6 \mu\text{g BaP}$ (inhal)/ m^3 , divided by mixture factor 5	3.12	10

Source: Study team

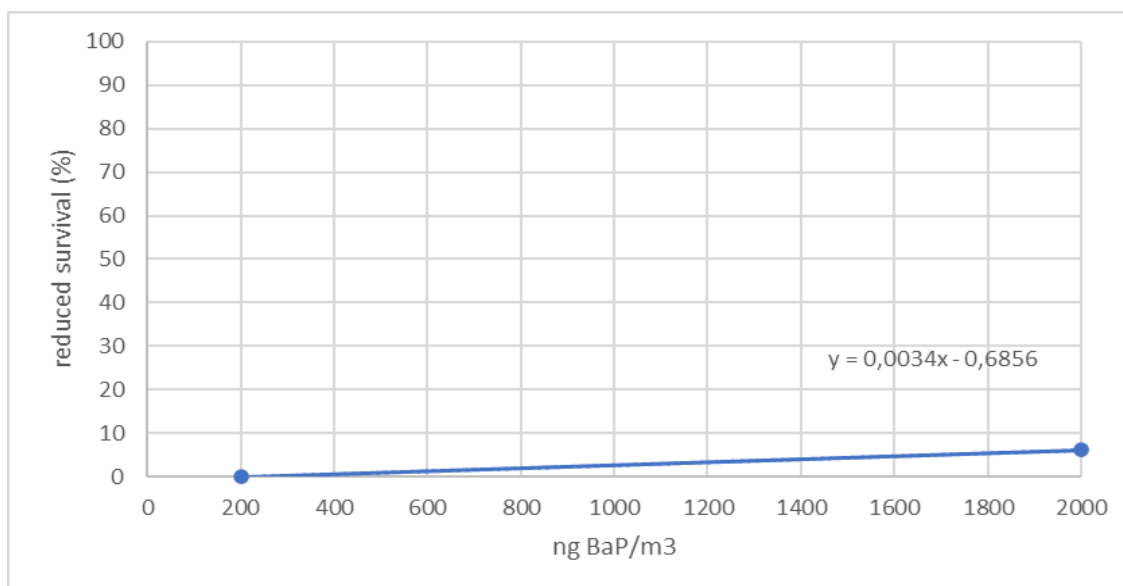


Figure 2-3: DRR for the endpoint reduced pup survival after PAH exposure

Source: Study team

The endpoint reduced pup survival is interpreted as a loss of a fertilised and implanted embryo, i.e. miscarriage or stillbirth. Percentage lost pups is interpreted as percentage of miscarriages or stillbirths caused by **exposure during pregnancy**.

Considering the uncertainties included we propose to use a simple linear approach for estimating the incidence of reduced pup survival at concentrations above $200 \text{ ng BaP}/\text{m}^3$:

Equation 2:

$$\text{Incidence}_{\text{conc}} = 0.0034 * \text{conc.} - 0.6856, \quad \text{conc.} \geq 200 \text{ ng BaP (inhal fraction)}/\text{m}^3$$

where

- $\text{Incidence}_{\text{conc}}$ refers to the incidence for reduced pup survival (%);

and

- Conc. is the exposure concentration given as ng BaP/m³ (inhalable fraction) (workplace scenario: 8 h/d, 5 d/w).

As it is unclear whether high short-term exposure can already cause have developmental effects, in line with the approach taken in previous assessments a minimal MinEx of 1 day (0 years) is assumed. MaxEx is set at 1 year to include a full pregnancy period.

The DRR starts at 200 ng BaP/m³ (no effect below that concentration). At the highest exposure concentration used for the policy options in this study (2000 ng BaP/m³, inhalable fraction, indicator for PAH mixture) a reduced survival of 0.061 (=6.2%) is estimated with this DRR.

DRR for male infertility

The DRR for male infertility is created from the points in the following table.

Table 2-12 DRR for male reproductive toxicity, derived from Ramesh et al. (2008)

	Concentration (µg BaP/m ³) (inhalable fraction)	Percentage individuals with 25% reduced sperm motility (%)
Starting point for fertility effects, analogue to RAC putative OEL for developmental toxicity, inhalable dust, BaP as indicator for mixture	0.34	0
Concentration of BaP (inhal)/m ³ corresponding to an 100% reduction of progr. sperm motility by 25%, adjusted to the workplace scenario, divided by mixture factor 5	25.2	100

Source: Study team

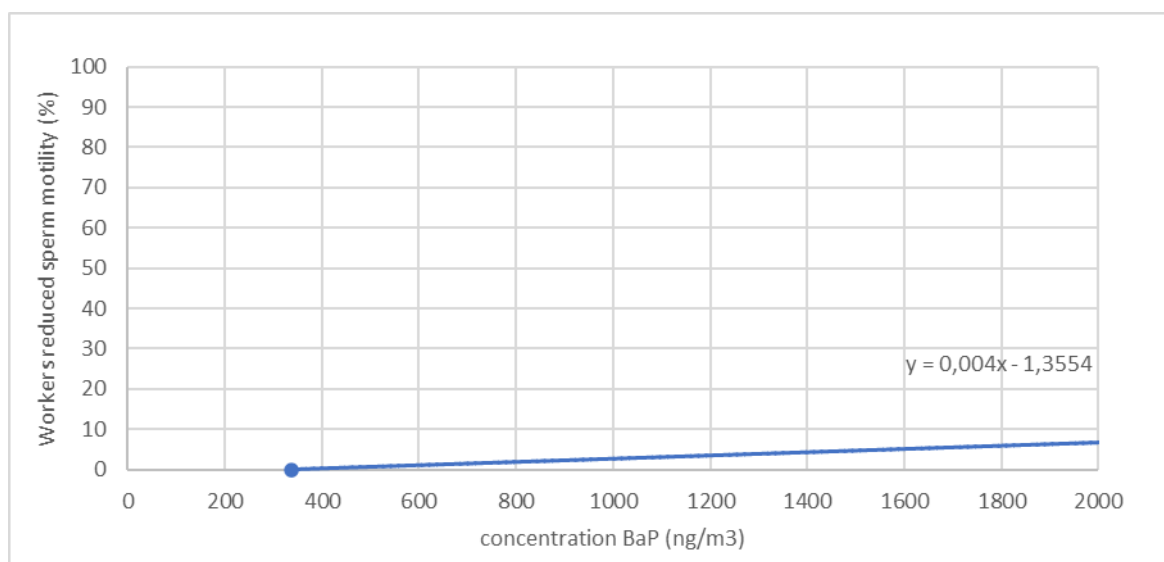


Figure 2-4: DRR for the endpoint reduced sperm motility after PAH exposure

Source: Study team

The endpoint reduction of progressive sperm motility by 25% is interpreted as a case of male infertility. 25% reduction is the difference between the median and the 5th percentile of the male human population (WHO, 2021).

The relationship between infertility cases and BaP concentration (as an indicator of PAH mixture effects) is estimated with a linear approach, starting at 336 ng BaP/m³:

Equation 3:

$$\text{Incidence}_{\text{conc}} = 0.004 * \text{conc.} - 1.3554, \quad \text{conc.} \geq 336 \text{ ng BaP (inhal fraction)}/\text{m}^3$$

where

- $\text{Incidence}_{\text{conc}}$ refers to the percentage of workers with a 25% reduction of progressive sperm motility;

and

- Conc. is the exposure concentration given as ng BaP/m³ (inhalable fraction, indicator for PAH mixture) (workplace scenario: 8 h/d, 5 d/w).

As it is unclear whether high short-term exposure can already cause impacts on sperm motility, in line with the approach in previous assessments a minimal MinEx of 1 day (0 years) is assumed. MaxEx is set at the duration of 3 m (0.25 years) to include a full sperm life cycle.

The DRR starts at 336 ng BaP/m³ (no effects expected below that concentration). At the highest exposure concentration used for the policy options in this study (2000 ng BaP/m³, inhalable fraction) it is estimated that 6.65% of workers are concerned.

2.2.3.3 Discussion

Reproductive toxicity is a relevant endpoint for BaP and, potentially, also for other PAH. BaP is classified as Repro Cat 1B for both fertility and developmental toxicity (H360FD). However, little is known regarding such effects after inhalation exposure or at workplaces. Studies from Archibong and colleagues (see above) point to developmental effects starting at 25 µg BaP/m³ and adverse effects on male fertility (50 µg BaP/m³ and above). However, no evidence from other inhalation studies exists and effects in studies with oral exposure occurred at higher corresponding doses only. Therefore, also RAC considered the uncertainties as high and only estimated a putative OEL from the Archibong data to bring reproductive toxicity into perspective compared to carcinogenicity. In the same way data from Archibong et al. (2002) is used to provide a rough estimate of potential effects at the higher concentration range. The obtained DRR concludes that at the highest concentration used as policy option (2 µg/m³), which is most likely relevant at a negligible number of workplaces only, might lead to 6% reduced survival of the progeny.

Apart from the uncertainty of the database as such there is further uncertainty introduced by the fact that Archibong et al. (2002) investigated exposure to BaP as a single substance in their experimental studies. RAC did not consider the potentially higher effect of PAH mixtures. In our assessment, giving consideration to relative potencies observed for the endpoint carcinogenicity, a factor of 5 was used to extrapolate from the effect of BaP alone to a PAH mixture containing BaP at the same concentration.

Further, it can be expected that pregnant female workers will not be exposed during later stages of their pregnancy and therefore the DRR might overestimate the health effect, if number of cases are calculated based on typical workplace concentrations. However, RAC explicitly addressed this endpoint foetal death based on the study by Archibong et al. (2002). This uncertainty has been addressed in section 13. Sensitivity analysis increasing the number of pregnant workers did not affect the overall results, and by extent, neither does a marginal reduction in the exposure period of pregnant workers. This uncertainty has not been considered further as it does not impact the overall results of the study.

Effects on male testis and testicular function were observed in several inhalation studies with rats (Inyang et al., 2003, Ramesh et al., 2008). Effect levels are slightly higher than those observed for developmental toxicity but considering the larger number of workers potentially exposed a DRR was derived also for this endpoint. Uncertainties are similarly high: no adequate human data are available and again an estimate for the difference between the potency of the PAH mixture versus BaP alone had to be included. The DRR derived estimates a fraction of 6.65% is affected at a concentration of 2 µg BaP/m³. This indicates that relevant effects can be expected at very high concentrations only, in agreement with conclusions by RAC that a BOEL set below a cancer risk level of 1.1E-03 would also cover reproductive toxicity effects.

2.3 Groups at extra risk

No specific groups at extra risk were identified by RAC (RAC, 2022b). The committee pointed out that smokers have a higher overall PAH exposure than non-smokers.

Regarding reproductive toxicity, both female (with regard to harm of the unborn child) and male workers (with regard to fertility) are risk groups.

2.4 Summary of background for analysing health impacts

2.4.1 Summary of exposure, uptake and health effects

2.4.1.1 Routes of exposure and uptake

Inhalation is the most relevant exposure pathway to PAH for workers. However, also dermal exposure both with regard to local tumorigenesis (PAH mixtures cause skin tumours after dermal exposure, see below) and systemic uptake is relevant. For the dermal exposure route absorption rates widely differ, depending on PAH components and model species. BaP is readily absorbed via inhalation, the oral and dermal route.

PAH are rapidly distributed via blood and lymph in the whole body. Biotransformation takes place predominantly via oxidative pathways by CYP enzymes (CYP1A1 and A2) in the liver. Initially formed epoxides are converted to dihydrodiol derivatives and phenols. Induction of the oxidative metabolising enzymes occurs via binding to the aryl hydrocarbon receptor AhR.

Glucuronide and sulphate conjugates of PAH metabolites are excreted in the bile and urine. Glutathione conjugates are further metabolized to mercapturic acids in the kidney and are excreted in the urine. A commonly measured urinary metabolite is 1-OHP. Renal PAH elimination was reported with a half-life range between 6 to 35 hours after occupational exposure. Excretion half-lives in faeces and urine have been reported in animal studies as 22 hours and 28 hours, respectively.

2.4.1.2 Adverse health effects

The most important health effect of PAH is carcinogenicity, most prominently lung cancer but also in the bladder, and skin. The International Agency for Research on Cancer (IARC) classified the substance benzo[a]pyrene (BaP) and certain occupational activities (e.g. coal tar distillation) as carcinogenic to humans (group 1). Also, there is sufficient evidence for the carcinogenicity of BaP and some other PAH in experimental animal studies.

PAH show moderate to low systemic toxicity after short- or long-term exposure. The most relevant non-cancer endpoint of PAH is reproductive toxicity, which has been shown for BaP in several animal studies.

Table 2-13: Relevant carcinogenic and non-carcinogenic endpoints and their use for deriving ERRs and DRRs

Endpoint	Assessment
Lung cancer	Considered quantitatively for ERR
Bladder cancer	Not considered quantitatively
Skin and other cancer localisations	Not considered (skin cancer relevant after dermal exposure)
Reproductive toxicity - developmental toxicity	Considered quantitatively for DRR
Reproductive toxicity – male fertility	Considered quantitatively for DRR

Source: Study team

2.4.2 Summary of ERR and DRR

2.4.2.1 ERR

PAH are considered non-threshold carcinogens by RAC and a linear exposure-risk relationship has been proposed by the committee:

$$ER_{conc} = 5.6E-06 * conc$$

where ER_{conc} refers to the excess lung cancer risk from PAH mixtures at a given concentration and $conc$ is the exposure concentration given as ng BaP/m³ (inhalable fraction) (under the assumption of continuous exposure over a work life, i.e. 40 years, 8 h/d, 5 d/w, 48 w/a).

2.4.2.2 DRR

Two DRRs for reproductive toxicity were derived.

Developmental toxicity

$$Incidence_{conc} = 0.0034 * conc - 0.6856, \quad conc \geq 200 \text{ ng BaP (inhal. fraction)}/m^3$$

where $Incidence_{conc}$ refers to the incidence for reduced foetal survival (%) and $conc$ is the exposure concentration given as ng BaP/m³ (inhalable fraction, indicator for PAH mixture) (workplace scenario: 8 h/d, 5 d/w).

This DRR is derived from observations in animal studies and the endpoint reduced pup survival is interpreted as miscarriage or stillbirth after exposure of female workers during pregnancy.

Male infertility

$$Incidence_{conc} = 0.004 * conc - 1.3554, \quad conc \geq 336 \text{ ng BaP (inhal fraction)}/m^3$$

where $Incidence_{conc}$ refers to the percentage of workers with a 25% reduction of progressive sperm motility and $conc$ is the exposure concentration given as ng BaP/m³ (inhalable fraction, indicator for PAH mixture) (workplace scenario: 8 h/d, 5 d/w).

The DRR is derived from observations in animal studies and the endpoint reduction of progressive sperm motility by 25% is interpreted as a case of male infertility.

3 CURRENT SITUATION

This chapter comprises the following sections:

- Section 3.1: Existing national limits;
- Section 3.2: Relevant sectors, processes and uses;
- Section 3.3: Exposure concentrations;
- Section 3.4: Exposed workforce;
- Section 3.5: Current risk management measures;
- Section 3.6: Voluntary industry initiatives;
- Section 3.7: Examples of good/best practice;
- Section 3.8: Standard monitoring methods/tools;
- Section 3.9: Intermediate uses not covered by certain REACH procedures;
- Section 3.10: Market analysis;
- Section 3.11: Alternatives;
- Section 3.12: Impact of Covid-19 on current situation;
- Section 3.13: Current disease burden (CDB); and
- Section 3.14: Summary of the current situation.

3.1 Existing national limits

3.1.1 OELs in Member States

The existing OELs in Member States are shown in Table 16-16.

3.1.2 BLVs in Member States

The existing OELs in Member States are shown in Table 16-17.

3.1.3 Minimum, maximum and average national OELs

The table below represents the distribution of EU OELs for PAH based on BaP in mg/m³.

Table 3-1 Maximum, minimum and average of OELs for PAH based on BaP in mg/m³ in those EU Member States where an OEL exists

Maximum, minimum and averages	PAH based on BaP as indicator of PAH mixture in mg/m ³	PAH based on BaP as indicator of PAH mixture in ng/m ³	Notes
Maximum	0.01	10,000	Finland
Minimum	0.00007	70	Germany*
Median	0.002	2,000	

Maximum, minimum and averages	PAH based on BaP as indicator of PAH mixture in mg/m ³	PAH based on BaP as indicator of PAH mixture in ng/m ³	Notes
Mode	0.002	2,000	
Mean	0.002351	2,351	

Source: Study team on basis of information presented in this section.

Notes: * value based on the acceptable level

3.2 Relevant uses, processes and sectors

3.2.1 Summary of REACH registration data

As also indicated in the RAC opinion, the REACH registration data are not relevant for PAH as they are process-generated or released during use rather than manufactured or imported substances.

3.2.2 Manufacture of PAH

With the exception of a few substances, the majority of PAH and the vast majority of PAH in terms of volume are process-generated and not intentionally manufactured.

3.2.3 Overview of key intentional uses

PAH are unintentionally generated or intrinsically present in substances and are generally not intentionally used. Some single substance PAH are manufactured in Europe (SCOEL, 2016). These include naphthalene, acenaphthene, acenaphthylene, fluorene, anthracene, phenanthrene, fluoranthene and pyrene. Of those, only naphthalene, acenaphthene, acenaphthylene and anthracene are produced in significant quantities (RAC, 2022b). Commercially produced PAH are mainly used for research purposes and some are used as chemical intermediates, such as: anthracene in dye production and in the synthesis of the chemotherapeutic agent amsacrine, acenaphthalene in the manufacture of pharmaceuticals and plastics, and fluorene in resin production (RAC, 2022b).

3.2.4 Processes unintentionally generating PAH – incomplete pyrolysis of carbon-based materials

Workers are exposed to various PAH that are formed through high temperature processes that result in the incomplete pyrolysis of organic materials. They result from burning coal, petroleum derived products, gas, wood, waste and tobacco, or any other organic compound. High heat when cooking meat and other foods will form PAH (CDC, 2022).

Sectors in this sector include firefighters, thermoelectric power plants, waste incineration, fish and meat smokehouses, cooks and chefs, casting of metals, crematoria and soil remediation workers.

3.2.5 Presence of PAH as impurity

In addition to the unintentional generation of PAH, are present naturally in coal and crude oil, and will be present in many petroleum or coal derived products. The further refinement of substances will lower the presence of PAH, e.g. as is the case in mineral oil derived from crude oil (Concawe, 2017).

Two sectors are worth mentioning here as they are overarching: laboratory work, research and development (R&D). Laboratory workers and researchers can be exposed to PAH through the use of reagents that are PAH or through analysis coal and petroleum streams within industry. These workers are included within the specific sectors.

3.2.5.1 Coal and coal-derived products

Coal-derived products are unknown or variable composition, complex reaction products or of biological materials (UVCB) and naturally contain PAH. Two of the major sources of occupational exposure to PAH are coking fumes, and use of coal tar obtained through coking (IARC, 2012).

Coal carbonisation is a process that yields **metallurgical coke** (also referred to simply as coke) and requires heating coal to temperatures as high as 1300°C in the absence of oxygen to distil out tars and light oils (IARC, 2012). The main use of coke is as a fuel reductant and support for other raw materials in iron-making blast furnaces. Coke is also used to synthesize calcium carbide and to manufacture graphite and electrodes, and coke-oven gas is used as a fuel (NTP, 2021).

Crude coal tar is a by-product of coke production. Crude coal tar is usually distilled, and blends of distillation fractions are used for various purposes, such as wood conservation. PAH concentrations in coal-tar products may range from less than 1% up to 70% or more (IARC, 2010). Since the 1990s coal tar is mainly a source of anti-corrosion coatings, wood preservatives, feed-stocks for the manufacture of carbon black and binders for electrodes. Further distillation of coal tar results in the formation of commodity chemicals and gas (also referred to as syngas) (IARC, 2012).

See Figure 3-1 for a simple schematic diagram of the production of coke and derivatives from coal.

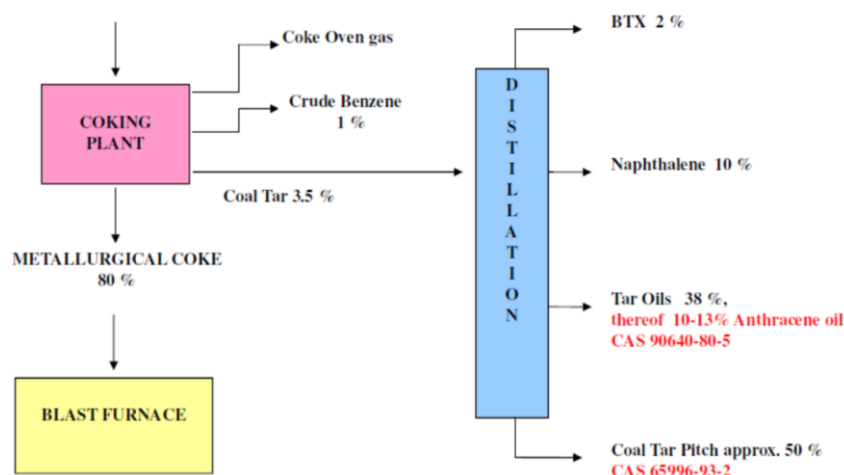


Figure 3-1: EU Coal tar processing

Source: Coal Chemicals Sector Group (CCSG)

Notes: BTX = benzene, toluene, and xylene

Sectors with exposure to PAH as impurities in coal and coal-derived products include: coking of coal, coal tar distillation, coal gasification, manufacture of carbon black, manufacture of tyre and rubber products (with an overlap on petroleum derived products), carbon and graphite electrode manufacture, aluminium production, steel and iron foundries, ferroalloy manufacture, refractory products, wood preservation (use of creosote), welding of train tracks (impregnated with creosote) and manufacture of clay shooting targets.

3.2.5.2 Petroleum-derived products

Crude oil, which naturally contains PAH, is subject to processing in the form of fractioning, distilling and thermal cracking results in petroleum streams with reduced (e.g. kerosene) or more concentrated PAH contents (e.g. heavy fuel oils) in petroleum refineries, which are further

refined or blended into products (e.g. lubricating oils, oxidised bitumen for asphaltting) or into articles (e.g. synthetic rubber).

Petcoke, a product derived from the fractioning of crude oil, can be further processed in a process similar to coking of coal, to produce calcinated coke which has the same function as coke derived from coal.

Sectors with exposure to PAH as impurities in petroleum and petroleum-derived products include: refineries, calcination of petcoke, manufacture of bituminous products, road paving, roofing, service activities incidental to water transportation (e.g. refuelling with heavy fuel oil), retail sale of auto-motive fuel in specialised stores, and machining oils.

3.2.5.3 *Vehicle exhaust fumes*

Internal combustion engines (ICE) will generate and/or emit fine particles and PAH, amongst other pollutants. Diesel Engine Exhaust Emissions (DEEE) have an OEL based on elemental carbon (EC) that is 0.05 mg/m³ from 2023, except for underground mining and tunnel construction to which the OEL applied from 2026.

Sectors with exposure to vehicle exhaust fumes are: underground mining and construction, including tunnels, motorvehicle maintenance and repair and forklift operators are thought to be the areas where the highest level of PAH exposure are likely to occur.

3.2.5.4 *Other uses*

The study devotes most attention to the sectors where occupational exposure is likely to be a significant issue based on exposure concentrations, number of workers exposed and trends in exposure.

Additional sectors to the ones mentioned below have also been referred to in the public domain and particularly in the Finnish ASA database, the Canadian CAREX database, SIREP via Scarselli publications and the DGUV report mentioned above. However, the study team have not taken them further because either: the practice appears to no longer take place, or the use is understood to be intermittent (not 8-hr TWA for 40 years), or the sector of use and/or source of PAH could not be identified or are not considered to be relevant for the current impact assessment on PAH using BaP as indicator for PAH mixtures.

Examples are: 'sign writers decorative painters engravers and etchers' in the Finnish ASA, the study team believes this is likely to relate to the use of oil-based or some acrylic paints formulated with naphthalene (a PAH that is not subject to CMRD, see below), or the practice of burning paint by decorators to remove paint, which is not a common way to remove paint ordinarily. The Canadian CAREX refers to 'traveller accommodation' and Scarselli (2013) to 'shop, stall and market salespersons and demonstrators', to which the study team cannot link a definitive source of PAH; it may be due to exposure to passive smoke. Another example is 'parquet laying with coal tar pitch' by DGUV, which no longer takes place in Europe.

It is important to note that this study uses BaP, a 5-ringed PAH with limited volatility as indicator for PAH mixtures (see section 2.1.1). There is more widespread use and there are higher levels of exposure to higher volatility PAH, resulting in an overall higher degree of exposure. BaP has been chosen by RAC as an indicator of exposure to PAH and the impacts of exposure to PAH other than BaP cannot be modelled. In particular, exposure measurements of total PAH reviewed by the study team indicate that naphthalene, the two-ringed PAH with the highest volatility, tends to be the dominating PAH in exposure

concentrations. Naphthalene is not classified as Carcinogenic Cat 1 under the CLP regulation (Table 1-5 presents the list of PAH classified as carcinogenic category 1 under the CLP).

Workers in several sectors will be exposed to PAH via fumes of DEEE or other process engines, for which further considerations to this type of exposure are given in section 3.2.10.4. Such workers include:

- Traffic enforcement officers;
- Taxi and bus drivers;
- Filling assistants at petrol stations (primarily Southern Europe and exposure to airborne lightweight PAH such as naphthalene is predominant); and
- Landscape and forestry workers using petrol-engine equipment, to name a few.

An additional sector for which exposure to PAH is likely to occur is:

- Manufacture of ferroalloys, e.g. ferromanganese: it was not possible to obtain exposure data for these manufacturers. The sector C24.1 steel and iron foundries, including ferroalloys, does however capture these industries and reads across the data available in steel and iron foundries that manufacture the ore and metal (as opposed to casting foundries);
- Manufacture of ceramics and glass requires the use of pitches, putties and refractory products that were traditionally made with coal tar pitch. It is understood that these have now largely been replaced with low PAH resins and petroleum pitch, resulting in low levels of PAH exposure. There are however no data to confirm this or on which to base modelling; and
- The use of Söderberg pastes is a small fraction (<5% according to industry) of the graphite and carbon electrode industry (C23.99b) but one that nonetheless exists. There are no data available to determine the levels of exposure and perform modelling.

In addition, the manufacture of phosphate mainly used in fertilisers, requires the use of graphite electrodes and other specialised graphite-based equipment. No exposure to PAH is expected to take place because graphite no longer contains PAH.

3.2.6 Sources of information about sectors with exposure PAH

The information on sectors with exposure to PAH has been taken from the following sources:

- The background report to the RAC opinion (RAC, 2022b) as one of the main sources;
- IARC monograph 100F with sources of occupational exposure (IARC, 2012), other IARC monographs were also consulted (IARC, 2010; IARC, 2013; IARC, 2022);
- CAREX Canada for the occupation and number of workers (CAREX, 2021);
- Finnish FIOH produced the ASA database, which has been reviewed for the occupations with exposure and number of workers (FIOH, 2021);

- Deutsche Gesetzliche Unfallversicherung e.V. (DGUV) report on the determination of BaP doses per sector (DGUV, 2022), contains a comprehensive analysis of sectors and temporal trends; and
- Data from the Italian SIREP database was accessed via peer-reviewed journal articles by Alberto Scarselli (Scarselli et al., 2013).

3.2.7 Sectors of use (SU) in REACH registration dossiers

REACH registrations are not considered to be relevant for PAH, therefore the SU in the REACH registration dossiers are not reported.

3.2.8 Summary of sector data sources

The table below summarises sectors, and the main sources of information on the sectors. Additionally, an extensive peer-reviewed literature search was performed online through Google scholar and PubMed. The data collection focused on sources with exposure measurements taken from 2000 onwards.

Table 3-2 Summary of sectors where exposure PAH can occur according to data sources.

NACE	Name	Consultation	DGUV	RAC	IARC 110	IARC 92	CAREX Canada	FIOH Finland (ASA)	Scarselli (SIREP)	Literature
	Year	2023	2022	2022	2012	2010	2021	2021	2013	2000-2023
B07	Underground mining (DEEE fumes)	E, M, W	E, M		M			W, M	E, M, W	E, M
B06.20	Coal gasification	M	E, M	M	M	M				
C10.13, C10.20	Fish and meat smokehouses ⁽¹⁾		E, M	E, M						E, M, W
C16.1	Wood preservation (creosote)	W	E, M	E, M	E, M	E, M	W, M	W, M		E, M
C19.10	Coking plants	E, M, W	E, M	E, M	E, M		W, M		E, M, W	E, M
C19.2	Petroleum refineries	E, M, W	E, M	E, M	E, M		W, M		E, M, W	E, M
C20.13	Manufacture of carbon black	E, M, W	E, M	M	E, M				E, M, W	E, M
C20.14	Coal tar distillation	E, M, W	E, M	M	E, M	E, M			E, M, W	E, M
C22.11, C22.19	Manufacture of tyres and other rubber products	M	E, M	M	E, M				E, M, W	
C23.2	Manufacture of refractory products	W	E, M	E, M						E, M

NACE	Name	Consultation	DGUV	RAC	IARC 110	IARC 92	CAREX Canada	FIOH Finland (ASA)	Scarselli (SIREP)	Literature
C23.99	Manufacture of bituminous products	W, M	E, M	E, W, M	E, M	E, M				E, M
C23.99	Carbon and graphite electrode manufacture	E, W, M	E, M	E, W, M	E, M	E, M			E, M, W	E, M
C24.1	Steel and iron foundries, ferroalloys	E, W, M	E, M	E, M	E, M	E, M		W, M	E, M, W	E, M
C24.5	Casting of metals	E, W, M	E, M	E, M	E, M	E, M		W, M	E, M, W	E, M
C24.42	Manufacture of aluminium	E, W, M	E, M	E, W, M	E, M	E, M	W, M		E, M, W	E, M
C24.45	Other non-ferrous, metallurgical processes	M	E, M	E, M	M		W, M		E, M, W	E, M
C25.62	Machining oils			E, M			M			E, M
D35.11	Thermoelectric power plants		E, M	M	M	M	W, M	W, M	E, M, W	E, M
D32.30	Manufacture of sports goods: clay shooting targets	M		E, M						E, M
E38.2	Waste incineration		E, M	M					E, M, W	E, M
E39.00	Soil remediation	E, W, M	E, M	E, M						

NACE	Name	Consultation	DGUV	RAC	IARC 110	IARC 92	CAREX Canada	FIOH Finland (ASA)	Scarselli (SIREP)	Literature
F41	Construction (DEEE fumes)	E, M		W, M				W, M	E, M, W	E, M
F42.11	Road paving	E, W, M	E, M	E, W, M		E, M, W	W, M		E, M, W	E, M
F42.12	Welding of train tracks	W, M								E
F43.91	Roofing activities		E, M	E, W, M	E, M	E, M				E, M
G45.2	Motor vehicle maintenance and repairs	E, W, M	E, M					W, M	E, M, W	E, M
G47.30	Retail sale of automotive fuel in specialised stores						W, M			
H52.22	Service activities incidental to water transportation	E, M								E, M
I56.10, I56.29	Chefs and cooks		E, M		M		W, M			E, M
M72.1	Research and development, laboratory workers	E, M					E, M	W, M		
N81.22	Chimney sweeps		E, M	E, W, M	E, W, M	E, W, M				E, M
O84.25	Firefighters			E, M			W, M	W, M		E, M

NACE	Name	Consultation	DGUV	RAC	IARC 110	IARC 92	CAREX Canada	FIOH Finland (ASA)	Scarselli (SIREP)	Literature
S96.03	Crematoria		E, M							E, M
N/A	Forklift operators ⁽¹⁾									E, M

Consultation responses include response received to data in the questionnaire and meetings with industry associations

W = workers, E = exposure, M = mention

3.2.9 Criteria for selection of sectors for further analysis

Exposure to PAH can occur in a wide range of sectors. In order to allocate the used resources on sectors where demonstrated exposure to PAH in concentrations relevant for the reference OELs takes place, a number of applications/sectors are excluded from further analysis.

The criteria for exclusion are as follows:

- The available data indicates that the 95th percentile of the exposure concentrations is below the lowest assessed OEL as the assessment would indicate no impact, when using BaP as indicator for PAH mixtures;
- As noted in the previous section, a higher degree of exposure is expected to the more volatile PAH compounds, but exposure data against PAH compounds other than BaP cannot be used to quantify costs and benefits from introducing an OEL based on BaP (as indicator for the mixture). Therefore, the impacts on sectors with exposure to PAH compounds other than BaP cannot be quantifiably assessed;
- Considerations are made for sectors where the study team has found exposure to carcinogenic PAH other than BaP (see 1.3.4 for a list of relevant PAH compounds), however, this has not been a comprehensive review such as the one undertaken for sectors with exposure to BaP;
- The available data indicates that the application may not take place today or that the application area is very small compared to other areas;
- For cross-sectoral applications, some sectors with limited use may be excluded and the estimated number of workers exposed are allocated to the main sectors for the application. For example, anode baking plants are part of aluminium manufacturing plants except for one plant, which is also understood to be in the process of shutting down; and
- For uses where no inhalation exposure concentration has been identified, a qualitative assessment will be undertaken, only.

3.2.10 Identified sectors with risk of exposure to PAH

The RAC background document (RAC, 2022b) summarises work areas/sectors where occupational exposures to PAH have been measured. The information has been supplemented with data from further publications (see Table 3-2) as well as information received during stakeholder consultation.

In each of the sub-sections a table is presented summarising the sector, source, temperature if relevant and potential for exposure. The potential for exposure, i.e. the 'estimated category of risk for worker exposure' is an expert judgement summary based upon likelihood of worker exposure, which in turn is based upon a combination of:

- How commonly the process or activity takes place in that sector or use (Stakeholder Consultation, 2023);
- Whether the process is automated and in a closed system therefore reducing worker exposure (various sources, mainly through (RAC, 2022b; Stakeholder Consultation, 2023); and

- Whether workers are likely to be using personal protection equipment (PPE) and/or respiratory protective equipment (RPE) limit exposure and uptake (Stakeholder Consultation, 2023).

The relevant NACE codes (identification codes in the Statistical classification of economic activities in the European Community) for each sector are presented in Table 3-2.

3.2.10.1 Processes unintentionally generating PAH

The major occupations and activities where combustion of organic materials and exposure to PAH may take place are presented in Table 3-3 and described after the table. In some of the sectors and activities described in this section, the use of substances and products containing PAH (such as coal and petroleum and derivatives) and therefore exposure via these may also take place. The exposure resulting mainly from the use of coal and petroleum derived products will be discussed in the following sections.

Table 3-3 Description of processes unintentionally generating PAH

Use or sector	Description	Examples of activities/occupations/exposure situations	Relevant substrate/material	Temperature	Estimated category of risk (airborne)	Estimated category of risk (skin)
Firefighting	Firefighting activities arising from accidental combustion	• Training exercise and live fire extinguishing: with RPE, supervising with and without the use of RPE; • Dermal contact from contaminated gear, RPE/PPE, equipment and office spaces.	Any material, however wood fires have been found to contain lower levels of BaP	Combustion	Low-High due to use of self-contained breathing apparatus (SCBA) in relevant settings, but not always followed	High due to residue on gear, skin and within office space
Thermoelectric power plants	Generation of electricity through the conversion of fuel into energy	• Combustion: within boilers, furnaces and other equipment and subsequent emission to air; • Cooling: cooling towers are used to regulate the temperature of water, PAH contained in the water may be released to air; • Storage and handling: of fuels used to generate electricity; • Waste: fly ash and bottom ash can contain PAH.	• Fossil fuel: mainly coal, diesel; • Biomass, such as wood and animal carcasses. • Studies indicate that coal is the fuel of concern.	Combustion	Low – due to use of abatement systems*	Low – estimated, thanks to industrial hygiene practices*
Waste incineration	Combustion of hazardous and non-hazardous waste, municipal or industrial	Similar to above	Any material	Combustion	Low – due to use of abatement systems*	Low – estimated, thanks to industrial hygiene practices*
Fish and meat smoke-houses	Thermal treatment of food (usually fish) with pyrolytically generated hot or cold smoke	• Smoke development and temperature setting; • Laying goods to be smoked and turning; • Quality control of smoke and cooking stage; • Discharging smoked goods and cleaning the ovens and smoke generator.	Wood and wood chip	Smoking takes place at 20-80°C	Medium – depending on abatement system and practices	Low – estimated, thanks to industrial hygiene practices
Cooks and chefs	Cooking fumes are thermal oxidative decomposition products	• Heating oil and fats to a high temperature (e.g. frying); • Grilling;	• Cooking oils, animal fat;	The higher the temperature the more	High	High

Use or sector	Description	Examples of activities/occupations/exposure situations	Relevant substrate/material	Temperature	Estimated category of risk (airborne)	Estimated category of risk (skin)
	containing several hazardous pollutants	Combustion of biomass fuel (mainly wood and charcoal).	Charcoal or wood for burning.	likelihood of PAH generation		
Casting of metals	Organic binders can generate PAH when molten metal (mainly) is in contact with the mould during industrial casting	- Moulding and core-making; - Melting; - Pouring; - Shakeout; - Fettling; - Maintenance technicians conducting	Organic binders such as: furan, phenol-formaldehyde, urea-formaldehyde and urethane resins as well as oleo-resinous oils	1350-1450°C	Medium	Medium
Crematoria	Cremation of human bodies within combustion units	PAH as VOC, may be released from the flue gas	- Wood - Human biomass - Plastic from prosthetics	300->800°C	Low*	Low*
Chimney sweeping	Cleaning furnaces and chimneys to remove soot and impurities through the use of vacuum systems	- Insertion and removal of suction or cleaning device; - Removal of soot and dust from the immediate area.	Soot resulting from the combustion of hard coal (highest PAH content), wood, lignite, fuel oil, or mixed firing	N/A	Low to medium	Low to Medium
Soil remediation	The removal of PAH or other pollutants from soil, and thermal treatment of PAH in soil	- Inspection of area - Sampling - Removal of soil - Heat conduction and volatilisation of PAH (in case of thermal soil remediation)	Usually petroleum or coal derived products	200-1000°C	Medium – even though high levels of exposure are possible RPE is expected to be used in this sector	Medium – as per airborne

Source: Study team.

Notes:

* Estimated with the help of occupational hygienist during consultation.

In all of the above activities contaminated surfaces can be a source of exposure to PAH via skin or ingestion after contamination with unwashed hands, gloves or clothing. PAH from the gas or particulate phase can deposit and accumulate on surfaces in the workplace, such as floors, walls, and equipment. Similarly, PAH can adhere to clothing resulting in contaminated clothing and secondary exposure.

Firefighters. Firefighters are exposed to combustion products, diesel exhaust, building materials, asbestos, chemicals, ultraviolet radiation, and are known to operate under shift-work which varies the exposure (IARC, 2022). Firefighters rely on PPE to reduce their exposures. Self-contained breathing apparatus (SCBA) is usually worn during firefighting activities involving structures or vehicles, but less commonly during wildland firefighting where firefighters stay at the site for weeks (IARC, 2022). However, fires in urban settings typically give rise to very complex mixtures because of the combustion of household equipment, whereas combustion of wood can be considered as a more “clean” type of smoke, and results in lower BaP content (Andersen et al., 2017; Oliveira et al., 2017).

A study indicates that while firefighters tackling a live fire during an event or training wear SCBA, team leaders standing at a distance from the fire (up to 10 m suggested in a study) do not wear any RPE (Sjöström et al. 2019). Stakeholder consultation indicates that while guidelines are in place to establish whether the use RPE is required by team leaders, it may not always take place for practical reasons. In addition, the consultation indicates that there are variations in the countries and even for firefighters tackling live fires, there may be a requirement to wear SCBA only when tackling fires in buildings or cars, leaving firefighters exposed to potentially extremely high levels of airborne PAH in other circumstances. A study in the UK revealed that up to 83% of firefighters often or sometimes attend fires without RPE (Wolffe et al., 2023). The main issue with wearing SCBA is the physical demand: it is heavy, hot and it can be difficult to manoeuvre whilst wearing it. The study by Wolffe et al. (2023) also found that RPE was described as “uncomfortable” and “impractical”, causing over-exertion, over-heating, difficulty breathing, difficulty communicating and/or hindering vision and movement.

Dermal absorption of chemicals can occur even in firefighters wearing PPE due to limitations of design, fit, maintenance or decontamination (IARC, 2022). Furthermore, exposures can occur when firefighters are not actively fighting fires and are not wearing PPE. Soot and chemical contaminants from fires has been tracked back to fire stations via fire vehicles, handling contaminated equipment and particularly through firefighters’ personal equipment such as boots, gloves and turnout gear (Oliveira et al., 2017; Andersen et al., 2017, Stec, et al. 2018).

A study by IARC found that lung cancer incidences and mortality rates were lower among firefighters than in the general population in most studies and in the meta-analysis, however negative confounding by smoking and healthy-worker hire bias were presumed to be likely (IARC, 2022).

Thermoelectric power plants. Thermoelectric power plants generate electricity by converting chemical energy into electrical energy via heat energy. This occurs through fuel combustion, heat transfer and subsequent electricity generation. Coal thermoelectric power plants are understood to present the highest risk of exposure to PAH in terms of levels of PAH. Coal is burned to heat water in a boiler and convert it to high-pressure steam. The high-pressure steam is directed into a steam turbine which turns the turbine shaft. The majority of workers in a power plant where exposure to PAH can occur are involved in maintenance work, where exposure to solvents, greases and oils, asbestos and welding fumes can also occur (IARC, 2010). Modern coal-fired power stations (large combustion plants) employ a series of abatement technologies

to remove pollutants including PAH, such as flue gas desulphurisation, electrostatic precipitators, selective catalytic reduction (Lilley et al. 2022) and exposure to workers is expected to be very low (occupational hygienist personal communication during the consultation).

Incineration and crematoria. Potential pollutants from unabated incineration consist of particulate matter (PM), hydrogen chloride, nitrogen oxides, carbon monoxide, volatile organic compounds (ranging from methane to PAH, mercury compounds and polychlorinated dibenzo-p-dioxins and furans (PCDD/F)) often simply referred to as dioxins (DEFRA, 2012; Mari & Domingo, 2010).

Specifically to crematoria, good combustion, i.e. complete combustion of carbons, and a secondary combustion zone are effective management system to minimise PAH emissions in crematoria. Emissions of PAH should not ordinarily arise, it is possible that these substances could arise, for example, from inappropriate materials being used in coffin construction in combination with poor combustion control. Emissions of PAH are not considered a key issue by the UK Environment Agency (DEFRA, 2012).

Cooks and chefs. Cooking fumes are thermal oxidative decomposition products containing several hazardous pollutants such as respirable particulate matter (PM), heavy metals, carbon black, heterocyclic amines, and volatile organic compounds including polycyclic aromatic hydrocarbons (PAH), aldehydes, and carbonyls (Oliveira et al. 2020). The amount, size distribution and composition profiles of PM and their bound chemicals (such as PAH) emitted from cooking are determined by the cooking style, cooking method, type of oil or fat, ingredients, additives, indoor and ambient conditions (Bandowe et al., 2021). The most important factor influencing indoor PM concentration is ventilation (Lachowicz et al., 2023).

PAH released during grilling activities originate from the incomplete combustion of charcoal on the food surface, the pyrolysis of fat, protein, and carbohydrates at high temperatures, and with the direct contact of deeply heated dripping lipids over the flame (Oliveira et al. 2020).

IARC Working Group concluded that emissions from high-temperature frying are “probably carcinogenic to humans (Group 2A)” and that indoor emissions from household combustion of biomass fuel (mainly wood) are “probably carcinogenic to humans (Group 2A)” (Straif et al., 2006).

Casting of metals. The majority of casting takes place using steel and iron. Foundries produce shaped castings from re-melted metal ingots and scrap. Although foundry work is assumed to start with re-melting of ingots and scrap and to end with the fettling of castings, the industry is often so integrated that the distinction is not obvious (IARC, 2012). The processes in iron and steel founding generally comprise pattern-making, moulding and core-making, melting, pouring and shake-out, and fettling. Occupational exposures to airborne PAH result mainly from the thermal decomposition of carbon-based compounds commonly found in foundry sand (IARC, 2012).

During casting, PAH are formed and partly vapourised under the extremely hot and reducing conditions at the mould-metal interface. Organic binder materials for cores and moulds include furan, phenol-formaldehyde, urea-formaldehyde and urethane resins as well as oleo-resinous oils. Curing reactions and thermal decomposition give rise to formation of additional compounds, which are released during pouring and shakeout. Partly vaporised PAH can be adsorbed onto soot, fume or sand particles and spread throughout the workplace during shake-out and dusty operations (IARC, 2012). The area where exposure to PAH may take place is during the pouring of molten steel and release from the moulds.

Smokehouse. The BaP content in the smoke is primarily dependent on the combustion temperature of the wood (smouldering temperature), thus hot smoking generates higher PAH concentrations than cold smoking (DGUV, 2022). The highest concentration of BaP is found during operation of traditional, poorly ventilated systems or in worn furnaces, while lowest values are found in automated systems with external smoke generators (DGUV, 2022).

Chimney sweeping. Chimney sweeps are exposed to soot, the composition of which depends on the starting material and the conditions of combustion, can contain PAH, metals (arsenic, chromium, cadmium, nickel, and lead), combustion gases (such as sulfur dioxide and carbon monoxide), and asbestos from pipe and furnace insulation (IARC, 2012). The use of hard coal has declined since the 1970s, recently there has also been a significant decrease in the use of petroleum derived oil and an increase in the use of pellets and wood (IARC, 2012; Hogstedt et al., 2013; Alhamdow et al., 2017).

Traditional chimney sweeping “**black sweeping**” includes removing soot from chimneys and connecting pipes, furnaces, and boilers with brushes and scrapers. However, nowadays the use of handheld machines and the collection of soot during the sweeping with vacuum cleaners is taking over (Hogstedt et al., 2013). Workers may also be exposed to soot while driving between jobs through contamination of their clothes as well as contamination of surfaces such as cars. After the sweeping, the soot is collected in closed containers, that are emptied in designated larger containers (Hogstedt et al., 2013). Since the middle of the last century, chimney sweepers perform additional tasks referred to as “**white sweeping**”; for example, the degreasing of kitchen ventilation equipment and fire safety inspections, with lower PAH exposure potential. On average, Swedish chimney sweeps spend about 50% of their working hours doing black sweeping, 25% performing fire safety inspections, and the remaining 25% degreasing kitchen and restaurant ventilation (Hogstedt et al., 2013).

Soil remediation. Sites may be heavily contaminated with PAH containing products. Soil remediation workers will be required to go on-site to assess the situation and develop and implement a remediation plan. PAH tends to be removed via thermal remediation, either in-situ or ex-situ (soil is excavated in the latter). Thermal remediation requires the soil to be heated to temperatures above the boiling point of the contaminant so that they are vaporised and collected. During the consultation it emerged that soil remediation work of sites contaminated with PAH takes place on average once every 1-2 years with a duration of 3-9 months. The air quality is monitored prior to site work and workers will be equipped with appropriate RPE (in some cases SCBA, or other types of masks and respirators) or for example work in excavators with ventilated cabs. Dermal exposure is possible but workers are required to wear gloves and/or suits and follow good hygiene measures to reduce exposures.

3.2.10.2 Presence of PAH as an impurity – coal derived products

The main sectors and processes where PAH exposure can occur due to the presence of PAH in coal and coal derived products are presented in Table 3-4.

Table 3-4 Description of uses and sectors using coal derived products where exposure to PAH can take place.

Use or sector	Description	Processes or activities where exposure to PAH can arise	Relevant sub-strate/material	Temperature	Estimated category of risk (air-borne)	Estimated category of risk (skin)
Manufacture and operation of coke oven products	Coal carbonisation yields coke for use in metallurgical processes. The heating coal at high temperatures in the absence of oxygen distils out tars and light oils are distilled and coke-oven gases are formed.	• Charging of coke ovens with fresh coal • Pushing of cokes from coke ovens during unloading • Processing of by-products of the coke oven process • Repair and maintenance operations • Fugitive emissions	• Coal (dust) • CTPht	1000-1300°C, up to 2000°C	High – even though use of RPE/PPE takes place	High - fumes and deposition of particles on surfaces and penetration of clothes
Coal tar distillation	Distillation of coal tar to produce coal tar pitch high temperature (CTPht) and other chemicals, such as naphthalene and creosote to name a few. The heating takes place in closed systems (distillation towers operating at different temperatures to allow fractionation)	• Transfer and (un)loading of raw material and finished products • Sampling for Quality Check (QC) and laboratory analysis • Repair and maintenance • Fugitive emissions	• Tar (raw material) • CTPht • Creosote • Scrubber oil • Anthracene oil • Others not listed	210->240°C	Low-High – depending on tasks, mostly a closed process	Low-High – depending on tasks, mostly a closed process
Coal gasification	Coal is reacted with oxygen, steam and carbon dioxide to form a gas containing hydrogen and carbon monoxide	This activity no longer takes place in Europe according to feedback received in the consultation				
Manufacture of carbon black	Distillation of heavy aromatic oils and in closed systems to manufacture carbon black	• Maintenance and cleaning of equipment • Unloading (coupling and uncoupling of hoses) of vessels containing substance	Anthracene and tar oils	210-400°C	Low	Low

Use or sector	Description	Processes or activities where exposure to PAH can arise	Relevant substrate/material	Temperature	Estimated category of risk (airborne)	Estimated category of risk (skin)
		- Repairs and maintenance operations - Fugitive emissions				
Manufacture of tyre and rubber products	Use of carbon black and extender oils containing PAH for the manufacture of tyre. As well as retreading of tyres	- Mixing and kneading - Vulcanising - Curing - Retreading	- Carbon black - Extender oils	120-160°C	Low – extender oils are limited in PAH content by the REACH Restriction, while carbon black is not bioavailable	Low
Carbon and graphite electrode manufacture	Materials made of carbon are produced by pyrolysis with the addition of binding agents such as tar and pitch	- Storage/processing of solid fillers - Mixing of fillers and binders - Shaping of green bodies - Firing in the absence of air - Impregnation - Graphitization - Repairs and maintenance operations - Sampling for Quality Check (QC) and laboratory analysis - Fugitive emissions	- CTPht - Coke/petcoke - Coal tar	- firing of green bodies at 1300°C - graphitization at 2800°C	High – use of RPE/PPE is common	Medium/high – due to dust deposition and surface contact
Aluminium production	Use of anodes, made with CTPht, for the reduction of alumina	- Moulding and pre-baking of anodes (done in adjacent plant on-site) - Start-up of furnace - Replacement of anode - Repairs and maintenance - Fugitive emissions	CTPht	940-980°C	Medium/low in aluminium plant, high in pre-baking area	Medium – due to dust deposition and surface contact

Use or sector	Description	Processes or activities where exposure to PAH can arise	Relevant sub-strate/material	Temperature	Estimated category of risk (airborne)	Estimated category of risk (skin)
Steel and iron foundries, including ferroalloy	Use of anodes, coke/petcoke as a source of heat in furnaces, graphite and coke as carbonaceous additives. Exhaust gases from engines, furnaces and ovens can be sources of PAH.	• Handling of raw materials • Loading into electric/electric arc furnaces • Repairs and maintenance • Fugitive emissions	• CTPht • Coke/petcoke • Coal powder • In addition, residual oils on melted steel (combustion)	Up to 2,300 °C	Medium/High depending on the anode or cathode used	Medium – due to dust deposition and surface contact
Refractory products, with a focus on the steel and iron industry	Impregnation of slide gate plates with CTPht, firing and shaping	• Storage/processing of binding material • Impregnation • Machining (shaping) • Firing of raw body	CTPht	Operating temperature up to 1600°C	Medium, RPE worn	Low (based on consultation with occupational hygienist)
Wood preservation	Impregnation of wood with creosote oils, e.g. railway sleepers, utility poles and marine pilings through vacuum	• Handling of impregnation materials • Loading and removal into/from vacuum tanks • Transport and installation • Repairs and maintenance • Fugitive emissions	Creosote and creosote oils (from coal tar)	50°C	Low during impregnation, medium in recycling	High
Welding of train tracks	Arc-welding or aluminothermic welding of train tracks on railways sleepers impregnated with creosote oil.	• Welding • Dermal contact with sleepers	Creosote	850-1200°C	High	Medium – hot process requires workers to wear PPE
Manufacture of clay shooting targets	Use of CTPht as binder for fire-arm flying target	Opinion adopted by RAC and SEAC limiting the amount of PAH in clay shooting targets, therefore prohibiting the use of CTPht in the manufacture of targets.				

Source: Study team

In this section the sectors and processes where exposure to PAH can occur are presented in more detail.

Coking. Coke is mostly produced from slot-type by-product coke ovens where coal is heated up to 1250°C in the absence of oxygen, this process is referred to as "dry distillation". Above the ovens is a roof system from which coal is discharged into each oven. Modern technology includes telescopic charging chutes to minimize dust emissions during charging. Many facilities also include automatic removal and replacement of the charging-hole lid. Volatile gases generated from the coal during carbonization flow to the top of the oven, into the free space and out through standpipes connected to large collecting mains that transport the gases to the by-product plant in which they are processed into various materials (IARC, 2012; Stakeholder Consultation, 2023). Some vapours may escape through the furnace as leaks (fugitive emissions) and lead to exposure to raw coke oven gases, that in addition to PAH, contain benzene and aromatic amines (DGUV, 2022). Water is sprayed into the mains to cool the gases and to condense out some of the tar. At the end of the coking cycle, which ranges from about 15 to 30 hours, the coke is pushed into a hot car (quench car). The hot car may have a moveable roof or partial roof to minimise gaseous and particulate emissions. The hot coke is then quenched before being dropped onto a conveyor system for transportation to a blast furnace, storage pile or out of the plant (IARC, 2012).

Coal tar distillation. Coal tar is obtained by cooling the gas that is formed during the destructive distillation of coal (see coking above). It is a black, viscous liquid composed primarily of a complex mixture of condensed-ring aromatic hydrocarbons. Distillation takes place in continuous tar stills, where light and heavier fractions are separated (IARC, 2010). As seen in Figure 3-1, the distillation of coal results in coal tar pitch (50%), also referred to as coal tar pitch-high temperature, CTPht⁵), tar oils, including anthracene oil (38%), naphthalene (10%) and benzene, toluene, and xylene (BTX, 2%). Another product, less known, is scrubber oil, which is used in the scrubber filtration system of coal tar distillation plants and coking plants.

Coal tar distillation takes place in only six plants in Europe, located in Belgium, Czech Republic, Germany, Denmark, Spain (two sites) and Poland. The vast majority of CTPht is used in the metallurgical industry, where it is used as a binder and impregnating agent and is transformed into pitch coke (after incomplete pyrolysis). The biggest use of tar oils is as feedstock for the manufacture of carbon black. **Petroleum tar distillation** is a similar process, where tar derived from petcoke (see next section) is distilled. The plants that process coal tar also may process petroleum tar.

Coal gasification. Coal gasification, where coal is reacted with oxygen, steam and carbon dioxide to form a gas containing hydrogen and carbon monoxide (also known as syngas), is mentioned in the IARC monographs. However, based on feedback received during the consultation, this activity no longer takes place in Europe and is not considered further.

Carbon black. Carbon black is produced by the reaction of a hydrocarbon fuel such as oil or gas with a limited supply of combustion air at temperatures of 1320 to 1540°C in a reaction chamber (US EPA, 1995).

Carbon black is a form of elemental carbon that is manufactured by the controlled vapour-phase pyrolysis and partial combustion of hydrocarbons. It is primarily used in the manufacture of

⁵ Pitch, coal tar, high-temp. EC 266-028-2, CAS 65996-93-2

rubber as a black pigment and because of its electrically conductive properties, it is also used as a nanomaterial (IARC, 2012). It is typically a closed process and the key environmental issues during manufacture of carbon black are emissions of NO_x and SO_x and dust (IPPC, 2007). Feedstock include gaseous or liquid hydrocarbons that be vaporised, such as certain fractions of coal tar and petrochemical oils, e.g. anthracene oil (coal) or slurry oil (refineries' residue). Natural gas constitutes the secondary feedstock (BREF, 2007a).

Around 65% of the world's consumption of carbon black is used in the production of tyres and tyre products, roughly 30% goes into other rubber products, with the rest (5%) being used mainly in printing inks, paint, paper and other small applications (Stakeholder Consultation 2023; IPPC, 2007).

Manufacture of tyre and rubber products. Exposure to PAH can occur during the manufacture of tyre and rubber products due to the use of carbon black, as one of its main feedstocks, and extender oils. The PAH content of extender oils has been limited since the introduction of the REACH Restriction Entry 50. PAH present in carbon black have very strong physical-chemical bonding to the carbon matrix and they do not extract easily from carbon black. PAH present in carbon black are hardly bioavailable and old extender oils have already been replaced by the new low-PAH content oils (RAC, 2022b).

The limited data available support a low level of exposure to BaP: DGUV 2022 reports non detectable limits while Unwin et al. (2006) report exposure levels of 10-20 ng/m³. However, the data were collected before the introduction of the REACH Restriction entry 50 on PAH came into force and since then exposure will be lower.

Graphite and carbon electrode. Materials made of carbon (solid fillers) are produced by pyrolysis with the addition of binding agents such as tar and pitch. The feedstock is comprised of solid fillers and binders. The solid fillers can be petroleum coke (also known as petcoke) or pitch coke, anthracite, but also graphite and soot. Coal tar pitch, petroleum pitch and synthetic resins are the main binders used. The components can be described in terms of carbon transformation:

- Primary carbon (coke) is the main, filler material;
- CTPht is transformed into coal tar pitch coke during baking of the green bodies, forming secondary carbon; and
- The impregnation with CTPht and subsequent re-baking form the tertiary carbon (Stakeholder Consultation, 2023).

The steps are described below (DGUV, 2022):

- 1 The first step is the processing of solid fillers, by grinding or milling. The pitch needs to be heated at 90°C to be used as a binder. Binders and mixers are usually mixed at room temperature (in some cases at 200->300°C) to form a plastic mass (with plasticity). Depending on the production technology, closed or open mixers with suction or ventilation are used.
- 2 The plastic masses are then shaped by pressing processes (such as stamping, extrusion etc.) to form so-called green shaped bodies, usually at a temperature up to 170°C.
- 3 In a further step, the green mouldings are fired in the absence of air at 600-1300°C in closed or covered firing units to coke the binder, which results in a porous carbon body.

- 4 The latter is densified by impregnation, usually with CTPht, which is normally re-fired and the impregnating agent is converted into solid, highly annealed carbon.
- 5 Products that require high electrical and/or thermal conductivity are graphitized by a further firing at approximately 2,800°C for several days. Synthetic graphite is produced in the same way, but the output is blocks that have not been machined (shaped).

The main types of graphite and carbon electrodes are (Stakeholder Consultation, 2023):

- **Synthetic graphite.** Graphite electrodes: mainly used in electric arc furnaces (EAF) for the production and recycling of steel, iron, ferroalloys and non-ferrous products. Graphite electrodes are used thanks to their resistance to high currents and high temperatures (steel requires particularly high temperatures). Specialties: used for the manufacture of products such as metal-ion batteries (up to 50% of graphite in batteries is synthetic graphite), fuel cells, carbon discs, graphite additives used in refractory products, carbon fibres, to name a few;
- **Carbon and graphitised anodes and cathodes.** Used in the manufacture of aluminium (electrolysis). The anodes are bought as machined green bodies and pre-baked on-site in a separate area of the aluminium plant. In contrast, cathodes are delivered baked to the site; and
- **Green Søderberg products.** Also known as Søderberg electrodes, usually made from calcined petroleum coke, calcined anthracite, CTPht and other materials. They are used as a conductor in submerged arc furnace under self-baking process while manufacturing different types of ferroalloys, silicon metal, silicon carbide and calcium carbide. Silicon is used in the photovoltaic industry (solar panels) as well as wind turbines. Søderberg briquettes or pastes are used for various furnaces in the metals and chemical industry.

The carbon and graphite products are supplied to the aluminium, steel, ferro and non-ferro-alloys, silicon, yellow phosphorous (precursor to fertilisers), semiconductors, defence, mobility, aviation and aerospace and chemical industries which require these materials for their production processes (ECGA, 2022a; RAC, 2022; DGUV, 2022). Petroleum pitch has been tested as an alternative, but the resulting products has reduced performance and it increases the carbon content of the manufactured material or metal (ECGA, 2022a).

Aluminium production. Alumina obtained from the mineral bauxite is reduced to metallic aluminium by electrolysis using the cryolite-alumina process. To do this, the aluminium oxide is mixed with additives that lower the melting point (e.g. cryolite) and melted in a tank (smelting cell) that serves as a cathode in the electrolysis process. In a modern alumina-smelting cell, electric current enters the cell through the anode (either pre-baked or continuously self-baking Søderberg anode) and leaves through (collector) bars connected to the carbon cathode at the bottom. Prebaked anodes, i.e. electrodes, are produced by moulding petroleum coke and coal-tar pitch binder into blocks which are baked at 1000–1200°C (see carbon and graphite electrodes above). Molten aluminium is generally removed from the cells daily by siphoning into a crucible (IARC, 2012; RAC, 2022b).

In all plants within the EU27 countries, anodes are formed and pre-baked on-site in a separate area. The carbon anodes need replacing as the electrolytic process consumes them (Di Corleto, 2010; DGUV, 2022; Stakeholder Consultation, 2023).

Today there is only one Söderberg plant in Europe, which is located in Norway, and exposure in aluminium plants is mainly related to the paste plants and anode baking plants in the pre-bake area (RAC, 2022b; Stakeholder Consultation, 2023).

Other potential exposures in these occupational settings include: sulphur dioxide and fluorides; aluminium fluoride, fibrous sodium aluminium tetrafluoride particles, fluorspar, alumina, carbon monoxide, carbon dioxide, various trace metals, such as vanadium, chromium and nickel, asbestos, extreme heat and high static magnetic fields (RAC, 2022b; IARC, 2012).

Steel and iron foundries, including ferroalloys. Organic binders, coal powder and other carbonaceous additives are the predominant sources of PAH in iron and steel foundries. In some cases, exhaust gases from engines, furnaces and ovens may increase the exposure of workers to these compounds (IARC, 2012). The area where exposure to PAH from coal and petroleum derived sources may take place is near the furnace (shop area) or in the casting area.

The production of steel is either via the 'primary' production route, which uses a blast furnace and basic oxygen furnace (BF-BOF), or via the 'secondary' route in EAF. In the primary route, the BF produces iron from iron ore and in a second step a BOF converter turns iron, with some additions of scrap, into steel. This primary process currently relies primarily on **coking coal**, which is both the reductant and is used to generate the high temperature necessary to melt the iron ore. In the BOF converter, oxygen is blown onto the liquid iron to burn unwanted elements (with added carbon) and turn the iron into steel. The liquid steel is then cast into solid slabs or ingots and processed into bars, wire or flat steel strips via several rolling operations. In the secondary route, the main feedstock is steel scrap, and the heat required to melt the metal comes from an electric arc that is generated at the tips of the electrodes when they make contact with the metal. Arc temperatures can reach 3,500°C, while the temperature of the molten metal is approximately 1,800°C. Approximately 60% of total EU steel is produced via the BF-BOF production route, and 40% is produced via the EAF route (EUROFER, 2020). Graphite electrodes are used in EAF to achieve the temperatures necessary to melt scrap steel and recycle steel (ECGA, 2022).

For iron and steel production, the average consumption of electrode is approximately 2–5 kg/tonne of steel, depending on the quality of the charge material, the quality of the electrodes and numerous factors related to the productivity and operation of the arc furnace (IARC, 2010). The residual oil on ferrous scrap that is heated during melting is an additional source of PAH (Stakeholder Consultation, 2023).

Söderberg anodes are understood to be used in some ferroalloy manufacturing, while briquettes or pastes are used in furnaces in the metals industry (Stakeholder Consultation, 2023).

With regards to exposure routes, as per casting of metals, partly vaporised PAH can be adsorbed onto soot, fume or sand particles and spread throughout the workplace during shake-out and dusty operations (IARC, 2012).

Non-ferrous metallurgical process. An example is the manufacture of silicon carbides (DGUV, 2022). The manufacture of silicon carbide requires the use of raw materials such as quicklime (calcium oxide) and silica in the form of quartz respectively, together with a source of carbon. The source of carbon can be coke/petcoke, while the anodes (made with CTPht) ensure high temperature is achieved. The materials are loaded into furnaces and heated to the required temperature and in plants that use Söderberg anodes, these are consumed during the process and release PAH. It is unclear how widespread the use of Söderberg anodes is – some industry representatives have indicated that they are used in the manufacture of silicon metal and

calcium carbide, while a report by DGUV (2022) indicate that their use in these industries was phased out several decades ago in Germany. In any case, Søderberg briquettes or pastes are used in furnaces in the metals industry, and once these are heated, they release PAH. When petroleum tar pitch is used instead of CTPht, there are lower levels of PAH emissions (DGUV, 2022). Workers are also exposed to asbestos among other chemicals (IARC, 2012).

Manufacture and use of refractory products. CTPht was used as a binder for tap hole clay, ramming mixes and gunning mixes, without which a safe operation of blast furnaces was not possible. CTPht was also used for the impregnation of refractory bricks and is still currently used on slide plates for the safe operation of converters. BaP-free or low contamination refractory materials have been used since 2011, e.g. resins.

Coal tar pitch continues to be used only for the manufacture of products that need to withstand intense stress, e.g. steel industries working at extremely high temperatures and more specifically, the slide gate system (anfre, 2016). The slide gate system is one of the flow control components in the steel casting process. In the casting process, liquid steel is transferred from the steel ladle into the continuous caster machine, in which the liquid steel is transformed into solid slabs. The basic function of the slide gate system is to control the flow of the liquid steel from the ladle to the tundish and from the tundish to the mould (anfre, 2016; Stakeholder Consultation, 2023). Therefore, exposure can occur at the site where refractory products are manufactured, where impregnation of CTPht takes place, as well as the casting area of steel foundries where the gates are baked on-site and the coal-tar pitch impregnated gate is graphitized.

According to information gathered during the consultation, resin as well as a novel binder made with low temperature coal tar pitch are used in several applications. For refractories, the pitch industry now proposes pitches with a higher softening point resulting in a BaP (B(a)P) content of 300 ppm compared to levels with CTPht ranging up to 20,000 ppm (EU RAR, 2008). The use of the modified pitch results in some exposure but to lower levels compared to CTPht (Stakeholder Consultation, 2023). Unfortunately, no data are available, but stakeholders indicated that manufacturers struggle to comply with existing limit values in Germany when the modified pitch.

Other refractory products are bricks made to line furnaces. These are manufactured in the same sites that manufacture graphite.

Wood preservation. Creosote has been historically used to protect railway sleepers, telegraph poles and other similar wooden from the elements and from insect infestation. The European standard EN 13991:2003 categorises creosote oils used for impregnation to three WEI grades. WEI grades B and C are restricted to 0.005% (v/v) BaP, whereas WEI A may contain up to 0.05% BaP. For wood impregnation, only grades B and C are currently allowed in the EU and vacuum processes and hot-and-cold dipping are the mostly applied techniques.

The use of creosote as a biocide for the impregnation of wood has been authorised in several Member States, but is only permitted by vacuum pressure impregnation in industrial installations and can only be placed on the market in those Member States included in the list for use on wooden railway sleepers and telecommunication poles from 30 April 2023 (ECHA, 2023b)⁶.

⁶ Railway sleepers treated with creosote can be placed on the market in the following Member States: Austria, Bulgaria, Belgium, Croatia, Czech Republic, Germany, Denmark, Spain, Estonia, Finland, France, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Poland, Portugal, Romania, Sweden, Slovakia and

Recycling of railways sleepers (processing) has been shown to lead to exposure to PAH (RAC, 2022b, referencing Hagmann et al. 2017), and welding of train tracks and wood impregnated with creosote oil can also lead to high levels of BaP exposure (IFA, 2014).

A REACH restriction is being developed on the use and recycling of wood impregnated with creosote and creosote related substances (ECHA, 2022a) and insufficient information is currently available on recycling practices.

Manufacture of clay shooting targets. The use of CTPht has been curtailed since the substance was added to REACH Annex XIV. The manufacture of clay shooting targets has been the subject of several REACH authorisations, which have not been granted further for this use. In addition, a Restriction Proposal Opinion by RAC and SEAC was published in September 2022 that limits the amount of PAH in clay shooting targets, which prevents the use of coal-tar pitch (ECHA, 2023a). Therefore, this use is considered of low priority and is not assessed further.

Similarly, the use of coal tar for coating of pipes (reported in (Unwin, Cocker, Scobbie, & Chambers, 2006)), no longer takes place in Europe.

3.2.10.3 Presence of PAH as an impurity – petroleum derived products

The main sectors and processes where exposure to PAH can occur due to the use of petroleum and petroleum derived processes are described in Table 3-5.

Slovenia. Utility poles treated with creosote can be placed on the market in the following Member States: Austria, Bulgaria, Cyprus, Czech Republic, Greece, Spain, Estonia, Finland, Hungary, Ireland, Italy, Poland and Sweden.

Table 3-5 Description of uses and sectors using petroleum derived products where exposure to PAH can take place.

Use or sector	Description	Examples of activities/occupations/exposure situations	Relevant sub-strate/material	Temperature	Estimated category of risk (airborne)	Estimated category of risk (skin)
Refineries	Processing of crude oil in refineries, closed systems.	- Loading and unloading of raw material - Sampling for Quality Check (QC) and laboratory analysis - Maintenance of pipes and equipment - Transfer of heated heavy streams for transport - Fugitive emissions	Crude oil and crude oil streams, with a focus on heavy streams	Variable but generally low, heavy fuel oil (HFO) is transferred at 60-80°C	Low, due to the use of closed processes	Low, due to use of PPE
Calcination of pet-coke	Calcination of petcoke (high temperature processing), similar to the manufacture of coke from coal	Similar to coking, in table 3-1	Petcoke	1150-1350°C	High	Medium
Manufacture of bituminous products	Bitumen from refineries is further processed to create asphalt products that can be used for road laying, e.g. oxidised asphalt, roofing felt, coatings etc.	- Loading of raw material/unloading of finished product (transfer) - Heating of bitumen for processing - Sampling	Bitumen	80-185°C	Medium	Low
Road paving	Construction of roads and motorways by laying hot bituminous asphalt. Removal of old roads.. Cold applications are outside of the scope. Warm applications, with lower PAH emissions, are on the rise but constitute a small portion.	- Heating of bitumen for processing - Raking - Measuring thickness of road layer - Rolling - Removal of old road	Bitumen (asphalt 99%) and mastic asphalt (1%)	80-185°C manufacture 112-162°C road laying 210-260°C mastic asphalt	Low (bitumen fumes have a low BaP content, however increasing the application temperature results in higher PAH emissions)	Medium - in a dermal study PAH were detected, but no BaP

Use or sector	Description	Examples of activities/occupations/exposure situations	Relevant substrate/material	Temperature	Estimated category of risk (airborne)	Estimated category of risk (skin)
Roofing	Construction of flat roofs by laying hot bitumen, or bitumen panels, sheets and roofing paper (felt roofs) that require hot asphalt as a binding agent. Removal of old roofs, in rare cases containing CTPht. Cold applications are outside of the scope.	• Heating of bitumen for processing • Transfer from "kettle" to laying area • Removal of old roofs	Bitumen (asphalt) and mastic asphalt	150-180°C 220°C mastic asphalt	Low (as above)	Low
Service activities incidental to water transportation	Refuelling of boats with hot heavy fuel oil (HFO) may give rise to PAH fumes, while the repair of ships and boats using HFO as fuel may give rise to dermal exposure	• Loading of fuel in barges and ships • Cleaning and maintenance operations	HFO	Refuelling: 60-80°C Repairs: ambient	Low	High
Retail sale of automotive fuel in specialised stores	Use of gasoline to refuel vehicles	Use of gasoline to refuel vehicles	Diesel and gasoline	Ambient	Low – volatile fractions do not contain BaP	Low – majority of refuelling station services are now self-service
Machining oils	Use of lubricating oils during metal machining processes	Examples are: grinding, cutting, boring, forming	Cutting and lubricating oils	Ambient	Low	Medium

Source: Study team.

Refineries. Crude oil is converted into petroleum products such as gasoline, kerosene, diesel fuel, jet fuel, lubricating oils, heavy fuel oils (HFO) and bitumen amongst others, through process such as distillation, cracking, reforming, desulfurization and blending. The processes take place in closed systems, this is also applicable to offshore production facilities (Hopf, 2010; Stakeholder Consultation, 2023). Workers may be at risk of exposure to PAH and other aromatic hydrocarbons when the system is opened for maintenance or quality checks and the duration of exposure is short (Hopf, 2010; Stakeholder Consultation, 2023). During maintenance operations, equipment is cleaned to maintain operations efficient and prevent hazards. When tanks are cleaned, they are emptied and left to ventilate for several weeks, to minimise the risk of airborne exposure to PAH. Gloves are worn as a standard PPE and good personal hygiene standards are in place to minimise dermal absorption (Stakeholder Consultation, 2023).

The manufacture of bituminous products articles, and of calcinated petcoke are not part of refinery operations (Concawe personal communication, 2023). This study has found that literature may sometimes attribute these activities to refineries, but for the purpose of this study they are considered as separate.

Information gathered through the consultation indicates that refinery streams with the highest PAH and BaP content are catalytically cracked substances (Concawe, 2019). Therefore, the study team is of the opinion that exposure to BaP as indicator for PAH mixtures is likely when crude oil and heavier streams, are handled. Based on data received in the consultation, further refining of streams results in very low levels of BaP ($<7 \text{ ng/m}^3$) and is not considered further. Exposure to lighter PAH is not excluded.

No data on exposure to BaP as indicator for PAH mixtures is available in activities of upstream oils refineries, i.e. **crude oil and shale oil extraction**.

Calcination of petcoke. Petroleum coke (or petcoke) is a by-product of the oil refining process. It can be heat-treated up to 1300°C , in a manner similar to coal-based coke, to remove impurities and produce calcinated coke which is then used like coke, as a high-grade fuel, in the manufacture of electrodes, graphite or in metallurgical processes (often referred to as needle coke). It contains much lower levels of PAH and BaP compared to coal derived coke. A measurement for petroleum coking is described by (Unwin, et al., 2006) and the study team believes this is related to calcination of petcoke due to the relatively high measurement (374 ng/m^3 BaP) and feedback from industry. Based on research and feedback during the consultation, calcination of petcoke is common in the US but not in Europe and the major European supplier of petcoke is located in the UK, which is outside the scope of this report.

Manufacture of bituminous products. Bitumen from refineries is further processed into products used for road paving, as well as roofing and in minor uses such as coatings. Bitumen is often referred to interchangeably as asphalt. The manufacture of bitumen takes place in petroleum refineries (discussed above): the lighter fractions are drawn off and sent to other refinery units and the heavier non-boiling components known as atmospheric residuum are sent to the vacuum distillation unit. The pressure and temperature conditions within the vacuum process determine the hardness of the residuum and the grade of bitumen produced.

Depending on the conditions several types are manufactured, and two types are registered under REACH: asphalt (EC 232-490-9) and oxidised asphalt (EC 265-196-4). Oxidised bitumen is used in roofing applications, while air rectified bitumen is used in paving applications and some roofing

applications (Eurobitume, 2021a). Several grades of bitumen are produced, but the amount of PAH does not vary.

Blending of higher and lower viscosity residues in the required proportions can take place at a refinery, or at third party facilities where blend components and finished products can be easily transported and distributed for use. Each processing technique results in different grades of bitumen products, most of which are used in road paving and roofing applications (Eurobitume, 2021a).

According to a study (Nilsson, et al., 2018) the application of oxidised bitumen, polymer modified bitumen and stone mastic asphalt contain similar levels of PAH and appear to result in comparatively similar exposure levels. An exception to this pattern is mastic asphalt (different to stone mastic asphalt), discussed further down. Approximately 85-90% of bitumen is used in the construction or maintenance of roads (Eurobitume, 2021b). Additional uses are for examples the manufacture of roof paper or roof felt and similar products for roofing purposes, or the manufacture of bituminous coatings and paints, however these are minor uses.

The manufacture of **roofing felt** uses hot straight-run bitumen grades (EC 232-490-9) to impregnate, during immersion, a dry felt made from waste paper or rags. A surface coating is then applied to both sides of the saturated felt using oxidised bitumens, which sometimes contain an added filler. Impregnated felts are also used for damp-proof courses in masonry (IARC, 2013). **In paving**, asphalt mixes are manufactured by heating and drying mixtures of graded crushed stone, sand and filler (the mineral aggregate) and mixing with straight-run or air-rectified bitumens (4-10%), which serve mainly as a binder to hold the aggregate together, in tower units (IARC, 2013). This is an open, mechanised process (based on a process viewed by the study team).

A report by EAPA indicates that in some cases the same company manufacture bituminous products for road paving and performs road paving operations (EAPA, 2021). Exposure from the manufacture of bituminous products can occur during loading and unloading of raw and finished materials, fumes during the manufacture (bitumen needs to remain heated or it will solidify) and during routine cleaning and maintenance operations.

Road paving. Roads used to be made with hot coal tar, which led to high levels of exposure to PAH. Bitumen is now exclusively used, which has much lower PAH content and exposure potential (2.9-8.6 ppm BaP in bitumen fumes, vs 553-2022 ppm BaP for coal-tar pitch fumes (IARC, 2013)). A large portion of **reclaimed asphalt** is re-used on-site, however the old road material is tested for PAH content and if high levels are found, it is rather sent to landfill or incineration (Stakeholder Consultation, 2023).

Bitumens are laid onto roads by a placement and compaction crew of about 5-9 people (IARC, 2012):

- Paver operators: drive the paver machine;
- Screed operators: work behind the paver, controlling the even spread of the asphalt mat;
- Labourers/rakers: work behind the paver, shovelling and raking excess asphalt. Labourers often work as rakers, but also handle other tasks away from asphalt; and

- Roller operators: drive the machinery that compact the asphalt mat, they work at varying distances from the paving machine.

Screed operators and rakers are the closest in contact with the bitumen fumes, and are thus the workers with the comparatively highest exposure levels (IARC, 2012).

Dermal exposure and uptake of PAH is visible (Stakeholder Consultation, 2023). A study measured PAH and individual BaP concentrations on road paving workers, and PAH exposure detected in the groin, neck, shoulder, ankle, upper arm, wrist however no BaP detected (Cirila et al., 2007)

Roofing. Hot-applied bitumen is heated on-site to 180-230°C (in a kettle) and pumped to the roof via a supply line or brought to the roof in buckets. A worker tends the kettle (filling, fluid and temp checks, skimming off debris), while other workers tear off the old roof and put down the new roof. Once the bitumen is delivered on the roof, it may be drawn directly into mop carts or buckets for manual installation jobs, in which it is applied like mopping a floor (IARC, 2013).

Similar to paving, roofs used to be laid with coal tar, but this is no longer the case. Cold bitumen applications do not result in exposure to carcinogenic PAH.

Limitations on use of coal tar pitch. Tar was used in the construction of roads, but has been banned since the mid-1960-1990s in all Member States (IARC, 2012). The removal of old roads involves first an analysis of PAH content, and if it is found to be high, the road surface made with tar is removed through milling, it is not heated and PAH exposure is not considered to be of concern (Stakeholder Consultation, 2023). Flat roofs also used to be made with tar, and the removal from roof coverings can result in exposure to extremely high levels of PAH, as the tar needs to be heated before it can be removed. This is further exacerbated where the removal needs to take place in an enclosed area due to the presence of other contaminants such as asbestos. However workers will be equipped with the appropriate RMMs in case of enclosure due to the presence of other contaminants. The activity is in decline since a roof made with tar can last up to 40 years (HousingHow, 2022), and it is considered to be an unusual, non-standard activity.

Mastic asphalt has a similar composition to normal asphalt, but it is heated to a higher temperature (210-260°C compared to 120-180°C) thus resulting in higher levels of PAH emissions. However, the use of mastic asphalt (EN 13108-6) represents <1% of the total asphalt used in road paving (not to be confused with stone mastic asphalt, EN 13108-5, which is not heated at higher temperatures) (EAPA, 2021). In Germany however, mastic asphalt wearing courses constitute 46% of the existing highway network (AIA, online), and it is used in buildings for soundproofing and roofing (Stakeholder Consultation, 2023). Elsewhere, it is primarily used in civil engineering such as in the construction of bridges and tunnels, or in car parking decks, because it is more hard-wearing, and has a greater degree of resistance to permanent deformation and fatigue (AIA, online). The use of mastic asphalt will be incorporated into the main road paving activities.

Service activities incidental to water transportation. Fuel powered ships and boats used HFO, one of the crude streams with the highest PAH content (Stakeholder Consultation, 2023). Exposure may take place during refuelling with hot HFO (airborne) and during engine building and repair operations (dermal).

Retail sale of automotive fuel in specialised stores. CAREX Canada (CAREX, 2021) mentions gasoline stations, intended as refuelling stations, as the third largest exposure group. Gasoline has a low PAH content in comparison to HFO (Concawe, 2019), and gasoline is not heated. Based on

the findings of the aforementioned Concawe study (Concawe, 2021), gasoline station workers are not expected to be exposed to airborne concentrations of BaP within the levels of the policy options being investigated (see section 5) and this sector is not considered further.

The (Concawe, 2021) study also recorded measurements at a truck loading facility with HFO (relevant to **land transport services**), where the BaP concentrations ranged from not detected to lower than the limit of quantification (LOQ were <37.9 and <41.5 ng BaP/m³). It is not possible to derive conclusions from this study and no other data are available to the study team, in addition HFO is mainly used for water transportation, therefore activities in relation to land transport services cannot be quantified.

Refuelling and consumption of petroleum derived products (kerosine jet fuel) also takes place in **airports**. Very little data are available, but one study reported an average concentration at an airport in Italy of 1.5 ng BaP/m³ (range 0.05-8.6 ng BaP/m³) (Mokalled, 2021, citing Iavicoli 2006). The study team calculated a P95 of 4.5 ng BaP/m³. While another study measured 1-hydroxypyrene concentrations (1-OHP) in Danish air force personnel. The crew members, engineers, fuel operators and munition specialist had an average of 3.29 µmol/mol creatinine, while the reference group consisting of office workers had a higher level at 4.76 µmol/mol creatinine (RAC, 2022b, citing Andersen et al. 2021). The data do not indicate that airport workers are likely to be exposed to levels of BaP as indicator for PAH mixtures, that would be impacted by the policy options being investigated (section 5) and this sector is not considered further.

Metal processing: metal working fluids, machining with oils. The use of oils in metal working and machining has been reported as a sector with exposure (RAC, 2022b; DGUV, 2022), these may be used in engineering and machining process. Metal processing requires oils for metal cutting, as hardening oils or forming oils, lubricating, as well as cooling lubricants, spindle oils and in cold forming. Oils are also used in precision engineering to lubricate and cool tools and materials on lathes and milling machines. The oils used after the 1970s are "severely refined mineral oils" (SRMO) and have a much lower PAH content.

The use of lubricating engine oils in internal combustion engines is considered with automotive service garages, in the next section.

3.2.10.4 Vehicle exhaust fumes and garages

Data for various sectors exposed to engine exhaust emissions are reported in (Petit et al., 2019), the sectors with highest BaP exposure levels are mechanics and underground workers, including tunnels, which are considered below.

The table below presents the main sector where exposure from vehicle exhaust fumes can occur.

Table 3-6 Description of uses and sectors using coal derived products where exposure to PAH can take place.

Use or sector	Description	Examples of activities/occupations/exposure situations	Relevant substrate/material	Temperature	Estimated category of risk (airborne)	Estimated category of risk (skin)
Underground mining	Workers working below ground level with limited air exchange	Emissions from vehicles and machinery	DEEE – Diesel Engine Exhaust fumes	N/A	high	low

Use or sector	Description	Examples of activities/occupations/exposure situations	Relevant sub- strate/ material	Temperature	Estimated category of risk (air-borne)	Estimated category of risk (skin)
Underground construction	As above					
Motor vehicle maintenance and repair	Mechanics, such as road-side assistance workers, garage technicians and similar occupations	Emissions from vehicles, and soot and lubricating oil whilst handling vehicle components	DEEE, petrol emissions and lubricating oils	N/A	Low/medium	High
Forklift operators	Use of forklifts in confined areas	Warehouse operations (underground construction are considered above)	DEEE	N/A	Low	Low

Source: Study team

Mining and underground workers. Workers in underground mines are exposed to diesel exhaust emissions from mining equipment and other vehicles powered with diesel fuels (Gren et al., 2022). Construction workers who work in tunnels or underground for other reasons, e.g. underground carparks, are exposed to exhaust emissions from similar sources and for this reason the work has been grouped together even though the industries in which exposure takes place are different.

Advances in emission legislation, engine development, and aftertreatment systems have reduced the hazardous exhaust emission from diesel vehicles, while emission legislation for heavy equipment (non-road engines) has become more stringent in recent years (Gren et al., 2022), so PAH exposure is also expected to have declined.

Other process engine fumes. As already indicated, many sectors will be exposed to PAH via fumes of diesel or other process engines, such as traffic enforcement officers. Petit et al. (2019) have reviewed several sectors with exposure to engine fumes. In their study, highway workers, e.g. toll collectors, and drivers have a P95 level of exposure that is below the lowest OEL (P95 0.78 and 1.5 ng/m³ of BaP, respectively) are not reviewed further since the introduction of OEL will not have an impact on these.

Of note are the two following uses. The use of two-stroke and four-stroke engines results in exposure levels with a P95 >8 ng/m³ (hedge trimmers have a geometric mean of 3.1 ng/m³ and a P95 of 14 ng/m³ of BaP), however these are open-air, seasonal jobs that are unlikely to be carried out by an individual throughout the year and have therefore not been considered further. The sector defined as "generator" (geometric mean 0.95 ng/m³ and a P95 of 8.3 ng/m³ of BaP) is also not investigated further since it is also considered unlikely that workers would be near a generator for an extended period of time (work with generators tends to be temporary and large generators, with supposedly the highest levels of emissions, are cordoned off, based on experience of the study team). In addition, the study uses data collected between 1995-2010 and it is possible that exposure levels have dropped since, for similar considerations to the ones made under mining. Workers in an enclosed environment such as underground construction workers and those involved in mining activities are thought to be the worst case scenario.

Garages and automotive repair mechanics. Mechanics conducting repairs and overhauls of automotive vehicles may be exposed to exhaust fumes as well as soot and used lubricating oils whilst handling car components. The use of PPE such as gloves is variable, while the use of RPE is uncommon. Based on literature, workers in bus depots and working with other types of heavy vehicles, such as trucks and agricultural machinery have the highest levels of airborne exposure to BaP.

According to ECHA, the PAH levels in used and unused engine lubricating oils are of the same order of magnitude. However, in petrol-fuelled engine oils, the PAH content rises dramatically by 30-500 times; in comparison, the total PAH levels in used diesel-fuelled engine oils was only 1.4-6.1 times greater than that in an unused sample. The major constituents of used oils are pyrene and fluoranthene (RAC, 2022b).

Forklift operators have also been identified as workers with the potential for exposure to PAH (Pośniak, et al., 2003). However, the study was conducted over 20 years ago and forklift operators, are thought to be exposed to relatively high levels of DEEE in closed spaces such as warehouses (as opposed to open areas such as construction sites) and these are not linked to a particular industry. Therefore, it has not been possible to assign the workers to a sector.

3.2.10.5 Complete list of sectors and NACE codes

The table below presents the complete list of sectors and NACE codes.

Table 3-7 Gross list of identified sectors with potential risk of exposure to PAH

Sector (NACE Code)	NACE description	Specific activity
B06.20	Coal gasification	• This activity no longer takes place in Europe
C10.13, C.20	Smokehouses	• Smoke development and temperature setting • Laying smoked goods • Quality control of smoke and cooking stage • Discharging smoked goods and cleaning the ovens and smoke generator
C16.1	Wood preservation (creosote)	• Vacuum processes and hot-and-cold dipping are the most applied techniques
C19.1	Coking plants	• Charging of coke ovens with fresh coal • Pushing of cokes from coke ovens during unloading • Maintenance operations • Fugitive emissions
C19.10	Calcination of pet-coke	• Similar to coking. However this activity appears to take place primarily in the UK and is therefore outside of scope.
C19.2	Petroleum refineries	• Loading and unloading of raw material • Sampling for QC • Laboratory analysis • Maintenance of pipes and equipment • Transfer of heated heavy streams for transport
C20.13	Manufacture of carbon black	• Maintenance and cleaning of equipment • Unloading (coupling and uncoupling of hoses) of vessels containing raw material • Fugitive emissions • Sampling and laboratory analysis
C20.14	Coal tar distillation	• Maintenance operations • Unloading (coupling and uncoupling of hoses) of vessels containing raw material and finished products

Sector (NACE Code)	NACE description	Specific activity
		- Fugitive emissions - Sampling and laboratory analysis
C22.11, C22.19	Manufacture of tyre and rubber products	- Mixing and kneading - Vulcanising - Curing - Retreading
C23.2	Manufacture of refractory products	- Storage/processing of binding material - Impregnation - Machining (shaping) - Firing of raw body
C23.99a	Manufacture of bituminous products	- Loading of raw material/unloading of finished product (transfer) - Heating of bitumen for processing - Sampling
C23.99b	Graphite and carbon electrodes manufacture	- Storage/processing of solid fillers - Mixing of fillers and binders - Shaping of green bodies - Firing in the absence of air - Impregnation - Graphitization - Repairs and maintenance operations - Sampling for Quality Check (QC) and laboratory analysis - Fugitive emissions
C24.1	Steel and iron foundries, ferroalloys	- Handling of raw materials - Loading into electric/electric arc furnaces - Repairs and maintenance - Fugitive emissions
C24.42	Manufacture of aluminium	- Moulding and pre-baking of anodes (done in adjacent plant on-site) - Start-up of furnace - Replacement of anode - Repairs and maintenance - Fugitive emissions
C24.45	Other non-ferrous metallurgical processes	- Handling of raw materials - Loading into electric/electric arc furnaces - Repairs and maintenance - Fugitive emissions
C24.5	Casting	- Moulding and core-making; - Melting; - Pouring; - Shakeout; - Fettling; - Maintenance technicians conducting
C25.62	Machining: metal working with lubricating oils	- Machining: grinding, cutting, boring, forming that lead to the vaporisation of oils - Dermal and inhalation exposure
D32.30	Manufacture of sports goods: clay shooting targets	The REACH restriction for this use limits the amount of PAH that can be present, therefore exposure from this use is considered limited going forward and is not considered further
D35.11	Coal fired power plants	- Combustion: within boilers, furnaces and other equipment and subsequent emission to air - Cooling: cooling towers are used to regulate the temperature of water, PAH contained in the water may be released to air - Storage and handling: of fuels used to generate electricity

Sector (NACE Code)	NACE description	Specific activity
		Waste: fly ash and bottom ash can contain PAH
E38.2	Waste incineration	See D35.11
E39.0	Soil remediation	- Inspection of area - Sampling - Removal of soil - Heat conduction and volatilisation of PAH
F42.11	Road paving	- Heating of bitumen for processing - Raking - Measuring thickness of road layer - Rolling - Removal of old road
F42.12	Welding of train tracks	- Arc-welding - Aluminothermic welding
F43.91	Roofing	- Heating of bitumen for processing - Transfer from "kettle" to laying area - Removal of old roofs
G45.2	Motor vehicles repair and maintenance	- Exposure to Diesel Engine Exhaust (DEEE) - Dermal exposure to soot - Dermal exposure to used lubricating oils
G47.3	Retail sale of automotive fuel in specialised stores	Fugitive emissions
H52.22	Service activities incidental to water transportation	- Loading of barges and ships - Cleaning and maintenance operations
I56.10, I56.21, I56.29	Cooks and chefs	- Heating oil and fats to a high temperature (e.g. frying) - Grilling - Combustion of biomass fuel (mainly wood and charcoal)
N81.22	Chimney sweeping	- Insertion and removal of suction or cleaning devise; - Removal of soot and dust from the immediate area.
O84.25	Firefighters	- Training exercise and live fire extinguishing: monitoring with-out the use of RPE - Dermal contact from contaminated, RPE/PPE, equipment and of-fice spaces
S96.03	Crematoria	Exposure from fumes released from abatement systems
F41	Underground construction workers	Exposure to engine exhaust fumes and particularly DEEE during enclosed operations.
B07	Underground mining	
N/A	Forklift operators	Exposure to exhaust fumes during normal work operations

Source: Study team on the basis of sources listed in section 3.2.8 and in text presented in the previous sections

3.2.11 Uses of sectors excluded from analysis

The exclusion criteria are presented in section 3.2.9. The table below presents the uses and sectors excluded from the analysis.

Table 3-8 Uses and sectors excluded from analysis

Use or sector		Source of information on use or sector	Reasons for exclusion
B06.20	Coal gasification	(Stakeholder Consultation, 2023)	This activity no longer takes place in Europe
C19.1	Calcination of petcoke	(Stakeholder Consultation, 2023)	Based on information gathered in the consultation, calcinated petcoke is purchased from UK manufacturers only, and unless additional manufacturers inside the EU are identified, the use is therefore outside of scope.
C22.11, C22.19	Manufacture of tyre and rubber products	(Unwin et al., 2006; DGUV, 2022)	As indicated by ECHA, the REACH restriction on PAH has greatly reduced exposure to PAH from extender oils, while PAH in carbon black are not bioavailable. Data from (DGUV, 2022) indicate that the level of exposure is below the limit of detection, while (Unwin et al., 2006) reports exposure values 10-20 ng/m ³ BaP but this was before the introduction of the REACH restriction.
C22.2	Manufacture and processing of plastics	(HSE, 2010; DGUV, 2022; Huang et al., 2013)	The manufacture of plastics and rubber from crude oil, and the further processing of plastic (e.g. via extrusion) as well as recycling, have been shown to lead to low levels of PAH (up to 2 ng/m ³ BaP) and are not considered further in this assessment.
C25.62	Machining oils	(Petit et al., 2019)	The paper presents values for “use of lubricating oils”. Exposure values are present that appear to be related to casting (discharge mould) and garages (vehicles and mechanic driver). When these data points are removed the highest P90 is 3.2 ng/m ³ BaP, which is below the lowest OEL.
D32.30	Manufacture of sports goods: clay shooting targets	(ECHA, 2023a)	The REACH Authorisations for this use of CTPht have not been granted and the RAC and SEAC Opinions on the in the manufacture of clay shooting targets limits the levels of PAH and precludes the use of CTPht, and therefore the use is not taken forward.
F43.91	Roofing	(Unwin et al., 2006; Persoons et al., 2020)	The available data indicate that measured concentrations of BaP during roofing activities are between 0.23 and 20 ng/m³ BaP. The study team has modelled a P95 of 4.9 ng/m³ BaP, which is below the lowest OEL. During the removal of tar roofs however, high concentrations of BaP have been recorded (37-145 ng/m³ BaP in open environment and 15,360-22,520 ng/m³ BaP in closed environments where asbestos is also present – but additional and adequate RMMs are anticipated in the latter case). The removal of old roofs is an activity that seldom takes place. See section 3.2.10.3. No additional sources with data on BaP are available.
G47.3	Retail sale of automotive fuel in specialised stores	Study team estimation based on composition and study with heavy	The volatile fractions of diesel and gasoline are unlikely to contain significant amounts BaP (<7 ng/m ³) at room temperature.

Use or sector		Source of information on use or sector	Reasons for exclusion
		streams (Concawe, 2019; Concawe, 2021)	
H52.22	Water transportation mechanics	(Concawe, 2016; Christopher et al., 2011)	The study by Concawe (2016) measured the levels of PAH exposure from workers loading tankers with HFO. The levels of BaP were below the limit of quantification in the range <9 to <76 ng/m³, so it is not possible to say whether the exposure would be within scope or not and the study team cannot model the exposure values. Another study analysed the dermal load of several workers, including workers during ship engine building and maintenance, using phenanthrene and naphthalene as markers when using gloves (Christopher, et al., 2011). The study found that even with the use of leather gloves, the markers were detectable on the hands and forearms of these workers and that good hygiene had a significant positive impact on the amount of dermal exposure, however BaP was not measured.
I56.10, I56.21, I56.29	Chefs and cooks	(Cirla et al., 2008; Almerud et al., 2018; Vicente et al., 2021; DGUV, 2022) and study team calculations.	The available data indicate exposure levels between 0.08 and 6 ng/m ³ BaP and has been modelled by the study team to a P95 of 1.6 ng/m ³ BaP. An exception is the use of open wood fires and charcoal, where exposure levels are extremely high, but the practice is not considered to be a usual activity but rather seasonal.
M72.1	Laboratory workers	Study team expert judgement; (Stakeholder Consultation, 2023)	CAREX Canada indicated that laboratory workers are exposed to PAH. The study team has found that consultation data reports values for laboratory workers within industry, who analyse samples. In addition, R&D and laboratory workers may be exposed to reagents that are PAH, which are single PAH rather than the PAH mixture. During the consultation R&D groups did not respond to the consultation as they indicated that this is not an area of concern for them. Furthermore, adequate ventilation and RMMs are thought to be in use. For these reasons the sector is not taken forward.
F41	Underground construction workers	(Park, et al., 2020)	The available data indicates that for underground miners the exposure concentrations of BaP are between 0.05 and 0.35 ng BaP/m ³ , while a study on basement excavations in South Korea presented a value of 7.5 ng BaP/m ³ . The data are pooled due to similar concerns (underground work) and due to the uncertainty with using data from outside of Europe. The study team has calculated that for underground workers the P95 is 3.7 ng BaP/m ³ and therefore they are outside of the scope.
B07	Underground mining	(Geitner et al., 2021; Gren et al., 2022)	
N/A	Forklift operators	(Pośniak et al., 2003)	Exposure levels in the range 8-63 ng BaP/m ³ have been reported. However, the study was conducted over 20 years ago and exposure levels are now likely to be lower, in addition it is also not possible to assign a sector to forklift

Use or sector		Source of information on use or sector	Reasons for exclusion
			drivers as they operate across several sectors (use of forklifts in open areas such as construction sites are not thought to be linked to relevant levels of PAH).
S96.03	Crematoria	(Santasiero et al., 2005; DEFRA, 2012)	Only one study is available measuring exposure to PAH with a measured BaP concentration of 2.8 ng/m ³ in flume emissions. In addition, PAH are not considered a priority chemical by DEFRA.

3.2.12 Sectors taken forward for analysis

The table below presents the list of sectors and NACE codes taken forward for the analysis. NACE codes and definitions include a multitude of sub-sectors that do not contain PAH exposure and are not relevant. Subsequently the study team has taken the most relevant NACE code for sectors with exposure and defined a subset as a basis for all calculations in this report. As shown in the table below, these NACE codes have been refined and renamed according to the relevant subset.

Table 3-9 Analysed sectors with risk of exposure to PAH

NACE code	NACE definition	Refined short name for relevant sub-sector	Description of activity
C10.13, C10.20	Production of meat and poultry meat products; Processing and preserving of fish, crustaceans and molluscs	Fish and meat smoke houses	Smoking of fish and meat for preservation purposes
C16.1	Sawmilling and planing of wood	Wood preservation (creosote)	Impregnation of wood with creosote
C19.10	Manufacture of coke oven products	Coking plants	Carbonation of coal
C19.2	Manufacture of refined petroleum products	Petroleum refineries	Refining of crude oil
C20.13	Manufacture of other inorganic basic chemicals	Manufacture of carbon black	Reaction of aromatic compounds to manufacture carbon black
C20.14	Manufacture of other organic basic chemicals	Coal tar distillation	Refining of coal tar
C23.2	Manufacture of refractory products	Manufacture of refractory products	Manufacture of refractory products with coal tar pitch high-temperature (CTPht)
C23.99a	Manufacture of other non-metallic mineral products n.e.c	Manufacture of bituminous products	Use of bitumen to manufacture road paving and roofing products
C23.99b		Graphite and carbon electrodes manufacture	Use of carbon solids and binding agents such as CTPht to manufacture graphite and carbon electrodes, via baking, impregnation, shaping and graphitisation at high temperatures
C24.1	Manufacture of basic iron and steel and of ferro-alloys	Steel and iron foundries, ferroalloys	Use of coal, coal powders and graphite electrodes to manufacture iron and steel
C24.45	Other non-ferrous metal production	Other non-ferrous metallurgical processes	Use of Söderberg electrodes, briquettes or paste at high

NACE code	NACE definition	Refined short name for relevant sub-sector	Description of activity
			temperature to manufacture non-ferrous metals and products
C24.42	Aluminium production	Manufacture of aluminium	Use of carbon and graphite electrodes to manufacture aluminium
C24.5	Casting of metals	Casting of metals	Casting of metals in sand moulds
D35.11	Production of electricity	Coal fired power plants	Use of coal to generate electricity
E38.2	Waste treatment and disposal	Waste incineration	Incineration of municipal or hazardous waste
E39	Remediation activities and other waste management services	Soil remediation	Thermal soil remediation of soil contaminated with PAH, may include excavation
F42.11	Construction of roads and motorways	Road paving	Paving of roads with bitumen
F42.12	Construction of railways and underground railways	Welding of train tracks	Welding of train tracks impregnated with creosote oil
G45.2	Maintenance and repair of motor vehicles	Motor vehicle maintenance and repairs	Maintenance and repair of motorised vehicles
N81.22	Other building and industrial cleaning activities	Chimney sweeps	Cleaning of chimneys
O84.25	Fire service activities	Firefighters	Extinguishing and monitoring fires

Source: Study team.

Notes:

The sectors presented are not an exhaustive list where exposure to any PAH can occur. The list is based on sectors where exposure to BaP as indicator for PAH mixtures can occur at levels relevant to this study (based on policy options) and where a large number of workers are expected to be affected. Exposure in other sectors and to other forms of carcinogenic PAH (see 1.3.4) or non-carcinogenic PAH cannot be excluded.

3.3 Exposure concentrations

It is recommended that this section is read in conjunction with section 3.2.10.

3.3.1 Data sources

The sources mentioned in section 3.2.6 have been used as data sources. CSR data have also been used by the study team but due to confidentiality reasons these are not presented. It should be noted that:

- Data from exposure studies conducted before the year 2000 was not collected;
- Where multiple values for the same activity and the same sector were available within the same source, e.g. DGUV (2022), preference was given to values within the last decade. Particularly if the sector was impacted by the introduction of REACH Restrictions or Authorisations; and
- Outliers were considered as values that were at least an order of magnitude different to the majority of the data, or where statistical analysis indicated they were likely to be

outliers (for example where the value reported for the average or median was higher than the P95 or P99 for the rest of the dataset and there was no obvious explanation for this).

3.3.2 Airborne vs metabolite

The policy options are based on BaP and its metabolite 3-hydroxybenzo[a]pyrene (3-OHBP) and risk relationships are available for BaP airborne exposure concentrations only (see section 5).

IARC indicates that there is growing awareness that occupational uptake of PAH through the skin can be substantial. For example, uptake of pyrene by the dermal route was estimated to account for as much as 75% of total body dose for coke-oven workers, for creosote-impregnating workers, dermal pyrene uptake was on average 15-fold higher than the estimated respiratory uptake (IARC, 2012).

1-Hydroxypyrene (1-OHP) is the metabolite of the PAH pyrene. The methodology for the collection of the metabolite in urine was established before 3-OHBP and until recently was more sensitive and reliable (see sections 2.1.5 and 3.8). RAC proposes a biological guidance value (BGV) for 1-OHP, based on the levels found in the non-smoking general population, and SCOEL has proposed a BGV of 0.5 µg 1-OHP in urine (equivalent to 0.26 µmol/mol), determined after conjugate hydrolysis. The BGV is outside the scope of this report but can be used as a reference point. In addition, it is possible to correlate 1-OHP measurements with airborne exposure concentrations (see section 2.1.5).

Data on metabolite have been presented for non-smokers, due to the influence of smoking and because the RAC proposed BGV is for non-smokers. However, due to a lack of risk relationship, the metabolite data cannot be used to quantify impacts.

3.3.3 Exposure data from national databases

The study team has not received data from national databases with the exclusion of the SIREP data published by (Scarselli et al., 2013). At the time of writing this report, it has not received data from the German MEGA database.

3.3.4 Exposure data by sector

The following section presents data as reported in the original studies or sources for the sectors under review in this report. Details on the activities and tasks that lead to exposure are presented in section 3.2.10 and are not repeated here. It should be noted that:

- Where less than (<) values are presented, these are <Limit of Detection (LOD). For further processing, half of the LOD has been used to calculate exposure values used for further analysis (section 3.3.7);
- The values from the consultation have been converted into ng/m³ if not already provided as such. The conversion from ppb/ppm into ng/m³ is based at a room temperature of 21°C;
- Data for total PAH exposure cannot easily be extrapolated to BaP. Olsson, et al. (2022) reported that out of 4,500 BaP personal exposure measurements taken between 1979 and 2009 in the EU and Canada 49% were below the LOD for BaP. Where data are available for total PAH and BaP, the study team have not been able to easily establish a relationship. This is likely due to the conditions of exposure, which is sector and activity specific; and

- Where specific type of RPE worn has been reported, the study team has minimum assigned protection factor according to EN 529:2005. Literature from the public domain usually gives no to little indication on whether RPE was worn or not. When RPE is said to be worn but not specified, the study team has assigned it the lowest protection factor according to EN 529:2005, which is a protection factor of 4.

Measurements of PAH and BaP as an indicator for PAH mixture, may be affected by background environmental concentrations, particularly at the lower levels. Cigarette smoke, burning of solid fuels and pollution caused by traffic are examples of sources of BaP that can impact airborne measurements (Ricardo Energy & Environment, 2020; RAC, 2022b). A study reports background concentrations in urban areas up to 10 ng/m³ BaP (Bukowska et al., 2022). However, in the Directive 2004/107/EC (Fourth Daughter Directive), the EU has set a target value for PAH based on BaP as a marker substance for PAH mixture of 1 ng/m³ BaP (for the total content in the PM₁₀ fraction averaged over a calendar year) from 31 December 2012.

With regards to metabolite data, it should be noted that:

- The search focused on data for the metabolite that the BLV is due to be based on, 3-OHBaP. If a study reported on both 1-OHP and 3-OHBaP, data on the latter are reported;
- Where less than (<) values are presented, these are <Limit of Detection (LOD). For further processing, half of the LOD has been used to calculate exposure values used for further analysis (section 3.3.7);
- All data have been converted into nmol/mol creatinine for 3-OHBaP and µmol/mol creatinine for 1-OHP, using the conversion factors reported by ECHA (RAC, 2022b) (see also section 5);
- Where data for non-smokers and smokers are reported or differentiated, data for non-smokers has been selected because smoking falsifies the biomonitoring measurements and because RAC has proposed a Biological Guidance Value (BGV) with 1-OHP for non-smokers (see section 2.1.5); and
- Similarly to airborne measurements, smoking, consumption of smoked or grilled foods and vicinity to open fires burning solid fuels, can increase metabolite concentrations (see section 3.8.2) and are potentially confounding factors.

3.3.4.1 C10.13 and C10.20 Fish and meat smokehouses

3.3.4.1.1 Airborne

The available data for fish and meat smokehouses are presented below. Only data for fish smokehouses are available and the measurements are understood to be taken in early to mid 2000s in the UK. The data show a range 10-220 ng/m³ BaP based on three samples. The range is likely linked to different smoking methods: the more traditional methods which are more labour intensive and where workers are sometimes in direct contact with the smoke, and more commercial, modern methods that are largely automated and take place in semi-closed processes that are intrinsic to the operations. There is no indication on whether RPE was worn, but see notes on biomonitoring. Based on feedback received during the consultation, contamination is reduced to a minimum during smoking activities, however the use of RPE is not necessarily a part of the measures taken to reduce contamination.

The average exposure concentrations (10-220 ng/m³ BaP) are below the second highest policy option (700 ng/m³ BaP).

Table 3-10 Airborne exposure concentrations (BaP ng/m³) from published sources and stakeholder consultation

Sector/ process	n	Mean	Median	P95	Range		RPE APF	Location	Reference (Source)
					Min	Max			
Fish smokehouse - wood	2	10	-	-	10	10	Not known	UK	(Unwin et al., 2006)
Fish smokehouse - wood	1	220	-	-	-	-	Not known	UK	(Unwin et al., 2006)

RPE = respiratory protection equipment

APF = assigned protection factor according to EN 529:2005

No data on meat smokehouses are available and no additional data on fish smokehouses are available.

Unwin et al. (2006) reports exposure to 4-6 ring PAH in the range 60-70 ng/m³ in the measurement with lower BaP concentrations and at 1550 ng/m³ in the measurement with the highest concentrations. 4-6 ring PAH are often used as markers for total exposure to carcinogenic PAH. In the Unwin study the measured 4-6 ring PAH were: benzo[a]anthracene (Carc. 1B), chrysene (Carc. 1B), benzo[b]fluoranthene (or benzo[e]acephenanthrylene, Carc. 1B), benzo[k]fluoranthene, benzo[a]pyrene (the marker in this OEL impact assessment, Carc. 1B), indeno(1,2,3-c,d)pyrene (a Persistent Organic Pollutant), benzo(g,h,i)perylene, dibenz(a,h)anthracene (Carc. 1B).

3.3.4.1.2 Metabolite

The table below presents metabolite data available for the sector. The data are from the same study (Unwin, et al., 2006) with the same number of samples. While the exposure data are a factor of 20 difference between two different sites, the 1-OHP metabolite data are both below the limit of detection and reported as 0.25 µmol/mol creatinine. This is possibly an indication that workers were wearing RPE and little to no dermal contact taking place.

Table 3-11 Fish smokehouses metabolite concentrations from published sources and stakeholder consultation

Sector/ process	Metabolite ^(a)	n	Smokers	Mean	Median	P95	Range		Location	Reference (Source)
							Min	Max		
Fish smokehouse - wood	1-OHP	2	N.R.	0.25	-	-	0.25 ^(b)	0.25 ^(b)	UK	(Unwin, et al., 2006)
Fish smokehouse - wood	1-OHP	1	N.R.	0.25	-	-	0.25 ^(b)	0.25 ^(b)	UK	(Unwin, et al., 2006)

Notes:

N.R. = not reported

^(a) 1-OHP unit µmol/mol creatinine

^(b) values are below the limit of detection

3.3.4.2 C16.1 Wood preservation (creosote)

3.3.4.2.1 Airborne

The preservation of wood using creosote can only take place for the treatment by vacuum pressure impregnation of wood in industrial installations to make railway sleepers, or utility poles for electricity or telecommunications (Commission Implementing Decision, 2022). The Implementing Decision also states that industrial application shall be conducted within a contained area or on impermeable hard standing with bunding; that freshly treated timber shall be stored after treatment under shelter or on impermeable hard standing, or both, to prevent direct losses to soil, sewer or water; and that any losses from the application of the product shall be collected for reuse or disposal. The plant operators receive training in operating the plants and in handling the wood preservatives as well as the newly impregnated timber, and plants are designed to recycle preservative back to chemical storage area (WEI-IEO, online).

The process is largely automated and in closed systems and the risk of exposure takes place when workers are undertaking operations related to the impregnation process but also during handling of the treated wood (e.g. shaping or brushing of areas that require additional treatment). Dermal exposure is perhaps more important than airborne exposure for this sector but there is no standard method to determine dermal contamination.

For professionals who are involved in the installation the Biocidal Product Committee (BPC) opinion indicates that the risks are tolerable and can be addressed sufficiently through the use of PPE and RPE (ECHA, 2020). The BPC opinion also makes recommendations for the use of PPE and RPE during treatment of wood procedures (see section 3.5.2) and it is therefore likely that workers are now actually exposed to less than the airborne concentrations reported in the following table.

The median exposure concentrations for workers in impregnation plants and installation range from not detected to 10 ng/m³ BaP, are below the lowest policy option of 70 ng/m³ BaP.

No information on exposure to other carcinogenic PAH.

Table 3-12 Airborne exposure concentrations (BaP ng/m³) in wood impregnation and handling from published sources and stakeholder consultation

Sector/ process	n	Mean	Median	P95	Range		RPE APF	Lo- ca- tion	Reference (Source)
					Min	Max			
Wood impregnation and boiler pressure systems: loading and unloading, operation, monitoring	≥10			N.D. (P90)			Not known	DE	(DGUV, 2022)
Boiler pressure process	not known				N.D.	N.D.	Not known	DE	(Riechert et al., 2011)
Timber impregnation	11	10			10	11	Not known	UK	(Unwin et al., 2006)
Vacuum impregnation, hot-and-cold dipping, and assembly of	27-44		<LOQ ^(a)				Not known	DE	(RAC, 2022b citing Hebisch et al. 2020)

Sector/ process	n	Mean	Median	P95	Range		RPE APF	Lo- ca- tion	Reference (Source)
					Min	Max			
impregnated rail- way sleepers									

Notes:

RPE = respiratory protection equipment

APF = assigned protection factor according to EN 529:2005

N.D. = not detected

^(a) LOQ = 16 ng/m³ BaP

Unwin et al. (2006) reports exposure to 4-6 ring PAH in the range 10-110 ng/m³.

There are data on recycling of railway sleepers that shows a high potential for exposure⁷, however this activity is subject to an upcoming restriction limiting the exposure to PAH during the activity and is not considered further.

3.3.4.2.2 Metabolite

The data presented in the study by Unwin et al. (2006) indicates that for wood preservation there is a lack of correlation between airborne and metabolite concentrations, and that this is likely due to the effect of dermal exposure on metabolite concentrations. Wood impregnation is a sector with low levels of airborne exposure and high dermal exposure.

Only one study is available with measurement on 3-OHBP in workers at either a creosote plant or during assembly on train tracks, showing metabolite concentration levels in the range 0.06-1.03 nmol/mol creatinine and a median of 0.06 nmol/mol creatinine (Alhamdow et al., 2018). The median is in between the second and third policy options (see section 5) and below existing 3-OHBP BLV for France and Germany.

Table 3-13 Metabolite concentrations from published sources during wood preservation and installation

Sector/ process	Metabolite ^(a)	n	Smokers	Mean	Median	P95	Range		Location	Reference (Source)
							Min	Max		
Workers at creosote impregnation plants or railway switch assembly workers	3-OHBP	19	50% ^(b)		0.32		0.06	1.0	SE	(Alhamdow et al., 2018)
Timber impregnation	1-OHP	11	N.R.	16			1.4	60	UK	(Unwin et al., 2006)
Vacuum impregnation, hot-and-cold dipping, secondary	1-OHP	27-44			9	50			DE	(RAC, 2022b citing Hebisch et al. 2020)

⁷ RAC 2022 reports a study by Hagmann et al. 2017 with median concentrations of 45-130 ng/m³ BaP. The highest concentrations were found during shredding activities. DGUV 2022 also reports levels in the range 50-300 ng/m³ BaP during recycling of railway sleepers, with highest concentrations found during shredding and flattening activities.

Sector/ process	Metab-olite ^(a)	n	Smok-ers	Mea-n	Me-dian	P95	Range		Loca-tion	Reference (Source)
							Min	Max		
exposure from assembly										
Boiler pressure process	1-OHP	68	Mixed				2.2	105	DE	(Riechert et al., 2011)

Notes:

N.R. = not reported

^(a) 1-OHP unit $\mu\text{mol/mol}$ creatinine, 3-OHBaP unit is nmol/mol creatinine

^(b) results are the same for both smokers and non-smokers

3.3.4.3 C19.1 Coking plants

3.3.4.3.1 Airborne

PAH are released during coking of coal (RAC, 2022b). Exposure to PAH occurs at the coke oven battery of the coke plant and exposure takes place during on the bench or on top of the oven battery due to leakages from lids and doors, coal charging and coke pushing (emptying the ovens after finished coking), maintenance, cleaning and rebuilding works (BREF, 2013; Stakeholder Consultation, 2023). In many cases, these activities will result in short-term peak exposures (<1 hour) and the workers with the highest level of exposure are those on the coke oven deck (personal communication with stakeholders). Leaking can be reduced, e.g. by thorough cleaning of the steel doors, but not entirely removed as the fitting of steel door and steel frame cannot be made entirely gas-tight due to large variations in temperature intrinsic to the coking process.

The overall pattern of exposure is that topside workers (including lidmen, tar chasers and Larry-car operators) have the highest exposures, followed by workers by the side of the ovens (such as coke-side machine operators, bench-men, door repairers, wharf-men, quenchers, pushers and temperature controllers). Workers in other areas of the plant such as maintenance, office and control workers have the lowest exposures. Modernization of coke plants, automation of the processes and improved control measures, have substantially reduced exposures over the years (IARC, 2012).

Available data from published sources and stakeholder consultation for PAH exposure is provided in the following table. Company exposure data have been received during stakeholder consultation. The obtained data are within the ranges of the data from published sources. During consultation it emerged that the majority of work conducted during coking operations is towards the containment of raw coke fumes.

Table 3-14 C19.10 exposure concentrations (BaP ng/m³) from published sources and stakeholder consultation

Sector/ process	n	Mean	Median	P95	Range		RPE APF	Location	Reference (Source)
					Min	Max			
Coke oven operation (high temperature)	11	2,140			130	6,210	not known	UK	(Unwin et al., 2006)
Coke oven operation (high temperature)	13	790			210	29,990	not known	UK	(Unwin et al., 2006)
Coke oven operation (low temperature)	13	1,130			10	2,910	not known	UK	(Unwin et al., 2006)
Coke pusher	14		2,412	5,945	0.33	6,338	not known	FR	(Petit et al., 2019)
Furnace door settings	10		201	4,784	96	4,770	not known	FR	(Petit et al., 2019)
Coke withdrawn	8		435	1,364	238	1,395	not known	FR	(Petit et al., 2019)
Furnace battery cleaning-up	16		2,193	4,912	89	9,471	not known	FR	(Petit et al., 2019)
Watchman	12		779	16,426	5	18,911	not known	FR	(Petit et al., 2019)
Mason - Furnace	12		732	2,540	201	2,889	not known	FR	(Petit et al., 2019)
Mason - Work in gallery	6		7,962	14,029	1540	14,807	not known	FR	(Petit et al., 2019)
Operation of coke ovens	79		890	6,190			not known	DE	(RAC, 2022b citing Förster et al., 2008)
Operation of coke ovens	37		1,000	2,500 (P75)			not known	DE	(Marczynski, et al., 2009)
Battery roof, machine side, coke side, quenching	9	0.79					4	PL	(Zajac et al., 2016)
Machine operators	8	0.21					4	PL	(Zajac et al., 2016)
Mechanical maintenance workers	4	0.10					4	PL	(Zajac et al., 2016)
Electrical maintenance workers	4	0.10					4	PL	(Zajac et al., 2016)
Heatermen	1	0.53					4	PL	(Zajac et al., 2016)
Coal derivatives production workers	3	0.10					No	PL	(Zajac et al., 2016)

Sector/ process	n	Mean	Median	P95	Range		RPE APF	Location	Reference (Source)
					Min	Max			
Shift managers	3	0.51					4	PL	(Zajac et al., 2016)
Laboratory	1	0.10					No	PL	(Zajac et al., 2016)
Refractories maintenance workers	1	1.00					4	PL	(Zajac et al., 2016)
Coke-oven workers: top, push, coke side and supervisors	194		280	921			Not known	PL	(Bieniek & Łusiak, 2012)*
Coke by-product workers	32		75	190			Not known	PL	(Bieniek & Łusiak, 2012)*
Other, e.g. electricians and supervising personnel	34		60	490			Not known	PL	(Bieniek & Łusiak, 2012)*
Top, side and maintenance	45		152	20,13	0.05		Not known	TN	(Campo, et al., 2012)
Battery side, oven topside, repair work at combustion chamber wall	N.R.		620	50,50 (P90)			Not known	DE	(DFG, 2012 citing Preuss et al. 2003c)
Oven topside; Machine operator	N.R.	7,440					Not known	DE	(DFG, 2012 citing Strunk et al. 2002)
Bench side, machine operator	N.R.	1,260					Not known	DE	(DFG, 2012 citing Strunk et al. 2002)
Pouring and ramming operation. All work areas	≥10			5,600 (P90)			Not known	DE	(DGUV, 2022)
Bulk operation. Sweeping, ceiling man	≥10			3,400 (P90)			Not known	DE	(DGUV, 2022)
Bulk operation, drive filler truck	≥10			4,200 (P90)			Not known	DE	(DGUV, 2022)
Bulk operation. Clean rinser pipe	≥10			800 (P90)			Not known	DE	(DGUV, 2022)
Bulk operation., Drive the printing press	≥10			2,800 (P90)			Not known	DE	(DGUV, 2022)
Bulk operation. Drive the coke	≥10			500 (P90)			Not known	DE	(DGUV, 2022)

Sector/ process	n	Mean	Median	P95	Range		RPE APF	Location	Reference (Source)
					Min	Max			
transfer machine.									
bulk operation. clean machine side	≥10			1,400 (P90)			Not known	DE	(DGUV, 2022)
Bulk operation. Clean coke side	≥10			4,000 (P90)			Not known	DE	(DGUV, 2022)
Bulk operation. Serviceman	≥10			2,900 (P90)			Not known	DE	(DGUV, 2022)
Driving and accompanying the filling gas transfer machine	≥10			3,000 (P90)			Not known	DE	(DGUV, 2022)
Clean receiver/riser pipe	≥10			4,000 (P90)			Not known	DE	(DGUV, 2022)
Measure temperature	≥10			1,700 (P90)			Not known	DE	(DGUV, 2022)
Driving, tamping, loading and expressing machine as well as coke transfer machine	≥10			100 (P90)			Not known	DE	(DGUV, 2022)
Door setting on the tamping, feeding and ejection machine as well as coke transfer machine	≥10			300 (P90)			Not known	DE	(DGUV, 2022)
PROC23 ^(a)	22	796	535	2,470	3	2,500	4 and 40 ^(d)	EEA	Consultation 1
PROC23 ^(a)	21	991	380	9,080	7	9,900	4 and 40 ^(d)	EEA	Consultation 2
PROC23 ^(a)	49	751	89	4,050	10	7,500	4 and 40 ^(d)	EEA	Consultation 3
PROC23 ^(a)	65	221	35	1,414	4	3,010	4 and 40 ^(d)	EEA	Consultation 4
PROC22 ^(b)	N.R.	727	170	2,433	70	6,875	40 ^(d)	EEA	Consultation 5
PROC28 ^(c)	N.R.	6,025	370	30,114	68	46,000	40 ^(d)	EEA	Consultation 6

Notes:

RPE = respiratory protection equipment

APF = assigned protection factor according to EN 529:2005

N.R. = not reported

* Values exclude the samples where measurement was below LOD/LOQ, so actual TWA when taking into account LOD/LOQ values would be lower

^(a) PROC23 Open processing and transfer operations with minerals/metals at elevated temperature

^(b) PROC22 Manufacturing and processing of minerals and/or metals at substantially elevated temperature

^(c) PROC28 Manual maintenance (cleaning and repair) of machinery

^(d) Further consultation clarified that where workers are exposed to concentrations equivalent to the median and above, they would be wearing as a minimum an EN 12942 mask with TM3.

Workers are wearing RPE (Respiratory Protection Equipment) during activities reported in the consultation, therefore exposure concentrations are recalculated, taking the filter class and assigned protection factors (APF) of RPE into account. Information on RPE has been provided by the companies for each workplace and APFs have therefore been considered on a site-by-site and workplace-by-workplace basis. However the majority of public domain sources did not indicate whether workers were wearing PPE or RPE. Based on consultation with industry, it is likely that workers would have been wearing PPE and RPE for measurements taken in the last 10-15 years. The exposure values taking into account RPE are presented in the table below, the values taken forward for the analysis are in bold.

Table 3-15 C19.10 summary of exposure concentrations (BaP ng/m³) with RPE

	Average	Geo mean	Median	Min	Max	P25	P75	P90	P95	P99
Average	269.3	367.3	216.9	37.6	1,644.8	100.0	625.0	620.4	874.3	-
Min	0.0	103.0	0.9	0.0	62.5	100.0	625.0	25.0	23.8	-
Max	2140.0	1,528.0	1,990.5	385.0	7,497.5	100.0	625.0	1,400.0	4,106.5	-
Median	11.9	205.5	42.6	2.5	938.8	100.0	625.0	700.0	296.3	-

Source: Study team

Notes: values in bold have been taken forward in the analysis

Unwin et al. (2006) reports exposure to 4-6 ring PAH (in the range 10-3593 ng/m³), often used as markers for total exposure to carcinogenic PAH, while Bieniek & Łusiak (2012) report exposure of coke oven workers to the carcinogenic benzo[a]anthracene, benzo[k]fluoranthene, chrysene and dibenz[a,h]anthracene.

3.3.4.3.2 Metabolite

Absorption **via skin uptake**, e.g. from contaminated surfaces, may contribute significantly to the total exposure (IARC, 2012). By means of 1-hydroxypyrene (1-OHP) it was demonstrated that in 12 coke oven workers an average of 75% of the total absorbed amount of pyrene has entered the body through the skin (DFG, 2012 citing Van Rooij et al. 1993).

The table below presents metabolite data available for the sector. Several data points are available for 3-OHBaP presenting values in the range 0.009 and 2.24 nmol/mol creatinine, and with medians and P95 in the range 0.045-0.34 and 0.27-2.82 nmol/mol creatinine, respectively. The P95 range between the second most stringent and the highest policy option.

The 1-OHP mean values are between 0.5-7.1 µmol/mol creatinine and are above the SCOEL proposed BGV (0.5 µg/g creatinine, equivalent to 0.26 µmol/mol creatinine).

Table 3-16 Metabolite concentrations from published sources and stakeholder consultation during coking activities

Sector/ process	Metab- olite ^(a)	n	Smok ers	Mean	Me- dian	P95	Range		Loca- tion	Reference (Source)
							Min	Max		
Coking plants	3- OHBaP	87	N.R.		0.34	2.82		8.22	DE	(RAC, 2022b citing Förster et al., 2008)
PROC23 ^(b)	3- OHBaP	67	N.R.	0.30	0.19	1.31	0.009	2.06	EEA	Consultation 1
PROC23 ^(b)	3- OHBaP	135	N.R.	0.087	0.045	0.273	0.009	2.242	EEA	Consultation 2
PROC23 ^(b)	1-OHP	210	N.R.	0.52	0.32	1.72	0.04	3.84	EEA	Consultation 3
PROC23 ^(b)	1-OHP	57	N.R.	1.24	0.78	4.87	0.03	7.05	EEA	Consultation 4
PROC23 ^(b)	1-OHP	46	N.R.	1.83	0.72	10.41	0.08	11.19	EEA	Consultation 5
Coke oven operation (high T)	1-OHP	11	N.R.	1.85			0.25	5.40	UK	(Unwin, et al., 2006)
Coke oven operation (high T)	1-OHP	13	N.R.	7.10			2.10	0.25	UK	(Unwin, et al., 2006)
Coke oven operation (low T)	1-OHP	13	N.R.	2.63			0.41	6.90	UK	(Unwin, et al., 2006)
Coking plants	1-OHP	37	73%		3.80				DE	(Marczynski, et al., 2009)
Battery roof, machine side, coke side, quench- ing	1-OHP	184	35%	3.70	2.46	9.99	0.03	27.77	PO	(Zajęc, et al., 2016)
Machine op- erators	1-OHP	144	35%	2.76	1.79	8.03	0.13	20.71	PO	(Zajęc, et al., 2016)
Mechanical maintenance workers	1-OHP	73	35%	1.18	0.71	3.98	0.11	7.41	PO	(Zajęc, et al., 2016)
Coke oven/mainte- nance	1-OHP	54	99%		15.40		1.10	147.1	PO	(IARC, 2012 citing Rossella et al., 2009)
Electrical maintenance workers	1-OHP	54	35%	0.88	0.69	2.29	0.05	3.65	PO	(Zajęc, et al., 2016)
Heatermen	1-OHP	27	35%	1.40	0.96	3.72	0.09	5.22	PO	(Zajęc, et al., 2016)
Coal deriva- tives produc- tion workers	1-OHP	27	35%	2.41	1.97	5.53	0.10	6.51	PO	(Zajęc, et al., 2016)

Sector/ process	Metab- olite ^(a)	n	Smok ers	Mean	Me- dian	P95	Range		Loca- tion	Reference (Source)
							Min	Max		
Shift manag- ers	1-OHP	21	35%	1.17	0.95	2.30	0.06	2.76	PO	(Zajac, et al., 2016)
Supervisor	1-OHP	36	35%	0.58	0.28	1.68	0.05	2.30	PO	(Zajac, et al., 2016)
Laboratory	1-OHP	15	35%	0.68	0.95	2.61	0.02	2.61	PO	(Zajac, et al., 2016)
Refractories maintenance workers	1-OHP	11	35%	1.28	1.06	3.77	0.07	3.77	PO	(Zajac, et al., 2016)
Top, side and maintenance	1-OHP	34	0%	1.79		5.15			IT	(Zajac, et al., 2016)
Coke oven workers	1-OHP	382	0%	2.32	2.03	4.92	0.20	14.89	PO	(Zajac, et al., 2016)
Oven topside workers, oven coke- side workers, and oven push-side workers	1-OHP	50	66%		9.00				PO	(Zajac, et al., 2016)
Coke oven workers	1-OHP	87	61%	6.81	4.31		0.25	31.40	PO	(Zajac, et al., 2016)
Coal deriva- tives produc- tion workers	1-OHP	27	35%	0.70	1.97	5.53	0.10	6.51	PO	(Campo, et al., 2012)
Refractories maintenance workers: Maintenance workers	1-OHP	11	35%	1.28	1.06	3.77	0.07	3.77	PO	(Zajac, et al., 2016)

Notes:

N.R. = not reported

^(a) 1-OHP unit $\mu\text{mol/mol creatinine}$, 3-OHBP unit is $\text{nmol/mol creatinine}$

^(b) PROC23 Risk of exposure to PAH during following steps of the coking process: pushing of cokes from coke ovens, charging of coke ovens with fresh coal, small leakages of raw cokes gas from coke oven doors, coke oven lids and ascension pipes, processing of by-products of the coke oven process.

^(c) (1) oventopside workers, $n=20$; (2) oven coke-side workers, $n=11$; and (3) oven push-side workers, $n=19$

3.3.4.4 C19.2 Petroleum refineries

3.3.4.4.1 Airborne

Refineries operate within closed systems. The potential for exposure occurs during sampling, maintenance and loading or unloading of heated or heavy streams (such as bitumen, heavy fuel oils, crude oil and lubricating base oils). The duration of exposure is normally short, from a few minutes for sampling operations to a few hours during loading and unloading operations. The frequency of tasks is also variable: from 2-4 times a week (sampling and loading/unloading) to once a month or once every few years (maintenance and shut down operations).

The table below presents all data from consultation and literature, without RPE and the applicable protection factor of RPE. In a number of measurements, the exposure concentrations are below the limit of detection and/or quantification, which can be relatively high (see section 3.8). Therefore, it is challenging to establish the actual exposure concentration to workers.

Table 3-17 C19.2 petroleum refineries exposure concentrations (ng/m³ BaP) from published sources and stakeholder consultation

Sector/ process	n	Mean	Median	P95	Range		Location	RPE APF	Reference (Source)
					Min	Max			
Integrated oil refinery	12	10	-	-	10	10	UK	Not known	(Unwin et al., 2006)
Bitumen refinery	12	10	-	-	10	10	UK	Not known	(Unwin et al., 2006)
Petroleum refineries	>100	-	-	3-5	-	-	EEA	Not known	Consultation 1
Bitumen truck loading	6	2.3	-	-	2.0	3.0	FR	Not known	(Deygout et al., 2011)
Laboratory QC sampling and production units	N.R.	-	-	-	<46 ^(c)	<46 ^(c)	EEA	Not known	Consultation 2
Petroleum refineries	≥10	-	-	N.D. (P90)	-	-	DE	Not known	(DGUV, 2022)
Barge loading of HFO on-site: onboard and onshore	5	-	-	-	<9 ^(d)	<74 ^(d)	EEA	No	(Concawe, 2016)
Barge loading of HFO on-site: offshore + onshore	-	-	-	-	<2 ^(d)	<12.3 ^(d)	EEA	No	(Concawe, 2016)
Barge loading of HFO on-site: close to vent, stationary	-	-	-	-	<9 ^(d)	<60 ^(d)	EEA	No	(Concawe, 2016)
Barge loading of HFO on-site: close to vent, stationary	-	-	-	-	<3 ^(d)	<9.19	EEA	No	(Concawe, 2016)
PROC8b ^(a)	5	220-450	-	-	-	-	EEA	4	Consultation 3
PROC1 ^(b)	5	15-75	-	-	-	-	EEA	4	Consultation 3
PROC8b ^(a)	5	-	-	-	<100 ^(d)	<100 ^(d)	EEA	4	Consultation 4
PROC1 ^(b)	5	-	-	-	<100 ^(d)	<100 ^(d)	EEA	4	Consultation 4
PROC8	-	-	-	-	2	320	EEA	Not known	Consultation 5

Notes :

RPE = respiratory protection equipment

APF = assigned protection factor according to EN 529:2005

N.D. = not detected

^(a) PROC8b Assessment of loading/unloading of charges

^(b) PROC1 Preparation of equipment prior to intervention by maintenance

^(c) data are below the limit of detection

^(d) data are below the limit of quantification

The data presented in Table 3-17 are without RPE, based on information provided in the consultation, the appropriate protection factor was applied where RPE are said to be worn. In the case where it is not possible to establish the specific RPE worn, a protection factor of 4 only was applied as a worst-case scenario. The summary of exposure data with the use of RPE, and taking into account confidential data are presented in the table below. The values taken forward for the assessment are in bold.

Table 3-18 C19.2 summary of exposure concentrations (BaP ng/m³) with RPE

			Average	Geo mean	Median	Min	Max	P25	P75	P90	P95	P99
Average	30.7	-	13.5	10.7	45.3	-		-	-	-	-	
Min	10.0	-	0.0	1.0	3.0	-		-	-	-	-	
Max	85.3	-	25.0	25.0	320.0	-		-	-	-	-	
Median			23.0	-	15	7.3	23.0	-	-	-	-	-

Source: Study team

Notes: values in bold have been taken forward in the analysis

The Unwin et al. (2006) study indicates the presence of 4-6 ring PAH in the range 10-30 ng/m³.

3.3.4.4.2 Metabolite

The table below presents metabolite data available for the sector. There are no data for 3-OHBaP and two studies with 1-OHP show that measurements are either below the limit of detection and reported as 0.25 µmol/mol creatinine (Unwin et al., 2006), or have a median of 0.1 µmol/mol creatinine. These are below the SCOEL proposed BGV (0.5 µg/g creatinine, equivalent to 0.26 µmol/mol creatinine).

Table 3-19 C19.2 metabolite concentrations from published sources in refineries

Sector/ process	Metabolite ^(a)	n	Smokers	Mean	Median	P95	Range		Location	Reference (Source)
							Min	Max		
Integrated oil refinery	1-OHP	12	N.R.				0.25 ^(b)	0.25 ^(b)	UK	(Unwin et al., 2006)
Bitumen refinery	1-OHP	12	N.R.				0.25 ^(b)	0.25 ^(b)	UK	(Unwin et al., 2006)
Bitumen refinery	1-OHP	N.R.	N.R.		0.1				EEA	(Boogard, 2007)

Notes:

N.R. = not reported

^(a) 1-OHP unit µmol/mol creatinine

^(b) data are below the limit of detection

3.3.4.5 C20.13 Manufacture of carbon black

3.3.4.5.1 Airborne

The manufacture of carbon black makes use of feedstock oils, which are often waste oils such as residual fuel oil (a type of HFO) or anthracene oil, but also coal tar, that are atomised in a closed processes to manufacture carbon black. The process tends to generate gases and steam that are turned into energy to be reused in the plant.

The potential for exposure arises mainly during loading and unloading of feedstock, maintenance operations and sampling. The feedstock used for the production of carbon black is usually high in PAH content, and may need to be heated to be moved from distribution to storage to use. While the process is closed systems due to the nature of the activity, the coupling and uncoupling of hoses or other connective equipment to transfer feedstock can result in fugitive emissions and exposure to PAH. In relation to maintenance, a respondent indicated that employees are specifically trained in how to drain down and/or flush or purge (e.g. with steam or air) the system prior to equipment break-in or maintenance. The activity is carried out under local exhaust ventilation in areas where emissions occur and/or the operation is undertaken outdoors, while the use of RPE is mandatory.

All the measured data available are presented in Table 3-20. Many values are below the limit of detection or quantification, and it is difficult to draw many conclusions. However, it appears that maintenance, sampling and unloading and transfer of raw materials are where exposure takes place.

Table 3-20 C20.13 exposure concentrations (ng/m³ BaP) from published sources and stakeholder consultation

Sector/ process	n	Mean	Median	P95	Range		Location	RPE APF	Reference (Source)
					Min	Max			
Manufacture of carbon black	11	50			10	410	UK	Not known	(Unwin et al., 2006)
PROC8b ^(a)	3				<21 ^(d)	<21 ^(d)	EEA	4	Consultation 1
PROC8b ^(a)	4				<51		EEA	4	Consultation 2
PROC15 ^(b)	N.R.				<10 ^(d)	<10 ^(d)	EEA	4	Consultation 3
PROC15 ^(b)	1				<1 ^(d)		EEA	No	Consultation 4
PROC28 ^(c)	1				<40		EEA	No	Consultation 4
PROC28 ^(c)	2	78			<52 ^(d)	104	DE	4	Consultation 5
PROC15 ^(b)	2	119			102	135	EEA	4	Consultation 5
PROC8b ^(a)	N.R.				<84 ^(e)	<84	EEA	4	Consultation 5
PROC8b ^(a)	4	57			6	200	EEA	4	Consultation 6
Repair of equipment containing anthracene or pyrolysis oil	4	12			6	25	EEA	4	Consultation 6

Notes:

RPE = respiratory protection equipment

APF = assigned protection factor according to EN 529:2005

N.R. = not reported

^(a) PROC8b Unloading (coupling and uncoupling of hoses) of vessels containing substance.

- (b) PROC15 Sampling and analysis for quality checks in laboratory.
(c) PROC28 Manual maintenance (cleaning and repair) of machinery
(d) data are below the limit of quantification
(e) data are below the limit of detection

The data presented in the table above are without RPE. One literature measurement is available that does not indicate the use of RPE and is likely 10-15 years older than the consultation data. It is probable that the workers would now be wearing RPE at the concentration levels reported. Based on information provided in the consultation, the appropriate protection factor was applied where RPE are said to be worn. The summary of exposure data with the use of RPE, and taking into account confidential data are presented in the table below. The values taken forward for the assessment are in bold.

Table 3-21 C20.13 summary of exposure concentrations (ng/m³ BaP) with RPE

	Average	Geo mean	Median	Min	Max	P25	P75	P90	P95	P99
Average	15.8	-	-	7.9	31.8	-	-	-	-	-
Min	3.0	-	-	0.5	1.3	-	-	-	-	-
Max	29.75	-	-	26.3	102.5	-	-	-	-	-
Median	14.25	-	-	6.4	26.0	-	-	-	-	-

Source: Study team

Notes: values in bold have been taken forward in the analysis

The Unwin et al. (2006) study indicates the presence of 4-6 ring PAH in the range 30-4490 ng/m³.

3.3.4.5.2 Metabolite

There are no data for 3-OHBaP and only one study is available presenting data for 1-OHP. The measurement has a mean of 0.63 µmol/mol creatinine (Unwin et al., 2006), which is above the SCOEL proposed BGV (0.5 µg/g creatinine, equivalent to 0.26 µmol/mol creatinine). The value cannot be correlated with air concentrations as it is below the range where it can be converted (1.13 µmol/mol creatinine).

Table 3-22 Metabolite concentrations from published sources and stakeholder consultation

Sector	Metabolite ^(a)	n	Smokers	Mean	Median	P95	Range		Location	Reference (Source)
							Min	Max		
Carbon black	1-OHP	11	N.R.	0.63			0.25	0.31	UK	(Unwin et al., 2006)

Notes:

N.R. = not reported

^(a) 1-OHP unit µmol/mol creatinine, 3-OHBaP unit is nmol/mol creatinine

3.3.4.6 C20.14 Coal tar distillation

3.3.4.6.1 Airborne

Coal tar distillation uses coal tar, a by-product of coking (fumes), to derive coal tar pitch and other chemicals (principally naphthalene, creosote, and BTX, benzene, toluene and xylene). As per the manufacture of carbon black, operations take place in closed systems similar to a chemical plant or refinery and exposure occurs during loading and unloading of raw material and output distillation

materials such as coal tar pitch and creosote, maintenance operations, sampling and fugitive emissions.

Maintenance and sampling are not everyday activities and the frequency is dependent on the site (roughly between once a week to once a month). Complete shutdown takes place rarely.

All the available data are presented in Table 3-27. The measurements are variable and depend on the type of activity being undertaken, with maintenance generally resulting in higher exposure values.

Table 3-23 C20.14 Coal tar distillation exposure concentrations (ng/m³ BaP) from published sources and stakeholder consultation

Sector/ process	N	Mean	Median	P95	Range		RPE APF	Location	Reference (Source)
					Min	Max			
Tar distillation (high temperature)	12	60			10	320	Not known	UK	(Unwin et al., 2006)
Tar distillation (low temperature)	8	10			10	10	Not known	UK	(Unwin et al., 2006)
Petroleum tar distillation	8	20			10	40	Not known	UK	(Unwin et al., 2006)
PROC28 ^(a)	3				100	2,000	4	EEA	Consultation 1
PROC8b ^(b)	2	280			60	500	No	EEA	Consultation 1
PROC2 ^(c)	2	105	90		90	120	No	EEA	Consultation 1
PROC15 ^(d)	3	25	25	25	0	50	No	EEA	Consultation 1
PROC1: Workers – operators ^(e)	3	245			25	580	4	EEA	Consultation 2
Workers – Logistics operators ^(f)	3	710			410	1,160	4	EEA	Consultation 2
Workers – ton bag ^(g) and drum fillers ^(h)	3	2,247			41	3,960	4	EEA	Consultation 2
Workers – maintenance ⁽ⁱ⁾	3	1,438			63	4,140	4	EEA	Consultation 2
Sampling and tank dipping, loading of product, maintenance, laboratory analysis	7	<LOD ^(j)					Dependent on activity	EEA	Consultation 3

Notes:

RPE = respiratory protection equipment

APF = assigned protection factor according to EN 529:2005

^(a) PROC28 Manual maintenance (cleaning and repair) of machinery

^(b) PROC8b loading and unloading of trucks, railroad tanks, tanks at the facility

^(c) PROC2 standard site operations

^(d) PROC15 laboratory activities with PAH

^(e) Operators: PROC1: Distillation process continuous - closed + PROC3: Distillation process, closed, batch + PROC9 Transfer of substances to small containers (sampling)

^(f) Logistic operators: PROC8b: transfer of substances + PROC8a Non-dedicated transfer by crane or shovel + PROC9 Transfer of substances to small containers (sampling)

^(g) Ton bag fillers: PROC8b transfer to drums + PROC9 Transfer of solid substances to small containers (sampling)

^(h) Drum fillers: PROC8b transfer of liquid pitch to drums + PROC9 Transfer to small containers (sampling)

⁽ⁱ⁾ Maintenance: PROC28 Cleaning and maintenance of equipment and facilities

^(j) LOD = 50 ng/m³

The data presented in the table above are without RPE. Based on information provided in the consultation, the appropriate protection factor was applied where RPE are said to be worn. The summary of exposure data with the use of RPE, and taking into account confidential data, e.g. CSR, are presented in the table below. The values taken forward for the assessment are in bold.

Table 3-24 C20.14 summary of exposure concentrations (BaP ng/m³) with RPE

	Average	Geo mean	Median	Min	Max	P25	P75	P90	P95	P99
Average	183.9	-	57.5	35.5	397.5	-	168.9	-	25.0	-
Min	25.0	-	25.0	0.0	25.0	-	25.0	-	25.0	-
Max	561.8	-	90.0	102.5	1035.0	-	394.0	-	25.0	-
Median	105.0	-	57.5	15.8	305.0	-	130.0	-	25.0	-

Source: Study team

Notes: values in bold have been taken forward in the analysis

The Unwin et al. (2006) study indicates the presence of 4-6 ring PAH in the range 110-4540 ng/m³.

3.3.4.6.2 Metabolite

There are no biomonitoring data for 3-OHBP. Several studies are available with 1-OHP data. The means are in the range 0.0-2.6 µmol/mol creatinine, and the majority of values are above the SCOEL proposed BGV (0.5 µg 1-OHP/g creatinine, equivalent to 1-OHP 0.26 µmol/mol creatinine).

Table 3-25 Metabolite concentrations from published sources and stakeholder consultation

Sector/ process	Metabolite ^(a)	n	Smokers	Mean	Median	P95	Range		Location	Reference (Source)
							Min	Max		
PROC2 ^(b)	1-OHP	2	N.R.	1.53			0.65	2.42	EEA	Consultation 1
PROC8b ^(c)	1-OHP	1	N.R.	1.84			1.84	1.84	EEA	Consultation 2
PROC28 ^(d)	1-OHP	2	N.R.	2.17			0.98	3.36	EEA	Consultation 3
Other ^(e)	1-OHP	2	N.R.	0.47			0.43	0.50	EEA	Consultation 4
PROC2 ^(f)	1-OHP	60	N.R.				0.08	0.47	EEA	Consultation 5
PROC8b ^(g)	1-OHP	60	N.R.				0.11	0.6	EEA	Consultation 6
Tar distillation (high temperature)	1-OHP	12	N.R.	2.60			0.78	5.7	UK	(Unwin et al., 2006)
Tar distillation (low temperature)	1-OHP	8	N.R.	0.36			0.25 _(m)	1.1	UK	(Unwin et al., 2006)
Petroleum tar distillation	1-OHP	8	N.R.	0.88			0.25 _(m)	3.8	UK	(Unwin et al., 2006)

Notes:

N.R. = not reported

- (a) 1-OHP unit $\mu\text{mol/mol}$ creatinine, 3-OHBaP unit is nmol/mol creatinine
- (b) PROC2: Sampling and tank dipping are normal tasks, for the data provided below a spill was cleaned up for the highest exposure level measured.
- (c) PROC8b: Loading of railcars, tankers, ISO containers.
- (d) PROC28: Maintenance
- (e) Other: Laboratory analysis of plant samples, all carried out in fume cupboards.
- (f) PROC2: The system is closed (Outdoor). Exposure outside could possibly arise with loading/unloading operations, sampling, maintenance, or in emergency cases (e.g. fires, leakages, or other)
- (g) PROC8b: The system is closed (Outdoor). Outside exposure could arise with loading/unloading operations, sampling, maintenance, or in emergencies (e.g. fires, leakages, or others). In addition, exposure could arise indoors from manual vacuuming of Big-Bags; change and transport takes place discontinuously; Note: in the future, this process will be changed to a closed system without dust generation at the workplace.
- (h) values are below the limit of detection

3.3.4.7 C23.2 Manufacture of refractory products

3.3.4.7.1 Airborne

In the manufacture of refractory products, the use of CTPht is said to be limited to one specific application (slide gates in the steel industry), where CTPht is transformed into pitch coke after baking in the steel plant and not in the refractory plant (Stakeholder Consultation, 2023). Only one study is available on the formation of refractory products which is thought to be using CTPht due to the age of the study: a median exposure value of 100 ng/m^3 BaP and a 75th percentile of 400 ng/m^3 BaP was reported in a study published in 2009 with data from 1999-2003 (Marczynski et al., 2009). The consultation indicated that the shift to low temperature coal tar pitch took place in 2010-2015.

The use of RPE is not reported in this study. Based on feedback from a stakeholder, workers wear FF P2, FF P3 masks (with a minimum protection factor of 10 based on standard EN 529:2005) or respirators with a powered air purifier pump on a need basis, but no additional information on the criteria for use of RPE is available. Therefore, the study team has assumed workers would now be wearing some form of RPE, particularly since the REACH Authorisation on CTPht in 2017. Based on the study from Marczynski et al. (2009) and using a minimum protection factor of 4, it is likely that workers will be exposed to concentrations that comply with the 700 ng/m^3 policy option.

Older data are available showing higher levels of exposure in 1999-2001 (DFG, 2012) citing Preuss et al. 2003 and 2006), but the data are thought to not be representative due to the age of the data and change in practices (as indicated above, the only product now made with CTPht are slide gates that are no longer baked on site).

One study is also available with the use of novel binders that shows relatively low levels of exposure (between $1\text{-}17 \text{ ng/m}^3$ BaP) (Sartorelli et al., 2020). In the study, the exposure concentrations are taken in the quality check area rather than the impregnation area, since the latter takes place in a closed system.

In consultation with industry, it was indicated that manufacturers are finding it challenging to adhere to existing, equivalent OEL in Germany even with the modified coal tar pitch heat treated binder and companies will be forced to move to close systems. However, there are no additional data available on exposure to PAH from novel coal tar pitch binder used to make refractory products, nor information on how many companies are involved in the activity.

Table 3-26 C23.2 Manufacture of refractory products exposure concentrations (ng/m^3 BaP) from published sources and stakeholder consultation

Sector/ process	N	Mean	Me- dian	P95	Range		RPE APF	Loca- tion	Reference (Source)
					Min	Max			
Clay and non-clay re- fractories in terms of formed objects and un- formed granulated compositions	96		100	400 (P75)	0 (P25)		No, but assumed 4*	DE	(Marczynski et al., 2009)
Presses - quality con- trol station. Binder: heat treated coal tar pitch and anthracene	6	3.0	3.0		1.1	17.0	Not known	IT	(Sartorelli et al., 2020)
Presses - quality con- trol station. Binder: heat treated coal tar pitch and anthracene	9	2.0	2.0		1.1	17.0	Not known	IT	(Sartorelli et al., 2020)

Notes: * workers in the study were not wearing RPE but during the consultation, stakeholders indicated that FFP2, FFP3 masks or Respirators with a powered air purifier pump are used where necessary, therefore the study team has assumed that RPE would now be worn with a protection factor of 4.

The study team does not have data that presents information on exposure to carcinogenic PAH other than BaP, but given that the CTPht is used, it is likely that workers will be exposed to other carcinogenic PAH in scope of the CRMD.

3.3.4.7.2 Metabolite

The table below presents metabolite data available for the sector. One data point is available with 3-OHBaP presenting a median of 0.49 nmol/mol creatinine, which is between the second and third policy options (see section 5).

Table 3-27 Metabolite concentrations from published sources and stakeholder consultation

Sector/ process	Metab- olite ^(a)	n	Smo kers	Mean	Me- dia n	P 9 5	Range		Lo- ca- tion	Reference (Source)
							Min	Max		
Refractories	3- OHBaP	84	N.R.		0.49				DE	(RAC, 2022b citing Förster et al., 2008)
Clay and non-clay refractories in terms of formed objects and un- formed granulated compositions	1-OHP	96	68%		8.40				DE	(Marczynski et al., 2009)
Presses - quality control station	1-OHP	15	0%	0.50	0.31		0.22	1.1	IT	(Sartorelli et al., 2020)
Packaging depart- ment	1-OHP	11	0%	0.96	0.59		0.14	2.8	IT	(Sartorelli et al., 2020)

Notes:

^(a) 1-OHP unit $\mu\text{mol/mol}$ creatinine, 3-OHBaP unit is nmol/mol creatinine

N.R.: Not Reported

3.3.4.8 C23.99a Manufacture of bituminous products

3.3.4.8.1 Airborne

The manufacture of bituminous products results in exposure to workers through the heating of bitumen that is then mixed with aggregate in towers for road paving, or in automated open processes where a substrate (paper usually) is coated with bitumen and then aggregates on a roller. In both it is thought that workers are unlikely to be wearing RPE – the data in the table below does not indicate either way.

The data shows that exposure concentrations are quite varied: from not detected-5 ng/m³ to 10-480 ng/m³ BaP. The highest value is in relation to roofing paper production, where the operator is in proximity of a machinery where heated bitumen is visible, but it is in contrast of the study where the exposure concentration was “not detected” as the 90th percentile.

Table 3-28 C23.99a Manufacture of bituminous products exposure concentrations (ng/m³ BaP) from published sources and stakeholder consultation

Sector/ process	n	Mean	Median	P95	Range		RPE APF	Location	Reference (Source)
					Min	Max			
Bitumen production and asphalting	7	100	40	140 (P75)	10	280	Not known	SK	(RAC, 2022b) citing Klöslova et al., 2016
Asphalt pump operators, proofing tank operators, plating tank operators, pasting machine operators, coiler operators, workers transporting the product, and five other operators	3	7			3	13	Not known	PL	(Pośniak et al., 2003)
Bitumen processing	N.R.	0.03					Not known	DE	(DFG, 2012 citing Preuss et al., 2003b)
Asphalt mixing plant worker	9		0.43	5.51 (P95)	0.11 (P05)		No	IT	(Cirla et al., 2007)
Roofing paper production	27	6			0	480	Not known	PL	(Pośniak et al., 2003)
Roofing felt, bitumen roofing sheets, manufacture	≥10			n.d. (P90)			Not known	DE	(DGUV, 2022)

Notes :

RPE = respiratory protection equipment

APF = assigned protection factor according to EN 529:2005

The summary of exposure data are presented in the table below. The values taken forward for the assessment are in bold.

Table 3-29 C23.99a summary of exposure concentrations (ng/m³ BaP) with RPE

	Average	Geo mean	Median	Min	Max	P25	P75	P90	P95	P99
Average	28.3	-	20.2	3.3	257.7	30.0	140.0	-	5.5	-
Min	0.0	-	0.4	0.0	13.0	30.0	140.0	-	5.5	-
Max	100.0	-	40.0	10.0	480.0	30.0	140.0	-	5.5	-
Median	6.5	-	20.2	1.6	280.0	30.0	140.0	-	5.5	-

Source: Study team

Notes: values in bold have been taken forward in the analysis

No data are available on exposure to other carcinogenic PAH.

3.3.4.8.2 Metabolite

The table below presents metabolite data available for the sector. No data are available with 3-OHBP. presenting a median of 0.49 nmol/mol creatinine, which is between the second and third policy options (see section 5).

The table below presents metabolite data available for the sector. There are no data for 3-OHBP and one study with 1-OHP with a mean of 1.37 µmol/mol creatinine, which is above the SCOEL proposed BGV (0.26 µmol/mol creatinine). The corresponding air concentration would be approximately 20 ng/m³ BaP, which is an order of magnitude lower than the actual measured concentration (40 ng/m³ BaP) for the same study.

Table 3-30 Metabolite concentrations from published sources and stakeholder consultation

Sector/ process	Metabolite ^(a)	n	Smokers	Mean	Median	P95	Range		Location	Reference (Source)
							Min	Max		
Bitumen production and asphalting	1-OHP	7	59%	1.37	1.32		1.05	2.04	SK	(RAC, 2022b citing Klöslova et al., 2016)

Notes:

^(a) 1-OHP unit µmol/mol creatinine, 3-OHBP unit is nmol/mol creatinine

N.R.: Not Reported

3.3.4.9 C23.99b Graphite and carbon electrodes manufacture

3.3.4.9.1 Airborne

The consultation data was provided by ECGA on behalf of all European manufacturers. The process deals with heated and baked CTPht so high levels of exposure are anticipated, which is confirmed by the data presented below. The literature and consultation data are in agreement.

As indicated in section 3.2.5, there are several areas where exposure to PAH can occur since: the process require the use of raw materials that contain PAH and need to be heated to be transferred and handled, the manufacturing process and graphitisation requires the materials to be heated at high temperatures repeatedly. The processes are closed or semi-closed systems.

Consultation with industry indicates that workers in the locations where measurements are taken are wearing RPE and that the highest levels of exposure are measured when a worker is required to manually screw the "nipple" on the electrode after the second baking (in an area with high

fumes). The process of impregnation with coal tar pitch can also be a source of high exposure levels and the work is generally already automated as much as reasonably possible. The data from the consultation is divided into three categories: Formulation of green mixtures (e.g. Søderberg pastes, ramming pastes, lining pastes); Formulation - Forming process through shaping of green mixtures (e.g. by extrusion) into green materials and Use at industrial site - Manufacture of carbonised materials (e.g. furnace linings, electrodes including cathodes and anodes) which is in line with the CSR. The data represents all graphite manufacturers in the EU and therefore is considered to be representative of the current exposure levels in Europe.

Table 3-31 C23.99b Graphite and carbon electrode manufacture exposure concentrations (ng/m³ BaP) from published sources and stakeholder consultation

Sector/ process	n	Mean	Median	P95	Range		RPE APF	Location	Reference (Source)
					Min	Max			
Cathodes production - raw cathode extruding	52		131	1,006	8.8	12562	N.R.	FR	(Petit et al., 2019)
Cathodes production - cathode baking	18		96	1,130	0.03	1579	N.R.	FR	(Petit et al., 2019)
Cathodes production - laboratory analysis	7		81	256	3.8	287	N.R.	FR	(Petit et al., 2019)
Production of green electrodes, impregnation, graphitization, and finishing	26		100	500 (P75)			N.R.	DE	(Marczynski et al., 2009)
Electrode manufacture - Molding (pressing)	≥10			900 (P90)			N.R.	DE	(DGUV, 2022)
Electrode manufacture - Production of materials carbon and electrographite - crusher, mill	≥10			820 (P90)			N.R.	DE	(DGUV, 2022)
Electrode manufacture - production of materials carbon and electrographite - mix, knead	≥10			3,300 (P90)			N.R.	DE	(DGUV, 2022)
Electrode manufacture - Production of materials carbon and electrographite - the press	≥10			1,500 (P90)			N.R.	DE	(DGUV, 2022)
Electrode manufacture - Production of materials carbon and electrographite - ovens	≥10			1,200 (P90)			N.R.	DE	(DGUV, 2022)
Electrode manufacture - Production of materials carbon and electrographite -impregnation	N.R.	750					N.R.	DE	(DGUV, 2022)

Sector/ process	n	Mean	Me- dian	P95	Range		RPE APF	Lo- ca- tion	Reference (Source)
					Min	Max			
Electrical carbon	1	240	0.0				N.R.	UK	(Unwin et al., 2006)
Graphite and carbon electrodes manufac- ture	64	1,310	1,250	2,100 (P75)	10	3,180	N.R.	SK	(RAC, 2022b citing Klöslova et al., 2016)
Cathodes production - cathode graphitiza- tion	8		9.5	34.0	1.7	36.0	N.R.	FR	(Petit et al., 2019)
Electrode manufac- ture - Production of materials carbon and electrographite - in- ternal transport	N.R.	480					N.R.	DE	(DGUV, 2022)
Formulation of green mixtures (e.g. Søderberg pastes, ramming pastes, lin- ing pastes) PROC2	4				170	770	20	EEA	Consultation 1
As above - PROC3	2	1,120					20	EEA	Consultation 1
As above - PROC8b	1				440	1900	20	EEA	Consultation 1
As above - PROC8b	2	77					20	EEA	Consultation 1
Formulation of green mixtures (e.g. Søderberg pastes, ramming pastes, lin- ing pastes)	3				77	1120	20	EEA	Consultation 1
Formulation of green mixtures	2	77					20	EEA	Consultation 1
Formulation of green mixtures	1	690					20	EEA	Consultation 1
Formulation of green mixtures	1	0.134					20	EEA	Consultation 1
Formulation of green mixtures	7						20	EEA	Consultation 1
Formulation of green mixtures	5				70	310	20	EEA	Consultation 1
Formulation - Form- ing process through shaping of green mixtures (e.g. by ex- trusion) into green materials PROC8b	11						20	EEA	Consultation 1
Formulation – as above - PROC8b	3	20					20	EEA	Consultation 1
Formulation - Form- ing process through	7				12	1,980	20	EEA	Consultation 1



Sector/ process	n	Mean	Me- dian	P95	Range		RPE APF	Lo- ca- tion	Reference (Source)
					Min	Max			
shaping of green mixtures (e.g. by extrusion) into green materials									
Formulation – as above - PROC5	3				120	1,020	20	EEA	Consultation 1
Formulation - Forming process through shaping of green mixtures (e.g. by extrusion) into green materials	3				37	1,020	20	EEA	Consultation 1
Formulation – as above - PROC2	5				44	600	20	EEA	Consultation 1
Formulation – as above - PROC3	8				120	1,980	20	EEA	Consultation 1
Formulation – as above - PROC4	4				12	525	20	EEA	Consultation 1
Formulation – as above - PROC5	2				56	470	20	EEA	Consultation 1
Formulation – as above - PROC5	1				1	42	20	EEA	Consultation 1
Formulation – as above - PROC8b	10				20	2,319	20	EEA	Consultation 1
Formulation – as above - PROC4	4				44	54	20	EEA	Consultation 1
Formulation – as above - PROC14	11				5	1,900	20	EEA	Consultation 1
Formulation – as above - PROC8a	9				300	400	20	EEA	Consultation 1
Formulation – as above - PROC8b	4				345	1,900	20	EEA	Consultation 1
Formulation – as above - PROC9	5				35	230	20	EEA	Consultation 1
Formulation – as above - PROC15	10				6	230	20	EEA	Consultation 1
Formulation – as above - PROC3	9				140	1,150	20	EEA	Consultation 1
Formulation – as above - PROC8a	10	1,150					20	EEA	Consultation 1
Use at industrial site. Manufacture of carbonised materials (e.g. furnace linings, electrodes including cathodes and anodes) PROC8b	1	<150					20	EEA	Consultation 1

Sector/ process	n	Mean	Me- dian	P95	Range		RPE APF	Lo- ca- tion	Reference (Source)
					Min	Max			
As above - PROC8a	7				12	440	20	EEA	Consultation 1
As above - PROC22	11				56	1,100	20	EEA	Consultation 1
As above - PROC3	8				267	1,000	20	EEA	Consultation 1
As above - PROC8a	7				210	350	20	EEA	Consultation 1
As above - PROC22	13				21	1,100	20	EEA	Consultation 1
As above - PROC9	1	0					20	EEA	Consultation 1
As above - PROC15	6				0	21	20	EEA	Consultation 1
As above - PROC3	10				53	1,150	20	EEA	Consultation 1

Notes :

RPE = respiratory protection equipment

APF = assigned protection factor according to EN 529:2005

N.R. = not reported

The data presented in the table above are without RPE. Based on information provided in the consultation, the appropriate protection factor was applied where RPE are said to be worn. The summary of exposure data with the use of RPE, and taking into account confidential data, e.g. CSR, are presented in the table below. The values taken forward for the assessment are in bold. The data have a wide distribution and due to data coming from different sources, in different locations and conducting different activities it does not appear to follow a log normal distribution. The average of the P75, P90 and P95 data is 270 ng/m³.

Table 3-32 C23.99b summary of exposure concentrations (ng/m³ BaP) with RPE

	Aver- age	Geo mean	Me- dian	Min	Max	P25	P75	P90	P95	P99
Aver- age	70.1	18.3	70.7	4.5	177.9	112.5	293.9	292.7	158.0	70.1
Min	0.0	8.7	9.5	0.0	1.1	112.5	101.0	55.0	34.0	0.0
Max	327.5	40.3	312.5	22.0	3,140.5	112.5	681.0	825.0	282.5	327.5
Me- dian	56.0	12.1	24.5	2.2	51.0	112.5	196.0	215.0	157.8	56.0

Source: Study team

Notes: values in bold have been taken forward in the analysis

The Unwin et al. (2006) study indicates the presence of 4-6 ring PAH at 1,720 ng/m³, while Marczynski et al. (2009) measured all eight carcinogenic PAH with a median of 1,000 ng/m³. Note that the latter study refers to exposure data from the period 1999-2003.

3.3.4.9.2 Metabolite

The table below presents metabolite data available for the sector. The median data with 3-OHBaP are 0.25-0.73 nmol/mol creatinine, which are within the third policy option (second highest, equivalent to 700 ng/m³).

Table 3-33 Metabolite concentrations from published sources on graphite and carbon electrodes manufacture

Sector/ process	Metabolite ^(a)	n	Smokers	Mean	Median	P95	Range		Location	Reference (Source)
							Min	Max		
Electrode maintenance, carbon department, electrode baking furnace	3-OHBaP	35	8%		0.73		<LOQ ^(b)	3.97	FR	(Barbeau et al., 2014)
Graphite cathode production	3-OHBaP	50	36%		0.25		0.01	3.02	FR	(Barbeau et al., 2014)
Graphite electrode production	3-OHBaP	24	N.R.		0.58				DE	(RAC, 2022b citing Förster et al., 2008)
Electrical carbon	1-OHP	12	N.R.	0.25			0.25 ^(c)	0.25 ^(c)	UK	(Unwin et al., 2006)
Bitumen production and asphalt-ing	1-OHP	7	59%	1.37	1.32		1.05	2.04	SK	(RAC, 2022b citing Klöslova et al., 2016)
Production of green electrodes, impregnation, graphitization, and finishing	1-OHP	26	62%		9.70				DE	(Marczynski et al., 2009)
Electrode manufacture and bricks of electrode paste	1-OHP		50%	2.64					IT	(Moretti et al., 2007)

Notes:

N.R. = not reported

^(a) 1-OHP unit $\mu\text{mol/mol creatinine}$, 3-OHBaP unit is $\text{nmol/mol creatinine}$

^(b) Data below the limit of quantification, equivalent to 0.05 ng/L

^(c) Data below the limit of detection

3.3.4.10 C24.1 Steel and iron foundries, ferroalloys

3.3.4.10.1 Airborne

The manufacture of steel and iron and other ferroalloys requires a large amount of electricity in order to heat iron and/or steel to the required temperatures. In this sector continuous casting takes place at the point of manufacture. This is different to casting (C24.5) of specific forms. Exposure data are in the range 1-200/1,100 ng/m³ BaP. It is possible that the highest concentrations are now lower, since the data span from 1995-2010 and desk-based research and consultation with stakeholders indicates that workers will not be near the furnace for long (10 mins) due to the high temperatures in the area, and that workers are likely wear RPE due to the presence of other chemical agents such as lead.

The source of PAH has been difficult to establish with industry. However, IARC indicates that organic binders (like for casting), coal powder and other carbonaceous additives are the predominant

sources of PAH in iron and steel foundries. In some cases, exhaust gases from engines, furnaces and ovens may increase the exposure of workers to these compounds (see section 3.4.4.10). In addition, stakeholder consultation indicates the use Söderberg anodes in the manufacture of some ferroalloys and the use of Söderberg briquettes or pastes to build and maintain the furnaces in the metals industry in general.

The data are in a wide range and the data indicate that workers near the furnace are exposed to the highest levels, which is consistent with the data on casting C24.5.

Only in the melting shop area of one study (Aries, et al., 2008) is the use of RPE reported. In other studies, there is no indication on the use of RPE. It was not possible to speak to industry to understand current practices to a level of detail that RPE can be assumed.

The study team was not able to access PAH exposure data during the manufacture of ferroalloys, which also require the use of electrodes, some refractory materials, coke as a reducing agent, in some cases solid fuels. According to a stakeholder active in category C23.99b, the manufacture of some ferroalloys requires the use of Söderberg anodes.

The exposure data on the manufacture of steel and iron has been read across to the manufacture of ferroalloys.

Table 3-34 C24.1 Steel and iron foundries and ferroalloys, exposure concentrations (ng/m³ BaP) from published sources and stakeholder consultation

Sector/ process	n	Mean	Median	P95	Range		Location	Reference (Source)
					Min	Max		
Iron foundry and continuous casting area	N.R.	26.30					IT	(Apostoli et al., 2003)
Oven, continuous furnace and refractory areas	N.R.	49					IT	(Apostoli et al., 2003)
Oven area of electric steel plant	N.R.	106.5					IT	(Apostoli et al., 2003)
Melting shop area ^(a)	20	7.0			1.4	24.5	UK	(Aries et al., 2008)
Casting area	6	2.9			2.2	14.2	UK	(Aries et al., 2008)
Control cabin	3	0.9			0.2	2.2	UK	(Aries et al., 2008)
Manufacture of steel: Melting shop area and casting area	3	0.11					UK	(Aries et al., 2008)
Metal production, pig iron and steel production: Furnace platform, smelter, transport and other activities in the furnace area.	≥10			100 (P90)			DE	(DGUV, 2022)

Sector/ process	n	Mean	Me- dian	P95	Range		Loca- tion	Reference (Source)
					Min	Max		
Continuous casting, Transport, cleaning, other activities	≥2	500					DE	(DGUV, 2022)
Continuous casting, other work areas	≥10			N.D. (P90)			DE	(DGUV, 2022)
Pan fireplace, when us- ing BaP-free or low con- tamination refractory materials (up to 10 ppm or 10 mg/kg) in 2011- 2014	≥2	N.D.					DE	(DGUV, 2022)
Fusion furnace operator	6		12.0		3.7	1,109	FR	(Petit et al., 2019)
Crucible activity	6		29.0		2.6	63	FR	(Petit et al., 2019)
Steel foundry: Heat at- tendant mason	21		7.70		0.44	219	FR	(Petit et al., 2019)
Iron Foundry	11	20				50	UK	(Unwin et al., 2006)
Iron Foundry	7	10				20	UK	(Unwin et al., 2006)
Refractories mainte- nance workers: Mainte- nance workers	3	1					PL	(Zajac et al., 2016)

Notes:

N.R. = not reported

N.D. = Not Detected

^(a) no information is available on the use of RPE except for this entry where a minimum protection factor of 4 is assumed according to EN 529

The summary of exposure data, with RPE, are presented in the table below. The values taken forward for the assessment are in bold.

Table 3-35 C24.1 summary of exposure concentrations (ng/m³ BaP) with RPE

	Aver- age	Geo mean	Me- dian	Min	Max	P25	P75	P90	P95	P99
Aver- age	21.8	15.9	16.2	1.5	181.3	-	35.0	100.0	21.8	15.9
Min	0.1	6.7	7.7	0.2	2.2	-	35.0	100.0	0.1	6.7
Max	106.5	22.0	29.0	3.7	1,109.0	-	35.0	100.0	106.5	22.0
Me- dian	6.5	19.0	12.0	1.0	50.0	-	35.0	100.0	6.5	19.0

Source: Study team

Notes: values in bold have been taken forward in the analysis

The Unwin et al. (2006) study indicates the presence of 4-6 ring PAH in the range 50-330 ng/m³, while Marczyński et al. (2009) measured all eight carcinogenic PAH with a median for all 8PAH of 12,700 ng/m³. Note that the latter study refers to exposure data from the period 1999-2003.

3.3.4.10.2 Metabolite

The table below presents metabolite data available for the sector. There is one data point monitoring 3-OHBaP with a median of 0.54 nmol/mol creatinine, which is between the second and third policy options. The concentration is within Germany's highest non-binding BLV and higher than France's BLV.

Table 3-36 Metabolite concentrations from published sources in steel and iron foundries

Sector/ process	Metabolite ^(a)	n	Smokers	Mean	Median	P95	Range		Location	Reference (Source)
							Min	Max		
Converter in-feed	3-OHBaP		N.R.		0.54				DE	(RAC, 2022b citing Förster et al., 2008)
Iron foundry	1-OHP	11	N.R.	0.29			0.25 ^(d)	0.66	UK	(Unwin et al., 2006)
Iron foundry	1-OHP	7	N.R.	0.25 ^(d)			0.25 ^(d)	0.25	UK	(Unwin et al., 2006)
Converter in-feed ^(b)	1-OHP	12	67%		13.5				DE	(Marczynski et al., 2009)
Smelters, moulders and casters	1-OHP	93	0%		0.27	1.74			TN	(Campo et al., 2016)
Rolling-mill operators, hot-dip platers, machine operator, and sweepers	1-OHP	93	0%		0.23	4.50			TN	(Campo et al., 2016)
Various ^(c)	1-OHP	93	0%		0.29				TN	(Campo et al., 2016)

Notes:

^(a) 1-OHP unit $\mu\text{mol/mol}$ creatinine, 3-OHBaP unit is nmol/mol creatinine

^(b) Brickwork lining and repair of converters were studied

^(c) Maintenance, security, QC and admin

^(d) values are below the limit of detection

3.3.4.11C24.42 Manufacture of aluminium

3.3.4.11.1 Airborne

The main source of PAH exposure in aluminium smelting is in the anode pre-bake areas. Studies where monitoring took place before 2015 will most likely have included (but not solely be based

on) plants using Söderberg anodes, which are consumed during the electrolytic process and generate high levels of PAH. However, the literature does not describe the type of plant.

The highest levels of BaP are in the anode pre-baking area, where anodes made with CTPht are baked and thus releasing PAH.

Table 3-37 C24.42 Manufacture of aluminium exposure concentrations (ng/m³ BaP) from published sources and stakeholder consultation

Sector/ process	n	Mean	Median	P95	Range		RPE APF	Location	Reference (Source)
					Min	Max			
Aluminium (green carbon, corresponding to pre-bake)	9	30			30	100	N.R.	UK	(Unwin et al., 2006)
Manufacture of aluminium	19		40	160 (P75)	10	2,000	N.R.	SK	(RAC, 2022b citing Klöslova et al., 2016)
Raw production, pot reconstruction, rod-ding section and furnaces	9				50	990	N.R.	EL	(Hatzis et al., 2006)
Pre-baked anode production - paste tower - manufacture operator	7		84	285	35	320	N.R.	FR	(Petit et al., 2019)
Pre-baked anode production - paste tower - watchperson, heat attendant	18		28	486	1.6	1,823	N.R.	FR	(Petit et al., 2019)
Pre-baked anode production - furnace - gas attendant, overhead crane operator	16		29	73	6	88	N.R.	FR	(Petit et al., 2019)
Pre-baked anode production - furnace - heat attendant mason	8		29.00	54	8.2	57	N.R.	FR	(Petit et al., 2019)
Maintenance of the paste tower and furnace - Maintenance operator	6		55	345	24	426	N.R.	FR	(Petit et al., 2019)
Maintenance of the paste tower and furnace - Mechanic	9		193	696	64	819	N.R.	FR	(Petit et al., 2019)
Maintenance of the paste tower and furnace - Electrician	6		43	183	16	206	N.R.	FR	(Petit et al., 2019)
Driver, smelter	8		0.75	2.9	0.03	3.20	N.R.	FR	(Petit et al., 2019)
Caster	7		0.80	2.3	0.03	1.50	N.R.	FR	(Petit et al., 2019)

Sector/ process	n	Mean	Me- dian	P95	Range		RPE APF	Lo- ca- tion	Reference (Source)
					Min	Max			
Electrolytic furnace operation, start-up of the furnace, metal suction, nipple transfer and pulling	≥2	100					N.R.	DE	(DGUV, 2022)
PROC8b ^(a)	N.R.				100	30,000	10-200	EEA	Consultation 1
PROC25 ^(b)	N.R.	200					10	EEA	Consultation 2
Manufacture of anodes	10	380		750	220	780	10	EEA	Consultation 3
Manufacture of anodes	60	130		830	10	830	20	EEA	Consultation 4

Notes:

RPE = respiratory protection equipment

APF = assigned protection factor according to EN 529:2005

N.R. = not reported

^(a) PROC8b: Transfer of substance or mixture (charging and discharging) at dedicated facilities

^(b) PROC25: Other hot work operations with metals

The data presented in the table above are without RPE. Based on information provided in the consultation, the appropriate protection factor was applied where RPE are said to be worn. For literature data where the use of RPE is not reported, the study team has assumed that RPE is worn based on feedback from the consultation. The summary of exposure data with the use of RPE, and taking into account confidential data, e.g. CSR, are presented in the table below. The values taken forward for the assessment are in bold. The data have a wide distribution and due to data coming from different sources, in different locations and conducting different activities it does not appear to follow a log normal distribution when taken altogether (for example the P95 data are lower than the P75 data). The average of the P75 and P95 data is 99 ng/m³.

Table 3-38 C24.42 summary of exposure concentrations (ng/m³ BaP) with RPE

	Aver- age	Geo mean	Me- dian	Min	Max	P25	P75	P90	P95	P99
Aver- age	36.9	14.0	13.2	6.2	131.9	7.5	149.0	-	58.1	-
Min	6.5	0.1	0.2	0.0	0.4	7.5	35.4	-	0.6	-
Max	100.0	51.8	48.3	22.0	500.0	7.5	495.0	-	174.0	-
Me- dian	25.0	10.8	8.6	4.0	78.0	7.5	101.0	-	45.8	-

Source: Study team

Notes: values in bold have been taken forward in the analysis

The Unwin et al. (2006) study indicates the presence of 4-6 ring PAH in the range 10-850 ng/m³.

3.3.4.11.2 Metabolite

The table below presents metabolite data available for the sector. There is one data point monitoring 3-OHBaP with a range 0.1-3 nmol/mol creatinine, where the maximum is between the third

and fourth policy options, and within Germany's highest non-binding BLV and higher than France's BLV.

Table 3-39 Metabolite concentrations in aluminium manufacturing from published sources and stakeholder consultation

Sector/ process	Metab- olite ^(a)	n	Smo kers	Mean	Me- dian	P95	Range		Loca- tion	Reference (Source)
							Min	Max		
PROC8b	3-OHBaP	15	N.R.				0.10	3.00	EEA	Consultation 1
Aluminium (green car- bon)	1-OHP	9	N.R.	0.72			0.25 ^(d)	2.60	UK	(Unwin et al., 2006)
Production of alumin- ium ^(b)	1-OHP	19	59%	4.99	1.20		0.00	24.40	SK	(RAC, 2022b citing Klöslova et al., 2016)
Anode plant - paste mix- ing and anode forming	1-OHP	44	24%	13.3	14.2		2.02	33.44	AU	(Di Corleto, 2010)
Anode plant - non-form- ing area	1-OHP	50	24%	1.64	4.11		0.09	26.99	AU	(Di Corleto, 2010)
Cell recon- struction	1-OHP	25	24%	1.20	0.17		0.00	2.47	AU	(Di Corleto, 2010)
Raw pro- duction, pot reconstruc- tion, rod- ding section and fur- naces	1-OHP	32	Mixed		0.26		0.02	1.93	GR	(Hatzis et al., 2006)
PROC25	1-OHP	30	N.R.				0.93	2.69	EEA	Consultation 2
Mainte- nance ^(c)	1-OHP	22	N.R.	0.76			0.09	7.39	EEA	Consultation 3

Notes:

N.R. = not reported

- (a) 1-OHP unit $\mu\text{mol/mol}$ creatinine, 3-OHBaP unit is nmol/mol creatinine
 (b) Production of aluminium by electrolysis
 (c) Cleaning of valves / leakage of equipment, open mixers (during maintenance stops)
 (d) value is below the limit of detection

3.3.4.12C24.45 Other non-ferrous metallurgical processes

3.3.4.12.1 Airborne

The manufacturing process for silicon metal, silicon carbide and calcium carbide follows a similar process (according to DGUV, 2022) that entails the release and exposure to PAH (DGUV, 2022). The use of Søderberg or pre-bake anodes, coke and tapping are reported. It is unclear how widespread the use of Søderberg anodes is – some industry representatives have indicated that they are used in the manufacture of silicon metal and calcium carbide, while a report by DGUV (2022) indicate that their use in these industries was phased out several decades ago in Germany.

The data in the table below is for the manufacture of silicon metal, and indicates high levels of exposure which is consistent with the use of Søderberg anodes (self-consuming during the reduction process, with subsequently high levels of PAH release).

Søderberg briquettes or pastes are used in furnaces in the metals industry, and once these are heated, they release PAH. The three industries (silicon metal, silicon carbide and calcium carbide) have been grouped since DGUV (2022) indicates that they have similar manufacturing methods and the study teams has read across the silicon metal exposure data available to silicon carbide and calcium carbide. The exposure to PAH during the manufacture silicon carbide was measured in a study by Petry et al. (1994), where a mean BaP concentration of 130 ng/m^3 was reported, which is within the exposure concentrations reported in Table 3-40.

It is likely that other non-ferrous manufacturing processes would fall in scope but it was not possible to identify them.

The available data source comes from a single source where samples was collected between 1995 and 2010 on silicon metal manufacture (Petit et al., 2019)⁸. Given the age of the study and changes in practices other metallurgical industries as discussed during the consultation, with more emphasis on RMM, it is possible that exposure levels are now lower.

Due to lack of data and engagement from stakeholders, the accuracy of the data and assumptions made could not be verified. It is possible that a larger proportion of the sector could be affected, and that the exposure values represent a worst-case scenario.

Table 3-40 C24.45 Other non-ferrous metallurgical processes exposure concentrations (BaP ng/m^3) from published sources and stakeholder consultation

⁸ Most samples (57.2%) were collected between 2006 and 2010 while 28.3% were collected between 2010 and 2014, 9.4% between 2001 and 2005, and 5.1% between 1995 and 1999.

Sector/ process	n	Mean	Median	P95	Range		Location	Reference (Source)
					Min	Max		
Composite electrodes: paste loading in and casing welding of the electrode	108		883	8,535	6.5	38,521	FR	(Petit et al., 2019)
Søderberg electrodes - incl. casing welding	8		126	1,097	12	1,536	FR	(Petit et al., 2019)
Manufacture - Post's Chief	15		22	148	0.57	201	FR	(Petit et al., 2019)
Manufacture - Raw material loading	42		22	260	1.1	318	FR	(Petit et al., 2019)
Manufacture - Caster	54		20	179	0.12	329	FR	(Petit et al., 2019)
Heat attendant mason ^(a)	25		3,218	23,026	2.6	26,573	FR	(Petit et al., 2019)
Annual maintenance - plate and/or ring dismantling	62		609	3,731	88	4,509	FR	(Petit et al., 2019)

Notes: (a) includes intervention in the furnace.

In the publication from which the data comes from there is no information on the use of RPE. Based on the current OEL level in France, consultation with other industries, and the age of the data (1995-2010) it is assumed that workers would today be wearing RPE at the higher concentration levels. If the lowest RPE APF is assumed, based on EN 529:2005 this would be equivalent to an APF of 4. The summary of exposure data with the use of RPE, and taking into account confidential data, e.g. CSR, are presented in the table below. The values taken forward for the assessment are in bold.

Table 3-41 C24.45 summary of exposure concentrations (BaP ng/m³) with RPE

	Average	Geo mean	Median	Min	Max	P25	P75	P90	P95	P99
Average	157.2	34.6	71.4	1.7	965.7	-	149.9	115.3	540.8	-
Min	157.2	5.0	5.0	0.0	50.3	-	46.0	84.0	37.0	-
Max	157.2	86.8	321.8	8.8	3,852.1	-	294.0	143.0	2,302.6	-
Median	157.2	13.1	12.6	0.5	276.6	-	143.0	117.0	109.7	-

Source: Study team

Notes: values in bold have been taken forward in the analysis

The study team does not have access to data on exposure to other carcinogenic PAH.

3.3.4.12.2 Metabolite

The study team does not have access to PAH metabolite data for the sector under consideration.

3.3.4.13 C24.5 Casting of metals

3.3.4.13.1 Airborne

The sources of PAH during casting of metals are primarily due to decomposition of organic material present in the sand moulds when the molten steel sinters the surface and generates PAH. However like for C24.1 steel and iron foundries, residual PAH in coke that is used to fuel the furnaces, as well as coal, can also be a source of PAH. The values are relatively low, with exposure in the range of not determined to 90th percentiles of 80 ng/m³ BaP. One study indicates that a concentration range of 210-240 ng/m³ but clarifications with the data provider indicate that this figure comes from static monitoring taken near the furnace and that workers are not stationed there during shifts since would not be able to withstand the high temperatures for a long period of time. According to the consultee, a worker may be near the furnace for up to 10 minutes and not more than once per shift.

Table 3-42 C24.5 exposure concentrations (BaP ng/m³) from published sources and stakeholder consultation

Sector/ process	N	Mean	Median	P95	Range		Location	Reference (Source)
					Min	Max		
Discharge mould	13		4.9 (GM)	18.0	1.6 (P05)		FR	(Petit et al., 2019)
Sand mould and permanent mould casting: All work areas	≥10			N.D. (P90)			DE	(DGUV, 2022)
Former hand moulds, moulding machines, mixing, core insertion	≥10			N.D. (P90)			DE	(DGUV, 2022)
Smelter, Operating/monitoring the furnaces (various types), tapping, charging platform (in 2011-2019)	≥10			80 (P90)			DE	(DGUV, 2022)
Pour with clay/resin-bonded moulding sands and in chill casting	≥10			10 (P90)			DE	(DGUV, 2022)
Forging in general, open-die forging, hand forging, forging press shop, drop forging: forging, pressing, hot pressing.	≥10			80 (P90)			DE	(DGUV, 2022)
PROC22: Casting of iron counterweights	2	19			5	67	DE	Consultation 1
PROC22: Melting of iron before casting	2	225			210	240 ^(a)	DE	Consultation 2

Notes:

N.D. = not detected

^(a) it emerged in follow up with the consultee that this figure is from a static monitoring near the furnace and a worker would be there for up to 10 minutes and not more than once in a shift.

The summary of exposure data are presented in the table below. The values taken forward for the assessment are in bold. Excluding the static monitoring near the furnace, average and median concentration are within the 70 ng/m³ policy option, while maximum concentrations are within the 700 ng/m³ policy option.

Table 3-43 C24.5 summary of exposure concentrations (BaP ng/m³) with RPE

	Average	Geo mean	Median	Min	Max	P25	P75	P90	P95	P99
Average	98.0	4.9	-	72.2	153.5	-	-	80.0	18.0	-
Min	19.0	4.9	-	1.6	67.0	-	-	80.0	18.0	-
Max	225.0	4.9	-	210.0	240.0	-	-	80.0	18.0	-
Median	50.0	4.9	-	5.0	153.5	-	-	80.0	18.0	-

Source: Study team

Notes: values in bold have been taken forward in the analysis

The study team does not have access to data on exposure to other carcinogenic PAH.

3.3.4.13.2 Metabolite

The study team does not have access to PAH metabolite data for the sectors under consideration.

3.3.4.14 D35.11 Coal fired power plants

3.3.4.14.1 Airborne

Coal fired power plants workers have the potential to be exposed to PAH due to the combustion of coal. However, the nature of the sector and the introduction of the BREF for large combustion plants in 2017 (BREF, 2017a) require emissions to be controlled. Limited data are available dated from 2000 onwards and the data show that a biomass plant has negligible exposure levels. This is thought to be attributable to both the nature of the solid fuel and the likely more recent age of the structure. Only one study is available with coal-fired power plants, with an average exposure concentration of 20 ng/m³ BaP, below the 70 ng/m³ BaP policy option, and a range of 5-100 ng/m³, which is below the 700 ng/m³ policy option. It is possible that exposure concentrations are now lower, given the age of the study and that monitoring took place before the BREF was published.

Table 3-44 D35.11 Coal fired power plants exposure concentrations (BaP ng/m³) from published sources and stakeholder consultation

Sector/ process	n	Mean	Median	P95	Range		Location	Reference (Source)
					Min	Max		
Coal fired power station	12	20			5	100	UK	(Unwin et al., 2006)
Biomass: wood, pellets, peat, recycled fuel (peat mainly)	24	0.15			0.15	0.15	FL	(Jumpponen et al., 2013)

Source: Study team

The Unwin et al. (2006) study indicates the presence of 4-6 ring PAH in the range 40-790 ng/m³.

3.3.4.14.2 Metabolite

Only one biomonitoring data point is available, and it is with 1-OHP, which is below the limit of detection and reported as 0.25 µmol/mol creatinine. Based on the corresponding air monitoring data, this would indicate that workers are wearing RPE where there is potential for exposure.

Table 3-45 Metabolite concentrations from published sources in coal fired power plants

Sector	Metabolite ^(a)	n	Smokers	Mean	Median	P95	Range		Location	Reference (Source)
							Min	Max		
Coal fired power station	1-OHP	12	N.R.	0.25 ^(b)			0.25 ^(b)	0.25 ^(b)	UK	(Unwin et al., 2006)

Notes:

N.R. = not reported

^(a) 1-OHP unit µmol/mol creatinine

^(b) values are below the limit of detection

3.3.4.15 E38.2 Waste incineration

3.3.4.15.1 Airborne

Waste incineration is a controlled process due to the nature of the sector; therefore low exposure levels are to be expected. The available data confirms this average and median concentrations varying from not detected to 1.1 ng/m³ BaP (see Table 3-46), which are below the lowest proposed OEL. The maximum concentration is 56 ng/m³ BaP, which is below the 70 ng/m³ BaP.

Additional confidential data points are available, which together with the data presented below, point to an overall median exposure concentration of 20 ng/m³, i.e. below the second policy option.

Table 3-47 E38.2 waste incineration exposure concentrations (BaP ng/m³) from published sources and stakeholder consultation

Sector/ process	N	Mean	Median	P95	Range		Location	Reference (Source)
					Min	Max		
Waste Incineration	17		0.81	25.00	0.03	56.00	FR	(Petit et al., 2019)
Municipal waste incinerator	19	1.09	0.06		N.D.	11.64	FR	(Maître et al., 2003)
Recycling plants	≥10			N.D. (P90)			DE	(DGUV, 2022)
Plastic waste recycling plant	3	0.50	N.D.				CN	(Huang et al., 2013)
Plastic waste recycling plant	3	0.30	N.D.				CN	(Huang et al., 2013)

Notes:

N.D. = not detected

In a study by Oh et al. (2005) personal sampling of workers in an incineration plant in South Korea have found that workers were exposed to benzo[a]anthracene, chrysene, benzo[b]fluoranthene (or benzo[e]acephenanthrylene), indeno(1,2,3-c,d)pyrene (a Persistent Organic Pollutant), dibenz(a,h)anthracene (Carc. 1B).

The table below shows the data analysed and taken forward for the assessment in bold.

Table 3-48 E38.2 summary of exposure concentrations (BaP ng/m³) with RPE

	Average	Geo mean	Median	Min	Max	P25	P75	P90	P95	P99
Average	0.63	1.20	0.44	0.02	33.82	-	-	-	25.0	-
Min	0.30	1.20	0.06	0	11.64	-	-	-	25.0	-
Max	1.09	1.20	0.81	0.03	56.0	-	-	-	25.0	-
Median	0.50	1.20	0.435	0.015	33.82	-	-	-	25.0	-

Source: Study team

Notes: values in bold have been taken forward in the analysis

3.3.4.15.2 Metabolite

Only one metabolite data point is available with 1-OHP in a study in South Korea, where the mean concentration is 0.53 µmol/mol creatinine. This is double the proposed SCOEL BGV, but should be treated with caution as there are no air monitoring data with the study and the measurement was taken outside of Europe.

Table 3-49 Metabolite concentrations from published sources and stakeholder consultation

Sector/ process	Metabolite (a)	n	Smokers	Mean	Median	P95	Range		Location	Reference (Source)
							Min	Max		
Waste incineration	1-OHP	31	77%	0.53			0.13	1.49	KR	(Oh et al., 2005)

Notes: (a) 1-OHP unit µmol/mol creatinine

3.3.4.16E39.0 Soil remediation

3.3.4.16.1 Airborne

Soil remediation of contaminated sites from PAH is normally through thermal remediation, either in-situ or ex-situ. In the latter, the soil is excavated and thermally processed off site. There are several thermal remediation techniques such as incineration, thermal desorption, stream enhanced

extraction, electrical resistance heating, microwave heating, smouldering, vitrification and pyrolysis (Alazaiza et al., 2022). Only one study is available (Hagmann et al., 2017 (as referenced by RAC 2022b)) to the study team where the soil has been excavated and transported for treatment: the soil is crushed, iron bodies removed, and fed into rotary kilns via wheel loaders where it is pyrolytically treated first at 500°C in rotary kilns and then at burned at 1,100°C. The study identified high levels particularly during critical operations such as repairs, maintenance and feeding of the decontamination device during soil remediation. The data presented by RAC indicates a median concentration of 170 ng/m³ BaP, below the 700 ng/m³ BaP policy option, and a maximum concentration of 2090 ng/m³ BaP, which is above the highest policy option. It is not known whether workers are wearing RPE or not during these operations, but based on feedback from consultation and due to the nature of the work the study team has assumed that RPE is worn with a minimum protection factor of 4.

Table 3-50 E39.0 soil remediation exposure concentrations (BaP ng/m³) from published sources and stakeholder consultation

Sector/ process	N	Mean	Median	P95	Range		Location	Reference (Source)
					Min	Max		
Thermal soil remediation	51		170*			2090*	DE	(RAC 2022b, citing Hagmann et al., 2017)

Notes: N.D. = not detected

* The study team assumes that RPE is worn, with a minimum protection factor of 4.

No studies are available measuring the concentration of other carcinogenic PAH during soil remediation. However the study by Hagmann et al. (2017) referenced by ECHA measured total 17 PAH and depending on the contaminant being removed from the soil, exposure to other carcinogenic PAH can be expected.

3.3.4.16.2 Metabolite

In the same study by Hagmann et al. 2017 urine concentration of one metabolite data point is available with 1-OHP were monitored. The median 1-OHP metabolite concentration is in the range 0.16-4.35 µmol/mol creatinine, which can exceed the proposed SCOEL BGV.

Table 3-51 Metabolite concentrations from published sources and stakeholder consultation

Sector/ process	Metabolite (a)	n	Smokers	Mean	Median	P95	Range		Location	Reference (Source)
							Min	Max		
Thermal soil remediation	1-OHP	51			0.16-4.35				DE	(RAC 2022b, citing Hagmann et al., 2017)

Notes: (a) 1-OHP unit µmol/mol creatinine

3.3.4.17F42.11 Road paving

3.3.4.17.1 Airborne

Road paving is a common activity throughout Europe. This sector includes paving of road, airfield runways, bridges, paving with normal asphalt and mastic asphalt, as well as other types of paving activities. The data are in the range <1 to 460 ng/m³ BaP.

The study with the highest value of 460 ng/m³ comes from a publication referring to the German Human Bitumen study and specifically concerns the use of mastic asphalt, both indoors and outdoors. Data indicates that mastic asphalt represents just 1% of all asphalt in Europe (EAPA, 2021) and according to consultation with relevant stakeholders, Germany is the country with the biggest use of mastic asphalt of all European countries in terms of volume and number of applications. Generally, mastic asphalt tends to be used for bridges and other civil engineering structures only. In Germany mastic asphalt is also used indoors for soundproofing purposes, but this use is not known to take place in other European countries.

There seems to be little difference between workers performing road paving in road traffic conditions and in rural areas (see for example data from ATS, 2015).

Data for hot mix asphalt (HMA) and warm mix asphalt (WMA) show that exposure levels for HMA are higher, as expected, with data in the range 0.03-12.0 ng/m³ BaP (P95 3.0 ng/m³ BaP) and 0.0-2.4 ng/m³ BaP (P95 3.0 ng/m³ BaP) respectively (Petit, et al., 2019).

Overall, the data show averages, geometric means and medians in the range not detected to 45 ng/m³, with a larger portion of studies below 5 ng/m³ BaP.

Table 3-52 F42.11 Road paving exposure concentrations (BaP ng/m³) from published sources and stakeholder consultation

Sector/ process	N	Mean	Median	P95	Range		RPE APF	Location	Reference (Source)
					Min	Max			
Road paving - no traffic, includes workers not directly laying asphalt	1	2.9					4	IT	(ATS, 2015)
Road paving - tunnel or in some traffic	1	6.4					4	IT	(ATS, 2015)
Road paving - tunnel	1	4.5					4	IT	(ATS, 2015)
Road paving -in some traffic - driver of roller	1	15.6					4	IT	(ATS, 2015)
Road paving -in some traffic - groundworker 1 near paver	1	7.3					4	IT	(ATS, 2015)
Road paving -in some traffic - groundworker 2 near paver	1	10.5					4	IT	(ATS, 2015)

Sector/ process	N	Mean	Me- dian	P95	Range		RPE APF	Loca- tion	Reference (Source)
					Min	Max			
Road paving -in some traffic - driver of paver	1	4.5					4	IT	(ATS, 2015)
Road paving -in some traffic - driver of roller	1	15.6					4	IT	(ATS, 2015)
Road paving -in some traffic - groundworker 1 near paver	1	7.3					4	IT	(ATS, 2015)
Road paving -in some traffic - groundworker 2 near paver	1	10.5					4	IT	(ATS, 2015)
Road paving -in some traffic - groundworker 3 near paver	1	109.2					4	IT	(ATS, 2015)
Road paving -in some traffic - driver of paver	1	22.6					4	IT	(ATS, 2015)
Asphalt road surfacing	7	10.0			10.0	10.0	Not known	UK	(Unwin et al., 2006)
Road construc- tion (base)	5	10.0			10.0	10.0	Not known	UK	(Unwin et al., 2006)
Road paving: application of hot bitumen (>150°C)	61		0.28	3.0	0.03	12.0	Not known	FR	(Petit et al., 2019)
Application of warm bitumen (≤150°C)	8		0.26	1.8	0.03	2.4	Not known	FR	(Petit et al., 2019)
Road paving	35		20 (GM)			220	Not known	FL	(RAC, 2022b citing Väänänen et al., 2006, Vaananen et al., 2003)
Remixing of as- phalt	35		30.00 (GM)			320	Not known	FL	(RAC, 2022b citing Väänänen et al., 2006, Vaananen et al., 2003)
Road paving	20		5.00 (GM)				Not known	FL	(RAC, 2022b citing Väänänen et al., 2006)
Asphalt-surfac- ing machine drivers	6		4.70				Not known	SE	(Nilsson et al., 2018)

Sector/ process	N	Mean	Median	P95	Range		RPE APF	Location	Reference (Source)
					Min	Max			
Screed operators ^(a)	7		2.60				Not known	SE	(Nilsson et al., 2018)
Roller vehicle drivers ^(b)	6		0.002				Not known	SE	(Nilsson et al., 2018)
Road paving	20					30	Not known	DE	(Nies et al., 2022 citing McClean et al. 2004a)
Asphalt-surfacing machine drivers	6		2.1				Not known	SE	(Nilsson et al., 2018)
Screed operators ^(a)	7		1				Not known	SE	(Nilsson et al., 2018)
Roller vehicle drivers ^(b)	5		0.18				Not known	SE	(Nilsson et al., 2018)
Transport truck driver	11		0.22	0.44	0.03	0.44	No	IT	(Cirila et al., 2007)
Screed man rakerman	11		0.19	0.32	0.05	0.32	No	IT	(Cirila et al., 2007)
Concrete asphalt rakerman	37		0.27	1.16	0.05	1.16	No	IT	(Cirila et al., 2007)
Roller driver	13		0.48	0.91	0.03	0.91	No	IT	(Cirila et al., 2007)
Paver operator	11		0.38	0.61	0.11	0.61	No	IT	(Cirila et al., 2007)
Road paving with stone mastic asphalt (cold application)	5				<10	<10	No	FL	(Väänänen et al., 2006)
Road paving	5				<10	<10	No	FL	(Väänänen et al., 2006)
Road paving	8		6.24	36.03	0.26	36.06	No	IT	(Cirila et al., 2007)
Mastic asphalt	15		45		6	460	Not known	DE	(Breuer & Hahn, 2011)
Indoor activities included - mastic asphalt laying	≥10			N.D.			Not known	DE	(DGUV, 2022)

Notes:

RPE = respiratory protection equipment

APF = assigned protection factor according to EN 529:2005

N.D. = Not determined, i.e. <LOD

^(a) Screed operators (using a rake to smoothen out the asphalt behind the surfacing machine)

^(b) Roller vehicle drivers (compacting the asphalt behind the paving machine and the screed operators)

Anecdotal evidence and literature suggests that workers in this sector seldom wear RPE. The summary of exposure data with the use of RPE, where reported, are presented in the table below. The values taken forward for the assessment are in bold.

Table 3-53 F42.11 summary of exposure concentrations (BaP ng/m³) with RPE

	Average	Geo mean	Median	Min	Max	P25	P75	P90	P95	P99
Average	5.30	11.09	4.62	2.81	69.62	-	-	-	5.43	-
Min	0.73	0.18	0.18	0.03	0.32	-	-	-	0.32	-
Max	27.30	30.00	45.00	10.00	460.00	-	-	-	36.03	-
Median	2.63	5.00	0.74	0.11	7.50	-	-	-	1.48	-

Source: Study team

Notes: values in bold have been taken forward in the analysis

The Unwin et al. (2006) study indicates the presence of 4-6 ring PAH in the range 10 ng/m³ for road surfacing and 70-720 ng/m³ for laying the base. Posniak et al. (2005) measured benzo[a]anthracene, benzo[k]fluoranthene, chrysene and dibenz[a,h]anthracene at low concentrations (median 3-7 ng/m³), and Cirla et al. (2007) also detected presence of chrysene (<LOQ-8.98 ng/m³), benzo[a]anthracene (<LOQ-8.05 ng/m³), benzo[k]fluoranthene (<LOQ-18 ng/m³), dibenzo[a,h]anthracene (<LOQ-12.29 ng/m³).

3.3.4.17.2 Metabolite

There are no biomonitoring data available with 3-OHBaP.

Data are available with 1-OHP metabolite with medians in the range 0.1-0.6 µmol/mol creatinine, which can be higher than the proposed BLV by SCOEL (0.26 µmol/mol creatinine). This is possibly due to the relatively low airborne exposure concentrations (for data points where both air and metabolite data are available) and the low correlation.

Väänänen et al. (2005) found that dermal contamination explained more of the variation in the urinary excretion of 1-OHP than airborne concentrations. The study Cirla et al. (2007) also measured dermal PAH exposure on the groin, neck, shoulder, ankle, upper arm, wrist. BaP was not detected in 53 samples (<LOD), neither was the cat. 1 carcinogen benzo[k]fluoranthene, whilst other, more volatile PAH such as naphthalene, fluorene, phenanthrene, pyrene, fluoranthene were detected, however these are not cat. 1 carcinogens (see section 1.3.4).

Table 3-54 Metabolite concentrations from published sources in road pavers

Sector/ process	Metabolite (a)	n	Smokers	Mean	Median	P95	Range		Location	Reference (Source)
							Min	Max		
Asphalt road surfacing	1-OHP	7	N.R.				0.25 (b)	0.25 (b)	UK	(Unwin et al., 2006)
Road construction (base)	1-OHP	5	N.R.				0.25 (b)	0.25 (b)	UK	(Unwin et al., 2006)

Sector/ process	Me-tabolite (a)	n	Smokers	Mean	Median	P95	Range		Location	Reference (Source)
							Min	Max		
Road paving: application of hot bitumen	1-OHP	19	N.R.		0.13	0.24			SE	(RAC, 2022b citing Xu et al., 2018a, Xu et al., 2018b)
Road paving: application of hot bitumen	1-OHP	18	N.R.		0.11	0.76			SE	(RAC, 2022b citing Xu et al., 2018a, Xu et al., 2018b)
Road paving	1-OHP	29	0%					2.20	FI	(RAC, 2022b citing Väänänen et al., 2006, Väänänen et al., 2003)
Road paving	1-OHP	29	0%				0.30	0.64	FI	(RAC, 2022b citing Väänänen et al., 2006)
road paving - no traffic, includes workers not directly laying asphalt	1-OHP	83	0%				0.02	2.86	IT	(ATS, 2015)
road paving - tunnel or in some traffic	1-OHP	6	0%				0.19	1.36	IT	(ATS, 2015)
road paving	1-OHP	67	0%		0.64		0.04	3.40	IT	(Garattini et al., 2010)
road paving	1-OHP	13	0%		0.12		0.03	0.45	IT	(Garattini et al., 2010)
road paving	1-OHP	94	0%		0.51		0.02	6.10	IT	(Garattini et al., 2010)

Notes:

(a) 1-OHP unit $\mu\text{mol/mol}$ creatinine

(b) values are below the limit of detection

3.3.4.18F42.12 Welding of railway sleepers

3.3.4.18.1 Airborne

Sector C16.1 deals with the impregnation of railway sleepers with creosote. The installation of sleepers and subsequent welding of train tracks on the sleepers, also for repairs, can result in high levels of airborne PAH exposure. Welding of train tracks can take place either via arc welding or aluminothermic welding (Stakeholder Consultation, 2023).

Only one study is available for exposure to PAH during welding, which measures average concentrations of 300-400 ng/m³ and in the range 280-1500 ng/m³ (IFA, 2014). The study is a reproduction for the purpose of taking measurements, during which a face shield was worn. Whilst there are industry guidelines and safety procedures in place to minimise risk and exposure to welders

(Stakeholder consultation, 2023), anecdotal evidence suggests that RPE or face shield are worn inconsistently or not at all across the EU during outdoor welding activities. Therefore the study team has assumed that no RPE is worn as a worst-case scenario.

Table 3-55 F42.12 Welding of train tracks (BaP ng/m³) from published sources

Sector/ process	N	Mean	Median	P95	Range		RPE APF	Location	Reference (Source) ^a
					Min	Max			
Arc welding	1	300-400			280	1500	Face shield*	DE	(IFA, 2014)

Source: Study team

Notes: * anecdotal evidence suggests that face shields and RPE are worn inconsistently across the EU during outdoor welding activities, even though there are industry guidelines in place for the use of RPE.

No data are available on exposure to other carcinogenic PAH during welding of train tracks, however given the nature of the substance generating exposure to BaP (creosote) in the available study, it is considered likely that workers will be exposed also to other carcinogenic PAH within the scope of the CMRD.

3.3.4.18.2 Metabolite

No metabolite data are available for this sector.

3.3.4.19G45.2 Motor vehicle maintenance and repairs

3.3.4.19.1 Airborne

Workers in garages for automotive maintenance and repairs tend to have minimal RPE and are often in ventilated areas. Exceptions are for garages located in bus depots, which reported the highest concentrations.

Air concentrations average, geometric mean and median concentrations are in the range 0.3-15 ng/m³ with the majority of data points around 1-2 ng/m³ BaP, which is below the lowest proposed policy option.

Table 3-56 G45.2 motor vehicle maintenance and repairs exposure concentrations (BaP ng/m³) from published sources and stakeholder consultation

Sector/ process	N	Mean	Median	P95	Range		Location	Reference (Source)
					Min	Max		
Light vehicles garage	70		0.98	10.0	0.03	10.0	FR	(Petit et al., 2019)
Truck repair workshop	3		0.28		0.27	0.52	CH	(Sauvin et al., 2003)
Truck repair workshop	2		0.25		0.20	0.29	CH	(Sauvin et al., 2003)

Sector/ process	N	Mean	Median	P95	Range		Location	Reference (Source)
					Min	Max		
Truck repair workshop	1		3.33				CH	(Sauvin et al., 2003)
Bus garage	4	13.2	12.0		1.0	25.0	PL	(Pośniak et al., 2003)
Bus garage	5	10.1	8.0		1.0	16.0	PL	(Pośniak et al., 2003)
Bus garage	13	15			5	31	PL	(Pośniak et al., 2003)
Bus garage - winter	104	1.0			0.45	29.0	FL	(Kuusimäki et al., 2003)
Bus garage - summer	106	0.3			0.45	3.3	FL	(Kuusimäki et al., 2003)
Heavy Truck mechanic	28		1.3 (GM)	8.5			FR	(Petit et al., 2019)
Roadwork mechanic	9		0.96 (GM)	36			FR	(Petit et al., 2019)
Agricultural mechanic	12		1.5 (GM)	6.1			FR	(Petit et al., 2019)
Vehicles – use of lubricating oils	13		2.4 (GM)	6.5			FR	(Petit et al., 2019)

Source: Study team

The summary of exposure data are presented in the table below. The values taken forward for the assessment are in bold.

Table 3-57 C24.42 summary of exposure concentrations (BaP ng/m³) with RPE

	Average	Geo mean	Median	Min	Max	P25	P75	P90	P95	P99
Average	7.92	1.43	4.14	1.05	14.39	-	-	-	13.42	-
Min	0.30	0.96	0.25	0.03	0.29	-	-	-	6.10	-
Max	15.00	2.40	12.00	5.00	31.00	-	-	-	36.00	-
Median	10.10	1.30	2.16	0.45	13.00	-	-	-	8.50	-

Source: Study team

Notes: values in bold have been taken forward in the analysis

Pośniak et al. (2003) detected benzo[a]anthracene, benzo[k]fluoranthene, chrysene, dibenzo[a,h]anthracene, with concentrations in the range 1-29 ng/m³, 0.3-5 ng/m³, 0.3-15 ng/m³ and 0.09-11 ng/m³.

3.3.4.19.2 Metabolite

Dermal exposure is to be expected, but there are no data with 3-OHBaP and only two data points with 1-OHP with means just above or below the proposed SCOEL.

Table 3-58 Metabolite concentrations from published sources and stakeholder consultation

Sector/ process	Me- tabo- lite ^(a)	n	Smok- ers	Mean	Me- dian	P95	Range		Loca- tion	Reference (Source)
							Min	Max		
Mechanic	1-OHP	18	48%	0.28					IT	(Trifuoggi et al., 2022)
Mechanic	1-OHP	32	11%	0.12					IT	(Trifuoggi et al., 2022)

Notes:

^(a) 1-OHP unit $\mu\text{mol/mol}$ creatinine, 3-OHBaP unit is nmol/mol creatinine

3.3.4.20N81.22 Chimney sweeps

3.3.4.20.1 Airborne

Chimney sweeps are mainly exposed to soot and are one of the first cases of recognised occupational exposure related ill-health. Practices have changed dramatically over the last 50 years, and even in the last 10 years the practice has changed thanks to the use of more efficient vacuum systems for domestic and the use of robotics for industrial cleaning. Hence the study team has focused on studies that are from the last two decades.

Only one study is available with measurements taken post-2000 (many earlier data points are available). The study indicates a median exposure concentration of 13 ng/m^3 and a maximum of 69 ng/m^3 BaP, just within the second policy option of 70 ng/m^3 BaP.

Table 3-59 N81.22 Chimney sweeps exposure concentrations (BaP ng/m^3) from published sources and stakeholder consultation

Sector/ process	N	Mean	Median	P95	Range		Loca- tion	Reference (Source)
					Min	Max		
Chimney Sweeps	10		13	51	3	69	FR	(Petit et al., 2019)

Source: Study team

The study team does not have access to exposure to other carcinogenic PAH for chimney sweep. However, given that combustion of solid fuels can lead to the generation of carcinogenic PAH other than BaP, it can be anticipated that exposure to other PAH within the scope of the CMRD will take place.

3.3.4.20.2 Metabolite

Data are available for 3-OHBaP from studies based in Sweden: the median concentrations are approximately 1.3 nmol/mol creatinine, which is between the second and third BLV policy options. Whilst there are no air monitoring data in the study, based on the only air monitoring data presented, it would suggest that dermal exposure is in fact a potential issue.

A study that measured the dermal presence of BaP on chimney sweep workers through tape-stripping found detectable levels after a shift (Kammer et al., 2011).

Note that for smokers, the median concentration was close to non-smokers but the maximum concentration was three times higher.

Table 3-60 Metabolite concentrations from published sources and stakeholder consultation

Sector/ process	Metab- olite ^(a)	n	Smo kers	Me an	Me- dian	P95	Range		Loca- tion	Reference (Source)
							Min	Max		
Chimney sweeper	3- OHBaP	90	0%		1.29		0.00	7.28	SE	(Alhamdow et al., 2017)
Chimney sweeper	3- OHBaP	116	59%		1.36				SE	(Alhamdow et al., 2019)

Notes:

^(a) 3-OHBaP unit is nmol/mol creatinine

3.3.4.21084.25 Firefighters

3.3.4.21.1 Airborne

Firefighters are required to enter areas where high levels of PAH are to be expected, due to the combustion of organic materials. During training and live fires, SCBA are worn presenting them with the highest level of protection from airborne exposure to PAH. However, as indicated in section 3.2.10.1, firefighters do not always wear SCBA. It is possible that firefighters will nonetheless be exposed to airborne concentrations even in these circumstances but no data on BaP are available that clearly indicate the potential and level of exposure.

Based on consultation (call with Anna Stec from University of Lancashire), the key factors that determine the PAH profile and their concentrations are the fuel (the material burning), and the fire scenario (i.e. the ventilation conditions). Additionally, firefighters' exposures and uptake of these chemicals will depend on:

- firefighters frequency of fire attendances;
- type and duration of exposures (inhalation, digestion, dermal); and
- decontamination methods, including workplace sanitation, PPE, as well as personal hygiene measures (see section 3.7).

A study has measured the PAH concentrations in the breathing zone of firefighters extinguishing fires in woodland, the total PAH levels are high, BaP could not be detected (Cherry et al., 2021). Other studies measured levels of PAH following wildfires and BaP does not feature as a PAH that is significantly increased (Wentworth et al., 2018; Ghetu et al., 2022). This is also a scenario where workers may be without SCBA if they are deployed for up to a week in remote areas to extinguish wildfires. Of concern is the potential for team leaders to be exposed during training and live fires as they site at the edge of the fire, coordinating activities without the use of RPE with exposure concentrations at approximately 50 ng/m³. Workers in fire stations and investigating fires in their aftermath are exposed to negligible airborne concentrations in comparison. However, a study revealed that PAH carcinogens, including BaP, were found on the skin (e.g., hands, throat), on PPE including helmets and clothing, on work surfaces, and that the main route of exposure appears to be via the skin (Stec et al., 2018). Dehydration and higher body temperature often associated with the firefighters' work increases an uptake of toxins via dermal route (personal communication with A. Stec).

Table 3-61 O84.23 firefighters exposure concentrations (BaP ng/m³) from published sources and stakeholder consultation

Sector/ process	N	Mean	Median	P95	Range		Location	Reference (Source)
					Min	Max		
Hot spotting and other	28				N.D.	N.D.	CA	(Cherry et al., 2021)
Firefighters team leaders ^(a)	7		8.67 (GM)		1.46	51.4	SE	(Sjöström et al., 2019)
Police Forensic Investigators - aftermath of fire events	9		0.43 (GM)		0.17	1.07	SE	Sjöström et al., 2019)
Firefighters - live fire - team leaders	8		13.20 (GM)		0.97	83.10	SE	Sjöström et al., 2019)
Firefighters	7		25.0	77	4.4	83.0	FR	(Petit et al., 2019)
Firefighters at the fire stations. Miranda do Douro	≥2		0.28 ^(b)		0.28 ^(b)	1.02	PT	(Oliveira et al., 2017)
Firefighters at the fire stations. Torre Dona Chama	≥2		0.28 ^(b)		0.28 ^(b)	0.40	PT	(Oliveira et al., 2017)
Firefighters at the fire stations. Sendim	≥2		0.28 ^(b)				PT	(Oliveira et al., 2017)
Firefighters at the fire stations. Mirandela	≥2		0.28 ^(b)		0.28 ^(b)	1.24	PT	(Oliveira et al., 2017)
Firefighters at the fire stations. Torre de Moncorvo	≥2		0.28 ^(b)				PT	(Oliveira et al., 2017)
Firefighters at the fire stations. Vinhais	≥2		1.22		0.28 ^(b)	2.45	PT	(Oliveira et al., 2017)
Firefighters at the fire stations. Braganca	≥2		0.28				PT	(Oliveira et al., 2017)
Firefighters at the fire stations. Freixo de Espada à Cinta	≥2		15.10		9.76	20.50	PT	(Oliveira et al., 2017)

Notes:

N.D. = not detected

^(a) Firefighters' team leaders - training standing 5–10 m from the entrance of the building used for training sessions

^(b) data below the limit of quantification (0.56 ng/m³ BaP)

In the study by Ghetu et al. (2022) a statistically significant increase in high molecular weight PAH was reported and benzo[a]anthracene, benzo[j]fluoranthene and chrysene are reported.

The summary of exposure data is presented in the table below. The values taken forward for the assessment are in bold.

Table 3-62 O84.25 summary of exposure concentrations (BaP ng/m³) with RPE

	Average	Geo mean	Median	Min	Max	P25	P75	P90	P95	P99
Average	-	12.58	4.78	1.99	27.13	-	-	-	77.0	-
Min	-	0.43	0.28	0.17	0.399	-	-	-	77.0	-
Max	-	28.0	25.00	9.76	83.10	-	-	-	77.0	-
Median	-	10.94	0.28	0.277	2.45	-	-	-	77.0	-

Source: Study team

Notes: values in bold have been taken forward in the analysis

3.3.4.21.2 Metabolite

The table below presents metabolite data available for the sector. A few data points are available with 3-OHBaP, but the values are not numerical ("very low") or below the limit of detection or quantification and in the studies the limits are presented for a range of metabolites and it is not possible to establish the detection limit for 3-OHBaP. From the data available it is difficult to ascertain the effectiveness of 3-OHBaP as a biomarker due to uncertainties surrounding the limit of detection in the studies.

The data on 1-OHP is more variable: from a median of 0.04 µmol/mol creatinine for firefighters who took part in forest fire activities in the last 24 hours (Wingfors, et al., 2018), to a median of 1.1 µmol/mol creatinine for training in smoke diving whilst wearing SCBA, suggesting that dermal exposure was the major route, to means of 0.4-1.3 µmol/mol after training (Andersen et al., 2019).

Dermal uptake is anticipated to be a major route of exposure. In a study that took dermal measurements via tape strips located on the wrist and neck, they found that wrists had higher levels than the collarbone area (Sjöström et al., 2019). In a second study, skin samples on the neck also revealed exposure to BaP and other carcinogenic PAH (Wingfors et al., 2018). A third study measured PAH on skin, PPE and work surfaces (offices, fire stations and engines) and found increased concentrations of PAH, including BaP as well as benzo[a]anthracene, benzo[j]fluoranthene, benzo[k]fluoranthene, chrysene, dibenz[a,h]anthracene, which are carcinogenic PAH under the scope of the CMRD.

Table 3-63 Metabolite concentrations from published sources and stakeholder consultation

Sector/ process	Metabolite ^(a)	n	Smokers	Mean	Median	P95	Range		Location	Reference (Source)
							Min	Max		
Fire extinguishing training - smoke container	3-OHBaP	20	0%				N.D. (b)	N.D. (b)	SE	(Wingfors et al., 2018)
Fire extinguishing training - all the steps of an	3-OHBaP	20	0%				N.D. (b)	N.D. (b)	SE	(Wingfors et al., 2018)

Sector/ process	Metab- olite ^(a)	n	Smo kers	Mean	Me- dia n	P 9 5	Range		Lo- ca- tion	Reference (Source)
							Min	Max		
emergency re- sponse turn-out										
Smoke diving exer- cise	3- OHBaP	20	0%				N.D. (b)	N.D. (b)	SE	(Wingfors et al., 2018)
Smoke diving exer- cise	1-OHP	20	0%		1.1				SE	(Wingfors et al., 2018)
Firefighters	3- OHBaP	78	38%	N.D.			N.D.	N.D.	PT	(Oliveira et al., 2019)
Firefighters	1-OHP	78	38%		0.0 4		0.02 (P25)	0.1 (P75)	PT	(Oliveira et al., 2019)
Firefighters at the fire stations	3- OHBaP	N.R.	N.R.				Null (c)	very low	PT	(Oliveira et al., 2017)
Training	1-OHP	54	0%	0.4- 1.3					DK	(Andersen et al., 2017)

Notes:

N.D. = not detected

N.R. = not reported

^(a) 1-OHP unit $\mu\text{mol/mol}$ creatinine, 3-OHBaP unit is nmol/mol creatinine

^(b) Data below the limit of detection (LOD $0.18 \mu\text{mol/mol}$ creatinine)

^(c) Data below the limit of quantification (LOQ 0.84 ng/l - $0.19 \mu\text{g/l}$ urine)

^(d) Data below the limit of quantification (LOQ 2.8 ng/l - $0.65 \mu\text{g/l}$ urine)

3.3.5 Exposure levels with and without respiratory protective equipment (RPE)

In theory, the benefits are based upon exposure data taken with RPE and the costs are calculated from exposure data taken without RPE. The benefits should reflect the exposure actually experienced by the worker, hence with RPE. The costs should be based upon the exposure without RPE, because ideally RPE should not be used and the costs of compliance should cover the risk management measures required to remove the requirement for RPE.

However, several significant issues arise. Firstly, many sources of exposure data do not indicate whether or not RPE is used. In some cases, they indicate the process, from which sometimes the presence or not of RPE could be inferred, but this is likely to be inaccurate. The exception is data from consultation.

Secondly, companies do not tend to rely on RPE for the majority of their risk management with the exception of welding of train tracks, for which the use of face shields is an industry standard for physical risk, coking, because they are not able to achieve low exposure concentrations via other means and to some extent also graphite and carbon electrode manufacturers who work with large articles in semi-closed processes with substances and activities that have the potential to generate high levels of airborne PAH. Even in the latter industry, RPE is complementary to other RMM. Generally, RPE is used occasionally and always to enable specific tasks such as: bulk handling of substances either at the beginning of the processing or packing the end product; sampling; and cleaning and maintenance inside closed systems as part of a shut down. In the latter two instances, operators have to enter a closed system and the only way of doing this (other than using expensive robotic systems) is with RPE.

Thirdly, although no company relies upon RPE for the majority of its risk management, many rely upon it to comply with limits during specific tasks, such as the ones described above, which only take a short period of time and usually cannot be easily done any other way. This is particularly true for C16.1, C19, C20, C23.99b and C24 sectors, but applies to all sectors.

Modelling the exposure levels for costs is complicated as, in theory, the exposure levels are adjusted to take account of the presence of RPE. Therefore if a sector is known to use a combination of for example 50% hooded systems and 50% RPE, the exposure levels for half of the companies will be increased significantly to take account of the fact that RPE will reduce the exposure by at least 95%. The problem is that the model does not know which exposure levels to adjust so it adjusts 50% of each level. However, there is a reasonably high chance that the highest levels will come from the hooded systems and not the levels with RPE. This results in some adjusted values in the model being so high that either very expensive RMMs are predicted to be required or the model cannot find an RMM that reduces the exposure sufficiently and the company is predicted to close.

After analysing the detailed results from the model under several scenarios, the study team came to the conclusion that the cost model's most realistic estimates used the exposure data without RPE with the current risk management profile for each sector based upon the primary RMMs in the sector as shown in section 3.5. This section shows that no sector has any companies using RPE as their primary RMM.

Overall, this may lead to some underestimation of the costs of compliance, but the study team believe the underestimation of cost would be low.

The data presented in section 3.3.4 presents the values as reported in the relevant sources. The use of RMMs, in particular the use of RPE will in some case drastically reduce the levels that workers are exposed to. Where information on the type of RPE is presented, the appropriate assigned protection factor (APF) has been applied based on EN 529:2005. Where the information on the type of RPE is not available, a conservative protection factor of 4 has been applied since this is the minimum protection factor for any RPE according to the standard.

3.3.6 Trends in exposure concentrations

Total PAH emissions in the EU27 decreased overall to 79% of 2005 emissions in 2020 based on data reported by EU MS under the United National Economic Commissions for Europe (UNECE) Air Convention (see Figure 3-2). This value is for total PAH rather than BaP and represents all emissions, including ones from the general population.

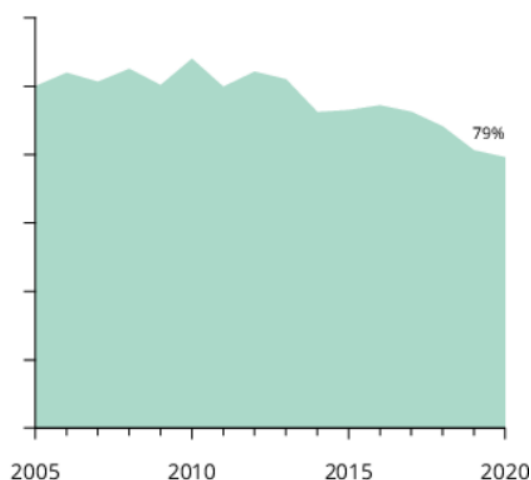


Figure 3-2 Changes in polycyclic aromatic hydrocarbon (PAH) emissions between 2005 and 2020, based on data reported by EU Member States under the United Nations Economic Commission for Europe (UNECE) Air Convention.

Source: (EEA, 2023)

Occupational exposure to PAH has also decreased over time. There are various reasons for this decrease, in particular:

- Changes in the production methods or application, such as the banning of the use of coal tar for paving, roofing applications from the 1960 to mid 1990s, and refractory products from early 2000s (bricks produced with coal tar pitch in the 1990's were loaded with BaP levels of 150–200 ppm, while their modern successors reach BaP levels <50 ppm (Ebner et al., 2017). There have also been considerable technical improvements in coking such as mechanisation and automation of oven operations, the reduction of coking time (IARC, 2010) that have lead to lower exposure concentrations as well as lower numbers of exposed workers. The amount of coke needed in the metallurgical sector has also decreased thanks to technical innovations;
- Developments in the engines, such as the reduction in PAH content from emissions from internal combustion engines;
- Improvements in occupational practices, for example in the aluminium industry, all plants within EU27 since 2000, Member States no longer make use of Söderberg electrodes (self-consuming electrodes that generate a large amount of PAH emissions) and the last plants were phased out in mid-2010. The use of pre-bake anodes has significantly reduced exposure levels to PAH; and
- New standards and legislations, such as the introduction of CTPht in the REACH Annex XVII (Authorisation list) and the introduction and implementation of Best Available Techniques (BAT) have been published and in place from mid 2000s through the publication of BREF (Best Available Techniques (BAT) Reference Documents, see section 3.5.5).

A study by Olsson et al., (2022) plotted BaP average exposure levels for in male and female workers from 1922 to 2020. The average annual percentage change in exposure level during the entire period was -0.5%. The graph shows a stable concentration until the 1970s and then a stepwise decrease for males until 2005-2010 where it plateaus. The study team attribute the step wise decreases to changes in the use of substances like coal tar in prevalently male industries, e.g. coal

tar no longer being used in paving and roofing, and the plateau to a concurrent plateau in technological advances that have achieved a reduction in emissions and exposure levels. The study team also believes that in Europe a further decrease would be observed in the period 2010-2020 thanks to the regulatory obligations such as the REACH Authorisation on CTPht.

Another study based on European and Canadian personal exposure concentrations calculated a time trend of -1.2% per year for BaP (95% Confidence Intervals -3.1% to -0.7%) between 1975 and 2009 (Peters et al., 2016). This study has used the overall decline measured in personal exposure concentrations as reported by Peters et al. 2016, i.e. -1.2% year-on-year between 1975 and 2009.

3.3.7 Summary of exposure concentrations used for the further analysis

The following table presents a summary of the current exposure data with RPE used for further analysis.

Table 3-64 Summary of exposure concentrations by sectors for PAH used for the further analysis – with adjustment for the use of RPE. All values in ng/m³.

Sector		AM	Median	P75	P90	P95	P100
C10.13, C10.20	Fish and meat smokehouses	10	0.50	2.8	13	32	220
C16.1	Wood preservation (creosote)	8.1	8	8.8	9.5	10	11
C19.10	Coking plants	329	216	405	700	942	1645
C19.2	Petroleum refineries	23	15	36	81	130	320
C20.13	Manufacture of carbon black	20.4	14.25	25.3	42.3	57.5	102.5
C20.14	Coal tar distillation	152	57.5	169	346	558	397.5
C23.2	Manufacture of refractory products	207	25	100	350	735	2982
C23.99a	Manufacture of bituminous products	38	20	43	86	130	280
C23.99b	Graphite and carbon electrode production	--	24.5	270	270	270	825
C24.1	Steel and iron foundries, ferroalloys	28	12	30	63	100	219
C24.42	Manufacture of aluminium	--	13.2	99	99	99	500
C24.45	Other non-ferrous metallurgical processes	152	71.4	164	345	540	1250

Sector		AM	Median	P75	P90	P95	P100
C24.5	Casting of metals	63	50	79	120	150	240
D35.11	Coal fired power plants	20	14	25	41	56	100
E38.2	Waste incineration	0.6	0.4	1.4	4.6	9.2	33.8
E39.0	Soil remediation	76	42.5	88	169	251	523
F42.11	Road paving	34	0.74	4.8	26	70	460
F42.12	Welding of train tracks	300-400	270	440	690	900	1500
G45.20	Motor vehicle maintenance and repairs	4.23	2.16	4.72	9.54	14.5	31
N81.22	Chimney sweeps	18	13	22	35	51	69
O84.25	Firefighters	29	25	35	48	58	83

Source: Study team on basis of information presented in this section.

Notes: The figures in italics are the modelled values. Sectors with an asterisk have been modelled but the impact assessment cannot be carried out.

The exposure data and proportion of exposed workers are further modelled according to criteria outlined in the next section.

3.3.8 Values used in the benefits and costs models

In both the benefits and costs models, the exposed workers or enterprises with exposed workers are split into five groups representing the groups shown in Table 3-65. The exposure level assumed to be experienced by this group is calculated as shown in Table 3-65.

Table 3-65 Calculation of exposure levels (inhalable) used in benefits and costs models

Percentiles	Proportion of workers or enterprises	Calculation for exposure level assumed for modelling
0 – 50	50%	50 th percentile
51 – 75	25%	Mean of 50 th and 75 th percentiles
76 – 90	15%	Mean of 75 th and 90 th percentiles
91 – 95	5%	Mean of 90 th and 95 th percentiles
96 – 100	5%	Geometric mean of 95 th and 100 th percentiles

3.4 Exposed workforce

3.4.1 Introduction

This section first summarises the estimates at the EU-27 level, showing that the different sources provide a range of estimates. Next, a sector breakdown is provided. The last sections provide trends and an overview of exposed workers and exposure concentrations.

3.4.1.1 *Workers with an existing health condition*

There is no group at extra risk (section 2.3) and workers with an existing health condition are not considered further.

3.4.2 Data on exposed workforce from national databases

Data on the numbers of exposed workforce are available from the Canadian CAREX (CAREX, 2021) and the Finnish ASA (FIOH, 2021) without exposure levels and are presented below. The only other national database data that are available are the SIREP data published by (Scarselli et al., 2013). The study team has not received and assessed data from other national databases at this stage.

As explained also previously, there are sectors included in the databases for which this study team could not identify concentrations of BaP that would bring them within scope of the assessment (see exclusion criteria in section 3.2.9), and therefore have not been included.

Based on the European CAREX database, it has been estimated that in 15 countries in Europe in 1990–93 almost 1,000,000 people were exposed to PAH above background levels through their occupations (IARC, 2010). Due to the age of the database, and the changes in exposure in the last 30 years (see sections 3.3.6 and 3.4.4) the data are considered unlikely to be representative of the current landscape in Europe and are not presented.

3.4.2.1 *CAREX Canada data*

CAREX Canada (CAREX, 2021) estimated the number of exposed workers in Canada at 467,000 in 2016, making up 1.3% of the 2016 Canadian population (Statistics Canada, 2023). Of these, 75% of the exposed were men and 25% were women. Based on a population of 446.7 million people in the EU in 2022⁹, the corresponding figure of total exposed workers in the EU would be 5.8 million if a similar per-capita ratio is assumed. The CAREX Canada data lists the five most significant exposure industries as shown below (Table 3-66).

Public administration is mentioned as a significant industry because firefighters belong under public administration in Canada and firefighters are exposed to PAH during smoke diving, training and supervising. However, the use of RPE during firefighting operations is mandatory, and exposure data indicate that firefighters' supervisors may be a relevant exposure group. This assessment is based on one study. Feedback from stakeholders indicate that each Member State (and to some extent it may also be region specific) have different protocols, and that firefighters will be required to wear SCBA in buildings but outdoors this may depend on the wind direction, level of smoke and material which is being consumed by the fire.

The number of workers exposed to PAH increased by approximately 117,000 workers from 2006 to 2016 (a 33% increase). This was driven by an increase in the total number of workers in food services and drinking establishments (CAREX, 2021).

⁹ 2022 taken as this is the latest year for which data are available in Eurostat

Table 3-66 CAREX Canada estimate on numbers of workers exposed to PAH

Industry	No. of exposed workers in Canada	% of total exposed workforce
Full-service restaurants and limited service eating places	166,000	17%
Automotive repair and maintenance	38,000	24%
Gasoline stations	36,000	55%
Local municipalities and regional public administration (incl. fire-fighters)	30,000	8%
Special food services	16,000	21%
Others	181,000	-
TOTAL NUMBER OF WORKERS	467,000	0.01%

Source: (CAREX, 2021)

Notes: The table above presents the top industries with worker exposure, the complete list is available online¹⁰

3.4.2.2 Finnish ASA register

In the Finnish ASA register is based on data between 2010-2019 (FIOH, 2021), the data indicate that about 4,500 workers in Finland were exposed to PAH in 2019, the majority are men (94%). The largest exposed occupations are firefighters, motor vehicle mechanics and repairers, other cleaners not elsewhere classified, agricultural and industrial machinery installers and repairers and building frame and related trades workers not elsewhere classified.

Based on a population of 5.5 million in Finland and 446.7 million people in the EU in 2020, the corresponding figure of exposed workers would be 367,300 in the EU if the same per-capita ratio is assumed.

Table 3-67 Finnish ASA estimate on workers exposed to PAH in 2019

Occupation	TOTAL	% workers exposed
Fire-fighters	717	17.7%
Motor vehicle mechanics and repairers	655	2.8%
Other cleaners not elsewhere classified	320	9.7%
Agricultural and industrial machinery mechanics and repairers	277	1.3%
Building frame and related trades workers not elsewhere classified	227	6.8%
Civil engineering labourers	154	2.9%
Electrical line installers and repairers	151	7.3%
Civil engineers	135	0.9%
Physical and engineering science technicians not elsewhere classified	118	0.9%
Miners and quarriers	107	9.2%

Source: (FIOH, 2021)

Notes: The table above presents the top 10 industries with worker exposure, the complete list is available online¹¹

¹⁰ [PAH - Occupational Exposures - CAREX Canada](#)

¹¹ [Occupational exposure to carcinogenic substances | Work-life knowledge service | www.worklifedata.fi \(tyoelamatiето.fi\)](#)

3.4.2.3 Italian occupational exposure estimates

Scarselli evaluated a total of 12,849 PAH exposure measurements from the Italian carcinogen exposure database SIREP from the period 1996-2010. In the publication, information about the companies (economic activity sector), the worker (demographic data and occupational characteristics) and exposure concentration are reported. The study PAH measured 16-PAH, BaP, benzo[a]anthracene, benzo[b]fluoranthene, benzo[k]fluoranthene, dibenz[a,h]anthracene, benzo[j]fluoranthene, chrysene, benzo[e]pyrene, benzo[g,h,i]perylene, dibenzo[a,h]pyrene, indeno[1,2,3]pyrene, pyrene and fluorene.

Overall, the study identified 295,638 workers exposed to PAH, for all of the above PAH, but it includes sectors that were not assessed in this study as the study team could not find data to indicate the presence of benzo[a]pyrene (for example, collection, purification and distribution of drinking water). Taking into account the sectors assessed in this study, 39,239 workers are estimated as potentially at risk of exposure to PAH in the industries surveyed and reported in the publication. Based on a population of 59.3 million in Italy and 446.7 million people in the EU in 2020, the corresponding figure of exposed workers would be 295,638 in the EU if the same per-capita ratio is assumed.

The sector with the highest number of exposed workers is in the construction of highways, roads airfields and sport facilities (N = 12,200).

The exposure concentrations reported in the study are for total PAH and not specifically for BaP.

The table below lists only the sectors better characterized in the database and for which the current study has conducted an assessment – the list may be modified in future.

Table 3-68 Scarselli 2013 estimate on workers exposed to PAH in Italy in 1996-2010

Sector of economic activity (NACE code)	% of companies	% of worker exposed	No. of workers exposed (male)	No. of workers exposed (female)	No. of workers exposed (total)
Extraction of crude petroleum (11.11.0)	6.1	53.8	250	26	276
Petroleum refinery (23.20.1)	2.1	5.9	2,378	63	2,441
Manufacture of petroleum products (excluding petrochemicals) (23.20.2)	1.9	6.2	1,239	0	1,239
Manufacture of bitumen, tar and binders for road use (23.20.4)	1.8	3.2	770	0	770
Manufacture of dyes and pigments (24.12.0)	0.8	1.2	204	0	204
Manufacture of other organic basic chemicals (24.14.0)	1.5	10.7	743	39	782
Manufacture of electrochemical and electrothermal products (24.66.2)	3.4	10.4	537	22	559
Manufacture of various chemical products for industrial use (24.66.4)	0.5	2.2	2,064	0	2,064

Sector of economic activity (NACE code)	% of companies	% of worker exposed	No. of workers exposed (male)	No. of workers exposed (female)	No. of workers exposed (total)
Manufacture of basic iron and steel and of ferro-alloys (27.10.0)	3.0	40.5	2,027	8	2,035
Aluminium production (27.42.0)	0.6	4.5	1,318	0	1,318
Casting of steel (27.52.0)	2.0	7.3	284	0	284
Recycling of municipal solid waste, industrial and biomass (37.20.2)	0.3	3.2	646	105	751
Construction of highways, roads, airfields and sport facilities (45.23.0)	1.4	5.4	12,200	0	12,200
TOTAL NUMBER OF WORKERS			37,598	1,632	39,230

Source: (Scarselli et al., 2013)

Notes: The table above presents the sectors with worker exposure, currently being assessed in this study.

3.4.3 Average number of exposed workers per company (consultation)

The data in the table below presents the total and average number of exposed workers from the consultation. The percentages have been taken into account in when calculating the total and percentage exposed workers, where relevant.

Table 3-69 Survey result for average number of exposed workers per company

Sector (n)	Number of workers per company exposed to PAH Average (min – max)	Percentage of workers in companies exposed to PAH Average (min – max)
C19.10 Manufacture of coke oven products (6)	330 (230 - 570)	89% (77% - 95%)
C19.20 Manufacture of refined petroleum products (15)	193 (0 - 836)	29% (0% - 74%)
C20.13 Manufacture of other inorganic basic chemicals (6)	43 (19 - 100)	34% (24% - 56%)
C20.14 Manufacture of other organic basic chemicals (7)	162 (49 - 328)	52% (16% - 91%)
C22.19 Manufacture of other rubber products (1)	35 (35 - 35)	*
C24.42 Aluminium production (6)	68 (30 - 133)	39% (5% - 80%)
C24.5 Casting of metals (2)	16 (10 - 21)	6% (0% - 11%)
F42.11 Construction of roads and motorways (7)	291 (4 - 3,000)	59% (4% - 100%)
G45.20 Maintenance and repair of motor vehicles (1)**	150,000 (150,000 - 150,000)	34% (34% - 34%)

Source: Study team on basis of stakeholder responses.

Notes: *Respondent did not provide data.

**Data was provided by a large association. Values represent membership within their Member State.

3.4.4 Exposed workforce by sector

The following section presents the considerations and calculations for the number of exposed workers in the sectors assessed.

3.4.4.1 C10.13 and C10.2 smokehouses

The NACE code C10.13 is for “Production of meat and poultry meat products”. It is anticipated that only a very small percentage is related to smokehouses operating with burning solid fuels, particularly given artificial smoke is predominant (according to consultation) and that meat processing encompasses activities such as cured meats, products such as sausages, boiled hams, pâté to name a few. The study team has assumed that 1% of workers are employed in meat smokehouses resulting in 4,754 workers.

The NACE code C10.2 is “Processing and preserving of fish, crustaceans and molluscs”. Similarly to C10.13 only a small percentage is thought to be related to smokehouses operating with burning solid fuels given that the use of artificial smoke is becoming predominant (according to consultation) and that the NACE code includes preservation of fish (e.g. freezing and canning) and production of fishmeal for human or animal consumption, to name a few. To note, artificial smoke is a liquid that does not contain PAHs. The study team has assumed that 10% of workers are employed in meat smokehouses resulting in 10,841 workers.

Based on information received from industry, workers in a large scale operations are likely to have a small percentage of workers who are exposed thanks to automation and activities other than smoking taking place in a company¹². Whereas in micro or small companies, the proportion of workers exposed is much higher. A total of 15% of workers are estimated to be exposed, for a total of 713 workers in C10.13 in meat smokehouses and 1,616 in C10.2 fish smokehouses.

Table 3-70 Data available for estimating exposed workforce in wood preservation

Number	Description	Comment	Source of number
475,677	C10.13 Production of meat and poultry meat products	Total no. of employed, all enterprises within category	Eurostat
108,209	C10.2 Processing and preserving of fish, crustaceans and molluscs	Total no. of employed, all enterprises within category	Eurostat
713	C10.13, Meat smokehouses exposed workers	Value calculated by the study team based on 1% Eurostat total enterprises, and 15% exposed workers	Study team calculations based on Eurostat and consultation
1,616	C10.2 Fish smokehouses, exposed workers	Value calculated by the study team based on 10% Eurostat total enterprises, and 15% exposed workers	Study team calculations based on Eurostat and consultation

¹² According to a publication (seafish, 2023), the number of sites conducting primary processing such as cutting and filleting in the UK was 67, while the number of sites doing secondary processing for secondary processing such as brining and smoking was 44, while the number of sites doing both was 240 in 2022

3.4.4.2 C16.1 Wood preservation (creosote)

The NACE C16.1 “Sawmilling and planing of wood” contains activities such as sawing, planing, machining and manufacture of wood chips amongst many others that are not relevant to wood preservation. The total number of workers for the NACE code is 227,000.

The majority of wood impregnation uses water-borne copper salts (71%), followed by solvent-based solutions (18%) and the use of creosote constitutes only 11% of impregnation activities (Algol Chemicals, 2021).

Stakeholder consultation indicates that there are approximately 40 companies in total in Europe with an average of 25 employees who are exposed to creosote. This results in a total of 1000 workers who are exposed to PAH via creosote impregnation of wood.

Table 3-71 Data available for estimating exposed workforce in wood preservation

Number	Description	Comment	Source of number
227,000	C16.1 Sawmilling and planing of wood	Total no. of employed, all enterprises within category	Eurostat
6	Wood treaters, exposed in Finland in 2019	EU27 (per capita estimate): 500	ASA database
1,072	Sawmills and wood preservation, number of exposed workers in Canada	EU27 (per capita estimate): 13,000	CAREX Canada
1,000	Based on 40 companies with 25 employees per company	Value used by the study team	Consultation (stakeholder personal communication)

3.4.4.3 C19.1 Coking plants

All activities under NACE code 19.1 “manufacture of coke oven products” are relevant to the manufacture and operation of coke ovens covered in this study. According to Eurostat there are a total of 55 companies and 2133 employees, the study team considers the figures to be representative.

The consultation indicates there are 2,275 workers including 30% of which are contractors. The figure from the consultation alone is higher than the total in Eurostat for the entire NACE code. This may be due to the inclusion of contractors, who will be exposed to PAH, as well as the fact that coking is integrated with steel plants and companies may identify under NACE C24.1 instead of C19.1. Interviews with industry confirmed it is a normal practice to have contractors in the coking sector.

The consultation indicates that 87% workers are exposed, therefore the study team assumes 90% of workers are exposed, and that in addition, companies have approximately 30% workers who are contractors and are exposed. A total of 2,795 workers are calculated, of which 90% are exposed.

Table 3-72 Data available for estimating exposed workforce in manufacture and operation of coke ovens

Number	Description	Comment	Source of number
2,133	C19.10 Manufacture and operation of coke oven products	Total no. of employed, all enterprises within category	Eurostat

Number	Description	Comment	Source of number
1,977	C19.10 Manufacture and operation of coke oven products	Based on the consultation 2,275 workers, including contractors, and 87% of exposed are workers	Consultation
2,516	Coking plants	Based on total employees in Eurostat + 30% contractors (2,795), and 90% workers exposed	Study team calculation, Eurostat and consultation

3.4.4.4 C19.2 Petroleum refineries

The NACE C19.2 “Manufacture of refined petroleum products” covers the manufacture of products from crude petroleum, bituminous minerals and their fractionation products. However, the Eurostat data may not be representative as some refineries have record activities under NACE C20.14 (based on the consultation). In addition, this sector includes further downstream, small refineries that manufacture petrochemicals and for which there are no data on exposure to BaP (there are data on exposure to more volatile PAH like naphthalene, as well exposure to benzene), which are out of scope.

The number of companies has been calculated based on Concawe membership data (see section 3.10.2), and the number of workers has been assigned based on the Eurostat number of workers per company.

Based on the number of companies and using the average number of workers per company in Eurostat a total of 57,941 workers are estimated.

According to the consultation approximately 25% of workers are exposed during petroleum refining operations, therefore the study team estimates that approximately 14,485 workers are exposed.

Table 3-73 Data available for estimating exposed workforce in petroleum refineries.

Number	Description	Comment	Source of number
164,143	C19.2 petroleum refineries	Total no. of employed, all enterprises within category	Eurostat
2,245	Refinery operations	Based on 8,924 workers with 25% exposed workers	Consultation
2,441	Petroleum Refineries, exposed workers in Italy	EU27 (per capita estimate): 18,400	SIREP (Scarselli, Di et al., 2013)
14,485	C19.2 petroleum refineries	Based on calculations by the study team of a total of 57,941 workers, and 25% workers are exposed	Study team based on Eurostat and consultation

3.4.4.5 C20.13 Manufacture of carbon black

The NACE code for the manufacture of carbon black is C20.13 “manufacture of other inorganic basic chemicals”, which includes the manufacture of chemicals using basic processes and thus covers a wide range of chemicals in addition to carbon black. The entire NACE has a total of 62,152 workers.

Stakeholders have indicated that Large and Medium companies only manufacture carbon black. A Large company in the consultation has approximately 400 workers and a Medium company has

approximately 70 workers, and these are taken as average values. Based on these data and the number of companies (see section 3.10.2), a total of 3,400 workers for the manufacture of carbon black have been calculated by the study team.

SIREP database indicates that based on a EU27 per-capita estimate there are a total of 1,500 workers exposed in the manufacture of dyes and pigments. The sector is thought to be applicable to carbon black as it is widely used as a pigment but will include other activities that are not relevant.

The consultation indicates there are 870 workers with 30% workers exposed. The percentage is applied to the calculated total number of workers resulting in 1,020 exposed workers.

Table 3-74 Data available for estimating exposed workforce in the manufacture of carbon black.

Number	Description	Comment	Source of number
62,152	C20.13 Manufacture of other inorganic basic chemicals	Total no. of employed, all enterprises within category	Eurostat
258	Carbon black manufacturing	Total of 870 workers reported in the consultation, with 30% workers exposed	Consultation
204	Manufacture of dyes and pigments*, exposed workers in Italy	EU27 (per capita estimate): 1,500	SIREP (Scarselli Di et al., 2013)
121	Manufacture of basic chemicals, exposed workers in Canada	EU27 (per capita estimate): 1,500	CAREX Canada
1,020	C20.13 Manufacture of carbon black	Based on calculations by the study team of a total of 3,400 workers, and 30% workers are exposed	Study team calculations

Notes: * the manufacture of dyes and pigments has been used as a source for manufacture of carbon black as one of the main uses of carbon black is to manufacture pigments.

3.4.4.6 C20.14 Coal tar distillation

Eurostat code C20.14 is the "manufacture of other organic basic chemicals", therefore the scope is wider than that of this study, and indicates a total of 208,149 workers.

The Coal Sector Group (personal communication) indicates that approximately 2000-2500 people work in coal tar distillation, 7 companies are involved and they are all Large companies. The study team has taken the maximum number of employees as a worst-case scenario.

The consultation indicates there are 870 workers with 24% workers exposed. In total four organisations provided a response to the consultation.

Based on approximately 30% workers being exposed out of 2,500 workers, the study team has calculated that 750 workers are exposed.

Table 3-75 Data available for estimating exposed workforce in coal tar distillation.

Number	Description	Comment	Source of number
208,149	C20.14 Manufacture of other organic basic chemicals	Total no. of employed, all enterprises within category	Eurostat

Number	Description	Comment	Source of number
782	Manufacture of other organic basic chemicals, exposed workers in Italy	EU27 (per capita estimate): 5,900	SIREP (Scarselli et al., 2013)
750	C20.14 Coal tar distillation	Based on the consultation: approx. 2500 workers, and 30% workers exposed	Study team based on consultation
354	Coal tar distillation	1483 workers and 24% workers exposed	Consultation

3.4.4.7 C23.2 Manufacture of refractory products

Based on information received during the interviews with stakeholders, there are less than five companies left in Europe that use CTPht for the manufacture of refractory products, which is <1% of the NACE code total number of companies. No data are available on the use of modified pitch, a replacement for CTPht which results in lower levels of exposure.

The Eurostat SME split and the relative number of workers is applied to 5 companies, which results in 171 workers.

No other information is available and it is estimated that 50% of total calculated workers are exposed. No additional information on the number of workers is available.

Table 3-76 Data available for estimating exposed workforce in the manufacture of refractory products

Number	Description	Comment	Source of number
23,960	C23.2 Manufacture of refractory products	Total no. of employed, all enterprises within category	Eurostat
110	Clay product and refractory manufacturing workers exposed in Canada	EU27 (per capita estimate): 1,350	CAREX Canada
86	C23.20 Manufacture of refractory products	Study team calculations based on consultation (5 companies), SME and worker split in Eurostat and estimating 50% workers exposed	Study team calculations, Consultation and Eurostat

3.4.4.8 C23.99a Manufacture of bituminous products

Eurostat indicates there are 2,360 companies under the NACE code C23.99 "manufacture of other non-metallic mineral products n.e.c." and 62,714 workers. This sector includes manufacture of articles with mineral substances as well as insulating materials, such as mineral wool (the largest insulating material in Europe).

The total number of workers has been calculated by the study team to be 32,000 based on 50% of the NACE code being relevant.

Based on the SIREP database (Scarselli et al., 2013), the equivalent EU27 per capita estimate of exposed workers is 5,800. The study team believes this value to be representative and corresponds to approximately 18% of the total workforce potentially exposed.

Table 3-77 Data available for estimating exposed workforce in the manufacture of bituminous products

Number	Description	Comment	Source of number
62,714	C23.99 Manufacture of other non-metallic mineral products n.e.c.	Total no. of employed, all enterprises within category	Eurostat
5,800	Manufacture of bituminous products	Based on study team total calculations and SIREP per capita basis	Study team
770	Manufacture of bitumen, tar and binders for road use, workers exposed in Italy	EU27 (per capita estimate): 5,803	SIREP (Scarselli et al. 2013)

3.4.4.9 C23.99b Graphite and carbon electrodes production

Consultation with the representative industry association, ECGA, indicates there are 10,000 workers, of which 800 have the potential to be exposed to PAH. In this sector there is also common use of contractors, approximately 25% of additional exposed workers. Totalling 1001 workers

The association represents all the manufacturers of carbon and graphite electrodes and pastes. Additional companies manufacturing speciality graphite products are present in Europe. According to ECGA, they do not manufacture synthetic graphite and work with either natural graphite or with synthetic graphite made by the workers covered by ECGA. Therefore no additional workers with exposure to PAH are expected in this sector.

Table 3-78 Data available for estimating exposed workforce in the manufacture of graphite and carbon electrodes

Number	Description	Comment	Source of number
62,714	C23.99 Manufacture of other non-metallic mineral products n.e.c.	Total no. of employed, all enterprises within category	Eurostat
1,001	Manufacture of carbon and graphite electrodes	Based on 800 exposed workers according to ECGA + 25% contractors	Consultation (ECGA)
559	Manufacture of electrochemical and electrothermal products, exposed workers in Italy	EU27 (per capita estimate): 4,213	SIREP (Scarselli et al., 2013)

3.4.4.10C24.1 Steel and iron foundries, ferroalloys

Eurostat NACE C24.1 "manufacture of basic iron and steel and of ferro-alloys" indicates that the sector has 319,174 workers.

The steel industry association EUROFER, indicates that the steel sector employs 310,000 people in Europe (EUROFER, 2023). Therefore the total number of workers in Eurostat seems to be relevant.

The equivalent EU27 per capita estimate of exposed workers based on CAREX and SIREP is 6,900-18,500.

No information is currently available on the number of workers exposed, and the study team has assumed that approximately 30% of workers from the NACE code (based on past experience with the sector) are exposed to PAH with BaP as indicator for PAH mixtures. A total of 95,752 workers are estimated to be exposed.

Table 3-79 Data available for estimating exposed workforce in steel and iron foundries

Number	Description	Comment	Source of number
319,174	C24.1 Steel and iron foundries	Total no. of employed, all enterprises within category	Eurostat
310,000	Steel sector	Total steel sector employees	EUROFER
95,752	C24.1 Steel and iron foundries	30% of Eurostat figures	Study team, based on Eurostat and expert knowledge
2,789	Iron and steel mills and ferro-alloy manufacturing, workers exposed in Canada	EU27 (per capita estimate): 18,500	CAREX Canada
2,035	Manufacture of basic iron and steel and of ferro-alloys, workers exposed in Italy	EU27 (per capita estimate): 15,336	SIREP (Scarselli et al. 2013)

3.4.4.11 C24.45 Other non-ferrous metallurgical processes

Eurostat NACE C24.45 "other non-ferrous metal production" indicates that the sector has 15,748 workers.

The steel industry association EUROFER, indicates that the steel sector employs 310,000 people in Europe (EUROFER, 2023). Therefore the total number of workers in Eurostat seems to be relevant.

The equivalent EU27 per capita estimate of exposed workers based on CAREX is 1,530.

Based on the number of companies estimated in section 3.10, the resulting number of workers using the Eurostat number of employees per company, there are approximately 2,410 workers. No information is currently available on the number of workers exposed, and the study team has assumed that approximately 20-30% of workers from the NACE code (average for C24 sector based on expert judgement) are exposed to PAH with BaP as indicator for PAH mixtures. A total of 616 workers are estimated to be exposed.

Table 3-80 Data available for estimating exposed workforce in steel and iron foundries

Number	Description	Comment	Source of number
15,748	C24.45 Other non-ferrous metal production	Total no. of employed, all enterprises within category	Eurostat
616	C24.45 Other non-ferrous metallurgy	30% of Eurostat distribution based on number of companies,	Study team, based on Eurostat and expert knowledge
124	Non-ferrous metal (except aluminum) production and processing, workers exposed in Canada	EU27 (per capita estimate): 1,530	CAREX Canada

3.4.4.12 C24.42 Manufacture of aluminium

According to relevant stakeholders, there are only nine companies now operating in EU27 countries after a series of recent closures and announcements. The figure takes into account operations that are currently mothballed but will resume operations in future.

The consultation indicates that medium enterprises have an average of 75 workers approximately, while large companies have 460 workers.

Assuming there are a majority of large companies (based on consultation) the study team has calculated a total of 2,985 workers.

The consultation indicates that approximately 20% workers are exposed, which when applied to the total number of workers calculated by the study team (2,985) results in 597 exposed workers.

The Canadian CAREX and SIREP database indicate a larger number of exposed workers EU27 per capita estimate, however the closures in the last two decades are likely to explain this discrepancy.

Table 3-81 Data available for estimating exposed workforce in aluminium manufacturing

Number	Description	Comment	Source of number
114,060	C24.42 Aluminium production	Total no. of employed, all enterprises within category	Eurostat, 2023
4,556	Alumina and aluminium production processing, exposed workers in Canada	EU per capita basis: 56,200	Canadian CAREX
1,318	Aluminium production, exposed workers in Italy	EU27 (per capita estimate): 9,932	SIREP (Scarselli et al., 2013)
597	C24.42 Manufacture of aluminium	Based on calculations by the study team of a total of 2,985 workers, and 20% workers are exposed according to the consultation	Study team calculation based on consultation
285	C24.42 Aluminium production	1,929 total workers and 21% exposed	Consultation

3.4.4.13C24.5 Casting of metals

The entire NACE C24.5 "casting of metals" (based on current understanding) is relevant, therefore all of the employees recorded in Eurostat are taken forward, which is 204,348 employees.

According to the European Foundry Association (CAEF) there are a total of 260,000 workers in Europe (CAEF, 2023). While the equivalent EU27 per capita estimate of exposed workers based on CAREX foundry workers in Canada is 6,900, and the equivalent estimate based on SIREP casting of steel exposed workers in Italy is 2,150.

The benzene OEL impact assessment indicates that, based on consultation, approximately a third of foundry workers are exposed, which applied to the NACE total results in 68,109 exposed workers.

Table 3-82 Data available for estimating exposed workforce during metal casting operations

Number	Description	Comment	Source of number
260,000	Number of people employed by the European foundry industry	Total no. employed	CAEF, 2023

Number	Description	Comment	Source of number
204,348	C24.5 Casting of metals	Total no. of employed, all enterprises within category	Eurostat, 2023
68,109	Potentially exposed workers in foundries	Eurostat total employed and Benzene consultation-based estimate (1/3 exposed)	Study team calculations, Eurostat, benzene OEL
558	Foundry, workers exposed in Canada	EU27 (per capita estimate): 6,900	Canadian CAREX
284	Casting of steel, exposed workers in Italy	EU27 (per capita estimate): 2,150	SIREP (Scarselli Di et al., 2013)
31	Casting	3,186 total workers and 1% exposed	Consultation
15	Metal moulders and coremakers, workers exposed in Finland (1.4% workers exposed)	EU27 (per capita estimate): 1,200	ASA database

3.4.4.14D35.11 Coal fired power plants

NACE D35.11 is the “production of electricity”, including thermal, nuclear, hydroelectric, gas, turbine, diesel and renewables with a total of 637,085 employees.

In Europe there are 196 companies that use coal as a fuel (see section 3.10.2). In the past decade more than half of Europe’s power plants have shut down or have announced closures and while some are re-opening due to current energy crisis, in the long-term the trend is thought to endure (Le Monde, 2022). According to a study published in 2018 there were a total of 53,000 workers were employed in coal power plants in the EU and it expects that direct job losses in power plant operation due to coal fired power plant decommissioning could reach around 34,000 jobs by 2035, that is 64% of the estimated current employment in this activity (JRC, 2018). According to the same report, approximately half of those jobs may be lost in the early 2020's. The study team has calculated that this results in approximately 36,000 estimated total workers. The study team has assumed that 50% workers will be exposed for a total of 18,000 workers.

The equivalent EU27 per capita estimate of exposed workers based on CAREX and ASA is between 5,500 and 10,300. Employment in the coal sector varies between regions and countries. Numbers of workers in coal power plants varies from about 100 in Sweden to around 13,500 in Poland. The regions with the highest number of direct jobs in the coal sector (mines and power plants) are located in Bulgaria, Czech Republic, Germany, Greece, Poland and Romania (JRC, 2018). For these reasons, the per capita estimate based on ASA may not be representative.

Table 3-83 Data available for estimating exposed workforce in coal fired power plants

Number	Description	Comment	Source of number
637,085	D35.11 Production of electricity	Total no. of employed, all enterprises within category	Eurostat, 2023
18,001	D35.11 coal fired power plant	Study team calculations based on research and consultation	Study team calculations
837	Electric power generation, transmission and distribution, workers exposed in Canada	EU27 (per capita estimate): 10,300	CAREX Canada

Number	Description	Comment	Source of number
68	Power production plant operators, workers exposed in Finland	EU27 (per capita estimate): 5,500	ASA database

3.4.4.15E38.2 Waste incineration

According to the Eurostat (The Structural Business Statistics database) there are a total of 650 companies that dispose of waste by incineration. Based on the Eurostat number of workers per company this results in 18,882 workers.

The equivalent EU27 per capita estimate of exposed workers based on CAREX and SIREP is between 1,300 and 10,500.

No additional information on the number of worker per companies is available.

Consultation with occupational hygienist (Hans Kromhout personal communication) indicates that very low exposure is expected in this sector due to existing abatement systems and control measures. On this basis, the study team, has estimated that 10% workers will be exposed which results in 1,888 workers.

Table 3-84 Data available for estimating exposed workforce in incineration of waste

Number	Description	Comment	Source of number
18,882	E38.2 Waste incineration	Total number of workers	Eurostat
1,888	Waste incineration	Eurostat total employed and 10% worker exposed	Study team calculations, Eurostat and consultation
850	Waste treatment and disposal, workers exposed in Canada	EU27 (per capita estimate): 10,500	Canadian CAREX
751	Recycling of municipal solid-waste, industrial and biomass (3.2% exposed workers for the sector)	EU27 (per capita estimate): 1,300	SIREP (Scarselli et al. 2013)

3.4.4.16E39.0 Soil remediation

According to the Eurostat, under NACE 39.0 "Remediation activities and other waste management services" there are a total of 36,087 workers and the majority of the NACE seems relevant. As it is a practical work, the study team has assumed that 35% of employees are exposed, for a total of 10,550 exposed workers.

The equivalent EU27 per capita estimate of exposed workers based on CAREX is between 9,179.

No additional information on the number of worker per companies is available.

Table 3-85 Data available for estimating exposed workforce in soil remediation

Number	Description	Comment	Source of number
30,144	E38.2 Remediation activities and other waste management services	Total number of workers	Eurostat

Number	Description	Comment	Source of number
10,550	Waste incineration	Eurostat total employed and 35% worker exposed	Study team calculations, Eurostat and consultation
744	Remediation and other waste management services, workers exposed in Canada	EU27 (per capita estimate): 9,179	Canadian CAREX

3.4.4.17 F42.11 Road paving

NACE F42.11 "Construction of roads and motorways" has a total of 715,157 workers and includes constructions of roads as well as surface dressing of roads, bridges and tunnels as well as airfield runways. A few activities are not relevant to road paving, for example instillation of crash barriers and traffic signs. The study team has assumed that 85% of companies are relevant, resulting in 607,877 workers.

In the consultation Large companies reported having more than 1000 employees. A total of 1,770 workers with between 4% to 100% workers exposed (36% on average when all figures are taken together) were reported.

The study team has estimated that 35% of the calculated workers are exposed for a total of 212,757 exposed workers.

Table 3-86 Data available for estimating exposed workforce in road paving

Number	Description	Comment	Source of number
715,157	F42.11 Construction of roads and motorways	Total no. of employed, all enterprises within category	Eurostat
212,757	Road paving	Eurostat total employed and SME % worker exposed according to the consultation	Study team calculations, Eurostat and consultation
12,200	Construction of highways, roads, airfields and sport facilities, workers exposed in Italy	EU27 (per capita estimate): 91,939	SIREP (Scarselli Di et al., 2013)
2,206	Road construction, workers exposed in Canada	EU27 (per capita estimate): 26,350	Canadian CAREX
1,770	Road construction	4,941 total workers and 36% exposed on average	Consultation
154	Civil engineering labourers (2.9% exposed), workers exposed in Finland	EU27 (per capita estimate): 12,400	ASA database

3.4.4.18 F42.12 Welding of railway sleepers

NACE F42.11 "Construction of railways and underground railways" has a total of 64,376 workers and includes constructions of subways as well as installation of lighting and electrical signals, project management for constructions.

Feedback has been received from industry in several Member States indicates that there are +200 train track welders per Member State, in one case 1,200. Based on this, the study team has estimated that 10% of the workers in the NACE code are exposed for a total of 6,438 exposed workers.

Table 3-87 Data available for estimating exposed workforce in welding of train tracks

Number	Description	Comment	Source of number
64,376	F42.12 Construction of railways and underground railways	Total no. of employed, all enterprises within category	Eurostat
6,438	Welding of train tracks	10% Eurostat total employed	Study team calculations, Eurostat and consultation

3.4.4.19G45.2 Motor vehicle maintenance and repairs

Eurostat estimates there are 1,365,931 workers under NACE G45.2 "Maintenance and repair of motor vehicles". Based on stakeholder consultation, approximately 80% of the NACE code is relevant, which results in 1,092,742 workers. The consultation indicated that there are a total of 435,000 workers with 150,000 workers exposed (34%).

The equivalent EU27 per capita estimate of exposed workers based on the Finnish ASA and the Canadian CAREX is between 53,000 and 473,000.

The study team has calculated 371,532 workers exposed, based on the total number of employees in Eurostat and approximately 34% workers exposed based on the consultation.

Table 3-88 Data available for estimating exposed workforce in motor vehicle maintenance and repair

Number	Description	Comment	Source of number
1,365,931	G452 - Maintenance and repair of motor vehicles	Total no. of employed, all enterprises within category	Eurostat
371,532	Maintenance and repair of motor vehicles	Based on Eurostat total employees and consultation % exposed workers	Study team calculations
150,000	Mechanics and related workers	From a national industry association, from a total of 435,000 workers	Consultation
38,336	Automotive repair and maintenance, number of exposed workers in Canada	EU27 (per capita estimate): 473,000	CAREX Canada
655	Motor vehicle mechanics and repairers. Exposed in Finland, 2014	EU27 (per capita estimate): 52,700	ASA database

3.4.4.20N81.22 Chimney sweeps

The NACE code N81.22 "Other building and industrial cleaning activities" includes several activities that are not related to chimney sweeping.

Data from industry (ESCHFOE, 2021) reported a total of 7983 chimney sweeping companies in Germany employing 8708 sweeps, and 383 enterprises employing 700 sweeps in Finland.

The ratio of employee per company in Finland is 2.1. This ratio has been applied to the calculated number of enterprises (see section 3.10.2). A total of 32,667 workers have been calculated in this manner.

The equivalent EU27 per capita estimate of exposed workers based on the Finnish ASA is 25,800.

Sweeps do approximately 50% black sweep and 50% white sweep work. Assuming that in some cases one of the two employees specialises in one or the other, a maximum of 75% of total workers are estimated to be exposed for a total of 24,500 exposed sweeps – which is close to the ASA EU per capita estimate.

Table 3-89 Data available for estimating exposed workforce in motor vehicle maintenance and repair

Number	Description	Comment	Source of number
361,120	N81.22 Other building and industrial cleaning activities	Total no. of employed, all enterprises within category	Eurostat
32,667	Total number of sweeps	Calculated by the study team based on 2.1 workers per company, plus Germany figures	Study team calculation based on eschfoe
24,500	Exposed number of sweeps	Based on 75% of study team calculations	Study team calculation based on eschfoe and Hogstedt, 2013
320	Other cleaners not elsewhere classified, workers exposed in Finland	EU27 (per capita estimate): 25,800	ASA database

3.4.4.21 084.25 Firefighters

The NACE code 084.25 “Fire service activities” includes several activities where exposure to fire fumes may not take place, such as fire prevention. The total number of workers in the sector is not reported for this NACE code. Based on information provided in Eurostat the study team estimates there are approximately 365,100 people employed as professional firefighters in the EU and 4,385,061 including volunteers.

The exposure data indicates that team leaders are the ones most at risk of airborne exposure to PAH, with BaP as a marker (see section 3.3.4.21). Assuming 10% of workers are team leaders, a total of 438,506 firefighters are exposed to airborne PAH with BaP as marker.

All firefighters have the potential to have significant dermal exposure, since as noted in section 3.2.10.1 and 3.3.4.21 PAH have been found also in office areas. Therefore 100% of the workforce and volunteers are considered for dermal exposure, i.e. 4,385,061 firefighters.

Table 3-90 Data available for estimating exposed workforce in firefighters

Number	Description	Comment	Source of number
4,385,061	Exposed number of firefighters, dermal	Based on study team calculations as 100% of professional and volunteer firefighters	Study team calculation based on Eurostat and literature
438,506	Exposed number of firefighters, airborne	Based on study team calculations as 10% of professional and volunteer firefighters	Study team calculation based on

Number	Description	Comment	Source of number
			Eurostat and literature
30,354	Local, municipal and regional public administration, exposed in Canada	EU27 (per capita estimate): 374,500	Canadian CAREX
717	Firefighters, exposed in Finland	EU27 (per capita estimate): 57,732	ASA database
4,385,061	Firefighters	Total no. of employed firefighters	Eurostat

3.4.5 Trends in exposed workers

Generally speaking, the number of exposed workers has decreased in the last 40 years thanks to technological advances and changes in the use of coal and petroleum based products. However, the study team does not have access to data that supports presenting a past trend value.

The EUROSTAT data is not sufficiently granular to be applied to the sectors under consideration and it in some cases only goes back a few years. Therefore, trends are not presented.

Below are some considerations on specific sectors, where information is available.

- C19.10 coking: Both the production of metallurgical coke as well as the purification of raw coke oven gas is nowadays executed in a largely automated manner in the European coking plants. As such, in recent years, the number of coke oven workers is said to have been drastically reduced (DGUV, 2022).
- In metallurgical operations (C24.1 steel and iron, C24.42 aluminium, C24.45) several plants have either mothballed or suspended or shut down operations due to high energy prices since 2022, resulting in lower numbers of exposed workers. This has led to job losses. The steel industry has also suffered from unfairly traded imports, and the 2008 economic crisis that had led around 90,000 direct jobs losses (EESC, 2016).

3.4.6 Summary of exposed workforce

A summary of the data on exposed workforce is included in the following tables. Extrapolating the total number of exposed workers from databases in Italy and Canada would give higher values, but this may be due to the fact that this study is focussing on BaP as an indicator of PAH exposure.

Table 3-91 Estimated number of workers in the EU27 exposed to PAH in key sectors

Sector		Number of exposed workers	Total number of workers in NACE code	% of all workers in NACE code	Workers with <u>air-borne</u> exposure, by NACE code, as % of total <u>airborne</u> exposed workers (3)	Workers with <u>dermal</u> exposure, by NACE code, as % of total <u>dermally</u> exposed workers (3)
C10.13	Meat and poultry smoke-houses	713	475,677	0.10%	0.1%	0.01%
C10.2	Seafood smokehouses	1,626	108,209	2%	0.1%	0.03%
C16.1	Wood preservation (creosote)	1,000	227,000	0.40%	0.1%	0.02%
C19.1	Coking plants	2,516	2,133	118% (1)	0.2%	0.05%
C19.2	Petroleum refineries	20,266	164,143	12%	1.6%	0.4%
C20.13	Manufacture of carbon black	1,020	62,152	2%	0.1%	0.02%
C20.14	Coal tar distillation	750	208,149	0.40%	0.1%	0.01%
C23.2	Manufacture of refractory products	86	23,960	0.40%	0.01%	0.002%
C23.99a	Manufacture of bituminous products	5,800	62,714	9%	0.5%	0.1%
C23.99b	Graphite and carbon electrode manufacture	1,001	62,714	2%	0.1%	0.02%
C24.1	Steel and iron foundries, ferroalloys	95,752	319,174	30%	7.5%	1.8%
C24.42	Manufacture of aluminium	626	114,060	1%	0.05%	0.01%
C24.45	Other non-ferrous metallurgy	616	15,748	4%	0.05%	0.01%
C24.5	Casting of metals	68,109	204,348	33%	5.3%	1.3%
D35.11	Coal fired power plants	18,001	637,085	3%	1.4%	0.3%
E38.2	Waste incineration	1,888	224,492	1%	0.1%	0.04%
E39	Soil remediation	10,550	36,087	29%	0.8%	0.2%

Sector		Number of exposed workers	Total number of workers in NACE code	% of all workers in NACE code	Workers with <u>air-borne</u> exposure, by NACE code, as % of total <u>airborne</u> exposed workers (3)	Workers with <u>dermal</u> exposure, by NACE code, as % of total <u>dermally</u> exposed workers (3)
F42.11	Road paving	212,757	715,157	30%	16.6%	4.1%
F42.12	Welding of rail-road tracks	6,437	81,999	8%	0.5%	0.1%
G45.2	Motor vehicle maintenance and repairs	371,532	1,365,931	27%	28.9%	7.1%
N81.22	Chimney sweeps	24,500	361,120	7%	1.9%	0.5%
O84.25	Firefighters (professional) (2)	36,500	365,000	10%	2.8%	7.0%
O84.25	Firefighters (voluntary) (2)	402,006	4,020,060	10%	31.3%	76.9%
Total		1,284,052	9,857,112	21.14%	100%	100%

Source: Study team based on information presented in this section.

Notes:

(1) The percentage of workers for C19.1 Coking plants is higher than 100% of the number of workers in Eurostat due to the prevalence of external contractors in this sector that are not captured in Eurostat data.

(2) The number of firefighters is split into professional firefighters and volunteers. The figures in the table for exposed workers (36,500 + 402,006 = 438,506) relate to airborne exposure only: only firefighter team leaders are assumed to be at risk of airborne exposure, and they are assumed to be 10% of all firefighters. All firefighters are at risk of dermal exposure, resulting in (365,000 + 4,020,060) 4,385,060 firefighters.

(3) The total number of workers with the potential to be exposed to airborne PAH is 1,284,052. The total number of workers at risk of dermal exposure to PAH is 5,230,606 (1,284,052 - 438,506 + 4,385,060).

The total number of workers with the potential to be exposed to airborne PAH with BaP as an indicator is 1,284,052. While the total number of workers with the potential to be exposed dermally to PAH with BaP as an indicator is 5,230,606. The difference is due to the fact that only firefighter team leaders are thought to be potentially exposed to airborne PAH with BaP as an indicator (i.e. 10% of firefighters, equivalent to 438,506), while all firefighters have the potential to be exposed dermally to BaP (i.e. 100%, equivalent to 4,385,060). Studies suggest that the main route of exposure to firefighters is via the dermal route and the main risk stems from remaining in their PPE after attending a fire incident (Stec et al., 2018; Wolffe et al., 2022; Stakeholder consultation, 2023).

It is worth noting that the total number of workers in this study is much lower than the previous study establishing the impact of introducing an OEL by IOM (IOM, 2011). The figures in the IOM study refer to the year 2006 and estimate that there were approximately 234,000 workers in the EU that were potentially exposed to high levels of BaP and 7 million to low levels of BaP. The study team thinks that this a reflection of the factors listed in the previous section on trends and the ones listed below:

- Coal tar pitch high temperature (CTPht) has been on the REACH Authorisation list since 2017 with a sunset date of 2020. Only the applications that applied for a REACH Authorisation would have carried on. For example, refractory products used to widely be made with coal tar pitch, but is now limited to only one specific use (slide gate in steel industry). Coating of pipes with coal tar pitch is no longer applicable. The Authorisation of CTPht for use in clay pigeon shooting targets was rejected in 2022 and the use is not considered in the assessment. Only seven plants remain in EU Member States that distil coal tar into coal tar pitch and other chemicals;
- The REACH Restriction on PAH reduced the amount of PAH in rubber and tyres and exposure in tyre manufacturing facilities;
- Creosote used to be widely used as method for preserving wood, but is now only possible for impregnation of railway sleepers and telegraph poles in a number of MS. For more details see 3.2.10.2;
- Roofing: the data available to the study team indicates that workers exposed to bitumen fumes used in roofing are exposed to BaP airborne concentrations below the lowest policy option;
- Mining: similar to roofing, the available data indicates that workers are exposed via DEEE and that the BaP airborne concentrations are below the lowest policy option;
- Aluminium: the sector used to employ Soderberg anodes, which led to very high exposure concentration levels. There are no Soderberg plants in EU27 Member States as they have been completely replaced with pre-bake anodes in the last five years. In addition, there have been a series of closures in the last two years due to high energy prices; and
- Firefighters: workers wear SCBA with an independent supply of oxygen, therefore these workers are not considered to be exposed to airborne BaP, but they are exposed to PAH dermally.

In general, the study focuses on BaP as a marker for PAH, but there are studies where exposure to PAH other than BaP is likely but have not been considered in this study, for example in distribution of gasoline.

The sectors C19.1 coking, C20.14 coal tar distillation and C23.99b graphite and carbon electrode manufacturers have a relatively small total combined number of workers (17,795 with 4,267 exposed workers), but enable the metallurgical sectors to exist (C24.1, C24.42, C24.45 and C24.5) and the impregnation of wood with creosote (C16.1) that combined have a total of 527,187 workers (165,477 exposed).

Table 3-92 Estimated number of workers in the EU27 exposed to PAH and companies with exposed workers in key sectors

Sector		Number of exposed workers	Number of companies with ex- posed workers	Total num- ber of workers in companies	Number exposed per com- pany	Percentage exposed in companies
C10.13	Meat and poultry smoke-houses	713	210	4,753	3	15%
C10.2	Seafood smoke-houses	1,626	330	10,841	5	15%
C16.1	Wood preservation (creosote)	1,000	40	1,200	25	83%
C19.1	Coking plants	2,516	55	2,795	46	90%
C19.2	Petroleum refineries	20,266	81	57,941	179	25%
C20.13	Manufacture of carbon black	1,020	25	3,400	41	30%
C20.14	Coal tar distillation	750	7	2,500	107	30%
C23.2	Manufacture of refractory products	86	5	171	17	50%
C23.99a	Manufacture of bituminous products	5,800	1,180	31,994	5	18%
C23.99b	Graphite and carbon electrode manufacture	1,001	22	12,500	46	8%
C24.1	Steel and iron foundries, ferroalloys	95,752	2,769	319,174	35	30%
C24.42	Manufacture of aluminium	626	9	2,985	70	21%
C24.45	Other non-ferrous metallurgy	616	80	2,465	8	25%
C24.5	Casting of metals	68,109	4,742	204,348	14	33%
D35.11	Coal fired power plants	18,001	196	36,000	92	50%
E38.2	Waste incineration	1,888	650	18,882	3	10%
E39	Soil remediation	10,550	3,378	30,144	3	35%
F42.11	Road paving	212,757	30,949	607,877	7	35%
F42.12	Welding of railway sleepers	6,437	2,016	64,376	3	10%
G45.2	Motor vehicles maintenance and repairs	371,532	374,183	1,092,742	1	34%

Sector		Number of exposed workers	Number of companies with exposed workers	Total number of workers in companies	Number exposed per company	Percentage exposed in companies
N81.22	Chimney sweeps	24,500	19,381	32,667	1	75%
O84.25	Firefighters	438,506/ 4,385,060	758	4,385,060	579/5785	10/100%
Total		1,284,052/ 5,230,606	441,066	6,947,938	2.9	21%/ 88%

Source: Study team based on information presented in this section.

Note: The number of firefighters refers to professional and volunteer firefighters, of which 10% are calculated to be most at risk of airborne exposure to PAH with BaP as an indicator of exposure.

The information available in the public domain (see e.g. the information provided by Scarselli et al., 2013 in section 3.4.2.3 which reports that over 90% of workers are male) indicate that the NACE code split of male and female employees according to Eurostat may not be applicable to the specific sectors under review. Therefore the study team has sought feedback from industry and revised the figures. The male and female split of workers is presented in the table below.

Table 3-93 Estimated split work male and female employees according to Eurostat and consultation

Sector		Total number of exposed workers	Percentage	
			Male	Female
C10.13	Meat and poultry smokehouses	713	60%	40%
C10.2	Seafood smokehouses	1,626	60%	40%
C16.1	Wood preservation (creosote)	1,000	87%	13%
C19.1	Coking plants	2,516	99%	1%
C19.2	Petroleum refineries	20,266	78%	22%
C20.13	Manufacture of carbon black	1,020	90%	10%
C20.14	Coal tar distillation	750	90%	10%
C23.2	Manufacture of refractory products	86	95%	5%
C23.99a	Manufacture of bituminous products	5,800	90%	10%
C23.99b	Graphite and carbon electrode manufacture	1,001	97%	3%
C24.1	Steel and iron foundries, ferroalloys	95,752	99%	1%
C24.42	Manufacture of aluminium	626	99%	1%
C24.45	Other non-ferrous metallurgy	616	99%	1%
C24.5	Casting of metals	68,109	99%	1%
D35.11	Coal fired power plants	18,001	92%	8%
E38.2	Waste incineration	1,888	93%	7%
E39	Soil remediation	10,550	93%	7%

Sector		Total number of exposed workers	Percentage	
			Male	Female
F42.11	Road paving	212,757	99%	1%
F42.12	Welding of railroad tracks	6,437	99%	1%
G45.2	Motor vehicles maintenance and repairs	371,532	95%	5%
N81.22	Chimney sweeps	24,500	99%	1%
O84.25	Firefighters*	438,506/ 4,385,060	93%	7%
Total		1,284,052/ 5,230,607	95%/94%	5%/6%

Source: Study team on basis of Eurostat Structural Business Statistics and consultation data.

Note:* The first number refers to airborne exposure, and the second to dermal exposure.

The reproductive age span of women is understood to be 15-49 years, and the male reproductive exceeds the average age of retirement, and subsequently all employed males with exposure are relevant. The proportion of employed women who are of childbearing age has been set to 66% based on Eurostat demographic data from 2020, the team has calculated the number of exposed female workers of reproductive age. Of note are soil remediation and smokehouses with relatively high numbers of female workers and relatively high concentrations. The industries with high exposure concentrations (e.g. coking plants), or with high number of workers and low exposure concentrations (e.g. motor vehicle maintenance and repair) are male dominated.

Table 3-94 Estimated split of workers exposed to PAH who are of reproductive age

Sector		Exposed workers		Exposed workers of reproductive age	
		Male	Female	Male	Female
C10.13	Meat and poultry smokehouses	428	285	428	189
C10.2	Seafood smokehouses	976	650	976	432
C16.1	Wood preservation (creosote)	870	130	870	86
C19.1	Coking plants	2,491	25	2,491	17
C19.2	Petroleum refineries	15,807	4,459	15,807	2,962
C20.13	Manufacture of carbon black	918	102	918	68
C20.14	Coal tar distillation	675	75	675	50
C23.2	Manufacture of refractory products	82	4	82	3
C23.99a	Manufacture of bituminous products	5,220	580	5,220	385
C23.99b	Graphite and carbon electrode manufacture	971	30	971	20

Sector		Exposed workers		Exposed workers of re-productive age	
		Male	Female	Male	Female
C24.1	Steel and iron foundries, ferroalloys	94,794	958	94,794	636
C24.42	Manufacture of aluminium	620	6	620	4
C24.45	Other non-ferrous metallurgy	610	6	610	4
C24.5	Casting of metals	67,428	681	67,428	453
D35.11	Coal fired power plants	16,561	1,440	16,561	957
E38.2	Waste incineration	1,756	132	1,756	88
E39	Soil remediation	9,812	739	9,812	491
F42.11	Road paving	210,629	2,128	210,629	1,414
F42.12	Welding of railroad tracks	6,373	64	6,373	43
G45.2	Motor vehicles maintenance and repairs	352,955	18,577	352,955	12,342
N81.22	Chimney sweeps	24,255	245	24,255	163
O84.25	Firefighters	407,811/ 4,078,106	30,695/ 306,954	407,811/ 4,078,106	20,394/ 203,943
Total		1,222,041/ 4,892,336	62,011/ 338,270	1,222,041/ 4,892,336	41,200/ 224,744

Source: Study team on basis of Eurostat Structural Business Statistics.

Note: Female reproductive age has been taken from 15-49 years. The male reproductive age band exceeds the average age of retirement, and subsequently all employed males with exposure are relevant. The proportion of employed women who are of childbearing age has been set to 66% based on Eurostat demographic data from 2020.

The table below estimates the number of pregnancies for females of reproductive age. Figures in this table have been calculated by using crude rate of annual pregnancies per female (0.01779) in EU27 Member States. The study team has multiplied the crude rate of annual pregnancies by the number of female workers to derive an estimated number of pregnant workers.

Reliable data on the number of pregnancies was not available, and instead the study team used the number of livebirths recorded in Eurostat for 2021 as the basis of calculations (these are known pregnancies). However, the study team recognises that developmental toxicity refers to miscarriage and stillbirth, neither of which are captured in the number of livebirths. This results in an underestimation of the number of annual pregnancies in the EU. Obtaining robust data on this is not possible due to issues related to unrecorded pregnancies, issues in classification of foetal mortality as either based on trimester of mortality vs weight of foetus, and data being obscured through the inclusion of figures throughout the perinatal period (beyond childbirth). Despite this, the study team has identified two sources which provide estimates on the proportion of pregnancies resulting in miscarriage and still birth. Using these sources, the study team has recalculated a possible crude rate (and number of pregnancies), however there is a lack of certainty on these figures. Therefore, the recalculation has been performed as a sensitivity analysis in section 13.2.2. Overall, the alternative crude rate did not significantly impact the calculated benefits due to a majority male workforce, and the study team opted to progress using only the crude rate based on live births due to higher confidence.

Table 3-95 Estimated number of pregnant employees exposed to PAH (annual)

Sector		Estimated number of pregnant employees exposed
C10.13	Meat and poultry smokehouses	5.1
C10.2	Seafood smokehouses	11.6
C16.1	Wood preservation (creosote)	2.3
C19.1	Coking plants	0.4
C19.2	Petroleum refineries	79.3
C20.13	Manufacture of carbon black	1.8
C20.14	Coal tar distillation	1.3
C23.2	Manufacture of refractory products	0.1
C23.99a	Manufacture of bituminous products	10.3
C23.99b	Graphite and carbon electrode manufacture	0.5
C24.1	Steel and iron foundries, ferroalloys	17.0
C24.42	Manufacture of aluminium	0.1
C24.45	Other non-ferrous metallurgy	0.1
C24.5	Casting of metals	12.1
D35.11	Coal fired power plants	25.6
E38.2	Waste incineration	2.4
E39	Soil remediation	13.1
F42.11	Road paving	37.9
F42.12	Welding of railroad tracks	1.1
G45.2	Motor vehicles maintenance and repairs	330.5
N81.22	Chimney sweeps	4.4
O84.25	Firefighters	546.1/5,461
Total		1,103.3/6,018.3

Source: Study team on basis of stakeholder result and Eurostat Structural Business Statistics.

3.5 Current risk management measures (RMMs)

3.5.1 Types of RMMs

A wide range of RMMs are considered, reflecting the hierarchy of RMMs in the CMD, as set out in Table 3-96 below. Data on these have been collected both through literature review and consultation.

Table 3-96 Hierarchy of measures to be applied by the employers, as listed in the CMD

Type of measure	Measures specified in the CMD
Reducing the quantities of the chemical agents used (substitution and material reduction)	(a) limitation of the quantities of a carcinogen or mutagen at the place of work;
Reducing the number of workers exposed	(b) keeping as low as possible the number of workers exposed or likely to be exposed;

Type of measure	Measures specified in the CMD
Reducing the concentration of the chemical agents at the workplace	(c) design of work processes and engineering control measures so as to avoid or minimise the release of carcinogens or mutagens into the place of work;
	(d) evacuation of carcinogens or mutagens at source, local extraction system or general ventilation, all such methods to be appropriate and compatible with the need to protect public health and the environment;
	(e) use of existing appropriate procedures for the measurement of carcinogens or mutagens, in particular for the early detection of abnormal exposures resulting from an unforeseeable event or an accident;
	(f) application of suitable working procedures and methods;
Reducing the exposure of workers by protective measures	(g) collective protection measures and/or, where exposure cannot be avoided by other means, individual protection measures;
	(h) hygiene measures, in particular regular cleaning of floors, walls and other surfaces;
	(i) information for workers;
	(j) demarcation of risk areas and use of adequate warning and safety signs including 'no smoking' signs in areas where workers are exposed or likely to be exposed to carcinogens or mutagens;
	(k) drawing up plans to deal with emergencies likely to result in abnormally high exposure;
Other measures	(l) means for safe storage, handling and transportation, in particular by using sealed and clearly and visibly labelled containers.

Source: CMRD

3.5.2 Current use of RMMs by sector

The RMMs based on information gathered during the consultation interviews and literature are presented in Table 3-97 below and the following text. These should be read in conjunction to information presented in Table 3-99.

Table 3-97 Identified documents with relevant information on technical measures (descriptions from BREFs are largely direct citations)

Sector		RPE	PPE	Other RMM	Source
C16.1	Wood preservation (creosote)	Respiratory protection, such as a full face mask with particle filter P2 or preferably P3 in combination with gas filter A (brown) should be worn at critical work tasks when there is a risk of inhalation exposure.	Creosote resistant boots, chemical resistant (coated) coveralls, long sleeves shirt and long pants, tight sealings at the border of gloves and sleeves and boots and trousers.	Bunds (secondary containment system), training, closed processes, personal hygiene measures. Respiratory protection and gloves to be changed frequently	(WEI-IEO, online; ECHA, 2020)
C19.1	Coking plants	See section 3.5.3			
C19.2	Petroleum refineries	See section 3.5.3.			
C20.1 3	Manufacture of carbon black	See section 3.5.3			
C20.1 4	Coal tar distillation	See section 3.5.3			
C23.2	Manufacture of refractory products	FFP2, FFP3 masks or Respirators with a powered air purifier pump	Gloves	Hygiene measures (surface decontamination), automation of work in a controlled and confined workstation; semi-closed systems	(Sartorelli et al., 2020; Stakeholder Consultation, 2023)
C23.9 9a	Manufacture of bituminous products	The use of respiratory protective equipment is not common place.	A face shield, arm protection (e.g. long sleeve shirt) and heat resistant gloves are required when transferring hot tack coat and hot asphalt cement	General ventilation in the form of open spaces. Hot mix asphalt needs to be maintained at a high temperature and therefore operators maintain themselves at a distance from the material.	(Gazzola Paving, 2022)
C23.9 9b	Graphite and carbon electrode manufacture	See section 3.5.3			

Sector		RPE	PPE	Other RMM	Source
C24.1	Steel and iron foundries, ferroalloys	No information currently available.	Appropriate PPE, such as helmets, gloves, aprons and boots should be provided and used. Where appropriate, molten metal resistant clothing should be provided and used.	General ventilation in the form of open spaces.	(ILO, 2005)
C24.4 2	Manufacture of aluminium	See section 3.5.3			
C24.5	Casting of metals	See section 3.5.3			
D35.11	Coal fired power plants	No information available	Gloves and shoes	Reduction of fugitive emissions	(IFC, 2008; BREF, 2017a)
E38.2	Waste incineration	Respiratory protection during maintenance or other work in which dust and noxious gases may be released into the atmosphere	Gloves, long sleeves	Reduction of fugitive emissions, local exhaust ventilation	(ILO, 2012)
E39.0	Soil remediation	Varies depending on activity and level of contamination: simple mask to Self Contained Breathing Apparatus	Varies: simple latex gloves to nitrile gloves and disposable body suit	Varies depending on activity: LEV, pressurised cabin, tent with extraction	(Stakeholder Consultation, 2023)
F42.1 1	Road paving	Not usually worn, only one study showed workers wearing face masks.	Gloves (hot material is being handled so gloves are usually worn)	Fume extraction on machinery such as pavers, is mandatory in some countries. Ventilated and sealed cabs. Reduction of asphalt temperature or use of additives to reduce fume emissions.	(EAPA, personal communication; ATS, 2015)
F42.1 2	Welding of train tracks	Face shield, depending on the type of activity	Protective clothing used in welding should conform to both EN 11611:2015 (Welding Class 2) and EN 11612 (Flame Retardant)		(Stakeholder Consultation, 2023)
G45.2	Motor vehicle maintenance and repairs	Respiratory protection is not usually worn.	Gloves, although not always worn	General ventilation in the form of open spaces and personal hygiene measures	(Stakeholder Consultation, 2023)

Sector		RPE	PPE	Other RMM	Source
N81.22	Chimney sweeps	Variable depending on work, generally no mask during white sweeping or black sweeping in domestic settings and a simple mask or mask with filter during sweeping work in industrial settings	Generally gloves during black sweeping operations	Personal hygiene measures, use of vacuum machines.	(Alhamdow et al., 2017)
O84.25	Firefighters	Self Contained Breathing Apparatus, sometimes FFP3 masks, in some cases no RPE	Protective fire gear, in some cases cotton undergear has been reported	Assessment of wind direction and smoke	(Stakeholder Consultation, 2023)

Source: Study team

In addition:

- C16.1 wood preservation with creosote is subject to the biological product regulation (BPR) and the authorisation of the active substance has put forward some clear RMM that employers must adhere to;
- C19.1 coking industry stakeholders were asked about the potential for workers near coke ovens to wear self-contained breathing apparatus (SCBA), who indicated that the working conditions would be too challenging to where SCBA (the work is physically intensive and the working area is at a high temperature). The use of powered respirators is sometimes already challenged by workers who are reluctant to wear the heavy and incumbent equipment in some cases, but comply nonetheless. Nonetheless, workers who are performing tasks while being in close contact with the coke ovens (e.g. workers performing maintenance tasks on the coke oven deck, workers near the coal charging machine, workers repairing the coke oven doors, workers conducting the pusher machine) are understood to always wear respiratory equipment with a high protection factor (e.g. powered air-purifying masks);
- In this sector it is particularly challenging to operate within a completely closed system due to wide range in temperatures that the manufacturing process requires (up to 2000°C) as well as the cooling down that takes place in the same vessel;
- C19.2 petroleum refineries operate in a closed system. It has come to light that in some instances the respondents provided the current RMM used on-site for the prevention of exposure to PAH, whereas some RMM may be used during the same activity but not for the purpose of preventing PAH exposure, and they have not been recorded in the survey. Based on follow up interviews, the information has been amended to reflect this in section 7.2.4;
- In addition to the RMMs report in section 3.5.3, stakeholders have indicated that in exceptional circumstances workers are required to enter the tanks via manholes for maintenance purposes and in these instances they are required to wear SCBA. Overhead ventilation and extraction units are now also available for loading and unloading operations;
- C20.13 Manufacture of carbon black takes place in closed systems, similar to chemical plants or refineries;
- C20.14 coal tar distillation also takes place in closed systems and some plants have indicated that they intend to operate or currently operate under negative pressure systems during loading of bags (dust exposure) and loading/unloading of tankers. During consultation it has emerged that there is worker resistance to the implementation of new or additional requirements of RPE, but that the introduction of OELs will aid the enforcement of new RMM;
- There are few data points and little engagement from stakeholders on C23.2 manufacture of refractory products. Therefore it is difficult to establish what is the norm. All RMM reported are presented in the table below, but all are unlikely to be applicable in all circumstances, e.g. the Sartorelli study indicated the use of an enclosure but not the use of masks and respirators as indicated by stakeholders;

- C23.99b graphite and carbon electrode manufacture takes place in closed or partially closed systems, depending on the activity or the site. General ventilation, local exhaust ventilation and hoods are also in place. The minimum RPE and associated minimum Assigned Protection Factor according to EN 529 are reported, but in some cases workers will wear RPE with independent source of oxygen;
- F42.11 road paving equipment used to apply surface bitumen such as pavers can be equipped with an extraction system that aims to capture fumes where workers are operating. This is now mandatory in France, while in Germany around 50% of machinery has one. It may also be retrofitted to old machines. According to industry, although not officially mandatory, it is also common when using new paving machinery in other countries. The technology is around 10 years old and machinery is replaced every 15-20 years. Therefore it can be anticipated that in 10 years time almost all equipment will have one;
- For some sectors there has been little information from industry or stakeholders, such as steel and iron foundries C24.1, coal-fired power plants D35.11, waste incineration E38.2, chimney sweeps N81.22 and firefighters O84.25 therefore the information reported is what has been gathered online and is reported in the table below;
- Consultation has indicated that workers wear RPE for the protection of workers against other workplace hazardous materials. For example in C24.1, C24.42, C24.45 and C24.5 (metallurgy and casting of metals), workers may also be exposed to silica dust, lead and carbon monoxide (but also potentially formaldehyde, amines, nickel, chromium etc.). This is also common in other industries and other substances subject to CMRD, e.g. C23.99c and silica, C19.1 and nitrosamine, C19.2 and benzene etc.; and
- O84.25 for firefighters and dermal exposure, it is said that good hygienic measures such as removal of PPE and taking a shower as soon as possible, will reduce dermal uptake (measured via metabolite concentrations). A study found that both laundering and wet soap preliminary exposure reduction methods (post-fire) are effective in reducing surface contamination and appear to prevent accumulation of contamination after repeated exposures (Wilkinson, et al., 2023).

In general, good hygiene measures are a key risk management measure to reduce contamination and exposure. These include measures such as clean clothing, clean PPE and RPE, separation of clean and contaminated areas of work, washing potential skin contaminated area as soon as possible after exposure or end of the shift (depending on circumstances). This is applicable to both dermal exposure through contamination via airborne BaP deposited on surfaces and clothing, and through contamination of substances containing PAH. Costs for the implementation of good hygiene measures are not currently known, but will require low initial capital investment and will be running costs.

For sectors not mentioned above, there is no additional information than what is reported in the Table 3-98 below.

3.5.2.1 Data from Chemical Safety Reports (CSRs)

The CSR for CTPht has been used as a reference for RMMs. The CSR is said to be from before the introduction of CTPht to Annex XV of REACH for Authorisation, and therefore practices may be different now and should be treated with caution.

Table 3-98 Current RMMs from CSRs for PAH

Worker contributing scenarios	Sector	Risk management measures		Substance
		Personal	Technical	
Worker contributing scenario 5: Dedicated transfer of liquid pitch to drums, container, truck, railcar or ship (PROC 8b); Worker contributing scenario 10: Cleaning and Maintenance - outdoors (PROC 8a) Worker contributing scenario 1: Dedicated transfer of liquid pitch (PROC 8b); Worker contributing scenario 7: Dedicated transfer of mixtures containing substance to drums, container, truck, railcar or ship (PROC 8b); Worker contributing scenario 10: Cleaning and Maintenance - outdoors (PROC 8a)	C20.14	Chemically resistant gloves conforming to EN37	Semi-closed process (Worker contributing scenario 1, 7)	CTPht
Worker contributing scenario 7: Non-dedicated transfer of solid pitch by crane or shovel (PROC 8a)	C20.14	Chemically resistant gloves conforming to EN37	Personal enclosure: Complete personal enclosure with ventilation	CTPht
Worker contributing scenario 8: Dedicated transfer of solid pitch (PROC 8b); Worker contributing scenario 11: Cleaning and Maintenance (dedicated) - indoors (PROC 8b);	C20.14	Respirator with APF of 10; chemically resistant gloves conforming to EN37	Semi-closed process with occasional controlled exposure (Worker contributing scenario 8)	CTPht
Worker contributing scenario 9: Laboratory activities / Quality control (PROC 15)	C20.14		LEV	CTPht
Worker contributing scenario 2: Mixing liquid pitch with other materials (closed continuous process with occasional controlled exposure) (PROC 2); Worker contributing scenario 3: Mixing liquid pitch with other materials (closed batch process) (PROC 3);	C23.99b	Respirator with APF of 10 (respirator conforming to EN 140 with a P3 filter);	Closed continuous process with occasional controlled exposure	CTPht

Worker contributing scenarios	Sector	Risk management measures		Substance
		Personal	Technical	
Worker contributing scenario 4: Mixing liquid pitch with other materials (batch and other process where opportunity for exposure arises) (PROC 4); Worker contributing scenario 5: Mixing liquid pitch with other materials (mixing or blending in batch processes (multistage and/or significant contact)) (PROC 5); Worker contributing scenario 6: Mixing liquid pitch with other materials (transfer at non-dedicated facilities) (PROC 8a); Worker contributing scenario 7: Mixing liquid pitch with other materials (transfer at dedicated facilities) (PROC 8b); Worker contributing scenario 8: Transfer and packaging of green products (solid) (transfer at non-dedicated facilities) (PROC 8a); Worker contributing scenario 9: Transfer and packaging of green products (solid) (transfer at dedicated facilities) (PROC 8b); Worker contributing scenario 10: Crushing and milling of cold green paste or (CTP) pellets (batch and other process where opportunity for exposure arises) (PROC 4); Worker contributing scenario 11: Crushing and milling of cold green paste or (CTP) pellets (mixing or blending in batch processes (multistage and/or significant contact)) (PROC 5); Worker contributing scenario 12: Crushing and milling of cold green paste or (CTP) pellets (High (mechanical) energy work-up of substances bound in materials and/or articles) (PROC 24); Worker contributing scenario 13: Handling of solid pitch (mixing or blending in batch processes (multistage and/or significant contact)) (PROC 5); Worker contributing scenario 14: Handling of solid pitch (transfer at non-dedicated facilities) (PROC 8a); Worker contributing scenario 15: Dedicated transfer of mixtures containing substance to small containers (sampling) (PROC 9);		chemically resistant gloves conforming to EN37	and good general ventilation (Worker contributing scenario 2, 3) Semi-closed process with occasional controlled exposure (Worker contributing scenario 4, 7, 9, 10, 15)	
Worker contributing scenario 1: Søderberg method: Transfer of paste and adding briquettes to pots (batch and other process where opportunity for exposure); Worker contributing scenario 4: In situ baking of Søderberg briquettes (potentially closed processing operations at elevated temperature) (PROC 22); Worker contributing scenario 5: Cleaning and maintenance (transfer activities, non-dedicated) (PROC 8a);	C24.45	Respirator with APF of 10; chemically resistant gloves conforming to EN37	Semi-closed process with occasional controlled exposure (Worker contributing scenario 1)	

Worker contributing scenarios	Sector	Risk management measures		Substance
		Personal	Technical	
Worker contributing scenario 1: Receiving, unloading and sampling of Søderberg briquettes / furnace lining paste / ramming paste (transfer at non-dedicated facilities) (PROC 8); Worker contributing scenario 5: Transfer and charging of Søderberg briquettes to the electrode (transfer at non-dedicated facilities) (PROC 8a); Worker contributing scenario 7: Installation of warm furnace lining pastes (plugging paste /tap hole plugging paste / grouting paste) (transfer at non-dedicated facilities) (PROC 8a); Worker contributing scenario 9: Cleaning and maintenance (transfer activities, non-dedicated) (PROC 8a)				
Worker contributing scenario 3: Storage of plugging pastes / grouting pastes / tap hole plugging pastes (closed batch process) (PROC3)	C24.45		Closed process	
Worker contributing scenario 2: Receiving, unloading and sampling of warm furnace lining repair pastes (plugging paste /tap hole plugging paste / grouting paste) (transfer at dedicated facilities) Worker contributing scenario 4: Preheating of plugging paste / tap hole plugging paste / grouting paste (PROC 4)	C24.45		Semi-closed process with occasional controlled exposure	
Worker contributing scenario 1: Installation of ramming paste (transfer at non-dedicated facilities) (PROC 8a); Worker contributing scenario 2: Installation of collar paste (transfer at non-dedicated facilities) (PROC 8a); Worker contributing scenario 4: Cleaning and maintenance (transfer activities, non-dedicated) (PROC 8a)	C24.42	Respirator with APF of 10; chemically resistant gloves conforming to EN37		CTPht
Worker contributing scenario 1: Receiving, unloading and sampling of Søderberg briquettes / furnace lining paste / ramming paste (transfer at non-dedicated facilities) (PROC 8a); Worker contributing scenario 2: Receiving, unloading and sampling of warm furnace lining repair pastes (plugging paste /tap hole plugging paste / grouting paste) (transfer at dedicated facilities) (PROC 8); Worker contributing scenario 5: Transfer and charging of Søderberg briquettes to the electrode (transfer at non-dedicated facilities) (PROC 8a);	C24.1	Respirator with APF of 10; chemically resistant gloves conforming to EN37		CTPht

Worker contributing scenarios	Sector	Risk management measures		Substance
		Personal	Technical	
Worker contributing scenario 7: Installation of warm furnace lining pastes (plugging paste /tap hole plugging paste / grouting paste) (transfer at non-dedicated facilities) (PROC 8a); Worker contributing scenario 9: Cleaning and maintenance (transfer activities, non-dedicated) (PROC 8a)				
Worker contributing scenario 3: Storage of plugging pastes / grouting pastes / tap hole plugging pastes (closed batch process)	C24.1		Closed batch process with occasional controlled exposure	CTPht
Worker contributing scenario 4: Preheating of plugging paste / tap hole plugging paste / grouting paste (PROC 4)	C24.1		Semi-closed process with occasional controlled exposure	CTPht
Worker contributing scenario 6: Cleaning and maintenance (transfer activities, non-dedicated) (PROC 8a)	C23.2	Respirator with APF of 10; chemically resistant gloves conforming to EN37		CTPht
Worker contributing scenario 5: Laboratory activities / Quality control (PROC 15)	C23.2		LEV	CTPht

Source: Chemical Safety Report on CTPht

3.5.3 Data from questionnaire survey

The following table presents the companies' used of RMMs based on the consultation survey.

Table 3-99 Companies' use of RMMs for individual process by sector based on consultation survey

Risk Management Measures (RMMs)	C19.10 Coking	C19.20 Refineries	C20.13 Carbon black	C20.14 Coal tar distilla- tion	C23.99b Graphite and carbon electrode	C24.42 Aluminium	C24.5 Casting of metals	F42.11 Road paving	G45.20 Automotive re- pair
Substitution						1	1	2	3
Discontinuation				1					

Risk Management Measures (RMMs)	C19.10 Coking	C19.20 Refineries	C20.13 Carbon black	C20.14 Coal tar distilla- tion	C23.99b Graphite and carbon electrode	C24.42 Aluminium	C24.5 Casting of metals	F42.11 Road paving	G45.20 Automotive re- pair
Reduce use		4					1		1
Reduce workers	5		14	2		1	1	13	3
Rotate workers	5	34	2	2		2		14	3
Redesign				2				20	3
Closed systems	2	8	2	16	1*	1			
Enclosure with extraction	2	1		3	1*	2	1		
Partial hood	7	5	3	1	1*	3			
Open hoods	7	1	7	7	1*	5	1	15	
General ventilation	7	7	14	10	1*	2	2	18	3
Pressurised control cabs	4			7	1*	5		2	
Simple control cabs	6				1*			2	
RPE (powered air-purifying respirators)	5	2		2	1*	4	1		
RPE (self-contained breathing apparatus (with bottled air) or airline respirators (air supplied by hose))		5		5	1*				
Formal/external RPE cleaning and filter changing regime	7		3	18	1*	3	1		
HEPA	2	7	9	13	1*	6		2	3
Masks	7			6	1*	1		4	
Continuous measurement to detect unusual exposures	2	1		14				2	
Conventional or disposable overalls, boiler suits, aprons	2		4	2	1*	3	1	4	

Risk Management Measures (RMMs)	C19.10 Coking	C19.20 Refineries	C20.13 Carbon black	C20.14 Coal tar distilla- tion	C23.99b Graphite and carbon electrode	C24.42 Aluminium	C24.5 Casting of metals	F42.11 Road paving	G45.20 Automotive re- pair
Coveralls/hazardous materials suits	5	8	2	20	1*	1	1		
Rubber boots	2		2	5	1*		1		
Safety boots and shoes	7	9	14	24	1*	7	2	20	
Face screens, face shields, visors	7	9	6	12	1*	2	2		
Goggles	7	12	12	23	1*	5	2	13	3
Gloves	3	12	12	24	1*	4	1	14	3
Gloves with a cuff, gauntlets and sleeving that covers part or all of the arm	4	1	6	2	1*	5	2	17	3
Continuous measurement to detect unusual exposures	2	1		14				2	
Training and education	7	41	14	24		7	3	19	3
REACH restriction training (future)	2			6					
Cleaning	7	7	14	24		7	3	16	3
Provision of separate storage facilities for work clothes	7	8	14	24		7	3	15	
Total number of processes analysed in sector	7	43	16	24	1	7	3	22	3

Source: Consultation survey.

Notes: Values in the above table represent the percentage of processes within each sector that are currently using each RMM. The number of processes is provided in brackets.

A total of 65 respondents provided information on RMMs for 132 processes.

*Respondent indicated the use of local exhaust ventilation, respiratory protective equipment (RPE), and personal protective equipment (PPE) but did not specify which were used.

3.5.4 Use of personal protective equipment

Please refer to information provided under section 3.5.2.

3.5.5 Technical measures

Only a few documents specifically describe technical measures to reduce PAH emissions and exposure in the concerned sectors have been identified.

The EU Best Available Techniques (BAT) Reference Documents (BREF) describes BAT for the various industries as concern reduction of emissions to the environment but do not address occupational exposure. For diffuse and fugitive¹³ emission, the measures taken to reduce emission to the environment, however, would potentially also reduce the exposures of workers. For industries such as petroleum refineries, coke ovens, carbon and graphite electrode production, coal-fired power plants and waste incineration, a significant part of the occupational exposure to PAH is due to fugitive emission sources. Consequently, technical measures such as use of seal-less pumps, bellowed valves, double seals, elimination of flanged couplings on piping, use of welded connections and minimizing the number of connections, and remote-controlled coupling can reduce occupational exposure, where not already implemented.

The table below presents BREFs for the industries where one is available. Relevant information will be extracted from the sources, where possible verified with industry to ensure the practice is still applicable, and the table below will be completed.

Table 3-100 Identified documents with relevant information on technical measures (descriptions from BREFs are largely direct citations)

Sector	Document	Technical measures regarding PAH exposure
Aluminium production and non-ferrous metallurgical industries;	(BREF, 2017b): Non-ferrous metal industries	The BREF describes a number of techniques to prevent diffuse emissions from raw material storage, handling and transport (see section 2.12.4.1), and are dependent on the type of raw material (e.g. dustiness), they include but are not limited to: use of enclosed buildings and bins, or sealed or covered storage, storage areas with bunds, leak detection systems, enclosed conveyors. To prevent emissions from the pretreatment of raw materials the BREF recommends as an example (many other activities are proposed in section 2.12.4.2.): the use of pretreatment and transfer processes with robust extraction and abatement equipment, thermal or mechanical pretreatment to minimise contamination of the furnace feed, the use of good design and construction practices and adequate maintenance. To prevent diffuse emissions and collect off-gases from metal production process, the BREF recommends but is not limited to (see section 2.12.4.3 of the BREF for a complete list): furnace sealing or other collection techniques to achieve gas collection; Some examples include sealed smelting furnaces, sealed electric arc furnaces and the sealed point feed cell for primary aluminium production; use of sealed charging systems; maintenance of collector hoods, ducts, filter systems and fans; use of damper systems and alternative extraction points to suction to the points where fumes are being emitted; use of secondary hood gas collection if diffuse emissions cannot be prevented or minimised to acceptable levels; use of tertiary collection systems

¹³ Fugitive emission: emission of gases or vapours from pressurized equipment due to leaks and other unintended or irregular releases of gases, mostly from industrial activities.

Sector	Document	Technical measures regarding PAH exposure
		for gases that are not collected by secondary hoods (e.g. house in house). To reduce dust and particle emissions the BREF suggests to use (see section 2.12.5.1 for more details): bag filters, wet dust scrubbers To reduce gaseous compounds emissions the BREF suggests to use (see section 2.12.5.2 for more details): afterburners/after-burning chambers (thermal oxidisers), wet scrubbers and dry scrubbers. The BREF describes a number of measures to be taken for the two types of emission sources (dust and gases) at different stages of the production process. There are consideration for pre-bake cells and Soderberg anode cells. It includes, but is not limited to: • collection of dusts and gases from hoods, bag filters and condensers, dry scrubbers and treatment via regenerative thermal oxidisers or catalytic thermal oxidisers, wet scrubber, regenerative thermal oxidisers with pre- and post-treatment; • automatic multiple point feeding of alumina; • complete hood coverage of the cell and the use of robust cell hoods and adequate extraction rates; • Minimisation of the time for changing anodes and other actions that require the removal of cell hoods. • Storage of removed anodes in a compartment near the cell where air is extracted and led to the gas treatment centre. • Efficient process control system to stop process upsets leading to an increased cell evolution and emissions. • Use of a programmed system for cell operations and maintenance. In the pre-bake plant emissions from the baking process are reduced by the use of dry paste combined with either an upper anode case or an anode top hood.
Graphite and carbon electrodes	(BREF, 2017b): Non-ferrous metal industries	Emissions from the storage, handling, and transport of solid materials, and during mechanical pretreatment processes like grinding are usually abated through bag filters. The general methods for prevention and collection of dusts and fumes from raw materials (handling, storage etc) and during the process are the ones presented in the previous entry.
Silicon metal, calcium carbide and silicon carbide	(BREF, 2017b): Non-ferrous metal industries	Semi-closed submerged arc furnaces are used to produce FeCr, FeMn, SiMn, FeNi, FeSi and silicon metal alloy and for the recovery of special ferro-alloys. To reduce dust emissions the technique to consider is the use of bag filters with or without injection of adsorbents
Petroleum refineries and coal tar distillation	(BREF, 2015): Refining of Mineral Oil and Gas	In the BREF for refining PAH emissions are considered under water emissions only. The BREF describes techniques for the prevention, detection and control of fugitive VOC emissions. Examples of techniques to reduce diffuse emissions resulting specifically from refinery process design can be (for each the report provides examples): • Limiting the number of potential emission sources, • Maximising inherent process containment features; • Selecting high-integrity equipment; • Selecting appropriate materials for equipment; • Facilitating monitoring and maintenance activities by ensuring good access to components that have the potential to leak;

Sector	Document	Technical measures regarding PAH exposure
		Collecting and treating emissions, such as conveying potentially collectable leaks (e.g. compressor seals, vents and purge lines) to flares or to flameless oxidisers.
Coke ovens	(BREF, 2013): Iron and Steel Production	The BREF describes a number of measures to be taken for the two types of emission sources: - Diffuse emissions which occur during regular operation, e.g. coal and coke handling, transport of coal and coke, coal blending beds, ascension pipes, coke pushing and coke quenching. If these are not captured, they can be released through the roof, roof-hatch, windows or from stored material. Minimisation is possible only by prevention and/or further treatment after transferring them into ducted emissions (i.e. by capturing them); - Fugitive emissions happen during irregular operation from leakages at the battery, e.g. because of leakage of vessels, oven doors, flanges etc. or at the by-product plant. For minimisation the first option is prevention by good maintenance. The BREF describes measures to be taken at different steps of the products; and include e.g. how measures to enable virtually gas-tight operation of the gas treatment plant should be considered and include the items listed below: - minimising the number of flanges by welding piping wherever possible using gas-tight pumps (e.g. magnetic pumps or double sealed pumps); - avoiding emissions from pressure valves in storage tanks. This is most commonly achieved by connecting the valve outlet to the coke oven gas collecting main (collection of the gases and subsequent combustion or gas blanketing or vent scrubbers could also be used); - using special sealings for flanges and valves to prevent air pollution as well as closed processes without emissions such as the Claus process with tail gas recycling or the tar and liquid treatment with tar sludge recycling; - enclosing the tar sludge system. The BREF includes a description of maximum achievable control technology (MACT). The BAT indicates that EPA 303 standard should be used in steel and iron foundries and coke ovens, which dictates that the maximum percentage of leaking door is <10%, calculated according to what is in EPA 303.
Steel and iron foundries, ferroalloys		The BREF identifies PAH in blast furnace and electric arc furnace gas and dusts. PAH emissions are not the main focus of the BREF. - The BREF suggests to reduce dust emissions from casting by covering the runners with moveable lids - Other sources are during the drying/crushing of coal and storing of pulverised coal. - The charging of furnaces should be done via a sealed charging system; - Reducing the need for coke in blast oxygen furnaces (BOF) and using direct injections; - thermal degradation of organic materials present on scrap steel can also result in the generation of PAH and emissions

Sector	Document	Technical measures regarding PAH exposure
		from charging. For these the BREF recommends that the secondary extraction system captures the emissions and dusts. General techniques to prevent or control diffuse and fugitive secondary emissions in BOF include: • independent capture and use of dedusting devices for each subprocess in the BOF shop; • maintaining the lid on when the hot metal ladle is not in use and hot metal ladles should be cleaned and undone of skulls on a regular basis; In electric arc furnaces (EAF) scrap preheating can result in the generation of PAH from the presence of paint, plastic lubricants or other organic compounds on the metal. These emissions can be minimised by post-combustion of the off-gas in a specially designed post-combustion chamber equipped with fossil fuel burners.
Foundries	Smitheries and foundries industry (BREF, 2005)	The BREF describe measures for reducing fugitive dust emission. For the optimisation of reducing fugitive emission the BREF mentions: For this optimisation one or more of the following measures are used, giving preference to the collection of fume nearest to the source: • hooding and ducting design to capture fume arising from hot metal, furnace charging, slag transfer and tapping; • applying furnace enclosures to prevent the release of fume losses into the atmosphere; • applying roofline collection, although this is very energy consuming and should only be applied as a last resort; See also the previous entry for steel, iron and ferroalloys.
Carbon black manufacture calcium and silicon carbide manufacture	(BREF, 2007b): Production of Large Volume Organic Chemicals.	Carbon black: the BREF focuses on NO_x and SO_x emissions. Incomplete decomposition of feedstock can result in the generation of PAH. The BREF indicates that emissions from the tail-gas are controlled with thermal combustion, e.g. flares or incinerators. With regards to fugitive emissions, BREF indicates that feedstock generally has low vapor pressure and the feedstock storage tanks are only a minor source of fugitive organic emissions. When operators adhere to good housekeeping practices, fugitive emissions can be insignificant. Calcium carbide: the BREF focuses on CO gas emissions and dusts. The collection of furnace gases is achieved via the use of modern electric furnaces that are completely closed. Silicon carbide: the BREF focuses on CO, H₂, CO₂ gas emissions and dusts, where PAH is present in the coke.
Wood preservation	(BREF, 2020): Surface treatment using organic solvents including preservation of wood and wood products with chemicals	For the application of creosote via pressure processes the BREF recommends precautionary design features, not limited to: • process controls to prevent operation unless the treatment vessel door is locked and sealed; • process controls to prevent the treatment vessel from opening while it is pressurised and/or filled with preservative solution; • catch-lock for the treatment vessel door; • use and maintenance of safety relief valves. In addition, • air extracted from pressure treatment vessels (i.e. the vacuum pump outlet) is to be treated (e.g. in a vapour-liquid separator) • to prevent or reduce aerosol formation and emissions to air, pressure processes can be operated with a drip-off and/or condensation phase at the end of the impregnation process

Sector	Document	Technical measures regarding PAH exposure
		before the treatment vessel is opened to remove the treated wood. To prevent or reduce aerosol formation and emissions to air, pressure processes can be operated with a drip-off and/or condensation phase at the end of the impregnation process before the treatment vessel is opened to remove the treated wood
Casting of metals	(BREF, 2005): Smitheries and foundries industry A Draft re-vised BREF is also available (BREF, 2022)	For the optimisation of reducing fugitive emission the BREF mentions optimisation one or more of the following measures are used, giving preference to the collection of fume nearest to the source: - hooding and ducting design to capture fume arising from hot metal, furnace charging, slag transfer and tapping; - applying furnace enclosures to prevent the release of fume losses into the atmosphere; - applying roofline collection, although this is very energy consuming and should only be applied as a last resort.
Coal fired power plants	(BREF, 2017a): Large combustion plants	For certain solid fuels, full enclosure during both transport and storage is now being specified. Integrated combustion process ensuring high boiler efficiency and including primary techniques for NOX reduction – this will also result in lower PAH emissions.
Manufacture of refractory products	(BREF, 2007c): Ceramic Manufacturing Industry	The BREF focuses on emissions from hydrogen fluoride, VOC, hydrogen chloride, SO_x etc. It advises to: reduce the input of pollutant precursor, which in the case of PAH is the binding agent, and heating curve optimisation. Secondary measures include the use of techniques to capture and process fumes, such as dry flue-gas cleaning with a filter (e.g. bag filter).
Waste incineration	(BREF, 2019): Waste incineration	The BREF on waste incineration presents a series of techniques to reduce emissions to air, the appropriateness of which depends on the type of incineration unit. For PAH, bag filters and wet scrubbers are used to treat captures emissions. To reduce fugitive emissions, the BREF identifies two main techniques, that cover the use of: - solid waste in enclosed buildings from which incineration air is drawn; - ducting tank vent to incineration air feed.

The coking industry as well as the carbon and graphite electrode industries have employed automation, closed systems, worker rotation to the extent possible (some activities still require human intervention) as well good ventilation and pressurised and sealed cabins where possible. These industries also supply their workers with supply air purified or SCBA when PAH levels are high.

3.6 Voluntary industry initiatives

Firefighters: The Rescue Services Academy Finland (Pelastusopisto) recommends using thin under gloves underneath the fire fighting glove to minimise the PAH exposure on hands/skin. They also recommend on using powered air purifying respirators at forest fires if needed.

No additional voluntary industry initiatives have been reported in the survey or during interviews.

3.7 Examples of good/best practice

3.7.1 O84.25 Firefighters

The Skelleftea operating model originated in Sweden aims at reducing contamination through the implementation of simple routines, such as removal of PPE and change of clothes at the site of the fire (i.e. as soon as possible), placing them in a bag to be cleaned (Swedish Civil Contingencies Agency, 2015). Based on stakeholder consultation, all new firefighting stations in Finland comply with the model, however old station can still apply many of the principles of the model to achieve reduced exposure levels at low cost. Further consultation indicates that Nordic countries have a higher level of occupational hygiene compared to the rest of European countries, and that other countries have only just started to follow. According to consultation, the most widely distributed and adopted document across many European countries is a best practice report from the University of Central Lancashire (UCLan), commissioned by the FBU, which “aims to help protect firefighters’ health by highlighting some of the risks and common sources and suggesting preventative measures for minimising exposure to contaminants and best practice for the decontamination of personnel and firefighting equipment after exposure to toxic fire effluent” (UCLan, 2020).

In Belgium, firefighters are provided with a hygiene kit for after fire events that includes clean water, soap, FFP3 masks and disposable nitrile gloves. As indicated in previous section, hygiene (such as taking off contaminated gear and clothing as soon as practicable, showering or cleaning hands) has a large, positive impact on reducing the amount of PAH uptake.

3.7.2 C19.1 Coking

EPA standard 303 deals with door monitoring of leakages of coke oven doors, lids and ascension pipes, and some plants use this standard to measure and reduce the number of leakages in order to reduce diffuse dust and diffuse PAH emissions for the coking plant. This helps to reduce exposure of the coke oven workers, and to comply with the air quality and emission targets.

3.7.3 C20.14 Coal tar distillation

An example of best practice in the has emerged in consultation with a manufacturer. The site is located inside an urban and residential area. Due to the inherent odour with the process, the company has had to minimise and reduce the potential for fugitive emissions, which is also a requirement for the environmental permit. This includes a series of negative pressure systems for all tank, ship and truck operations and pumps where there could be fugitive emissions are housed in a pump house with negative pressure. The company indicated that the improvements were made over time in the last 30 years and it would not be economically feasible to implement these measures at the same time today should they be required.

During consultation with industry and stakeholders, no additional guidance or standards for best practices have come to light. This is potentially due to the fact that PAH are not handled as a substance as such, and are not intentionally generated, and that several sectors have been concerned with exposure to heavy metals and chemicals other than PAH (for example in the aluminium industry workers are potentially exposed to a number of pollutants, such as sulphur dioxide, chromium and carbon monoxide among many others, see section 3.2.10.2). A number of technical measures are in place since the redaction of BREFs as reported in section 3.5.5.

3.7.4 Options for making good practice available to stakeholders

Good practices could be described and made available to stakeholders via the relevant BREF.

3.8 Standard monitoring methods/tools

3.8.1 Compliance monitoring

Procedures for monitoring of contaminants in the workplace are typically established by national guidelines prepared by the national working environment authorities. These guidelines would typically refer to European standards to be used for the monitoring.

As concerns the monitoring of substances in the workplace, guidelines refer to two European standards:

- EN 482:2012+A1:2015 : Workplace exposure. General requirements for the performance of procedures for the measurement of chemical agents; and
- EN 689:2018+AC:2019: Workplace exposure. Measurement of exposure by inhalation to chemical agents. Strategy for testing compliance with occupational exposure limit values.

The strategy described in EN 689:2018 gives a procedure for the employer to overcome the problem of variability and to use a relatively small number of measurements to demonstrate with a high degree of confidence that workers are unlikely to be exposed to concentrations exceeding the OELs. The procedures are further described in the Methodological Note. [to be further developed]

As described in the Methodological Note, in order to undertake the screening tests, ideally an analytical method with a limit of quantification (LOQ) at $0.1 \times \text{OEL}$ would be required; otherwise, it will be necessary to undertake more tests and the costs of monitoring increases. For the lowest of the reference values proposed in this study this would correspond to 0.7 ng/m^3 BaP.

3.8.2 Available analytical methods

The methods shown in Table 3-101 have validation data that demonstrate compliance with the requirements of the standard EN 482 or the potential to meet these requirements for some of the proposed OELs.

Table 3-101 Overview of sampling and analytical methods for monitoring of PAH in workplace air

No	Method/ Fraction	Analytical Technique	LOQ and sampling volume and time	Similar methods/ comments
1	MétroPol Fiche 322 Hydrocarbures aromatiques polycycliques (HAP), 2018	HPLC/FLD	LOQ: $<10 \text{ ng/m}^3$ (480 l), 1 l/min (closed cassette), 2 l/min (open cassette) 240-480 l	Validated for 8 PAH
2	IFA - Arbeitsmappe, Kennzahl 8408, 2018	HPLC/FLD	LOD for B(a)P: $0.003 \text{ } \mu\text{g/m}^3$ (1200 l)	Particle bound PAH (semi-volatile PAH)
3	DFG Method Nr 1, 2017	HPLC/FLD	LOQ for B(a)P: $0.0016 \text{ } \mu\text{g/m}^3$ (1200 l), 10 l/min (sampler GSM/SG10 type), at least 2 h	Particle bound PAH; Validated for six semi-volatile PAH
4	DFG Method Nr 2, 2002	HPLC/UV/FLD	LOQ $0.13 - 1.80 \text{ } \mu\text{g/m}^3$ (120 l); Range $0.8-40 \text{ } \mu\text{g/m}^3$, 2 l/min, at least 1 h	Validated for 17 PAH
5	DFG Method Nr 3, 2002	GC/MS	LOQ $0.017-0.195 \text{ } \mu\text{g/m}^3$ (360 l), $\leq 1 \text{ l/min}$, 240-480 l	Validated for 16 PAH both as particles and in gaseous form

No	Method/ Fraction	Analytical Technique	LOQ and sampling volume and time	Similar methods/ comments
6	MTA/MA 039, 2000	HPLC/FLD	LOQ 1.5 to 0.08 µg/m ³ (200 l), 2 l/min 200 to 1000 l	Validated for 17 PAH
7	NIOSH 5506, 1998	HPLC/FLD/UV	0.001-0.2 µg/sample (LOD); 0.01-0.4 µg/sample (LOQ), 2 l/min; 200-1000 l	Validated for 17 PAH
8	NIOSH 5515, 1994	GC-FID	0.3-0.5 µg/sample (LOD), 3-150 µg/m ³ (400 l), 2 l/min; 200- 1000 l	Validated for 17 PAH

Source: RAC 2022b

As noted by RAC (2022b), some shortcomings in validation data (e.g., sampling and recovery efficiencies, expanded uncertainty) can be encountered during sampling. Due to the demands for achieving a very low limit of detection and quantification, increases to the sampling time and/or change to a sampler allows a higher flow rate for sampling and also more sophisticated analytical methods to be applied.

IARC (2023) suggests that the analysis of 3-OHBaP requires particularly sensitive analytical procedures because the pathway for urinary excretion of the metabolite is much less significant than that for faecal excretion.

See also feedback from consultation below.

The methods shown in Table 3-102 are available for biomonitoring campaigns for the metabolite of 3-OHBaP.

Table 3-102 Overview of biomonitoring methods and analytical methods for biomonitoring of 3-OHBaP in the workplace

No	Method	Analytical Technique	LOD / LOQ	Comment
1	3-OHBaP - Enzymatic hydrolysis	HPLC/FLD	- / 0.05 ng/l	(Barbeau et al., 2011)
2	3-OHBaP - Enzymatic hydrolysis	GC-APLI-MS	0.6 pg/l / 1.8 pg/l	(Richter-Brockmann et al., 2019)
3	3-OHBaP - Enzymatic hydrolysis	LC-MS/MS	17 pg/l / 50 pg/l	(Rögner et al., 2021)

Source: (RAC, 2022b)

The determination of 3-OHBaP, based on the above analytical techniques outlined above, allow for the detection of the urinary metabolite down to very low detection limits, thus capturing not only the range of occupationally exposed workers but also the general population. However, the applied analytical methodologies are very sophisticated and some biomonitoring stability issues are highlighted by RAC (2022b) for 3-OHBaP, 1-OHP and Tetraol-BaP.

The analysis of 3-OHBaP requires several pre-treatment steps: enzymatic hydrolysis, solid-phase extraction, derivatisation and HPLC/FLD analysis. The HPLC analysis is the most common form of analysis. RAC indicates that only a small fraction is excreted as 3-OHBaP in the urine and the elimination of 3-OHBaP is slow compared to 1-OHP which may then require another sampling time

than end-shift, particularly for cases with high exposure variability. The GC-APLI-MS method is highly sensitive (LOQ 1.8 pg/L) but there have been stability problems with the metabolite in the lower concentration range. The LC-MS/MS method has been published and validated by the US Food and Drug Administration (Rögner et al., 2021) through the use of glucuronide conjugates.

Feedback from biomonitoring experts in France have indicated that the validation and application of the LC-MS/MS method in laboratories has not been successful, as actual limit of detection achieved is not very sensitive. Currently, only two laboratories in France are able to analyse 3-OHBP using the Barbeau, et al., 2011 method. The theoretical LOQ of 0.05 ng/L is sometimes (but not always) challenging to achieve in practice and in some cases the LOQ is 0.1 or 0.15 ng/L. Using a conversion based on average creatinine content¹⁴, the LOQ of 0.05, 0.1 and 0.15 ng/L are sufficiently sensitive to measure 10% of the lowest, second and third lowest BLV policy options, respectively, as a minimum. The experts also indicated that the samples should not be stored frozen, as the thawing process may cause the metabolite to be unstable and/or underestimate exposure levels. The samples are to be stored in the fridge and analysed within 2-3 weeks.

Some specific comments received during the consultation with industry and follow up interviews:

- C19.2 and F42.11 Bitumen fumes: Comparison of data is hampered by the absence of a generally accepted method of analysis and differences in the collection methods for bitumen fumes. Measurements are based on coal tar fumes which differ in composition to bitumen fumes, so findings are said to be difficult to replicate;
- C19.2 Refineries: the tasks where exposure can occur are often of short (1-3 hours) or very short duration (<1 hour) and due to the relatively low levels of PAH the theoretical LOQ is not always achieved. An example was given of the (Concawe, 2016) study that followed an analytical method closely related to the MétroPol Fiche 322 2018 method, but was able to achieve an LOQ <10 ng/m³ on one occasion only;
- Some respondents, as well as experts, have indicated that there is currently a lack of accredited laboratories to analyse for 3-OHBP in Europe, especially with the new and more sensitive analytical method. It is anticipated that should a BLV with 3-OHBP come into force, laboratories will adopt existing methods and offer the urine analysis of 3-OHBP. Although there may be a short-term capacity issue, this should resolve itself;
- Confounding variables such as smoking, eating smoked foods or grilled food, meats in particular, and vicinity to open fires are known to increase PAH metabolite concentrations (see section 2.1.5). The urinary 1-OHP levels are about 2 to 3 times higher for smokers than for non-smokers (RAC, 2022a). For 1-OHP SCOEL has proposed a background level in urine of people not occupationally exposed to PAH that includes smokers (see section 1.2.3), while RAC proposed to set a BGV corresponding to the background level of the occupationally not PAH exposed, non-smoking general population. Background levels of 3-OHBP have not been proposed. Consultees have expressed concern at the potential confounding factors and how these can be mitigated during biomonitoring campaigns; and

¹⁴ Based on conversions presented on the INRS website and assuming an average creatinine concentration (which depends on the level of hydration of the individual), the LOQ of 0.05, 0.1 and 0.15 ng/L are equivalent to 0.015, 0.03 and 0.045 nmol/mol creatinine, respectively. Available at [Benzo\[a\]pyrène \(50-32-8\) / 3-Hydroxybenzo\(a\)pyrène urinaire - Biotox - INRS](#)

- Furthermore, it became clear during stakeholder consultation, that companies use different compliance schemes, e.g. some stakeholders interpret an OEL as a maximum value (which should never be exceeded), whilst most stakeholders and consultees use the European Standard EN 689 for documenting compliance. Under this standard companies strive to achieve 10% of the OEL, and therefore will require an equally sensitive analytical method.

3.8.3 Summary of monitoring methods/tools

Analytical methods are available for the monitoring of PAH in the workplace at the required concentrations, both in air and as a metabolite. There are however potential sensitivity and stability issues with 3-OHBP, and sector specific issues, such as for refineries and road paving, which could make it challenging to conduct air monitoring or biomonitoring at the lowest policy options level, particularly for those seeking to adhere to EN 689.

3.9 Intermediate uses not covered by certain REACH procedures

Under REACH, an intermediate is a substance that is manufactured for and consumed in or used for chemical processing in order to be transformed into another substance (REACH Article 3(15)). Substances used as intermediates would not be covered by parts of the REACH registration. Substances which are used as on-site isolated intermediates are not subject to authorisation, and are exempted from restriction (ECHA, 2023). Transported isolated intermediates are not subject to authorisation, but may be subject to evaluation and restriction. Residues of the isolated intermediates, which are not transformed into another substance in a manufacturing process, will be typically discarded or disposed of as waste or recycled as intermediates and are not subject to neither authorisation nor restrictions.

PAH are not REACH registered substances, therefore this section is not relevant for PAH. It should be noted however that there are intermediate uses of substances containing PAH such as CTPht. For example, graphitisation of CTPht is not covered under REACH (whilst its formulation and shaping into green anodes, for example, is), this affects several sectors: C23.99b, C23.2, C24.1, C24.42 and C24.45.

3.10 Market analysis

3.10.1 Sources of data on enterprises with exposed workers

Eurostat figures, consultation with industry associations and responses to the survey are the main sources of information on enterprises with exposed workers.

3.10.2 Study team analysis of Eurostat, survey and industry data

The study team has taken data from Eurostat on the number and distribution of companies, as well information gathered during the stakeholder surveys and interviews and documentation made available via the consultation.

3.10.2.1 C10.2 and C10.13 smokehouses

According to feedback received during the consultation process, the largest manufacturers of smoked meat and fish use liquid smoke, which is a flavoring, and therefore no combustion takes place and these companies are outside of scope.

NACE C10.13 meat processing will be a large sector as meat processing is a big industry, with a total of 21,014 companies. 1% is taken as representative of meat smokehouses that gives a total of 210 companies.

NACE C10.2 fish processing will also include activities outside of the scope of the report, such as freezing and canning. The sector has a total of 3,294 companies and 10% is taken as representative for a total of 329 companies.

Based on feedback received from consultation it is likely that companies operating in the smoking sector will be SME.

3.10.2.2C16.1 Wood preservation

According to feedback received during the consultation there are a total of 40 companies across Europe who treat wood with creosote. This is taken as the maximum split.

Based on the Eurostat split, the study team has estimated that 39 enterprises are small companies and 1 is medium. No additional input from industry is available.

3.10.2.3C19.10 Manufacture and operation of coke ovens

Coking plants are often part of integrated steelworks, where the coke is used in furnaces as a reducing agent or as fuel (BREF, 2013).

The entire NACE code activities are considered to be relevant as indicated in section 3.4. According to Eurostat there are 55 companies.

The consultation suggests there are more Large companies than the ones indicated in Eurostat and split of company size figures have been amended to reflect that.

3.10.2.4C19.2 Petroleum refineries

Eurostat indicates that there are 821 companies under NACE C19.2, which includes several small, specialised refineries that further refine streams that are initially refined from crude oil. The activities of refineries that refine crude oil into the heavier streams (bitumen, heavy fuel oils and lubricating base oils) are of interest to this study. In the consultation some petroleum refineries were assigned to NACE code C20.14 (manufacturers of organic chemicals), therefore the figures from Eurostat for NACE C19.2 may not be representative.

According to Statista there were 68 mainstream oil refineries in Europe in 2021 (Statista, 2023).

According to Concawe there were a total of 89 refineries in Europe in 2021, of which 75 are mainstream refineries and 14 are specialised bitumen and lube or condensate refineries. The figure includes 7 in the UK, 1 Switzerland, and therefore there are 81 refineries in total of relevance to this study (Concawe, 2023). In addition, there are 39 members of Concawe, which are thought to represent the number of large companies. Consultation with the bitumen and paving industry indicate that the figure of 80 companies is correct when taking into account bitumen manufacturing companies in Europe. Therefore, a total of 81 companies has been taken of which 39 are understood to be large.

3.10.2.5C20.13 Manufacture of carbon black

Eurostat indicates there are 858 companies under NACE C10.13, which covers the manufacture of inorganic basic chemicals.

The BREF for large volume inorganic chemicals (BREF, 2007a) indicates that there were approximately 25 companies in the EU MS in 2002. Feedback from different stakeholders has been received, indicating that the number of companies has remained roughly stable, with the market being dominated by big groups producing on several continents, and also indicating that the number

of companies is smaller than indicated in the BREF. The value from the BREF has been used as a worst-case scenario.

Consultation with stakeholders indicates that the market is dominated by Medium and Large companies, so the SME split has been adjusted to reflect that.

3.10.2.6C20.14 Coal tar distillation

The Eurostat for NACE C20.14 indicates there are 1949 companies, but the NACE code includes all organic chemicals and is not considered to be representative.

The Coal Sector Group (personal communication) reported that there are seven companies left in EU Member States who undertake coal tar distillation and based on stakeholder feedback, the seven companies are a split between medium and large companies.

3.10.2.7C23.2 Manufacture of refractory products

According to information received during stakeholder consultation there are less than five companies using CTPht for the manufacture of refractory products.

The SME split from Eurostat for the NACE code has been applied.

3.10.2.8C23.99a Manufacture of bituminous products

The majority of bitumen products are produced for used within paving (85%, including road, airports, bridges, parking lots etc.), followed by roofing applications (15%, hot and cold applied) and the remaining (5%) is used in other small volume applications such as coating of pipes, sound deadening, waterproofing and sealing (ashpalt institute and eurobitume, 2015).

A publication on road paving in Europe indicates there were approximately 700 companies in 2021 that manufacture asphalt for paving (EAPA, 2021). But several Member States are not represented in the source.

Eurostat indicates there are 2,360 companies under NACE C23.99 "Manufacture of other non-metallic mineral products n.e.c.". This includes the manufacture of mineral wool used as insulating material, which is the main insulating material in Europe (JRC, 2018) and therefore is not thought to be representative.

Taking 50% of the Eurostat figures results in 1180 companies, which is thought to be a conservative estimate. This is above the figure presented by EAPA where some MS were not represented. The SME split from Eurostat was applied to the calculated number of companies.

3.10.2.9C23.99b Graphite and carbon electrode production

ECGA indicate that there are 23 facilities over eight countries including one in Norway, therefore a total of 22 in EU27. The same considerations on the representativeness of the industry association made to the number of workers in section 3.4 apply to the number of companies. Therefore no additional companies with exposure to PAH are expected in this sector.

Feedback from industry indicates that the companies where exposure can take place are Large companies only.

3.10.2.10 C24.1 Steel and iron foundries, including ferroalloys.

According to EUROFER there are 156 companies in the steel industry (EUROFER, online). While Eurostat indicates there are a total of 2769 companies under NACE C24.1 and all of the NACE code is

considered to be relevant as there are processes in steel and iron foundries, including the manufacture of ferroalloys such as ferrous manganese where exposure to PAH can occur via similar pathways.

The Eurostat split is considered to be representative of and the figures along with SME split have been applied.

3.10.2.11 C24.42 Manufacture of aluminium

According to relevant stakeholders, there are nine companies left in EU27 that manufacture aluminium, after recent closure announcements and taking into account operations that are currently mothballed. The majority of these are Large companies, based on the survey. In addition, there are 7 Smelters in Norway, 3 Iceland.

Eurostat indicates there are 1,218 companies, but this includes companies other than smelters (e.g. aluminium foil manufacturers).

3.10.2.12 C24.45 Other non-ferrous metallurgical processes

It is unclear how widespread this industry currently is in EU27. A source indicates that silicon metal is currently manufactured in France, Germany and Spain, plus Norway, Bosnia and Iceland (CRM Alliance, online)).

Based on REACH registrations for silicon metal, silicon carbide and calcium carbide, the study team has estimated that there are approximately 80 companies, the majority of which manufacture silicon metal. The Eurostat SME split indicates that the majority of companies are small.

3.10.2.13 C24.5 Casting of metals

According to CAEF there are 6000 casters in Europe (CAEF, 2023), while Eurostat indicates there are 4742 foundries under NACE C24.5 casting of metals. The figures presented by CAEF may include European countries that are not Member States, which might explain the discrepancy.

The entire Eurostat figures and SME split have been taken forward.

3.10.2.14 D35.11 Coal fired power plants

Eurostat indicates there are 145,912 companies under NACE D35.11 but this includes several other types of electricity generating plants.

The Climate Action Network (CAN) Europe reported that there were 256 coal-fired power plants in operation in 2017 throughout the EU, which includes the UK and potentially other EEA members not in EU-27 (CAN, 2017). An article by EURACTIVE reports that half of Europe's 324 coal-fuelled power plants had either closed or announced a retirement date before 2030 in 2021 (EURACTIVE, 2021). While this trend is reversing due to the recent energy crisis, this is thought to be a short-term trend (see section 3.4.4).

According to the Global Energy Monitor there are 196 coal fired power plants operating in 2023 in EU MS, with 210 plants retired between 2000-2022 and 2 in construction (Global Energy Monitor, 2023). This figure is taken forward for the analysis.

The figure by the Global Energy Monitor is taken forward and the SME split in Eurostat is applied, taking out Micro companies.

3.10.2.15 E38.2 Waste incineration

According to the Eurostat (The Structural Business Statistics database) there are a total of 650 companies that dispose of waste by incineration. The figure is considered as representative and is taken forward.

3.10.2.16 E39.0 Soil remediation

Eurostat indicates there are 4,223 companies under NACE E39.0, which includes decontamination of soils and groundwater, industrial plants and sites, oil spills and specialised pollution-control activities including asbestos.

The team has estimated that up to 80% of the NACE is relevant based on literature searches and feedback from some stakeholders, which results in approximately 3,280 enterprises.

3.10.2.17 F42.11 Road paving

A report by EAPA indicates there were over 7200 companies that perform road paving activities in 2021 (EAPA, 2021). The report also indicates that some companies are responsible for both road paving and production. However several MS are missing from the report.

According to Eurostat indicates there are 36,411 companies under NACE F42.11, this includes road painting and other marking, installation of crash barriers, traffic signs and the like, therefore 85% is taken for a total of 30,949 companies. The Eurostat SME split has been applied where the majority of companies are small.

3.10.2.18 F42.12 Welding of railway sleepers

Eurostat indicates there are 2,520 companies under NACE F42.12, which includes construction of railways and subways. The team has estimated that up to 80% of the NACE is relevant, which results in 2,016 enterprises.

3.10.2.19 G45.2 Motor vehicle maintenance and repairs

Eurostat indicates there are 467,730 companies operating under NACE G45.2. The NACE includes window repairing, washing and polishing, and seat repairing companies that are not likely to have significant exposure to PAH. Feedback from consultation indicates that there are in the EU there are approximately 380,000 garages, 80% of Eurostat figures are taken for a total of 374,183 companies.

The Eurostat SME split is applied where the majority of companies are small.

3.10.2.20 N81.22 Chimney sweeps

According to Eurostat NACE code N81.22 indicates there are a total of 44,029 companies and it includes several activities that are not related to chimney sweeping, such as window cleaning (see section 3.4.4).

Data from industry (ESCHFOE, 2021) reported a total of 7,983 chimney sweeping companies in Germany employing 8708 sweeps, and 383 enterprises employing 700 sweeps in Finland.

The figures for Germany are taken as such, whereas the figures for Finland are taken as a proxy for other MS. The ratio of sweeping companies for Finland to all companies are applied to all MS (as a portion of each MS total enterprises).

A total of 19,381 enterprises have been calculated based on the above figures, and the study team estimates they are all small companies (max 2 employees each, see section 3.4.4).

3.10.2.21 O82.45 Firefighters

The number of companies is not applicable to firefighters as they are not private organisations. The study team assumes that local authorities or municipalities are responsible for the administration of firefighters.

The number of counties and provinces in Member States has been calculated by the study team to be 758. There are likely to be private firefighting agencies and workers in addition to these but it has not been possible to calculate them.

3.10.3 Summary of enterprises with exposed workers

Table 3-103 Estimated number of EU enterprises with workers exposed to PAH using Eurostat, survey and industry data

Sector		Number of enterprises in EU (Eurostat)	% of enterprises with exposed workers	Estimated enterprises with exposed workers in EU
C10.13	Meat and poultry smokehouses	21,014	1%	210
C10.2	Seafood smokehouses	3,294	10%	330
C16.1	Wood preservation (creosote)	32,000	0%	40
C19.1	Coking plants	55	100%	55
C19.2	Petroleum refineries	821	10%	81
C20.13	Manufacture of carbon black	858	3%	25
C20.14	Coal tar distillation	1,949	0%	7
C23.2	Manufacture of refractory products	702	1%	5
C23.99a	Manufacture of bituminous products	2,360	50%	1,180
C23.99b	Graphite and carbon electrode manufacture	2,360	1%	22
C24.1	Steel and iron foundries, ferroalloys	2,769	100%	2,769
C24.42	Manufacture of aluminium	1,218	1%	9
C24.45	Other non-ferrous metallurgy	522	15%	80
C24.5	Casting of metals	4,742	100%	4,742
D35.11	Coal fired power plants	145,912	0%	196
E38.2	Waste incineration	7,728	8%	650
E39	Soil remediation	4,223	80%	3,378
F42.11	Road paving	36,411	85%	30,949
F42.12	Welding of railway sleepers	2,520	80%	2,016
G45.2	Motor vehicles maintenance and repairs	467,730	80%	374,183
N81.22	Chimney sweeps	44,029	44%	19,381
O84.25	Firefighters*	758	100%	758
Total		783,975	56%	441,066

Source: Study team on basis of stakeholder result and Eurostat Structural Business Statistics.

Note: The 'number of enterprises in EU' refers to Eurostat data for the entire NACE code, of which the subsectors of relevance (i.e. those with exposed workers) are a proportion.

*A mixture of sources was used for O84.25 as Eurostat data was comprehensive.

The number of firefighting enterprises refers to the number of public authorities responsible for fire services.

3.10.4 Enterprises with exposed workers by sector and by size of enterprise

Table 3-104 Distribution of EU enterprises by sector and by size of enterprise according to Eurostat

Sector		Total number of enterprises	Percentage of enterprises		
			Small <50 employees	Medium 50-249 employees	Large >249 employees
C10.13	Meat and poultry smoke-houses	21,014	92%	6%	2%
C10.2	Seafood smokehouses	3,294	87%	11%	2%
C16.1	Wood preservation (creosote)	32,000	98%	2%	0%
C19.1	Coking plants	55	93%	4%	4%
C19.2	Petroleum refineries	821	83%	8%	9%
C20.13	Manufacture of carbon black	858	86%	10%	4%
C20.14	Coal tar distillation	1,949	86%	10%	4%
C23.2	Manufacture of refractory products	702	87%	11%	3%
C23.99a	Manufacture of bituminous products	2,360	90%	8%	2%
C23.99b	Graphite and carbon electrode manufacture	2,360	90%	8%	2%
C24.1	Steel and iron foundries, ferroalloys	2,769	91%	4%	5%
C24.42	Manufacture of aluminium	1,218	84%	10%	6%
C24.45	Other non-ferrous metal-lurgy	522	84%	10%	6%
C24.5	Casting of metals	4,742	85%	11%	4%
D35.11	Coal fired power plants	145,912	99%	1%	0%
E38.2	Waste incineration	7,728	92%	7%	2%
E39	Soil remediation	4,223	97%	3%	0%
F42.11	Road paving	36,411	95%	4%	1%
F42.12	Welding of railway sleepers	2,520	95%	4%	1%
G45.2	Motor vehicles maintenance and repairs	467,730	100%	0%	0%
N81.22	Chimney sweeps	44,029	98%	2%	1%
O84.25	Firefighters	758	N/A	N/A	N/A
Total		783,975	98.56%	1.10%	0.34%

Source: Study team on basis of stakeholder result and Eurostat Structural Business Statistics.

Note: The number of firefighter enterprises refers to the number of local authorities responsible for the employment of firefighters, which are not classed as either SME or Large companies.

The table below is based on information received during consultation as well adapted Eurostat data and it shows that the overall number of enterprises is 441,066, of which 99.1% are micro and small, 0.7% are medium and 0.2% are Large. Most sectors have a larger proportion of companies as small, chimney sweeps (N81.22) have only small companies, while a few sectors have only, or a majority of medium and large companies (refineries C19.2, graphite and carbon electrode manufacturers C23.99b, aluminium C24.42).

Firefighters are classed as small for the purpose of modelling the impacts but are in fact owned by Local Authorities or government bodies depending on how the Member State manages them.

Table 3-105 Estimated number of EU enterprises with exposed workers by sector and by size of enterprise used in the study

Sector		Total number of enterprises	Number of enterprises with exposed workers		
			Small <50 employees	Medium 50-249 employees	Large >249 employees
C10.13	Meat and poultry smokehouses	210	194	13	3
C10.2	Seafood smokehouses	330	287	36	7
C16.1	Wood preservation (creosote)	40	39	1	-
C19.1	Coking plants	55	48	2	5
C19.2	Petroleum refineries	81	30	12	39
C20.13	Manufacture of carbon black	25	-	20	5
C20.14	Coal tar distillation	7	-	3	4
C23.2	Manufacture of refractory products	5	4	1	-
C23.99a	Manufacture of bituminous products	1,180	1,057	99	24
C23.99b	Graphite and carbon electrode manufacture	22	-	-	22
C24.1	Steel and iron foundries, ferroalloys	2,769	2,523	112	134
C24.42	Manufacture of aluminium	9	-	3	6
C24.45	Other non-ferrous metallurgy	80	67	8	5
C24.5	Casting of metals	4,742	4,017	541	184
D35.11	Coal fired power plants	196	126	45	25
E38.2	Waste incineration	650	597	43	10
E39	Soil remediation	3,378	3,280	88	10
F42.11	Road paving	30,949	29,375	1,285	289
F42.12	Welding of railway sleepers	2,016	1,914	83	19
G45.2	Motor vehicles maintenance and repairs	374,183	373,527	606	50
N81.22	Chimney sweeps	19,381	19,381	-	-
O84.25	Firefighters	758	N/A	N/A	N/A
Total		441,066	436,466	3,001	841

Source: Study team on basis of stakeholder result and Eurostat Structural Business Statistics.

Note: The number of firefighter enterprises refers to the number of local authorities responsible for the

employment of firefighters, which are not classed as either SME or Large companies.

The sum of all small, medium and large enterprises with exposed workers does not equal the 'total number of enterprises'. The difference is the number of firefighting enterprises which has not been included in the split by size, as the share of each size is not known.

3.10.5 Enterprises with exposed workers by size of enterprise and by Member State

Table 3-106 Estimated number of EU enterprises and exposed workers by Member State

Member State	Number of enterprises with exposed workers	Percentage of enterprises with exposed workers	Estimated number of exposed workers	Percentage of exposed workers
Belgium	10,931	2%	28,797	2%
Bulgaria	7,295	2%	21,365	2%
Czech Republic	22,185	5%	38,464	3%
Denmark	4,938	1%	15,252	1%
Germany	48,681	11%	267,876	21%
Estonia	1,919	0.4%	4,905	0.4%
Ireland	6,071	1%	12,000	1%
Greece	13,324	3%	23,766	2%
Spain	40,937	9%	112,529	9%
France	49,385	11%	177,844	14%
Croatia	3,977	1%	12,330	1%
Italy	64,499	15%	152,986	12%
Cyprus	1,923	0.4%	2,608	0.2%
Latvia	3,102	1%	7,037	1%
Lithuania	7,126	2%	10,775	1%
Luxembourg	241	0.1%	2,612	0.2%
Hungary	12,035	3%	30,486	2%
Malta	727	0.2%	1,039	0.1%
Netherlands	14,679	3%	41,181	3%
Austria	5,537	1%	35,704	3%
Poland	64,777	15%	126,390	10%
Portugal	15,586	4%	29,264	2%
Romania	12,666	3%	51,492	4%
Slovenia	3,019	1%	8,696	1%
Slovakia	8,107	2%	18,343	1%
Finland	5,597	1%	17,717	1%
Sweden	11,800	3%	32,585	3%
Total	441,061	100%	1,284,046	100%

Source: Study team on basis of stakeholder consultation results and Eurostat Structural Business Statistics.

Note: The numbers presented in this table may not align with totals presented elsewhere in this report due to rounding, although this does not have an impact on the overall analysis.

The figures in the above table illustrate that the number of estimated enterprises with exposure is higher in France, Germany, Italy, Poland, and Spain than other Member States; collectively making up 61% (268,279) of all enterprises. These Member States (MSs) also comprise of 65% (834,436) of all exposed workers.

For most Member States the number of workers appears to be proportional to the number of enterprises. In some MS this is not the case. For example, Germany has 11% of enterprises and 21% of workers, but Italy 15% share of enterprises and only 12% of workers. This is attributable to:

- the manpower requirements of specific industries in specific countries;
- likely also to the level of automation for the same industry in different countries; and
- the split of SME in Member States (large companies have more employees).

For example, the Czech Republic has approximately 22% of coking plants, while Poland and Romania have 19% and 17% each (estimated based on Eurostat figures). On average, without taking into account the size of the company, coking plants have approximately 46 exposed employees, whereas garages (G45.2) and road paving (F42.11) have 1. Similarly, France has 25% of enterprises manufacturing carbon and graphite electrodes, and Poland and Germany both have 20%. This industry employs on average 46 exposed employees per enterprise¹⁵.

Table 16-20 depicts the percentile distribution of exposed workers per EU Member State, by sector, as well as the population percentage of each Member State of the total EU27 population. This illustrates sectors that may have a higher concentration of exposed workers than their population share of the EU, and by extent may represent Member States which would be more heavily impacted by the policy options. Percentages in this table should also be understood in the context of the number of enterprises in each sector (also provided at the bottom of the table), as sectors with few enterprises will naturally present higher percentages as each company makes up a more significant proportion of the EU market. The distribution of sectors across Member States has primarily been conducted using Eurostat data which has a high degree of uncertainty due to complex issues with NACE code classification. Alternatively, the study team obtained data from industry for six sectors (C19.2 petroleum refineries, C20.14 coal tar distillation, C23.99b graphite and carbon electrode manufacture, C24.42 manufacture of aluminium, D35.11 coal fired power plants, and O84.25 firefighters) regarding the distribution of enterprises. Overall, the study team has a higher degree of confidence in the geographic distribution of these sectors. The following bullets outline where sectors may have a high concentration of companies/workers and subsequently where impacts may be felt to a greater degree:

- C10.13 Meat and poultry smokehouses:
 - Bulgaria, Czech Republic, Germany, Estonia, Ireland, Spain, France, Croatia, Italy, Cyprus, Latvia, Lithuania, Hungary, Netherlands, Austria, Poland, Portugal, Romania, Slovenia, Slovakia, Finland, and Sweden;
- C10.2 Seafood smokehouses:

¹⁵ The average number of employees per enterprise has been calculated by dividing the total number of exposed employees presented in Table 3-91, by the number of total enterprises with exposed workers presented in Table 3-105.

- Bulgaria, Denmark, Estonia, Ireland, Greece, Spain, France, Croatia, Latvia, Lithuania, Netherlands, Poland, Portugal, Finland, and Sweden;
- C16.1 Wood preservation (creosote):
 - Bulgaria, Czech Republic, Germany, Estonia, Ireland, France, Croatia, Latvia, Lithuania, Hungary, Austria, Poland, Portugal, Romania, Slovenia, Slovakia, Finland, and Sweden;
- C19.1 Coking plants:
 - Czech Republic, Italy, Hungary, and Poland;
- C19.2 Petroleum refineries:
 - Belgium, Bulgaria, Ireland, Greece, Spain, Croatia, Italy, Lithuania, Hungary, Austria, Poland, Slovakia, Finland, and Sweden;
- C20.13 Manufacture of carbon black:
 - Belgium, Bulgaria, Denmark, Germany, France, Italy, Netherlands, Austria, Poland, Romania, Slovenia, Finland, and Sweden;
- C20.14 Coal tar distillation:
 - Belgium, Czech Republic, Denmark, Germany, Spain, and Poland;
- C23.2 Manufacture of refractory products:
 - Hungary, Netherlands, Austria, Poland, Portugal, Slovenia, Slovakia, and Sweden;
- C23.99a Manufacture of bituminous products:
 - Belgium, Bulgaria, Czech Republic, Denmark, Germany, Ireland, Greece, Spain, Croatia, Italy, Lithuania, Luxembourg, Hungary, Austria, Poland, Portugal, Romania, Slovenia, Slovakia, Finland, and Sweden;
- C23.99b Graphite and carbon electrode manufacture:
 - Germany, Spain, France, Austria, Poland, Romania, and Slovakia;
- C24.1 Steel and iron foundries, ferroalloys:
 - Belgium, Czech Republic, Denmark, Germany, Spain, France, Italy, Luxembourg, Hungary, Austria, Poland, Romania, Slovenia, Slovakia, and Finland;
- C24.42 Manufacture of aluminium:
 - Germany, Greece, Spain, France, Romania, and Sweden;
- C24.45 Other non-ferrous metallurgy:

- Belgium, Germany, France, Italy, Netherlands, Austria, Slovakia, and Finland;
- C24.5 Casting of metals:
 - Bulgaria, Czech Republic, Denmark, Germany, Spain, France, Croatia, Italy, Hungary, Austria, Poland, Portugal, Slovenia, Slovakia, Finland, and Sweden;
- D35.11 Coal fired power plants:
 - Bulgaria, Czech Republic, Denmark, Germany, Greece, Croatia, Hungary, Netherlands, Poland, Romania, Slovenia, Slovakia, and Finland;
- E38.2 Waste incineration:
 - Belgium, Bulgaria, Czech Republic, Denmark, Germany, Estonia, Ireland, Spain, France, Croatia, Italy, Cyprus, Latvia, Lithuania, Luxembourg, Hungary, Malta, Netherlands, Austria, Poland, Portugal, Slovenia, Slovakia, and Finland;
- E39 Soil remediation:
 - Belgium, Bulgaria, Czech Republic, Denmark, Germany, Estonia, Ireland, France, Croatia, Italy, Cyprus, Latvia, Lithuania, Luxembourg, Hungary, Malta, Netherlands, Austria, Poland, Portugal, Romania, Slovenia, Finland, and Sweden;
- F42.11 Road paving:
 - Belgium, Bulgaria, Germany, Estonia, Ireland, Greece, Spain, France, Croatia, Cyprus, Latvia, Lithuania, Luxembourg, Hungary, Netherlands, Austria, Poland, Portugal, Romania, Slovenia, Slovakia, Finland, and Sweden;
- F42.12 Welding of railroad tracks:
 - Belgium, Bulgaria, Denmark, Germany, Estonia, Spain, Croatia, Italy, Latvia, Lithuania, Luxembourg, Hungary, Netherlands, Austria, Poland, Portugal, Romania, Slovenia, Slovakia, Finland, and Sweden;
- G45.2 Motor vehicles maintenance and repairs:
 - Belgium, Bulgaria, Czech Republic, Denmark, Germany, Estonia, Ireland, Greece, Spain, France, Croatia, Italy, Cyprus, Latvia, Lithuania, Luxembourg, Hungary, Malta, Netherlands, Austria, Poland, Romania, Slovenia, Slovakia, Finland, and Sweden; and
- N81.22 Chimney sweeps:
 - Belgium, Bulgaria, Denmark, Germany, Estonia, Ireland, France, Italy, Cyprus, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Austria, Poland, Portugal, Slovenia, Finland, and Sweden.

Table 3-107 Estimated number of enterprises with exposed workers by key sector and by Member State

EU MS	C10.13	C10.2	C16.1	C19.1	C19.2	C20.13	C20.14	C23.2	C23.99a	C23.99b	C24.1	C24.42	C24.45	C24.5	D35.11	E38.2	E39	F42.11	F42.12	G45.2	N81.22	O84.25
BE	2	6	1	-	6	1	1	-	17	-	71	-	1	51	-	19	121	1,250	71	7,750	1,545	19
BG	2	4	1	-	1	1	-	-	72	-	3	-	-	77	11	10	26	476	45	6,453	101	12
CZ	3	2	2	12	-	-	1	-	67	-	65	-	3	835	25	29	112	-	-	21,009	-	20
DK	-	9	-	-	-	-	1	-	14	-	24	-	-	45	4	6	22	78	41	3,790	893	11
DE	83	21	3	2	-	5	1	1	142	4	459	3	44	661	60	132	345	2,676	220	38,687	4,973	159
EE	-	7	-	-	-	-	-	-	3	-	1	-	-	5	-	3	12	213	11	1,598	63	3
IE	1	11	-	-	1	-	-	-	15	-	263	-	-	53	1	10	43	647	11	4,756	249	9
EL	2	10	-	6	6	1	-	-	43	-	31	1	1	76	3	10	37	1,023	61	11,884	114	15
ES	24	62	1	6	15	2	2	1	95	2	260	1	5	442	7	46	85	511	173	38,687	434	76
FR	32	35	3	-	-	1	-	-	120	6	37	2	6	269	6	67	960	750	60	43,426	3,499	106
HR	1	5	1	-	4	-	-	-	12	-	8	-	-	47	1	10	15	227	12	3,459	168	6
IT	17	44	3	4	22	4	-	1	217	1	545	-	10	937	7	94	644	2,584	108	58,636	534	86
CY	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1	9	46	-	1,804	60	2
LV	1	9	1	2	-	-	-	-	2	-	4	-	-	5	-	2	9	281	15	2,622	146	3
LT	1	8	1	-	1	-	-	-	3	-	-	-	-	9	-	9	12	114	7	6,898	57	5
LU	-	-	-	-	-	-	-	-	3	-	2	-	-	-	-	1	3	37	3	172	19	1
HU	1	1	1	3	4	1	-	-	31	-	19	-	-	136	3	16	50	1,290	131	9,825	505	18
MA	-	-	-	-	-	-	-	-	3	-	22	-	-	-	-	1	3	-	-	693	4	1
NL	3	16	-	-	-	1	-	-	26	-	49	-	1	95	4	16	85	5,934	121	6,104	2,188	36
AU	7	1	1	-	1	1	-	-	28	2	9	-	2	43	-	26	21	281	35	4,723	339	16

EU MS	C10.13	C10.2	C16.1	C19.1	C19.2	C20.13	C20.14	C23.2	C23.99a	C23.99b	C24.1	C24.42	C24.45	C24.5	D35.11	E38.2	E39	F42.11	F42.12	G45.2	N81.22	O84.25
PL	13	32	7	10	7	4	1	1	143	4	73	-	2	472	43	33	323	9,420	501	51,548	2,076	64
PT	5	15	1	-	-	-	-	-	30	-	27	-	-	120	-	11	78	412	25	14,654	190	18
RO	4	4	3	9	-	1	-	-	39	1	35	1	1	139	8	11	226	1,559	83	10,258	254	30
SI	2	1	1	-	-	-	-	-	10	-	5	-	-	71	2	4	14	174	9	2,616	106	4
SK	1	-	7	-	1	-	-	-	15	1	701	-	-	41	4	65	43	130	16	6,924	148	10
FI	1	12	1	-	3	1	-	-	9	-	25	-	-	38	7	11	28	253	40	4,884	274	10
SE	2	18	1	-	7	1	-	-	16	-	31	1	2	74	-	10	55	582	217	10,324	439	20
Total	208	333	40	54	81	25	7	4	1,176	22	2,769	9	78	4,741	196	653	3,381	30,948	2,016	374,184	19,378	758
Of total (%)	0.05	0.08	0.01	0.01	0.02	0.01	0.002	0.001	0.27	0.005	0.63	0.002	0.02	1.08	0.04	0.15	0.77	7.03	0.46	84.96	4.40	0.17

Source: Study team on basis of stakeholder result and Eurostat Structural Business Statistics.

Notes: The sum totals presented in the above table may not match the totals presented elsewhere in this report due to rounding.

The number of firefighter enterprises refers to the number of local authorities responsible for the employment of firefighters.

3.10.6 Cross border aspects

When one common EU standard replaces 27 different standards, businesses active cross border in the internal market will experience a simplification in the regulatory environment that needs to be considered.

As a part of this study, it should also be considered that in some cases differences in OEL values between individual Member States may create difficulties in harmonising processes to meet required OELs. For example, a company operating in one Member State may have different OELs to another Member State where they also have operations. This means companies may have difficulty in implementing RMMs, as they may be required in one Member State but not others. This may be the case for companies with multiple sites (such as refineries, some manufacturers of graphite and carbon electrode, carbon black, coking plants and foundries) within the EU if the Member States operated within have national OELs (Austria, Bulgaria, Czech Republic, Denmark, Estonia, Finland, Germany, Greece, Hungary, Latvia, Lithuania, Netherlands, Poland, Slovakia, Slovenia, Sweden).

In the case of PAH, the impacts of introduced OELs are expected to be felt at the 7, 70 and 700 ng/m³ policy options due to the current exposure concentrations, and current OEL for each MS that has one. Germany has the lowest OEL where the tolerable concentration is 70 ng/m³ however the acceptable concentration is 700 ng/m³. Latvia and Bulgaria have the second lowest OEL at 150 ng/m³, followed by The Netherlands at 550 ng/m³ (see Table 16-17).

Manufacturers of carbon black, coking plants, coal tar distillation plants, foundries, refineries, graphite and carbon electrode manufacturers tend to be owned by multinational companies who operate at the European and/or global levels. For these companies it is expected that they would be able to draw expertise and experience in reducing exposure levels if operating across multiple Member States.

Chimney sweeps, road paving, smokehouses, soil remediation companies, motor vehicle maintenance and repairs and refractories are dominated by small companies, for which cross-border aspects would not apply. Firefighters are owned by public authorities for which cross-border aspects also do not apply.

3.10.7 Market trends

Generally speaking, metallurgical (e.g. aluminium, steel and iron, other metallurgy) and related industries (coking, graphite and carbon electrodes) have been hard hit from high energy costs and there have been several closures in the last few years (Stakeholder consultation, 2023, see also section 3.4.5 for further details). The impact of the closures is taken into account in the baseline, both in terms of the current number of companies that has been estimated based on feedback from stakeholders, where available, and also in terms of trends where for example refineries and coal powered plants are expected to close in future. There are some upward trends going forward in terms of aluminium and silicon metal demand, see section 4.5 for further details.

Refineries have also experienced a downward trend: since 2009, out of nearly 100 refineries operating in Europe, 26 mainstream refineries were closed or transformed. Currently, five refineries in Europe have undergone a transformation process, converting from oil to biorefineries (Fuels Europe, 2022). There has been a downward trend of demand for oil products in the last decade in EU27 countries, and even with a recent spike (Fuels Europe, 2023), given the EU drive for low Green House Gas (GHG) emissions and to be climate neutral by 2050 (European Commission, 2020 a,b), this trend is likely to continue. More details on future trends are presented in section 4.5.

The number of coal fired power plants has halved in the last decade (see section 3.4.4.14) and since 2012, total coal power generation has dropped by almost a third in the EU, two thirds of the coal power plants currently operating in Europe are expected to close between 2020 and 2030 (JRC, 2018).

The baseline reflects the current number of refineries taking into account recent closures and future trends are given consideration in section 4.4.

3.11 Alternatives

Substitution is a key risk management measure for companies having difficulty achieving an OEL. Therefore, it is important to know whether alternatives exist for PAH. The possible alternatives are discussed below.

3.11.1 C10.13 and C10.20 Fish and meat smokehouses

Smoking was initially developed as a means for preservation, but this is no longer the driver for smoking foods. The use of liquid smoke flavouring can replace the need for combustion processes that impart the smoke flavour to foods.

Smoked meat and fish can have a maximum content of 2 µg/kg of BaP in the EU (Commission Regulation (EU) No 835/2011¹⁶, regardless of the source. A study on smoked salmon found that the BaP PAH content in fish was higher in “naturally” smoked food (from not quantified to 0.111 µg/kg) but still present in similar levels in artificially smoked food (0.047-0.085 µg/kg) (Varlet, et al., 2007).

Liquid smoke flavourings are produced by controlled thermal degradation of wood in a limited supply of oxygen (pyrolysis), subsequent condensation of the vapours and fractionation of the resulting products. The primary products, i.e. primary smoke condensates and primary tar fractions, obtained through this process, may be further processed to produce smoke flavourings which can be applied in or on the surface of foods. Smoke flavourings primary products are derived from hardwoods such as beech and oak (Theobald et al., 2012).

Because the process is closed (to collected condensed vapours), as opposed to semi-closed for food smoking, there is likely less exposure to workers, particularly in comparison to traditional methods. It is unclear to the study team how exposure compares to the more modern methods of fish smoking that use automation and semi-closed systems. Industry was not available for additional input.

3.11.2 C16.1 Wood impregnation (creosote)

There are alternatives to the impregnation of wood with creosote for preservation processes, such as the use of steel, plastic or concrete posts or the use of copper-based preservatives. However, the Biocidal Product Committee indicated that additional time is needed to enable the necessary progress on the availability and technical applicability of these alternatives. The technical feasibility and the technical applicability of the alternatives for the use of creosote differs per Member State, for example due to a difference in geographical conditions (ECHA, 2020). Time is needed to test and have a sufficient return on experience of those alternative products, and to ensure that they can meet the long service life expected of railway sleepers (Commission Implementing Decision, 2022).

¹⁶ Available at <https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:215:0004:0008:En:PDF>

The Commission Implementing Decision concluded that the non-approval of creosote as an active substance for use in biocidal products would have a disproportionate negative impact on society in comparison to the risks. The active substance is due for renewal on 31 October 2029 and a review of technical and economic feasibility of alternatives will be conducted. The study team is not able to say with any certainty whether the active substance will be renewed or not.

3.11.3 C19.1 and C24.1, C24.45, C24.5: Coking, metallurgical processes and casting

In the metallurgical sector, coke is needed since coal does not have the mechanical strength to be used in blast furnaces and it contains impurities that would affect the resulting product, therefore metallurgical coke must be used. The amount of coke used in the blast furnaces per ton of hot metal produced has already been reduced as far as is currently possible without compromising on the resulting product (Stakeholder Consultation, 2023). This has been achieved through e.g. the injection of pulverized coal into the blast furnace. However, the use of coke in blast furnaces cannot be avoided and therefore the operation of coking ovens to manufacture coke is also essential for blast furnaces in steel and iron foundries, including ferroalloys, and in casting.

Coking coal has a high mechanical strength, which makes it stable thanks to the high content of non-volatile carbon and good gas permeability. Petcoke is not a suitable alternative because it does not have the same level of mechanical strength.

The European steel industry is testing and gradually transitioning to hydrogen-based steel production processes, either using hydrogen as a pulverized coal injection replacement or using hydrogen-based direct reduction. This reduces the need for coal products in this industry and also reduces the temperature needs and thus electricity consumption of the industry. The technology however is not widespread and there are barriers such as, mainly: the higher cost of hydrogen compared to coal products, the lack of suitable infrastructure to produce and transport hydrogen and safety (hydrogen is flammable), the availability of green hydrogen (from renewables) and last but not least, the technology is feasible but has yet to be proven on a large scale (McKinsey & Company, 2020).

The use of hydrogen powered plants is dependent on the availability of electrolyzers, which in turn require graphite (natural or synthetic graphite, but the latter is made with coal tar pitch), see considerations for C23.99b graphite and carbon electrodes further down.

3.11.4 C19.2 Petroleum refineries

Due to the nature of the sector, refining petroleum, there is no alternative. However, traditional refineries are diversifying and developing alternative fuels such as biofuels. BP for example has been heavily investing in biogas and bioenergy, and they are the most common renewable fuel and can often be produced in refinery processes by mixing bio-based and fossil-based raw materials. The EU aims to increase the share of renewable energy in transport to at least 14%, including a minimum share of 3.5% of advanced biofuels (European Commission, 2023a).

Refineries also produce bitumen for road paving and a large number of petrochemicals. It is beyond the scope of this report to provide an analysis of alternatives for all petrochemicals, but it is likely that while there are currently available drop-in substitutions for some substances and processes, others will take time and additional research and development (R&D).

3.11.5 C20.13 Manufacture of carbon black

Similarly to refineries, due to the nature of the business, the availability of alternatives focuses on alternatives of the products in which the output of the carbon black and coal tar distillation plants feed into.

Carbon black is primarily used in tyres. Technologies are emerging that recover carbon black from tyres, through pyrolysis and mineralisation to produce recovered carbon black. Tyres can be recycled into other products, such as hoses but it is not currently possible to make tyres out of 100% recycled materials. Companies are working towards this goal and at least one company has indicated that by 2050 latest its tyres will be made entirely with sustainable materials (Continental, 2023). It is important to note that pyrolysis processes will still be required, and the level of exposure is not known.

Carbon black is used in a myriad of other sectors: non-tyre rubbers (such as belts, hoses and gaskets to name a few, to enhance mechanical properties), plastics (to provide UV protection, colour and conductivity), inks and coatings (to provide colour and protection from UV radiation), batteries (to improve conductivity and ultimately battery efficiency) (ICBA, online). It is beyond the scope of this report to analyse the availability of alternatives in all applications, and whether recovered carbon black can be used in these.

3.11.6 C20.14 Coal tar distillation

Similarly to refineries, due to the nature of the business, the availability of alternatives focuses on alternatives of the products in which the output of coal tar distillation plants feed into.

Coal tar distillation uses coal tar and it has the potential to be replaced with petroleum tar in order to obtain chemicals such as petroleum pitch. Petroleum pitch has a lower PAH and BaP content and is used instead of CTPht as a resin for refractory purposes and to a certain extent also in the manufacture of carbon electrodes. See considerations under C23.99b graphite and carbon electrodes.

Other chemicals manufactured from coal tar distillation are creosote, naphthalene, benzene, scrub oil to name a few. Organic chemicals such as benzene and naphthalene can be obtained via refineries and other streams. Creosote can be obtained via the distillation of petroleum tar rather than coal tar, but it could not be made in coal tar distillation plants as the process is different (EPA 2023).

During the consultation it emerged that coal tar distillation plants also manufacture wash oil, an industrial scrubbing agent (scrub oil), which is used in industrial installations to capture emissions. The study team has insufficient knowledge of the topic to comment on whether alternatives are available, however, companies are using scrubber oil as a bargaining chip in feedstock negotiations/procurement, indicating that alternatives to the oil may be scarce.

3.11.7 C23.2 Manufacture of refractory products

Refractory products such as bricks, ceramics and pastes have largely successfully been replaced with bitumen derived products or resins, which contain a lower amount of PAH and BaP, also thanks to the regulatory drivers.

The slide gates used in steel foundries and casting still require the use of CTPht due to the high temperature and use (where molten steel is poured). See section 3.3.6 for further information.

3.11.8 C23.99a Manufacture of bituminous products and F42.11 Road paving

Road paving requires bitumen. In situ recycling of roads is possible (see text under Table 3-5), saving material and transport costs and related emissions. Bitumen will still need to be heated, leading to similar levels of exposure to BaP.

Asphalt foaming and additives allows the manufacturing of asphalt at reduced temperatures, referred to as “warm mix asphalt” (WMA) (whereas traditional methods are referred to as “hot mix asphalt” HMA). A pilot study was undertaken in Norway in 2011, which assessed the working environment at 11 trial sections during road paving works with both HMA and WMA on the same day showed an average (arithmetic mean) statistically significant reduction in asphalt fumes of 58-67% (depending on the measurement method) at a mean reduction in asphalt temperature of 29°C (FAV, 2011). The application is roughly 20-30°C cooler than HMA, and results in both fume emission reductions and energy savings. In Norway around 30% of asphalt is WMA (where the government incentivised the manufacture and use of WMA). The technology can also be applied to mastic asphalt. The barrier to entry in the market is the concern and need to meet customer (Local Authority) specifications and the initial investment to ensure these are met (Stakeholder Consultation, 2023). Mixing of asphalt at lower temperatures will also impact the plants where asphalt is produced.

Very recently, some bitumen companies have also developed bitumens containing special additives, which (according to the manufacturers) can reduce the fumes emissions from asphalt when it is hot. The sector does not have yet enough experience to fully assess the potential of this kind of solution (Stakeholder Consultation, 2023).

3.11.9 C23.99b Graphite and carbon electrode manufacture, and dependent sectors

The manufacture of graphite and carbon electrodes has been trialled with petroleum tar, coal-extracted and gasification pitches. The carbon, graphite as well as the steel and aluminium industries’ experience with 100% petroleum pitch has resulted in uneconomical carbon consumption and poor performance. The lower carbon yield of petroleum pitch leads to products with less strength failing in application. All other tested alternatives failed to be used on a commercial scale for the majority of products and tonnages produced (Stakeholder Consultation, 2023).

ECGA have indicated that a study on the substitution potential of CTPht is underway but the study will not be ready in time for this study. In general, an alternative needs to be stable, conductive and graphitizable, and the bigger the object the harder it is to find a substitute (e.g. electrode in electric arc furnace) (Stakeholder Consultation, 2023). As pointed by stakeholders, should an alternative become available in the near future, it is likely that a full replacement of CTPht will take several years. Carbon and graphite products feed into the aluminium and steel industries, which are in turn raw materials in sectors such as automotive and aircraft that have strict safety standards that need to be tested and fulfilled.

The sectors affected are thus C24.1 steel and iron foundries and C24.5 casting of metals with electric arc furnaces, C24.42 aluminium manufacture and C24.45 other metallurgical processes.

Graphite in itself is used in a myriad of applications, see Figure 3-3, see and may be substituted by natural graphite, however natural graphite has been identified as a critical raw material (JRC, 2020).

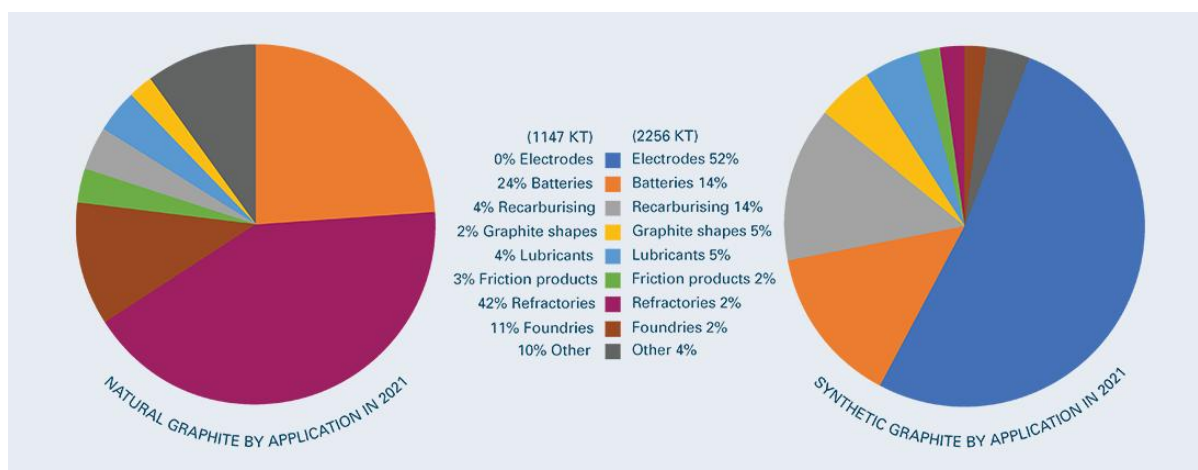


Figure 3-3: Applications of natural and synthetic graphite
Source: ECGA 2023b

Approximately 50% of weight of Li-ion batteries is made with graphite, where a battery for an electric vehicle or for stationary applications contains on average 65% synthetic, 35% natural graphite, and batteries for electronics contain both at varying ratios, but roughly 50%/50% of both (ECGA, 2023b).

Natural graphite and synthetic graphite are used interchangeably in most applications, see Figure 3-4. Of note in the figure below is that synthetic graphite cannot be used for electrolyzers. It is not clear to the study team what type of electrolyzers are intended but it is likely referring to graphite bipolar plates in water electrolyzers for green hydrogen production among other types of electrolyser such as chlor-alkali electrolyzers for the production of chlorine and sodium hydroxide.

Technology	Natural Graphite	Synthetic Graphite
Li-ion batteries	✓	✓
Fuel cells	✓	✓
Electrolysers	✓	
Wind turbines	✓	✓
Traction motors	✓	✓
Solar PV		✓
Heat Pumps		✓
H2 -DRI		✓
Data transmission networks	✓	
Data storage and services		✓
Smartphones, tablets and laptops	✓	✓
Additive manufacturing	✓	✓
Robotics	✓	✓
drones	✓	✓
Space launchers and satellites	✓	✓

Figure 3-4: Overlap in applications of natural and synthetic graphite
Source: ECGA, 2023b

3.11.10 D35.11 Coal fired power plants

Coal fired power plants can be retrofitted to operate on biomass (JRC, 2018), and they can be retrofitted with carbon capture, utilisation and storage technologies to reduce emissions (IEA, 2021).

Alternative ways to generate power such as renewable energy are well established and coal is gradually being phased out, even though there is no target to remove coal fired power plants, the EU has a target to reduce GHG emissions that will impact coal fired power plants (see section 4.4).

3.11.11 E38.2 Incineration of waste

The nature of the sector requires pyrolysis, which in turn can generate PAH. Reduction of waste and a more circular economy have the potential to reduce emissions and exposure related to incineration of waste.

3.11.12 E39.0 Soil remediation

Due to the nature of this work, an alternative is not applicable for this sector.

3.11.13 F42.12 Welding of train tracks

The welding of train tracks impregnated with creosote is unavoidable, however it is possible that in future train tracks will not require wood impregnated with creosote (see section 3.11.2), removing this activity altogether.

3.11.14 G45.2 Motor vehicle maintenance and repair

The exposure to PAH may become negligible once internal combustion engines (ICE) are less prevalent. The EU is on a path to ban the sale of new ICE by 2035.

3.11.15 N81.22 Chimney sweeps

Chimney sweeps do not use materials that generate PAH, but are exposed to PAH through surveys and clean-up operations. Domestic solid fuel burners account for roughly 50% of the work of chimney sweeps. The removal of domestic fuel burners could significantly reduce exposure of chimney sweeps to PAH, but it would also reduce the number of workers needed overall in the sector.

3.11.16 O84.25 Firefighters

Similarly to soil remediation workers, an alternative is not applicable for this sector.

3.11.17 Summary of availability of alternatives by sector

A summary of availability of alternatives by sector is provided in the table below.

Table 3-108 Summary of availability of alternatives by sector

Sector		Availability of alternatives
C10.13, C10.20	Smokehouses	Smoke flavouring can be used instead. Reduced PAH exposure is to be expected thanks to the use of closed systems, however the process still relies on incomplete pyrolysis of wood and food will still contain PAH.
C16.1	Wood impregnation - creosote	Potentially steel, plastic or concrete posts or the use of copper-based preservatives can be used instead. However, additional time is needed to test the durability and technical applicability in different geographical locations.
C19.1	Coking	Coking coal is mainly used in steel furnaces as a reducing agent. Hydrogen as a reducing agent is a new technology that is gaining traction but it is not yet widely available. In any case, the by-product of coking coal, coal tar, is currently needed to make electrodes that will be needed also when hydrogen is used as a reducing agent (see 23.99b).
C19.2	Refineries	Refineries refine crude petroleum, therefore there is limited scope for alternatives. Traditional refineries are diversifying and developing alternative fuels such as biofuels. Refineries also manufacture bitumen for road paving, heavy fuel oil used in ships and a myriad of other products and further refinement into petrochemicals. It is beyond the scope of this report to identify alternatives for all streams.
C20.13	Carbon black	Recovered carbon black from used tyres can result in lower PAH products. At the time of writing the report, there are no tyres made of 100% recovered carbon black. It is unclear whether recovered carbon black can be used in all products in which virgin carbon black is used.
C20.14	Coal tar distillation	Coal tar distillation plants can potentially transfer to petroleum tar distillation. However the output products will differ. Of note are: coal tar pitch, which is needed in the manufacture of graphite and carbon electrodes, which are then used in all metallurgy, and in specialised refractory products. It is unclear whether scrubber oil, which is used in abatement system of coking plants, has any alternatives.
C23.2	Refractory products	The specific use of CTPht in refractory products used in the slide gates of steel and iron foundries has currently no alternative.
C23.99a and F42.11	Bitumen products and road paving	Bitumen for road paving can be manufactured as a "warm mix asphalt" (WMA) through the use of foaming and additives that results in asphalt being applied at reduced temperatures. It is not known whether manufacturing of WMA can also result in lower exposure during production or whether the same technique can be used for bitumen used in the manufacture of other products such as roofing felts.

Sector		Availability of alternatives
C23.99b	Graphite and carbon electrodes	Currently, there is currently no alternative to CTPht in the manufacture of carbon and graphite electrodes. Carbon and graphite products feed into the aluminium and steel industries, which are in turn raw materials in sectors such as automotive and aircraft that have strict safety standards that need to be tested and fulfilled.
C24.1, C24.45, C24.5	Metallurgical sectors: coke	The amount of coke used in blast furnaces has already been reduced as much as possible. Petcoke is not a suitable alternatives because it is does not have the same level of mechanical strength.
C24.1	Blast furnaces	The steel industry is testing and gradually transitioning to hydrogen-based steel production processes, either using hydrogen as a pulverized coal injection replacement or using hydrogen-based direct reduction.
C24.1, C24.5	Blast furnaces	Electric arc furnaces can be used for secondary steel production (but still require electrodes) and to heat scrap steel before casting.
D35.11	Coal fired power plants	Coal fired power plants can be retrofitted to operate on biomass, but this may not be applicable to all plants. Electricity can be generated via other means, notably the choice of renewables is location dependent.
E38.2	Incineration of waste	Alternatives are not applicable to these sectors.
E39.0	Soil remediation	
F42.12	Welding of train tracks	The removal of creosote impregnated wood would no longer require the train tracks to be welded to them. Alternatives explored under BPR regulations have been concrete or PVC sleepers but with limited success due to reduced durability.
G45.2	Motor vehicle maintenance	There are no alternatives that can be used by the sector, however exposure to PAH is likely to reduce once the impact of the sale of new ICE from 2035 on total fleet numbers becomes substantial.
N81.22	Chimney sweeps	Similar to the previous sector, there are no alternatives that the sector can use. However, domestic use of solid fuel can be replaced by alternatives, such as electric heating and heat pumps, which will reduce exposure to workers via these sources, but will also reduce the number of workers overall.
O84.25	Firefighters	Alternatives are not applicable to this sector.

Source: Study team summary on the basis of information presented in this section.

3.12 Impact of Covid-19 on current situation

The Covid-19 pandemic slowed down production in all sectors, some of which have yet to recover since pre-pandemic levels due to changes in supply chain and chronic shortages of workers. In the steel sector for example, the employment rate in 2021 and 2022 did not recover to pre-COVID levels. Other recent factors have also been of great influence. Always in the steel sector the war in Ukraine and subsequent increases in energy prices have reduced output, coupled while strong increases in imports. (EUROFER, 2023)

According to the consultation, Covid-19 has not impacted the use of masks, which in many sectors were required regardless or respondents have indicated that masks used for the purpose of Covid cannot be used as respiratory protective equipment (RPE) for their sector.

The impact of Covid on production is not being modelled because the study team is basing the analysis on data from Eurostat that reflects the market pre-Covid. The markets are anticipated to have recovered to pre-pandemic levels by the end of this year.

3.13 Current disease burden (CDB)

The current burden of disease for lung cancer, and male and female reproductive toxicity is estimated using the data in the preceding sections for exposed workers, combined with data on exposure concentrations and the exposure response relationship (ERR) and dose response relationship (DRR). The data are combined with data on past trend in exposure concentrations and exposed workforce, latency and workforce turnover.

3.13.1 Past trend in exposure concentrations and exposed workforce

Overall, (Peters, et al., 2016) have found decreasing a time trend of -1.2% per year (0.7-3.1% 95% CI) for personal BaP exposure between the 1970s and 2009 (see section 3.3.6).

Another study has estimated that in 1980 BaP exposure concentrations were 0.019 $\mu\text{g}/\text{m}^3$ for low and 0.032 $\mu\text{g}/\text{m}^3$ for high exposure jobs, while in 2000 the concentrations were respectively 0.015 $\mu\text{g}/\text{m}^3$ and 0.025 $\mu\text{g}/\text{m}^3$ (Olsson et al., 2022).

PAH exposure has previously shown to decrease more rapidly over time: -11% in road paving per year between 1972-1998 in several European countries and Israel, and -19% in the aluminium industry in Norway between 1978-1996 (Creely et al., 2007). These figures are not applied as they present a sub-section of countries and are applicable to a shorter time period than the figures presented by Peters et al. (2016).

Eurostat provides data for the relevant sectors dating back until 2005, however many datapoints are unavailable or are not suitable to devise historic trends to use for the CDB. Eurostat is also problematic for some sectors as data are only available at high/generic NACE code level and figures include multiple subsectors that are not relevant to this study.

3.13.2 Latency and workforce turnover

The time required for the endpoints to develop over an average working life takes into account the minimum and maximum time required to develop the condition (MinEx and MaxEx) and the distribution of new cases between these two points in time, combined with the latency period with which the effects are diagnosed.

The MinEx and MaxEx for the two endpoints and the latency are summarised in Table 3-109.

Table 3-109 Latency and maximum exposure duration to develop a condition (MaxEx)

Endpoint	MinEx (years)	MaxEx (years)	Latency (years)
Lung cancer	0	40	30
Developmental toxicity	0	0	0
Male infertility	0	0	0

Source: See Methodological note for more details

3.13.3 Current disease burden

The current burden of disease (i.e. the number of cases diagnosed in 2023) is estimated on the basis of historical exposure. For example, if cancer endpoint has a latency of 30 years, the model assumes that the cases diagnosed in 2023 reflect the risk that occurred 30 years ago in 1993 due to latency. Alternatively developmental toxicity and male infertility do not have a latency period meaning that cases in 2023 would occur from exposure in the past year.

The study team were unable to estimate the number of workers exposed in 1993 due to a lack of robust employment trend data from Eurostat. Instead, the study team has modelled the current disease burden on the basis that the number of exposed workers in 1993 is the same as in 2023 as used for the calculation of the future disease burden; 1,284,052 exposed workers. This may under or overestimate the number of lung cancer cases occurring in 2023 due to previous exposure, although an accurate number of exposed workers in 1993 is not known. EU CAREX (1999) data supports this modelling approach due to having similar numbers of exposed workers in this period. Current cases of development toxicity and male infertility are unaffected by the absence of robust trend data.

For the current disease burden the study team modelled historic exposure levels from those estimated in 2023, by -1.2% annually for 40 years (a historic annual increase 1.2% each year).

Table 3-110 Current burden of disease due to past exposure (based upon modelled data from 2000 to 2023)

Endpoint	New cases per year (incidence) in 2023
Lung cancer	5.1
Developmental toxicity	0.94
Male infertility	78

Source: Study team on basis of information presented in this section.

In addition to the above, endpoints with latency greater than zero (lung cancer) will continue to produce cases due to exposure in the last 40 years which will occur in the next 40 years. These are referred to in section 4.9.2 as the legacy burden of disease, together with the current burden of disease.

3.13.4 Comparison with data on recognised cases and epidemiological data

In the study by Petit et al. 2019 a comprehensive BaP exposure data collection in France and analysis was undertaken that includes many of the sectors covered in this study and divided by task where possible.

The study found that workers exposed to products from coal was found to be higher than in workers exposed to PAH mixtures via products derived from petroleum. The study calculated the risk of developing cancer based on exposure levels and the carcinogenic potency of BaP (ERR) and found that workers in coke production had the highest level of risk, regardless of the activity, and those in the manufacture of silicon also had a high risk, particularly those in maintenance. Other sectors with high risk are aluminium plant workers, particularly conducting maintenance tasks, in the paste tower and ramming operations. In the manufacture of carbon electrodes and graphite raw cathode extrusion activities were of particular concern, and steel foundries had the highest risk on fusion furnace operators.

The study concluded that a total of 27 additional lung cancer cases could be expected per year in French exposed workers, alone.

In this study a total of 5.1 additional lung cancer cases have been calculated for the EU. The difference is due to:

- In the Petit et al. 2019 study the use of PPE was not taken into account, although 65% workers were wearing gloves and 43% were wearing respiratory protective equipment

(RPE). Whereas the calculation of costs and benefits of an OEL in this study does take into account the use of RPE, with a minimum protection factor of 4 and up to 30 (minimum);

- The exposure data from the Petit et al. 2019 has also been evaluated in this study, but not always given the same weight when calculating current exposure levels. More recent data with the higher degree of detail are preferred. In addition, the scope of the study by Petit et al. is wider than in this report as sectors with measurements below the lowest OEL were not assessed (since the introduction of an OEL in this case would not impact the sector). However, BaP is a non-threshold carcinogen therefore cancer cases are expected to occur even at concentrations lower than the lowest policy option.
- The current study has not applied a trend to the number of exposed workers, but it is likely that these would have been significantly higher forty years ago, resulting in a higher current burden of disease.

A study in Canada has estimated that there are approximately 130 lung cancer cases each year due to occupational exposure to PAH based on past exposures (1961-2001) (CAREX, 2019). The same considerations made for the French study by Petit et al. 2019 apply here too.

3.14 Summary of the current situation

3.14.1 Risk to workers' health

Worker exposure to PAH (with BaP inhalable fraction as indicator for PAH mixtures) has three primary risks to workers health. For all workers exposed there is a risk of developing lung cancer. For all women of reproductive age who are exposed during pregnancy there is a risk of miscarriage or stillbirth (developmental toxicity). For all men of reproductive age there is a risk of reduced sperm motility (reproductive toxicity). For more details see section 2.2.

Table 3-111 Summary of estimates taken forward for the assessment of options

Carcinogen	Exposed workforce (number of workers)	Health effects caused	Major occupational exposure route
PAH, with BaP inhalable fraction as indicator for PAH mixtures	1,284,052/ 5,230,606* (of which 94-95% are male and 5-6% are female)	Lung cancer, developmental toxicity in females (miscarriage or stillbirth) and reproductive toxicity in males (reduced sperm motility)	Airborne and dermal

Source: Study team.

Notes: * the 1,284,052 figure in the table relates to airborne exposure only. However all firefighters are at risk of dermal exposure, resulting in 5,230,606 total workers (includes volunteer firefighters).

Table 3-112 Summary of exposure concentrations (adjusted for the use of RPE), exposed workforce and number of companies by sectors for PAH using BaP as indicator for PAH mixtures

Sector		Exposure concentration [ng/m ³] [inhalable fraction]			Number of exposed workers	Number of companies
		AM	Median	P95		
C10.13	Meat and poultry smokehouses	10	0.5	32.2	713	210

Sector		Exposure concentration [ng/m ³] [inhalable fraction]			Number of ex- posed workers	Number of compa- nies
		AM	Median	P95		
C10.2	Seafood smoke- houses	10	0.5	32.2	1,626	330
C16.1	Wood preserva- tion (creosote)	8.1	8	10	1,000	40
C19.1	Coking plants	330	220	940	2,516	55
C19.2	Petroleum refin- eries	23	15	130	14,485	81
C20.13	Manufacture of carbon black	20	14	58	1,020	25
C20.14	Coal tar distilla- tion	150	58	560	750	7
C23.2	Manufacture of refractory prod- ucts	210	25	730	86	5
C23.99a	Manufacture of bituminous prod- ucts	38	20	130	5,800	1,180
C23.99b	Graphite and carbon electrode manufacture	-	25	270	1,001	22
C24.1	Steel and iron foundries, fer- roalloys	28	12	63	95,752	2,769
C24.42	Manufacture of aluminium	-	13	99	626	9
C24.45	Other non-fer- rous metallurgi- cal processes	150	71	540	616	80
C24.5	Casting of metals	63	60	150	68,109	4,742
D35.11	Coal fired power plants	20	14	56	18,001	196
E38.2	Waste incinera- tion	0.6	0.4	9.2	1,888	650
E39	Soil remediation	76	42.5	251	10,550	3,378
F42.11	Road paving	34	0.74	70	212,757	30,949
F42.12	Welding of rail- road tracks	350	270	900	6,437	2,016
G45.2	Motor vehicle maintenance and repairs	4.2	2.2	9.5	371,532	374,183
N81.22	Chimney sweeps	18	13	51	24,500	19,381

Sector		Exposure concentration [ng/m ³] [inhalable fraction]			Number of ex- posed workers	Number of compa- nies
		AM	Median	P95		
O84.25	Firefighters (pro- fessional)	29	25	58	36,500/365,000 ⁽¹⁾	758
	Firefighters (vol- unteers)				402,006/4,020,060 ⁽¹⁾	
	Firefighters (to- tal)				438,506/4,385,060 ⁽¹⁾	

Source: Study team.

Note: *Italicised figures represent calculated exposure concentrations*

The number of cases for developmental toxicity is calculated on the basis that one case of miscarriage or still birth could be experienced by each female worker of reproductive working age (16-49), each year for 40 years. This method may overestimate the number of pregnancies over 40 years, although it is not possible to estimate an accurate number of pregnancies experienced by workers over their careers. Modelling has been performed on the basis that once developed, male infertility is permanent, and workers will only experience this once in their careers. The accuracy of this is uncertain due to a lack of robust scientific data, although this approach provides a more conservative means of calculating cases. The male reproductive age is expected to be the entirety of the male working life.

The following table outlines the estimated number of cases occurring in 2023 due to historic exposure.

Table 3-113 Current disease burden related to occupational exposure to PAH (number of cases)

Carcinogen	Health effects caused	Current disease burden (number of cases) *
PAH	Lung cancer	5.1
	Developmental toxicity	0.94
	Male infertility	78

Source: Study team.

Note: * incidence in 2023

3.14.2 Relationship with other EU policies

Individual PAH or PAH as a mixture are referred to in several EU legislations. Please refer to section 1.1.2.

3.14.3 National OELs

Table 3-114 Summary of national OELs in EU Member States

Carcinogen	Lowest (strictest) na- tional binding OEL (ng/m ³)	Highest (least strict) national binding OEL (ng/m ³)	Member States with no OEL
PAH, with BaP as indicator for PAH mixture	70 (acceptable level in Germany)	200,000 (Denmark and Romania)	Belgium Bulgaria Croatia Cyprus Ireland Italy

Carcinogen	Lowest (strictest) national binding OEL (ng/m³)	Highest (least strict) national binding OEL (ng/m³)	Member States with no OEL
			Luxembourg Malta Portugal Slovakia Slovenia Spain

Source: Study team on the basis of section 3.1.

4 BASELINE SCENARIO

The baseline scenario describes how the problem (workplace exposure to PAH) is expected to evolve in case no action is taken at EU level.

This chapter comprises the following sections:

- Section 4.1: Impact of the implementation of other OELs;
- Section 4.2: Effects of forthcoming changes in national OELs or protective regulation, self-regulatory initiatives;
- Section 4.3: Effects of REACH;
- Section 4.4: Effects of megatrends;
- Section 4.5: Future trend in use of the substance[s];
- Section 4.6: Future trend in exposure concentrations due to technical improvements;
- Section 4.7: Future trend in exposed workforce;
- Section 4.8: Other factors of importance for the baseline;
- Section 4.9: Future disease burden (FDB); and
- Section 4.10: Summary of the baseline scenario.

4.1 Impact of the implementation of other OELs

The introduction of welding fumes to the CMRD, are likely to have a positive impact on the prevention of PAH exposure only during welding of railway tracks due to fumes arising from the wooden railway sleepers impregnated with creosote. In addition, a small amount of PAH could be present in welding metals contaminated with oil, but best practice is to remove surface oil before welding.

During the consultation respondents did not indicate that the introduction of other OELs considered in this study, including welding fumes, would affect exposure to PAH.

With regards to newly introduced OELs, outside the scope of this study, the respondents indicated that (see Table 4-1) OELs on:

- Diesel Exhaust Engine Emission (DEEE) fumes may reduce exposure to PAH by <50% in coal tar distillation, aluminium manufacturing and road paving; and
- Benzene could also reduce exposure to PAH by <50% in aluminium manufacturing and road paving.

Table 4-1 Consultation responses on the impact of newly introduced OELs to PAH exposure concentrations considered in the study.

Sector	Diesel engine exhaust emissions			Benzene			Used mineral oils ^(a)			Other		
	No	Exposure reduced by <50 %	Exposure reduced by >50 %	No	Exposure reduced by <50 %	Exposure reduced by >50 %	No	Exposure reduced by <50 %	Exposure reduced by >50 %	No	Exposure reduced by <50 %	Exposure reduced by >50 %
C19.10	100% (5)			100% (5)						100% (5)		
C19.20	100% (15)			100% (15)						93% (14)		
C20.13	100% (6)			100% (6)						83% (5)	17% (1) ^(b)	
C20.14	83% (5)	17% (1)		117% (7)						83% (5)		
C24.42	83% (5)	17% (1)		83% (5)	17% (1)					33% (2)		
F42.11	87% (13)	13% (2)		87% (13)	13% (2)					87% (13)		
G45.20	100% (1)			100% (1)						100% (1)		
Grand Total	92% (45)	8% (4)		94% (47)	6% (3)					98% (40)	2% (1)	

Notes:

^(a) mineral oils that have been used before in internal combustion engines to lubricate and cool the moving parts within the engine

^(b) the company who provided this response is not willing to be contacted for further clarifications

4.1.1 DEEE OEL impact on PAH OEL

The OEL on DEEE came into force in February 2023. The study team believes this will have minimal impact on the OEL on PAH based on the parameters of this study (i.e. using BaP as a marker for airborne PAH exposure). Firstly, half of the minority respondents that indicated that the OEL on DEEE will reduce exposure to PAH (8%) are in the coal tar distillation and aluminium industries, where the products, raw materials and processes are the major source of PAH and insignificant in comparison to DEEE. In addition, the available data available suggests that exposure to BaP from diesel internal combustion engines is less than the lowest policy option. Secondly, the company in coal tar distillation who indicated that DEEE OEL will reduce PAH exposure is not willing to be contacted further. However, three other respondents in this sector did not indicate that the OEL DEEE will reduce exposure to PAH. The respondent in the aluminium industry who indicated that DEEE OEL will reduce PAH exposure, has been contacted but no response was received. The remaining five aluminium manufacturers who responded to the survey did not indicate that DEEE will reduce exposure to PAH.

With regards to road paving, a study by Cirla et al. (2007) found no significant difference in BaP exposure of road construction workers active on a road with traffic or with no traffic. In the same study, PAH from DEEE in the breathing zone of ground construction workers and found that the median BaP concentration was 0.6 ng/m³ (P95 2.07 ng/m³).

Therefore while exposure to total PAH is likely to decrease in occupational settings where exposure to DEEE takes place, overall, exposure to BaP through DEEE and its reduction as a result of the OEL are not considered to be significant in the sectors under review.

4.1.2 Benzene OEL impact on PAH OEL

One aluminium manufacturer out of five respondents, and two road construction companies out of 13 indicated in the survey that the benzene OEL would reduce PAH exposure. The respondents were not available for further clarification.

The route for PAH and benzene exposure in foundries can be the same, which is through the generated and release during casting (resulting in exposure to the tens of ng BaP/m³). However, the major source of PAH in the aluminium industry is from the baking and use of pre-bake anodes (resulting in exposure to the hundreds or thousands ng BaP/m³ without RPE) and therefore the impact of a benzene OEL in the aluminium industry is thought to be minimal.

Road paving has not been identified as a source of benzene exposure and therefore it is unclear how a benzene OEL can impact PAH exposure.

For these reasons, and because the companies identifying the benzene OEL as impacting exposure to PAH are in the minority, and not available for further commenting, the study team does not consider the benzene OEL to have a significant impact on PAH exposure in these sectors to amend a baseline.

4.2 Effects of forthcoming changes in national OELs or protective regulation, self-regulatory initiatives

No information on forthcoming changes in national OELs, self-regulatory initiatives, e.g. forthcoming voluntary industry targets, or new protective regulation in Member States, which may lead to lower exposure to PAH have been identified.

It is possible that in case of no action at EU level, more Member States would lower their OELs, amend the existing OEL to be based on BaP rather than other parameters such as benzene soluble fraction, or establish OELs as consequence of assessment in the RAC opinion, but this has not been taken into account in the baseline scenario.

4.3 Effects of REACH

REACH has impacted worker exposure to PAH via its Authorisation and Restriction processes. There are no upcoming REACH Authorisations known that are thought to affect the baseline. The Authorisation renewal application for coal-tar pitch high temperature (CTPht) for use in clay pigeon shooting targets was rejected in 2022. This has already been taken into account for this study.

Anthracene oil and CTPht are authorised under REACH and ECHA is obliged to perform an assessment on these substances on whether a Restriction is appropriate. Under the review of CTPht and anthracene oil, ECHA concluded that further examination of the risks from the presence of PAH from the use of CTPht, anthracene oil and from other sources in articles should be considered as part of a larger investigation to address risks of PAH in articles. If risks are not minimised, a restriction proposal targeting PAH could be initiated by the European Commission (ECHA 2023c, d).

Existing REACH Authorisations and Restrictions are presented in section 1.1.2. The table below summarises known upcoming Restrictions.

Table 4-2 Upcoming REACH Restrictions

Substance	Status	Conclusion	Entry into force
CTPht	In May 2023 an assessment was published on whether the substance should be restricted under REACH. (ECHA, 2023c)	No restriction proposed at present but a wider investigation to address risks of PAH in <i>articles</i> in general is proposed. If risks are not minimised, a restriction proposal targeting PAH could be initiated.	N/A
Anthracene oil	In May 2023 an assessment was published on whether the substance should be restricted under REACH. (ECHA 2023d)	As above for CTPht	N/A
Creosote and related substances	Opinion Adopted (ECHA 2023e). Annex XV report published	Restriction on the placing on the market, re-use and secondary use of wood treated with creosote or related substances is in progress	Not known, possibly 2025-2026
PAH	Opinion Adopted (ECHA 2023a). Final Background Document published	Restriction on the placing on the market and use of substances containing polycyclic aromatic hydrocarbons (PAH) in clay targets for shooting is in progress	Not known, possibly 2024

The use of creosote or related substances on railways sleepers and communication poles is subject to the biological product regulation (BPR). The assessment currently assumes that restriction on recycling of wood treated with creosote will go ahead. Similarly, the assessment has assumed that the restriction on the content of PAH in clay targets for shooting will go ahead.

It is not possible to anticipate whether a wider restriction of PAH in articles will go ahead, the timeline, its conclusions, and how it may affect the baseline.

4.4 Effects of megatrends

The baseline scenario may be affected by three EU megatrends, which in fact may affect the baseline in opposite directions:

- Climate change and other environmental factors – the need to address climate change and emissions that aggravate it (such as the closing down coal fired power plants and refineries closing down to meet the targets of the Paris Agreement and Net zero by 2050 ambition of the EU) are likely to result in lower emissions and exposure in some sectors. However the need for a stable supply of certain products (such as increase in demand for aluminium, silicon metal and graphite that feed into “green infrastructure”, e.g. solar panels, wind turbines, or for e.g. to replace internal combustion engines with electric vehicles powered with li-ion batteries which are made with graphite) may result in an increase in manufacture and therefore exposure;
- Aggravating resource scarcity – aluminium (C24.42) and silicon metal (C24.45) are considered as Critical Raw Materials (CRM), while natural graphite, rather than synthetic is also a CRM (but note that they can be used in similar applications (see Figure 3-4). Natural graphite (battery grade) and silicon metal are also strategic raw materials (SRM). This may result in an increase in PAH exposure as the EU works towards securing and diversifying their supply; and

- Acceleration of technological change – which is transforming production systems and reducing the number of workers, particularly in the manufacturing, should result in reduced exposure to workers.

The rest of this section indicates the response by the EU and how sectors will be impacted by the above megatrends.

4.4.1 EU response

Below are the key EU policies that have been issued in response to the first two megatrends identified above:

- European Trading Scheme (ETS), the principles of which are spelled out in the ETS Directive 2003/87/EC: it aims at reducing greenhouse gas emissions in a cost-effective manner using a 'cap and trade' principle. A cap is set on the emissions by the operators of an industry and is reduced over time. Operators can buy or receive emissions allowances within the cap. The intention is to incentivise investment in low-carbon technologies. Carbon dioxide emissions from manufacturing of steel using basic oxygen furnaces (BOF) in particular is impacted (CO₂ is a by-product). Other sectors such as electricity generation from coal (D35.11), refineries (C19.1), aluminium (C24.42), other metallurgy (C24.5), other bulk organic chemicals (such as C20.14 coal tar distillation plants) are affected;
- European Climate Law Regulation (EU) 2021/1119: the EU aims to reduce emissions by 40% compared to 1990 by 2030 and to be climate neutral by 2050. To achieve this it has set out a series of legislative processes that affect and will continue to impact the sectors under review;
- Critical Raw Materials (CRM) Act¹⁷: the act aims to strengthen domestic supply chains and reinforce international partnerships of critical raw materials. The list of CRM was last revised in 2023 and contains coking coal (C19.1), aluminium/bauxite (C24.42), silicon metal (C24.45) and natural graphite;
- European Chips Act: silicon and synthetic graphite are needed in the manufacture of semiconductors (C23.99b); and
- EU Hydrogen strategy (COM/2020/301)¹⁸ which aims to install at least 6 GW of renewable hydrogen electrolyzers in the EU by 2024 and 40 GW of renewable hydrogen electrolyzers by 2030. From 2030 to 2050 renewable hydrogen technologies should reach maturity and be deployed at large scale. According to the communication, in this phase renewable electricity production needs to massively increase as about a quarter of renewable electricity might be used for renewable hydrogen production by 2050. This impacts both the production of synthetic graphite (C23.99b), needed for the manufacture of fuel cells, and the production of silicon, needed in photovoltaic solar panels and wind turbines.

4.4.2 Impact on specific sectors

Several sectors have the potential to be impacted in future by the megatrends and EU policy options, and whilst the magnitude and significance of these contain a degree of uncertainty, trends

¹⁷ Available at https://single-market-economy.ec.europa.eu/publications/european-critical-raw-materials-act_en

¹⁸ Available at <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0301>

have been derived by analysing industry exposure figures against known and expected market, technological and regulatory developments. The study team has identified the following sectors as having definitive and quantifiable impacts on future trends:

4.4.2.1 C19.2 Refineries

The transport sector currently relies on fossil fuels, but a transition to electric vehicles in the automotive sector as well alternative fuels in the maritime and aviation sectors are envisaged under the EU's fit for 55 package. Refining capacity is expected to decrease in the next 40 years as demand for petroleum products decreases. According to a study, the refinery capacity in Europe will decrease between 19-58% (current trajectory of 46%) of the 2019 capacity by 2040 (McKinsey, 2022).

It is expected that refinery capacity in the EU will decrease by 6% per year corresponding to a decrease to 36% of today's level after 20 years and to 14% of today's level by the end of the 40 years' assessment period.

4.4.2.2 C24.42 Aluminium

Aluminium has been assessed in the critical raw material Foresight Study (European Commission, 2020c) as being of critical importance with a supply risk score of 1.2. The study identifies aluminium as being the most widespread raw materials, being used in all of the 15 technologies assessed and in all five sectors. Aluminium is mainly used for electric vehicles for reducing weight and in batteries, electricity networks and solar panels (JRC, 2023). Other clean energy technologies also require aluminium thanks to its light weight, though the annual demand for these applications is estimated to be lower (Eurometaux, 2022). Aluminium has not been identified as a critical raw material in the Foresight study published by the European Commission (2020c) but its demand is expected to grow and it is identified as a strategic raw material used in all the 15 technologies assessed in a report by JRC (2023). Depending on the potential for recycling, Eurometaux has estimated that aluminium demand will experience an increase between 0.6-1.4% year on year. The study team has taken an average of these and applied a growth of 1% year on year to aluminium manufacturing, which is considered a conservative estimate.

4.4.2.3 C24.45 Silicon metal

Silicon metal has been assessed in the critical raw material Foresight Study (European Commission, 2020c) as being of strategic importance with a supply risk score of 1.4. A JRC study on the supply chain analysis of materials in strategic technologies identifies silicon as being necessary in 14 out of the 15 technologies assessed, and in all five sectors assessed (JRC 2023). Its use and demand is expected to grow as the emphasis and shift towards renewable energy will drive an increase in demand for silicon metal. The metal is a key component in silicon-based photovoltaic (PV) solar panels (semiconductor in crystalline or amorphous solar cells), it is also anticipated to be used more heavily in future in Li-ion batteries anodes to enhance energy density (and improve battery range), it is used in electric motors (found in, from e-bikes to large motors found electric drive trains) as electronic grade silicon in semiconductors, in control electronics and as an alloying element of steel and aluminium, and silicon metal is the current main raw material for the manufacture of semiconductors (European Commission, 2020c; Eurometaux, 2022, JRC 2023). The use of silicon metal in semiconductors mean it is essential in many technologies essential to achieve Net Zero, such as EVs and heat pumps. Silicon is also used in electrolyzers, which split water into oxygen and hydrogen and are a critical technology for the production of low emission hydrogen (IEA, 2023).

Depending on the potential for recycling, Eurometaux has estimated that silicon demand will experience an increase between 1.6-2.3%. There are currently some challenges in the recycling of silicon, and the study team has taken an average of these and applied a growth of 1.95% year on year to silicon metal manufacturing.

4.4.2.4 C23.99b Synthetic graphite

Natural graphite has been assessed in the critical raw material Foresight Study (European Commission, 2020c) as being of critical importance with a supply risk score of 1.8. The JRC study on strategic technologies indicates that natural graphite is used in eight of the 15 technologies assessed. The study identifies natural graphite as a raw material but when analysing future needs it combines synthetic and natural graphite. Synthetic graphite is manufactured by the graphite and carbon electrode manufacturers. Natural and synthetic graphite are both used in Li-ion batteries in EVs, in fuel cells (proton exchange membrane fuel cells and water electrolyzers for the production of energy and hydrogen) and photovoltaic (PV) panels. Natural graphite has been assessed in the critical raw material Foresight Study (European Commission, 2020c) as being of medium criticality in the supply bottleneck in the development of the renewable energy sector in the EU.

The study models two scenarios: a high demand scenario (HDS) and a low demand scenario (LDS). The EU demand for graphite (both natural and synthetic) is forecast to be 10 and 14 times the demand of 2020 in 2030 in the LDS and HDS, respectively, and 18 and 26 in 2050 in the LDS and HDS, respectively. This is equivalent to a year-on-year growth rate of 26-30% to 2030, and 2.8-3.1% in the period 2030-2050. By extrapolating the growth rate to 2063 (the 40-year assessment period of this study), the study team has calculated an overall year on year growth rate between 7.8% and 8.91% in the LDS and HDS, respectively.

In the Li-ion battery market alone, consultation with industry experts has indicated that in Europe synthetic and natural graphite consumption is expected to increase steadily to 2040 and then plateau (see Figure 4-1 for a projection of synthetic vs natural graphite demand for the battery market). The projections are in slight contrast to the projections in the Foresight report which predict a steady increase to 2050 overall.

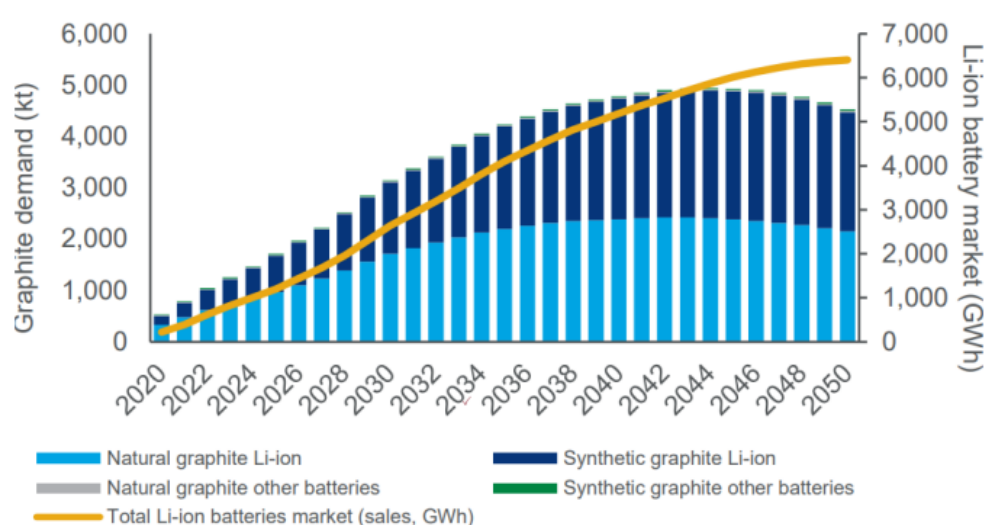


Figure 4-1 Graphite demand in batteries by type

Source: (ECGA, 2022) citing Wood McKenzie

Although an increase in demand for synthetic graphite is anticipated, the study team has not been able to establish how the production levels will be shaped in future, because the potential for recycling is not taken into account when focusing on demand alone, and the difference in demand between natural vs synthetic, and between imports vs manufacture are also not determined. Using growth rates between 7.8% and 8.91% would likely be a considerable overestimation of the growth in manufacture of synthetic graphite in Europe.

4.4.2.5 D35.11 Coal fired power plants

D35.11 coal fired power plants: the adherence to the 2016 Paris Agreement and the objective for the EU to achieve climate neutrality by 2050 are the main drivers behind coal power plant closures, which will take place regardless of any OEL set for PAH. the JRC has predicted that in some Member States, up to 100% of existing coal power plants will be decommissioned by 2030, such as Ireland, Hungary, the Netherlands, Austria, Portugal, Slovakia, Finland and Sweden (JRC, 2018). Large numbers of job losses are anticipated in Poland, Germany, Romania, Bulgaria, Spain and Greece by 2030 (see Figure 4-2).

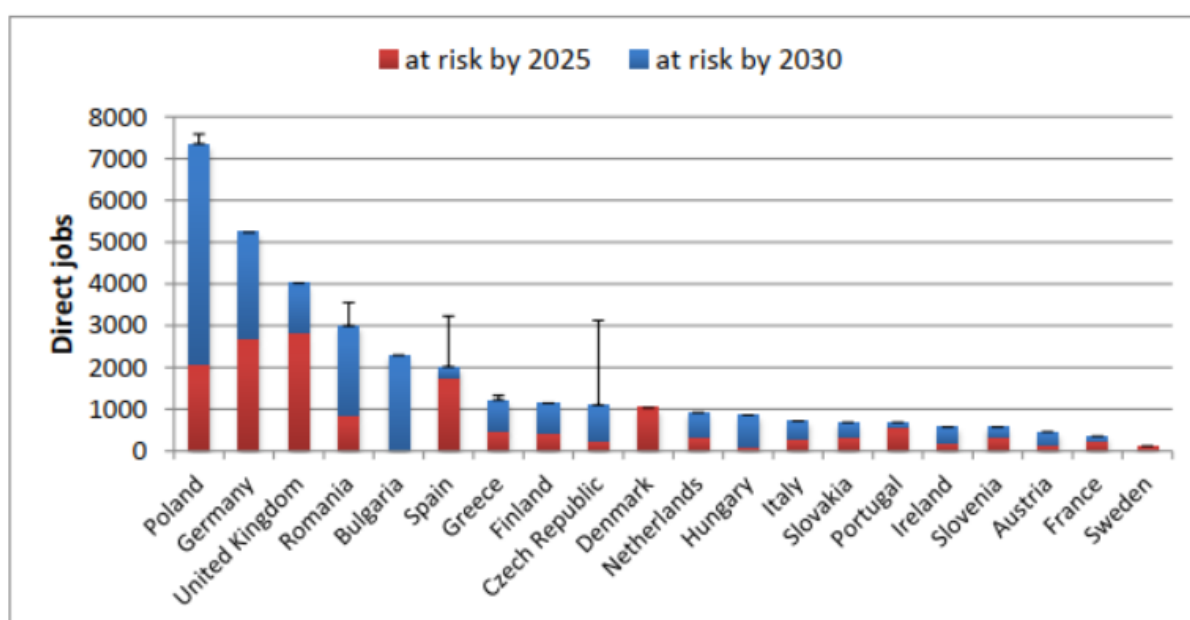


Figure 4-2 Probable impact of power plant decommissioning on jobs at country level.
Source: (JRC, 2018)

JRC (2018) predicted approximately 64% job losses in coal power plants to take place by mid-2030 and half of those by mid-2020s. The study team has taken the estimate of job losses by mid-2020 to calculate the current level of exposed workforce. Coal power plants have experienced a recent resurgence due to the current geopolitical climate. For this reason the study team estimates that the remainder of the job losses predicted by JRC will be spread across the duration of the study and a -2.5% decrease year on year in the number of workers is estimated, resulting in approximately an additional third decrease in jobs by the end of the study period.

4.5 Future trend in use of the substances (containing or generating PAH)

The trends outlined in the previous section will impact the production and demand in the sectors outlined. Similarly, the upcoming REACH Restrictions will impact the demand of particular substances containing PAH.

Coking plants will be impacted in a particular way: coking coal is defined as a CRM. Coking units are often part of integrated steel plants as the main purpose of coke is as a reducing agent and carbon for the manufacture of steel (89% of coking coal is destined for this use). The manufacture of steel using Basic Oxygen Furnace (BOF) generates CO₂. To achieve Net Zero by 2050 and comply with the Paris Agreement, steel plants are likely moving towards the use of hydrogen as a reducing agent by 2050. This will remove the need to manufacture coke for the purpose of steel making. However, an important by-product of coking is coal tar, which is further distilled into coal tar pitch (C20.14), which is subsequently used by manufactures of carbon electrodes and synthetic graphite. Graphite and carbon electrodes (anodes and cathodes) are essential in most metallurgical processes (such as steel, iron, ferroalloys, silicon, silicon and calcium carbide and potentially many others). Therefore, unless an alternative to coal tar pitch in the manufacture of electrode becomes available, and unless natural graphite (identified as a critical raw material) can meet the total demands for graphite, coking of coal will still be needed even though steel plants would no longer require them to exist.

According to consultation, and based on information in Eurostat, there is little surplus in coal tar manufactured in Europe (when taking into account EEA countries), and there is current competition for its use by different industries (e.g. carbon black manufacturers and coal tar distillation plants).

Therefore demand for coal tar as a by-product of coking is expected to continue and the study team has therefore assumed that the coking industry will continue to be stable.

4.6 Future trend in exposure concentrations due to technical improvements

Technical improvements such as further automatization and further used of closed systems may lead to decreased exposure concentrations.

Employers stated in the stakeholder consultation that lowering exposure concentrations is a continuous goal as a result of the companies' intentional work on reducing the risk to the workers from exposure to other hazardous substances in order to comply with national OELs and other OSH legislation (e.g. carbon monoxide and lead in steel plants) or driven by the companies' internal targets for workers protection.

The technical improvements known so far are reported below:

- C16.1 wood impregnation: the Biocidal Product Committee (BPC) has made recommendations on the use of creosote for wood impregnation (ECHA, 2020). The data presented in the previous chapter was collected prior to the renewal of the active substance under the Biocidal Product Regulation (BPR) and it is possible that workers will be exposed to less airborne and dermal concentrations going forward. But a value establishing the reduction going forward, and an associated timeline cannot be established. Therefore, future trends in exposure concentrations were neither derived nor modelled for this sector; and
- F42.11: as indicated in section 3.11, it is possible (if not likely) that road paving in future will be done with Warm Mix Asphalt (WMA) as opposed to Hot Mix Asphalt (HMA) resulting in lower exposure concentrations. However the amount of BaP in WMA fumes during use has not been quantified. In addition, there is resistance from local municipalities who commission roadworks to move to WMA, which is currently only being used in Norway, therefore a trend and timeline cannot be established. Therefore, future trends in exposure concentrations were neither derived nor modelled for this sector.

Past trends in exposure concentrations were derived from a study based on European and Canadian personal exposure concentrations which calculated a time trend of -1.2% per year for BaP (95% Confidence Intervals -3.1% to -0.7%) between 1975 and 2009 (Peters, et al., 2016). The study team has used this overall decline, i.e. -1.2% year-on-year between 1975 and 2009 (Peters, et al., 2016), as the future trend for exposure concentrations, see sections 3.3.6 and 3.13.1.

4.7 Future trend in exposed workforce

It is assumed that the trend in exposed workforce follows the trend in the sectors where PAH is unintentionally released or generated. Based on the description of the future trends in the use and manufacture of products containing or generating PAH, or activities generating PAH, the following trends are factored into the assessment:

- C19.2 Refineries: -6%;
- C24.2 Aluminium manufacturing: +1%;
- C24.45 Silicon metal manufacture: +1.95%; and
- D35.11 Coal fired power plants: -2.5%.

The four sectors represent together <0.1% of all companies with exposed workers and <4% of the exposed workforce. The trends to some extent counterbalance each other, and consequently they have a small effect on the total estimated benefits and costs.

Further automatization and introduction of robots for work processes with exposure to hazardous substances can potentially reduce the number of exposed workers. As indicated in a recent publication, digital technologies can enhance prevention of exposures at workplaces: they can help to separate workers from hazardous working situations, facilitate better and innovative ways of monitoring exposure, and might improve the quality of work by relieving workers from repetitive or routine tasks (EU-OSHA, 2023). However, data demonstrating that automatization has had a significant impact on the number of workers exposed to PAH in the last ten years have not been identified. Considering that the PAH exposure consumption may be slightly increasing for other applications, e.g. for the manufacture of graphite and carbon electrodes, a possible effect of further automatization may be counterbalanced by increased exposure of PAH for other applications.

The study team were not able to derive an appropriate trend of levels of exposure to PAH for workers producing graphite. This is due to a high level of uncertainty regarding: the extent of increasing demand for natural versus synthetic graphite; variation in exposure pathways depending on the sourcing of products; the extent to which each type is sourced from within EU Member States; as well as the extent to which Member State sourced products are derived from recycled materials. That is, there is too much complexity and ambiguity in the supply chain of natural and synthetic graphite to derive a meaningful trend, and for this reason trends to worker exposure were not factored into sectors concerning graphite (notably C23.99b carbon and graphite electrode manufacture).

It is therefore assumed that the number of exposed workers is stable in the remaining sectors, and the trend is set at 0%.

4.8 Other factors of importance for the baseline

No other factors have been identified.

4.9 Future disease burden (FDB)

4.9.1 Future disease burden

The future disease burden is given below as the number of cases generated by exposure in over the next 40 years (not the number of cases actually happening in the next 40 years). Latency may cause many of the cases caused by exposure in the next 40 years, particularly cancer, to occur beyond the 40-year period. For this reason, the number of cases is not divided by 40 to indicate a number of cases per year; this would be misleading.

Table 4-3 Baseline future burden of disease; staff turnover of 5% for all sectors

Endpoint	Number of cases over 40 years
Lung cancer	160
Developmental toxicity	38
Male infertility	3,157

Source: Study team.

In Table 4-4, the number of cases is distributed by the sector where exposure takes place. Male infertility produces a significantly higher number of cases than lung cancer and developmental toxicity due to the prevalence of sectors with a male dominated workforce. Developmental toxicity has a lower occurrence due to a low proportion of female workers in general, although this endpoint also only refers to a subset of females of reproductive age (approximately two-thirds of female workers), and those who are pregnant during employment. Lung cancer refers to all exposed workers (male and female of all ages) although this produces fewer cases than male infertility due to both the latency period for lung cancer being 30 years (whereas the latency for reproductive toxicity is zero years), and due to the more severe slope of the ERR for lung cancer compared with the DRR for reproductive toxicity.

Sectors with the highest number of cases reflect those with the highest exposure levels, for example C19.1 coking plants, C20.14 coal tar distillation, C24.45 other non-ferrous metallurgy, and F42.12 welding of railroad tracks. O84.25 firefighters produces a high number of lung cancer cases due to a proportionally higher number of workers.

Table 4-4 Baseline future burden of disease; staff turnover of 5% for all sectors

Sector		Number of cases over 40 years			Percent of total cases	Trend in exposure * (annual)
		Lung cancer	Developmental toxicity	Male infertility		
C10.13	Meat and poultry smokehouses	0.02	-	-	0.0005%	-
C10.2	Seafood smokehouses	0.04	-	-	0.001%	-
C16.1	Wood preservation (creosote)	0.05	-	-	0.001%	-
C19.1	Coking plants	5	5	784	24%	-
C19.2	Petroleum refineries	1	-	-	0.4%	-6%

Sector		Number of cases over 40 years			Percent of total cases	Trend in exposure * (annual)
		Lung cancer	Developmental toxicity	Male infertility		
C20.13	Manufacture of carbon black	0.1	-	-	0.004%	-
C20.14	Coal tar distillation	1	4	73	2%	-
C23.2	Manufacture of refractory products	0.1	0.2	10	0.3%	-
C23.99a	Manufacture of bituminous products	1	-	-	0.03%	-
C23.99b	Graphite and carbon electrode manufacture	1	1	8	0.3%	-
C24.1	Steel and iron foundries, ferroalloys	13	-	-	0.4%	-
C24.42	Manufacture of aluminium	0.2	-	-	0.01%	+1%
C24.45	Other non-ferrous metallurgy	1	0.5	100	3%	+1.95%
C24.5	Casting of metals	25	-	-	1%	-
D35.11	Coal fired power plants	1	-	-	0.04%	-2.5%
E38.2	Waste incineration	0.02	-	-	0.0005%	-
E39	Soil remediation	4	7	-	0.3%	-
F42.11	Road paving	10	-	-	0.3%	-
F42.12	Welding of railroad tracks	13	20	2,183	66%	-
G45.2	Motor vehicle maintenance and repairs	8	-	-	0.2%	-
N81.22	Chimney sweeps	2	-	-	0.1%	-
O84.25	Firefighters^	74	-	-	2%	-
Total		160	38	3,157	100.0%	-

Source: Study team.

Notes: * Multiple of trend in workforce and exposure concentration

^ the calculations for firefighters are for volunteers and professional firefighter team leaders (with risk of airborne exposure)

Table 4-5 presents the baseline future burden of disease based on two methods. Despite having far more cases of male infertility (as above), the table below illustrates that a high proportion of the costs relate to lung cancer which has higher treatment costs, as well as the potential for mortality (which has the largest cost of all) which cannot occur for the other two endpoints. Method 1 (M1) includes costs for informal care, the value of statistical life (VSL), and the value for cancer morbidity (VCM). Collectively this produces a higher cost as modelling estimates 80% of lung cancer cases result in mortality (high costs associated with VSL and VCM). Alternatively, M2 includes costs of informal care related to lost working days, and costs associated with disability adjusted life years (DALY). Again, sectors with the highest exposures produce the highest number of cases and by extent the majority of costs.

Table 4-5 Baseline future burden of disease (PV40), 5% turnover of workforce a year, static discount rate (€ millions)

Sector		PV40 over 40 years, static discount rate Range of Method 1 – Method 2 (€ millions)			
		Lung cancer M1 – M2	Developmental toxicity M1 – M2	Male infertility M1 – M2	Total High-low
C10.13	Meat and poultry smokehouses	€0.01 - €0.007	-	-	€0.01 - €0.007
C10.2	Seafood smokehouses	€0.03 - €0.02	-	-	€0.03 - €0.02
C16.1	Wood preservation (creosote)	€0.48 - €0.02	-	-	€0.04 - €0.02
C19.1	Coking plants	€3.7 - €1.9	€0.04 - €0.02	€18.04 - €1.3	€21.8 - €3.2
C19.2	Petroleum refineries	€1.3 - €0.7	-	-	€1.3 - €0.7
C20.13	Manufacture of carbon black	€0.1 - €0.05	-	-	€0.1 - €0.05
C20.14	Coal tar distillation	€0.4 - €0.2	€0.03 - €0.01	€1.7 - €0.1	€2.1 - €0.4
C23.2	Manufacture of refractory products	€0.04 - €0.02	€0.002 - €0.0009	€0.2 - €0.02	€0.3 - €0.04
C23.99a	Manufacture of bituminous products	€0.9 - €0.5	-	-	€0.9 - €0.5
C23.99b	Graphite and carbon electrode manufacture	€0.4 - €0.2	€0.007 - €0.003	€0.2 - €0.01	€0.6 - €0.2
C24.1	Steel and iron foundries, ferroalloys	€10.3 - €5.3	-	-	€10.3 - €5.3
C24.42	Manufacture of aluminium	€0.1 - €0.07	-	-	€0.1 - €0.07
C24.45	Other non-ferrous metallurgy	€0.5 - €0.3	€0.003 - €0.002	€2.05 - €0.15	€2.6 - €0.4
C24.5	Casting of metals	€20.2 - €10.5	-	-	€20.2 - €10.5
D35.11	Coal fired power plants	€1.2 - €0.6	-	-	€1.2 - €0.6
E38.2	Waste incineration	€0.01 - €0.006	-	-	€0.01 - €0.006
E39	Soil remediation	€3.4 - €1.8	€0.05 - €0.02	-	€3.5 - €1.8
F42.11	Road paving	€8.04 - €4.2	-	-	€8.04 - €4.2
F42.12	Welding of railroad tracks	€10.5 - €5.4	€0.15 - €0.07	€50.3 - €3.6	€60.9 - €9.1
G45.2	Motor vehicle maintenance and repairs	€6.5 - €3.4	-	-	€6.5 - €3.4
N81.22	Chimney sweeps	€2.004 - €1.04	-	-	€2.004 - €1.04

Sector		PV40 over 40 years, static discount rate Range of Method 1 – Method 2 (€ millions)			
		Lung cancer M1 – M2	Developmental toxicity M1 – M2	Male infertility M1 – M2	Total High-low
O84.25	Firefighters [^]	€60 - €31.1	-	-	€60 - €31
Totals		€130 - €67	€0.3 - €0.1	€72.4 - €5.2	€202 - €73

Source: Study team.

Notes: [^] the calculations for firefighters are for volunteers and professional firefighter team leaders (with risk of airborne exposure)

Table 4-6 below presents the baseline costs of ill health for workers (M1 and M2), employers and public authorities associated with the three health endpoints modelled for PAH. These figures represent the cost prior to any intervention being put in place to reduce exposure to PAH and reduce the number of resulting cases. Definitions of the calculations for each type of cost can be found in the methodological note.

Table 4-6 Baseline costs of ill health for workers (M1 and M2), employers and public administrations (€ millions)

Sector	Workers and families (M1)	Workers and families (M2)	Employers	Public Authorities	Grand total (M1)	Grand total (M2)
C10.13 Meat and poultry smoke-houses	€ 0.01	€ 0.01	€ 0.0001	€ 0.0002	€ 0.01	€ 0.01
C10.2 Sea-food smoke-houses	€ 0.03	€ 0.02	€ 0.0001	€ 0.0005	€ 0.03	€ 0.02
C16.1 Wood preservation (creosote)	€ 0.04	€ 0.02	€ 0.000	€ 0.001	€ 0.04	€ 0.02
C19.1 Coking plants	€ 20.87	€ 2.33	€ 0.02	€ 0.90	€ 21.79	€ 3.25
C19.2 Petroleum refineries	€ 1.29	€ 0.66	€ 0.01	€ 0.02	€ 1.31	€ 0.68
C20.13 Manufacture of carbon black	€ 0.09	€ 0.05	€ 0.0004	€ 0.002	€ 0.10	€ 0.05
C20.14 Coal tar distillation	€ 2.03	€ 0.26	€ 0.002	€ 0.09	€ 2.13	€ 0.36
C23.2 Manufacture of refractory products	€ 0.26	€ 0.03	€ 0.0002	€ 0.01	€ 0.27	€ 0.04
C23.99a Manufacture of bituminous products	€ 0.91	€ 0.46	€ 0.004	€ 0.01	€ 0.93	€ 0.48

Sector	Workers and families (M1)	Workers and families (M2)	Employers	Public Authorities	Grand total (M1)	Grand total (M2)
C23.99b Graphite and carbon electrode manufacture	€ 0.61	€ 0.23	€ 0.002	€ 0.02	€ 0.63	€ 0.25
C24.1 Steel and iron foundries, ferroalloys	€ 10.16	€ 5.19	€ 0.05	€ 0.17	€ 10.37	€ 5.41
C24.42 Manufacture of aluminium	€ 0.13	€ 0.07	€ 0.001	€ 0.002	€ 0.13	€ 0.07
C24.45 Other non-ferrous metallurgy	€ 2.48	€ 0.32	€ 0.002	€ 0.10	€ 2.58	€ 0.42
C24.5 Casting of metals	€ 19.86	€ 10.16	€ 0.09	€ 0.33	€ 20.28	€ 10.58
D35.11 Coal fired power plants	€ 1.13	€ 0.58	€ 0.01	€ 0.02	€ 1.16	€ 0.60
E38.2 Waste incineration	€ 0.01	€ 0.01	€ 0.0001	€ 0.0002	€ 0.01	€ 0.01
E39 Soil remediation	€ 3.40	€ 1.73	€ 0.02	€ 0.07	€ 3.49	€ 1.81
F42.11 Road paving	€ 7.92	€ 4.05	€ 0.04	€ 0.13	€ 8.09	€ 4.22
F42.12 Welding of railroad tracks	€ 58.40	€ 6.63	€ 0.05	€ 2.52	€ 60.97	€ 9.20
G45.2 Motor vehicle maintenance and repairs	€ 6.39	€ 3.27	€ 0.03	€ 0.11	€ 6.52	€ 3.40
N81.22 Chimney sweeps	€ 1.97	€ 1.01	€ 0.01	€ 0.03	€ 2.02	€ 1.05
O84.25 Fire-fighters	€ 59.10	€ 30.22	€ 0.28	€ 0.97	€ 60.35	€ 31.47
Total	€ 197.09	€ 67.28	€ 0.61	€ 5.51	€ 203.21	€ 73.40

Source: Study team.

Notes: Values for workers and values are calculated using two different methodologies (M1-M2), for more information on the differences between these methods, please see the methodological note. Grand total (M1) is the sum value of Workers & Families (M1), Employers, and Public Authorities. Grand total (M2) is the sum value of Workers & Families (M2), Employers, and Public Authorities.

4.9.2 Legacy burden of disease

Previous OEL studies have not included the calculation of future burden of disease from legacy exposure. The reason is that this burden of disease would not be affected by the assessed policy options and just be added to all scenarios and will make differences in the scenarios less prominent.

A mean latency period of 30 years is assumed for lung cancer. This means that exposure before 2023 may lead to cancer cases for a period of 30 years i.e. from 2024-2054. The total number of cases are calculated in the same way as described for the current burden of disease where the total burden for each year due to exposure during the period 1993-2023 is calculated using the past trends in workforce and exposure concentrations as described in section 3.12.1.

For the non-cancer endpoints, the latency time is assumed to be zero years and past exposure would not lead to future cases.

The future burden of disease from past exposure is reported in Table 4-4, but is not presented with the policy options.

Table 4-7 Legacy burden of disease that will occur in the next 40 years due to exposure in the last 30 years

Endpoint	Number of cases over 40 years
Lung cancer	152
Developmental toxicity	-
Male infertility	-

Source: Study team

Table 4-8 Legacy burden of disease that will occur in the next 40 years due to exposure in the last 30 years

Endpoint	Number of cases over 40 years
Lung cancer	152
Developmental toxicity	-
Male infertility	-

Source: Study team

4.10 Summary of the baseline scenario

Please note that values are subject to change pending further investigations.

Table 4-9 Baseline scenario over 40 years for PAH

Item	Detail
Chemical agent	PAH, as BaP inhalable fraction (indicator for PAH mixture)
Classification	Ten PAH have a harmonised classification under the CLP that indicates they are carcinogenic (Carc. 1B); of these, BaP is further classified as mutagenic (Muta. 1B) and reprotoxic (Repr. 1B) (see Table 1-5)
Sectors	C10.13 Meat and poultry smokehouses C10.2 Seafood smokehouses C16.1 Wood preservation (creosote) C19.1 Coking plants C19.2 Petroleum refineries C20.13 Manufacture of carbon black C20.14 Coal tar distillation C23.2 Manufacture of refractory products

Item	Detail
	C23.99a Manufacture of bituminous products C23.99b Graphite and carbon electrode manufacture C24.1 Steel and iron foundries, ferroalloys C24.42 Manufacture of aluminium C24.5 Casting of metals D35.11 Coal fired power plants E38.2 Waste incineration F42.11 Road paving G45.2 Motor vehicle maintenance and repairs N81.22 Chimney sweeps O84.25 Firefighters
Period for estimation	40 years
Types of cancer caused	Lung cancer
Other adverse health effects	Developmental toxicity (in females, miscarriage and still-birth) Reproductive toxicity (in males, reduced sperm motility)
No. of exp. workers	1,284,052 (firefighters team leaders only)/5,230,606 (all firefighters)
Change exp. level	-1.2% overall
Change no. of exp. workers (annual)	C19.2 Petroleum refineries (-6%) C24.42 Manufacture of aluminium (+1%) C24.45 Other non-ferrous metallurgy (+1.95%) D35.11 (-2.5%) Exposed worker trends in all other sectors are stable (0%)
Current disease burden (CDB) - no. of cancer cases/year (2023)	5.1
Future disease burden (FDB) - no. of cancer cases/ over 40 years	160
CDB - no. of developmental toxicity cases	0.94
FDB - no. of developmental toxicity cases	38
CDB - no. of male infertility cases/year (2023)	78
FDB - no. of male infertility cases over 40 years	3,157
Estimated deaths due to FDB lung cancer over 40 years	128
Estimated deaths due to FDB developmental toxicity over 40 years	0
Estimated deaths due to FDB male infertility over 40 years	0
Monetary value FDB cancer over 40 years [M1/high to M2/low] (millions)	€130- €67
Monetary value FDB other adverse health effects over 40 years [M1/high to M2/low] (millions)	€72.7-€5.3

Source: Study team summary on basis of the information presented in this chapter.

Table 4-10 Estimated number of exposed workers, expected number of cancers and other hazardous diseases cases and related health costs in case no action is taken (baseline scenario), over a 40 year period

Carcinogen	No. of exposed workers	Expected no. of cancer cases	Expected no. of cases of other adverse health effects	Estimated health costs, EUR [M1-M2] (€ millions)	Possible underestimations (non exhaustive list)
PAH, BaP as an indicator	1,284,052 (benefits/cases for dermal exposure (5,230,606 workers exposed) cannot be quantified)	160	3,195	€202 - €73	Some health endpoints could not be quantified (skin cancer and potentially bladder cancer) - The CDB for lung cancer is likely to be underestimated since the number of workers has changed but the study team has not identified a relevant trend that can be applied - BaP is a non-threshold carcinogen and the study team has included sectors with exposure values that have a P95 above the lowest policy option. It is possible that benefits will be seen in a larger number of sectors. - There is uncertainty on the split of male and female workers exposed as robust data is unavailable. As two endpoints are sex specific it is possible cases are under/overestimated although the study team cannot be certain as to an appropriate split. The split of male and female workers has been based on stakeholder feedback where possible. - There is uncertainty on the number of pregnancies expected in sectors with exposure due to the absence of robust data. However, further exploration of impacts associated with this issue has been provided in a sensitivity analysis in section 13.2. This issue did not strong impact results and was not considered further.

Source: Study team summary on basis of the information presented in this chapter.

5 POLICY OPTIONS

5.1 Occupational Exposure Limit (OEL)

The ACSH has in its "Opinion on limit value setting for non-threshold carcinogens, a Risk-Based Approach" agreed on the on the following regarding the levels of OELs:

- "In the future, limit values for non-threshold substances will be set in between the pre-determined "upper risk level" and the "lower risk level". It is agreed that the upper risk is 4:1000 (corresponding to 4 predicted cancer cases in 1000 employees) and the lower risk level is 4:100,000. This assumes exposure occurs over 8 hours per day, 5 days a week and 40 years of working life." (ACSH, 2022)

Risk estimate based on the ERR for PAH using benzo[a]pyrene (BaP) ng/m³ (inhalable fraction, indicator for PAH mixture) derived by RAC is shown in the table below (see further description of the ERR in section 2).

Table 5-1 Risk estimate based on the ERR for respirable fraction derived by RAC

Risk estimate	PAH concentration based on BaP ng/m ³ (inhalable fraction, indicator for PAH mixture), long-term mean value, 40 years of work-place exposure
Risk 4:1000	700
Risk 4:10,000	70
Risk 4:100,000	7

Source: Study team on the basis of the applied ERR.

The 2000 ng BaP/m³ has been selected the statistical mode and median of EU Member State' OELs (or equivalent). The Commission Staff Working Document (SWD) (European Commission, 2017), referencing the conclusions of the IOM impact assessment (IOM, 2011), reports that "exposure levels in the EU were already below 2000 ng/m³ and no significant health benefits or costs or social or macro-economic costs should result from introducing an OEL at that value". The SWD also indicates that according to the Advisory Committee on Safety and Health at Work (ACSH) there are insufficient added health benefits in a 2000 ng/m³ OEL. However, the value is retained in accordance with the Terms of Reference. In addition, the conclusion from the ACSH is understood to be based on the IOM report, which said that exposure data were very limited and concluded that in 2006, 234,000 workers were exposed to 1,000-10,000 ng BaP/m³ or higher.

The 700, 70 and 7 ng BaP/m³ values are based on the ERR (Exposure Risk Relationship) and the excess risk for lung cancer (4 in 1,000, 10,000 and 100,000 respectively, see section 2.2.2). There is also indication of elevated risk of bladder cancer with PAH exposure, but it may only be linked to certain industries and parallel exposure to aromatic amines (known carcinogens causing bladder tumours) cannot be ruled out.

Table 5-2 Policy options acting as reference points for this study for PAH, using BaP ng/m³ (inhalable fraction, indicator for PAH mixture) (see comments in the body text)

Policy option	Level, ng/m ³	Reason for inclusion
1	7	This is 10% of the lowest OEL for EU MS and equivalent to a lung cancer excess risk of 4 per 100,000
2	70	This is the lowest OEL (acceptable concentration in Germany, equivalent to lung cancer excess risk 4 per 10,000). Proposed EU-OEL adopted by the ACSH

Policy option	Level, ng/m ³	Reason for inclusion
3	700	This is equivalent to lung cancer excess risk of 4 per 1,000
4	2000	This is the Median and Mode limit value (or equivalent) observed among Member States
5	140*	Proposed transitional EU-OEL(s) adopted by the ACSH

Source: Study team

Notes: * This only refers to at risk sectors identified in the ACSH opinion for a limited period. Further details are provided in section 14.6.

5.2 Biological Limit Value (BLV)

RAC notes that post-shift urinary hydroxybenzo(a)pyrene (3-OHBaP) levels correlate well ($r^2 = 0.89$) with airborne BaP levels in workers that are not wearing respiratory protective equipment (RPE) and that are not subject to significant dermal exposure (RAC, 2022a).

Exposure levels are correlated to 3-OHBaP levels in urine using the following relationship:

- Urinary post-shift concentration of 3-OHBaP ($\mu\text{mol/mol creatinine}$) = $0.001835 \times 8\text{h TWA BaP concentration in air } (\mu\text{g/m}^3) + 0.1729$ ¹⁹.

RAC recommends setting a biological limit value (BLV) for (3-OHBaP) in urine, once the air limit value according to the correlation equation presented above has been decided. The values presented in Table 5-2 have been converted to achieve the corresponding BLV and are presented in Table 5-3.

Table 5-3 Policy options acting as reference points for this study for PAH metabolite (see comments in the body text) - BLVs for 3-hydroxybenzo(a)pyrene (3-OHBaP) as indicator for PAH exposure Risk estimate based on the ERR for inhalable fraction derived by RAC

Policy option	Level, nmol/mol creatinine	Reason for inclusion
1	0.2	As in Table 5-2 above – based on conversion from airborne to equivalent metabolite concentration
2	0.3	As in Table 5-2 above – based on conversion from airborne to equivalent metabolite concentration
3	1.5	As in Table 5-2 above – based on conversion from airborne to equivalent metabolite concentration
4	3.8	As in Table 5-2 above – based on conversion from airborne to equivalent metabolite concentration

¹⁹ Calculated by the study team: to convert μg 3-OHBaP/g creatinine into μmol 3-OHBaP/mol creatinine, a factor of 2.37 is applied based on MW 3-OHBaP (268.3) / MW creatinine (113.12).

6 BENEFITS OF THE MEASURES UNDER CONSIDERATION

This chapter comprises the following sections:

- Section 6.1: Summary of the assessment framework;
- Section 6.2: Improved welfare, assumptions and avoided cases of ill health;
- Section 6.3: Benefits to workers & families;
- Section 6.4: Benefits to employers;
- Section 6.5: Benefits to the public sector; and
- Section 6.6: Summary of the benefits of the measures.

6.1 Summary of the assessment framework

6.1.1 Summary of the key features of the model

The model developed to estimate the benefits in terms of reduced costs takes into account the cost categories set out in Table 6-1 below. More details are presented in the methodology report.

Table 6-1 The benefits framework

Category		Benefits	Notes
Direct	Improved welfare	Reduced healthcare costs	Avoided cost of medical treatment, including hospitalisation, surgery, consultations, radiation therapy, chemotherapy/immunotherapy, etc. Avoided private direct and indirect medical costs and rehabilitation costs
		Reduced informal care costs ²⁰	Avoided opportunity cost of unpaid care (i.e. the monetary value of the working and/or leisure time that relatives or friends provide to those with ill health)
		Reduced cost for employers	Avoided costs due to insurance payments and absence from work
		Safety	
		Direct economic benefits	
		Environment	See section 7.6, not monetised
	Improved market efficiency	Cost savings	Includes higher economic productivity, improved allocation of resources, removal of regulatory or market failures or cost savings.
		Improved information	Includes improved information availability
		Wider range of products/services	Enhanced product and service variety and quality for end consumers

²⁰ A decision has been taken to include informal care costs in this analysis even though some elements of these costs may also have been included in individuals' willingness to pay values to avoid a future case of ill health. This decision may result in an overestimate of the benefits as generated by this study.

Category		Benefits	Notes
Indirect	Indirect compliance benefits	Reduced mortality – productivity loss.	Avoided costs to society due to premature death
		Reduced morbidity – lost working days.	Avoided earnings and output due to absence from work due to illness or treatment
		Other indirect benefits to workers and families	
		Indirect benefits to administrations	Avoided tax revenue losses Avoided administrative and legal costs Avoided costs linked to the process of defining a national OEL
	Wider economic benefits	Including higher GDP, productivity enhancements, greater employment rates, improved job quality etc.	Employment may increase as a result of industry 'clean up' due to better perception of workplaces and increased acceptability of risks
	Other, non-monetary benefits	Protection of fundamental rights, social cohesion, reduced gender discrimination, international and national stability	
Intangible	Improved welfare	Approach 1 WTP ²¹ : Mortality	A monetary value of the impact on quality of life of affected workers Avoided moral pain and suffering Avoided loss of present and future income Avoided cost of time claiming benefits, waiting for treatment etc. Reduction in insurance contributions
		Approach 1 WTP: Morbidity	
		Approach 2 DALY ²² : Mortality	
		Approach 2 DALY: Morbidity	

Source: Study team

The total avoided cost of ill health is calculated using the following two methods:

$$\text{Method 1: } C_{\text{total}} = Ch + Ci + Ce + Cp + C_{\text{vsl}} + C_{\text{vsm}}$$

$$\text{Method 2: } C_{\text{total}} = Ch + Ci + Ce + Cp + Cl + C_{\text{daly}}$$

Cl is not considered under Method 1 since C_{vsm} may already include these costs.

The abbreviations are explained in Table 6-2 below.

6.2 Improved welfare, assumptions and avoided cases of ill health

6.2.1 Benefits categories for improved welfare

The cost savings (benefits) that have been estimated for each substance are summarised below.

²¹ Willingness to Pay: The maximum sum an individual is willing to pay for a service/goods in order to avoid loss, in this case, in terms of health treatment.

²² DALY = Disability Adjusted Life Year. DALY is whereby one year of health is lost. It is used to calculate the gap between current health status and the ideal health situation (WHO, accessed Feb 2018).

Table 6-2 Overview of benefits categories for improved welfare

Category	Code	Cost to be avoided
Direct	Ch	Healthcare
	Ci	Informal care
	Ce	Total cost to an employer
Indirect	Cp	Productivity loss due to mortality
	Cl	Lost earnings due to morbidity
Intangible	Cvsl	Value of statistical life
	Cvsm	Value of cancer morbidity/value of statistical morbidity
	Cdaly	Value of DALYs

Source: Study team.

The benefit model provides the following two outputs:

- The number of new cases for each health endpoint assigned to a specific year in the 40-year assessment period; and
- The Present Value (PV) of the direct, indirect, and intangible costs of each case.

A detailed overview of the key features of the model for the estimation of the benefits and the assumptions underpinning it are set out in the methodology report.

6.2.2 Relevant health endpoints for PAH

Relevant health endpoints for PAH include

- Lung cancer;
- Developmental toxicity (miscarriage and still birth); and
- Male infertility (reduced sperm motility).

See section 2 for more information.

6.2.3 Summary of the key assumptions for PAH

This section provides an overview of key assumptions used in the modelling of monetary benefits (the absence of ill-health) related to PAH airborne exposure and introduction of an OEL.

6.2.3.1 Onset of the disease

The time required for the endpoints to develop over an average working life takes into account the minimum and maximum time required to develop the condition (MinEx and MaxEx) and the distribution of new cases between these two points in time, combined with the latency period with which the effects are diagnosed. No information on the exposure duration of workers exposed to PAH are available.

As developmental toxicity refers to periods of pregnancy (zero to nine months), the MinEx of one day (zero years) and MaxEx of zero years is assumed. Male infertility has been modelled as

permanent, with no latency, and cases occurring from day one of exposure. To model this male infertility is set to zero years MinEx. MaxEx is set to one year to account for model nuances, although this does not imply that male infertility only occurs for one year. As previously stated, male infertility is modelled as a permanent illness. For lung cancer, the MaxEx is typically a full working life, i.e., 40 years.

Table 6-3 Minimum & maximum exposure duration to develop a condition (MinEx & MaxEx)

Endpoint	MinEx (years)	MaxEx (years)
Lung cancer	0	40
Developmental toxicity	0	0
Male infertility	0	1

Source: Study team.

Table 6-4 outlines the latency periods used in modelling, although this is only relevant for lung cancer. A value of 30 years has been taken in relation to Bevan et al. (2012) who indicate that all solid tumours are expected to have a latency of 10-50 years, of which the average latency is 30 years.

Table 6-4 Latency by endpoint

Endpoint	Latency (years)
Lung cancer	30
Developmental toxicity	0
Male infertility	0

Source: Study team.

6.2.3.2 The effects of the disease

The primary adverse health effects for lung cancer, developmental toxicity, and male infertility are present below in Table 6-5.

Table 6-5 Primary ill-health effects for each endpoint

Endpoint	Primary ill-health effects
Lung cancer	Mortality, lethargy, loss of appetite/weight loss, feeling tired/unwell
Developmental toxicity	Miscarriage/stillbirth
Male infertility	Low/reduced sperm motility (reduced chance of conception)

Source: Study team.

The study team have considered the possibility of maternal mortality (death of the mother) as a result of miscarriage or stillbirth. Wider statistical data on maternal mortality includes any underlying cause of death within the perinatal period (conception to 12 months after birth) which may not be attributable to miscarriage or stillbirth. Therefore, it is not possible to quantify the number of maternal mortality cases related to PAH exposure. Noting that most sectors in this study primarily employ males, and that a case of maternal mortality only reflects those exposed during pregnancy (not all female workers) there is a minimal population of workers at risk. Therefore, maternal mortality resulting from miscarriage or stillbirth is not expected to significantly influence the calculation of benefits and has not been included in the modelling of benefits.

6.2.3.3 Treatment period and years lived with the disease.

The table below presents treatment periods and years lived with disability/disease for all endpoints as defined in the Methodological Note.

Table 6-6 Treatment period

Type of illness	Treatment period (years)
Lung cancer	5
Developmental toxicity	1
Male infertility	1

Source: See Methodological note for more details.

Table 6-7 Years lived with disability/disease (YLD)

Type of illness	Treatment period (years)
Lung cancer	5
Developmental toxicity	1
Male infertility	1

Source: See Methodological note for more details.

Note: *Male infertility is set to a value of 1 for the nuances of modelling, however this endpoint is modelled as irreversible (lasting a lifetime).

6.2.3.4 Mortality rate and additional life expectancy at death

The mortality rates for all endpoints are presented in Table 6-8 below. The prognosis for lung cancer is usually unfavorable and has been set to 80% as used in previous OELs studies. Developmental toxicity and male infertility are not directly related to mortality and have been set to zero. As previously stated, it is possible for developmental toxicity to result in mortality of the mother although it is not possible to quantify this.

Table 6-8 Fatality rates (MoR)

Type of illness	MoR
Lung cancer	80%
Developmental toxicity	0%
Male infertility	0%

Source: See Methodological note for more details.

Table 6-9 presents additional life expectancy at death. The average life expectancy used for the calculations in the model is 82 years. In the absence of other information and taking into account the age distribution of cancer deaths, it is assumed that a typical cancer death occurs at the age of 60 and the number of years lost is thus 22.

Table 6-9 Additional life expectancy at death

Type of illness	Additional life expectancy at death (years)
Lung cancer	22
Developmental toxicity	0
Male infertility	0

Source: See Methodological note for more details.

6.2.3.5 Cost of treatment

Table 6-10 Cost of healthcare treatment

Type of illness	Unit cost in €
Lung cancer	11,500
Developmental toxicity	3,500
Male infertility	1,400

Source: See Methodological note for more details.

The cost of treating lung cancer is based on the value used in previous OELs studies. See the Methodological Note for further description.

The cost of treating developmental toxicity has been derived from UK 2021 NHS data on miscarriage (NHS, 2022) and an academic paper modelling the economic costs of stillbirth (Campbell et al., 2017). The study team have calculated the average cost of miscarriage as £1,884 (approximately €2,220 in 2023), and the average cost of stillbirth as £4,200 (approximately €4,850 in 2023). As developmental toxicity refers to both health effects, and both stillbirth and miscarriage have varying degrees of severity and by extent, varying costs, the study team have taken an approximate median value of €3,500.

The cost of treating male infertility varies depending on the severity of illness, the types of treatment available, and personal preferences to repeat treatment campaigns. Cost of treatment have been taken from values used in previous studies.

6.2.3.6 Willingness to Pay (WTP) values

The WTP for a statistical life is presented in the table below. The method for deriving this value for cancer endpoints is described in the methodology report. As non-cancer endpoints do not lead to death, WTP for these endpoints has been set to 0.

Table 6-11 WTP for a statistical life (one life lost)

Type of illness	WTP, €
Lung cancer	4,710,000
Developmental toxicity	0
Male infertility	0

Source: See Methodological note for more details.

Table 6-12 WTP for a statistical morbidity

Type of illness	WTP, €
Lung cancer	455,000
Developmental toxicity	9,600
Male infertility	30,000

Source: See Methodological note for more details.

There is uncertainty regarding the value of intangible WTP (approach 1) for male infertility as the study team have been unable to identify a robust value. The study team have calculated the value of €30,000 based on assumed treatment options typically used, their iterations over a lifespan, and the costs of individual elements in the UK and Germany based on many sources.

6.2.3.7 Disability weights

As outlined in the Methodological Note, the following disability weights have been applied in the modelling. The first is taken from the WHO Global Burden of Disease (GBD) study (2013) which was updated in 2015. The second set of weights are taken from the European Disability Weights Project (2015) conducted by the European Centre for Disease Prevention and Control

Table 6-13 Disability weights

Type of illness	During treatment	After treatment
Lung cancer	0.265	0.515
Developmental toxicity	0.114	0
Male infertility	0.008	0

Source: See Methodological note for more details.

6.2.3.8 Summary

Further explanation of the sourcing of figures presented in this section can be found in section 4.3 of the Methodological Note.

Table 6-14 Unit costs used for the benefits assessment

Category	Code		Cost, €/case		
			Lung cancer	Developmental toxicity	Male infertility
Direct	Ch	Healthcare	11,500	3,500	1,400
	Ci	Informal care	3,000	0	0
	Ce	Cost for employers	13,200	0	0
Indirect	Cp	Mortality – productivity loss due to mortality	5,000	0	0
	Cl	Morbidity – lost working days due to morbidity	1,000	2,800	0
Intangible	Cvsl	Approach 1 WTP: Value of statistical life	4,710,000	0	0
	Cvsm	Approach 1 WTP: Value of cancer morbidity/value of statistical morbidity	455,000	9,600	30,000
	Cdaly	Approach 2 DALY: Value of DALYs	100,000	100,000	100,000

Source: Study team.

Notes: Additional information on the calculation of the above figures can be found in the Methodological Note.

6.2.4 Avoided cases of ill health (cancer and non-cancer)

The number of avoided cases over 40 years by the different policy options is shown in the table below. The number of cases is further plotted in a continuous form in the figure below.

Table 6-15 Cases over 40 years for each OEL policy option

OEL policy option	Lung cancer	Developmental toxicity	Male infertility
7 ng/m ³	19	0	0
70 ng/m ³	125	0	0
700 ng/m ³	158	31	2,549

OEL policy option	Lung cancer	Developmental toxicity	Male infertility
2000 ng/m ³	160	38	3,157

Source: Study team.

Table 6-16 illustrates the number of cases avoided at each of the policy option levels relative to the baseline. As shown, at 2000 ng/m³ no cases are avoided for any endpoint. At 70ng/m³ modelling estimates that developmental toxicity and male infertility no longer produce cases, and at 7ng/m³ there is a vast reduction in the number of lung cancer cases.

Table 6-16 Avoided cases over 40 years for each OEL policy option

Policy option	Lung cancer	Developmental toxicity	Male infertility
7 ng/m ³	141	38	3,157
70 ng/m ³	35	38	3,157
700 ng/m ³	2	7	608
2000 ng/m ³	0	0	0

Source: Study team.

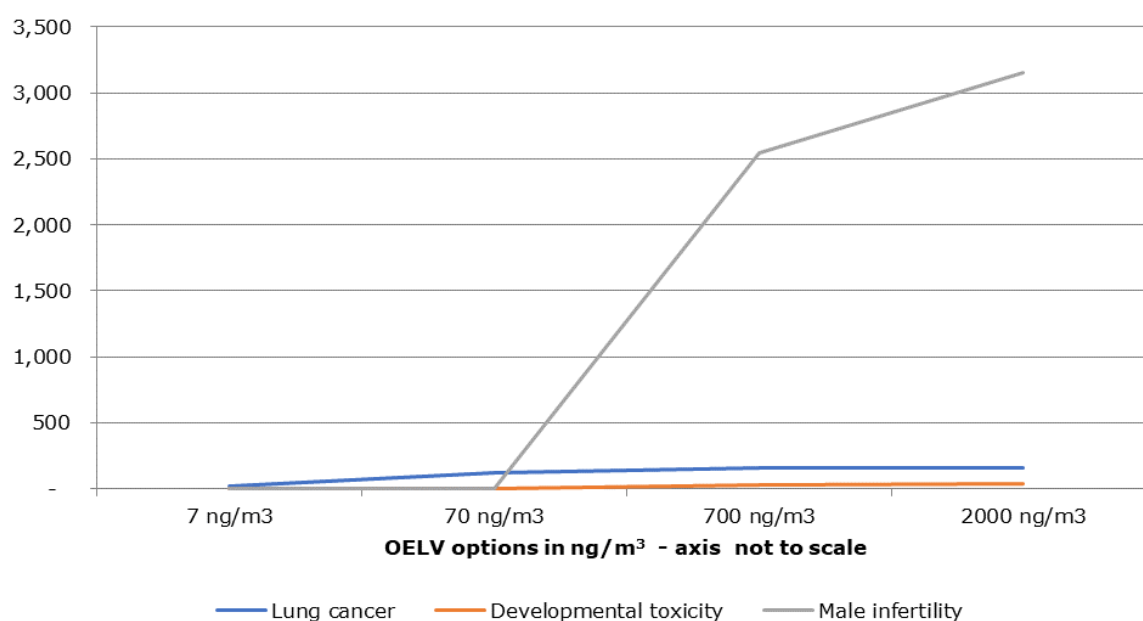


Figure 6-1 Cases over 40 years due in relation to different OEL levels

Source: Study team

6.3 Benefits to workers & families

6.3.1 Avoided costs of ill health

The benefits that will be realised by exposed workers and their families are first of all intangible benefits of reduced mortality rates. All the categories are presented in the table below.

Table 6-17 Benefits for workers and their families (avoided cost of ill health)

Stakeholder group	Costs	Method of summation
Workers/family	Ci, Cl, Cvsl, Cvcn, Cdaly	Method 1: CtotalWorker&Family=Ci+Cvsl+Cvcn Method 2: CtotalWorker&Family=Ci+Cl+Cdaly

Source: See Methodological note for more details.

The benefits of each policy option (relative to the baseline) are summarised below. Method 1 relies on WTP values for morbidity, with the resulting estimates given in Table 6-18 and Figure 6-2. Developmental toxicity results in lower benefits due to low frequency of cases and lower morbidity costs compared with other endpoints. Lung cancer produces the most benefits due to high morbidity costs per case. Male infertility benefits have proportionally lower morbidity costs per case but make up a significant proportion of total benefits due to a high number of cases.

Table 6-18 METHOD 1: Benefits to WORKERS & FAMILIES (relative to the baseline) (€ millions)

Policy option	Lung cancer	Developmental toxicity	Male infertility	Total
7 ng/m ³	€ 112.29	€ 0.20	€ 69.11	€ 181.60
70 ng/m ³	€ 27.92	€ 0.20	€ 69.11	€ 97.23
700 ng/m ³	€ 1.78	€ 0.04	€ 13.35	€ 15.17
2000 ng/m ³	€ -	€ -	€ -	€ -

Source: Study team.

Note: Workforce turnover 5% per year

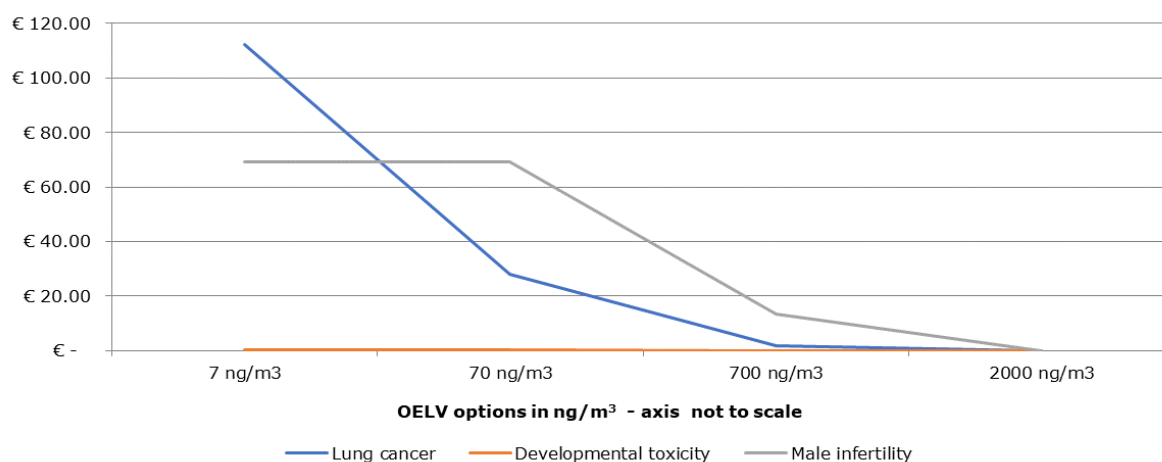


Figure 6-2 METHOD 1: Benefits to WORKERS & FAMILIES (policy options, relative to the baseline)

Source: Study team

Method 2 relies on monetised DALYs, with the estimates given in Table 6-19 and depicted in Figure 6-3.

Table 6-19 METHOD 2: Benefits to WORKERS & FAMILIES (policy options, relative to the baseline) (€ millions)

Policy option	Lung cancer	Developmental toxicity	Male infertility	Total
7 ng/m ³	€ 57.42	€ 0.05	€ 1.90	€ 59.36
70 ng/m ³	€ 14.28	€ 0.05	€ 1.90	€ 16.22
700 ng/m ³	€ 0.91	€ 0.01	€ 0.37	€ 1.29
2000 ng/m ³	€ -	€ -	€ -	€ -

Source: Study team.

Note: Workforce turnover 5% per year

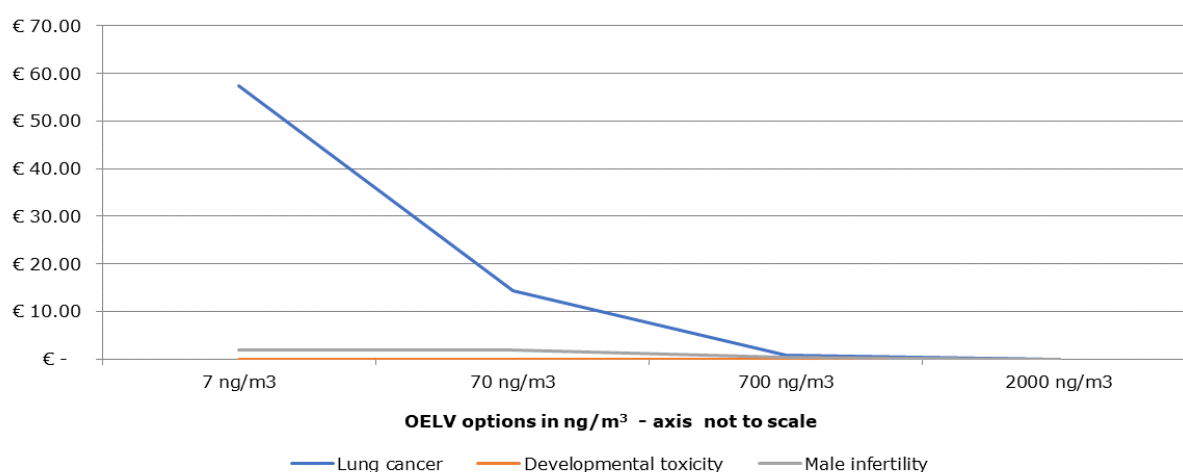


Figure 6-3 METHOD 2: Benefits to WORKERS & FAMILIES (policy options, relative to the baseline).

Source: Study team

6.3.2 Other benefits to workers and families

No other benefits have been identified.

6.4 Benefits to employers

6.4.1 Avoided costs of ill health

The benefits (avoided costs of ill health relative to the baseline) accrued by employers are calculated using the method summarised below.

Table 6-20 Benefits to EMPLOYERS (avoided cost of ill health)

Stakeholder group	Costs	Method of summation
Employers	Ce, Cp	$C_{totalEmployer} = C_e + 0.8 * C_p$

Source: Study team.

The benefits of each policy option are summarised below in Table 6-21 and depicted in Figure 6-4. The workforce turnover is 5% per year and a static discount rate of 3% is used. As shown, benefits to employers make up a much smaller proportion of overall benefits than other benefit types. Benefits for employers only refer to cases related to lung cancer. Modelling of benefits were assessed for all endpoints, however calculations related to developmental toxicity and male infertility did not produce monetary benefits for employers. The reason for this is multifaceted and considers the following:

- Developmental toxicity refers only to pregnant workers which significantly reduces the exposed population (noting that the majority of the sectors identified for analysis are male dominant), that pregnancies typically occur in younger age ranges, and that pregnancies are not typically experienced frequently during a worker's career.
- Developmental toxicity is estimated to have the following costs used in the calculation of benefits: Direct healthcare costs, indirect morbidity (lost workdays), and WTP to avoid sickness. None of which are relevant to the calculation of benefits for employers, subsequently resulting in no benefits being calculated.
- Male infertility has a higher occurrence than other endpoints, however the avoided costs associated with this endpoint refer to direct healthcare costs, and WTP to avoid sickness. Neither are relevant to the calculation of benefits for employers, again resulting in no benefits being calculated.

The benefits referred to in this section include both industry sectors and firefighters (public authority benefits).

Table 6-21 Benefits to EMPLOYERS (OEL policy options, relative to the baseline) (€ millions)

Policy option	Lung cancer	Developmental toxicity	Male infertility	Total
7 ng/m ³	€ 0.54	€ -	€ -	€ 0.54
70 ng/m ³	€ 0.13	€ -	€ -	€ 0.13
700 ng/m ³	€ 0.01	€ -	€ -	€ 0.01
2000 ng/m ³	€ -	€ -	€ -	€ -

Source: Study team.

Note: "€ -" refers to no monetary benefit.

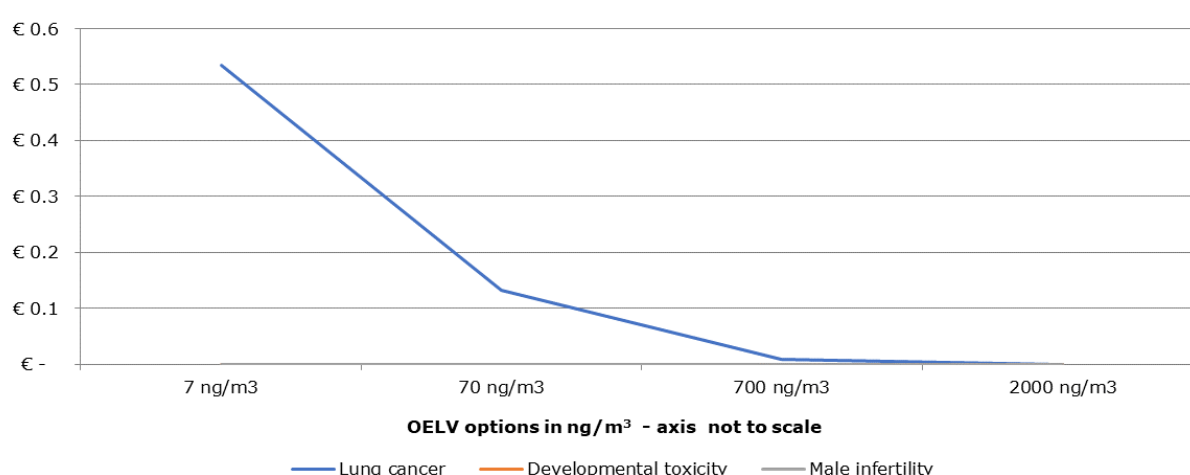


Figure 6-4 Benefits to EMPLOYERS (OEL policy options, relative to the baseline).

Source: Study team.

6.4.1.1 Result of stakeholder survey regarding other benefits

Companies' answers to the question "do you think your company will benefit from any of these indirect benefits if an EU-wide OEL for PAH is introduced?" are summarised in the table below. Of the

42 answering the question, 55% indicated there will no benefit. Benefits for which more than 10% answered “Yes” were healthier staff (19%), improved public image (14%) and level playing field with EU competitors (31%). The benefit of healthier staff is covered by the sections above, whereas some of the other benefits are briefly described below (although respondents did not provide any further comments on their answers).

Table 6-22 Companies’ survey answer to question regarding benefits of establishing an OEL.

Sector	Percent answering yes (number of respondents)
Healthier staff	19% (8)
Increased productivity of workers	0% (0)
Improved public image	14% (6)
Easier to recruit staff	10% (4)
Easier to retain staff	7% (3)
Reduced cost of recruitment	2% (1)
Easier monitoring of exposure	2% (1)
Savings because company currently has multiple locations in different Member States with different regulations or OELs	2% (1)
Level playing field with EU competitors	31% (13)
Other indirect benefits, please specify	0% (0)
There will be no indirect benefits	55% (23)
Number of responses	100% (42)

Source: Study team.

6.4.1.1.1 Better company image, public perception

A total of 14% (6) of companies responding to the PAH questionnaire believed improved public image would be a result of establishing an EU OEL.

6.4.1.1.2 Level playing field

The establishment of an EU Level playing field was the second highest selected answer for the question regarding benefits of establishing an EU OEL; a total of 31% (13) respondents selected this answer. The companies selecting this answer represent 75% (6) of the sectors that responded. These include C19.1 Coking Plants, C19.2 Petroleum Refineries, C20.13 Manufacture of Carbon Black, C20.14 Coal Tar Distillation, C24.42 Manufacture of Aluminium, C24.5 Casting of Metals, F42.11 Road Paving, G45.2 Motor Vehicle Maintenance and Repair.

6.4.1.1.3 One set of limit values across all Member States

The harmonisation of OEL would make it easier for companies working in more than one EU Member State, because only one set of limit value would have to be followed. Companies could achieve savings in research and design cost as well as expect an administrative simplification. If there is a single OEL across the EU, the company can have a centralised group of people dealing with the OEL, which would likely be more efficient.

However, only one respondent from the automotive repair sector stated that they expect an overall saving as their company has sites in multiple locations across Member States with different regulations or OELs. The remainder of respondents did not feel this was the case.

6.4.1.1.4 Moving away from respiratory protective equipment (RPE) can be cheaper over a long period

Based on literature, interview and site visit information, the study team has modelled each sector on the basis of risk management measures (RMMs) currently used (see section Table 3-3). Modelling estimates that all types of RPE have high first year and or recurrent costs compared to other long-term measures (such as closed systems). For example, whilst simple facemasks only contain one-off costs to purchase (no recurrent costs), the single use element requires considerable units to be purchased. Alternatively filtered facemasks are estimated to require replaced every two months due to wear and tear and require a new set of filters for every 30 hours of use. Filtered facemasks are estimated to have a moderate single unit cost with high recurrent costs. Alternatively full facemasks/breathing apparatus have a high one-off unit cost, and a high recurrent cost due to the need for replenished air supplies and specialist maintenance. Sectors with a higher reliance on RPE may benefit from a shift to other measures where possible. Modelling estimates these sectors may include:

- C16.1 Wood preservation;
- C19.2 Petroleum refineries;
- C20.13 Manufacture of carbon black;
- C20.14 Coal tar distillation;
- C23.2 Manufacture of refractory products;
- C23.99b Graphite and carbon electrode manufacture;
- C24.42 Manufacture of aluminium;
- C24.45 other non-ferrous metallurgy;
- C24.5 Casting of metals;
- E38.2 Waste incineration; and
- E39 Soil remediation.

6.5 Benefits to public administrations

6.5.1 Avoided costs of ill health

The benefits (avoided costs of ill health, relative to the baseline) for the public administrations are calculated using the method summarised Table 6-23 and shown in Figure 6-5. These costs include healthcare treatment costs, which assume that the costs are borne by the public administrations. These costs do not include informal care costs, which are costs for workers and families covered in section 6.3. The workforce turnover is 5% per year and a static discount rate of 3% is used.

Table 6-23 Benefits to the PUBLIC ADMINISTRATIONS (avoided cost of ill health)

Stakeholder group	Costs	Method of summation
Governments	Ch, part of Cp (loss of tax revenue), part of CI (loss of tax revenue)	$C_{totalGov} = Ch + 0.2(Cp + CI)$ (Note 1)

Source: Study team.

Note: 1 Assumes 20% tax

The benefits of each policy option (relative to the baseline) are summarised in Table 6-24 below and depicted in Figure 6-5.

Table 6-24 Benefits to the PUBLIC ADMINISTRATIONS (policy option, relative to the baseline) (€ millions)

Policy option	Lung cancer	Developmental toxicity	Male infertility	Total
7 ng/m ³	€ 1.85	€ 0.09	€ 3.32	€ 5.26
70 ng/m ³	€ 0.46	€ 0.09	€ 3.32	€ 3.87
700 ng/m ³	€ 0.03	€ 0.02	€ 0.64	€ 0.69
2000 ng/m ³	€ -	€ -	€ -	€ -

Source: Study team.

Note: "€ -" refers to no monetary benefit.

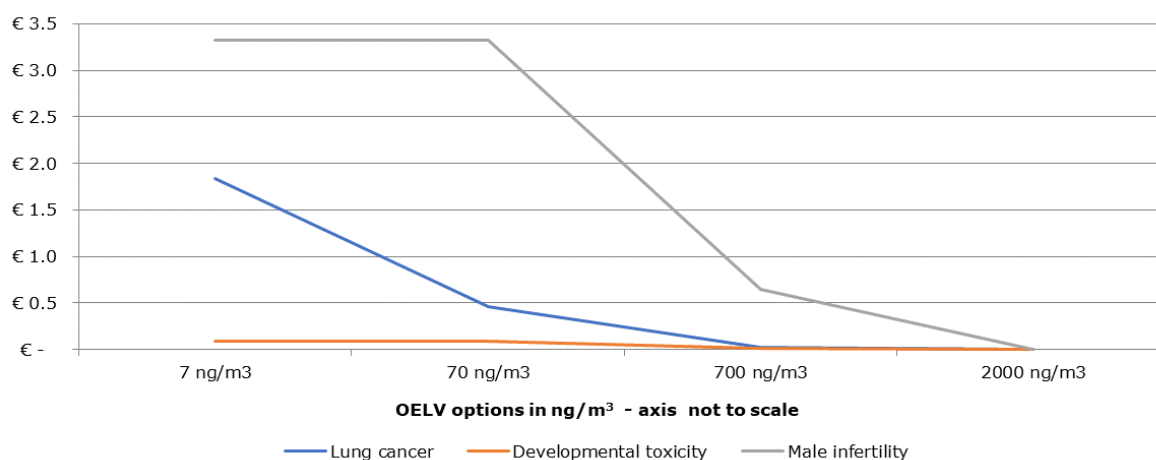


Figure 6-5 Benefits to the PUBLIC ADMINISTRATIONS (OEL policy options, relative to the baseline).

Source: Study team.

6.5.2 Other benefits to public administrations

6.5.2.1 Avoided costs linked to the process of defining a national OEL

below provides the indirect benefits that may be gained by member states not having to define their own national OEL as a result of the introduction of an EU OEL. Defining a national OEL and/or BLV has associated costs for member states public administrations to carry out impact assessments and define a suitable level of avoided risk. The data used are based on the assumption that all Member States without a national OEL and/or BLV would want to implement one and that all Member States with an existing OEL and/or BLV would want to revise them to ensure higher degrees of worker protection. This calculation is based on the number of Member States with and without an existing binding or indicative OEL. Both binding and indicative OELs must exist within legislation and by extent if legislation exists above the proposed policy option an amendment is

possible (i.e. it does not matter whether the existing OEL is binding or indicative). As shown in the below table, public authority benefits related to avoided costs of implementing a national OEL and BLV are approximately four million euros despite the policy option put in place. The avoided costs of only implementing an OEL range from €1.2 million to €1.8 million. Comparably this illustrates that there are higher benefits to implementing both OEL and BLV as only two Member States currently have a BLV in place. below provides the indirect benefits that may be gained by member states not having to define their own national OEL as a result of the introduction of an EU OEL. Defining a national OEL and/or BLV has associated costs for member states public administrations to carry out impact assessments and define a suitable level of avoided risk. The data used are based on the assumption that all Member States without a national OEL and/or BLV would want to implement one and that all Member States with an existing OEL and/or BLV would want to revise them to ensure higher degrees of worker protection. This calculation is based on the number of Member States with and without an existing binding or indicative OEL. Both binding and indicative OELs must exist within legislation and by extent if legislation exists above the proposed policy option an amendment is possible (i.e. it does not matter whether the existing OEL is binding or indicative). As shown in the below table, public authority benefits related to avoided costs of implementing a national OEL and BLV are approximately four million euros despite the policy option put in place. The avoided costs of only implementing an OEL range from €1.2 million to €1.8 million. Comparably this illustrates that there are higher benefits to implementing both OEL and BLV as only two Member States currently have a BLV in place.

Table 6-25 Avoided costs of implementing Policy Options for Member State Authorities

Member State situation	Number of Member States	Avoided cost per Member State	Total cost across the EU
7 ng/m³ & 0.2 nmol/mol creatinine (3-OHBaP) & 1-OHP			
Member States without an existing OEL	9	€ 100,000	€ 900,000
Member States requiring alteration of an existing OEL	18	€ 50,000	€ 900,000
Member States without an existing BLV	21	€ 100,000	€ 2,100,000
Member States requiring alteration of an existing BLV	6	€ 50,000	€ 300,000
Total (OEL only)			€ 1,800,000
Total (OEL+BLV)			€ 4,200,000
70 ng/m³ & 0.3 nmol/mol creatinine (3-OHBaP) & 1-OHP			
Member States without an existing OEL	9	€ 100,000	€ 900,000
Member States requiring alteration of an existing OEL	17	€ 50,000	€ 850,000
Member States without an existing BLV	21	€ 100,000	€ 2,100,000
Member States requiring alteration of an existing BLV	6	€ 50,000	€ 300,000
Total (OEL only)			€ 1,750,000
Total (OEL+BLV)			€ 4,150,000
700 ng/m³ & 1.5 nmol/mol creatinine (3-OHBaP) & 1-OHP			
Member States without an existing OEL	9	€ 100,000	€ 900,000
Member States requiring alteration of an existing OEL	14	€ 50,000	€ 700,000
Member States without an existing BLV	21	€ 100,000	€ 2,100,000

Member State situation	Number of Member States	Avoided cost per Member State	Total cost across the EU
Member States requiring alteration of an existing BLV	5	€ 50,000	€ 250,000
Total (OEL only)			€ 1,600,000
Total (OEL+BLV)			€ 3,950,000
2000 ng/m³ & 3.8 nmol/mol creatinine (3-OHBP) & 1-OHP			
Member States without an existing OEL	9	€ 100,000	€ 900,000
Member States requiring alteration of an existing OEL	6	€ 50,000	€ 300,000
Member States without an existing BLV	21	€ 100,000	€ 2,100,000
Member States requiring alteration of an existing BLV	4	€ 50,000	€ 200,000
Total (OEL only)			€ 1,200,000
Total (OEL+BLV)			€ 3,500,000

Source: Study team.

6.6 Introduction of a BLV

The policy options include the introduction of a BLV, corresponding to the equivalent air concentrations (see section 5). BaP is readily absorbed via inhalation, oral and dermal route and the measurement of a metabolite in urine implies that the substance has been taken up and metabolised (see section 2.4.1).

The difficulty in quantifying benefits of a BLV lie in the fact that the presence of a substance in a biological matrix does not necessarily mean that it is causing harm, nor does the absence of a substance indicate that an individual was not exposed (IARC 2023). Moreover, the levels of chemical metabolites in biomonitoring samples does not necessarily permit the identification of the source(s) and/or route(s) of exposure (IARC 2023). Ultimately, there is no exposure risk relationship (ERR) for the metabolite 3-OHBP in urine (the benefits of the OEL are calculated based on lung cancer cases resulting from airborne exposure to BaP).

Dermal exposure can occur through contact with the substance or article containing PAH or through deposition of PAH from air and soot in the surrounding areas. A worker may be wearing appropriate PPE and RPE in the designated areas and still be exposed via particle penetration through clothing or through contaminated surfaces. In the case of firefighters, while PPE restricts the contact with chemicals, exposure can occur via gear penetration, contact with exposed areas of the face, neck and wrist, and/or contact with contaminated gear (IARC, 2023; Stec, et al., 2018). Skin cancer is identified in many studies as more prevalent than lung cancer in firefighters, suggesting that dermal uptake is more relevant for firefighters (IARC, 2023; A. Stec personal communication 2023).

For more details on the potential for dermal exposure for each sector please refer to section 3.2.5.

6.6.1 Benefits of introducing a BLV

6.6.2 Benefits background

Evidence for skin cancer induction by PAH is conclusive, however no quantitative data are available and skin cancer is not taken into account in the ERR (RAC, 2022a). There is also a non-conclusive link between bladder cancer and PAH (see section 2.1.3.1). RAC's sensitivity analysis calculations

indicate that assuming no confounding by other factors, bladder cancer would at maximum influence the ERR by a factor of 1.7. Both cancers may be prevented through biomonitoring, which would result in measures put in place to achieve a pre-determined or reduce internal loading of PAH (through metabolite concentration measurements).

The main routes for occupational exposure to PAH are inhalation and skin contact. In coke-oven workers uptake of pyrene by the dermal route was estimated to account for as much as 75% of the total body dose for coke-oven workers (Van Rooij et al., 1993a); for creosote-impregnating workers, dermal pyrene uptake was on average 15-fold higher than the estimated respiratory uptake (RAC, 2023 citing Van Rooij et al., 1993 and IARC 2010). In creosote wood impregnation processes, dermal uptake is more prominent than in inhalation as demonstrated in a study where air measurements showed low exposure concentrations, but workers had high 1-OHP levels (see section 3.3.4.2, RAC 2023 Hebisch et al., 2020). In firefighters, studies suggest that the main route of exposure is via the dermal route (Stec et al., 2018; Wolffe, et al., 2022; Stakeholder consultation, 2023) and that skin cancer was by far the most prevalent type of cancer reported in firefighters in the UK (Wolffe et al., 2022).

6.6.3 Sectors impacted

The introduction of a BLV is particularly beneficial in sectors where dermal exposure is the prevalent route of exposure (e.g. wood preservation), but also in sectors where significant dermal exposure is anticipated in addition to airborne exposure (e.g. coking, firefighters). The table below identifies these sectors.

Table 6-26 Sectors where the introduction of a BLV will be of particular benefit

Sectors with high dermal exposure and low airborne exposure	Sectors with high dermal exposure and airborne exposure
C16.1 wood impregnation with creosote	C19.1 coking plants
G45.2 motor vehicle repair and maintenance	C20.14 coal tar distillation
N81.22 chimney sweeps	C23.99b graphite and carbon electrodes manufacture
O84.25 firefighters	C24.45 other metallurgy
	C24.1 iron and steel foundries
	C24.42 aluminium manufacture
	E39.0 soil remediation workers
	F42.12 railway welders

Source: Study team.

The estimations of high dermal load are based on literature reviews, mainly IARC monographs. There are very few data points on 3-OHBP, but data available on 1-OHP metabolite confirm the potential for high internal doses, likely because of dermal exposure.

In firefighter only team leaders are assessed via inhalation route, but PAH have been found on the skin of firefighters of any position (not only team leaders) after attending a live fire, and furthermore exposures can occur when they are not attending fires and are not wearing PPE. This is because of handling contaminated RPE/PPE, equipment, fire vehicles and office space. Therefore, all firefighters are potentially exposed to PAH via the dermal route. In this study, a total of 4,385,060 professional and volunteers firefighters are estimated to be exposed to PAH via the dermal route,

and 10% via the inhalation route only (i.e. 10% of firefighters are assumed to be team leaders, which corresponds to 438,506).

All the sectors assessed in this study (see section 3.2.12) will benefit from the introduction of a BLV, even if they are not reported in the above table – but to a lesser extent.

6.6.4 Benefits of a BLV

There is no quantifiable method for assessing dermal exposure, and PAH are known to conclusively cause skin cancer but there are no quantitative data on skin cancer to conclude on an exposure risk relationship (RAC, 2022b). RAC also concludes that PAH are distributed to internal organs following dermal exposure, including the lungs. There is also indication that PAH increase the risk of bladder cancer in certain industries. In these industries exposure to bladder carcinogens such as aromatic amines is also known and it is not possible to unequivocally link bladder cancer risks to PAH (RAC, 2022b). A quantitative assessment is therefore not possible.

On the basis of the data available, it can be concluded that the introduction of the BLV will:

- Reduce the risk of skin cancer. A skin notation has a similar aim however it is not possible to measure dermal uptake and the implementation of a BLV will ensure that specific measures and steps are taken to reduce potential uptake via the dermal route;
- Reduce bladder cancer. While it is not possible to conclude the risk relationship between PAH and bladder cancer, RAC conducted a sensitivity analysis and concluded that assuming no confounding by other factors is possible, exposure to PAH would at maximum influence the ERR by a factor of 1.7; and
- A larger number of workers have the potential to be exposed via the dermal route and inhalatory route, as opposed to the inhalation route only. Therefore a large portion of workers will be protected via the introduction of a BLV.

The study team has conducted a qualitative assessment based on the number of workers exposed (see section 3.4.6) and potential for dermal exposure (See Table 6-26). The benefit of introducing a BLV is determined on the potential for dermal exposure which the study team has classed as low, medium or high. This classification is based on stakeholder consultation with an occupational hygienist, a comparison of inhalation vs metabolite data presented in section 3.3 and information gathered during the critical literature review, including but not only, IARC monographs.

The number of workers in this section takes into account the total number of firefighters that are at risk of dermal exposure. This figure is higher than firefighters who are most at risk from airborne exposure only – because in this study only team leaders, i.e. 10% of the workforce, can be assessed to quantify the risks from airborne exposure (see section 3.3.4.21 for more details).

Table 6-27 Qualitative assessment of the benefits of a BLV

Sectors with high dermal exposure and low airborne exposure	No. of workers potentially exposed via dermal route	Benefit of introducing a BLV ^(a)
C16.1 wood impregnation with creosote	1,000	High
C19.1 coking plants	2,516	Medium
C20.14 coal tar distillation	750	Medium

Sectors with high dermal exposure and low airborne exposure	No. of workers potentially exposed via dermal route	Benefit of introducing a BLV ^(a)
C23.99b graphite and carbon electrodes manufacture	1,001	Medium
C24.1 Steel and iron foundries, ferroalloys	95,752	Medium
C24.42 Manufacture of aluminium	626	Medium
C24.45 Other non-ferrous metallurgy	616	Medium
G45.2 motor vehicle repair and maintenance	371,532	High
N81.22 chimney sweeps	24,500	High
O84.25 firefighters	4,385,060 ^(b)	High
Total	4,883,353	101,261 Medium 4,782,708 High

Source: Study team.

Notes:

(a) qualitative assessment based on the potential for dermal exposure and inhalation exposure vs inhalation only, based on stakeholder consultation with an occupational hygienist, a comparison of inhalation vs metabolite data presented in section 3.3 and information gathered during the critical literature review, including but not only, IARC monographs.

(b) the total number of firefighters that are at risk from dermal exposure is higher than those who are at risk from airborne exposure only, because only team leaders are considered in the latter group, i.e. 10% of firefighters.

It is concluded that in total 4,782,708 workers and applicable volunteers (firefighters) will experience a high level of benefits from the introduction of a BLV. While in total 101,261 workers will experience a medium level of benefit from the introduction of a BLV.

Workers in other sectors that are not presented in the above table, e.g. road paving, will still benefit from the introduction of a BLV but to a lesser extent (low level of benefit). This is equal to 346,637 workers experiencing some level of benefit from the introduction of a BLV.

6.7 Summary of the benefits of the measures

6.7.1 Benefits from avoided ill health

Method 1 relies on WTP values for mortality, with the resulting estimates given in Table 6-28.

Table 6-28 METHOD 1: Benefits from avoided ill health (OEL policy options, relative to the baseline) (€ millions)

Policy option	Lung cancer	Developmental toxicity	Male infertility	Total
7 ng/m ³	€ 114.67	€ 0.28	€ 72.43	€ 187.38
70 ng/m ³	€ 28.34	€ 0.28	€ 72.43	€ 101.06
700 ng/m ³	€ 1.81	€ 0.05	€ 13.99	€ 15.85
2000 ng/m ³	€ -	€ -	€ -	€ -

Source: Study team.

Note: "€ -" refers to no monetary benefit.

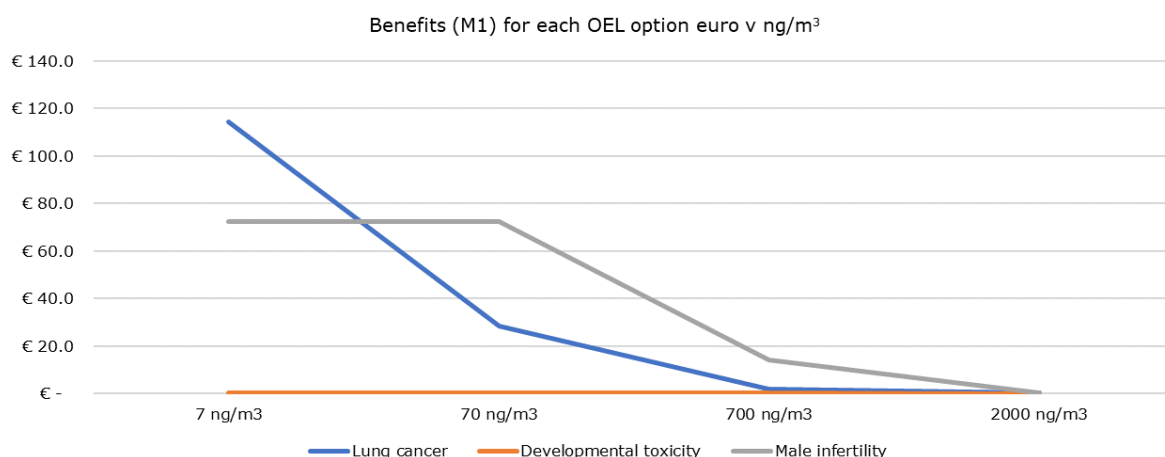


Figure 6-6METHOD 1: Benefits from avoided ill health (OEL policy options, relative to the baseline).
Source: Study team.

The Method 1 benefits at different OEL policy options, split by sector are presented in Table 6-29.

Please note that modelling has only been undertaken on air-based exposure. Sectors are expected to have additional dermal exposure, although this cannot be quantified or modelled. In particular, exposure to firefighters (operational/coordinating roles) are known to have a higher degree of dermal exposure which has not been quantified in this section.

Table 6-29 METHOD 1: Benefits from avoided ill health by sector by OEL policy options, relative to the baseline (€ millions)

Sector	Lung cancer	Developmental toxicity	Male infertility	Total
7 ng/m³				
C10.13 Meat and poultry smokehouses	€ 0.01	€ -	€ -	€ 0.01
C10.2 Seafood smokehouses	€ 0.02	€ -	€ -	€ 0.02
C16.1 Wood preservation (creosote)	€ 0.01	€ -	€ -	€ 0.01
C19.1 Coking plants	€ 3.7	€ 0.04	€ 18.0	€ 21.8
C19.2 Petroleum refineries	€ 1.2	€ -	€ -	€ 1.2
C20.13 Manufacture of carbon black	€ 0.1	€ -	€ -	€ 0.1
C20.14 Coal tar distillation	€ 0.4	€ 0.03	€ 1.7	€ 2.1
C23.2 Manufacture of refractory products	€ 0.04	€ 0.002	€ 0.2	€ 0.3
C23.99a Manufacture of bituminous products	€ 0.9	€ -	€ -	€ 0.9
C23.99b Graphite and carbon electrode manufacture	€ 0.4	€ 0.01	€ 0.2	€ 0.6
C24.1 Steel and iron foundries, ferroalloys	€ 9.5	€ -	€ -	€ 9.5
C24.42 Manufacture of aluminium	€ 0.1	€ -	€ -	€ 0.1
C24.45 Other non-ferrous metallurgy	€ 0.5	€ 0.003	€ 2.1	€ 2.6
C24.5 Casting of metals	€ 19.2	€ -	€ -	€ 19.2

Sector	Lung cancer	Developmental toxicity	Male infertility	Total
D35.11 Coal fired power plants	€ 1.0	€ -	€ -	€ 1.0
E38.2 Waste incineration	€ -	€ -	€ -	€ -
E39 Soil remediation	€ 3.3	€ 0.1	€ -	€ 3.4
F42.11 Road paving	€ 6.9	€ -	€ -	€ 6.9
F42.12 Welding of railroad tracks	€ 10.5	€ 0.1	€ 50.3	€ 60.9
G45.2 Motor vehicle maintenance and repairs	€ 2.7	€ -	€ -	€ 2.7
N81.22 Chimney sweeps	€ 1.7	€ -	€ -	€ 1.7
O84.25 Firefighters	€ 52.4	€ -	€ -	€ 52.4
Total	€ 114.7	€ 0.3	€ 72.4	€ 187.4
70 ng/m³				
C10.13 Meat and poultry smokehouses	€ -	€ -	€ -	€ -
C10.2 Seafood smokehouses	€ -	€ -	€ -	€ -
C16.1 Wood preservation (creosote)	€ -	€ -	€ -	€ -
C19.1 Coking plants	€ 3.4	€ 0.04	€ 18.0	€ 21.5
C19.2 Petroleum refineries	€ 0.4	€ -	€ -	€ 0.4
C20.13 Manufacture of carbon black	€ -	€ -	€ -	€ -
C20.14 Coal tar distillation	€ 0.4	€ 0.03	€ 1.7	€ 2.1
C23.2 Manufacture of refractory products	€ 0.04	€ 0.002	€ 0.2	€ 0.3
C23.99a Manufacture of bituminous products	€ 0.3	€ -	€ -	€ 0.3
C23.99b Graphite and carbon electrode manufacture	€ 0.3	€ 0.01	€ 0.2	€ 0.5
C24.1 Steel and iron foundries, ferroalloys	€ 1.4	€ -	€ -	€ 1.4
C24.42 Manufacture of aluminium	€ 0.04	€ -	€ -	€ 0.04
C24.45 Other non-ferrous metallurgy	€ 0.4	€ 0.003	€ 2.1	€ 2.5
C24.5 Casting of metals	€ 9.8	€ -	€ -	€ 9.8
D35.11 Coal fired power plants	€ -	€ -	€ -	€ -
E38.2 Waste incineration	€ -	€ -	€ -	€ -
E39 Soil remediation	€ 2.3	€ 0.1	€ -	€ 2.3
F42.11 Road paving	€ -	€ -	€ -	€ -
F42.12 Welding of railroad tracks	€ 9.6	€ 0.1	€ 50.3	€ 60.0
G45.2 Motor vehicle maintenance and repairs	€ -	€ -	€ -	€ -
N81.22 Chimney sweeps	€ -	€ -	€ -	€ -
O84.25 Firefighters	€ -	€ -	€ -	€ -

Sector	Lung cancer	Developmental toxicity	Male infertility	Total
Total	€ 28.3	€ 0.3	€ 72.4	€ 101.1
700 ng/m³				
C10.13 Meat and poultry smokehouses	€ -	€ -	€ -	€ -
C10.2 Seafood smokehouses	€ -	€ -	€ -	€ -
C16.1 Wood preservation (creosote)	€ -	€ -	€ -	€ -
C19.1 Coking plants	€ 0.5	€ 0.01	€ 4.4	€ 4.9
C19.2 Petroleum refineries	€ -	€ -	€ -	€ -
C20.13 Manufacture of carbon black	€ -	€ -	€ -	€ -
C20.14 Coal tar distillation	€ -	€ -	€ -	€ -
C23.2 Manufacture of refractory products	€ -	€ -	€ -	€ -
C23.99a Manufacture of bituminous products	€ -	€ -	€ -	€ -
C23.99b Graphite and carbon electrode manufacture	€ -	€ -	€ -	€ -
C24.1 Steel and iron foundries, ferroalloys	€ -	€ -	€ -	€ -
C24.42 Manufacture of aluminium	€ -	€ -	€ -	€ -
C24.45 Other non-ferrous metallurgy	€ -	€ -	€ -	€ -
C24.5 Casting of metals	€ -	€ -	€ -	€ -
D35.11 Coal fired power plants	€ -	€ -	€ -	€ -
E38.2 Waste incineration	€ -	€ -	€ -	€ -
E39 Soil remediation	€ -	€ -	€ -	€ -
F42.11 Road paving	€ -	€ -	€ -	€ -
F42.12 Welding of railroad tracks	€ 1.3	€ 0.04	€ 9.6	€ 10.9
G45.2 Motor vehicle maintenance and repairs	€ -	€ -	€ -	€ -
N81.22 Chimney sweeps	€ -	€ -	€ -	€ -
O84.25 Firefighters	€ -	€ -	€ -	€ -
Total	€ 1.8	€ 0.1	€ 14.0	€ 15.9
2000 ng/m³				
C10.13 Meat and poultry smokehouses	€ -	€ -	€ -	€ -
C10.2 Seafood smokehouses	€ -	€ -	€ -	€ -
C16.1 Wood preservation (creosote)	€ -	€ -	€ -	€ -
C19.1 Coking plants	€ -	€ -	€ -	€ -
C19.2 Petroleum refineries	€ -	€ -	€ -	€ -
C20.13 Manufacture of carbon black	€ -	€ -	€ -	€ -

Sector	Lung cancer	Developmental toxicity	Male infertility	Total
C20.14 Coal tar distillation	€ -	€ -	€ -	€ -
C23.2 Manufacture of refractory products	€ -	€ -	€ -	€ -
C23.99a Manufacture of bituminous products	€ -	€ -	€ -	€ -
C23.99b Graphite and carbon electrode manufacture	€ -	€ -	€ -	€ -
C24.1 Steel and iron foundries, ferroalloys	€ -	€ -	€ -	€ -
C24.42 Manufacture of aluminium	€ -	€ -	€ -	€ -
C24.45 Other non-ferrous metallurgy	€ -	€ -	€ -	€ -
C24.5 Casting of metals	€ -	€ -	€ -	€ -
D35.11 Coal fired power plants	€ -	€ -	€ -	€ -
E38.2 Waste incineration	€ -	€ -	€ -	€ -
E39 Soil remediation	€ -	€ -	€ -	€ -
F42.11 Road paving	€ -	€ -	€ -	€ -
F42.12 Welding of railroad tracks	€ -	€ -	€ -	€ -
G45.2 Motor vehicle maintenance and repairs	€ -	€ -	€ -	€ -
N81.22 Chimney sweeps	€ -	€ -	€ -	€ -
O84.25 Firefighters	€ -	€ -	€ -	€ -
Total	€ -	€ -	€ -	€ -

Source: Study team.

Note: "€ -" refers to no monetary benefit.

Method 2 relies on monetised DALYs, with the results presented in Table 6-30 below. The total net benefits calculated on the basis of Method 2 are depicted in Figure 6-7. The workforce turnover is 5% per year and a static discount rate of 3% is used.

Table 6-30 METHOD 2: Benefits from avoided ill health (OEL policy options, relative to the baseline)

Policy option	Lung cancer	Developmental toxicity	Male infertility	Total
7 ng/m ³	€ 59.13	€ 0.14	€ 5.22	€ 64.48
70 ng/m ³	€ 14.70	€ 0.14	€ 5.22	€ 20.06
700 ng/m ³	€ 0.94	€ 0.02	€ 1.01	€ 1.97
2000 ng/m ³	€ -	€ -	€ -	€ -

Source: Study team.

Note: "€ -" refers to no monetary benefit.

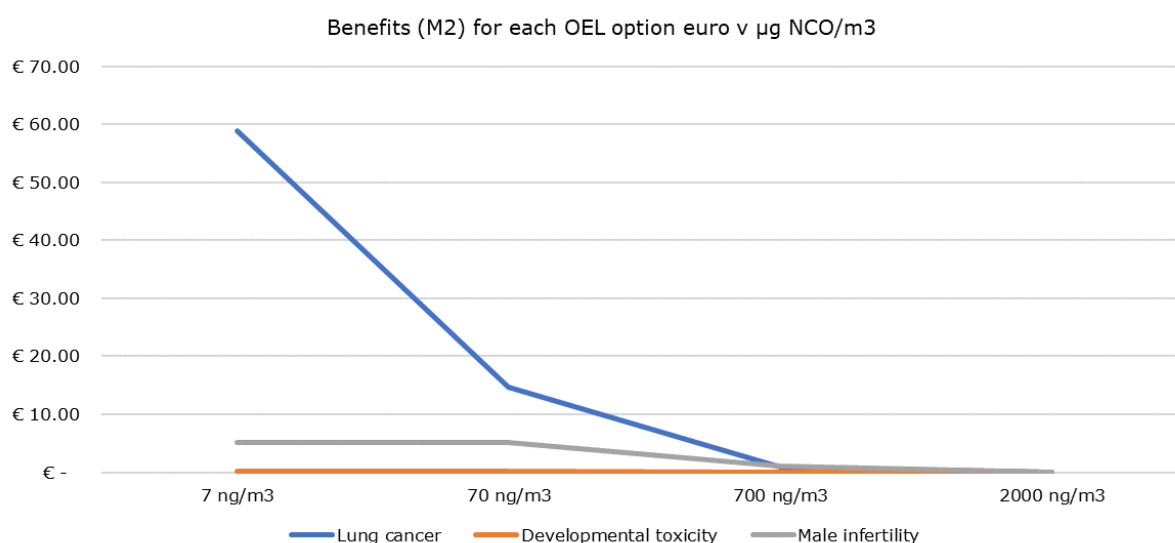


Figure 6-7METHOD 2: Benefits from avoided ill health (OEL policy options, relative to the baseline).
Source: Study team.

The Method 2 benefits at different OEL policy options, split by sector are presented in Table 6-29.

Table 6-31 METHOD 2: Benefits from avoided ill health by sector by OEL policy options, relative to the baseline (€ millions)

Sector	Lung cancer	Developmental toxicity	Male infertility	Total
7 ng/m³				
C10.13 Meat and poultry smokehouses	€ 0.005	€ -	€ -	€ 0.005
C10.2 Seafood smokehouses	€ 0.01	€ -	€ -	€ 0.01
C16.1 Wood preservation (creosote)	€ 0.01	€ -	€ -	€ 0.01
C19.1 Coking plants	€ 1.89	€ 0.02	€ 1.30	€ 3.21
C19.2 Petroleum refineries	€ 0.64	€ -	€ -	€ 0.64
C20.13 Manufacture of carbon black	€ 0.04	€ -	€ -	€ 0.04
C20.14 Coal tar distillation	€ 0.22	€ 0.01	€ 0.12	€ 0.35
C23.2 Manufacture of refractory products	€ 0.02	€ 0.001	€ 0.02	€ 0.04
C23.99a Manufacture of bituminous products	€ 0.45	€ -	€ -	€ 0.45
C23.99b Graphite and carbon electrode manufacture	€ 0.22	€ 0.003	€ 0.01	€ 0.24
C24.1 Steel and iron foundries, ferroalloys	€ 4.89	€ -	€ -	€ 4.89
C24.42 Manufacture of aluminium	€ 0.06	€ -	€ -	€ 0.06
C24.45 Other non-ferrous metallurgy	€ 0.27	€ 0.002	€ 0.15	€ 0.42
C24.5 Casting of metals	€ 9.92	€ -	€ -	€ 9.92
D35.11 Coal fired power plants	€ 0.51	€ -	€ -	€ 0.51
E38.2 Waste incineration	€ -	€ -	€ -	€ -

Sector	Lung cancer	Developmental toxicity	Male infertility	Total
E39 Soil remediation	€ 1.71	€ 0.02	€ -	€ 1.74
F42.11 Road paving	€ 3.56	€ -	€ -	€ 3.56
F42.12 Welding of railroad tracks	€ 5.40	€ 0.07	€ 3.62	€ 9.09
G45.2 Motor vehicle maintenance and repairs	€ 1.41	€ -	€ -	€ 1.41
N81.22 Chimney sweeps	€ 0.87	€ -	€ -	€ 0.87
O84.25 Firefighters	€ 27.04	€ -	€ -	€ 27.04
Total	€ 59.1	€ 0.1	€ 5.2	€ 64.5
70 ng/m³				
C10.13 Meat and poultry smokehouses	€ -	€ -	€ -	€ -
C10.2 Seafood smokehouses	€ -	€ -	€ -	€ -
C16.1 Wood preservation (creosote)	€ -	€ -	€ -	€ -
C19.1 Coking plants	€ 1.7	€ 0.02	€ 1.3	€ 3.1
C19.2 Petroleum refineries	€ 0.2	€ -	€ -	€ 0.2
C20.13 Manufacture of carbon black	€ -	€ -	€ -	€ -
C20.14 Coal tar distillation	€ 0.2	€ 0.01	€ 0.1	€ 0.3
C23.2 Manufacture of refractory products	€ 0.02	€ 0.001	€ 0.02	€ 0.04
C23.99a Manufacture of bituminous products	€ 0.2	€ -	€ -	€ 0.2
C23.99b Graphite and carbon electrode manufacture	€ 0.2	€ 0.003	€ 0.01	€ 0.2
C24.1 Steel and iron foundries, ferroalloys	€ 0.7	€ -	€ -	€ 0.7
C24.42 Manufacture of aluminium	€ 0.02	€ -	€ -	€ 0.02
C24.45 Other non-ferrous metallurgy	€ 0.2	€ 0.002	€ 0.1	€ 0.4
C24.5 Casting of metals	€ 5.0	€ -	€ -	€ 5.0
D35.11 Coal fired power plants	€ -	€ -	€ -	€ -
E38.2 Waste incineration	€ -	€ -	€ -	€ -
E39 Soil remediation	€ 1.2	€ 0.02	€ -	€ 1.2
F42.11 Road paving	€ -	€ -	€ -	€ -
F42.12 Welding of railroad tracks	€ 5.0	€ 0.1	€ 3.6	€ 8.7
G45.2 Motor vehicle maintenance and repairs	€ -	€ -	€ -	€ -
N81.22 Chimney sweeps	€ -	€ -	€ -	€ -
O84.25 Firefighters	€ -	€ -	€ -	€ -
Total	€ 14.7	€ 0.1	€ 5.2	€ 20.1
700 ng/m³				

Sector	Lung cancer	Developmental toxicity	Male infertility	Total
C10.13 Meat and poultry smokehouses	€ -	€ -	€ -	€ -
C10.2 Seafood smokehouses	€ -	€ -	€ -	€ -
C16.1 Wood preservation (creosote)	€ -	€ -	€ -	€ -
C19.1 Coking plants	€ 0.3	€ 0.01	€ 0.3	€ 0.6
C19.2 Petroleum refineries	€ -	€ -	€ -	€ -
C20.13 Manufacture of carbon black	€ -	€ -	€ -	€ -
C20.14 Coal tar distillation	€ -	€ -	€ -	€ -
C23.2 Manufacture of refractory products	€ -	€ -	€ -	€ -
C23.99a Manufacture of bituminous products	€ -	€ -	€ -	€ -
C23.99b Graphite and carbon electrode manufacture	€ -	€ -	€ -	€ -
C24.1 Steel and iron foundries, ferroalloys	€ -	€ -	€ -	€ -
C24.42 Manufacture of aluminium	€ -	€ -	€ -	€ -
C24.45 Other non-ferrous metallurgy	€ -	€ -	€ -	€ -
C24.5 Casting of metals	€ -	€ -	€ -	€ -
D35.11 Coal fired power plants	€ -	€ -	€ -	€ -
E38.2 Waste incineration	€ -	€ -	€ -	€ -
E39 Soil remediation	€ -	€ -	€ -	€ -
F42.11 Road paving	€ -	€ -	€ -	€ -
F42.12 Welding of railroad tracks	€ 0.7	€ 0.02	€ 0.7	€ 1.4
G45.2 Motor vehicle maintenance and repairs	€ -	€ -	€ -	€ -
N81.22 Chimney sweeps	€ -	€ -	€ -	€ -
O84.25 Firefighters	€ -	€ -	€ -	€ -
Total	€ 0.9	€ 0.02	€ 1.0	€ 2.0
2000 ng/m³				
C10.13 Meat and poultry smokehouses	€ -	€ -	€ -	€ -
C10.2 Seafood smokehouses	€ -	€ -	€ -	€ -
C16.1 Wood preservation (creosote)	€ -	€ -	€ -	€ -
C19.1 Coking plants	€ -	€ -	€ -	€ -
C19.2 Petroleum refineries	€ -	€ -	€ -	€ -
C20.13 Manufacture of carbon black	€ -	€ -	€ -	€ -
C20.14 Coal tar distillation	€ -	€ -	€ -	€ -
C23.2 Manufacture of refractory products	€ -	€ -	€ -	€ -

Sector	Lung cancer	Developmental toxicity	Male infertility	Total
C23.99a Manufacture of bituminous products	€ -	€ -	€ -	€ -
C23.99b Graphite and carbon electrode manufacture	€ -	€ -	€ -	€ -
C24.1 Steel and iron foundries, ferroalloys	€ -	€ -	€ -	€ -
C24.42 Manufacture of aluminium	€ -	€ -	€ -	€ -
C24.45 Other non-ferrous metallurgy	€ -	€ -	€ -	€ -
C24.5 Casting of metals	€ -	€ -	€ -	€ -
D35.11 Coal fired power plants	€ -	€ -	€ -	€ -
E38.2 Waste incineration	€ -	€ -	€ -	€ -
E39 Soil remediation	€ -	€ -	€ -	€ -
F42.11 Road paving	€ -	€ -	€ -	€ -
F42.12 Welding of railroad tracks	€ -	€ -	€ -	€ -
G45.2 Motor vehicle maintenance and repairs	€ -	€ -	€ -	€ -
N81.22 Chimney sweeps	€ -	€ -	€ -	€ -
O84.25 Firefighters	€ -	€ -	€ -	€ -
Total	€ -	€ -	€ -	€ -

Source: Study team.

Note: "€ -" refers to no monetary benefit.

Table 6-32 shows that at current exposure levels there are significantly higher benefits at the 7 ng/m³ and 70 ng/m³ policy options than all other levels.

Table 6-32 Overview of benefits (total for all provisions), million € over 40 years (without transition measures)

Description		7 ng/m ³ & 0.2 nmol/mol creatinine	70 ng/m ³ & 0.3 nmol/mol creatinine	700 ng/m ³ & 1.5 nmol/mol creatinine	2000 ng/m ³ & 3.8 nmol/mol creatinine
Health and safety	Avoided costs for workers & families (M1)	€ 181.60	€ 97.23	€ 15.17	€ -
	Avoided costs for workers & families (M2)	€ 59.36	€ 16.22	€ 1.29	€ -
	Avoided costs for employers	€ 0.54	€ 0.13	€ 0.01	€ -
	Avoided costs for public administrations	€ 5.26	€ 3.87	€ 0.69	€ -
Other benefits	Avoided costs for workers & families	€ -	€ -	€ -	€ -
	Avoided costs for employers	€ -	€ -	€ -	€ -

Description		7 ng/m ³ & 0.2 nmol/mol creatinine	70 ng/m ³ & 0.3 nmol/mol creatinine	700 ng/m ³ & 1.5 nmol/mol creatinine	2000 ng/m ³ & 3.8 nmol/mol creatinine
	Avoided costs for public administrations (OEL)	€ 1.80	€ 1.75	€ 1.60	€ 1.20
	Avoided costs for public administrations (OEL+BLV)	€ 4.20	€ 4.15	€ 3.95	€ 3.50

Source: Study team.

Note: Estimates are relative to the baseline as a whole (i.e. the impact of individual actions/obligations of the preferred option are aggregated together).

“€ -“ refers to no monetary benefit.

6.7.2 Other benefits

The introduction of a BLV has the potential to further reduce skin and lung cancer cases, and potentially also bladder cancer. It is not possible to quantify the benefits because there are no quantitative data on skin cancer, but PAH are distributed to internal organs following dermal exposure, including the lungs.

All workers have the potential to benefit from the introduction of the BLV – the higher the potential for dermal uptake, the higher the benefit. In total 4,782,708 workers and applicable volunteers (firefighters) will experience a high level of benefits from the introduction of a BLV. While in total 101,261 workers will experience a medium level of benefit from the introduction of a BLV, and 346,637 workers will experience some benefit from the introduction of a BLV.

6.7.3 Total benefits

Table 6-33 shows that at current exposure levels there are significantly higher benefits at the low-est policy option level than all other policy options.

Table 6-33 Overview of benefits (total for all provisions), (€ millions) over 40 years (without transition measures)

Description		7 ng/m ³	70 ng/m ³	700 ng/m ³	2000 ng/m ³	Comments
Health and safety	Avoided costs for workers & families M1	€ 181.60	€ 97.23	€ 15.17	€ -	
	Avoided costs for workers & families M2	€ 59.36	€ 16.22	€ 1.29	€ -	
	Avoided costs for employers	€ 0.54	€ 0.13	€ 0.01	€ -	
	Avoided costs for public administrations	€ 5.26	€ 3.87	€ 0.69	€ -	
Other benefits	Avoided costs for workers & families	€ -	€ -	€ -	€ -	
	Avoided costs for employers	€ -	€ -	€ -	€ -	Non-monetary benefits may include:

Description		7 ng/m ³	70 ng/m ³	700 ng/m ³	2000 ng/m ³	Comments
						Healthier staff; improved public image; easier to recruit; easier to retain staff; reduced cost of recruitment; easier monitoring of exposure; savings for multinational companies; increased level playingfield. Most consultees believed there would be no indirect benefit (55%. 23)
	Avoided costs for public administrations (OEL)	€ 1.80	€ 1.75	€ 1.60	€ 1.20	
	Avoided costs for public administrations (OEL+BLV)	€ 4.20	€ 4.15	€ 3.95	€ 3.50	

Source: Study team.

Note: Estimates are relative to the baseline as a whole (i.e. the impact of individual actions/obligations of the preferred option are aggregated together). "€ -" refers to no monetary benefit.

7 COSTS OF THE MEASURES UNDER CONSIDERATION

This chapter comprises the following sections:

- Section 7.1: The cost framework;
- Section 7.2: Direct compliance costs for companies;
- Section 7.3: Indirect costs for companies;
- Section 7.4: Costs for public administrations;
- Section 7.5: Impact of transitional periods on costs; and
- Section 7.6: Summary of the costs of the measures.

7.1 The cost framework

The costs assessed in this section, together with an indication of which stakeholders are likely to be affected, are presented Table 7-1 below.

Table 7-1 Impact of costs on different stakeholders

Type of cost		Citizens	Con- sumers	Work- ers	Busi- ness	Public admin- istra- tion
Direct costs						
Direct compliance costs	Adjustment costs - First year (RMMs) - Recurrent (RMMs) - Discontinuations - Air monitoring - Biomonitoring and health surveillance				✓	✓
	Administrative costs Relating to air monitoring and biomonitoring and health surveillance)				✓	✓
	Charges					
Enforcement costs	Transposition					✓
	Information & monitoring (Inspections by enforcement agencies)				✓	✓
	Inspections and sanctions				✓	✓
	Complaint handling				✓	✓
	Adjudication/litigation				✓	✓
Hassle costs					✓	✓

Type of cost		Citizens	Con- sumers	Work- ers	Busi- ness	Public admin- istra- tion
Indirect costs						
Indirect compliance costs			✓		✓	
Other indirect costs	Offsetting/substitution effects		✓		✓	✓
	Transaction costs		✓		✓	
	Opportunity costs		✓		✓	✓
	Reduced competition		✓		✓	
	Reduced market access		✓		✓	
	Reduced investment/innovation		✓		✓	

Source: Study team on the basis of the Better Regulation Toolbox (European Commission, 2023c).
Notes: ✓= key cost, quantified where possible, ✓= minor cost, covered qualitatively where possible

7.2 Direct compliance costs to companies

7.2.1 Introduction

Compliance costs are defined as the additional costs of complying with a limit value such as the costs incurred by companies in bringing down their exposure to levels below the limit value. This depends on the number of companies above the limit value and the cost for each company of reducing the exposure concentration to a level below the limit value. The costs for each company depend on the size of the relevant activities such as the number of machines and number of workers, and the gap between the actual exposure and the limit value, as well as the type of risk management measures required to bridge the gap.

A cost model developed for the previous OELs studies estimates the costs of complying with the different limit value options. In summary, the characteristics of the relevant sectors, the risk management measures (RMMs) in place, the sizes of the companies, and the required reduction in exposure, are used to propose suitable RMMs for each company. The model subsequently selects the cheapest of the suitable options. The results are summed up across all companies and sectors. A detailed description of the model is provided in the methodological note.

7.2.2 Summary of the key features of the adjustment cost model

The cost model is described in the methodology report accompanying this report. The cost model takes several inputs and calculates the predicted costs incurred for a range of OEL policy options. There are eleven types of inputs:

- Limit value options, see Section 5;
- Number of small, medium and large enterprises at each of the current exposure concentrations for each sector, see Section 7.2.3;
- Estimated breakdown of primary RISK management measures (RMMs) used by enterprises for each sector, see Section 7.2.4;

- Characteristics of PAH and type of work, see Section 7.2.7;
- Effectiveness of RMMs, see the methodological note;
- Cost of RMMs, see the methodological note;
- Discount rates, see the methodological note;
- Level of compliance with the OEL policy option, see the methodological note;
- Discontinuation costs per sector;
- Estimated average number of exposed workers per company, see Section 7.2.5; and
- Estimated average number of workstations exposed to PAH in small, medium and large enterprises, see Section 7.2.6.

The output is the cost of implementing the OEL, split by:

- Sector;
- Company size: small, medium and large; and
- Capital expenditure (first year), operating expenditure (recurrent).

7.2.3 Number of enterprises at current exposure levels

The key parameter in the cost model is the distribution of companies across different exposure levels. The cost model is based on small, medium and large enterprises, and the number of companies and their distribution across different size bands is taken as a proxy in the model.

The exposure data for PAH were collected through questionnaires, CSRs, and literature review, as discussed in section Table 3-1. The exposure data was analysed to provide estimated percentile values (50th or median, 75th, 90th, 95th and 100th). To obtain a cost estimate for each sector, the numbers of small, medium and large companies affected by PAH at different exposure levels are entered into the model for each OEL policy option. These numbers are based upon the analysis described in section 3.3.8, and particularly the exposure levels in Table 3-64, adjusted according to Table 3-65. Table 7-2 contains numbers of companies allocated to each exposure level.

Non-standard modelling was performed for C20.14 coal tar distillation, C23.99b carbon and graphite electrode manufacture, and C24.42 manufacture of aluminium. This was due to the low number of enterprises which caused errors in the modelling and that more accurate feedback was retrieved from consultation regarding the split of companies. In the table below, O84.25 firefighters shows that all enterprises have been allocated as small, although this was for modelling purposes and does not suggest they are small in reality.

Table 7-2 Number of enterprises with workers exposed to PAH at current exposure levels, by size of enterprise and sector

Sector & exposure levels [ng/m ³]	Small	Medium	Large	Total
C10.13 Meat and poultry smoke-houses	194	13	3	210
0.5	97	7	2	105
1.7	49	3	1	53
7.8	29	2	0.5	32
22.5	10	1	0.2	11
84.2	10	1	0.2	11
C10.2 Seafood smokehouses	287	36	7	330
0.5	144	18	4	165
1.7	72	9	2	83
7.8	43	5	1	50
22.5	14	2	0.4	17
84.2	14	2	0.4	17
C16.1 Wood preservation (creosote)	39	1	-	40
8	20	1	-	20
8.4	10	0.3	-	10
9.2	6	0.2	-	6
9.8	2	0.1	-	2
10.5	2	0.1	-	2
C19.1 Coking plants	48	2	5	55
216	24	1	3	28
310.6	12	1	1	14
552.6	7	0.3	1	8
820.9	2	0.1	0.3	3
1244.7	2	0.1	0.3	3
C19.2 Petroleum refineries	17	7	57	81
15	9	4	29	41
25.7	4	2	14	20
58.7	3	1	9	12
105.8	1	0.4	3	4
204.4	1	0.4	3	4

Sector & exposure levels [ng/m ³]	Small	Medium	Large	Total
C20.13 Manufacture of carbon black	-	20	5	25
14.3	-	10	3	13
19.8	-	5	1	6
33.8	-	3	1	4
49.9	-	1	0.3	1
76.8	-	1	0.3	1
C20.14 Coal tar distillation	-	3	4	7
57.5	-	1	-	1
113.3	-	1	1	2
257.6	-	2	2	4
451.9	-	0.2	0.2	0.4
759.7	-	0.2	0.2	0.4
C23.2 Manufacture of refractory products	4	1	-	5
25	2	1	-	3
62.5	1	0.3	-	1
224.1	1	0.2	-	1
541.5	0.2	0.1	-	0.3
1480.2	0.2	0.1	-	0.3
C23.99a Manufacture of bituminous products	1,057	99	24	1,180
20	529	50	12	590
31.5	264	25	6	295
64.3	159	15	4	177
107.4	53	5	1	59
190.2	53	5	1	59
C23.99b Graphite and carbon electrode manufacture	-	-	22	22
24.5	-	-	1	1
147.3	-	-	7	7
270	-	-	5	5
270	-	-	4	4

Sector & exposure levels [ng/m ³]	Small	Medium	Large	Total
472	-	-	5	5
C24.1 Steel and iron foundries, ferro alloys	2,523	112	134	2,769
12	1,262	56	67	1,385
20.9	631	28	34	692
46.2	378	17	20	415
81.3	126	6	7	138
148	126	6	7	138
C24.42 Manufacture of aluminium	-	3	6	9
13.2	-	-	2	2
56.1	-	1	1	2
99	-	1	1	2
99	-	1	1	2
222.5	-	0	1	1
C24.45 Other non-ferrous metallurgy	67	8	5	80
71.4	34	4	3	40
117.6	17	2	1	20
254.4	10	1	1	12
442.5	3	0.4	0.3	4
821.2	3	0.4	0.3	4
C24.5 Casting of metals	4,017	541	184	4,742
50	2,009	271	92	2,371
64.4	1,004	135	46	1,186
98.9	603	81	28	711
135.3	201	27	9	237
190.7	201	27	9	237
D35.11 Coal fired power plants	126	45	25	196
14	63	23	13	98
19.5	32	11	6	49
33.2	19	7	4	29
48.8	6	2	1	10

Sector & exposure levels [ng/m ³]	Small	Medium	Large	Total
75	6	2	1	10
E38.2 Waste incineration	597	43	10	650
0.4	299	22	5	325
0.9	149	11	3	163
3	90	6	2	98
6.9	30	2	1	33
17.6	30	2	1	33
E39 Soil remediation	3,280	88	10	3,378
42.5	1,640	44	5	1,689
65.2	820	22	3	845
128.6	492	13	2	507
209.9	164	4	1	169
361.8	164	4	1	169
F42.11 Road paving	29,375	1,285	289	30,949
0.7	14,688	643	145	15,475
2.8	7,344	321	72	7,737
15.2	4,406	193	43	4,642
47.7	1,469	64	14	1,547
179.3	1,469	64	14	1,547
F42.12 Welding of railroad tracks	1,914	83	19	2,016
265.2	957	42	10	1,008
351.8	479	21	5	504
563.6	287	12	3	302
795.9	96	4	1	101
1163.8	96	4	1	101
G45.2 Motor vehicle maintenance and repairs	373,527	606	50	374,183
2.2	186,764	303	25	187,092
3.4	93,382	152	13	93,546
7.1	56,029	91	8	56,127
12.	18,676	30	3	18,709

Sector & exposure levels [ng/m ³]	Small	Medium	Large	Total
21.6	18,676	30	3	18,709
N81.22 Chimney sweeps	19,381	-	-	19,381
13	9,691	-	-	9,691
17.5	4,845	-	-	4,845
28.6	2,907	-	-	2,907
43.	969	-	-	969
59.3	969	-	-	969
O84.25 Firefighters*	758	-	-	758
25	379	-	-	379
30.2	190	-	-	190
41.9	114	-	-	114
53.4	38	-	-	38
69.6	38	-	-	38
Totals	437,211	2,996	859	441,066

Source: Study team.

Notes: Sum of enterprises may not equal totals elsewhere in this report due to rounding

*Firefighters: Modelling of firefighters has been undertaken on the basis that local authorities are typically the employer for firefighters within Member States. Subsequently the number of enterprises for this sector refers to the number of counties/provinces assumed to be the primary employer. Firefighters have been assigned to small enterprises due to complexities in modelling, however it is not assumed that all firefighters belong to small organisations in any calculations of this report. “-” refers to no companies with exposure.

7.2.4 Estimated breakdown of RMMs used by enterprises

The model requires a profile of the primary risk management measure used by enterprises in each sector. This is based upon the information in section 3.5, which has been obtained through stakeholder consultation and literature review. It is difficult to define the primary risk management measure as most companies use several RMMs, but generally the primary is taken to be the highest level of RMM upon which the company depends.

Table 7-3 Percentage breakdown of primary RMMs currently used by sector (row total = 100%)

Sector	Full enclosure	Partial enclosure	Open hood	Pressurised or sealed cabin	Simple enclosed cabin	Breathing apparatus	HEPA filter	Simple mask	Org. measures	General dilution ventilation	No ventilation
C10.13 & C10.2	5%	80%	-	-	-	-	-	5%	-	10%	-
C16.1	40%	-	-	-	-	-	40%	-	-	10%	10%
C19.1	-	40%	20%	-	-	-	20%	-	20%	-	-
C19.2	60%	-	10%	-	-	-	-	10%	-	-	20%
C20.13	50%	10%	20%	-	-	-	10%	-	-	10%	-
C20.14	50%	10%	20%	-	-	-	10%	-	-	10%	-
C23.2	-	25%	50%	-	-	-	25%	-	-	-	-
C23.99a	-	-	-	-	-	-	-	-	-	-	100%
C23.99b	15%	15%	15%	-	15%	2%	18%	10%	-	10%	-
C24.1	20%	10%	-	-	20%	-	-	-	-	50%	-
C24.42	10%	15%	25%	25%	-	-	25%	-	-	-	-
C24.45	10%	15%	25%	25%	-	-	25%	-	-	-	-
C24.5	-	-	40%	-	-	-	20%	-	-	40%	-
D35.11	40%	-	-	-	-	-	-	-	-	20%	40%
E38.2	50%	-	-	-	-	10%	10%	10%	-	20%	-
E39	-	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
F42.11	-	-	20%	-	20%	-	-	-	10%	-	50%
F42.12	-	-	-	-	-	-	-	10%	-	-	90%
G45.2	-	-	-	-	-	-	-	-	-	-	100%
N81.22	5%	10%	35%	-	10%	-	10%	10%	-	-	20%
O84.25	-	-	-	-	-	-	30%	-	20%	-	50%

Source: Study team.

7.2.5 Estimated average number of exposed workers per enterprise

The model requires an estimate of the average number of exposed workers per enterprise by size of enterprise in each sector. These estimates made by the study team are based upon the information in Table 3-92, and data in Table 3-103 split by size of enterprise according to Eurostat data about employees and the size of enterprise for which they work.

Table 7-4 Estimated average number of exposed workers per enterprise by size of enterprise and sector

Sector name	Number of exposed workers per enterprise		
	Small	Medium	Large
C10.13 Meat and poultry smokehouses	0	13	118
C10.2 Seafood smokehouses	1	16	95
C16.1 Wood preservation (creosote)	24	83	-
C19.1 Coking plants	6	276	335
C19.2 Petroleum refineries	2	29	509
C20.13 Manufacture of carbon black	-	21	120
C20.14 Coal tar distillation	-	60	143
C23.2 Manufacture of refractory products	15	25	-
C23.99a Manufacture of bituminous products	1	20	96
C23.99b Graphite and carbon electrode manufacture	-	-	46
C24.1 Steel and iron foundries, ferroalloys	1	35	658
C24.42 Manufacture of aluminium	-	16	97
C24.45 Other non-ferrous metallurgy	0.5	13	92
C24.5 Casting of metals	3	38	202
D35.11 Coal fired power plants	28	31	522
E38.2 Waste incineration	0.5	10	108
E39 Soil remediation	2	34	179
F42.11 Road paving	2	34	405
F42.12 Welding of railroad tracks	0.5	16	188
G45.2 Motor vehicle maintenance and repairs	0.5	30	189
N81.22 Chimney sweeps	1.3	-	-
O84.25 Firefighters*	578.5	-	-

Source: Study team.

Note: *Firefighters have been assigned to small enterprises due to complexities in modelling, however it is not assumed that all firefighters belong to small organisations in any calculations of this report. This figure represents the average number of managing/coordinating firefighting personnel within a local authority. “-” refers to no exposed workers.

7.2.6 Estimated average number of workstations per enterprise

The model requires an estimate of the average number of workstations per enterprise by size of enterprise in each sector. These estimates made by the study team are based upon the information in Table 7-3 and the assumption that there will be five exposed employees per

workstation; the numbers are rounded to the nearest integer and all values of 0.5 or lower are set to 0.5 for modelling purposes. The only exceptions for this method are in cases where each worker requires their own equipment, such as N81.22 chimney sweeps and O84.25 firefighters. In these cases the number of workstations has been set to equal one per exposed worker.

Table 7-5 Estimated average number of workstations per enterprise by size of enterprise and sector

Sector name	Number of workstations per company		
	Small	Medium	Large
C10.13 Meat and poultry smokehouses	1	3	24
C10.2 Seafood smokehouses	1	3	19
C16.1 Wood preservation (creosote)	5	17	-
C19.1 Coking plants	1	55	67
C19.2 Petroleum refineries	1	6	102
C20.13 Manufacture of carbon black	-	4	24
C20.14 Coal tar distillation	-	12	29
C23.2 Manufacture of refractory products	3	5	-
C23.99a Manufacture of bituminous products	0.5	4	19
C23.99b Graphite and carbon electrode manufacture	-	-	9
C24.1 Steel and iron foundries, ferroalloys	0.5	7	132
C24.42 Manufacture of aluminium	-	3	19
C24.45 Other non-ferrous metallurgy	0.5	3	18
C24.5 Casting of metals	0.5	8	40
D35.11 Coal fired power plants	6	6	104
E38.2 Waste incineration	0.5	2	22
E39 Soil remediation	1	7	36
F42.11 Road paving	2	34	405
F42.12 Welding of railroad tracks	0.5	3.0	38.0
G45.2 Motor vehicle maintenance and repairs	0.5	6.0	38
N81.22 Chimney sweeps	1.3	-	-
O84.25 Firefighters	579	-	-

Source: Study team.

Notes: “-” refers to no exposed workers.

7.2.7 Characteristics of PAH and type of work

Exposure routes to PAH differ in each sector have unique characteristics depending on the types of work being undertaken. This information helps to determine the type of risk and management measures that are suitable. These characteristics are split into three groups:

- Duration of exposure over one day;
- Form of PAH to which workers are exposed; and
- Extent to which PAH disperse or spread when emitted.

The amount of exposure is split into work where the worker is exposed to PAH for less than an hour a day and for more than an hour a day. This also equates to exposure for more or less than 2.5 days/month.

The form of substance to which workers are exposed varies considerably from dust and fibres to vapour, fumes, gas, mist, and aerosol. The form of a substance has a direct bearing on the types of RMM that are suitable. For this analysis, the substance form is split into two types: dust which also includes fibres and gas which includes all the other types.

The extent of the spread is the final characteristic that affects the choice of RMM, and this is split into three types: local, diffuse and peripheral. Local means the dust or gas is created around a specific machine and often means that highly targeted ventilation can effectively remove the chemical. Other processes spread the substance over a wider area, which is known as diffuse. In this case, dilution ventilation, workers enclosures or full enclosures are more suitable, the choice depending upon the decrease in exposure required. Peripheral means that the substance spreads more widely and cause exposure to workers beyond the area where the PAH is being used. This means that administrators, managers and sales staff may also be exposed.

In Table 7-6 below, the percentage split for each characteristic used in the analysis is given for each sector. These values were built into the cost model.

Table 7-6 PAH: amount of exposure, form of exposure and extent of spread, by sector

Sector name	Amount		Form		Spread		
	<1h	>1h	Dust	Gas	Local	Diffuse	Peripheral
C10.13 Meat and poultry smokehouses	80%	20%	20%	80%	80%	20%	0%
C10.2 Seafood smokehouses	80%	20%	20%	80%	80%	20%	0%
C16.1 Wood preservation (creosote)	50%	50%	20%	80%	80%	20%	0%
C19.1 Coking plants	20%	80%	50%	50%	50%	50%	0%
C19.2 Petroleum refineries	80%	20%	20%	80%	80%	20%	0%
C20.13 Manufacture of carbon black	80%	20%	50%	50%	80%	20%	0%
C20.14 Coal tar distillation	80%	20%	50%	50%	80%	20%	0%
C23.2 Manufacture of refractory products	50%	50%	50%	50%	80%	20%	0%
C23.99a Manufacture of bituminous products	20%	80%	50%	50%	80%	20%	0%
C23.99b Graphite and carbon electrode manufacture	50%	50%	50%	50%	50%	50%	0%
C24.1 Steel and iron foundries, ferroalloys	20%	80%	50%	50%	50%	50%	0%
C24.42 Manufacture of aluminium	20%	80%	50%	50%	50%	50%	0%

Sector name	Amount		Form		Spread		
	<1h	>1h	Dust	Gas	Local	Diffuse	Peripheral
C24.45 Other non-ferrous metallurgy	20%	80%	50%	50%	50%	50%	0%
C24.5 Casting of metals	20%	80%	50%	50%	50%	50%	0%
D35.11 Coal fired power plants	20%	80%	50%	50%	50%	50%	0%
E38.2 Waste incineration	20%	80%	50%	50%	50%	50%	0%
E39 Soil remediation	50%	50%	50%	50%	80%	20%	0%
F42.11 Road paving	20%	80%	50%	50%	80%	20%	0%
F42.12 Welding of rail-road tracks	80%	20%	20%	80%	80%	20%	0%
G45.2 Motor vehicle maintenance and repairs	80%	20%	50%	50%	80%	20%	0%
N81.22 Chimney sweeps	50%	50%	50%	50%	80%	20%	0%
O84.25 Firefighters*	50%	50%	50%	50%	0%	100%	0%

Source: Study team.

Note: Dust = dust and fibres, Gas = vapour, fumes, gas, mist and aerosol.

*The proportion of firefighters exposed at more or less than an hour has been set to 100% <1 hour to account for complexities in modelling, however this report does not assume exposure only occurs at this rate.

7.2.8 Survey and stakeholder consultation data on adjustment costs

7.2.8.1 Survey - RMMs needed to achieve compliance

Table 7-7 outlines the number of processes (by sector) that are currently using RMMs and which RMM they would likely change to meet the require reduction of exposure for each policy option. The study team have not taken the exact proportion of RMMs from the survey due to biases and the fact that RMMs are often unique to facility designs that may not be typical of the sector. However, the study team have triangulated these RMMs with information gathered from interviews, site visits and literature more generally to generate a general RMM scenario used in the modelling of costs.

For C19.1 coking plants, few respondents provided details on what RMMs they could put in place beyond their current measures. This may represent industry belief that actors within the sector may struggle to reach the lower OELs and are unaware of what measures they could put in place. This point is supported by the fact that five of seven respondents stated they would discontinue at the two lowest policy option levels. For C19.2 manufacture of refined petroleum products, respondents placed heavy emphasis on the use of powered air purifying respirators at all policy option levels. However, respondents from this sector also stated to a higher degree that there would be no action needed to alter existing processes. This is particularly true at the 2000ng/m³, 700ng/m³, and 70ng/m³ levels.

For respondents in C20.13 manufacture of other inorganic basic chemicals, existing processes were generally felt to be meeting the 2000 ng/m³ and 700 ng/m³ levels. Existing measures vary by

Finally, regarding G45.2 maintenance and repair of motor vehicles, respondents defined few processes, although none were indicated to already be meeting the policy options or would result in discontinuations. This suggests uncertainty from the respondents on which RMMs would be feasible to achieve any required reductions in exposure.

[illegible]

RMMs required	Sector (n) OEL: ng/m³ & BLV: nmol/mol creatinine																																				
	No action required as OEL already achieved Continuous measurement to detect unusual exposures Formal RPE cleaning & filter changing regime Further cleaning Further training and education Separate storage facilities for work clothes REACH restriction training (future) Conventional or disposable overalls, boiler suits, aprons Coveralls/hazardous materials suits Disposable respirators (FFP masks) Face screens, face shields, visors Gloves Gloves with a cuff, gauntlets and sleeving Half and full facemasks (negative pressure respirators) Powered air-purifying respirators PPE is essential regardless of the OEL Rubber boots Safety boots and shoes Safety spectacles, goggles Self-contained breathing apparatus or airline respirators Redesign of work processes Reduced amount of substance-generating PAH used Reduced the number of workers exposed Rotation of workers exposed Discontinuation of the activity generating PAH Partial substitution of processes or activities generating PAH Partial substitution of substances or materials generating PAH Substitution of processes or activities generating PAH Substitution of substances or materials generating PAH Installing closed systems Installing enclosure with extraction Installing general ventilation Installing open hoods over equipment or local extraction Installing partially closed systems Installing pressurised or sealed control cabs Installing simple enclosed control cabs Other																																				
2000 & 3.8																																					
Never	7	5					5	5	2			4	3	5	2		5			7	7	7	2	2	2	7	7	7	7	5	5				3	1	2
C19.20 Manufacture of refined petroleum products (47)																																					
Current		1	4	11	45	12		12		11	16	1	7		45		13	16	5		4		34						12	1	7	1	2				8
7 & 0.2	16														22					3				7	7				4							6	
70 & 0.3	34				4			4			4		4		23		4	4		3		3	3													12	
700 & 1.5	36				4			4			4		4		19		4	4																		5	
2000 & 3.8	45														23																					2	
Never	2	46	43	36	2	35	47	47	35	47	36	31	46	40	47	2	47	34	31	42	44	43	44	11	40	40	47	47	47	35	42	40	46	45	47	47	34
C20.13 Manufacture of other inorganic basic chemicals (16)																																					
Current			3	14	14	14		4	2		6	12	6	9		12	2	14	12				14	2					2		14	7	3				
7 & 0.2	1		1	2	2		1	2						7	3	1				3	1	2	2	1	1		2		4	4		4	2		2		
70 & 0.3	5			2	2			2		2		2	6	2			2		2			2	1	2		2			1	1		1	4				
700 & 1.5	11																																				
2000 & 3.8	11																																				
Never	5	16	12	2	2	2	15	12	13	16	10	4	10	3	13	3	14	2	4	13	15	14	2	14	15	14	16	14	16	10	12	2	6	9	16	14	16
C20.14 Manufacture of other organic basic chemicals (20)																																					
Current		14	14	20	20	20	6	2	16	6	10	20	2	13	2	8	5	20	19	5	2		2	6	1				12	3	10	7	1	7		7	
7 & 0.2				4												6				4	2				13	5	1	1								2	
70 & 0.3	5	3		3				3								6				3	4			3	6	4										8	
700 & 1.5	11	1			1											6				1	2			1	4	2			1							2	
2000 & 3.8	12				2		2									6									4											7	
Never	8	6	6				12	15	4	14	10		18	7	18	12	15		1	11	16	20	18	11	7	13	19	19	20	8	17	10	13	19	13	20	8
C22.19 Manufacture of other rubber products (1)																																					
Current				1	1	1					1	1			1			1	1													1		1			
7 & 0.2																																					
70 & 0.3																																					
700 & 1.5																																					
2000 & 3.8																																					
Never	1	1	1				1	1	1	1			1	1		1	1			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	

RMMs required	Sector (n)
	OEL: ng/m ³ & BLV: nmol/mol creati-nine
	No action required as OEL already achieved
	Continuous measurement to detect unusual exposures
	Formal RPE cleaning & filter changing regime
	Further cleaning
	Further training and education
	Separate storage facilities for work clothes
	REACH restriction training (future)
	Conventional or disposable overalls, boiler suits, aprons
	Coveralls/hazardous materials suits
	Disposable respirators (FFP masks)
	Face screens, face shields, visors
	Gloves
	Gloves with a cuff, gauntlets and sleeving
	Half and full facemasks (negative pressure respirators)
	Powered air-purifying respirators
	PPE is essential regardless of the OEL
	Rubber boots
	Safety boots and shoes
	Safety spectacles, goggles
	Self-contained breathing apparatus or airline respirators
	Redesign of work processes
	Reduced amount of substance-generating PAH used
	Reduced the number of workers exposed
	Rotation of workers exposed
	Discontinuation of the activity generating PAH
	Partial substitution of processes or activities generating PAH
	Partial substitution of substances or materials generating PAH
	Substitution of processes or activities generating PAH
	Substitution of substances or materials generating PAH
	Installing closed systems
	Installing enclosure with extraction
	Installing general ventilation
	Installing open hoods over equipment or local extraction
	Installing partially closed systems
	Installing pressurised or sealed control cabs
	Installing simple enclosed control cabs
	Other

C24.42 Aluminium production (7)

Current			3	7	7	7		3	1	1	2	4	5	6	4	2		7	5				1	2		1				1	2	2	5	3	5			
7 & 0.2	2							2					4	3	3			4	4										1	4	4	4	4	4	3	3		
70 & 0.3	2							2					4	1	3			3	4	2									1	4	4	4	4	4	3	3		
700 & 1.5	2							2					3	2	2	1		3	3											3	3	3	3	3	2	2		
2000 & 3.8	4			1	1				1			1	2	1	2	1		2	2						1		1			2	1	2	2	1	1	1		
Never	2	7	4					7	3	6	6	5	3	1	1	2	4	7		2	5	7	7	6	5	7	5	7	6	6	1	1	1	2	2	2	4	7

C24.5 Casting of metals (3)

Current			1	3	3	3		1	1		2	1	2				1	2	2	1		1	1			1						1	2	1				
7 & 0.2																1					1		1															
70 & 0.3	1																							1														
700 & 1.5	2																																					
2000 & 3.8	2																																					
Never	1	3	2					3	2	2	3	1	2	1	3	2	3	2	1	1	1	3		2	3	3	2	3	3	3	3	2	1	2	3	3	3	3

F42.11 Construction of roads and motorways (22)

Current		2		16	19	15		4		4		14	17	2				20	13		20		13	14		2						18	15		2	2	4
7 & 0.2	1		6	6	19	19	6	2	4			15	17	4	2			19	19		19	2	19	19				6	2	2	2	19	16	2	5	2	
70 & 0.3	10	6			6	6	6	6		6		6			6		6	6				2	4	6				4	2		2		6		2	2	
700 & 1.5	9	6			6		6	4		2		6		2	2		6	6				2		4			6	6			2	4	2		2	2	
2000 & 3.8	13				6		6	4		2		7		2	2		7	6				2		4			6				2	5	2		2	2	
Never	9	16	16	2	3	3	16	16	18	16	22	2	5	18	18	16	22	2	3	22	2	20	3	2	22	20	16	16	20	20	20	2	3	20	17	20	18

G45.20 Maintenance and repair of motor vehicles (3)

Current			3	3					3	3	3			3	3	1	3	3		3					3			
7 & 0.2			3				3							3	3	1	1	3	3						3		3	
70 & 0.3			3				3	3			3			3	3	1	1	3	3						3		3	
700 & 1.5			3				3	3			3			3	3	1	1	3	3						3		3	
2000 & 3.8	3		3				3	3			3			3	3	1	1	3	3						3		3	
Never		3	3		3	3	3	3	3		3	3			3	2			3		3	3	3	3	3	3	3	3

Source: Consultation survey.

Notes: Calculation of respondent's never selecting an RMM has not been performed for this report. Each respondent could provide information on up to four processes at their facility

Table 7-8 Percentage of respondent processes exposed to PAH that already meet the policy options (no alternative RMMs required)

Sector (N)	OEL: 2000 ng/m ³ - BLV: 3.8 nmol/mol creatinine	OEL: 700 ng/m ³ - BLV: 1.5 nmol/mol creatinine	OEL: 70 ng/m ³ - BLV: 0.3 nmol/mol creatinine	OEL: 7 ng/m ³ - BLV: 0.2 nmol/mol creatinine
C19.20 Manufacture of refined petroleum products (43)	95% (41)	81% (35)	74% (32)	37% (16)
C20.13 Manufacture of other inorganic basic chemicals (16)	69% (11)	69% (11)	31% (5)	6% (1)
C20.14 Manufacture of other organic basic chemicals (24)	67% (16)	50% (12)	29% (7)	
C22.19 Manufacture of other rubber products (0)				
C24.42 Aluminium production (7)	57% (4)	29% (2)	29% (2)	29% (2)
C24.5 Casting of metals (3)	67% (2)	67% (2)	33% (1)	
F42.11 Construction of roads and motorways (22)	59% (13)	41% (9)	45% (10)	5% (1)
G45.20 Maintenance and repair of motor vehicles (3)	100% (3)			
Grand Total (132)	70% (93)	56% (74)	43% (57)	15% (20)

Source: Consultation survey.

Notes: Each respondent could provide information on up to four processes at their facility.

7.2.8.2 Survey - Companies' estimated costs of compliance

Table 7-9 illustrates the overall survey responses regarding the anticipated cost range of initial investments of RMMs needed to achieve the policy options. Only six relevant sectors provided feedback. Relatively few respondents provided feedback and as such the results should not be considered representative of the sector.

For C19.2, two medium sized respondents believe the initial costs would range from <€10,000 at the 2000ng/m³ and 700ng/m³ levels, to between €10,000 and €100,000 at 70ng/m³, and €10,000 and €1,000,000 at 7ng/m³. Two large enterprises in the same sector estimate approximately 10 times the costs as medium enterprises. Of these costs two medium sized enterprises estimate approximately half would be used to meet a BLV at the lowest two policy option levels. Annual recurrent costs are proportionally similar to initial costs.

In C20.13, six respondents provided feedback, of which none feedback at the 2000ng/m³ or 700ng/m³ levels. At 70ng/m³ three believe costs would range from €100,000 to €10,000,000 depending on the size of enterprise. And at 7ng/m³ five of six (mainly medium sized enterprises) believe initial costs would be between €1,000,000 and €10,000,000. Medium sized enterprises estimate 30-40% of these costs would be related to meeting a biological limit value (BLV) at the lowest policy option level, 20-30% at the second lowest, and <5% at the lowest level. Compared with other sectors, respondents believe BLV costs would be lower in this sector. Annual recurrent costs were generally estimated to be between €100,000-1,000,000 at 7ng/m³, €10,000-€100,000 at 70ng/m³.

For C20.14 four large enterprises estimate costs to be <€10,000 at 2000ng/m³ and 700ng/m³, with initial investment costs rising to €100,000-€1,000,000 at the 70ng/m³ level. At 7ng/m³ costs for large companies are less consistent and range from €100,000->€1,000,000,000. Five large enterprises were less consistent in terms of the proportion of initial costs related to meeting a BLV. At the lowest policy option, three believe this would consist of <5% of the costs, whereas two believe it would be in excess of 80% of the costs. Recurrent costs are estimated to be between €1,000-€100,000 at 700ng/m³, €10,000-€10,000,000 at 70ng/m³ and 7ng/m³.

Respondents from C24.42 were not able to provide initial cost estimates for any of the policy option levels. Those from F42.11 only provided feedback at the 7ng/m³ level, suggesting initial investment costs of between €100,000-€10,000,000 (although all eight small enterprises estimated between €100,000-€1,000,000).

Finally, respondents from G45.2 did not give feedback on the cost estimates at any of the policy option levels.

Table 7-9 Companies anticipated cost range for RMM *initial investment costs* required to achieve OEL/BLV options, by company size (values = count)

OEL/BLV	< €10,000			€10,000 - €100,000			€100,000 - €1 million			€1 -10 million			€10 - 100 million			€100 – 1 billion			Over €1 billion			Don't know			Number of responses per sector		
Sector	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L
7 ng/m³ – 0.2 nmol/mol creatinine																											
C19.20 Manufacture of re-fined petroleum products								2				2													2	2	
C20.13 Manufacture of other inorganic basic chemicals								1			4	1													5	1	
C20.14 Manufacture of other organic basic chemicals									1					2			1			1						5	
C24.42 Aluminium production																						2				2	
F42.11 Construction of roads and motorways							8	2	1			1								1	1			8	3	3	
G45.20 Maintenance and repair of motor vehicles																					1					1	
70 ng/m³ – 0.3 nmol/mol creatinine																											
C19.20 Manufacture of re-fined petroleum products		1			1							1													2	1	
C20.13 Manufacture of other inorganic basic chemicals								1			1	1													2	1	
C20.14 Manufacture of other organic basic chemicals						2						1		2												5	
C24.42 Aluminium production																						2				2	

OEL/BLV	< €10,000			€10,000 - €100,000			€100,000 - €1 million			€1 -10 million			€10 - 100 million			€100 – 1 billion			Over €1 billion			Don't know			Number of responses per sector		
Sector	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L
F42.11 Construction of roads and motorways																						1	1		1	1	
G45.20 Maintenance and repair of motor vehicles																							1			1	
700 ng/m³ – 1.5 nmol/mol creatinine																											
C19.20 Manufacture of re-fined petroleum products		1			1				1			1													2	2	
C20.13 Manufacture of other inorganic basic chemicals																											
C20.14 Manufacture of other organic basic chemicals			3									1											1			5	
C24.42 Aluminium produc-tion																								2		2	
F42.11 Construction of roads and motorways																						1	1		1	1	
G45.20 Maintenance and repair of motor vehicles																								1		1	
2000 ng/m³ – 3.8 nmol/mol creatinine																											
C19.20 Manufacture of re-fined petroleum products		2							1																2	1	
C20.13 Manufacture of other inorganic basic chemicals																											
C20.14 Manufacture of other organic basic chemicals			4																							4	

OEL/BLV Sector	< €10,000			€10,000 - €100,000			€100,000 - €1 million			€1 - 10 million			€10 - 100 million			€100 - 1 billion			Over €1 billion			Don't know			Number of responses per sector		
	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L
C24.42 Aluminium production								1																		1	
F42.11 Construction of roads and motorways																						2	1	1	2	1	1
G45.20 Maintenance and repair of motor vehicles																								1			1

Source: Consultation survey.

Table 7-10 Proportion of companies' initial investment costs attributed solely to RMMs to meet the BLV

OEL/BLV	<5%			20-30%			30-40%			40-50%			50-60%			70-80%			80-90%			90-100%			Number of responses per sector		
Sector	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L
7 ng/m³ – 0.2 nmol/mol creatinine																											
C19.20 Manufacture of re-fined petroleum products										1			1									1			2	1	
C20.13 Manufacture of other inorganic basic chemicals							1																		1		
C20.14 Manufacture of other organic basic chemicals			3										1						1							5	
C24.42 Aluminium produc-tion																											
F42.11 Construction of roads and motorways															8	2	2							8	2	2	

OEL/BLV	<5%			20-30%			30-40%			40-50%			50-60%			70-80%			80-90%			90-100%			Number of responses per sector		
Sector	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L
70 ng/m³ – 0.3 nmol/mol creatinine																											
C19.20 Manufacture of re-fined petroleum products											1						1									2	
C20.13 Manufacture of other inorganic basic chemicals					1																					1	
C20.14 Manufacture of other organic basic chemicals						1						1								1				2			5
C24.42 Aluminium production																											
F42.11 Construction of roads and motorways																											
700 ng/m³ – 1.5 nmol/mol creatinine																											
C19.20 Manufacture of re-fined petroleum products																	1							1			2
C20.13 Manufacture of other inorganic basic chemicals																											
C20.14 Manufacture of other organic basic chemicals																		1							4		5
C24.42 Aluminium production																											
F42.11 Construction of roads and motorways																											
2000 ng/m³ – 3.8 nmol/mol creatinine																											

OEL/BLV Sector	<5%			20-30%			30-40%			40-50%			50-60%			70-80%			80-90%			90-100%			Number of responses per sector		
	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L
C19.20 Manufacture of re-fined petroleum products																						2			2		
C20.13 Manufacture of other inorganic basic chemicals		1																							1		
C20.14 Manufacture of other organic basic chemicals																							4			4	
C24.42 Aluminium production											1														1		
F42.11 Construction of roads and motorways																											

Source: Consultation survey.

Note: Only percentiles with responses have been presented in the above table. No respondent selected 5-10%, 10-20%, or 60-70%.

Table 7-11 Companies anticipated cost range for RMM annual recurrent investment costs required to achieve OEL/BLV options, by company size (values = count)

OEL/BLV Sector	< €1,000			€1,000 - €10,000			€10,000 - €100,000			€100,000 - 1 million			€1 - 10 million			€10 - 100 million			Over €100 million			Don't know			Number of responses per sector		
	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L
7 ng/m³ – 0.2 nmol/mol creatinine																											
C19.10 Manufacture of coke oven products																											
C19.20 Manufacture of re-fined petroleum products										1	1		1									1			2	2	
C20.13 Manufacture of other inorganic basic chemicals							1			4	1														5	1	

OEL/BLV	< €1,000			€1,000 - €10,000			€10,000 - €100,000			€100,000 -1 million			€1 - 10 mil-lion			€10 – 100 million			Over €100 million			Don't know			Number of responses per sector		
Sector	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L
C20.14 Manufacture of other organic basic chemicals									1			1			2									1			5
C24.42 Aluminium produc-tion																								2			2
C24.5 Casting of metals																											
F42.11 Construction of roads and motorways							4															1	1	4	1	1	
F42.11 Construction of roads and motorways - mastic asphalt							4	2	1			1												4	2	2	
G45.20 Maintenance and re-pair of motor vehicles																								1			1
70 ng/m³ – 0.3 nmol/mol creatinine																											
C19.10 Manufacture of coke oven products																											
C19.20 Manufacture of re-fined petroleum products								2																1		2	1
C20.13 Manufacture of other inorganic basic chemicals					1			1	1																	2	1
C20.14 Manufacture of other organic basic chemicals									3			1			1												5
C24.42 Aluminium produc-tion																									2		2

OEL/BLV	< €1,000			€1,000 - €10,000			€10,000 - €100,000			€100,000 -1 million			€1 - 10 mil-lion			€10 – 100 million			Over €100 million			Don't know			Number of responses per sector			
Sector	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	
C24.5 Casting of metals																												
F42.11 Construction of roads and motorways																						1	1			1	1	
F42.11 Construction of roads and motorways - mastic asphalt																												
G45.20 Maintenance and re- pair of motor vehicles																								1			1	
700 ng/m³ – 1.5 nmol/mol creatinine																												
C19.10 Manufacture of coke oven products																												
C19.20 Manufacture of re- fined petroleum products					2				1														1			2	2	
C20.13 Manufacture of other inorganic basic chemicals																												
C20.14 Manufacture of other organic basic chemicals						1			3															1			5	
C24.42 Aluminium produc- tion																									2		2	
C24.5 Casting of metals																												
F42.11 Construction of roads and motorways																							1	1			1	1

OEL/BLV Sector	< €1,000			€1,000 - €10,000			€10,000 - €100,000			€100,000 - 1 million			€1 - 10 million			€10 - 100 million			Over €100 million			Don't know			Number of responses per sector		
	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L
F42.11 Construction of roads and motorways - mastic asphalt																											
G45.20 Maintenance and repair of motor vehicles																								1			1
2000 ng/m³ – 3.8 nmol/mol creatinine																											
C19.10 Manufacture of coke oven products																											6
C19.20 Manufacture of refined petroleum products																											
C20.13 Manufacture of other inorganic basic chemicals																											
C20.14 Manufacture of other organic basic chemicals																											
C24.42 Aluminium production													1													1	
C24.5 Casting of metals																											
F42.11 Construction of roads and motorways																											
F42.11 Construction of roads and motorways - mastic asphalt																											
G45.20 Maintenance and repair of motor vehicles																											

Source: Consultation survey.

Table 7-12 Proportion of companies' annual recurrent investment costs attributed solely to RMMs to meet the BLV

OEL/BLV	<5%			5-10%			30-40%			40-50%			50-60%			70-80%			80-90%			90-100%			Number of responses per sector		
Sector	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L
7 ng/m³ – 0.2 nmol/mol creatinine																											
C19.20 Manufacture of refined petroleum products		2																				1			2	1	
C20.13 Manufacture of other inorganic basic chemicals								1																	1		
C20.14 Manufacture of other organic basic chemicals			3											1					1							5	
C24.42 Aluminium production																											
F42.11 Construction of roads and motorways																					8	2	2	8	2	2	
70 ng/m³ – 0.3 nmol/mol creatinine																											
C19.20 Manufacture of refined petroleum products										1					1										2		
C20.13 Manufacture of other inorganic basic chemicals								1																	1		
C20.14 Manufacture of other organic basic chemicals											1			2					1			1				5	
C24.42 Aluminium production																											
F42.11 Construction of roads and motorways																											

OEL/BLV Sector	<5%			5-10%			30-40%			40-50%			50-60%			70-80%			80-90%			90-100%			Number of responses per sector		
	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L
700 ng/m³ – 1.5 nmol/mol creatinine																											
C19.20 Manufacture of refined petroleum products													1									1			2		
C20.13 Manufacture of other inorganic basic chemicals																											
C20.14 Manufacture of other organic basic chemicals																						4			4		
C24.42 Aluminium production																											
F42.11 Construction of roads and motorways																											
2000 ng/m³ – 3.8 nmol/mol creatinine																											
C19.20 Manufacture of refined petroleum products																						1			1		
C20.13 Manufacture of other inorganic basic chemicals		1																							1		
C20.14 Manufacture of other organic basic chemicals						1																3			4		
C24.42 Aluminium production																						1			1		
F42.11 Construction of roads and motorways																											

Source: Consultation survey.

7.2.8.3 Survey - Lowest technically possible and economically feasible option

Survey respondents were also questioned on the lowest technically and economically feasible BLV however respondents did not provide usable information regarding a BLV.

Table 7-13 Lowest technically and economically feasible 8-hour OEL,

Sector	Technically feasible 8-hour OEL, average (min-max), ng/m ³	Economically feasible 8-hour OEL, average (min-max), ng/m ³
C19.20 Manufacture of refined petroleum products	1,109 (10 - 4,000)	1,413 (100 - 4000)
C20.13 Manufacture of other inorganic basic chemicals	50 (50 - 50)	500 (500 - 500)
C20.14 Manufacture of other organic basic chemicals	122 (4 - 260)	488 (100 - 1,250)
C24.42 Aluminium production	70 (70 - 70)	70 (70 - 70)
F42.11 Construction of roads and motorways	3,875,000 (500,000 - 5,000,000) ^(a)	10,000,000 (10,000,000 - 10,000,000) ^(a)

Source: Consultation survey.

Note: ^(a) the study team attempted to clarify these figures with the data providers as they are not realistic

The figures for F42.11 road paving are extremely high and do not depict a use scenario. A clarification from survey respondent was sought, but there was no feedback. The figures were submitted by users of mastic asphalt, and it is correct that it will be more challenging to achieve the OEL for companies using mastic asphalt for road paving. These figures were treated as anomalous and not taken further.

7.2.8.4 Survey - EU Member State Authorities

A total of 19 questionnaire responses were received from Member State Authorities related to PAH, including representatives from Belgium, Bulgaria, Denmark, Finland, Germany, Ireland, Italy, Latvia, Netherlands, Poland, Slovakia, Slovenia, Spain, and Sweden. Seven to nine respondents answered the questions covering the impacts of the policy options for PAH on costs for companies, costs for public authorities, competitiveness, SMEs, occupational health, and environment. The results are shown in Table 7-14.

As shown in the below table, the majority of Member State authorities believed there would be negative impacts for companies at the lowest two policy options, and little to no impact at the highest two policy options.

Similarly, respondents generally believe there would be minimal impact as costs to public authorities. Although, again respondents felt the impacts would more likely result in moderately negative impacts (although some believed there would be positive impacts (no explanation was received)).

Respondents also felt that the lower the OEL, the more negative impacts would be felt on the competitiveness of businesses and SMEs. Despite this, respondents generally felt that occupational health and environmental impacts would be positively impacted.

Table 7-14 Impact of the OEL policy options for PAH (n = number of answers)

Impact (number of answers)	Policy option (ng BaP/m ³)	Significant negative impact	Moderate negative impact	No impact	Moderate positive impact	Significant positive impact
Costs for Companies	2000 ng/m ³		2	5		
	700 ng/m ³		4	2		
	70 ng/m ³	2	4			
	7 ng/m ³	4	2	1		
Costs for pub- lic authorities	2000 ng/m ³		1	7	1	
	700 ng/m ³		2	5	1	
	70 ng/m ³		2	4		1
	7 ng/m ³		2	4		1
Competitive- ness	2000 ng/m ³		1	6		
	700 ng/m ³	1	1	3	1	
	70 ng/m ³	1	2	2	1	
	7 ng/m ³	2	2	1	1	
SMEs	2000 ng/m ³		2	5		
	700 ng/m ³	1	3	2		
	70 ng/m ³	3	3			
	7 ng/m ³	4	2			
Occupational health	2000 ng/m ³	1		4	4	1
	700 ng/m ³	1		2	4	2
	70 ng/m ³			1	3	5
	7 ng/m ³			1	2	6
Environment	2000 ng/m ³			4	2	2
	700 ng/m ³			3	1	3
	70 ng/m ³			3	1	3
	7 ng/m ³			3	1	3

Source: Consultation survey.

7.2.9 Estimated adjustment costs

The cost model considers companies using each type of RMM and works out which new RMM is required to achieve the OEL policy option. The model calculates the first year and recurrent costs of the new RMM. It also calculates the recurrent cost of the old RMM and the first year costs of the old RMM that would have been expected at 20 and 40 years: these are deducted from the costs for the new RMMs as the company was already expecting to pay for these.

The total costs presented in Table 7-15 include discontinuation costs. The percentage of discontinuation costs in the total PV40 adjustment costs are estimated below.

Table 7-15 Total PV adjustment costs over 40 years for the different OEL policy options by sector, excluding monitoring and administrative costs (€ millions)

Sector	Total PV cost by OEL policy option			
	7 ng/m ³	70 ng/m ³	700 ng/m ³	2000 ng/m ³
C10.13 Meat and poultry smokehouses	€ 8.85	€ 0.74	-	-
C10.2 Seafood smokehouses	€ 27.85	€ 2.16	-	-
C16.1 Wood preservation (creosote)	-€ 8.92	-	-	-
C19.1 Coking plants	€ 721.17	€ 334.97	-€ 0.41	-
C19.2 Petroleum refineries	€ 15,297.40	€ 769.73	-	-
C20.13 Manufacture of carbon black	€ 829.57	€ 0.64	-	-
C20.14 Coal tar distillation	€ 1,083.72	€ 593.42	-	-
C23.2 Manufacture of refractory products	€ 5.96	€ 0.67	-	-
C23.99a Manufacture of bituminous products	€ 87.11	€ 4.62	-	-
C23.99b Graphite and carbon electrode manufacture	€ 254.46	€ 99.93	-	-
C24.1 Steel and iron foundries, ferroalloys	€ 3,242.18	€ 315.49	-	-
C24.42 Manufacture of aluminium	€ 228.77	€ 27.70	-	-
C24.45 Other non-ferrous metallurgy	€ 191.33	€ 43.73	€ 0.42	-
C24.5 Casting of metals	€ 1,609.96	€ 42.81	-	-
D35.11 Coal fired power plants	€ 3,125.90	€ 2.55	-	-
E38.2 Waste incineration	€ 81.90	-	-	-
E39 Soil remediation	€ 1,339.03	€ 112.23	-	-
F42.11 Road paving	€ 1,774.48	€ 161.48	-	-
F42.12 Welding of railroad tracks	€ 5,705.41	€ 152.75	€ 2.98	-
G45.2 Motor vehicle maintenance and repairs	€ 562.59	-	-	-
N81.22 Chimney sweeps	€ 822.76	-	-	-
Total	€ 36,992.88	€ 2,666.17	€ 3.41	-

Source: Study team.

The estimated adjustment costs over 40 years (first year, discontinuations, and recurrent) that are incremental to the baseline are summarised in Table 7-16, Table 7-17, Table 7-18, and are combined to represent the overall costs in Table 7-19. Discontinuation costs make up a significant proportion of the overall costs (Table 7-19) and are presented in Table 7-20 as discontinuation costs as a percentage of the overall 40-year costs. The estimated combined adjustment costs over 40 years are also split by company size and shown in Table 7-21, followed by adjustment costs per company in Table 7-22.

Table 7-16, Table 7-17, Table 7-18 should be read comparatively to understand the full extent of impacts. Results in each table directly correspond with the equivalent entry in other tables and requires the context of all findings in the three tables to be fully understood – the values in the tables should not be read in isolation. For example, in Table 7-16, at 7 ng/m³ C19.1 coking plants

have zero first year costs, however Table 7-17 shows there are significant costs at the same level due to companies discontinuing. Furthermore, Table 7-20 shows that 100% of the 40-year costs for this sector at 7 ng/m³ are due to discontinuations. Therefore, the zero costs in Table 7-16 are not an indication of low-to-no costs, but the absence of this specific type of cost due to discontinuations.

Calculations of adjustment costs do not include costs associated with O84.25 firefighters. Adjustment costs for this sector have been provided in Section 7.4 (costs for public administrations) as the costs provided in this section (Section 7.2.9) refer to adjustment costs for industry.

First year PV costs in Table 7-16 include the initial capital costs of purchasing/installing alternative RMMs (less the cost of operating existing RMMs being replaced) and its associated operating cost in the first year of the adjustment period. Costs in this table only relate to companies implementing alternative RMMs and does not include the cost of companies discontinuing as a consequence of their inability to comply with the OEL.

First year adjustment costs in Table 7-16 include the first year costs of purchasing/installing alternative RMMs, plus associated operating cost in the first year, minus the first year cost of operating existing RMMs which are being replaced.

Table 7-16 First year PV adjustment costs over 40 years by policy options, sector and company size (excluding the costs of monitoring and associated administrative burden)

Sector	€ millions			
	Small	Medium	Large	Total
7 ng/m³				
C10.13 Meat and poultry smokehouses	€ 0.27	€ 0.18	€ 0.90	€ 1.35
C10.2 Seafood smokehouses	€ 0.47	€ 1.17	€ 1.92	€ 3.57
C16.1 Wood preservation (creosote)	€ 3.27	€ 0.53		€ 3.80
C19.1 Coking plants	-	-	-	-
C19.2 Petroleum refineries	€ 0.15	€ 1.07	€ 19.27	€ 20.49
C20.13 Manufacture of carbon black		€ 1.80	€ 2.81	€ 4.61
C20.14 Coal tar distillation		€ 0.90	€ 2.62	€ 3.52
C23.2 Manufacture of refractory products	€ 0.17	€ 0.26		€ 0.42
C23.99a Manufacture of bituminous products	€ 10.96	€ 11.53	€ 10.03	€ 32.52
C23.99b Graphite and carbon electrode manufacture			€ 9.95	€ 9.95
C24.1 Steel and iron foundries, ferroalloys	€ 28.93	€ 23.99	€ 159.64	€ 212.56
C24.42 Manufacture of aluminium		€ 0.79	€ 5.73	€ 6.52
C24.45 Other non-ferrous metallurgy	€ 1.42	€ 1.43	€ 4.33	€ 7.19
C24.5 Casting of metals	€ 99.12	€ 184.85	€ 247.34	€ 531.31
D35.11 Coal fired power plants	€ 0.87	€ 3.03	€ 6.63	€ 10.53
E38.2 Waste incineration	€ 0.99	€ 0.53	€ 0.75	€ 2.28
E39 Soil remediation	€ 72.54	€ 25.23	€ 12.51	€ 110.28
F42.11 Road paving	€ 25.38	€ 22.64	€ 27.68	€ 75.69

Sector	€ millions			
	Small	Medium	Large	Total
F42.12 Welding of railroad tracks	€ 11.46	€ 3.77	€ 10.72	€ 25.95
G45.2 Motor vehicle maintenance and repairs	€ 245.59	€ 22.89	€ 9.95	€ 278.43
N81.22 Chimney sweeps	€ 386.50			€ 386.50
Total	€ 888.11	€ 306.58	€ 532.78	€ 1,727.47
70 ng/m³				
C10.13 Meat and poultry smokehouses	€ 0.02	€ 0.02	€ 0.18	€ 0.22
C10.2 Seafood smokehouses	€ 0.04	€ 0.10	€ 0.39	€ 0.53
C16.1 Wood preservation (creosote)	-	-		-
C19.1 Coking plants	€ 0.88	€ 1.38	€ 4.75	€ 7.01
C19.2 Petroleum refineries	€ 0.06	€ 0.31	€ 6.09	€ 6.46
C20.13 Manufacture of carbon black		€ 0.33	€ 0.39	€ 0.71
C20.14 Coal tar distillation		€ 0.96	€ 3.20	€ 4.17
C23.2 Manufacture of refractory products	€ 0.05	€ 0.07		€ 0.11
C23.99a Manufacture of bituminous products	€ 0.64	€ 1.01	€ 0.91	€ 2.57
C23.99b Graphite and carbon electrode manufacture			€ 7.02	€ 7.02
C24.1 Steel and iron foundries, ferroalloys	€ 1.90	€ 2.33	€ 14.99	€ 19.22
C24.42 Manufacture of aluminium		€ 0.44	€ 2.89	€ 3.33
C24.45 Other non-ferrous metallurgy	€ 1.14	€ 1.36	€ 4.99	€ 7.49
C24.5 Casting of metals	€ 12.74	€ 28.66	€ 40.19	€ 81.59
D35.11 Coal fired power plants	€ 0.50	€ 0.65	€ 2.12	€ 3.27
E38.2 Waste incineration	-	-	-	-
E39 Soil remediation	€ 14.68	€ 5.59	€ 2.72	€ 22.99
F42.11 Road paving	€ 8.27	€ 5.13	€ 5.91	€ 19.31
F42.12 Welding of railroad tracks	€ 12.20	€ 9.43	€ 13.27	€ 34.91
G45.2 Motor vehicle maintenance and repairs	-	-	-	-
N81.22 Chimney sweeps	-			-
Total	€ 53.14	€ 57.77	€ 110.00	€ 220.90
700 ng/m³				
C10.13 Meat and poultry smokehouses	-	-	-	-
C10.2 Seafood smokehouses	-	-	-	-
C16.1 Wood preservation (creosote)	-	-		-
C19.1 Coking plants	€ 0.18	€ 0.21	€ 0.80	€ 1.19
C19.2 Petroleum refineries		-	-	-
C20.13 Manufacture of carbon black		-	-	-

Sector	€ millions			
	Small	Medium	Large	Total
C20.14 Coal tar distillation	-	€ 0.09	€ 0.34	€ 0.42
C23.2 Manufacture of refractory products	€ 0.01	€ 0.01		€ 0.02
C23.99a Manufacture of bituminous products	-	-	-	-
C23.99b Graphite and carbon electrode manufacture			-	-
C24.1 Steel and iron foundries, ferroalloys	-	-	-	-
C24.42 Manufacture of aluminium		-	-	-
C24.45 Other non-ferrous metallurgy	€ 0.06	€ 0.07	€ 0.27	€ 0.41
C24.5 Casting of metals	-	-	-	-
D35.11 Coal fired power plants	-	-	-	-
E38.2 Waste incineration	-	-	-	-
E39 Soil remediation	-	-	-	-
F42.11 Road paving	-	-	-	-
F42.12 Welding of railroad tracks	€ 0.26	€ 0.63	€ 1.63	€ 2.52
G45.2 Motor vehicle maintenance and repairs	-	-	-	-
N81.22 Chimney sweeps	-			-
Total	€ 0.51	€ 1.00	€ 3.04	€ 4.55
2000 ng/m³				
C10.13 Meat and poultry smokehouses	-	-	-	-
C10.2 Seafood smokehouses	-	-	-	-
C16.1 Wood preservation (creosote)	-	-		-
C19.1 Coking plants	-	-	-	-
C19.2 Petroleum refineries	-	-	-	-
C20.13 Manufacture of carbon black		-	-	-
C20.14 Coal tar distillation		-	-	-
C23.2 Manufacture of refractory products	-	-		-
C23.99a Manufacture of bituminous products	-	-	-	-
C23.99b Graphite and carbon electrode manufacture			-	-
C24.1 Steel and iron foundries, ferroalloys	-	-	-	-
C24.42 Manufacture of aluminium		-	-	-
C24.45 Other non-ferrous metallurgy	-	-	-	-
C24.5 Casting of metals	-	-	-	-
D35.11 Coal fired power plants	-	-	-	-
E38.2 Waste incineration	-	-	-	-
E39 Soil remediation	-	-	-	-
F42.11 Road paving	-	-	-	-

Sector	€ millions			
	Small	Medium	Large	Total
F42.12 Welding of railroad tracks	-	-	-	-
G45.2 Motor vehicle maintenance and repairs	-	-	-	-
N81.22 Chimney sweeps	-	-	-	-
Total	-	-	-	-

Source: Study team.

Note: '-' refers to zero costs incurred by companies, blank cells refer to no companies with exposure.

Table 7-17 illustrates the costs associated with company discontinuations. Discontinuations include proportions of companies (see section 8.3.1.2), representing partial closure of companies or the cessation of production lines where exposures occur. Discontinuation costs may also represent high adjustment costs that cannot be easily modelled. For small and medium companies' discontinuations typically refer to the full closure of a company, whereas large companies are more likely to close specific production lines or absorb high adjustment costs. Discontinuation costs presented in the following table may exceed the PV40 costs presented in Table 7-19, as discontinuation costs refers to the raw cost of a company ceasing operation, whereas PV40 costs include deductions for the avoided cost of operating existing RMMs where companies shift to alternative measures.

Negative values are present in Table 7-17 for large companies in E39 soil remediation at 7 and 70 ng/m³. Whilst it may seem counterintuitive for companies facing closure to produce a cost saving, it is possible for sectors where the 40-year cost of operating existing RMMs (and their avoided payment upon closure) outweighs 20 years of lost profits of companies discontinuing. This is particularly true for sectors using RMMs with high recurrent costs such as RPE (of which E39 is one).

Table 7-17 Discontinuation PV adjustment costs over 40 years by policy options, sector and company size

Sector	€ millions			
	Small	Medium	Large	Total
7 ng/m³				
C10.13 Meat and poultry smokehouses	€ 1.14	€ 1.63	€ 0.34	€ 3.12
C10.2 Seafood smokehouses	€ 3.89	€ 7.70	€ 0.95	€ 12.54
C16.1 Wood preservation (creosote)	-	-	-	-
C19.1 Coking plants	€ 416.05	€ 222.31	€ 82.81	€ 721.17
C19.2 Petroleum refineries	€ 78.06	€ 802.13	€ 14,380.48	€ 15,260.66
C20.13 Manufacture of carbon black		€ 628.45	€ 190.07	€ 818.52
C20.14 Coal tar distillation		€ 517.37	€ 557.03	€ 1,074.40
C23.2 Manufacture of refractory products	€ 0.93	€ 4.24		€ 5.16
C23.99a Manufacture of bituminous products	-	-	-	-
C23.99b Graphite and carbon electrode manufacture			€ 200.69	€ 200.69
C24.1 Steel and iron foundries, ferroalloys	€ 341.84	€ 925.91	€ 1,727.31	€ 2,995.06
C24.42 Manufacture of aluminium		€ 105.67	€ 111.38	€ 217.05
C24.45 Other non-ferrous metallurgy	€ 25.54	€ 106.68	€ 41.80	€ 174.03

Sector	€ millions			
	Small	Medium	Large	Total
C24.5 Casting of metals	€ 127.74	€ 239.49	€ 26.52	€ 393.76
D35.11 Coal fired power plants	€ 20.06	€ 1,810.07	€ 1,273.55	€ 3,103.68
E38.2 Waste incineration	€ 37.16	€ 37.70	€ 6.58	€ 81.44
E39 Soil remediation	€ 702.49	€ 376.66	-€ 2.15	€ 1,076.99
F42.11 Road paving	-	-	€ 613.73	€ 613.73
F42.12 Welding of railroad tracks	€ 2,350.69	€ 2,409.78	€ 821.80	€ 5,582.27
G45.2 Motor vehicle maintenance and repairs	-	-	-	-
N81.22 Chimney sweeps	€ 58.10			€ 58.10
Total	€ 4,163.69	€ 8,195.81	€ 20,032.89	€ 32,392.40
70 ng/m³				
C10.13 Meat and poultry smokehouses	-	-	-	-
C10.2 Seafood smokehouses	-	-	-	-
C16.1 Wood preservation (creosote)	-	-		-
C19.1 Coking plants	€ 186.89	€ 99.49	€ 35.59	€ 321.98
C19.2 Petroleum refineries	€ 3.90	€ 40.11	€ 719.02	€ 763.03
C20.13 Manufacture of carbon black		-	-	-
C20.14 Coal tar distillation		€ 257.10	€ 330.78	€ 587.88
C23.2 Manufacture of refractory products	€ 0.07	€ 0.38		€ 0.45
C23.99a Manufacture of bituminous products	-	-	-	-
C23.99b Graphite and carbon electrode manufacture			€ 67.23	€ 67.23
C24.1 Steel and iron foundries, ferroalloys	€ 34.18	€ 92.59	€ 172.73	€ 299.51
C24.42 Manufacture of aluminium		-	€ 23.67	€ 23.67
C24.45 Other non-ferrous metallurgy	€ 4.99	€ 21.16	€ 8.32	€ 34.47
C24.5 Casting of metals	-	-	-	-
D35.11 Coal fired power plants	-	-	-	-
E38.2 Waste incineration	-	-	-	-
E39 Soil remediation	€ 64.91	€ 34.86	-€ 0.31	€ 99.46
F42.11 Road paving	-	-	-	-
F42.12 Welding of railroad tracks	€ 21.35	€ 21.87	€ 7.38	€ 50.61
G45.2 Motor vehicle maintenance and repairs	-	-	-	-
N81.22 Chimney sweeps	-			-
Total	€ 316.30	€ 567.56	€ 1,364.42	€ 2,248.28
700 ng/m³				
C10.13 Meat and poultry smokehouses	-	-	-	-
C10.2 Seafood smokehouses	-	-	-	-
C16.1 Wood preservation (creosote)	-	-		-

Sector	€ millions			
	Small	Medium	Large	Total
C19.1 Coking plants	-	-	-	-
C19.2 Petroleum refineries	-	-	-	-
C20.13 Manufacture of carbon black		-	-	-
C20.14 Coal tar distillation		-	-	-
C23.2 Manufacture of refractory products	-	-		-
C23.99a Manufacture of bituminous products	-	-	-	-
C23.99b Graphite and carbon electrode manufacture			-	-
C24.1 Steel and iron foundries, ferroalloys	-	-	-	-
C24.42 Manufacture of aluminium		-	-	-
C24.45 Other non-ferrous metallurgy	-	-	-	-
C24.5 Casting of metals	-	-	-	-
D35.11 Coal fired power plants	-	-	-	-
E38.2 Waste incineration	-	-	-	-
E39 Soil remediation	-	-	-	-
F42.11 Road paving	-	-	-	-
F42.12 Welding of railroad tracks	-	-	-	-
G45.2 Motor vehicle maintenance and repairs	-	-	-	-
N81.22 Chimney sweeps	-			-
Total	-	-	-	-
2000 ng/m³				
C10.13 Meat and poultry smokehouses	-	-	-	-
C10.2 Seafood smokehouses	-	-	-	-
C16.1 Wood preservation (creosote)	-	-		-
C19.1 Coking plants	-	-	-	-
C19.2 Petroleum refineries	-	-	-	-
C20.13 Manufacture of carbon black		-	-	-
C20.14 Coal tar distillation		-	-	-
C23.2 Manufacture of refractory products	-	-		-
C23.99a Manufacture of bituminous products	-	-	-	-
C23.99b Graphite and carbon electrode manufacture			-	-
C24.1 Steel and iron foundries, ferroalloys	-	-	-	-
C24.42 Manufacture of aluminium		-	-	-
C24.45 Other non-ferrous metallurgy	-	-	-	-
C24.5 Casting of metals	-	-	-	-
D35.11 Coal fired power plants	-	-	-	-

Sector	€ millions			
	Small	Medium	Large	Total
E38.2 Waste incineration	-	-	-	-
E39 Soil remediation	-	-	-	-
F42.11 Road paving	-	-	-	-
F42.12 Welding of railroad tracks	-	-	-	-
G45.2 Motor vehicle maintenance and repairs	-	-	-	-
N81.22 Chimney sweeps	-	-	-	-
Total	-	-	-	-

Source: Study team.

Note: '-' refers to zero costs incurred by companies, blank cells refer to no companies with exposure.

Table 7-18 presents the recurrent costs for companies installing alternative RMMs. Recurrent costs are defined as those from year 2-40 and include 20-year reinvestment costs as well as 39 years of operational costs. All negative values in this table are due to the avoided recurrent costs of existing RMMs over 40 years being greater than the cost of implementing new RMMs over 40 years. To repeat, this is most typical for sectors with existing reliance upon RMMs with high recurrent costs, such as RPE, moving to RMMs with lesser recurrent costs over the same period, such as closed systems.

Table 7-18 Recurrent PV adjustment costs over 40 years by policy options, sector and company size (excluding the costs of monitoring and associated administrative burden)

Sector	€ millions			
	Small	Medium	Large	Total
7 ng/m³				
C10.13 Meat and poultry smokehouses	€ 0.90	€ 1.78	€ 1.71	€ 4.38
C10.2 Seafood smokehouses	€ 2.92	€ 5.07	€ 3.75	€ 11.74
C16.1 Wood preservation (creosote)	-€ 11.97	-€ 0.75		-€ 12.72
C19.1 Coking plants	-	-	-	-
C19.2 Petroleum refineries	€ 0.39	€ 1.62	€ 14.24	€ 16.25
C20.13 Manufacture of carbon black		€ 3.26	€ 3.18	€ 6.44
C20.14 Coal tar distillation		€ 1.10	€ 4.70	€ 5.80
C23.2 Manufacture of refractory products	-€ 0.10	€ 0.47		€ 0.37
C23.99a Manufacture of bituminous products	€ 14.08	€ 19.68	€ 20.84	€ 54.60
C23.99b Graphite and carbon electrode manufacture			€ 43.82	€ 43.82
C24.1 Steel and iron foundries, ferroalloys	-€ 37.01	€ 7.43	€ 64.14	€ 34.56
C24.42 Manufacture of aluminium		€ 1.04	€ 4.15	€ 5.20
C24.45 Other non-ferrous metallurgy	€ 2.36	€ 2.95	€ 4.80	€ 10.11
C24.5 Casting of metals	€ 243.77	€ 241.67	€ 199.45	€ 684.90
D35.11 Coal fired power plants	€ 0.99	€ 2.87	€ 7.84	€ 11.69
E38.2 Waste incineration	-€ 0.53	-€ 0.34	-€ 0.95	-€ 1.82

Sector	€ millions			
	Small	Medium	Large	Total
E39 Soil remediation	€ 113.67	€ 29.10	€ 8.98	€ 151.75
F42.11 Road paving	€ 343.49	€ 319.08	€ 422.48	€ 1,085.05
F42.12 Welding of railroad tracks	€ 15.88	€ 22.04	€ 59.27	€ 97.19
G45.2 Motor vehicle maintenance and re-pairs	€ 276.88	€ 5.32	€ 1.96	€ 284.16
N81.22 Chimney sweeps	€ 378.15			€ 378.15
Total	€ 1,343.87	€ 663.39	€ 864.37	€ 2,871.63
70 ng/m³				
C10.13 Meat and poultry smokehouses	€ 0.077	€ 0.239	€ 0.202	€ 0.52
C10.2 Seafood smokehouses	€ 0.37	€ 0.79	€ 0.47	€ 1.63
C16.1 Wood preservation (creosote)	-	-		-
C19.1 Coking plants	€ 0.51	€ 1.46	€ 4.02	€ 5.99
C19.2 Petroleum refineries	€ 0.01	€ 0.04	€ 0.18	€ 0.24
C20.13 Manufacture of carbon black		-€ 0.03	-€ 0.04	-€ 0.07
C20.14 Coal tar distillation		€ 0.03	€ 1.34	€ 1.37
C23.2 Manufacture of refractory products	-€ 0.03	€ 0.13		€ 0.10
C23.99a Manufacture of bituminous products	€ 0.65	€ 0.59	€ 0.82	€ 2.05
C23.99b Graphite and carbon electrode manufacture			€ 25.69	€ 25.69
C24.1 Steel and iron foundries, ferroalloys	-€ 5.34	-€ 0.40	€ 2.50	-€ 3.23
C24.42 Manufacture of aluminium		€ 0.07	€ 0.64	€ 0.70
C24.45 Other non-ferrous metallurgy	-€ 0.25	€ 0.75	€ 1.26	€ 1.77
C24.5 Casting of metals	€ 0.55	-€ 7.43	-€ 31.90	-€ 38.78
D35.11 Coal fired power plants	-€ 0.04	-€ 0.34	-€ 0.35	-€ 0.72
E38.2 Waste incineration	-	-	-	-
E39 Soil remediation	-€ 3.77	-€ 3.16	-€ 3.29	-€ 10.22
F42.11 Road paving	€ 42.39	€ 30.10	€ 69.68	€ 142.16
F42.12 Welding of railroad tracks	€ 21.25	€ 18.27	€ 27.72	€ 67.24
G45.2 Motor vehicle maintenance and re-pairs	-	-	-	-
N81.22 Chimney sweeps	-			-
Total	€ 56.38	€ 41.11	€ 98.95	€ 196.44
700 ng/m³				
C10.13 Meat and poultry smokehouses	-	-	-	-
C10.2 Seafood smokehouses	-	-	-	-
C16.1 Wood preservation (creosote)	-	-		-
C19.1 Coking plants	-€ 0.19	-€ 0.35	-€ 1.05	-€ 1.60

Sector	€ millions			
	Small	Medium	Large	Total
C19.2 Petroleum refineries	-	-	-	-
C20.13 Manufacture of carbon black		-	-	-
C20.14 Coal tar distillation		-€ 0.02	-€ 0.03	-€ 0.05
C23.2 Manufacture of refractory products	-€ 0.01	€ 0.02		€ 0.01
C23.99a Manufacture of bituminous products	-	-	-	-
C23.99b Graphite and carbon electrode manufacture			-	-
C24.1 Steel and iron foundries, ferroalloys	-	-	-	-
C24.42 Manufacture of aluminium		-	-	-
C24.45 Other non-ferrous metallurgy	-€ 0.04	€ 0.02	€ 0.03	€ 0.01
C24.5 Casting of metals	-	-	-	-
D35.11 Coal fired power plants	-	-	-	-
E38.2 Waste incineration	-	-	-	-
E39 Soil remediation	-	-	-	-
F42.11 Road paving	-	-	-	-
F42.12 Welding of railroad tracks	€ 0.51	-	-€ 0.05	€ 0.46
G45.2 Motor vehicle maintenance and repairs	-	-	-	-
N81.22 Chimney sweeps	-			-
Total	€ 0.27	-€ 0.33	-€ 1.10	-€ 1.17
2000 ng/m³				
C10.13 Meat and poultry smokehouses	-	-	-	-
C10.2 Seafood smokehouses	-	-	-	-
C16.1 Wood preservation (creosote)	-	-		-
C19.1 Coking plants	-	-	-	-
C19.2 Petroleum refineries	-	-	-	-
C20.13 Manufacture of carbon black		-	-	-
C20.14 Coal tar distillation		-	-	-
C23.2 Manufacture of refractory products	-	-		-
C23.99a Manufacture of bituminous products	-	-	-	-
C23.99b Graphite and carbon electrode manufacture			-	-
C24.1 Steel and iron foundries, ferroalloys	-	-	-	-
C24.42 Manufacture of aluminium		-	-	-
C24.45 Other non-ferrous metallurgy	-	-	-	-
C24.5 Casting of metals	-	-	-	-

Sector	€ millions			
	Small	Medium	Large	Total
D35.11 Coal fired power plants	-	-	-	-
E38.2 Waste incineration	-	-	-	-
E39 Soil remediation	-	-	-	-
F42.11 Road paving	-	-	-	-
F42.12 Welding of railroad tracks	-	-	-	-
G45.2 Motor vehicle maintenance and re-pairs	-	-	-	-
N81.22 Chimney sweeps	-	-	-	-
Total	-	-	-	-

Source: Study team.

Notes: '-' refers to zero costs incurred by companies, blank cells refer to no companies with exposure.

Table 7-19 illustrates the combined first year, recurrent, and discontinuation costs for all sectors, split by company size (apart from firefighters which are presented in section 7.4.1). At 7 ng/m³ C16.1 presents an overall cost saving as companies change from using filtered facemasks (with high first year and recurrent costs) to closed systems which is cheaper to run over 40 years. This is also true for large companies in E39 soil remediation at 70 ng/m³. At 700 ng/m³ negative costs for C19.1 coking plants and C23.2 manufacture of refractory products are also due to more cost effective RMMs being selected.

Despite the presence of negative recurrent costs, there is an overall cost of €37 billion at 7 ng/m³, and €2.7 billion at 70 ng/m³. Most of these costs originate from nine sectors at 7 ng/m³; C19.1 coking plants, C19.2 petroleum refineries, C20.13 manufacture of carbon black, C20.14 coal tar distillation, C24.1 steel and iron foundries, ferroalloys, C24.5 casting of metals, D35.11 coal fired power plants, E39 soil remediation, F42.11 road paving, F42.12 welding of railroad tracks, G45.2 motor vehicle repair, and N81.22 chimney sweeps. At 70 ng/m³, costs primarily occur due to an alternative nine sectors; C19.1 coking plants, C19.2 petroleum refineries, C20.14 coal tar distillation, C23.99b graphite and carbon electrode manufacture, C24.1 steel and iron foundries, ferroalloys, C24.5 casting of metals, E39 soil remediation, F42.11 road paving, and F42.12 welding of railroad tracks.

Whilst PV40 costs for C19.2 oil refineries includes high levels of discontinuation costs (see Table 7-20) at the 7 ng/m³ (49 enterprises discontinuing) and 70 ng/m³ (two enterprises discontinuing) levels, the study team does not anticipate actual discontinuation of enterprises in this sector as they are more likely to absorb the costs and find alternative means to reduce exposure without closure.

Again, regarding PV40 costs for D35.11 coal fired power plants, modelling predicts high levels of discontinuation costs at the 7ng/m³ level due to enterprises already using fully closed systems to a high degree, and it seems as though enterprises may not be able to install a more efficient RMMs (although the study team does not have certainty on this point).

PV40 costs for F42.11 road paving includes the possibility of substitution of PAH containing substances. Substitution for other sectors has not been considered viable to model as it would fundamentally change the definition of the sector and thus omit the sector from the study. For example, smokehouses may substitute with artificial smoke flavouring, but the sector would no longer be

smoking meat/fish. Coal fired power plants may substitute to alternative fuel sources, but by definition they would no longer be coal fired power plants. Whilst substitution produces an overall cost for F42.11, the costs for substitution are far lower than installing/utilising alternative RMMs.

PV40 costs for F42.12 welding of railway tracks has been performed on the basis that the only suitable RMMs for this sector include open hood ventilation, simple enclosures, filtered face masks or simple facemasks, organisational hygiene measures, and general ventilation. Other measures are not suitable as this activity requires continuous movement in complex terrain and conditions.

Table 7-19 Total PV adjustment costs over 40 years by policy options, sector and company size (excluding the costs of monitoring and associated administrative burden)

Sector	€ millions			
	Small	Medium	Large	Total
7 ng/m³				
C10.13 Meat and poultry smokehouses	€ 2.31	€ 3.59	€ 2.95	€ 8.85
C10.2 Seafood smokehouses	€ 7.29	€ 13.95	€ 6.62	€ 27.85
C16.1 Wood preservation (creosote)	-€ 8.69	-€ 0.22		-€ 8.92
C19.1 Coking plants	€ 416.05	€ 222.31	€ 82.81	€ 721.17
C19.2 Petroleum refineries	€ 78.59	€ 804.82	€ 14,413.99	€ 15,297.40
C20.13 Manufacture of carbon black		€ 633.51	€ 196.06	€ 829.57
C20.14 Coal tar distillation		€ 519.37	€ 564.35	€ 1,083.72
C23.2 Manufacture of refractory products	€ 0.99	€ 4.97		€ 5.96
C23.99a Manufacture of bituminous products	€ 25.03	€ 31.21	€ 30.87	€ 87.11
C23.99b Graphite and carbon electrode manufacture			€ 254.46	€ 254.46
C24.1 Steel and iron foundries, ferroalloys	€ 333.76	€ 957.33	€ 1,951.09	€ 3,242.18
C24.42 Manufacture of aluminium		€ 107.50	€ 121.26	€ 228.77
C24.45 Other non-ferrous metallurgy	€ 29.33	€ 111.07	€ 50.94	€ 191.33
C24.5 Casting of metals	€ 470.63	€ 666.01	€ 473.32	€ 1,609.96
D35.11 Coal fired power plants	€ 21.92	€ 1,815.97	€ 1,288.02	€ 3,125.90
E38.2 Waste incineration	€ 37.62	€ 37.90	€ 6.38	€ 81.90
E39 Soil remediation	€ 888.70	€ 430.99	€ 19.33	€ 1,339.03
F42.11 Road paving	€ 368.87	€ 341.71	€ 1,063.89	€ 1,774.48
F42.12 Welding of railroad tracks	€ 2,378.04	€ 2,435.58	€ 891.79	€ 5,705.41
G45.2 Motor vehicle maintenance and repairs	€ 522.48	€ 28.20	€ 11.91	€ 562.59
N81.22 Chimney sweeps	€ 822.76			€ 822.76
Total	€ 6,395.67	€ 9,165.88	€ 21,431.33	€ 36,992.88
70 ng/m³				
C10.13 Meat and poultry smokehouses	€ 0.10	€ 0.26	€ 0.38	€ 0.74
C10.2 Seafood smokehouses	€ 0.41	€ 0.90	€ 0.86	€ 2.16

Sector	€ millions			
	Small	Medium	Large	Total
C16.1 Wood preservation (creosote)	-	-		-
C19.1 Coking plants	€ 188.28	€ 102.34	€ 44.35	€ 334.97
C19.2 Petroleum refineries	€ 3.98	€ 40.46	€ 725.29	€ 769.73
C20.13 Manufacture of carbon black		€ 0.29	€ 0.35	€ 0.64
C20.14 Coal tar distillation		€ 258.09	€ 335.32	€ 593.42
C23.2 Manufacture of refractory products	€ 0.09	€ 0.58		€ 0.67
C23.99a Manufacture of bituminous products	€ 1.29	€ 1.59	€ 1.73	€ 4.62
C23.99b Graphite and carbon electrode manufacture			€ 99.93	€ 99.93
C24.1 Steel and iron foundries, ferroalloys	€ 30.75	€ 94.52	€ 190.22	€ 315.49
C24.42 Manufacture of aluminium		€ 0.51	€ 27.19	€ 27.70
C24.45 Other non-ferrous metallurgy	€ 5.89	€ 23.27	€ 14.57	€ 43.73
C24.5 Casting of metals	€ 13.29	€ 21.23	€ 8.29	€ 42.81
D35.11 Coal fired power plants	€ 0.46	€ 0.31	€ 1.78	€ 2.55
E38.2 Waste incineration	-	-	-	-
E39 Soil remediation	€ 75.82	€ 37.28	-€ 0.87	€ 112.23
F42.11 Road paving	€ 50.66	€ 35.23	€ 75.59	€ 161.48
F42.12 Welding of railroad tracks	€ 54.79	€ 49.58	€ 48.38	€ 152.75
G45.2 Motor vehicle maintenance and repairs	-	-	-	-
N81.22 Chimney sweeps	-			-
Total	€ 425.81	€ 666.48	€ 1,573.88	€ 2,666.17
700 ng/m³				
C10.13 Meat and poultry smokehouses	-	-	-	-
C10.2 Seafood smokehouses	-	-	-	-
C16.1 Wood preservation (creosote)	-	-		-
C19.1 Coking plants	-€ 0.01	-€ 0.15	-€ 0.25	-€ 0.41
C19.2 Petroleum refineries	-	-	-	-
C20.13 Manufacture of carbon black		-	-	-
C20.14 Coal tar distillation		€ 0.06	€ 0.30	€ 0.37
C23.2 Manufacture of refractory products	-€ 0.0003	-		€ 0.03
C23.99a Manufacture of bituminous products	-	-	-	-
C23.99b Graphite and carbon electrode manufacture			-	-
C24.1 Steel and iron foundries, ferroalloys	-	-	-	-
C24.42 Manufacture of aluminium		-	-	-

Sector	€ millions			
	Small	Medium	Large	Total
C24.45 Other non-ferrous metallurgy	€ 0.02	€ 0.09	€ 0.30	€ 0.42
C24.5 Casting of metals	-	-	-	-
D35.11 Coal fired power plants	-	-	-	-
E38.2 Waste incineration	-	-	-	-
E39 Soil remediation	-	-	-	-
F42.11 Road paving	-	-	-	-
F42.12 Welding of railroad tracks	€ 0.77	€ 0.63	€ 1.58	€ 2.98
G45.2 Motor vehicle maintenance and repairs	-	-	-	-
N81.22 Chimney sweeps	-	-	-	-
Total	€ 0.78	€ 0.67	€ 1.95	€ 3.41
2000 ng/m³				
C10.13 Meat and poultry smokehouses	-	-	-	-
C10.2 Seafood smokehouses	-	-	-	-
C16.1 Wood preservation (creosote)	-	-	-	-
C19.1 Coking plants	-	-	-	-
C19.2 Petroleum refineries	-	-	-	-
C20.13 Manufacture of carbon black	-	-	-	-
C20.14 Coal tar distillation	-	-	-	-
C23.2 Manufacture of refractory products	-	-	-	-
C23.99a Manufacture of bituminous products	-	-	-	-
C23.99b Graphite and carbon electrode manufacture	-	-	-	-
C24.1 Steel and iron foundries, ferroalloys	-	-	-	-
C24.42 Manufacture of aluminium	-	-	-	-
C24.45 Other non-ferrous metallurgy	-	-	-	-
C24.5 Casting of metals	-	-	-	-
D35.11 Coal fired power plants	-	-	-	-
E38.2 Waste incineration	-	-	-	-
E39 Soil remediation	-	-	-	-
F42.11 Road paving	-	-	-	-
F42.12 Welding of railroad tracks	-	-	-	-
G45.2 Motor vehicle maintenance and repairs	-	-	-	-
N81.22 Chimney sweeps	-	-	-	-
Total	-	-	-	-

Source: Study team.

Note: '-' refers to zero costs incurred by companies, blank cells refer to no companies with exposure.

The table below illustrates the proportion of overall PV40 costs attributed to discontinuations. To note:

- Percentages may exceed 100% as a result of modelling nuances. This is due to the PV40 costs including deductions for the avoided cost of maintaining existing RMMs where companies are expected to implement alternative measures (resulting in lower PV40 costs than discontinuation costs); and
- Negative discontinuation costs are present where the avoided cost of operating existing RMMs over 40 years exceeds the cost of discontinuing.

At 7 ng/m³ and to a lesser extent at 70 ng/m³, discontinuation costs make up the significant majority of costs across all company sizes and sectors. There are no discontinuations and hence no discontinuation costs at the 700 and 2000 ng/m³ policy options.

Table 7-20 PV Discontinuation adjustment costs over 40 years as a percentage of total PV compliance costs, by policy options, sector and company size

Sector	Percentage			
	Small	Medium	Large	Total
7 ng/m³				
C10.13 Meat and poultry smokehouses	49.40%	45.50%	11.69%	35.26%
C10.2 Seafood smokehouses	53.39%	55.23%	14.31%	45.03%
C16.1 Wood preservation (creosote)	-	-		-
C19.1 Coking plants	100.00%	100.00%	100.00%	100.00%
C19.2 Petroleum refineries	99.32%	99.67%	99.77%	99.76%
C20.13 Manufacture of carbon black		99.20%	96.95%	98.67%
C20.14 Coal tar distillation		99.62%	98.70%	99.14%
C23.2 Manufacture of refractory products	93.46%	85.36%		86.70%
C23.99a Manufacture of bituminous products	-	-	-	-
C23.99b Graphite and carbon electrode manufacture			78.87%	78.87%
C24.1 Steel and iron foundries, ferroalloys	102.42%	96.72%	88.53%	92.38%
C24.42 Manufacture of aluminium		98.30%	91.85%	94.88%
C24.45 Other non-ferrous metallurgy	87.10%	96.05%	82.07%	90.96%
C24.5 Casting of metals	27.14%	35.96%	5.60%	24.46%
D35.11 Coal fired power plants	91.53%	99.68%	98.88%	99.29%
E38.2 Waste incineration	98.77%	99.48%	103.06%	99.44%
E39 Soil remediation	79.05%	87.39%	-11.13%	80.43%
F42.11 Road paving	-	-	57.69%	34.59%
F42.12 Welding of railroad tracks	98.85%	98.94%	92.15%	97.84%
G45.2 Motor vehicle maintenance and repairs	-	-	-	-
N81.22 Chimney sweeps	7.06%			7.06%
Total	65.10%	89.42%	93.48%	87.57%

Sector	Percentage			
	Small	Medium	Large	Total
70 ng/m³				
C10.13 Meat and poultry smokehouses	-	-	-	-
C10.2 Seafood smokehouses	-	-	-	-
C16.1 Wood preservation (creosote)	-	-	-	-
C19.1 Coking plants	99.26%	97.22%	80.24%	96.12%
C19.2 Petroleum refineries	98.04%	99.13%	99.14%	99.13%
C20.13 Manufacture of carbon black	-	-	-	-
C20.14 Coal tar distillation	-	99.61%	98.65%	99.07%
C23.2 Manufacture of refractory products	76.24%	66.16%	-	67.55%
C23.99a Manufacture of bituminous products	-	-	-	-
C23.99b Graphite and carbon electrode manufacture	-	-	67.27%	67.27%
C24.1 Steel and iron foundries, ferroalloys	111.18%	97.96%	90.81%	94.93%
C24.42 Manufacture of aluminium	-	-	87.05%	85.45%
C24.45 Other non-ferrous metallurgy	84.78%	90.94%	57.08%	78.83%
C24.5 Casting of metals	-	-	-	-
D35.11 Coal fired power plants	-	-	-	-
E38.2 Waste incineration	-	-	-	-
E39 Soil remediation	85.61%	93.50%	34.91%	88.62%
F42.11 Road paving	-	-	-	-
F42.12 Welding of railroad tracks	38.96%	44.12%	15.26%	33.13%
G45.2 Motor vehicle maintenance and repairs	-	-	-	-
N81.22 Chimney sweeps	-	-	-	-
Total	74.28%	85.16%	86.72%	84.34%
700 ng/m³				
C10.13 Meat and poultry smokehouses	-	-	-	-
C10.2 Seafood smokehouses	-	-	-	-
C16.1 Wood preservation (creosote)	-	-	-	-
C19.1 Coking plants	-	-	-	-
C19.2 Petroleum refineries	-	-	-	-
C20.13 Manufacture of carbon black	-	-	-	-
C20.14 Coal tar distillation	-	-	-	-
C23.2 Manufacture of refractory products	-	-	-	-
C23.99a Manufacture of bituminous products	-	-	-	-
C23.99b Graphite and carbon electrode manufacture	-	-	-	-
C24.1 Steel and iron foundries, ferroalloys	-	-	-	-

Sector	Percentage			
	Small	Medium	Large	Total
C24.42 Manufacture of aluminium		-	-	-
C24.45 Other non-ferrous metallurgy	-	-	-	-
C24.5 Casting of metals	-	-	-	-
D35.11 Coal fired power plants	-	-	-	-
E38.2 Waste incineration	-	-	-	-
E39 Soil remediation	-	-	-	-
F42.11 Road paving	-	-	-	-
F42.12 Welding of railroad tracks	-	-	-	-
G45.2 Motor vehicle maintenance and repairs	-	-	-	-
N81.22 Chimney sweeps	-			-
Total	-	-	-	-
2000 ng/m³				
C10.13 Meat and poultry smokehouses	-	-	-	-
C10.2 Seafood smokehouses	-	-	-	-
C16.1 Wood preservation (creosote)	-	-		-
C19.1 Coking plants	-	-	-	-
C19.2 Petroleum refineries	-	-	-	-
C20.13 Manufacture of carbon black		-	-	-
C20.14 Coal tar distillation		-	-	-
C23.2 Manufacture of refractory products	-	-		-
C23.99a Manufacture of bituminous products	-	-	-	-
C23.99b Graphite and carbon electrode manufacture			-	-
C24.1 Steel and iron foundries, ferroalloys	-	-	-	-
C24.42 Manufacture of aluminium		-	-	-
C24.45 Other non-ferrous metallurgy	-	-	-	-
C24.5 Casting of metals	-	-	-	-
D35.11 Coal fired power plants	-	-	-	-
E38.2 Waste incineration	-	-	-	-
E39 Soil remediation	-	-	-	-
F42.11 Road paving	-	-	-	-
F42.12 Welding of railroad tracks	-	-	-	-
G45.2 Motor vehicle maintenance and repairs	-	-	-	-
N81.22 Chimney sweeps	-			-
Total	-	-	-	-

Source: Study team.

Note: '-' refers to zero costs incurred by companies, blank cells refer to no companies with exposure.

Table 7-21 Total PV adjustment costs over 40 years by policy options and company size (excluding the costs of monitoring and associated administrative burden) (€ millions)

Enterprise size	OEL policy options			
	7 ng/m ³	70 ng/m ³	700 ng/m ³	2000 ng/m ³
Small	€ 6,396	€ 426	€ 1	-
Medium	€ 9,166	€ 666	€ 1	-
Large	€ 21,431	€ 1,574	€ 2	-
Total	€ 36,993	€ 2,666	€ 3	-

Source: Study team.

Notes: '-' refers to zero costs incurred by companies.

Table 7-22 Total PV adjustment costs per company over 40 years per company by policy options and company size (excluding the costs of monitoring and associated administrative burden) (€ millions)

Enterprise size	OEL policy options			
	7 ng/m ³	70 ng/m ³	700 ng/m ³	2000 ng/m ³
Small	€ 0.01	€ 0.001	€ 0.000002	-
Medium	€ 3.05	€ 0.22	€ 0.0002	-
Large	€ 25.48	€ 1.87	€ 0.002	-
Total	€ 0.08	€ 0.01	€ 0.00001	-

Source: Study team.

Notes: '-' refers to zero costs incurred by companies.

7.2.10 Costs of air monitoring, biomonitoring and health surveillance

7.2.10.1 Air monitoring costs

7.2.10.1.1 Air monitoring campaigns

A significant number of the companies are expected to measure exposure concentration to refine their risk assessment and possibly to demonstrate compliance with the new OEL. The costs are based on the following overall considerations:

- Additional monitoring would not be needed in Member States where the OEL is already at the level of the policy option or lower;
- Larger companies in general undertake more often monitoring than smaller companies;
- The percentage of companies which would need to monitor increases as the OEL decreases (the larger the difference between the new OEL and current exposure concentrations);
- Not all companies would need additional monitoring - some companies already undertake monitoring and some companies, in particular smaller companies, would install additional RMMs without monitoring; and
- Companies that only implement better RPE would not need an additional monitoring campaign to demonstrate efficiency of the RMM.

It is assumed that those companies that monitor would need either one or two monitoring campaigns:

- For all companies that monitor, one monitoring campaign before the new RMMs are introduced to establish which RMMs are required; and
- For some of the companies, one further monitoring campaign after the introduction of the RMMs to demonstrate compliance if there is uncertainty as to whether the new RMMs will achieve compliance.

Further detail about the assumptions and calculations behind the modelling of air monitoring, bio-monitoring and health surveillance are provide in the Methodological Note.

7.2.10.1.2 Companies with exposed workers operating above each policy option

Percentage of companies in the EU with exposed workers that would not need additional monitoring because they already need to meet an OEL at same or lower level is shown in Table 7-23. The input for the calculation is Table 7-23 with national OELs in section 3.1.1 and the existing OELs in Member States are shown in Table 6-16 with number of companies by sector and Member State in section 0.

Table 7-23 Percentage of companies in the EU with exposed workers that would not need additional monitoring because they already need to meet an OEL at same or lower level

Policy option	7 ng/m ³	70 ng/m ³	700 ng/m ³	2000 ng/m ³
C10.13 Meat and poultry smokehouses	0%	40%	43%	56%
C10.2 Seafood smokehouses	0%	6%	18%	38%
C16.1 Wood preservation (creosote)	0%	8%	13%	60%
C19.1 Coking plants	0%	4%	7%	31%
C19.2 Petroleum refineries	0%	0%	2%	29%
C20.13 Manufacture of carbon black	0%	20%	28%	56%
C20.14 Coal tar distillation	0%	14%	29%	43%
C23.2 Manufacture of refractory products	0%	25%	25%	50%
C23.99a Manufacture of bituminous products	0%	12%	22%	43%
C23.99b Graphite and carbon electrode manufacture	0%	20%	20%	55%
C24.1 Steel and iron foundries, ferroalloys	0%	17%	19%	50%
C24.42 Manufacture of aluminium	0%	33%	33%	44%
C24.45 Other non-ferrous metallurgy	0%	56%	58%	65%
C24.5 Casting of metals	0%	14%	19%	37%
D35.11 Coal fired power plants	0%	31%	40%	67%
E38.2 Waste incineration	0%	20%	25%	51%

Policy option	7 ng/m ³	70 ng/m ³	700 ng/m ³	2000 ng/m ³
E39 Soil remediation	0%	10%	14%	30%
F42.11 Road paving	0%	9%	31%	70%
F42.12 Welding of railroad tracks	0%	11%	22%	68%
G45.2 Motor vehicle maintenance and repairs	0%	10%	15%	41%
N81.22 Chimney sweeps	0%	26%	43%	62%
Total	0%	11%	18%	44%

Source: Study team.

As shown above, all enterprises would need to undertake additional air monitoring at the 7ng/m³ level, over 80% at the 70ng/m³ and 700ng/m³ levels, and over half at the 2000ng/m³ level.

7.2.10.1.3 Costs of air monitoring

The total costs of air monitoring per size of the company and based on two campaigns are presented in Table 7-24. As shown air monitoring costs are incurred at all policy option levels. Sectors with higher costs for small and/or medium enterprises than large refer to those with a higher proportion of enterprises, by extent, more substance exposure groups to monitor. For example F42.11 and G45.2.

Table 7-24 Estimated costs of air monitoring costs in € over 40 years, based on two campaigns (€ millions)

Sector	Total costs € millions (based on two campaigns)			
	Small	Medium	Large	Total
7 ng/m³				
C10.13 Meat and poultry smokehouses	€ 0.22	€ 0.16	€ 0.05	€ 0.43
C10.2 Seafood smokehouses	€ 0.33	€ 0.44	€ 0.12	€ 0.89
C16.1 Wood preservation (creosote)	€ 0.04	€ 0.01		€ 0.06
C19.1 Coking plants	€ 0.05	€ 0.02	€ 0.09	€ 0.17
C19.2 Petroleum refineries	€ 0.03	€ 0.15	€ 0.69	€ 0.87
C20.13 Manufacture of carbon black		€ 0.24	€ 0.09	€ 0.33
C20.14 Coal tar distillation		€ 0.04	€ 0.07	€ 0.11
C23.2 Manufacture of refractory products	€ 0.005	€ 0.01		€ 0.02
C23.99a Manufacture of bituminous products	€ 1.21	€ 1.20	€ 0.43	€ 2.83
C23.99b Graphite and carbon electrode manufacture			€ 0.39	€ 0.39
C24.1 Steel and iron foundries, ferroalloys	€ 2.88	€ 1.35	€ 2.38	€ 6.61
C24.42 Manufacture of aluminium		€ 0.04	€ 0.11	€ 0.14
C24.45 Other non-ferrous metallurgy	€ 0.08	€ 0.10	€ 0.09	€ 0.26
C24.5 Casting of metals	€ 4.59	€ 6.54	€ 3.27	€ 14.39
D35.11 Coal fired power plants	€ 0.14	€ 0.54	€ 0.44	€ 1.13
E38.2 Waste incineration	€ 0.68	€ 0.52	€ 0.18	€ 1.38

Sector	Total costs € millions (based on two campaigns)			
	Small	Medium	Large	Total
E39 Soil remediation	€ 3.74	€ 1.06	€ 0.18	€ 4.99
F42.11 Road paving	€ 33.53	€ 15.54	€ 5.13	€ 54.20
F42.12 Welding of railroad tracks	€ 2.18	€ 1.00	€ 0.34	€ 3.53
G45.2 Motor vehicle maintenance and re-pairs	€ 426.40	€ 7.33	€ 0.89	€ 434.61
N81.22 Chimney sweeps	€ 22.12			€ 22.12
Total	€ 498.25	€ 36.28	€ 14.93	€ 549.46
70 ng/m³				
C10.13 Meat and poultry smokehouses	€ 0.08	€ 0.08	€ 0.03	€ 0.18
C10.2 Seafood smokehouses	€ 0.18	€ 0.33	€ 0.09	€ 0.60
C16.1 Wood preservation (creosote)	€ 0.02	€ 0.01		€ 0.03
C19.1 Coking plants	€ 0.03	€ 0.02	€ 0.07	€ 0.12
C19.2 Petroleum refineries	€ 0.02	€ 0.12	€ 0.56	€ 0.69
C20.13 Manufacture of carbon black		€ 0.15	€ 0.06	€ 0.21
C20.14 Coal tar distillation		€ 0.02	€ 0.05	€ 0.07
C23.2 Manufacture of refractory products	€ 0.002	€ 0.01		€ 0.01
C23.99a Manufacture of bituminous products	€ 0.61	€ 0.84	€ 0.30	€ 1.75
C23.99b Graphite and carbon electrode manufacture			€ 0.25	€ 0.25
C24.1 Steel and iron foundries, ferroalloys	€ 1.39	€ 0.90	€ 1.59	€ 3.88
C24.42 Manufacture of aluminium		€ 0.02	€ 0.06	€ 0.08
C24.45 Other non-ferrous metallurgy	€ 0.02	€ 0.03	€ 0.03	€ 0.08
C24.5 Casting of metals	€ 2.28	€ 4.50	€ 2.26	€ 9.03
D35.11 Coal fired power plants	€ 0.06	€ 0.30	€ 0.25	€ 0.61
E38.2 Waste incineration	€ 0.31	€ 0.33	€ 0.11	€ 0.76
E39 Soil remediation	€ 1.94	€ 0.76	€ 0.13	€ 2.83
F42.11 Road paving	€ 17.69	€ 11.34	€ 3.76	€ 32.79
F42.12 Welding of railroad tracks	€ 1.12	€ 0.71	€ 0.24	€ 2.08
G45.2 Motor vehicle maintenance and re-pairs	€ 220.73	€ 5.25	€ 0.64	€ 226.62
N81.22 Chimney sweeps	€ 9.50			€ 9.50
Total	€ 255.97	€ 25.72	€ 10.47	€ 292.16
700 ng/m³				
C10.13 Meat and poultry smokehouses	€ 0.05	€ 0.05	€ 0.02	€ 0.12
C10.2 Seafood smokehouses	€ 0.10	€ 0.21	€ 0.06	€ 0.38
C16.1 Wood preservation (creosote)	€ 0.01	€ 0.01		€ 0.02
C19.1 Coking plants	€ 0.02	€ 0.01	€ 0.05	€ 0.08

Sector	Total costs € millions (based on two campaigns)			
	Small	Medium	Large	Total
C19.2 Petroleum refineries	€ 0.01	€ 0.09	€ 0.42	€ 0.52
C20.13 Manufacture of carbon black		€ 0.10	€ 0.04	€ 0.14
C20.14 Coal tar distillation		€ 0.02	€ 0.03	€ 0.05
C23.2 Manufacture of refractory products	€ 0.001	€ 0.01		€ 0.01
C23.99a Manufacture of bituminous products	€ 0.36	€ 0.56	€ 0.20	€ 1.13
C23.99b Graphite and carbon electrode manufacture			€ 0.19	€ 0.19
C24.1 Steel and iron foundries, ferroalloys	€ 0.89	€ 0.65	€ 1.18	€ 2.72
C24.42 Manufacture of aluminium		€ 0.01	€ 0.04	€ 0.06
C24.45 Other non-ferrous metallurgy	€ 0.01	€ 0.02	€ 0.02	€ 0.06
C24.5 Casting of metals	€ 1.44	€ 3.20	€ 1.63	€ 6.26
D35.11 Coal fired power plants	€ 0.03	€ 0.19	€ 0.16	€ 0.39
E38.2 Waste incineration	€ 0.20	€ 0.23	€ 0.08	€ 0.51
E39 Soil remediation	€ 1.23	€ 0.55	€ 0.09	€ 1.87
F42.11 Road paving	€ 8.97	€ 6.48	€ 2.19	€ 17.64
F42.12 Welding of railroad tracks	€ 0.66	€ 0.47	€ 0.16	€ 1.29
G45.2 Motor vehicle maintenance and repairs	€ 138.83	€ 3.72	€ 0.46	€ 143.01
N81.22 Chimney sweeps	€ 4.87			€ 4.87
Total	€ 157.69	€ 16.60	€ 7.04	€ 181.33
2000 ng/m³				
C10.13 Meat and poultry smokehouses	€ 0.04	€ 0.04	€ 0.01	€ 0.09
C10.2 Seafood smokehouses	€ 0.08	€ 0.16	€ 0.04	€ 0.28
C16.1 Wood preservation (creosote)	€ 0.01	€ 0.003		€ 0.01
C19.1 Coking plants	€ 0.01	€ 0.01	€ 0.03	€ 0.06
C19.2 Petroleum refineries	€ 0.01	€ 0.06	€ 0.28	€ 0.35
C20.13 Manufacture of carbon black		€ 0.06	€ 0.02	€ 0.09
C20.14 Coal tar distillation		€ 0.01	€ 0.02	€ 0.04
C23.2 Manufacture of refractory products	€ 0.001	€ 0.004		€ 0.004
C23.99a Manufacture of bituminous products	€ 0.26	€ 0.41	€ 0.14	€ 0.81
C23.99b Graphite and carbon electrode manufacture			€ 0.10	€ 0.10
C24.1 Steel and iron foundries, ferroalloys	€ 0.56	€ 0.41	€ 0.68	€ 1.64
C24.42 Manufacture of aluminium		€ 0.01	€ 0.03	€ 0.05
C24.45 Other non-ferrous metallurgy	€ 0.01	€ 0.02	€ 0.02	€ 0.05
C24.5 Casting of metals	€ 1.12	€ 2.47	€ 1.17	€ 4.76

Sector	Total costs € millions (based on two campaigns)			
	Small	Medium	Large	Total
D35.11 Coal fired power plants	€ 0.02	€ 0.11	€ 0.08	€ 0.21
E38.2 Waste incineration	€ 0.13	€ 0.15	€ 0.05	€ 0.33
E39 Soil remediation	€ 1.01	€ 0.44	€ 0.07	€ 1.52
F42.11 Road paving	€ 3.88	€ 2.78	€ 0.87	€ 7.53
F42.12 Welding of railroad tracks	€ 0.27	€ 0.19	€ 0.06	€ 0.52
G45.2 Motor vehicle maintenance and repairs	€ 97.40	€ 2.59	€ 0.30	€ 100.29
N81.22 Chimney sweeps	€ 3.23			€ 3.23
Total	€ 108.03	€ 9.94	€ 3.98	€ 121.95

Source: Study team.

Note: Blank cells refer to no companies with exposure.

7.2.10.2 Biomonitoring and health surveillance costs

7.2.10.2.1 Biomonitoring and health surveillance campaigns

Some companies are expected to conduct health surveillance already to refine their risk assessment or to comply with national BLVs. The model is developed under the following overall considerations:

- Additional monitoring would not be needed in Member States where the BLV is already at the level of the policy option or lower, provided that the company's BLVs and OELs are less than 50% of the BLV and OEL set down in Annexes IIIa and III of the CMRD. An explanation of this can be found in section 7.3.1 of the method note.
- The percentage of exposed workers which would need biomonitoring and health surveillance increases as the BLV decreases (the larger the difference between the new BLV and current BLVs in the Member State).

It is assumed that those companies that monitor would need either one, two or three biomonitoring and health surveillance campaigns:

- For all companies that monitor at all, one monitoring campaign before the new RMMs are introduced to establish which RMMs are required
- For some of the companies, one further monitoring campaign after the introduction of the RMMs to demonstrate compliance if there is uncertainty as to whether the new RMMs will achieve compliance.
- Campaign 1: Year 1, biomonitoring only of all exposed workers except those in Member States with a BLV that is at least 50% below the target BLV.
- Campaign 2: Years 2 to 6, biomonitoring and health surveillance by the proportion of exposed workers in each sector whose exposure will take them above 50% of the new BLV.

- Campaign 3: Years 7 to 40, biomonitoring and health surveillance by a factor set for each sector multiplied by the number of exposed workers in campaign 2.

The study team believes that some sectors will never be able to achieve the lowest policy options for BLVs and this factor enables this to be modelled by setting the proportion of companies in a sector unable to achieve the BLV to 100%; although none of the sectors for PAH are set to this percentage. Alternatively, sectors that would find it difficult to meet the policy options, albeit technically/economically feasible, are provided unique percentages based on consultation feedback. These sectors include C19.1, C23.99b, C24.42, and C24.45. The default value for the remaining sectors is assumed to be 10%.

7.2.10.2.2 Companies with exposed workers operating above each policy option

The percentage of companies in the EU with exposed workers that would not need additional monitoring because they already need to meet an BLV at same or lower level is shown in Table 7-23. The input for the calculation is Table 7-25 with national BLVs in section 3.1.2 and Table 16-17 with number of companies by sector and Member State in section 0.

Table 7-25 Percentage of exposed workers in the EU that would not need additional monitoring because they already need to meet an BLV at same or lower level

Policy option	0.2 nmol/mol creatinine	0.3 nmol/mol creatinine	1.5 nmol/mol creatinine	3.8 nmol/mol creatinine
C10.13 Meat and poultry smokehouses	0%	0%	44%	44%
C10.2 Seafood smokehouses	0%	0%	19%	19%
C16.1 Wood preservation (creosote)	0%	0%	22%	22%
C19.1 Coking plants	0%	0%	3%	3%
C19.2 Petroleum refineries	0%	0%	0%	0%
C20.13 Manufacture of carbon black	0%	0%	56%	56%
C20.14 Coal tar distillation	0%	0%	14%	14%
C23.2 Manufacture of refractory products	0%	0%	31%	31%
C23.99a Manufacture of bituminous products	0%	0%	32%	32%
C23.99b Graphite and carbon electrode manufacture	0%	0%	45%	45%
C24.1 Steel and iron foundries, ferroalloys	0%	0%	34%	34%
C24.42 Manufacture of aluminium	0%	0%	56%	56%
C24.45 Other non-ferrous metallurgy	0%	0%	64%	64%
C24.5 Casting of metals	0%	0%	43%	43%
D35.11 Coal fired power plants	0%	0%	34%	34%
E38.2 Waste incineration	0%	0%	42%	42%
E39 Soil remediation	0%	0%	47%	47%
F42.11 Road paving	0%	0%	40%	40%

Policy option	0.2 nmol/mol creatinine	0.3 nmol/mol creatinine	1.5 nmol/mol creatinine	3.8 nmol/mol creatinine
F42.12 Welding of railroad tracks	0%	0%	21%	21%
G45.2 Motor vehicle maintenance and re-pairs	0%	0%	31%	31%
N81.22 Chimney sweeps	0%	0%	41%	41%
Total	0%	0%	35%	35%

Source: Study team.

As shown above, biomonitoring and health surveillance would be needed for all exposed workers at the 0.2 and 0.3 nmol/mol creatinine levels, and approximately two thirds at the 1.5 and 3.8 nmol/mol creatinine levels.

7.2.10.2.3 Costs of biomonitoring and health surveillance

The total costs of biomonitoring and health surveillance, per size of the company, based on three potential campaigns are presented in Table 7-24. Significant costs are incurred at all policy option levels. Sectors with higher costs for small and/or medium enterprises than large refer to those with a higher proportion of enterprises and exposed workers to monitor, for example F42.11 and G45.2.

Table 7-26 Estimated costs of biomonitoring and health surveillance costs in € over 40 years, based on three campaigns (€ millions)

Sector	Total costs € millions (based on three campaigns)			
	Small	Medium	Large	Total
0.2 nmol/mol creatinine				
C10.13 Meat and poultry smoke-houses	€ 0.13	€ 0.12	€ 0.25	€ 0.50
C10.2 Seafood smokehouses	€ 0.27	€ 0.40	€ 0.47	€ 1.14
C16.1 Wood preservation (creosote)	€ 2.18	€ 0.20		€ 2.37
C19.1 Coking plants	€ 1.80	€ 3.44	€ 10.45	€ 15.69
C19.2 Petroleum refineries	€ 0.14	€ 0.82	€ 47.12	€ 48.08
C20.13 Manufacture of carbon black		€ 1.00	€ 1.42	€ 2.42
C20.14 Coal tar distillation		€ 0.43	€ 1.35	€ 1.78
C23.2 Manufacture of refractory products	€ 0.14	€ 0.06		€ 0.20
C23.99a Manufacture of bituminous products	€ 3.64	€ 4.68	€ 5.44	€ 13.76
C23.99b Graphite and carbon electrode manufacture			€ 4.58	€ 4.58
C24.1 Steel and iron foundries, ferroalloys	€ 8.82	€ 9.23	€ 209.13	€ 227.18
C24.42 Manufacture of aluminium		€ 0.16	€ 2.01	€ 2.18
C24.45 Other non-ferrous metallurgy	€ 0.23	€ 0.49	€ 2.11	€ 2.82
C24.5 Casting of metals	€ 25.38	€ 48.23	€ 87.98	€ 161.60

Sector	Total costs € millions (based on three campaigns)			
	Small	Medium	Large	Total
D35.11 Coal fired power plants	€ 8.44	€ 3.32	€ 30.95	€ 42.71
E38.2 Waste incineration	€ 0.16	€ 0.20	€ 0.49	€ 0.85
E39 Soil remediation	€ 13.62	€ 7.16	€ 4.25	€ 25.03
F42.11 Road paving	€ 36.75	€ 30.42	€ 82.09	€ 149.25
F42.12 Welding of railroad tracks	€ 3.63	€ 3.17	€ 8.47	€ 15.27
G45.2 Motor vehicle maintenance and repairs	€ 277.21	€ 14.63	€ 7.61	€ 299.44
N81.22 Chimney sweeps	€ 58.13			€ 58.13
Total	€ 440.68	€ 128.15	€ 506.17	€ 1,075.00
0.3 nmol/mol creatinine				
C10.13 Meat and poultry smoke-houses	€ 0.05	€ 0.04	€ 0.09	€ 0.18
C10.2 Seafood smokehouses	€ 0.10	€ 0.14	€ 0.17	€ 0.41
C16.1 Wood preservation (creosote)	€ 0.17	€ 0.02		€ 0.18
C19.1 Coking plants	€ 1.21	€ 2.32	€ 7.04	€ 10.57
C19.2 Petroleum refineries	€ 0.03	€ 0.16	€ 9.10	€ 9.29
C20.13 Manufacture of carbon black		€ 0.13	€ 0.19	€ 0.33
C20.14 Coal tar distillation		€ 0.28	€ 0.89	€ 1.17
C23.2 Manufacture of refractory products	€ 0.05	€ 0.02		€ 0.07
C23.99a Manufacture of bituminous products	€ 0.81	€ 1.04	€ 1.21	€ 3.06
C23.99b Graphite and carbon electrode manufacture			€ 1.77	€ 1.77
C24.1 Steel and iron foundries, ferroalloys	€ 1.70	€ 1.78	€ 40.40	€ 43.89
C24.42 Manufacture of aluminium		€ 0.07	€ 0.85	€ 0.91
C24.45 Other non-ferrous metallurgy	€ 0.15	€ 0.33	€ 1.41	€ 1.89
C24.5 Casting of metals	€ 16.66	€ 31.65	€ 57.74	€ 106.04
D35.11 Coal fired power plants	€ 1.04	€ 0.41	€ 3.83	€ 5.29
E38.2 Waste incineration	€ 0.07	€ 0.08	€ 0.20	€ 0.35
E39 Soil remediation	€ 8.94	€ 4.70	€ 2.79	€ 16.43
F42.11 Road paving	€ 12.50	€ 10.35	€ 27.93	€ 50.78
F42.12 Welding of railroad tracks	€ 2.38	€ 2.08	€ 5.56	€ 10.02
G45.2 Motor vehicle maintenance and repairs	€ 63.20	€ 3.33	€ 1.73	€ 68.27
N81.22 Chimney sweeps	€ 7.19			€ 7.19
Total	€ 116.26	€ 58.94	€ 162.90	€ 338.10
1.5 nmol/mol creatinine				

Sector	Total costs € millions (based on three campaigns)			
	Small	Medium	Large	Total
C10.13 Meat and poultry smoke-houses	€ 0.02	€ 0.02	€ 0.04	€ 0.07
C10.2 Seafood smokehouses	€ 0.06	€ 0.09	€ 0.10	€ 0.24
C16.1 Wood preservation (creosote)	€ 0.13	€ 0.01		€ 0.14
C19.1 Coking plants	€ 0.28	€ 0.53	€ 1.60	€ 2.41
C19.2 Petroleum refineries	€ 0.01	€ 0.06	€ 3.65	€ 3.72
C20.13 Manufacture of carbon black		€ 0.03	€ 0.05	€ 0.08
C20.14 Coal tar distillation		€ 0.04	€ 0.14	€ 0.18
C23.2 Manufacture of refractory products	€ 0.01	€ 0.01		€ 0.02
C23.99a Manufacture of bituminous products	€ 0.19	€ 0.25	€ 0.29	€ 0.72
C23.99b Graphite and carbon electrode manufacture			€ 0.14	€ 0.14
C24.1 Steel and iron foundries, ferroalloys	€ 0.45	€ 0.47	€ 10.62	€ 11.54
C24.42 Manufacture of aluminium		€ 0.004	€ 0.05	€ 0.05
C24.45 Other non-ferrous metallurgy	€ 0.01	€ 0.02	€ 0.07	€ 0.09
C24.5 Casting of metals	€ 1.12	€ 2.13	€ 3.89	€ 7.14
D35.11 Coal fired power plants	€ 0.43	€ 0.17	€ 1.59	€ 2.19
E38.2 Waste incineration	€ 0.04	€ 0.05	€ 0.12	€ 0.20
E39 Soil remediation	€ 0.69	€ 0.36	€ 0.22	€ 1.27
F42.11 Road paving	€ 5.74	€ 4.75	€ 12.83	€ 23.33
F42.12 Welding of railroad tracks	€ 0.64	€ 0.56	€ 1.48	€ 2.68
G45.2 Motor vehicle maintenance and repairs	€ 43.36	€ 2.29	€ 1.19	€ 46.84
N81.22 Chimney sweeps	€ 2.65			€ 2.65
Total	€ 55.83	€ 11.83	€ 38.05	€ 105.71
3.8 nmol/mol creatinine				
C10.13 Meat and poultry smoke-houses	€ 0.02	€ 0.02	€ 0.04	€ 0.07
C10.2 Seafood smokehouses	€ 0.06	€ 0.09	€ 0.10	€ 0.24
C16.1 Wood preservation (creosote)	€ 0.13	€ 0.01		€ 0.14
C19.1 Coking plants	€ 0.11	€ 0.21	€ 0.62	€ 0.94
C19.2 Petroleum refineries	€ 0.01	€ 0.06	€ 3.65	€ 3.72
C20.13 Manufacture of carbon black		€ 0.03	€ 0.05	€ 0.08
C20.14 Coal tar distillation		€ 0.03	€ 0.09	€ 0.12
C23.2 Manufacture of refractory products	€ 0.01	€ 0.003		€ 0.01

Sector	Total costs € millions (based on three campaigns)			
	Small	Medium	Large	Total
C23.99a Manufacture of bituminous products	€ 0.19	€ 0.25	€ 0.29	€ 0.72
C23.99b Graphite and carbon electrode manufacture			€ 0.10	€ 0.10
C24.1 Steel and iron foundries, ferroalloys	€ 0.45	€ 0.47	€ 10.62	€ 11.54
C24.42 Manufacture of aluminium		€ 0.004	€ 0.05	€ 0.05
C24.45 Other non-ferrous metallurgy	€ 0.003	€ 0.01	€ 0.03	€ 0.04
C24.5 Casting of metals	€ 1.12	€ 2.13	€ 3.89	€ 7.14
D35.11 Coal fired power plants	€ 0.43	€ 0.17	€ 1.59	€ 2.19
E38.2 Waste incineration	€ 0.04	€ 0.05	€ 0.12	€ 0.20
E39 Soil remediation	€ 0.56	€ 0.30	€ 0.18	€ 1.03
F42.11 Road paving	€ 5.74	€ 4.75	€ 12.83	€ 23.33
F42.12 Welding of railroad tracks	€ 0.24	€ 0.21	€ 0.56	€ 1.00
G45.2 Motor vehicle maintenance and repairs	€ 43.36	€ 2.29	€ 1.19	€ 46.84
N81.22 Chimney sweeps	€ 2.65			€ 2.65
Total	€ 55.13	€ 11.07	€ 35.98	€ 102.17

Source: Study team.

Note: Blank cells refer to no companies with exposure.

7.2.10.3 Total costs of air monitoring, biomonitoring and health surveillance

Total estimated total costs of air monitoring, biomonitoring and health surveillance by sector and policy option discounted over 40 years is summarised in Table 7-27.

The basis for the calculations is described above and in the Methodological Note.

Overall air monitoring, biomonitoring and health surveillance makes up a significant additional cost to the PV40 adjustment costs at all policy option levels.

Table 7-27 Estimated costs of total costs of air monitoring, biomonitoring and health surveillance by sector and policy option discounted over 40 years (€ millions)

Sector	Total costs € millions (based on all campaigns)			
	Small	Medium	Large	Total
7 ng/m³ & 0.2 nmol/mol creatinine				
C10.13 Meat and poultry smokehouses	€ 0.36	€ 0.27	€ 0.30	€ 0.93
C10.2 Seafood smokehouses	€ 0.60	€ 0.84	€ 0.59	€ 2.03
C16.1 Wood preservation (creosote)	€ 2.22	€ 0.21		€ 2.43
C19.1 Coking plants	€ 1.86	€ 3.46	€ 10.54	€ 15.85
C19.2 Petroleum refineries	€ 0.18	€ 0.96	€ 47.81	€ 48.95
C20.13 Manufacture of carbon black		€ 1.24	€ 1.51	€ 2.75
C20.14 Coal tar distillation		€ 0.46	€ 1.42	€ 1.89

Sector	Total costs € millions (based on all campaigns)			
	Small	Medium	Large	Total
C23.2 Manufacture of refractory products	€ 0.15	€ 0.07		€ 0.22
C23.99a Manufacture of bituminous products	€ 4.84	€ 5.88	€ 5.87	€ 16.59
C23.99b Graphite and carbon electrode manufacture			€ 4.97	€ 4.97
C24.1 Steel and iron foundries, ferroalloys	€ 11.70	€ 10.59	€ 211.51	€ 233.79
C24.42 Manufacture of aluminium		€ 0.20	€ 2.12	€ 2.32
C24.45 Other non-ferrous metallurgy	€ 0.31	€ 0.58	€ 2.20	€ 3.08
C24.5 Casting of metals	€ 29.97	€ 54.77	€ 91.25	€ 175.99
D35.11 Coal fired power plants	€ 8.58	€ 3.87	€ 31.39	€ 43.84
E38.2 Waste incineration	€ 0.84	€ 0.72	€ 0.66	€ 2.23
E39 Soil remediation	€ 17.36	€ 8.22	€ 4.43	€ 30.02
F42.11 Road paving	€ 70.28	€ 45.95	€ 87.22	€ 203.45
F42.12 Welding of railroad tracks	€ 5.82	€ 4.17	€ 8.81	€ 18.80
G45.2 Motor vehicle maintenance and repairs	€ 703.61	€ 21.95	€ 8.49	€ 734.05
N81.22 Chimney sweeps	€ 80.25			€ 80.25
Total	€ 938.92	€ 164.43	€ 521.10	€ 1,624.45
70 ng/m³ & 0.3 nmol/mol creatinine				
C10.13 Meat and poultry smokehouses	€ 0.13	€ 0.12	€ 0.12	€ 0.36
C10.2 Seafood smokehouses	€ 0.27	€ 0.47	€ 0.26	€ 1.01
C16.1 Wood preservation (creosote)	€ 0.19	€ 0.02		€ 0.22
C19.1 Coking plants	€ 1.24	€ 2.33	€ 7.11	€ 10.69
C19.2 Petroleum refineries	€ 0.05	€ 0.27	€ 9.66	€ 9.98
C20.13 Manufacture of carbon black		€ 0.29	€ 0.25	€ 0.54
C20.14 Coal tar distillation		€ 0.31	€ 0.94	€ 1.24
C23.2 Manufacture of refractory products	€ 0.06	€ 0.03		€ 0.08
C23.99a Manufacture of bituminous products	€ 1.42	€ 1.88	€ 1.51	€ 4.81
C23.99b Graphite and carbon electrode manufacture			€ 2.02	€ 2.02
C24.1 Steel and iron foundries, ferroalloys	€ 3.09	€ 2.69	€ 42.00	€ 47.77
C24.42 Manufacture of aluminium		€ 0.09	€ 0.90	€ 0.99
C24.45 Other non-ferrous metallurgy	€ 0.17	€ 0.36	€ 1.44	€ 1.97
C24.5 Casting of metals	€ 18.93	€ 36.15	€ 59.99	€ 115.08
D35.11 Coal fired power plants	€ 1.10	€ 0.71	€ 4.08	€ 5.89
E38.2 Waste incineration	€ 0.38	€ 0.41	€ 0.31	€ 1.11
E39 Soil remediation	€ 10.88	€ 5.46	€ 2.92	€ 19.26

Sector	Total costs € millions (based on all campaigns)			
	Small	Medium	Large	Total
F42.11 Road paving	€ 30.19	€ 21.69	€ 31.69	€ 83.57
F42.12 Welding of railroad tracks	€ 3.51	€ 2.79	€ 5.80	€ 12.10
G45.2 Motor vehicle maintenance and re-pairs	€ 283.93	€ 8.58	€ 2.37	€ 294.88
N81.22 Chimney sweeps	€ 16.69			€ 16.69
Total	€ 372.23	€ 84.66	€ 173.37	€ 630.26
700 ng/m³ & 1.5 nmol/mol creatinine				
C10.13 Meat and poultry smokehouses	€ 0.07	€ 0.07	€ 0.06	€ 0.19
C10.2 Seafood smokehouses	€ 0.16	€ 0.30	€ 0.16	€ 0.62
C16.1 Wood preservation (creosote)	€ 0.15	€ 0.02		€ 0.17
C19.1 Coking plants	€ 0.30	€ 0.54	€ 1.65	€ 2.49
C19.2 Petroleum refineries	€ 0.02	€ 0.15	€ 4.07	€ 4.24
C20.13 Manufacture of carbon black		€ 0.14	€ 0.09	€ 0.23
C20.14 Coal tar distillation		€ 0.06	€ 0.17	€ 0.23
C23.2 Manufacture of refractory products	€ 0.01	€ 0.01		€ 0.02
C23.99a Manufacture of bituminous products	€ 0.55	€ 0.81	€ 0.49	€ 1.85
C23.99b Graphite and carbon electrode manufacture			€ 0.33	€ 0.33
C24.1 Steel and iron foundries, ferroalloys	€ 1.34	€ 1.12	€ 11.80	€ 14.26
C24.42 Manufacture of aluminium		€ 0.02	€ 0.09	€ 0.11
C24.45 Other non-ferrous metallurgy	€ 0.02	€ 0.04	€ 0.09	€ 0.15
C24.5 Casting of metals	€ 2.56	€ 5.33	€ 5.52	€ 13.41
D35.11 Coal fired power plants	€ 0.47	€ 0.37	€ 1.75	€ 2.58
E38.2 Waste incineration	€ 0.23	€ 0.28	€ 0.20	€ 0.71
E39 Soil remediation	€ 1.92	€ 0.91	€ 0.31	€ 3.14
F42.11 Road paving	€ 14.71	€ 11.23	€ 15.02	€ 40.96
F42.12 Welding of railroad tracks	€ 1.29	€ 1.03	€ 1.65	€ 3.96
G45.2 Motor vehicle maintenance and re-pairs	€ 182.19	€ 6.01	€ 1.65	€ 189.85
N81.22 Chimney sweeps	€ 7.52			€ 7.52
Total	€ 213.52	€ 28.43	€ 45.09	€ 287.04
2000 ng/m³ & 3.8 nmol/mol creatinine				
C10.13 Meat and poultry smokehouses	€ 0.06	€ 0.06	€ 0.05	€ 0.17
C10.2 Seafood smokehouses	€ 0.14	€ 0.25	€ 0.14	€ 0.52
C16.1 Wood preservation (creosote)	€ 0.14	€ 0.01		€ 0.15
C19.1 Coking plants	€ 0.12	€ 0.22	€ 0.66	€ 1.00
C19.2 Petroleum refineries	€ 0.02	€ 0.12	€ 3.93	€ 4.07

Sector	Total costs € millions (based on all campaigns)			
	Small	Medium	Large	Total
C20.13 Manufacture of carbon black		€ 0.10	€ 0.07	€ 0.17
C20.14 Coal tar distillation		€ 0.04	€ 0.11	€ 0.15
C23.2 Manufacture of refractory products	€ 0.01	€ 0.01		€ 0.02
C23.99a Manufacture of bituminous products	€ 0.46	€ 0.65	€ 0.42	€ 1.53
C23.99b Graphite and carbon electrode manufacture			€ 0.20	€ 0.20
C24.1 Steel and iron foundries, ferroalloys	€ 1.01	€ 0.87	€ 11.30	€ 13.18
C24.42 Manufacture of aluminium		€ 0.02	€ 0.08	€ 0.10
C24.45 Other non-ferrous metallurgy	€ 0.01	€ 0.03	€ 0.05	€ 0.09
C24.5 Casting of metals	€ 2.24	€ 4.60	€ 5.06	€ 11.90
D35.11 Coal fired power plants	€ 0.45	€ 0.28	€ 1.67	€ 2.40
E38.2 Waste incineration	€ 0.17	€ 0.20	€ 0.16	€ 0.53
E39 Soil remediation	€ 1.57	€ 0.74	€ 0.25	€ 2.56
F42.11 Road paving	€ 9.62	€ 7.54	€ 13.70	€ 30.86
F42.12 Welding of railroad tracks	€ 0.51	€ 0.40	€ 0.62	€ 1.53
G45.2 Motor vehicle maintenance and repairs	€ 140.76	€ 4.88	€ 1.49	€ 147.13
N81.22 Chimney sweeps	€ 5.88			€ 5.88
Total	€ 163.16	€ 21.01	€ 39.95	€ 224.12

Source: Study team.

Note: Blank cells refer to no companies with exposure.

7.2.11 Cost to companies of administrative burden relating to air monitoring, biomonitoring and health surveillance

7.2.11.1 Air monitoring administration burden

The administrative burden costs for air monitoring per company by size are shown below, together with the days assumed to be required by companies by size to set up the monitoring each year. As in the previous calculations of cost of the monitoring, the cost of a worker or manager is assumed to be €500/day.

Table 7-28 Costs per company of administrative burden to manage first and second campaigns for air monitoring, by size of enterprise, discounted as appropriate over 40 years

	Small	Medium	Large
Days to administrate monitoring one campaign	1	3	6
Campaign 1 costs	€500	€1,500	€3,000
Campaign 2 costs (discounted)	€458	€1,373	€2,745

Source: Study team.

The cost of the administrative burden of running air monitoring for companies is shown below, by sector and size of company for each policy option.

Table 7-29 Estimated costs of administrative burden of air monitoring by sector and policy option discounted as appropriate over 40 years (€ millions)

Sector	Total costs € millions (based on two campaigns)			
	Small	Medium	Large	Total
7 ng/m³				
C10.13 Meat and poultry smokehouses	€ 0.05	€ 0.04	€ 0.02	€ 0.10
C10.2 Seafood smokehouses	€ 0.07	€ 0.10	€ 0.04	€ 0.21
C16.1 Wood preservation (creosote)	€ 0.01	€ 0.003		€ 0.01
C19.1 Coking plants	€ 0.01	€ 0.01	€ 0.03	€ 0.05
C19.2 Petroleum refineries	€ 0.01	€ 0.03	€ 0.22	€ 0.26
C20.13 Manufacture of carbon black		€ 0.05	€ 0.03	€ 0.08
C20.14 Coal tar distillation		€ 0.01	€ 0.02	€ 0.03
C23.2 Manufacture of refractory products	€ 0.001	€ 0.003		€ 0.003
C23.99a Manufacture of bituminous products	€ 0.25	€ 0.27	€ 0.14	€ 0.66
C23.99b Graphite and carbon electrode manufacture			€ 0.13	€ 0.13
C24.1 Steel and iron foundries, ferroalloys	€ 0.60	€ 0.31	€ 0.77	€ 1.68
C24.42 Manufacture of aluminium		€ 0.01	€ 0.03	€ 0.04
C24.45 Other non-ferrous metallurgy	€ 0.02	€ 0.02	€ 0.03	€ 0.07
C24.5 Casting of metals	€ 0.96	€ 1.48	€ 1.06	€ 3.50
D35.11 Coal fired power plants	€ 0.03	€ 0.12	€ 0.14	€ 0.30
E38.2 Waste incineration	€ 0.14	€ 0.12	€ 0.06	€ 0.32
E39 Soil remediation	€ 0.79	€ 0.24	€ 0.06	€ 1.08
F42.11 Road paving	€ 7.03	€ 3.52	€ 1.66	€ 12.21
F42.12 Welding of railroad tracks	€ 0.46	€ 0.23	€ 0.11	€ 0.79
G45.2 Motor vehicle maintenance and repairs	€ 89.42	€ 1.66	€ 0.29	€ 91.36
N81.22 Chimney sweeps	€ 4.64			€ 4.64
Total	€ 104.49	€ 8.21	€ 4.83	€ 117.53
70 ng/m³				
C10.13 Meat and poultry smokehouses	€ 0.02	€ 0.02	€ 0.01	€ 0.04
C10.2 Seafood smokehouses	€ 0.04	€ 0.08	€ 0.03	€ 0.15
C16.1 Wood preservation (creosote)	€ 0.01	€ 0.002		€ 0.01
C19.1 Coking plants	€ 0.01	€ 0.004	€ 0.02	€ 0.03
C19.2 Petroleum refineries	€ 0.004	€ 0.03	€ 0.19	€ 0.22
C20.13 Manufacture of carbon black		€ 0.04	€ 0.02	€ 0.06
C20.14 Coal tar distillation		€ 0.01	€ 0.02	€ 0.02
C23.2 Manufacture of refractory products	€ 0.0004	€ 0.002		€ 0.002
C23.99a Manufacture of bituminous products	€ 0.13	€ 0.20	€ 0.10	€ 0.44

Sector	Total costs € millions (based on two campaigns)			
	Small	Medium	Large	Total
C23.99b Graphite and carbon electrode manufacture			€ 0.09	€ 0.09
C24.1 Steel and iron foundries, ferroalloys	€ 0.30	€ 0.22	€ 0.55	€ 1.07
C24.42 Manufacture of aluminium		€ 0.005	€ 0.02	€ 0.02
C24.45 Other non-ferrous metallurgy	€ 0.004	€ 0.01	€ 0.01	€ 0.02
C24.5 Casting of metals	€ 0.50	€ 1.08	€ 0.78	€ 2.35
D35.11 Coal fired power plants	€ 0.01	€ 0.07	€ 0.08	€ 0.17
E38.2 Waste incineration	€ 0.07	€ 0.08	€ 0.04	€ 0.19
E39 Soil remediation	€ 0.42	€ 0.18	€ 0.04	€ 0.65
F42.11 Road paving	€ 3.85	€ 2.71	€ 1.29	€ 7.86
F42.12 Welding of railroad tracks	€ 0.24	€ 0.17	€ 0.08	€ 0.50
G45.2 Motor vehicle maintenance and repairs	€ 48.10	€ 1.26	€ 0.22	€ 49.58
N81.22 Chimney sweeps	€ 2.07			€ 2.07
Total	€ 55.79	€ 6.15	€ 3.60	€ 65.54
700 ng/m³				
C10.13 Meat and poultry smokehouses	€ 0.01	€ 0.01	€ 0.01	€ 0.03
C10.2 Seafood smokehouses	€ 0.02	€ 0.05	€ 0.02	€ 0.10
C16.1 Wood preservation (creosote)	€ 0.003	€ 0.002		€ 0.005
C19.1 Coking plants	€ 0.004	€ 0.003	€ 0.02	€ 0.02
C19.2 Petroleum refineries	€ 0.003	€ 0.02	€ 0.14	€ 0.17
C20.13 Manufacture of carbon black		€ 0.03	€ 0.01	€ 0.04
C20.14 Coal tar distillation		€ 0.004	€ 0.01	€ 0.01
C23.2 Manufacture of refractory products	€ 0.0003	€ 0.001		€ 0.002
C23.99a Manufacture of bituminous products	€ 0.08	€ 0.13	€ 0.07	€ 0.28
C23.99b Graphite and carbon electrode manufacture			€ 0.07	€ 0.07
C24.1 Steel and iron foundries, ferroalloys	€ 0.19	€ 0.16	€ 0.40	€ 0.76
C24.42 Manufacture of aluminium		€ 0.003	€ 0.01	€ 0.02
C24.45 Other non-ferrous metallurgy	€ 0.003	€ 0.01	€ 0.01	€ 0.02
C24.5 Casting of metals	€ 0.31	€ 0.76	€ 0.56	€ 1.64
D35.11 Coal fired power plants	€ 0.01	€ 0.05	€ 0.06	€ 0.11
E38.2 Waste incineration	€ 0.04	€ 0.06	€ 0.03	€ 0.13
E39 Soil remediation	€ 0.27	€ 0.13	€ 0.03	€ 0.43
F42.11 Road paving	€ 1.95	€ 1.55	€ 0.75	€ 4.26
F42.12 Welding of railroad tracks	€ 0.14	€ 0.11	€ 0.06	€ 0.31
G45.2 Motor vehicle maintenance and repairs	€ 30.26	€ 0.89	€ 0.16	€ 31.31
N81.22 Chimney sweeps	€ 1.06			€ 1.06
Total	€ 34.37	€ 3.97	€ 2.42	€ 40.76

Sector	Total costs € millions (based on two campaigns)			
	Small	Medium	Large	Total
2000 ng/m³				
C10.13 Meat and poultry smokehouses	€ 0.01	€ 0.01	€ 0.004	€ 0.02
C10.2 Seafood smokehouses	€ 0.02	€ 0.03	€ 0.01	€ 0.06
C16.1 Wood preservation (creosote)	€ 0.001	€ 0.001		€ 0.002
C19.1 Coking plants	€ 0.003	€ 0.002	€ 0.01	€ 0.01
C19.2 Petroleum refineries	€ 0.002	€ 0.01	€ 0.08	€ 0.09
C20.13 Manufacture of carbon black		€ 0.01	€ 0.01	€ 0.02
C20.14 Coal tar distillation		€ 0.002	€ 0.01	€ 0.01
C23.2 Manufacture of refractory products	€ 0.0002	€ 0.001		€ 0.001
C23.99a Manufacture of bituminous products	€ 0.06	€ 0.07	€ 0.04	€ 0.17
C23.99b Graphite and carbon electrode manufacture			€ 0.03	€ 0.03
C24.1 Steel and iron foundries, ferroalloys	€ 0.12	€ 0.07	€ 0.20	€ 0.39
C24.42 Manufacture of aluminium		€ 0.002	€ 0.01	€ 0.01
C24.45 Other non-ferrous metallurgy	€ 0.002	€ 0.004	€ 0.01	€ 0.01
C24.5 Casting of metals	€ 0.24	€ 0.45	€ 0.34	€ 1.03
D35.11 Coal fired power plants	€ 0.004	€ 0.02	€ 0.02	€ 0.05
E38.2 Waste incineration	€ 0.03	€ 0.03	€ 0.01	€ 0.07
E39 Soil remediation	€ 0.22	€ 0.08	€ 0.02	€ 0.32
F42.11 Road paving	€ 0.85	€ 0.51	€ 0.25	€ 1.60
F42.12 Welding of railroad tracks	€ 0.06	€ 0.03	€ 0.02	€ 0.11
G45.2 Motor vehicle maintenance and repairs	€ 21.23	€ 0.47	€ 0.09	€ 21.79
N81.22 Chimney sweeps	€ 0.70			€ 0.70
Total	€ 23.54	€ 1.81	€ 1.15	€ 26.50

Source: Study team.

Note: Blank cells refer to no companies with exposure.

7.2.11.2 Biomonitoring and health surveillance administration burden

The administrative burden costs for biomonitoring and health surveillance per company by size are shown below, together with the days assumed to be required by companies by size to set up the biomonitoring and health surveillance each year. As in the previous calculations of cost of the biomonitoring and health surveillance, the cost of a worker or manager is assumed to be €500/day.

Table 7-30 Costs per company of administrative burden to manage first, second and third campaigns for biomonitoring and health surveillance, by size of enterprise, discounted as appropriate over 40 years

	Small	Medium	Large
Days to administrate monitoring one campaign	1	3	6
Campaign 1 (year 1)	€500	€1,500	€3,000

	Small	Medium	Large
Campaign 2, (year 2-6 discounted*)	€2,290	€6,870	€13,739
Campaign 3, (year 7-40 discounted*)	€9,114	€27,343	€54,686

Source: Study team.

Note: *Campaign 2 and 3 have been discounted annually by 3%.

The cost of the administrative burden of running biomonitoring and health surveillance for companies is shown below, by sector and size of company for each policy option.

Table 7-31 Estimated costs of administrative burden of biomonitoring and health surveillance by sector and policy option discounted as appropriate over 40 years (€ millions)

Sector	Total costs € millions (based on three campaigns)			
	Small	Medium	Large	Total
0.2 nmol/mol creatinine				
C10.13 Meat and poultry smokehouses	€ 0.22	€ 0.04	€ 0.02	€ 0.29
C10.2 Seafood smokehouses	€ 0.33	€ 0.12	€ 0.05	€ 0.50
C16.1 Wood preservation (creosote)	€ 0.14	€ 0.01		€ 0.16
C19.1 Coking plants	€ 0.48	€ 0.06	€ 0.30	€ 0.85
C19.2 Petroleum refineries	€ 0.11	€ 0.13	€ 0.87	€ 1.11
C20.13 Manufacture of carbon black		€ 0.22	€ 0.11	€ 0.33
C20.14 Coal tar distillation		€ 0.03	€ 0.09	€ 0.12
C23.2 Manufacture of refractory products	€ 0.01	€ 0.01		€ 0.03
C23.99a Manufacture of bituminous products	€ 3.91	€ 1.10	€ 0.53	€ 5.54
C23.99b Graphite and carbon electrode manufacture			€ 0.97	€ 0.97
C24.1 Steel and iron foundries, ferroalloys	€ 9.34	€ 1.24	€ 2.98	€ 13.56
C24.42 Manufacture of aluminium		€ 0.05	€ 0.20	€ 0.25
C24.45 Other non-ferrous metallurgy	€ 0.49	€ 0.18	€ 0.22	€ 0.89
C24.5 Casting of metals	€ 14.87	€ 6.01	€ 4.09	€ 24.96
D35.11 Coal fired power plants	€ 0.47	€ 0.50	€ 0.56	€ 1.52
E38.2 Waste incineration	€ 0.45	€ 0.10	€ 0.05	€ 0.59
E39 Soil remediation	€ 12.14	€ 0.98	€ 0.22	€ 13.34
F42.11 Road paving	€ 33.50	€ 4.40	€ 1.98	€ 39.87
F42.12 Welding of railroad tracks	€ 7.08	€ 0.92	€ 0.42	€ 8.43
G45.2 Motor vehicle maintenance and repairs	€ 485.70	€ 2.36	€ 0.39	€ 488.46
N81.22 Chimney sweeps	€ 71.73			€ 71.73
Total	€ 640.99	€ 18.47	€ 14.03	€ 673.49
0.3 nmol/mol creatinine				
C10.13 Meat and poultry smokehouses	€ 0.22	€ 0.04	€ 0.02	€ 0.29
C10.2 Seafood smokehouses	€ 0.33	€ 0.12	€ 0.05	€ 0.50

Sector	Total costs € millions (based on three campaigns)			
	Small	Medium	Large	Total
C16.1 Wood preservation (creosote)	€ 0.14	€ 0.01		€ 0.16
C19.1 Coking plants	€ 0.48	€ 0.06	€ 0.30	€ 0.85
C19.2 Petroleum refineries	€ 0.11	€ 0.13	€ 0.87	€ 1.11
C20.13 Manufacture of carbon black		€ 0.22	€ 0.11	€ 0.33
C20.14 Coal tar distillation		€ 0.03	€ 0.09	€ 0.12
C23.2 Manufacture of refractory products	€ 0.01	€ 0.01		€ 0.03
C23.99a Manufacture of bituminous products	€ 3.91	€ 1.10	€ 0.53	€ 5.54
C23.99b Graphite and carbon electrode manufacture			€ 0.97	€ 0.97
C24.1 Steel and iron foundries, ferroalloys	€ 9.34	€ 1.24	€ 2.98	€ 13.56
C24.42 Manufacture of aluminium		€ 0.05	€ 0.20	€ 0.25
C24.45 Other non-ferrous metallurgy	€ 0.49	€ 0.18	€ 0.22	€ 0.89
C24.5 Casting of metals	€ 14.87	€ 6.01	€ 4.09	€ 24.96
D35.11 Coal fired power plants	€ 0.47	€ 0.50	€ 0.56	€ 1.52
E38.2 Waste incineration	€ 0.45	€ 0.10	€ 0.05	€ 0.59
E39 Soil remediation	€ 12.14	€ 0.98	€ 0.22	€ 13.34
F42.11 Road paving	€ 33.50	€ 4.40	€ 1.98	€ 39.87
F42.12 Welding of railroad tracks	€ 7.08	€ 0.92	€ 0.42	€ 8.43
G45.2 Motor vehicle maintenance and repairs	€ 485.70	€ 2.36	€ 0.39	€ 488.46
N81.22 Chimney sweeps	€ 71.73			€ 71.73
Total	€ 640.99	€ 18.47	€ 14.03	€ 673.49
1.5 nmol/mol creatinine				
C10.13 Meat and poultry smokehouses	€ 0.10	€ 0.02	€ 0.01	€ 0.13
C10.2 Seafood smokehouses	€ 0.27	€ 0.10	€ 0.04	€ 0.41
C16.1 Wood preservation (creosote)	€ 0.12	€ 0.01		€ 0.13
C19.1 Coking plants	€ 0.47	€ 0.06	€ 0.29	€ 0.82
C19.2 Petroleum refineries	€ 0.11	€ 0.13	€ 0.87	€ 1.11
C20.13 Manufacture of carbon black		€ 0.17	€ 0.08	€ 0.25
C20.14 Coal tar distillation		€ 0.03	€ 0.08	€ 0.10
C23.2 Manufacture of refractory products	€ 0.01	€ 0.01		€ 0.02
C23.99a Manufacture of bituminous products	€ 3.04	€ 0.85	€ 0.41	€ 4.31
C23.99b Graphite and carbon electrode manufacture			€ 0.53	€ 0.53
C24.1 Steel and iron foundries, ferroalloys	€ 7.67	€ 1.02	€ 2.44	€ 11.13
C24.42 Manufacture of aluminium		€ 0.02	€ 0.09	€ 0.11
C24.45 Other non-ferrous metallurgy	€ 0.18	€ 0.06	€ 0.08	€ 0.32
C24.5 Casting of metals	€ 11.95	€ 4.83	€ 3.28	€ 20.06
D35.11 Coal fired power plants	€ 0.31	€ 0.33	€ 0.37	€ 1.01
E38.2 Waste incineration	€ 0.31	€ 0.07	€ 0.03	€ 0.41

Sector	Total costs € millions (based on three campaigns)			
	Small	Medium	Large	Total
E39 Soil remediation	€ 7.45	€ 0.60	€ 0.14	€ 8.19
F42.11 Road paving	€ 29.79	€ 3.91	€ 1.76	€ 35.45
F42.12 Welding of railroad tracks	€ 6.10	€ 0.79	€ 0.36	€ 7.26
G45.2 Motor vehicle maintenance and repairs	€ 379.12	€ 1.85	€ 0.30	€ 381.27
N81.22 Chimney sweeps	€ 40.37			€ 40.37
Total	€ 487.37	€ 14.87	€ 11.17	€ 513.41
3.8 nmol/mol creatinine				
C10.13 Meat and poultry smokehouses	€ 0.10	€ 0.02	€ 0.01	€ 0.13
C10.2 Seafood smokehouses	€ 0.27	€ 0.10	€ 0.04	€ 0.41
C16.1 Wood preservation (creosote)	€ 0.12	€ 0.01		€ 0.13
C19.1 Coking plants	€ 0.47	€ 0.06	€ 0.29	€ 0.82
C19.2 Petroleum refineries	€ 0.11	€ 0.13	€ 0.87	€ 1.11
C20.13 Manufacture of carbon black		€ 0.17	€ 0.08	€ 0.25
C20.14 Coal tar distillation		€ 0.03	€ 0.08	€ 0.10
C23.2 Manufacture of refractory products	€ 0.01	€ 0.01		€ 0.02
C23.99a Manufacture of bituminous products	€ 3.04	€ 0.85	€ 0.41	€ 4.31
C23.99b Graphite and carbon electrode manufacture			€ 0.53	€ 0.53
C24.1 Steel and iron foundries, ferroalloys		€ 1.02	€ 2.44	€ 11.13
C24.42 Manufacture of aluminium		€ 0.02	€ 0.09	€ 0.11
C24.45 Other non-ferrous metallurgy	€ 0.18	€ 0.06	€ 0.08	€ 0.32
C24.5 Casting of metals	€ 11.95	€ 4.83	€ 3.28	€ 20.06
D35.11 Coal fired power plants	€ 0.31	€ 0.33	€ 0.37	€ 1.01
E38.2 Waste incineration	€ 0.31	€ 0.07	€ 0.03	€ 0.41
E39 Soil remediation	€ 7.45	€ 0.60	€ 0.14	€ 8.19
F42.11 Road paving	€ 29.79	€ 3.91	€ 1.76	€ 35.45
F42.12 Welding of railroad tracks	€ 6.10	€ 0.79	€ 0.36	€ 7.26
G45.2 Motor vehicle maintenance and repairs	€ 379.12	€ 1.85	€ 0.30	€ 381.27
N81.22 Chimney sweeps	€ 40.37			€ 40.37
Total	€ 487.37	€ 14.87	€ 11.17	€ 513.41

Source: Study team.

Note: Blank cells refer to no companies with exposure.

7.2.11.3 Total costs for administrative burden of air monitoring, biomonitoring and health surveillance.

Table 7-32 displays the overall administrative burden of air monitoring, biomonitoring and health surveillance by sector. As illustrated, costs are incurred at all policy option levels.

Table 7-32 Estimated costs of administrative burden of air monitoring, biomonitoring and health surveillance by sector and policy option discounted as appropriate over 40 years (€ millions)

Sector	Total costs € millions (based on all campaigns)			
	Small	Medium	Large	Total
7 ng/m³ & 0.2 nmol/mol creatinine				
C10.13 Meat and poultry smokehouses	€ 0.27	€ 0.08	€ 0.04	€ 0.39
C10.2 Seafood smokehouses	€ 0.40	€ 0.22	€ 0.09	€ 0.71
C16.1 Wood preservation (creosote)	€ 0.15	€ 0.01		€ 0.17
C19.1 Coking plants	€ 0.50	€ 0.07	€ 0.33	€ 0.89
C19.2 Petroleum refineries	€ 0.12	€ 0.17	€ 1.09	€ 1.37
C20.13 Manufacture of carbon black		€ 0.28	€ 0.14	€ 0.42
C20.14 Coal tar distillation		€ 0.04	€ 0.11	€ 0.15
C23.2 Manufacture of refractory products	€ 0.02	€ 0.01		€ 0.03
C23.99a Manufacture of bituminous products	€ 4.17	€ 1.37	€ 0.67	€ 6.21
C23.99b Graphite and carbon electrode manufacture			€ 1.10	€ 1.10
C24.1 Steel and iron foundries, ferroalloys	€ 9.94	€ 1.55	€ 3.75	€ 15.24
C24.42 Manufacture of aluminium		€ 0.06	€ 0.23	€ 0.29
C24.45 Other non-ferrous metallurgy	€ 0.51	€ 0.20	€ 0.25	€ 0.96
C24.5 Casting of metals	€ 15.83	€ 7.49	€ 5.14	€ 28.46
D35.11 Coal fired power plants	€ 0.50	€ 0.62	€ 0.70	€ 1.82
E38.2 Waste incineration	€ 0.59	€ 0.22	€ 0.10	€ 0.91
E39 Soil remediation	€ 12.93	€ 1.22	€ 0.28	€ 14.42
F42.11 Road paving	€ 40.53	€ 7.91	€ 3.64	€ 52.08
F42.12 Welding of railroad tracks	€ 7.54	€ 1.15	€ 0.53	€ 9.22
G45.2 Motor vehicle maintenance and repairs	€ 575.12	€ 4.02	€ 0.68	€ 579.82
N81.22 Chimney sweeps	€ 76.37			€ 76.37
Total	€ 745.48	€ 26.68	€ 18.86	€ 791.02
70 ng/m³ & 0.3 nmol/mol creatinine				
C10.13 Meat and poultry smokehouses	€ 0.24	€ 0.06	€ 0.03	€ 0.33
C10.2 Seafood smokehouses	€ 0.37	€ 0.20	€ 0.08	€ 0.65
C16.1 Wood preservation (creosote)	€ 0.15	€ 0.01		€ 0.16
C19.1 Coking plants	€ 0.49	€ 0.06	€ 0.33	€ 0.88
C19.2 Petroleum refineries	€ 0.12	€ 0.16	€ 1.06	€ 1.33
C20.13 Manufacture of carbon black		€ 0.26	€ 0.13	€ 0.39
C20.14 Coal tar distillation		€ 0.04	€ 0.11	€ 0.14
C23.2 Manufacture of refractory products	€ 0.02	€ 0.01		€ 0.03
C23.99a Manufacture of bituminous products	€ 4.05	€ 1.30	€ 0.64	€ 5.98
C23.99b Graphite and carbon electrode manufacture			€ 1.06	€ 1.06
C24.1 Steel and iron foundries, ferroalloys	€ 9.64	€ 1.46	€ 3.52	€ 14.62
C24.42 Manufacture of aluminium		€ 0.05	€ 0.22	€ 0.27
C24.45 Other non-ferrous metallurgy	€ 0.50	€ 0.18	€ 0.23	€ 0.91

Sector	Total costs € millions (based on all campaigns)			
	Small	Medium	Large	Total
C24.5 Casting of metals	€ 15.36	€ 7.08	€ 4.86	€ 27.31
D35.11 Coal fired power plants	€ 0.48	€ 0.57	€ 0.64	€ 1.69
E38.2 Waste incineration	€ 0.52	€ 0.18	€ 0.08	€ 0.78
E39 Soil remediation	€ 12.56	€ 1.16	€ 0.27	€ 13.99
F42.11 Road paving	€ 37.35	€ 7.11	€ 3.27	€ 47.73
F42.12 Welding of railroad tracks	€ 7.33	€ 1.09	€ 0.50	€ 8.93
G45.2 Motor vehicle maintenance and repairs	€ 533.81	€ 3.62	€ 0.61	€ 538.04
N81.22 Chimney sweeps	€ 73.80			€ 73.80
Total	€ 696.78	€ 24.62	€ 17.63	€ 739.03
700 ng/m³ & 1.5 nmol/mol creatinine				
C10.13 Meat and poultry smokehouses	€ 0.11	€ 0.03	€ 0.02	€ 0.16
C10.2 Seafood smokehouses	€ 0.29	€ 0.15	€ 0.06	€ 0.51
C16.1 Wood preservation (creosote)	€ 0.13	€ 0.01		€ 0.14
C19.1 Coking plants	€ 0.47	€ 0.06	€ 0.31	€ 0.84
C19.2 Petroleum refineries	€ 0.11	€ 0.15	€ 1.01	€ 1.28
C20.13 Manufacture of carbon black		€ 0.19	€ 0.10	€ 0.29
C20.14 Coal tar distillation		€ 0.03	€ 0.09	€ 0.12
C23.2 Manufacture of refractory products	€ 0.01	€ 0.01		€ 0.02
C23.99a Manufacture of bituminous products	€ 3.12	€ 0.99	€ 0.48	€ 4.59
C23.99b Graphite and carbon electrode manufacture			€ 0.60	€ 0.60
C24.1 Steel and iron foundries, ferroalloys	€ 7.86	€ 1.18	€ 2.85	€ 11.88
C24.42 Manufacture of aluminium		€ 0.03	€ 0.10	€ 0.13
C24.45 Other non-ferrous metallurgy	€ 0.18	€ 0.07	€ 0.09	€ 0.34
C24.5 Casting of metals	€ 12.26	€ 5.59	€ 3.85	€ 21.70
D35.11 Coal fired power plants	€ 0.32	€ 0.38	€ 0.42	€ 1.12
E38.2 Waste incineration	€ 0.36	€ 0.12	€ 0.06	€ 0.54
E39 Soil remediation	€ 7.72	€ 0.73	€ 0.17	€ 8.62
F42.11 Road paving	€ 31.74	€ 5.46	€ 2.51	€ 39.71
F42.12 Welding of railroad tracks	€ 6.24	€ 0.91	€ 0.42	€ 7.57
G45.2 Motor vehicle maintenance and repairs	€ 409.38	€ 2.74	€ 0.46	€ 412.57
N81.22 Chimney sweeps	€ 41.43			€ 41.43
Total	€ 521.74	€ 18.84	€ 13.59	€ 554.17
2000 ng/m³ & 3.8 nmol/mol creatinine				
C10.13 Meat and poultry smokehouses	€ 0.11	€ 0.03	€ 0.01	€ 0.15
C10.2 Seafood smokehouses	€ 0.29	€ 0.13	€ 0.05	€ 0.47
C16.1 Wood preservation (creosote)	€ 0.12	€ 0.01		€ 0.13

Sector	Total costs € millions (based on all campaigns)			
	Small	Medium	Large	Total
C19.1 Coking plants	€ 0.47	€ 0.06	€ 0.30	€ 0.83
C19.2 Petroleum refineries	€ 0.11	€ 0.14	€ 0.95	€ 1.20
C20.13 Manufacture of carbon black		€ 0.18	€ 0.09	€ 0.27
C20.14 Coal tar distillation		€ 0.03	€ 0.08	€ 0.11
C23.2 Manufacture of refractory products	€ 0.01	€ 0.01		€ 0.02
C23.99a Manufacture of bituminous products	€ 3.10	€ 0.93	€ 0.45	€ 4.48
C23.99b Graphite and carbon electrode manufacture			€ 0.56	€ 0.56
C24.1 Steel and iron foundries, ferroalloys	€ 7.79	€ 1.09	€ 2.64	€ 11.52
C24.42 Manufacture of aluminium		€ 0.02	€ 0.10	€ 0.12
C24.45 Other non-ferrous metallurgy	€ 0.18	€ 0.07	€ 0.08	€ 0.33
C24.5 Casting of metals	€ 12.20	€ 5.28	€ 3.62	€ 21.10
D35.11 Coal fired power plants	€ 0.31	€ 0.35	€ 0.39	€ 1.06
E38.2 Waste incineration	€ 0.34	€ 0.10	€ 0.05	€ 0.48
E39 Soil remediation	€ 7.67	€ 0.68	€ 0.16	€ 8.51
F42.11 Road paving	€ 30.63	€ 4.42	€ 2.01	€ 37.06
F42.12 Welding of railroad tracks	€ 6.16	€ 0.83	€ 0.38	€ 7.37
G45.2 Motor vehicle maintenance and repairs	€ 400.35	€ 2.32	€ 0.39	€ 403.05
N81.22 Chimney sweeps	€ 41.08			€ 41.08
Total	€ 510.92	€ 16.68	€ 12.32	€ 539.91

Source: Study team.

Note: Blank cells refer to no companies with exposure.

7.2.12 Aggregated costs for companies by sector (OEL only)

The aggregated costs of implementing OEL (only) include adjustment, monitoring and administrative burden for companies by sector are shown in Table 7-33; by sector and size of company in Table 7-34; by size of company in Table 7-35; and as costs per company by size of company in Table 7-37. The total aggregated costs of adjustment, air monitoring and administrative burden for businesses are shown in Table 7-45. Table 7-36 presents annualised compliance, air monitoring and administrative costs by company size and Table 7-38 shows annualised compliance, air monitoring and administrative burden costs per company, by company size for all OEL policy options.

Table 7-33 illustrates two negative figures, C16.1 wood preservation at 7 ng/m³ and C19.1 coking plants at 700 ng/m³. Negative costs are present due to companies selecting alternative RMMs to comply with the policy option with lower costs over 40 years than already installed. The same reasons are provided for the equivalent negative values in Table 7-34.

Table 7-33 Total PV compliance costs (RMMs, monitoring and administrative burden) discounted over 40 years by policy options and sector (€ millions)

Sector	Total costs OEL policy options, € millions			
	7 ng/m ³	70 ng/m ³	700 ng/m ³	2000 ng/m ³
C10.13 Meat and poultry smokehouses	€ 9.45	€ 0.97	€ 0.15	€ 0.11

Sector	Total costs OEL policy options, € millions			
	7 ng/m ³	70 ng/m ³	700 ng/m ³	2000 ng/m ³
C10.2 Seafood smokehouses	€ 29.04	€ 2.92	€ 0.48	€ 0.34
C16.1 Wood preservation (creosote)	-€ 8.85	€ 0.04	€ 0.03	€ 0.01
C19.1 Coking plants	€ 721.38	€ 335.19	-€ 0.29	€ 0.07
C19.2 Petroleum refineries	€ 15,298.54	€ 770.65	€ 0.68	€ 0.44
C20.13 Manufacture of carbon black	€ 830.02	€ 0.91	€ 0.18	€ 0.10
C20.14 Coal tar distillation	€ 1,083.88	€ 593.53	€ 0.43	€ 0.04
C23.2 Manufacture of refractory products	€ 5.98	€ 0.68	€ 0.04	€ 0.01
C23.99a Manufacture of bituminous products	€ 90.61	€ 6.81	€ 1.41	€ 0.98
C23.99b Graphite and carbon electrode manufacture	€ 255.06	€ 100.48	€ 0.26	€ 0.13
C24.1 Steel and iron foundries, ferroalloys	€ 3,251.34	€ 320.53	€ 3.48	€ 2.03
C24.42 Manufacture of aluminium	€ 229.01	€ 27.83	€ 0.08	€ 0.06
C24.45 Other non-ferrous metallurgy	€ 191.76	€ 43.92	€ 0.50	€ 0.06
C24.5 Casting of metals	€ 1,627.86	€ 54.19	€ 7.90	€ 5.79
D35.11 Coal fired power plants	€ 3,127.33	€ 3.33	€ 0.50	€ 0.26
E38.2 Waste incineration	€ 83.61	€ 0.95	€ 0.64	€ 0.40
E39 Soil remediation	€ 1,345.16	€ 115.73	€ 2.31	€ 1.84
F42.11 Road paving	€ 1,840.89	€ 202.12	€ 21.89	€ 9.13
F42.12 Welding of railroad tracks	€ 5,709.73	€ 155.33	€ 4.58	€ 0.63
G45.2 Motor vehicle maintenance and repairs	€ 1,088.56	€ 276.20	€ 174.32	€ 122.08
N81.22 Chimney sweeps	€ 849.52	€ 11.56	€ 5.93	€ 3.93
Total	€ 37,659.87	€ 3,023.87	€ 225.50	€ 148.45

Source: Study team.

Table 7-34 Total PV compliance costs (RMMs, monitoring and administrative burden) discounted over 40 years by policy options, sector and company size (€ millions)

Sector	Aggregated costs of PV compliance, monitoring, and administrative burden over 40 years, size of enterprise, by sector and OEL policy option, € millions			
	Small	Medium	Large	Total
7 ng/m³				
C10.13 Meat and poultry smokehouses	€ 2.58	€ 3.82	€ 3.06	€ 9.45
C10.2 Seafood smokehouses	€ 7.68	€ 14.48	€ 6.87	€ 29.04
C16.1 Wood preservation (creosote)	-€ 8.64	-€ 0.21		-€ 8.85
C19.1 Coking plants	€ 416.12	€ 222.34	€ 82.93	€ 721.38
C19.2 Petroleum refineries	€ 78.63	€ 805.00	€ 14,414.91	€ 15,298.54

Sector	Aggregated costs of PV compliance, monitoring, and administrative burden over 40 years, size of enterprise, by sector and OEL policy option, € millions			
	Small	Medium	Large	Total
C20.13 Manufacture of carbon black		€ 633.81	€ 196.21	€ 830.02
C20.14 Coal tar distillation		€ 519.42	€ 564.47	€ 1,083.88
C23.2 Manufacture of refractory products	€ 1.00	€ 4.98		€ 5.98
C23.99a Manufacture of bituminous products	€ 26.49	€ 32.68	€ 31.43	€ 90.61
C23.99b Graphite and carbon electrode manufacture			€ 255.06	€ 255.06
C24.1 Steel and iron foundries, ferroalloys	€ 337.25	€ 958.99	€ 1,955.11	€ 3,251.34
C24.42 Manufacture of aluminium		€ 107.55	€ 121.46	€ 229.01
C24.45 Other non-ferrous metallurgy	€ 29.42	€ 111.24	€ 51.10	€ 191.76
C24.5 Casting of metals	€ 476.18	€ 674.04	€ 477.64	€ 1,627.86
D35.11 Coal fired power plants	€ 22.09	€ 1,816.63	€ 1,288.60	€ 3,127.33
E38.2 Waste incineration	€ 38.44	€ 38.55	€ 6.61	€ 83.61
E39 Soil remediation	€ 893.23	€ 432.29	€ 19.63	€ 1,345.16
F42.11 Road paving	€ 409.44	€ 360.76	€ 1,070.68	€ 1,840.89
F42.12 Welding of railroad tracks	€ 2,380.68	€ 2,436.81	€ 892.24	€ 5,709.73
G45.2 Motor vehicle maintenance and repairs	€ 1,038.29	€ 37.19	€ 13.09	€ 1,088.56
N81.22 Chimney sweeps	€ 849.52			€ 849.52
Total	€ 6,998.40	€ 9,210.37	€ 21,451.09	€ 37,659.87
70 ng/m³				
C10.13 Meat and poultry smokehouses	€ 0.19	€ 0.36	€ 0.43	€ 0.97
C10.2 Seafood smokehouses	€ 0.62	€ 1.30	€ 1.00	€ 2.92
C16.1 Wood preservation (creosote)	€ 0.03	€ 0.01		€ 0.04
C19.1 Coking plants	€ 188.32	€ 102.36	€ 44.51	€ 335.19
C19.2 Petroleum refineries	€ 4.01	€ 40.60	€ 726.04	€ 770.65
C20.13 Manufacture of carbon black		€ 0.49	€ 0.43	€ 0.91
C20.14 Coal tar distillation		€ 258.12	€ 335.41	€ 593.53
C23.2 Manufacture of refractory products	€ 0.09	€ 0.59		€ 0.68
C23.99a Manufacture of bituminous products	€ 2.04	€ 2.64	€ 2.14	€ 6.81
C23.99b Graphite and carbon electrode manufacture			€ 100.48	€ 100.48
C24.1 Steel and iron foundries, ferroalloys	€ 32.44	€ 95.64	€ 192.45	€ 320.53
C24.42 Manufacture of aluminium		€ 0.53	€ 27.30	€ 27.83
C24.45 Other non-ferrous metallurgy	€ 5.91	€ 23.35	€ 14.66	€ 43.92
C24.5 Casting of metals	€ 16.06	€ 26.80	€ 11.33	€ 54.19
D35.11 Coal fired power plants	€ 0.53	€ 0.69	€ 2.11	€ 3.33
E38.2 Waste incineration	€ 0.38	€ 0.41	€ 0.15	€ 0.95
E39 Soil remediation	€ 78.19	€ 38.23	-€ 0.69	€ 115.73

Sector	Aggregated costs of PV compliance, monitoring, and administrative burden over 40 years, size of enterprise, by sector and OEL policy option, € millions			
	Small	Medium	Large	Total
F42.11 Road paving	€ 72.20	€ 49.28	€ 80.64	€ 202.12
F42.12 Welding of railroad tracks	€ 56.16	€ 50.46	€ 48.70	€ 155.33
G45.2 Motor vehicle maintenance and repairs	€ 268.83	€ 6.50	€ 0.86	€ 276.20
N81.22 Chimney sweeps	€ 11.56			€ 11.56
Total	€ 737.57	€ 698.35	€ 1,587.94	€ 3,023.87
700 ng/m³				
C10.13 Meat and poultry smokehouses	€ 0.06	€ 0.07	€ 0.03	€ 0.15
C10.2 Seafood smokehouses	€ 0.13	€ 0.27	€ 0.08	€ 0.48
C16.1 Wood preservation (creosote)	€ 0.02	€ 0.01		€ 0.03
C19.1 Coking plants	€ 0.01	-€ 0.13	-€ 0.17	-€ 0.29
C19.2 Petroleum refineries	€ 0.02	€ 0.11	€ 0.56	€ 0.68
C20.13 Manufacture of carbon black		€ 0.13	€ 0.05	€ 0.18
C20.14 Coal tar distillation		€ 0.08	€ 0.35	€ 0.43
C23.2 Manufacture of refractory products	€ 0.001	€ 0.04		€ 0.04
C23.99a Manufacture of bituminous products	€ 0.44	€ 0.70	€ 0.28	€ 1.41
C23.99b Graphite and carbon electrode manufacture			€ 0.26	€ 0.26
C24.1 Steel and iron foundries, ferroalloys	€ 1.09	€ 0.81	€ 1.58	€ 3.48
C24.42 Manufacture of aluminium		€ 0.02	€ 0.06	€ 0.08
C24.45 Other non-ferrous metallurgy	€ 0.04	€ 0.12	€ 0.33	€ 0.50
C24.5 Casting of metals	€ 1.75	€ 3.96	€ 2.19	€ 7.90
D35.11 Coal fired power plants	€ 0.04	€ 0.24	€ 0.22	€ 0.50
E38.2 Waste incineration	€ 0.24	€ 0.29	€ 0.11	€ 0.64
E39 Soil remediation	€ 1.50	€ 0.68	€ 0.13	€ 2.31
F42.11 Road paving	€ 10.92	€ 8.03	€ 2.94	€ 21.89
F42.12 Welding of railroad tracks	€ 1.57	€ 1.21	€ 1.80	€ 4.58
G45.2 Motor vehicle maintenance and repairs	€ 169.09	€ 4.61	€ 0.62	€ 174.32
N81.22 Chimney sweeps	€ 5.93			€ 5.93
Total	€ 192.84	€ 21.23	€ 11.42	€ 225.50
2000 ng/m³				
C10.13 Meat and poultry smokehouses	€ 0.05	€ 0.05	€ 0.02	€ 0.11
C10.2 Seafood smokehouses	€ 0.10	€ 0.19	€ 0.06	€ 0.34
C16.1 Wood preservation (creosote)	€ 0.01	-		€ 0.01
C19.1 Coking plants	€ 0.02	€ 0.01	€ 0.04	€ 0.07
C19.2 Petroleum refineries	€ 0.01	€ 0.07	€ 0.36	€ 0.44

Sector	Aggregated costs of PV compliance, monitoring, and administrative burden over 40 years, size of enterprise, by sector and OEL policy option, € millions			
	Small	Medium	Large	Total
C20.13 Manufacture of carbon black		€ 0.07	€ 0.03	€ 0.10
C20.14 Coal tar distillation		€ 0.01	€ 0.03	€ 0.04
C23.2 Manufacture of refractory products	-	-		€ 0.01
C23.99a Manufacture of bituminous products	€ 0.32	€ 0.48	€ 0.18	€ 0.98
C23.99b Graphite and carbon electrode manufacture			€ 0.13	€ 0.13
C24.1 Steel and iron foundries, ferroalloys	€ 0.68	€ 0.48	€ 0.87	€ 2.03
C24.42 Manufacture of aluminium		€ 0.01	€ 0.04	€ 0.06
C24.45 Other non-ferrous metallurgy	€ 0.01	€ 0.02	€ 0.02	€ 0.06
C24.5 Casting of metals	€ 1.36	€ 2.92	€ 1.51	€ 5.79
D35.11 Coal fired power plants	€ 0.02	€ 0.13	€ 0.11	€ 0.26
E38.2 Waste incineration	€ 0.16	€ 0.18	€ 0.06	€ 0.40
E39 Soil remediation	€ 1.23	€ 0.52	€ 0.09	€ 1.84
F42.11 Road paving	€ 4.72	€ 3.29	€ 1.12	€ 9.13
F42.12 Welding of railroad tracks	€ 0.33	€ 0.23	€ 0.08	€ 0.63
G45.2 Motor vehicle maintenance and repairs	€ 118.63	€ 3.06	€ 0.38	€ 122.08
N81.22 Chimney sweeps	€ 3.93			€ 3.93
Total	€ 131.58	€ 11.75	€ 5.13	€ 148.45

Source: Study team.

Note: Blank cells refer to no companies with exposure.

Table 7-35 Total PV compliance costs (RMMs, monitoring and administrative burden) discounted over 40 years by policy options and company size (€ millions)

Sector	OEL policy options			
	7 ng/m ³	70 ng/m ³	700 ng/m ³	2000 ng/m ³
Small	€ 6,998.40	€ 737.57	€ 192.84	€ 131.58
Medium	€ 9,210.37	€ 698.35	€ 21.23	€ 11.75
Large	€ 21,451.09	€ 1,587.94	€ 11.42	€ 5.13
Total	€ 37,659.87	€ 3,023.87	€ 225.50	€ 148.45

Source: Study team.

Table 7-36 Annual PV compliance costs (RMMs, monitoring and administrative burden) by policy options and company size (€ millions)

Sector	OEL policy options (value = € millions)			
	7 ng/m ³	70 ng/m ³	700 ng/m ³	2000 ng/m ³
Small	€ 174.96	€ 18.44	€ 4.82	€ 3.29
Medium	€ 230.26	€ 17.46	€ 0.53	€ 0.29

Sector	OEL policy options (value = € millions)			
	7 ng/m ³	70 ng/m ³	700 ng/m ³	2000 ng/m ³
Large	€ 536.28	€ 39.70	€ 0.29	€ 0.13
Total	€ 941.50	€ 75.60	€ 5.64	€ 3.71

Source: Study team.

Table 7-37 Total PV compliance costs (RMMs, monitoring and administrative burden) per company discounted over 40 years by policy options and company size (€ millions)

Sector	OEL policy options (value = € millions)			
	7 ng/m ³	70 ng/m ³	700 ng/m ³	2000 ng/m ³
Small	€ 0.02	€ 0.002	€ 0.0004	€ 0.0003
Medium	€ 3.07	€ 0.23	€ 0.01	€ 0.004
Large	€ 25.51	€ 1.89	€ 0.01	€ 0.01
Total	€ 0.09	€ 0.01	€ 0.001	€ 0.0003

Source: Study team.

Table 7-38 Annual PV compliance costs (RMMs, monitoring and administrative burden) per company by policy options and company size (€ millions)

Sector	OEL policy options (value = € millions)			
	7 ng/m ³	70 ng/m ³	700 ng/m ³	2000 ng/m ³
Small	€ 0.0004	€ 0.00004	€ 0.00001	€ 0.00001
Medium	€ 0.08	€ 0.006	€ 0.0002	€ 0.0001
Large	€ 0.6	€ 0.05	€ 0.0003	€ 0.0002
Total	€ 0.002	€ 0.0002	€ 0.00001	€ 0.00001

Source: Study team.

Overall, the study team estimate that costs for industry at the 2000 ng/m³ would only be incurred for air monitoring and administration reasons (no adjustment costs would occur as companies are already expected to be complying at this level). At the 700 ng/m³ level low adjustment, air monitoring and administrative costs would occur. At 70 ng/m³ adjustment costs significantly outweigh all air monitoring and administrative costs. At 7 ng/m³, adjustment costs are approximately 12 times higher than those at the 70 ng/m³ level which represents the difficulty sectors may have in achieving this policy option. Although costs at 70 ng/m³ are also 13 times higher than those at 700 ng/m³, also representing difficulties at the second most stringent policy option.

7.2.12.1 Aggregated costs for companies by sector (OEL & BLV)

The aggregated costs of implementing both an OEL and BLV include adjustment costs, air monitoring, biomonitoring and health surveillance and their corresponding administrative burden for companies by sector are shown in Table 7-33; by sector and size of company in Table 7-34; by size of company in Table 7-35; and as costs per company by size of company in Table 7-37. The total aggregated costs of adjustment, air monitoring and administrative burden for businesses are shown in Table 7-45. Table 7-36 presents annualised compliance, air monitoring and administrative costs by company size and Table 7-38 shows annualised compliance, air monitoring and administrative burden costs per company, by company size for all OEL policy options.

Compared with the previous section, the following tables illustrate the significant increase in costs associated with implementing a BLV, primarily due to the need for biomonitoring and health surveillance.

Table 3-35 illustrates two negative figures, C16.1 wood preservation at 7 ng/m³ and C19.1 coking plants at 700 ng/m³. Negative costs are present due to companies selecting alternative RMMs to comply with the policy option with lower costs over 40 years than already installed. The same reasons are provided for the equivalent negative values in Table 3-36.

Table 7-39 Total PV compliance costs (RMMs, monitoring and administrative burden) discounted over 40 years by policy options and sector (€ millions)

Sector	Total costs OEL & BLV options, € millions			
	7 ng/m ³ & 0.2 nmol/mol creatinine	70 ng/m ³ & 0.3 nmol/mol creatinine	700 ng/m ³ & 1.5 nmol/mol creatinine	2000 ng/m ³ & 3.8 nmol/mol creatinine
C10.13 Meat and poultry smokehouses	€ 10.24	€ 1.44	€ 0.35	€ 0.31
C10.2 Seafood smokehouses	€ 30.68	€ 3.83	€ 1.13	€ 1.00
C16.1 Wood preservation (creosote)	-€ 6.32	€ 0.38	€ 0.30	€ 0.29
C19.1 Coking plants	€ 737.91	€ 346.60	€ 2.93	€ 1.83
C19.2 Petroleum refineries	€ 15,347.73	€ 781.05	€ 5.52	€ 5.27
C20.13 Manufacture of carbon black	€ 832.77	€ 1.57	€ 0.52	€ 0.44
C20.14 Coal tar distillation	€ 1,085.78	€ 594.82	€ 0.72	€ 0.27
C23.2 Manufacture of refractory products	€ 6.21	€ 0.78	€ 0.08	€ 0.04
C23.99a Manufacture of bituminous products	€ 109.91	€ 15.41	€ 6.45	€ 6.01
C23.99b Graphite and carbon electrode manufacture	€ 260.61	€ 103.22	€ 0.93	€ 0.76
C24.1 Steel and iron foundries, ferroalloys	€ 3,492.08	€ 377.98	€ 26.15	€ 24.70
C24.42 Manufacture of aluminium	€ 231.43	€ 28.99	€ 0.24	€ 0.22
C24.45 Other non-ferrous metallurgy	€ 195.47	€ 46.70	€ 0.90	€ 0.42
C24.5 Casting of metals	€ 1,814.41	€ 185.20	€ 35.11	€ 33.00
D35.11 Coal fired power plants	€ 3,171.56	€ 10.14	€ 3.70	€ 3.46
E38.2 Waste incineration	€ 85.06	€ 1.89	€ 1.25	€ 1.02
E39 Soil remediation	€ 1,383.53	€ 145.50	€ 11.76	€ 11.07
F42.11 Road paving	€ 2,030.01	€ 292.77	€ 80.68	€ 67.92
F42.12 Welding of railroad tracks	€ 5,733.43	€ 173.78	€ 14.52	€ 8.89
G45.2 Motor vehicle maintenance and repairs	€ 1,876.46	€ 832.92	€ 602.42	€ 550.18
N81.22 Chimney sweeps	€ 979.38	€ 90.49	€ 48.95	€ 46.96
Total	€ 39,408.35	€ 4,035.46	€ 844.61	€ 764.04

Source: Study team.

Table 7-40 Total PV compliance costs (RMMs, monitoring and administrative burden) discounted over 40 years by policy options, sector and company size (€ millions)

Sector	Aggregated costs of PV compliance, monitoring, and administrative burden over 40 years, size of enterprise, by sector and OEL/BLV option, € millions			
	Small	Medium	Large	Total
7 ng/m³ & 0.2 nmol/mol creatinine				
C10.13 Meat and poultry smokehouses	€ 2.93	€ 3.98	€ 3.33	€ 10.24
C10.2 Seafood smokehouses	€ 8.28	€ 15.01	€ 7.39	€ 30.68
C16.1 Wood preservation (creosote)	-€ 6.32	€ 0.0004		-€ 6.32
C19.1 Coking plants	€ 418.40	€ 225.83	€ 93.68	€ 737.91
C19.2 Petroleum refineries	€ 78.89	€ 805.95	€ 14,462.90	€ 15,347.73
C20.13 Manufacture of carbon black		€ 635.03	€ 197.74	€ 832.77
C20.14 Coal tar distillation		€ 519.88	€ 565.91	€ 1,085.78
C23.2 Manufacture of refractory products	€ 1.16	€ 5.05		€ 6.21
C23.99a Manufacture of bituminous products	€ 34.04	€ 38.46	€ 37.40	€ 109.91
C23.99b Graphite and carbon electrode manufacture			€ 260.61	€ 260.61
C24.1 Steel and iron foundries, ferroalloys	€ 355.41	€ 969.46	€ 2,167.21	€ 3,492.08
C24.42 Manufacture of aluminium		€ 107.76	€ 123.67	€ 231.43
C24.45 Other non-ferrous metallurgy	€ 30.14	€ 111.90	€ 53.43	€ 195.47
C24.5 Casting of metals	€ 516.43	€ 728.28	€ 569.71	€ 1,814.41
D35.11 Coal fired power plants	€ 31.00	€ 1,820.46	€ 1,320.11	€ 3,171.56
E38.2 Waste incineration	€ 39.06	€ 38.85	€ 7.15	€ 85.06
E39 Soil remediation	€ 918.99	€ 440.43	€ 24.11	€ 1,383.53
F42.11 Road paving	€ 479.68	€ 395.58	€ 1,154.75	€ 2,030.01
F42.12 Welding of railroad tracks	€ 2,391.40	€ 2,440.90	€ 901.13	€ 5,733.43
G45.2 Motor vehicle maintenance and repairs	€ 1,801.20	€ 54.18	€ 21.08	€ 1,876.46
N81.22 Chimney sweeps	€ 979.38			€ 979.38
Total	€ 8,080.07	€ 9,356.99	€ 21,971.30	€ 39,408.35
70 ng/m³ & 0.3 nmol/mol creatinine				
C10.13 Meat and poultry smokehouses	€ 0.46	€ 0.44	€ 0.54	€ 1.44
C10.2 Seafood smokehouses	€ 1.05	€ 1.57	€ 1.22	€ 3.83
C16.1 Wood preservation (creosote)	€ 0.34	€ 0.04		€ 0.38
C19.1 Coking plants	€ 190.02	€ 104.74	€ 51.85	€ 346.61
C19.2 Petroleum refineries	€ 4.14	€ 40.89	€ 736.01	€ 781.05
C20.13 Manufacture of carbon black		€ 0.84	€ 0.73	€ 1.57
C20.14 Coal tar distillation		€ 258.44	€ 336.39	€ 594.82
C23.2 Manufacture of refractory products	€ 0.16	€ 0.62		€ 0.78
C23.99a Manufacture of bituminous products	€ 6.76	€ 4.78	€ 3.88	€ 15.41
C23.99b Graphite and carbon electrode manufacture			€ 103.22	€ 103.22

Sector	Aggregated costs of PV compliance, monitoring, and administrative burden over 40 years, size of enterprise, by sector and OEL/BLV option, € millions			
	Small	Medium	Large	Total
C24.1 Steel and iron foundries, ferroalloys	€ 43.48	€ 98.67	€ 235.83	€ 377.98
C24.42 Manufacture of aluminium		€ 0.65	€ 28.34	€ 28.99
C24.45 Other non-ferrous metallurgy	€ 6.56	€ 23.85	€ 16.29	€ 46.70
C24.5 Casting of metals	€ 47.59	€ 64.46	€ 73.15	€ 185.20
D35.11 Coal fired power plants	€ 2.05	€ 1.60	€ 6.50	€ 10.14
E38.2 Waste incineration	€ 0.90	€ 0.59	€ 0.40	€ 1.89
E39 Soil remediation	€ 99.27	€ 43.90	€ 2.33	€ 145.49
F42.11 Road paving	€ 118.20	€ 64.03	€ 110.55	€ 292.77
F42.12 Welding of railroad tracks	€ 65.63	€ 53.46	€ 54.68	€ 173.78
G45.2 Motor vehicle maintenance and repairs	€ 817.74	€ 12.20	€ 2.98	€ 832.92
N81.22 Chimney sweeps	€ 90.49			€ 90.49
Total	€ 1,494.82	€ 775.76	€ 1,764.88	€ 4,035.46
700 ng/m³ & 1.5 nmol/mol creatinine				
C10.13 Meat and poultry smokehouses	€ 0.18	€ 0.10	€ 0.07	€ 0.35
C10.2 Seafood smokehouses	€ 0.46	€ 0.45	€ 0.22	€ 1.13
C16.1 Wood preservation (creosote)	€ 0.27	€ 0.03		€ 0.30
C19.1 Coking plants	€ 0.75	€ 0.45	€ 1.72	€ 2.93
C19.2 Petroleum refineries	€ 0.14	€ 0.30	€ 5.08	€ 5.52
C20.13 Manufacture of carbon black		€ 0.33	€ 0.19	€ 0.52
C20.14 Coal tar distillation		€ 0.16	€ 0.56	€ 0.72
C23.2 Manufacture of refractory products	€ 0.02	€ 0.05		€ 0.08
C23.99a Manufacture of bituminous products	€ 3.67	€ 1.80	€ 0.98	€ 6.45
C23.99b Graphite and carbon electrode manufacture			€ 0.93	€ 0.93
C24.1 Steel and iron foundries, ferroalloys	€ 9.20	€ 2.30	€ 14.64	€ 26.15
C24.42 Manufacture of aluminium		€ 0.04	€ 0.19	€ 0.24
C24.45 Other non-ferrous metallurgy	€ 0.22	€ 0.20	€ 0.48	€ 0.90
C24.5 Casting of metals	€ 14.82	€ 10.92	€ 9.37	€ 35.11
D35.11 Coal fired power plants	€ 0.78	€ 0.74	€ 2.18	€ 3.70
E38.2 Waste incineration	€ 0.59	€ 0.40	€ 0.26	€ 1.25
E39 Soil remediation	€ 9.65	€ 1.64	€ 0.48	€ 11.76
F42.11 Road paving	€ 46.45	€ 16.69	€ 17.53	€ 80.68
F42.12 Welding of railroad tracks	€ 8.31	€ 2.56	€ 3.65	€ 14.52
G45.2 Motor vehicle maintenance and repairs	€ 591.57	€ 8.74	€ 2.11	€ 602.42
N81.22 Chimney sweeps	€ 48.95			€ 48.95
Total	€ 736.05	€ 47.93	€ 60.64	€ 844.61

Sector	Aggregated costs of PV compliance, monitoring, and administrative burden over 40 years, size of enterprise, by sector and OEL/BLV option, € millions			
	Small	Medium	Large	Total
2000 ng/m³ & 3.8 nmol/mol creatinine				
C10.13 Meat and poultry smokehouses	€ 0.16	€ 0.09	€ 0.06	€ 0.31
C10.2 Seafood smokehouses	€ 0.42	€ 0.38	€ 0.20	€ 1.00
C16.1 Wood preservation (creosote)	€ 0.26	€ 0.02		€ 0.29
C19.1 Coking plants	€ 0.59	€ 0.28	€ 0.96	€ 1.83
C19.2 Petroleum refineries	€ 0.13	€ 0.27	€ 4.87	€ 5.27
C20.13 Manufacture of carbon black		€ 0.28	€ 0.16	€ 0.44
C20.14 Coal tar distillation		€ 0.07	€ 0.20	€ 0.27
C23.2 Manufacture of refractory products	€ 0.02	€ 0.02		€ 0.04
C23.99a Manufacture of bituminous products	€ 3.55	€ 1.58	€ 0.88	€ 6.01
C23.99b Graphite and carbon electrode manufacture			€ 0.76	€ 0.76
C24.1 Steel and iron foundries, ferroalloys	€ 8.79	€ 1.97	€ 13.93	€ 24.69
C24.42 Manufacture of aluminium		€ 0.04	€ 0.18	€ 0.22
C24.45 Other non-ferrous metallurgy	€ 0.19	€ 0.09	€ 0.13	€ 0.42
C24.5 Casting of metals	€ 14.44	€ 9.88	€ 8.68	€ 33.00
D35.11 Coal fired power plants	€ 0.77	€ 0.63	€ 2.07	€ 3.46
E38.2 Waste incineration	€ 0.51	€ 0.30	€ 0.21	€ 1.02
E39 Soil remediation	€ 9.24	€ 1.42	€ 0.40	€ 11.07
F42.11 Road paving	€ 40.25	€ 11.95	€ 15.71	€ 67.91
F42.12 Welding of railroad tracks	€ 6.67	€ 1.23	€ 1.00	€ 8.89
G45.2 Motor vehicle maintenance and repairs	€ 541.11	€ 7.20	€ 1.88	€ 550.18
N81.22 Chimney sweeps	€ 46.96			€ 46.96
Total	€ 674.08	€ 37.68	€ 52.28	€ 764.04

Source: Study team.

Note: Blank cells refer to no companies with exposure.

Table 7-41 Total PV compliance costs (RMMs, monitoring and administrative burden) discounted over 40 years by policy options and company size (€ millions)

Sector	OEL & BLV options			
	7 ng/m ³ & 0.2 nmol/mol creatinine	70 ng/m ³ & 0.3 nmol/mol creatinine	700 ng/m ³ & 1.5 nmol/mol creatinine	2000 ng/m ³ & 3.8 nmol/mol creatinine
Small	€ 8,080.07	€ 1,494.82	€ 736.05	€ 674.08
Medium	€ 9,356.99	€ 775.76	€ 47.93	€ 37.68
Large	€ 21,971.30	€ 1,764.88	€ 60.64	€ 52.28
Total	€ 39,408.35	€ 4,035.46	€ 844.61	€ 764.04

Source: Study team.

Table 7-42 Annual PV compliance costs (RMMs, monitoring and administrative burden) by policy options and company size (€ millions)

Sector	OEL & BLV options (value = € millions)			
	7 ng/m ³ & 0.2 nmol/mol creatinine	70 ng/m ³ & 0.3 nmol/mol creatinine	700 ng/m ³ & 1.5 nmol/mol creatinine	2000 ng/m ³ & 3.8 nmol/mol creatinine
Small	€ 202.00	€ 37.37	€ 18.40	€ 16.85
Medium	€ 233.92	€ 19.39	€ 1.20	€ 0.94
Large	€ 549.28	€ 44.12	€ 1.52	€ 1.31
Total	€ 985.21	€ 100.89	€ 21.12	€ 19.10

Source: Study team.

Table 7-43 Total PV compliance costs (RMMs, monitoring and administrative burden) per company discounted over 40 years by policy options and company size (€ millions)

Sector	OEL & BLV options (value = € millions)			
	7 ng/m ³ & 0.2 nmol/mol creatinine	70 ng/m ³ & 0.3 nmol/mol creatinine	700 ng/m ³ & 1.5 nmol/mol creatinine	2000 ng/m ³ & 3.8 nmol/mol creatinine
Small	€ 0.02	€ 0.003	€ 0.002	€ 0.002
Medium	€ 3.12	€ 0.26	€ 0.02	€ 0.01
Large	€ 26.13	€ 2.10	€ 0.07	€ 0.06
Total	€ 0.09	€ 0.01	€ 0.002	€ 0.002

Source: Study team.

Table 7-44 Annual PV compliance costs (RMMs, monitoring and administrative burden) per company by policy options and company size (€ millions)

Sector	OEL & BLV options (value = € millions)			
	7 ng/m ³ & 0.2 nmol/mol creatinine	70 ng/m ³ & 0.3 nmol/mol creatinine	700 ng/m ³ & 1.5 nmol/mol creatinine	2000 ng/m ³ & 3.8 nmol/mol creatinine
Small	€ 0.0005	€ 0.0001	€ 0.00004	€ 0.00004
Medium	€ 0.08	€ 0.006	€ 0.0004	€ 0.0003
Large	€ 0.7	€ 0.05	€ 0.002	€ 0.002
Total	€ 0.002	€ 0.0002	€ 0.00005	€ 0.00004

Source: Study team.

7.2.12.2 Summary of aggregated costs for companies

Table 7-45 Aggregated costs of PV adjustment, air monitoring, biomonitoring and health surveillance and administrative burden, single-market costs, discounted over 40 years, by sector, by policy options (millions)

Description	Stakeholders affected	Total costs of OEL/BLV options, € millions			
		7 ng/m ³ & 0.2 nmol/mol creatinine	70 ng/m ³ & 0.3 nmol/mol creatinine	700 ng/m ³ & 1.5 nmol/mol creatinine	2000 ng/m ³ & 3.8 nmol/mol creatinine
Risk management measures - first year	Companies	€ 1,727.47	€ 220.90	€ 4.55	-
Risk management measures – recurrent	Companies	€ 2,871.63	€ 196.44	-€ 1.17	-
Risk management measures - discontinuation	Companies	€ 32,392.40	€ 2,248.28	-	-
Monitoring costs (air monitoring)	Companies	€ 549.46	€ 292.16	€ 181.33	€ 121.95
Monitoring costs (bio-monitoring and health surveillance)	Companies	€ 1,075.00	€ 338.10	€ 105.71	€ 102.17
Administrative costs (air monitoring)	Companies	€ 117.53	€ 65.54	€ 40.76	€ 26.50
Administrative costs (biomonitoring and health surveillance)	Companies	€ 673.49	€ 673.49	€ 513.41	€ 513.41
Total across all sectors/companies/stakeholders (OEL)		€ 37,659.87	€ 3,023.87	€ 225.50	€ 148.45
Total across all sectors/companies/stakeholders (OEL & BLV)		€ 39,408.35	€ 4,035.46	€ 844.61	€ 764.04

Source: Study team.

Note: Further explanation of social costs are provided in section 8.5. Totals have been presented as two scenarios, 'OEL' including first year and recurring adjustment costs, air monitoring, and administrative burden. Alternatively, 'OEL & BLV' also includes the costs of biomonitoring and health surveillance and its associated administrative burden. Health surveillance is expected to already be undertaken and has not been factored in as an additional cost for firefighters in the above calculations. Total rows present alternative scenarios and should be read independently of each other (they should not be read together as additional costs).

7.2.13 Regulatory charges

No regulatory charges are foreseen due to the introduction of an EU level OEL.

7.2.14 Comparison of costs estimates

Further comparison of the cost estimates is presented in Section 7.6.

7.3 Indirect costs for companies

Indirect costs could arise in terms of the availability of products, the choice and quality of products, as well as possible ripple effects through the value chain.

Of note is the potential for the graphite and carbon electrode manufacturers (C23.99b) to have insufficient quantities of coal-tar pitch available to manufacture their products, which are used in the metallurgical sectors (C24.1, C24.42, C24.45, C24.5 that use electrodes to manufacture and/or scrap metal) which would also potentially suffer at the lowest policy options (7 and 70 ng/m³) due to closures of coking plants and coal tar distillation plants. During consultation it emerged that carbon and graphite electrode manufacturers compete with cheaper imports by manufacturing higher

quality electrodes, which are more durable and reliable. The use of lower quality electrodes requires the electrode to be replaced more often and higher exposure (e.g. an aluminium industry would need to change and therefore pre-bake its anodes more often – baking of anodes is the activity with the highest exposure levels in C24.42).

Costs are also discussed in more detail in Section 8 on Market Effects, in particular sections 8.3.1 and 0.

7.4 Costs for public administrations

7.4.1 Estimated adjustment, air monitoring, biomonitoring, health surveillance and admin costs to achieve compliance: Firefighters

As outlined previously in this report, 'firefighters' only refers to operational members that manage and coordinate firefighters tackling flames during an incident. These operational members are not directly tackling fires and are assumed to supervise from a safe distance whilst remaining operationally effective. However, some circumstances may require operational members to be closer to incidents depending on the environment (e.g. narrow roads). This includes both occupational firefighters and volunteers.

The modelling of costs for firefighting services has been undertaken with the same methodology as costs for companies, however it has been modelled so that the only RMMs suitable for firefighting services could be selected. These are RPE and organisational hygiene measures. Study team research indicates that breathing apparatus and filtered facemasks are suitable RMMs for firefighters as communication devices can be fitted to allow effective coordination of teams during exposure scenarios. Modelling also assumes that discontinuation is not possible for this sector. Cost modelling has only been performed on air-based exposure. Section 7.2.7 outlines the assumptions made for the modelling of firefighting services.

The following table outlines the estimated costs incurred by public administrations regarding firefighting service compliance with the policy options. The current exposure data presented in 3.3.7 estimates that all firefighters are exposed to levels below 70 ng/m³, and thus explains why there are no adjustment costs at the 2000 ng/m³ and 700 ng/m³ levels. Whilst current exposures are expected to be lower than the 70 ng/m³, modelling predicts costs for the 5% of public authorities with the worst exposure²³ (69.62 ng/m³)²⁴. This is due to the exposure level being so close to the (within 5%) the policy option level that these authorities are still expected to put alternative RMMs in place as a precaution.

At 7 ng/m³, modelling estimates all public authorities would incur costs as the exposure data is higher than the policy option.

²³ The precise Member States where this could occur is not known.

²⁴ The value of 69.62 ng/m³ is the geometric mean of the P95 and P100 exposure values outlined in section 3.3.7 used for modelling purposes.

Table 7-46 Total costs incurred by public authorities over 40 years: firefighting services (€ millions)

Description	Total costs of policy options, € millions			
	7 ng/m ³ & 0.2 nmol/mol creatinine	70 ng/m ³ & 0.3 nmol/mol creatinine	700 ng/m ³ & 1.5 nmol/mol creatinine	2000 ng/m ³ & 3.8 nmol/mol creatinine
Risk management measures - first year	€ 543.99	€ 16.06	€ -	€ -
Risk management measures - recurrent	€ 5,328.03	€ 46.52	€ -	€ -
Risk management measures - discontinuation	€ -	€ -	€ -	€ -
Air monitoring costs	€ 0.87	€ 0.39	€ 0.24	€ 0.18
Biomonitoring costs	€ 9,509.88	€ 1,574.89	€ 524.28	€ 524.28
Administrative costs (air monitoring)	€ 0.18	€ 0.09	€ 0.05	€ 0.04
Administrative costs (biomonitoring)	€ 16.83	€ 16.83	€ 10.95	€ 10.95
Total (OEL)	€ 5,873.07	€ 63.06	€ 0.29	€ 0.22
Total (OEL & BLV)	€ 15,399.78	€ 1,654.78	€ 535.52	€ 535.45

Notes: Totals have been presented as two scenarios, '(OEL)' including first year and recurring adjustment costs, air monitoring, and administrative burden. Alternatively, '(OEL & BLV)' also includes the costs of biomonitoring and its associated administrative burden. Health surveillance is expected to already be undertaken by firefighters and has not been factored in as an additional cost in the above calculations. Total rows present alternative scenarios and should be read independently of each other (they should not be read together as additional costs).

Air monitoring costs exist at all policy option levels and differs depending on the number of Member States with existing OELs. These costs are relatively low as public authorities would only undertake air monitoring on sample exposure groups. Similarly, the administrative cost for air monitoring is proportionally low for the same reasons. It is assumed that SEG sampling would be used for air monitoring due to the fact that it would not be practical or cost effective for air monitoring to be undertaken for all firefighter operators at all incidents. Unlike air monitoring for industry, firefighters do not have the benefit of having constant exposure routes (i.e. incidents occur at different locations) and are high pressure situations in which transporting, setting up, and using monitoring tools may not be feasible. Furthermore, firefighting operators that use RMMs with high effectiveness (e.g. breathing apparatus) would not experience air exposure assuming the RMMs had been correctly maintained, which suggests that intensive air monitoring would not be considered necessary.

Member States with existing OELs are outlined in Annex 4. This illustrates that at 7 ng/m³ all EU Member States would be required to undertake air monitoring as none of them are already in compliance. Similarly at 700 ng/m³ all Member States except Germany would incur additional air monitoring costs (Germany is already complying with this OEL).

At 7 ng/m³, based on the estimated enterprise population density for firefighters, the bulk of costs related to air monitoring would be felt in Germany, France, Italy, Spain and Poland as the Member States with the most enterprises. However, this does not imply that the lower costs borne by other Member States are less impactful on said Member State. It is not possible to comment on the extent to which these cost impacts are (dis)proportionate to each Member State. At 70 ng/m³ costs

additional costs are not incurred by Germany (already in compliance), but are incurred in France, Italy, Spain, and Poland.

At the 700 and 2000 ng/m³ levels several Member States have an existing OEL in place which would reduce the need for additional air monitoring amongst firefighters. At 700 ng/m³ additional costs air monitoring costs would be incurred by Austria, Belgium, Croatia, Cyprus, Czech Republic, Estonia, Finland, France, Greece, Hungary, Ireland, Italy, Lithuania, Luxembourg, Malta, Poland, Portugal, Romania, Slovakia, Slovenia, Spain and Sweden (all Member States except Bulgaria, Denmark, Germany, Latvia, and the Netherlands). At 2000 ng/m³ additional air monitoring costs would be experienced by Belgium, Croatia, Cyprus, Czech Republic, Finland, France, Greece, Ireland, Italy, Luxembourg, Malta, Portugal, Romania, and Spain (all Member States except Austria, Bulgaria, Denmark, Estonia, Germany, Hungary, Latvia, Lithuania, the Netherlands, Poland, Slovakia, Slovenia, and Sweden). Again, it is not possible to comment on the impact of the costs related to each individual Member State.

Air monitoring costs presented in

Table 7-46 illustrate this gradual decrease in Member States that incur additional air monitoring costs the less stringent the policy option becomes. The significant decrease in costs from 7 and 70 ng/m³ is explained by the proportion of firefighting enterprises that would not have to undertake additional monitoring in Germany at 70 ng/m³ (Germany is the only Member State with an OEL that already complies). The significant decrease is due to the high proportion of enterprises estimated to be in Germany. For the remaining three policy options, the decreases are marginal, but reflect the decreasing number of Member States needing to comply (as outlined in the previous paragraph).

Conversely biomonitoring costs for this sector are substantially higher. This is because biomonitoring would be required for all 4.4 million firefighters (including volunteers) with air and dermal exposure, in all EU Member States, except France and Germany at the third (1.5 nmol/mol creatinine) and fourth (3.8 nmol/mol creatinine) policy option levels. Like air-monitoring, biomonitoring costs also exist at all policy option levels as this would be a new cost for all Member States should a BLV be introduced. Health surveillance for firefighters has not been modelled as an additional cost as it is assumed it is already undertaken as part of usual monitoring duties in the sector.

Overall, costs related to firefighters make up a substantial proportion of the costs incurred by all sectors regardless of whether an OEL or OEL & BLV are adopted.

7.4.2 Costs of transposition

Table 7-47 outlines the transpositions costs for a PAH OEL and BLV. As illustrated, transposition costs are complex and unique to each Member State. The study team has categorised each Member State into a corresponding cost scenario (each scenario represented by a row). As shown the total transposition costs are approximately € 1.2-1.3 million for all policy options.

If Member States introduce multiple OELs/BLVs at the same time, the costs of transposition may be less than if each OEL/BLV is introduced individually. However, the study team does not know which, if any, OELs/BLVs will actually be introduced and when, and therefore this factor cannot be incorporated into the cost of transposition.

The costs calculations assume that by implementing an OEL/BLV at an EU level the costs to derive an OEL/BLV, e.g. to establish background concentrations, are combined and are not incurred by

each Member State. Therefore, the costs would only be avoided if Member States intend to set or revise their national OEL.

Table 7-47 Overview of costs, over 40 years (without transition measures) (in €)

Cost scenario						7 ng/m ³ & 0.2 nmol/mol creatinine (3-OHBaP) & 1-OHP		70 ng/m ³ & 0.3 nmol/mol creatinine (3-OHBaP) & 1-OHP		700 ng/m ³ & 1.5 nmol/mol creatinine (3-OHBaP) & 1-OHP		2000 ng/m ³ & 3.8 nmol/mol creatinine (3-OHBaP) & 1-OHP	
Current OEL scenario	Current OEL transp. cost	Current BLV scenario	Additional BLV trans. cost	Total cost scenario	Scenario cost per Member State	Transp. Costs	Member States	Transp. Costs	Member States	Transp. Costs	Member States	Transp. Costs	Member States
None	Major	None	None	Major	€ 50,000	€ 350,000	BE; CY; HR; IT; LU; MT; PT;	€ 350,000	BE; CY; HR; IT; LU; MT; PT;	€ 350,000	BE; CY; HR; IT; LU; MT; PT;	€ 400,000	BE; CY; DK; HR; IT; LU; MT; PT;
Yes, at or below policy option	None	None	Major	Major	€ 50,000					€ 150,000	BG; LV; NL;	€ 500,000	AU; BG; EE; HU; LT; LV; NL; PL; SE; SI;
None	Major	Yes, for 1-OHP	None	Major	€ 50,000	€ 50,000	IE;	€ 50,000	IE;	€ 50,000	IE;	€ 50,000	IE;
None	Major	Yes, for 3-OHBaP at or below policy option	None	Major	€ 50,000					€ 50,000	FR;	€ 50,000	FR;
None	Major	Yes, for 3-OHBaP above policy option	None	Major	€ 50,000	€ 50,000	FR;	€ 50,000	FR;				
Yes, above policy option	Minor	None	Major – minor	Major	€ 50,000	€ 700,000	AU; BG; CZ; DK; EE; ES; HU; LT; LV; NL; PL; RO; SE; SI;	€ 700,000	AU; BG; CZ; DK; EE; ES; HU; LT; LV; NL; PL; RO; SE; SI;	€ 550,000	AU; CZ; DK; EE; ES; HU; LT; PL; RO; SE; SI;	€ 150,000	CZ; ES; RO;
Yes, at or below policy option	None	Yes, for 1-OHP	Minor	Minor	€ 30,000							€ 30,000	SK

Cost scenario						7 ng/m ³ & 0.2 nmol/mol creatinine (3-OHBaP) & 1-OHP		70 ng/m ³ & 0.3 nmol/mol creatinine (3-OHBaP) & 1-OHP		700 ng/m ³ & 1.5 nmol/mol creatinine (3-OHBaP) & 1-OHP		2000 ng/m ³ & 3.8 nmol/mol creatinine (3-OHBaP) & 1-OHP	
Current OEL scenario	Current OEL transp. cost	Current BLV scenario	Additional BLV trans. cost	Total cost scenario	Scenario cost per Member State	Transp. Costs	Member States	Transp. Costs	Member States	Transp. Costs	Member States	Transp. Costs	Member States
Yes, above policy option	Minor	Yes, for 1-OHP	Minor	Minor	€ 30,000	€ 90,000	EL; FI; SK	€ 90,000	EL; FI; SK	€ 90,000	EL; FI; SK	€ 60,000	EL; FI;
Yes, at or below policy option	None	Yes, for 3-OHBaP at or below policy option	None	None	€ 0			€0	DE;	€0	DE;	€0	DE;
Yes, at or below policy option	None	Yes, for 3-OHBaP above policy option	Minor	Minor	€ 30,000					€ 30,000	DE*;		
Yes, above policy option	Minor	Yes, for 3-OHBaP at or below policy option	None	Minor	€ 30,000								
Yes, above policy option	Minor	Yes, for 3-OHBaP above policy option	Minor	Minor	€ 30,000	€ 30,000	DE;	€ 30,000	DE*;				
Total costs						€ 1,270,000		€ 1,270,000		€ 1,270,000		€ 1,240,000	

Source: Study team.

Note: *Refers to Germany having two existing OELs and two proposed BLVs. Major costs are calculated as €50,000, and minor as €30,000. Modelling assumes all OELs are binding, and all BLVs would be in addition to an OEL. Modelling does not assume the possibility of a BLV without an OEL.

Should only an OEL be implemented (no BLV), costs in the above table will be unchanged. This is due to the costs of implementing one or both policy options being the same (costs are determined by which Member States have an existing policy, those without, and those that require editing, not the number of policy options being implemented).

7.4.3 Enforcement costs

The enforcement, monitoring and adjudication costs depend on the number of companies that will be covered by the policy option. In principle, national authorities are supposed to inspect companies already as they have the general obligation to protect workers. However, there could be an additional cost due to the need to ensure compliance with the new rules. These enforcement costs depend on the inspection regime in each Member State, however such costs for each Member State are unknown (and by extent are not estimated in this study). Despite this some costs are expected for each Member State authority although the study team cannot comment on the extent of these costs.

7.5 Impact of transitional periods on costs

A transition period will help industries identify the necessary changes to comply with the OEL and implement them. This is particularly true for sectors such as coking plants where the production process requires coal to be treated at very high temperatures and there are limitations on the risk management measures that can be put place, and in some plants these limits have been reached.

There are two different impacts of the transitional period:

- A reduction in the adjustment costs;
- Make the financing of the adjustment costs easier and cheaper.

The transitional period might affect the adjustment costs: the more time companies have to implement more stringent compliance measures, the lower are the likely overall costs. This is because companies will have more time to plan and integrate investments, and they may be able to invest into more effective technologies or alternatives that become available after the OEL comes into force, or in changes motivated by other objectives to be combined with OEL compliance actions. Transitional periods may also make the financing of the investments easier because by spreading the substantial first year investments over a number of years, it will be easier to finance the investments out of the companies' annual budgets for investments.

7.5.1 Sectors requiring a transitional period at the different policy options

A high level of exposure is one measure to establish which sectors may require a transitional period. Below are sectors with high levels of exposure, identified via median values (as presented in Table 3-64):

- C19.1 Coking;
- C20.14 Coal tar distillation;
- C23.2 Refractory products;
- C24.42 Aluminium;
- C24.45 Non-ferrous metallurgy;
- C24.5 Casting of metals;
- E39 Soil remediation; and
- F42.12 Welding of train tracks.

Exposure level alone does not take into account socioeconomic factors, such as the use of existing RMMs and how easy (economically and technically) it is to implement additional RMMs, capacity for companies to invest and other socioeconomic factors.

Considering socioeconomic factors and exposure levels, the study team has reviewed the need for a transitional period at the different OEL policy options for the sectors under review. The requirements are different between the policy options, as follows:

- At the 7 ng/m³, the lowest policy option, many sectors would face severe financial and technical difficulties in achieving the OEL. This is demonstrated by the high level of discontinuations (Table 8-13), first year costs (Table 7-8 and Table 7-9), PV40 total costs (as a representation of total impacts on the sector) compared to turnover (Table 8-5) and gross operating surplus (Table 8-6). The majority of sectors will benefit from additional time to identify the actions they need to take to achieve the OEL, source funding, and ultimately implement changes to working practices;
- At the 70 ng/m³, the second lowest policy option, some sectors face high costs and/or are at risk of closure. A portion of these sectors are considered to be key in the development of green infrastructure, and some products are identified as critical and/or strategic raw materials. The analysis of which sectors would benefit the most from a transitional period are presented in Table 7-48; and
- At the 700 and 2000 ng/m³, the two highest policy options, companies are thought to largely be able to cope with the introduction of an OEL at these levels without significant disruption to manufacturing and EU supply chains.

Table 7-48 Sector that would benefit from a transition period

Sector	Reason for transition period
C19.1 Coking plants	Based on consultation, the players in the sector who have invested in all the risk management measures that are currently technically feasible are not able to achieve 70 ng/m ³ . This is due to the nature of the work and the high temperatures in which coking takes place. The SEA supports these finding, with 45% discontinuations, and first year costs at 0.6-1.8% of turnover and 10-27% of gross operating surplus (GOS). The by-product of coking, coal tar pitch, is used in many other sectors and coking coal is listed as a critical raw material.
C20.14 Coal tar distillation plants	There are only seven coal tar distillation plants left in Europe and 34% discontinuations are estimated, a concentration of markets following closures cannot be certain. The products of this sector feed into key industries (see section 8.4.5). Coal tar pitch is needed to manufacture carbon and graphite electrodes, which are used in the metallurgical sectors, and there is currently no suitable alternative. Several metals are listed as critical and/or strategic raw materials and this is considered an enabling industry.
C23.2 manufacture of refractory products	Similarly, it is understood that there a five companies that manufacture slide gates (using CTPht temperature) that are essential in the manufacture of iron and steel. According to consultation, companies in Germany are struggling to meet the 70 ng/m ³ acceptable level. 14% of companies are estimated to discontinue at this level and these will experience first year costs at 1.5-4% of the turnover, and 20-50% of gross operating surplus (GOS).
C23.99b graphite and carbon electrodes	The carbon and graphite electrodes manufacturing process currently uses heated CTPht in several processes. Electrodes are essential in most metallurgical processes (including recycling of metals) and with approximately only 20 players on the market, potential closures or relocations have the potential to disrupt the market. The plants tend to be large sites and will require significant investments to meet the 70 ng/m ³ level – which is reflected in 16% discontinuations and first year costs at 240% of GOS. In addition, graphite is used in key technologies, (see section 8.4.5 and JRC 2023), and natural graphite has been identified as a critical and strategic raw material.

Sector	Reason for transition period
C24.1 Steel and iron foundries, including ferroalloys	During consultation it emerged that PAH exposure in these sectors is difficult to establish. However, literature data and IARC report measured concentrations of exposure to PAH. Foundries are investing in decarbonisation and are facing cheaper imports. Therefore, companies will benefit from additional time to identify sources of PAH exposure, source funding and implement measures at this level. Steel is not identified as a critical or strategic raw material but it is used in most strategic technologies (JRC 2023). Of note is that coking plants tend to be integrated with steelworks, and they may not be represented by the NACE code C19.1 but rather C24.1.
C24.5 Casting of metals	Casting and foundries (C24.1, C24.42 and C24.45), particularly steel and iron foundries, are often integrated and it may be difficult to distinguish operations (IARC 2012). The mechanisms for exposure are similar (via furnaces, dust and mould releases). The products are also essential in the delivery of green infrastructure and technology (infrastructure, technologies and vehicles made with metal mostly need to be cast).
C24.42 Aluminium plants	The pre-baking of anodes is an essential activity that leads to particularly high exposure levels. Aluminium plants will need to identify and implement technically feasible measures to comply with an OEL of 70 ng/m ³ which are understood to not be currently available based on consultation. First year costs equivalent to 2-4% of GOS and 4% discontinuations and are estimated at this level, which is likely to be an underestimation based on the considerations above. Aluminium is required for the manufacture of cars and solar panels, and it is used in all 15 strategic technologies assessed by JRC (see section 4.4.2). There are only nine plants left in the EU27 that manufacture aluminium.
C24.45 Non-ferrous metallurgy	Similarly to other sectors in C24, the non-ferrous metallurgical industry may need additional time to establish sources of PAH exposure and implement measures. Silicon metal is essential for the manufacture of semiconductors and solar panels (see section 4.4.2) and is a critical and strategic raw material. At this level, first year costs equivalent to 1-3% turnover and 9% discontinuations are estimated.

Source: Study team.

The study team has identified the above sectors on the basis of costs and impacts that have been modelled in sections 7 and 8, consideration of the criticality of the products manufactured to the EU economy and megatrends (section 4.4), alongside current exposure levels, current RMMs implemented and technical feasibility, as well as feedback received during the consultation and site visits. Therefore the selection of sectors is based on both quantifiable impacts and those that are not easily quantifiable. There are some further considerations that are made in section 8 and reproduced below:

- The metallurgical sectors and graphite and carbon electrode manufacturers are experiencing pressures from cheaper imports. They are also sectors that are energy intensive, together with electrode and coking, and have been impacted from high energy prices since 2021. These factors are driving down profits and outputs and have initiated plant closures or mothballing in the last two years. These sectors, as well coking (C19.1), carbon black manufacturers (C20.13) and coal tar distillation (C20.14) also tend to be part of multinationals, which may review the profitability and viability of the EU plants following the implementation of a more stringent OEL;
- For already concentrated sectors such as coal tar distillation, refractory products and aluminium plants, with only seven, five and nine plants in total in the EU market, respectively, it may be challenging to consolidate and concentrate operations following discontinuations;

- Most of the identified sectors and their products are considered important in the delivery of green policies due to the key role they play in the creation of essential infrastructure (steel and aluminium, in solar panels, electric vehicles and wind turbines) and technology (graphite, silicon in electric vehicles, fuel cells and digitalisation) see also JRC (2023) for a complete list;
- At 70 ng/m³ significant discontinuations occur in C19.1 coking plants (45% discontinuing), C20.14 coal tar distillation (34% discontinuing), C23.99b graphite and carbon electrode (16.2%) and C24.45 non-ferrous metallurgy (8.8%); and
- The 70 ng/m³ level produces the greatest variation of potential disadvantage across all sectors. Sectors with a higher degree of competitive disadvantage as identified in section 8.3.3 include: C20.14 Coal tar distillation, C23.2 manufacture of refractory products, C23.99b graphite and carbon electrode manufacture, C24.42 manufacture of aluminium, C24.5 casting of metals, and E39 soil remediation.

The following sectors have been considered when reviewing the potential for a transition period: refineries (C19.2), coal-fired power plants (D35.11), soil remediation (E39), welding of train tracks (F42.12) and chimney sweeps (N81.22). The use of mastic asphalt is also worth mentioning.

- Refineries (C19.2) experience high costs at this level, but it is understood that high exposure occurs during maintenance and specific operations (e.g. transfer of crude oil or bitumen). The modelled high costs are also a reflection of the high turnover of the companies. It is thought that refineries will be able to fund the necessary changes;
- Coal-fired power plants (D35.11), particularly small companies, face high costs and are a high percentage of turnover. There is a high level of uncertainty on the exposure levels as they are based on one study only. Nonetheless, the mean concentration is below the policy option of 70 ng/m³ without the use of RPE;
- Soil remediation (E39). Similarly to coal fired power plants, the assessment is based on only one study and, similarly to refineries, the high exposure takes places during particular tasks (repairs, maintenance and feeding of the decontamination device during soil remediation) and a minimum level RPE was assumed to be worn by the study team;
- Welding of train tracks (F42.12). Similarly to the previous sectors, the exposure level is based on one study and no RPE is assumed to be worn by the study team based on anecdotal evidence. The consultation indicates that there are guidelines already in place which recommend the use of RPE. It is anticipated that there already are procedures and mechanisms in place to reduce exposure, which may just need to be enforced without substantial additional costs;
- Chimney sweeps (N81.22) are estimated to require substantial first year investments and total PV40 costs. However, the study team understands that the vast majority of companies are micro businesses with one employee and no dependents. These companies are highly unlikely to undertake air monitoring and will upgrade the equipment on a need basis. In the meantime there are simple and cheap measures that can be undertaken, such as taping sheets to prevent dust fall out, simple HEPA filter masks (a study indicates that these measures are not widespread), wearing gloves and other hygiene measures; and

- Mastic asphalt is mentioned because it is used particularly in Germany for road paving, bridge building, tunnels, other civil infrastructure and indoors for soundproofing. While an OEL at 70 ng/m³ will impact Germany, there are alternatives available that are used throughout Europe particularly when used indoors for soundproofing where the highest levels of exposure are expected.

7.5.2 Duration of transition period

The study team believes that a transitional period of 5-10 years is likely to be sufficient for companies to implement measures for an OEL. A shorter period is likely insufficient in the case of large companies and large plants. Coking of coal may require the whole 10-year period due to the difficulty in lowering PAH exposure levels.

7.5.3 Transition period OEL

The study team has assessed policy options at 7, 70, 700 and 2000 ng/m³ and the transitional period OEL is based on these. Germany has a tolerable level of 700 ng/m³ and an acceptable level at 70 ng/m³. Based on the costs and SEA findings of this study, the study team believes that for an OEL of 70 ng/m³ a transitional period of 700 ng/m³ would be appropriate.

7.6 Summary of costs of the measures [incl. previous Aggregated costs]

The overall costs for each policy option are presented in Table 7-31 below. Adjustment costs at the lowest policy option are significantly higher than all other options although this is due to significant discontinuations at this level compared with all others (for more information on discontinuation costs see section 8. Biomonitoring and health surveillance also make up a significant proportion of the overall costs, although at the 7ng/m³ level €10 billion specifically relate to firefighters due to the high volume of workers requiring monitoring.

Please note that the negative recurrent adjustment cost at the 700 ng/m³ is due to multiple factors. First that there are relatively few sectors incurring costs at this level (see Table 7-18), of which all companies are estimated to select RMMs with lower recurrent costs than their current installation/method. For example shifting from filtered facemasks to closed systems. This is only present for industrial sectors; adjustment costs for firefighters are not present above the 7 ng/m³ level.

Table 7-49 Overview of costs, € millions over 40 years (without transition measures)

Description	Stakeholders affected	7 ng/m ³ & 0.2 nmol/mol creatinine	70 ng/m ³ & 0.3 nmol/mol creatinine	700 ng/m ³ & 1.5 nmol/mol creatinine	2000 ng/m ³ & 3.8 nmol/mol creatinine
Risk management measures - first year	Companies Public authorities	€ 2,271.46	€ 236.96	€ 4.55	€ -
Risk management measures - recurrent	Companies Public authorities	€ 8,199.66	€ 242.96	-€ 1.17	€ -
Risk management measures - discontinuation	Companies	€ 32,392.40	€ 2,248.28	€ -	€ -
Monitoring costs (air monitoring)	Companies Public authorities	€ 551.19	€ 292.95	€ 181.81	€ 122.30
Monitoring costs (biomonitoring and health surveillance)	Companies Public authorities	€ 10,584.88	€ 1,912.99	€ 629.99	€ 626.45

Description	Stakeholders affected	7 ng/m ³ & 0.2 nmol/mol creatinine	70 ng/m ³ & 0.3 nmol/mol creatinine	700 ng/m ³ & 1.5 nmol/mol creatinine	2000 ng/m ³ & 3.8 nmol/mol creatinine
Administrative costs (air monitoring)	Companies Public authorities	€ 117.71	€ 65.63	€ 40.81	€ 26.54
Administrative costs (biomonitoring and health surveillance)	Companies Public authorities	€ 690.32	€ 690.32	€ 524.36	€ 524.36
Transposition costs	Public authorities	€ 1.27	€ 1.24	€ 1.24	€ 1.24
Total across all sectors/companies/stakeholders (OEL)		€ 43,532.94	€ 3,086.93	€ 225.79	€ 148.67
Total across all sectors/companies/stakeholders (OEL & BLV)		€ 54,808.13	€ 5,690.24	€ 1,380.13	€ 1,299.49

Note: Totals have been presented as two scenarios, '(OEL)' including first year and recurring adjustment costs, air monitoring, and administrative burden. Alternatively, '(OEL & BLV)' also includes the costs of biomonitoring and health surveillance and its associated administrative burden. Health surveillance is expected to already be undertaken by firefighters and has not been factored in as an additional cost in the above calculations. Totals present alternative scenarios and should be read independently of each other (they should not be read together as additional costs). '-' refers to zero costs incurred by companies.

8 MARKET EFFECTS - OEL ONLY

This chapter comprises the following sections:

- Section 8.1: Overall impact;
- Section 8.2: Research and innovation;
- Section 8.3: Single market;
- Section 8.4: Competitiveness of EU businesses;
- Section 8.5: Employment; and
- Section 8.6: Summary of the market effects.

Please note that figures in this section only refer to the impacts of implementing an OEL only, and not of both an OEL and BLV. Due to the costs of monitoring and implementing a BLV (see sections 7.2.10 and 7.2.11), the market effects can be expected to increase in severity in comparison to an OEL only option.

8.1 Overall impact

Overall, market impacts (in terms of the effect on the single market, research and development (R&D), competitiveness of EU businesses and employment) are strongly influenced by two key drivers, the extent to which costs are incurred to comply with the OEL and by the feasibility of meeting the required air concentrations. In extreme cases companies will be forced out of business if they are unable to meet the OEL at a cost that maintains profitability.

The likely costs that would be incurred at each of the OEL policy options considered in this study are set out in section 7 above. These have then been modelled to predict the likely number of companies (or business units) that would discontinue operations.

Table 8-1 provides estimates of the compliance costs that are estimated to be incurred on a per company basis (discounted at 3% over 40 years) including the cost of discontinuations. The rest of the section provides an analysis of the likely impacts arising from the key drivers of competition in both the EU and overseas markets. Zero values indicate there are no costs for compliance as enterprises are already achieving the OEL/STEL level.

- Blank cells indicate there are no companies operating in sector/company size;
- '-' values indicate companies are expected to exist but no compliance costs are incurred as enterprises are already achieving the OEL value.; and
- Negative values (red) indicates that at a particular policy option companies are estimated to move to a risk management measure (RMM) that over 40 years results in an overall cost-saving. For example, respiratory protective equipment (RPE) tends to have a small one-off cost, but a high recurrent cost, whereas local exhaust ventilation (LEV) has high one-off costs and lower recurrent costs, moving from RPE to LEV may result in lower costs over 40 years. The negative value for wood preservation in the table below shows that in this instance, over 40 years, the cost of operating RPE is higher than installing and running LEV.

This sounds irrational, but companies may prefer to pay an additional sum e.g. €10,000 over 60 years, rather than face a substantial one-off sum: in particular, small companies may find it difficult to borrow the funds for the investment.

As already noted in section 7, the costs at the two highest policy options are limited, whereas the costs per company at the second lowest policy option (70 ng/m³) are substantial in many sectors, particularly in C19.1 coking, C19.2 petroleum refineries, C20.14 coal tar distillation. At the lowest policy option, the majority of sectors experience large costs at a company level.

The rest of this section provides an analysis of the likely impacts arising from the key drivers of competition in both the EU and overseas markets.

Table 8-1 Total PV compliance costs (RMMs, discontinuations, monitoring and administrative burden) per company discounted over 40 years by policy options and sector) (€ millions)

Sector	Compliance cost per company, OEL in ng/m ³			
	7 ng/m ³	70 ng/m ³	700 ng/m ³	2000 ng/m ³
C10.13 Meat and poultry smokehouses	€ 0.04	€ 0.005	€ 0.001	€ 0.001
C10.2 Seafood smokehouses	€ 0.09	€ 0.01	€ 0.001	€ 0.001
C16.1 Wood preservation (creosote)	-€ 0.22	€ 0.001	€ 0.001	€ 0.0003
C19.1 Coking plants	€ 13.12	€ 6.09	-€ 0.01	€ 0.001
C19.2 Petroleum refineries	€ 188.87	€ 9.51	€ 0.01	€ 0.01
C20.13 Manufacture of carbon black	€ 33.20	€ 0.04	€ 0.01	€ 0.01
C20.14 Coal tar distillation	€ 154.84	€ 84.79	€ 0.1	€ 0.01
C23.2 Manufacture of refractory products	€ 1.20	€ 0.14	€ 0.01	€ 0.001
C23.99a Manufacture of bituminous products	€ 0.08	€ 0.01	€ 0.001	€ 0.001
C23.99b Graphite and carbon electrode manufacture	€ 11.59	€ 4.56	€ 0.01	€ 0.01
C24.1 Steel and iron foundries, ferroalloys	€ 1.17	€ 0.12	€ 0.001	€ 0.001
C24.42 Manufacture of aluminium	€ 25.44	€ 3.09	€ 0.01	€ 0.01
C24.45 Other non-ferrous metallurgy	€ 2.40	€ 0.55	€ 0.01	€ 0.001
C24.5 Casting of metals	€ 0.34	€ 0.01	€ 0.002	€ 0.001
D35.11 Coal fired power plants	€ 15.96	€ 0.02	€ 0.003	€ 0.001
E38.2 Waste incineration	€ 0.13	€ 0.001	€ 0.001	€ 0.001
E39 Soil remediation	€ 0.40	€ 0.03	€ 0.001	€ 0.001
F42.11 Road paving	€ 0.06	€ 0.01	€ 0.001	€ 0.0003
F42.12 Welding of railroad tracks	€ 2.83	€ 0.08	€ 0.002	€ 0.0003
G45.2 Motor vehicle maintenance and repairs	€ 0.003	€ 0.001	€ 0.0005	€ 0.0003
N81.22 Chimney sweeps	€ 0.04	€ 0.001	€ 0.0003	€ 0.0002
Total (weighted average)	€ 0.09	€ 0.01	€ 0.001	€ 0.0003

Source: Study team.

Note: '-' refers to zero costs incurred by companies.

Table 8-2 Total PV compliance costs (RMMs, discontinuations, monitoring and administrative burden) per company discounted over 40 years by policy options, sector and company size (€ millions)

Sector	Compliance cost per business, OEL in ng/m ³ , by size		
	Small	Medium	Large
7 ng/m³			
C10.13 Meat and poultry smokehouses	€ 0.01	€ 0.29	€ 1.02
C10.2 Seafood smokehouses	€ 0.03	€ 0.40	€ 0.98
C16.1 Wood preservation (creosote)	-€ 0.22	-€ 0.21	
C19.1 Coking plants	€ 8.67	€ 111.17	€ 16.59
C19.2 Petroleum refineries	€ 2.62	€ 67.08	€ 369.61
C20.13 Manufacture of carbon black		€ 31.69	€ 39.24
C20.14 Coal tar distillation		€ 173.14	€ 141.12
C23.2 Manufacture of refractory products	€ 0.25	€ 4.98	
C23.99a Manufacture of bituminous products	€ 0.03	€ 0.33	€ 1.31
C23.99b Graphite and carbon electrode manufacture			€ 11.59
C24.1 Steel and iron foundries, ferroalloys	€ 0.13	€ 8.56	€ 14.59
C24.42 Manufacture of aluminium		€ 35.85	€ 20.24
C24.45 Other non-ferrous metallurgy	€ 0.44	€ 13.91	€ 10.22
C24.5 Casting of metals	€ 0.12	€ 1.25	€ 2.60
D35.11 Coal fired power plants	€ 0.18	€ 40.37	€ 51.54
E38.2 Waste incineration	€ 0.06	€ 0.90	€ 0.66
E39 Soil remediation	€ 0.27	€ 4.91	€ 1.96
F42.11 Road paving	€ 0.01	€ 0.28	€ 3.70
F42.12 Welding of railroad tracks	€ 1.24	€ 29.36	€ 46.96
G45.2 Motor vehicle maintenance and repairs	€ 0.003	€ 0.06	€ 0.26
N81.22 Chimney sweeps	€ 0.04		
Total (weighted average)	€ 0.02	€ 3.07	€ 25.51
70 ng/m³			
C10.13 Meat and poultry smokehouses	€ 0.001	€ 0.03	€ 0.14
C10.2 Seafood smokehouses	€ 0.002	€ 0.04	€ 0.14
C16.1 Wood preservation (creosote)	€ 0.001	€ 0.01	
C19.1 Coking plants	€ 3.92	€ 51.18	€ 8.90
C19.2 Petroleum refineries	€ 0.13	€ 3.38	€ 18.62

Sector	Compliance cost per business, OEL in ng/m ³ , by size		
	Small	Medium	Large
C20.13 Manufacture of carbon black		€ 0.02	€ 0.09
C20.14 Coal tar distillation		€ 86.04	€ 83.85
C23.2 Manufacture of refractory products	€ 0.02	€ 0.59	
C23.99a Manufacture of bituminous products	€ 0.002	€ 0.03	€ 0.09
C23.99b Graphite and carbon electrode manufacture			€ 4.57
C24.1 Steel and iron foundries, ferroalloys	€ 0.01	€ 0.85	€ 1.44
C24.42 Manufacture of aluminium		€ 0.18	€ 4.55
C24.45 Other non-ferrous metallurgy	€ 0.09	€ 2.92	€ 2.93
C24.5 Casting of metals	€ 0.004	€ 0.05	€ 0.06
D35.11 Coal fired power plants	€ 0.004	€ 0.02	€ 0.08
E38.2 Waste incineration	€ 0.001	€ 0.01	€ 0.02
E39 Soil remediation	€ 0.02	€ 0.43	-€ 0.07
F42.11 Road paving	€ 0.00	€ 0.04	€ 0.28
F42.12 Welding of railroad tracks	€ 0.03	€ 0.61	€ 2.56
G45.2 Motor vehicle maintenance and repairs	€ 0.001	€ 0.01	€ 0.02
N81.22 Chimney sweeps	€ 0.001		
Total (weighted average)	€ 0.002	€ 0.23	€ 1.89
700 ng/m³			
C10.13 Meat and poultry smokehouses	€ 0.0003	€ 0.01	€ 0.01
C10.2 Seafood smokehouses	€ 0.0004	€ 0.01	€ 0.01
C16.1 Wood preservation (creosote)	€ 0.0005	€ 0.01	
C19.1 Coking plants	€ 0.0002	-€ 0.07	-€ 0.03
C19.2 Petroleum refineries	€ 0.001	€ 0.01	€ 0.01
C20.13 Manufacture of carbon black		€ 0.01	€ 0.01
C20.14 Coal tar distillation		€ 0.03	€ 0.09
C23.2 Manufacture of refractory products	€ 0.0003	€ 0.04	
C23.99a Manufacture of bituminous products	€ 0.0004	€ 0.01	€ 0.01
C23.99b Graphite and carbon electrode manufacture			€ 0.01
C24.1 Steel and iron foundries, ferroalloys	€ 0.0004	€ 0.01	€ 0.01
C24.42 Manufacture of aluminium		€ 0.01	€ 0.01

Sector	Compliance cost per business, OEL in ng/m ³ , by size		
	Small	Medium	Large
C24.45 Other non-ferrous metallurgy	€ 0.0006	€ 0.02	€ 0.07
C24.5 Casting of metals	€ 0.0004	€ 0.01	€ 0.01
D35.11 Coal fired power plants	€ 0.0003	€ 0.01	€ 0.01
E38.2 Waste incineration	€ 0.0004	€ 0.01	€ 0.01
E39 Soil remediation	€ 0.0005	€ 0.01	€ 0.01
F42.11 Road paving	€ 0.0004	€ 0.01	€ 0.01
F42.12 Welding of railroad tracks	€ 0.001	€ 0.01	€ 0.09
G45.2 Motor vehicle maintenance and repairs	€ 0.0005	€ 0.01	€ 0.01
N81.22 Chimney sweeps	€ 0.0003		
Total (weighted average)	€ 0.0004	€ 0.01	€ 0.01
2000 ng/m³			
C10.13 Meat and poultry smokehouses	€ 0.0002	€ 0.004	€ 0.01
C10.2 Seafood smokehouses	€ 0.0003	€ 0.01	€ 0.01
C16.1 Wood preservation (creosote)	€ 0.0002	€ 0.003	
C19.1 Coking plants	€ 0.0004	€ 0.01	€ 0.01
C19.2 Petroleum refineries	€ 0.0004	€ 0.01	€ 0.01
C20.13 Manufacture of carbon black		€ 0.004	€ 0.01
C20.14 Coal tar distillation		€ 0.005	€ 0.01
C23.2 Manufacture of refractory products	€ 0.0003	€ 0.004	
C23.99a Manufacture of bituminous products	€ 0.0003	€ 0.005	€ 0.01
C23.99b Graphite and carbon electrode manufacture			€ 0.01
C24.1 Steel and iron foundries, ferroalloys	€ 0.0003	€ 0.004	€ 0.01
C24.42 Manufacture of aluminium		€ 0.005	€ 0.01
C24.45 Other non-ferrous metallurgy	€ 0.0002	€ 0.003	€ 0.004
C24.5 Casting of metals	€ 0.0003	€ 0.01	€ 0.01
D35.11 Coal fired power plants	€ 0.0002	€ 0.003	€ 0.004
E38.2 Waste incineration	€ 0.0003	€ 0.004	€ 0.01
E39 Soil remediation	€ 0.0004	€ 0.01	€ 0.01
F42.11 Road paving	€ 0.0002	€ 0.003	€ 0.004
F42.12 Welding of railroad tracks	€ 0.0002	€ 0.003	€ 0.004

Sector	Compliance cost per business, OEL in ng/m ³ , by size		
	Small	Medium	Large
G45.2 Motor vehicle maintenance and repairs	€ 0.0003	€ 0.01	€ 0.01
N81.22 Chimney sweeps	€ 0.0002		
Total (weighted average)	€ 0.0003	€ 0.004	€ 0.01

Source: Study team.

Note: Blank cells refer to no companies with exposure.

The annual turnover and gross operating surplus, by sector and size of companies are presented below. Further analysis in the following pages below has been based on the comparison of the total compliance costs over the 40-year period with turnover and gross operating surplus of the same 40-year period.

Table 8-3 Average annual turnover per company based on Eurostat figures, by size and sector (€, millions)

Sector	Small	Medium	Large
C10.13 Meat and poultry smokehouses	€ 0.85	€ 17.26	€ 182.50
C10.2 Seafood smokehouses	€ 1.86	€ 28.77	€ 209.09
C16.1 Wood preservation (creosote)	€ 0.46	€ 20.60	€ 197.20
C19.1 Coking plants	€ 5.74	€ 75.35	€ 145.55
C19.2 Petroleum refineries	€ 2.92	€ 73.54	€ 4,042.99
C20.13 Manufacture of carbon black	€ 1.70	€ 41.85	€ 528.70
C20.14 Coal tar distillation	€ 5.92	€ 146.73	€ 1,831.41
C23.2 Manufacture of refractory products	€ 1.28	€ 20.54	€ 136.88
C23.99a Manufacture of bituminous products	€ 2.08	€ 30.20	€ 156.21
C23.99b Graphite and carbon electrode manufacture	€ 2.08	€ 30.20	€ 156.21
C24.1 Steel and iron foundries, ferroalloys	€ 0.97	€ 54.79	€ 873.75
C24.42 Manufacture of aluminium	€ 2.02	€ 66.25	€ 459.51
C24.45 Other non-ferrous metallurgy	€ 0.62	€ 20.30	€ 142.22
C24.5 Casting of metals	€ 1.11	€ 15.37	€ 96.19
D35.11 Coal fired power plants	€ 0.35	€ 66.47	€ 863.65
E38.2 Waste incineration	€ 1.43	€ 19.92	€ 185.44
E39 Soil remediation	€ 0.76	€ 14.60	€ 72.27
F42.11 Road paving	€ 0.70	€ 16.41	€ 251.51
F42.12 Welding of railroad tracks	€ 1.46	€ 34.46	€ 514.52
G45.2 Motor vehicles maintenance and repairs	€ 0.22	€ 15.22	€ 106.51
N81.22 Chimney sweeps	€ 0.13	€ 3.24	€ 35.39

Source: Study team.

Table 8-4 Average annual gross operating surplus per company based on Eurostat figures, by size and sector (€, millions)

Sector	Small	Medium	Large
C10.13 Meat and poultry smokehouses	€ 0.06	€ 1.21	€ 12.80
C10.2 Seafood smokehouses	€ 0.11	€ 1.76	€ 12.77
C16.1 Wood preservation (creosote)	€ 0.05	€ 2.23	€ 21.32
C19.1 Coking plants	€ 0.38	€ 4.94	€ 9.55
C19.2 Petroleum refineries	€ 0.04	€ 1.06	€ 58.11
C20.13 Manufacture of carbon black	€ 0.22	€ 5.42	€ 68.52
C20.14 Coal tar distillation	€ 0.42	€ 10.36	€ 129.28
C23.2 Manufacture of refractory products	€ 0.10	€ 1.58	€ 10.56
C23.99a Manufacture of bituminous products	€ 0.12	€ 1.70	€ 8.81
C23.99b Graphite and carbon electrode manufacture	€ 0.002	€ 0.03	€ 0.16
C24.1 Steel and iron foundries, ferroalloys	€ 0.01	€ 0.81	€ 12.98
C24.42 Manufacture of aluminium	€ 0.12	€ 3.93	€ 27.24
C24.45 Other non-ferrous metallurgy	€ 0.03	€ 1.03	€ 7.24
C24.5 Casting of metals	€ 0.06	€ 0.89	€ 5.57
D35.11 Coal fired power plants	€ 0.06	€ 10.59	€ 137.55
E38.2 Waste incineration	€ 0.26	€ 3.68	€ 34.28
E39 Soil remediation	€ 0.09	€ 1.68	€ 8.32
F42.11 Road paving	€ 0.06	€ 1.34	€ 20.48
F42.12 Welding of railroad tracks	€ 0.12	€ 2.82	€ 42.04
G45.2 Motor vehicles maintenance and repairs	€ 0.04	€ 3.04	€ 21.30
N81.22 Chimney sweeps	€ 0.02	€ 0.45	€ 4.95

Source: Study team.

Based on the estimated number of small, medium, and large companies, as well as Eurostat data on the turnover and gross operating surplus of companies in different size classes and sectors where exposure to [substance] can occur, the likely significance of the compliance costs modelled in Section 7 is estimated in Table 8-5. The average annual turnover of companies (which is presented in Table 8-3) has been used to calculate PV40 costs, additional to the baseline, as a percentage of 40 years (discounted) turnover.

The comparison of total compliance costs (adjustment costs, such as additional first year and re-current RMMs, discontinuations, and air monitoring, plus administrative costs) to turnover and gross operating surplus is an indicator of the overall impact to the sector over time. The discontinuation costs are sometimes a reflection of the high cost of measures that need to be implemented, where the model is insufficiently sensitive to describe and categorise them.

The negative values represent a cost-saving. These are due to companies being modelled to move from RMMs with high operating costs (such as RPE that requires frequent changes) to RMMs with high capital expenditure but low operating costs (such as closed systems), that over the assessment period result in cost savings.

The table below shows that at 7 ng/m³ approximately half of all sectors' small and medium sized enterprises will experience high costs as a percentage of turnover (1-6%), with exceptions (<1%) being C10.13 and C10.2 smokehouses, C16.1 wood preservation with creosote, C23.99a Manufacture of bituminous products, C23.99b graphite and carbon electrode manufacture, C24.1 steel and iron foundries, C24.5 casting of metals, E38.2 waste incineration, F42.11 road paving, and G45.2 Motor vehicle maintenance and repair. The hardest hit with ≥3% costs as a percentage of turnover over 40 years are: coking plants (C19.1), refineries (C19.2), manufacturers of carbon black (C20.13), coal tar distillation (C20.14), non-ferrous metallurgy (C24.45). Percentages for large enterprises are lower at this level, between 0.01-0.5% turnover. In the sectors where SMEs are active, clearly the costs represent a significantly higher percentage of turnover than for large companies.

At the 70 ng/m³ policy option, the companies that are most affected are small/medium within C19.1 coking plants, and C20.14 coal tar distillation plants (>1%).

At the 700 and 2000 ng/m³ policy options a similar pattern is observed but the values are never higher than 0.01% of the turnover of a company. Again, large businesses are least affected.

Table 8-5 Total PV compliance costs (RMMs, discontinuations, monitoring and administrative burden) as percentage of turnover discounted over 40 years, by policy options, sector and company size and proportion of companies discontinuing at least a part of their business

Sector	Compliance costs as a percentage of turnover, per company			Percentage of companies discontinuing
	Small	Medium	Large	
7 ng/m³				
C10.13 Meat and poultry smokehouses	0.07%	0.07%	0.02%	0%
C10.2 Seafood smokehouses	0.06%	0.06%	0.02%	1%
C16.1 Wood preservation (creosote)	-2.04%	-0.04%		0%
C19.1 Coking plants	6.34%	6.20%	0.48%	100%
C19.2 Petroleum refineries	3.78%	3.83%	0.38%	60%
C20.13 Manufacture of carbon black		3.18%	0.31%	50%
C20.14 Coal tar distillation		4.96%	0.32%	62%
C23.2 Manufacture of refractory products	0.82%	1.02%		14%
C23.99a Manufacture of bituminous products	0.05%	0.05%	0.04%	0%
C23.99b Graphite and carbon electrode manufacture			0.31%	44%
C24.1 Steel and iron foundries, ferroalloys	0.58%	0.66%	0.07%	10%
C24.42 Manufacture of aluminium		2.27%	0.19%	30%
C24.45 Other non-ferrous metallurgy	2.96%	2.88%	0.30%	44%

Sector	Compliance costs as a percentage of turnover, per company			Percentage of companies discontinuing
	Small	Medium	Large	
<i>C24.5 Casting of metals</i>	0.45%	0.34%	0.11%	2%
<i>D35.11 Coal fired power plants</i>	2.13%	2.55%	0.25%	40%
<i>E38.2 Waste incineration</i>	0.19%	0.19%	0.01%	3%
<i>E39 Soil remediation</i>	1.50%	1.41%	0.11%	22%
<i>F42.11 Road paving</i>	0.08%	0.07%	0.06%	0%
<i>F42.12 Welding of railroad tracks</i>	3.58%	3.58%	0.38%	55%
<i>G45.2 Motor vehicles maintenance and repairs</i>	0.05%	0.02%	0.01%	0%
<i>N81.22 Chimney sweeps</i>	1.47%			5%
70 ng/m³				
<i>C10.13 Meat and poultry smokehouses</i>	0.005%	0.01%	0.003%	0%
<i>C10.2 Seafood smokehouses</i>	0.005%	0.005%	0.003%	0%
<i>C16.1 Wood preservation (creosote)</i>	0.01%	0.002%		0%
<i>C19.1 Coking plants</i>	2.87%	2.85%	0.26%	45%
<i>C19.2 Petroleum refineries</i>	0.19%	0.19%	0.02%	3%
<i>C20.13 Manufacture of carbon black</i>		0.002%	0.001%	0%
<i>C20.14 Coal tar distillation</i>		2.46%	0.19%	34%
<i>C23.2 Manufacture of refractory products</i>	0.08%	0.12%		1%
<i>C23.99a Manufacture of bituminous products</i>	0.004%	0.004%	0.002%	0%
<i>C23.99b Graphite and carbon electrode manufacture</i>			0.12%	16%
<i>C24.1 Steel and iron foundries, ferroalloys</i>	0.06%	0.07%	0.01%	1%
<i>C24.42 Manufacture of aluminium</i>		0.01%	0.04%	4%
<i>C24.45 Other non-ferrous metallurgy</i>	0.60%	0.60%	0.09%	9%
<i>C24.5 Casting of metals</i>	0.02%	0.01%	0.003%	0%
<i>D35.11 Coal fired power plants</i>	0.05%	0.001%	0.0004%	0%
<i>E38.2 Waste incineration</i>	0.00%	0.002%	0.0003%	0%
<i>E39 Soil remediation</i>	0.13%	0.12%	0.00%	2%
<i>F42.11 Road paving</i>	0.01%	0.01%	0.005%	0%
<i>F42.12 Welding of railroad tracks</i>	0.08%	0.07%	0.02%	1%
<i>G45.2 Motor vehicles maintenance and repairs</i>	0.014%	0.003%	0.0007%	0%
<i>N81.22 Chimney sweeps</i>	0.020%			0%

Sector	Compliance costs as a percentage of turnover, per company			Percentage of companies discontinuing
	Small	Medium	Large	
700 ng/m³				
C10.13 Meat and poultry smokehouses	0.002%	0.001%	0.0002%	0%
C10.2 Seafood smokehouses	0.001%	0.001%	0.0002%	0%
C16.1 Wood preservation (creosote)	0.004%	0.002%		0%
C19.1 Coking plants	0.0001%	-0.004%	-0.001%	0%
C19.2 Petroleum refineries	0.001%	0.001%	0.00001%	0%
C20.13 Manufacture of carbon black		0.001%	0.0001%	0%
C20.14 Coal tar distillation		0.001%	0.0002%	0%
C23.2 Manufacture of refractory products	0.001%	0.01%		0%
C23.99a Manufacture of bituminous products	0.001%	0.001%	0.0003%	0%
C23.99b Graphite and carbon electrode manufacture			0.0003%	0%
C24.1 Steel and iron foundries, ferroalloys	0.002%	0.001%	0.0001%	0%
C24.42 Manufacture of aluminium		0.0004%	0.0001%	0%
C24.45 Other non-ferrous metallurgy	0.004%	0.003%	0.002%	0%
C24.5 Casting of metals	0.002%	0.002%	0.001%	0%
D35.11 Coal fired power plants	0.004%	0.0003%	0.00004%	0%
E38.2 Waste incineration	0.001%	0.001%	0.0002%	0%
E39 Soil remediation	0.003%	0.002%	0.001%	0%
F42.11 Road paving	0.002%	0.002%	0.0002%	0%
F42.12 Welding of railroad tracks	0.002%	0.002%	0.001%	0%
G45.2 Motor vehicles maintenance and repairs	0.01%	0.002%	0.0005%	0%
N81.22 Chimney sweeps	0.01%			0%
2000 ng/m³				
C10.13 Meat and poultry smokehouses	0.001%	0.001%	0.0001%	0%
C10.2 Seafood smokehouses	0.001%	0.001%	0.0002%	0%
C16.1 Wood preservation (creosote)	0.002%	0.001%		0%
C19.1 Coking plants	0.0003%	0.0003%	0.0003%	0%
C19.2 Petroleum refineries	0.0005%	0.0003%	0.00001%	0%
C20.13 Manufacture of carbon black		0.0004%	0.00005%	0%
C20.14 Coal tar distillation		0.0001%	0.00002%	0%

Sector	Compliance costs as a percentage of turnover, per company			Percentage of companies discontinuing
	Small	Medium	Large	
<i>C23.2 Manufacture of refractory products</i>	0.001%	0.001%		0%
<i>C23.99a Manufacture of bituminous products</i>	0.001%	0.001%	0.0002%	0%
<i>C23.99b Graphite and carbon electrode manufacture</i>			0.0002%	0%
<i>C24.1 Steel and iron foundries, ferroalloys</i>	0.001%	0.0003%	0.00003%	0%
<i>C24.42 Manufacture of aluminium</i>		0.0003%	0.0001%	0%
<i>C24.45 Other non-ferrous metallurgy</i>	0.001%	0.001%	0.0001%	0%
<i>C24.5 Casting of metals</i>	0.001%	0.001%	0.0004%	0%
<i>D35.11 Coal fired power plants</i>	0.002%	0.0002%	0.00002%	0%
<i>E38.2 Waste incineration</i>	0.001%	0.001%	0.0001%	0%
<i>E39 Soil remediation</i>	0.002%	0.002%	0.001%	0%
<i>F42.11 Road paving</i>	0.001%	0.001%	0.0001%	0%
<i>F42.12 Welding of railroad tracks</i>	0.0005%	0.0003%	0.00003%	0%
<i>G45.2 Motor vehicles maintenance and repairs</i>	0.01%	0.001%	0.0003%	0%
<i>N81.22 Chimney sweeps</i>	0.01%			0%

Source: Study team.

Note: blank cells refer to no companies with exposure.

The average annual operating surplus presented in Table 8-4 has been used to calculate PV40 costs additional to the baseline as a percentage of gross operating surplus (GOS). Figures on GOS have been extracted from Eurostat, however there is a high degree of uncertainty on the reliability of the data used due to missing entries, and data only being available at one decimal level NACE code (e.g. C15.1) suggesting that figures may include irrelevant subsectors. Figures relating to GOS have been recalculated to better reflect the subsectors of interest but should be read with caution. The study team has not been able to verify the accuracy of average GOS per company (Table 8-4) through consultation.

As shown in Table 8-6, at the lowest policy option small and medium companies in C19.1 coking plants, C19.2 petroleum refineries, C20.14 coal tar distillation plants, C24.45 other non-ferrous metallurgy would have between 50% to >100% of the GOS dedicated to implementing compliance costs over 40 years, whereas large companies in the same sectors would have 5-27% diverted to implementing compliance costs. C23.99b graphite and carbon electrode manufacturers are all large companies and they would be required to invest almost three times their operating surplus; albeit these are all sectors with high levels of discontinuation. Small and medium companies in C20.13 manufacture of carbon black, C23.2 manufacture of refractory products, C24.1 steel, iron and ferroalloy foundries, C24.42 aluminium manufacturers, D35.11 coal power plants, E39.0 soil remediation and F42.12 train track welders would still need to invest between 10% and 50% of their gross operating surplus. Casting of metals C24.5 and chimney sweeps, N81.22 would need to invest 5-10% of their GOS.

As indicated in previous sections, the cost savings for C16.1 wood preservation using creosote result from the model predicting that companies will choose to invest in RMMs that have a lower operating cost over the assessment period (in this case moving to closed systems).

At the 70 ng/m³ policy option small and medium companies in: coking (C19.1), refineries (C19.2), coal tar distillation (C20.14) and non-ferrous metallurgy (C24.45) would need to invest a significant amount of their gross operating surplus (10-50%), with coking companies requiring the largest proportion of investments over 40 years. Large companies in these sectors would require 1-5% investments. Graphite and carbon electrode manufacturers are only large companies, and they would require approximately 117% of their gross operating surplus to be invested over 40 years. In general, manufacturers of refractory products (C23.2), steel and iron foundries (C24.1), coal fired power plants (D35.11), soil remediation (E39.0) small and medium businesses would need to spend 1-10% of their gross operating surplus over 40 years at this level.

The study team believes that aluminium, steel, iron and ferroalloy manufacturers would also require large investments at this level. For aluminium manufacturers, the pre-baking of anodes is an essential part of the manufacturing process that generates high levels of exposure. The plants where this takes place are large and therefore investments are expected to be high. Consultation revealed that manufacturers of iron, steel and ferroalloys do not believe that their sectors have exposure to PAH, however literature data as well as IARC indicate that they do. While the latter sectors will have exposure to other pollutants and are likely to have risk management measures in place to protect their workers from them, initial investigations and additional initial investments that are not picked up via modelling are likely to be needed.

The metallurgical sectors and graphite and carbon electrode manufacturers are experiencing high pressures from imports from outside the EU that are driving down profits and outputs. These sectors, as well coking (C19.1), carbon black manufacturers (C20.13) and coal tar distillation (C20.14), foundries (C24.1, C24.42, C24.45), graphite and carbon electrode manufacturers (C23.99b) also tend to be part of multinationals, which may review the profitability and viability of the EU plants following the implementation of a more stringent OEL.

At the 700 ng/m³ manufacturers of graphite and carbon electrodes (C23.99b) and steel and iron foundries (C24.1) are required to invest the most overall (up to 1%). Wood preservation companies (C16.1), refineries (C19.2), other metallurgical operations (C25.45) and casters (C24.5) are the groups that require the second most financial investment.

At the 2000 ng/m³ policy option investments are less than 0.5% of gross operating surplus, except for C16.1, C19.2, C23.99b, C24.1, D35.11 and N81.22 but do not exceed 1% apart from small foundries (C24.1) and graphite and carbon electrodes are at 0.89%.

Of note, is that the market impacts and discontinuations for C23.99b graphite and carbon electrodes are thought to not have accurately modelled the difficulties that companies in this sector would face to meet the two lowest policy options. This is because, based on stakeholder consultation, there are a number of activities with high exposure levels, the plants cover a large surface area (resulting in large areas and high costs needed to implement exposure reduction measures) and alternatives are not currently available. Therefore, the total costs as a percentage of turnover and GOS are likely to be underestimated.

Table 8-6 Total PV compliance costs (RMMs, discontinuations, monitoring and administrative burden) as percentage of gross operating surplus discounted over 40 years, by policy options, sector and company size and proportion of companies discontinuing at least a part of their business

Sector	Compliance costs as a percent- age of gross operating surplus, per company			Percentage of companies discontinuing
	Small	Medium	Large	
7 ng/m³				
C10.13 Meat and poultry smokehouses	0.93%	1.02%	0.33%	0%
C10.2 Seafood smokehouses	0.99%	0.96%	0.32%	1%
C16.1 Wood preservation (creosote)	-18.88%	-0.39%		0%
C19.1 Coking plants	96.68%	94.43%	7.29%	100%
C19.2 Petroleum refineries	262.66%	266.54%	26.71%	60%
C20.13 Manufacture of carbon black		24.54%	2.41%	50%
C20.14 Coal tar distillation		70.21%	4.58%	62%
C23.2 Manufacture of refractory products	10.59%	13.21%		14%
C23.99a Manufacture of bituminous products	0.90%	0.81%	0.62%	0%
C23.99b Graphite and carbon electrode manufacture			296.54%	44%
C24.1 Steel and iron foundries, ferroalloys	38.96%	44.19%	4.72%	10%
C24.42 Manufacture of aluminium		38.34%	3.12%	30%
C24.45 Other non-ferrous metallurgy	58.14%	56.51%	5.93%	44%
C24.5 Casting of metals	7.75%	5.89%	1.96%	2%
D35.11 Coal fired power plants	13.37%	16.02%	1.57%	40%
E38.2 Waste incineration	1.02%	1.02%	0.08%	3%
E39 Soil remediation	13.07%	12.28%	0.99%	22%
F42.11 Road paving	1.03%	0.88%	0.76%	0%
F42.12 Welding of railroad tracks	43.87%	43.80%	4.69%	55%
G45.2 Motor vehicles maintenance and repairs	0.27%	0.08%	0.05%	0%
N81.22 Chimney sweeps	10.49%			5%
70 ng/m³				
C10.13 Meat and poultry smokehouses	0.07%	0.10%	0.05%	0%
C10.2 Seafood smokehouses	0.08%	0.09%	0.05%	0%
C16.1 Wood preservation (creosote)	0.06%	0.02%		0%
C19.1 Coking plants	43.75%	43.48%	3.91%	45%
C19.2 Petroleum refineries	13.38%	13.44%	1.35%	3%
C20.13 Manufacture of carbon black		0.02%	0.01%	0%
C20.14 Coal tar distillation		34.89%	2.72%	34%

Sector	Compliance costs as a percentage of gross operating surplus, per company			Percentage of companies discontinuing
	Small	Medium	Large	
C23.2 Manufacture of refractory products	1.00%	1.55%		1%
C23.99a Manufacture of bituminous products	0.07%	0.07%	0.04%	0%
C23.99b Graphite and carbon electrode manufacture			116.82%	16%
C24.1 Steel and iron foundries, ferroalloys	3.75%	4.41%	0.46%	1%
C24.42 Manufacture of aluminium		0.19%	0.70%	4%
C24.45 Other non-ferrous metallurgy	11.69%	11.86%	1.70%	9%
C24.5 Casting of metals	0.26%	0.23%	0.05%	0%
D35.11 Coal fired power plants	0.32%	0.01%	0.003%	0%
E38.2 Waste incineration	0.01%	0.01%	0.002%	0%
E39 Soil remediation	1.14%	1.09%	-0.03%	2%
F42.11 Road paving	0.18%	0.12%	0.06%	0%
F42.12 Welding of railroad tracks	1.03%	0.91%	0.26%	1%
G45.2 Motor vehicles maintenance and repairs	0.07%	0.015%	0.003%	0%
N81.22 Chimney sweeps	0.14%			0%
700 ng/m³				
C10.13 Meat and poultry smokehouses	0.02%	0.02%	0.003%	0%
C10.2 Seafood smokehouses	0.02%	0.02%	0.004%	0%
C16.1 Wood preservation (creosote)	0.04%	0.01%		0%
C19.1 Coking plants	0.002%	-0.06%	-0.01%	0%
C19.2 Petroleum refineries	0.05%	0.04%	0.001%	0%
C20.13 Manufacture of carbon black		0.01%	0.001%	0%
C20.14 Coal tar distillation		0.01%	0.003%	0%
C23.2 Manufacture of refractory products	0.01%	0.10%		0%
C23.99a Manufacture of bituminous products	0.02%	0.02%	0.01%	0%
C23.99b Graphite and carbon electrode manufacture			0.30%	0%
C24.1 Steel and iron foundries, ferroalloys	0.13%	0.04%	0.004%	0%
C24.42 Manufacture of aluminium		0.01%	0.002%	0%
C24.45 Other non-ferrous metallurgy	0.08%	0.06%	0.04%	0%
C24.5 Casting of metals	0.03%	0.03%	0.01%	0%
D35.11 Coal fired power plants	0.02%	0.002%	0.0003%	0%

Sector	Compliance costs as a percentage of gross operating surplus, per company			Percentage of companies discontinuing
	Small	Medium	Large	
E38.2 Waste incineration	0.01%	0.01%	0.001%	0%
E39 Soil remediation	0.02%	0.02%	0.01%	0%
F42.11 Road paving	0.03%	0.02%	0.002%	0%
F42.12 Welding of railroad tracks	0.03%	0.02%	0.01%	0%
G45.2 Motor vehicles maintenance and repairs	0.04%	0.01%	0.002%	0%
N81.22 Chimney sweeps	0.07%			0%
2000 ng/m³				
C10.13 Meat and poultry smokehouses	0.02%	0.01%	0.002%	0%
C10.2 Seafood smokehouses	0.01%	0.01%	0.003%	0%
C16.1 Wood preservation (creosote)	0.02%	0.01%		0%
C19.1 Coking plants	0.004%	0.005%	0.004%	0%
C19.2 Petroleum refineries	0.04%	0.02%	0.001%	0%
C20.13 Manufacture of carbon black		0.003%	0.0003%	0%
C20.14 Coal tar distillation		0.002%	0.0002%	0%
C23.2 Manufacture of refractory products	0.01%	0.01%		0%
C23.99a Manufacture of bituminous products	0.01%	0.01%	0.004%	0%
C23.99b Graphite and carbon electrode manufacture			0.15%	0%
C24.1 Steel and iron foundries, ferroalloys	0.08%	0.02%	0.002%	0%
C24.42 Manufacture of aluminium		0.01%	0.001%	0%
C24.45 Other non-ferrous metallurgy	0.02%	0.01%	0.003%	0%
C24.5 Casting of metals	0.02%	0.03%	0.01%	0%
D35.11 Coal fired power plants	0.01%	0.001%	0.0001%	0%
E38.2 Waste incineration	0.004%	0.005%	0.001%	0%
E39 Soil remediation	0.02%	0.01%	0.005%	0%
F42.11 Road paving	0.01%	0.01%	0.001%	0%
F42.12 Welding of railroad tracks	0.01%	0.004%	0.0004%	0%
G45.2 Motor vehicles maintenance and repairs	0.03%	0.01%	0.002%	0%
N81.22 Chimney sweeps	0.05%			0%

Source: Study team.

Note: Blank cells refer to no companies with exposure.

Table 8-7 provides an overview of the aggregated first year compliance costs for companies that continue. First year costs include the initial capital expenditure of installing alternative RMMs as well as one year of alternative operational costs (minus one year of existing RMM operational costs), one year of air monitoring costs, one year of biomonitoring costs, and their associated administrative burden.

Table 8-7 First year compliance costs (RMMs, monitoring and administrative burden), by policy options, sector and company size (minus discontinuations)

Sector	First year PV compliance costs			
	Small	Medium	Large	Total
7 ng/m³				
C10.13 Meat and poultry smoke-houses	€ 0.47	€ 0.31	€ 0.98	€ 1.76
C10.2 Seafood smokehouses	€ 0.85	€ 1.62	€ 2.15	€ 4.62
C16.1 Wood preservation (creosote)	€ 3.46	€ 0.55		€ 4.01
C19.1 Coking plants	€ 0.11	€ 0.14	€ 0.43	€ 0.67
C19.2 Petroleum refineries	€ 0.19	€ 1.25	€ 24.02	€ 25.46
C20.13 Manufacture of carbon black		€ 2.02	€ 2.94	€ 4.96
C20.14 Coal tar distillation		€ 0.95	€ 2.75	€ 3.69
C23.2 Manufacture of refractory products	€ 0.18	€ 0.27		€ 0.45
C23.99a Manufacture of bituminous products	€ 12.23	€ 12.69	€ 10.68	€ 35.61
C23.99b Graphite and carbon electrode manufacture			€ 10.38	€ 10.38
C24.1 Steel and iron foundries, ferroalloys	€ 32.15	€ 25.51	€ 172.69	€ 230.34
C24.42 Manufacture of aluminium		€ 0.82	€ 5.87	€ 6.68
C24.45 Non-ferrous metallurgy	€ 1.48	€ 1.51	€ 4.42	€ 7.41
C24.5 Casting of metals	€ 104.38	€ 192.10	€ 254.28	€ 550.76
D35.11 Coal fired power plants	€ 1.39	€ 3.58	€ 8.46	€ 13.43
E38.2 Waste incineration	€ 1.62	€ 0.98	€ 1.04	€ 3.64
E39 Soil remediation	€ 76.41	€ 26.38	€ 12.86	€ 115.64
F42.11 Road paving	€ 64.68	€ 40.25	€ 47.25	€ 152.18
F42.12 Welding of railroad tracks	€ 13.81	€ 4.79	€ 11.69	€ 30.29
G45.2 Motor vehicle maintenance and repairs	€ 678.82	€ 31.09	€ 12.08	€ 721.98
N81.22 Chimney sweeps	€ 407.29			€ 407.29
Total	€ 1,399.53	€ 346.79	€ 584.94	€ 2,331.26

Sector	First year PV compliance costs			
	Small	Medium	Large	Total
70 ng/m³				
C10.13 Meat and poultry smoke-houses	€ 0.12	€ 0.10	€ 0.23	€ 0.45
C10.2 Seafood smokehouses	€ 0.30	€ 0.45	€ 0.55	€ 1.30
C16.1 Wood preservation (creo-sote)	€ 0.13	€ 0.02		€ 0.14
C19.1 Coking plants	€ 0.95	€ 1.48	€ 5.04	€ 7.47
C19.2 Petroleum refineries	€ 0.10	€ 0.45	€ 9.29	€ 9.84
C20.13 Manufacture of carbon black		€ 0.48	€ 0.48	€ 0.96
C20.14 Coal tar distillation		€ 1.00	€ 3.29	€ 4.29
C23.2 Manufacture of refractory products	€ 0.05	€ 0.08		€ 0.13
C23.99a Manufacture of bitumi-nous products	€ 1.46	€ 1.88	€ 1.39	€ 4.73
C23.99b Graphite and carbon electrode manufacture			€ 7.31	€ 7.31
C24.1 Steel and iron foundries, ferroalloys	€ 4.02	€ 3.42	€ 23.65	€ 31.09
C24.42 Manufacture of aluminium		€ 0.46	€ 2.97	€ 3.43
C24.45 Other non-ferrous metal-lurgy	€ 1.17	€ 1.39	€ 5.03	€ 7.58
C24.5 Casting of metals	€ 16.11	€ 33.92	€ 45.01	€ 95.03
D35.11 Coal fired power plants	€ 0.83	€ 1.00	€ 3.30	€ 5.13
E38.2 Waste incineration	€ 0.38	€ 0.31	€ 0.20	€ 0.89
E39 Soil remediation	€ 17.17	€ 6.44	€ 2.97	€ 26.58
F42.11 Road paving	€ 35.21	€ 18.50	€ 19.31	€ 73.02
F42.12 Welding of railroad tracks	€ 13.78	€ 10.21	€ 13.94	€ 37.93
G45.2 Motor vehicle maintenance and repairs	€ 286.03	€ 6.11	€ 1.48	€ 293.63
N81.22 Chimney sweeps	€ 11.74			€ 11.74
Total	€ 389.55	€ 87.68	€ 145.44	€ 622.66
700 ng/m³				
C10.13 Meat and poultry smoke-houses	€ 0.08	€ 0.06	€ 0.05	€ 0.19
C10.2 Seafood smokehouses	€ 0.21	€ 0.27	€ 0.15	€ 0.63
C16.1 Wood preservation (creo-sote)	€ 0.12	€ 0.01		€ 0.13

Sector	First year PV compliance costs			
	Small	Medium	Large	Total
C19.1 Coking plants	€ 0.25	€ 0.29	€ 1.08	€ 1.62
C19.2 Petroleum refineries	€ 0.03	€ 0.15	€ 3.24	€ 3.42
C20.13 Manufacture of carbon black		€ 0.15	€ 0.09	€ 0.24
C20.14 Coal tar distillation		€ 0.12	€ 0.42	€ 0.54
C23.2 Manufacture of refractory products	€ 0.02	€ 0.02		€ 0.03
C23.99a Manufacture of bituminous products	€ 0.66	€ 0.68	€ 0.40	€ 1.75
C23.99b Graphite and carbon electrode manufacture			€ 0.26	€ 0.26
C24.1 Steel and iron foundries, ferroalloys	€ 1.80	€ 0.93	€ 8.37	€ 11.10
C24.42 Manufacture of aluminium		€ 0.02	€ 0.07	€ 0.09
C24.45 Other non-ferrous metal-lurgy	€ 0.08	€ 0.10	€ 0.31	€ 0.48
C24.5 Casting of metals	€ 2.83	€ 4.40	€ 4.37	€ 11.60
D35.11 Coal fired power plants	€ 0.31	€ 0.28	€ 1.12	€ 1.71
E38.2 Waste incineration	€ 0.31	€ 0.25	€ 0.17	€ 0.73
E39 Soil remediation	€ 2.04	€ 0.71	€ 0.22	€ 2.97
F42.11 Road paving	€ 21.39	€ 10.02	€ 12.26	€ 43.67
F42.12 Welding of railroad tracks	€ 1.55	€ 1.23	€ 2.24	€ 5.03
G45.2 Motor vehicle maintenance and repairs	€ 233.95	€ 5.10	€ 1.36	€ 240.41
N81.22 Chimney sweeps	€ 8.80			€ 8.80
Total	€ 274.42	€ 24.79	€ 36.18	€ 335.39
2000 ng/m³				
C10.13 Meat and poultry smoke-houses	€ 0.08	€ 0.06	€ 0.04	€ 0.18
C10.2 Seafood smokehouses	€ 0.21	€ 0.25	€ 0.14	€ 0.60
C16.1 Wood preservation (creo-sote)	€ 0.11	€ 0.01		€ 0.13
C19.1 Coking plants	€ 0.06	€ 0.08	€ 0.26	€ 0.41
C19.2 Petroleum refineries	€ 0.03	€ 0.12	€ 3.07	€ 3.21
C20.13 Manufacture of carbon black		€ 0.10	€ 0.07	€ 0.17
C20.14 Coal tar distillation		€ 0.03	€ 0.07	€ 0.10

Sector	First year PV compliance costs			
	Small	Medium	Large	Total
C23.2 Manufacture of refractory products	€ 0.01	€ 0.01		€ 0.01
C23.99a Manufacture of bituminous products	€ 0.64	€ 0.63	€ 0.38	€ 1.65
C23.99b Graphite and carbon electrode manufacture			€ 0.18	€ 0.18
C24.1 Steel and iron foundries, ferroalloys	€ 1.59	€ 0.70	€ 7.96	€ 10.25
C24.42 Manufacture of aluminium		€ 0.01	€ 0.06	€ 0.08
C24.45 Other non-ferrous metallurgy	€ 0.02	€ 0.02	€ 0.03	€ 0.08
C24.5 Casting of metals	€ 2.63	€ 3.60	€ 3.96	€ 10.19
D35.11 Coal fired power plants	€ 0.30	€ 0.20	€ 1.05	€ 1.56
E38.2 Waste incineration	€ 0.26	€ 0.17	€ 0.15	€ 0.58
E39 Soil remediation	€ 1.90	€ 0.59	€ 0.20	€ 2.69
F42.11 Road paving	€ 18.16	€ 6.96	€ 11.22	€ 36.34
F42.12 Welding of railroad tracks	€ 1.04	€ 0.38	€ 0.53	€ 1.95
G45.2 Motor vehicle maintenance and repairs	€ 207.60	€ 3.99	€ 1.22	€ 212.81
N81.22 Chimney sweeps	€ 7.76			€ 7.76
Total	€ 242.38	€ 17.92	€ 30.63	€ 290.93

Source: Study team.

Note: Blank cells indicate that there are no companies with exposure, e.g. there are no medium and large companies predicted in N81.22 chimney sweeping.

The table presents costs for the proportion of companies continuing operation, i.e. costs for those not discontinuing. For example, 100% of coking plants will have discontinued at 7 ng/m³ and therefore the costs may seem low, but in reality this is because there are no companies left (100% discontinuation) and the costs are due to the initial monitoring costs incurred by companies before closing down. Also, as indicated previously, the figures should be treated with caution as discontinuation costs have been removed from the calculations, but the modelling uses discontinuation costs as a representation of high costs that companies will incur but that cannot be easily modelled.

Whilst first year cost percentages only represent the initial cost burden for companies, they are a better gauge of the difficulty for continuing companies over 40 years than Table 8-5 and Table 8-6 (PV40 costs) which include the cost of discontinuations (discontinued companies would not incur the same costs over 40 years) and presents the overall impact of all costs on the sector. Subsequently Table 8-8 (first year costs as a percentage of turnover) and Table 8-9 (first year costs as a percentage of operating surplus) provide a better description of where sectors may increase the price of products/services to mitigate their compliance costs, although this is also dependent on the elasticity of demand for products/services in a given sector. If a company cannot pass on the costs down the supply chain, it will have to cover the costs out of its profit. They also provide a better indication of whether high upfront investments could be preventative for market entry and force existing companies to cease their activities.

Percentages in the following two tables only relate to the proportion of the sector that are not discontinuing (i.e. the costs for continuing companies as a percentage of the estimated turnover/operating surplus of only continuing companies). Percentages in these tables should be read with caution as they do not represent the entirety of impacts on the sectors, only the impacts for those continuing operation. For example, 100% of coking plants will have discontinued at 7 ng/m³ and therefore the costs may seem low as a percentage of turnover (as below), but this is because there are no companies left. The remaining costs for this sector are due to the initial monitoring costs incurred by companies before closing and not the cost of discontinuing. Other sectors with high discontinuations at 7 ng/m³ include C19.2 petroleum refineries (60% discontinuing), C20.13 manufacture of carbon black (50% discontinuing), C20.14 coal tar distillation (62% discontinuing), C23.99b graphite and carbon electrode manufacture (44% discontinuing), C24.42 manufacture of aluminium (30% discontinuing), C24.45 other non-ferrous metallurgy (44% discontinuing), D35.11 coal fired power plants (40% discontinuing), E39 soil remediation (21% discontinuing) and F42.12 welding of railroad tracks (55% discontinuing).

The figures should also be treated with caution due to discontinuation costs being removed from these calculations, whereas discontinuation costs also represent the difficulties some sectors may have in complying (i.e. very high costs without companies discontinuing) which cannot be easily modelled. In removing discontinuation costs, it is possible that impacts may be underestimated.

At the lowest policy option first year costs are particularly high (around 1% or more) for remaining small and/or medium businesses in C16.1 wood preservation, C23.2 manufacture of refractory products, C24.1 steel and iron foundries, ferroalloys, C24.45 non-ferrous metallurgy, C24.5 Casting of metals, D35.11 coal fired power plants, E39 soil remediation, F42.12 welding of train tracks and N81.22 chimney sweeps.

At the 70 ng/m³ coking plants (C19.1, medium and large companies), manufacturers of refractory products (C23.2, small), manufacturers of non-ferrous metallurgy (C25.45, small and medium) and coal fired power plants (D35.11, small) may face the biggest difficulties in implementing RMMs as values are >1% turnover. However, this does not take into account that in some sectors (C19.1, C20.14 and C23.99b) a significant number of discontinuations (>15%) are estimated.

At the 700 ng/m³ and 2000 ng/m³ the costs are largely negligible.

Table 8-8 First year compliance costs (RMMs, monitoring and administrative burden) minus discontinuation as percentage of annual turnover, by policy options, sector and company size, and the proportion of companies expected to continue operations

Sector	First year costs % of annual turnover (incurred by % of companies continuing)			% of companies continuing
	Small	Medium	Large	
7 ng/m³				
C10.13 Meat and poultry smokehouses	0.26%	0.14%	0.18%	100%
C10.2 Seafood smokehouses	0.16%	0.16%	0.15%	100%
C16.1 Wood preservation (creosote)	19.48%	2.67%		100%
C19.1 Coking plants	-	-	-	0%
C19.2 Petroleum refineries	0.53%	0.35%	0.04%	40%

Sector	First year costs % of annual turnover (incurred by % of companies continuing)			% of companies continuing
	Small	Medium	Large	
C20.13 Manufacture of carbon black		0.48%	0.22%	50%
C20.14 Coal tar distillation		0.94%	0.08%	38%
C23.2 Manufacture of refractory products	4.07%	1.51%		86%
C23.99a Manufacture of bituminous products	0.56%	0.42%	0.28%	100%
C23.99b Graphite and carbon electrode manufacture			0.53%	56%
C24.1 Steel and iron foundries, ferroalloys	1.45%	0.46%	0.16%	90%
C24.42 Manufacture of aluminium		0.63%	0.29%	70%
C24.45 Non-ferrous metallurgy	6.31%	1.65%	1.11%	56%
C24.5 Casting of metals	2.39%	2.36%	1.47%	98%
D35.11 Coal fired power plants	5.26%	0.20%	0.06%	60%
E38.2 Waste incineration	0.19%	0.12%	0.06%	97%
E39 Soil remediation	3.89%	2.61%	2.26%	79%
F42.11 Road paving	0.32%	0.19%	0.07%	100%
F42.12 Welding of railroad tracks	1.06%	0.36%	0.26%	45%
G45.2 Motor vehicle maintenance and repairs	0.83%	0.34%	0.23%	100%
N81.22 Chimney sweeps	17.64%			95%
70 ng/m³				
C10.13 Meat and poultry smokehouses	0.07%	0.04%	0.04%	100%
C10.2 Seafood smokehouses	0.06%	0.04%	0.04%	100%
C16.1 Wood preservation (creosote)	0.70%	0.08%		100%
C19.1 Coking plants	0.62%	1.78%	1.26%	55%
C19.2 Petroleum refineries	0.11%	0.05%	0.01%	97%
C20.13 Manufacture of carbon black		0.06%	0.02%	100%
C20.14 Coal tar distillation		0.37%	0.06%	66%
C23.2 Manufacture of refractory products	1.08%	0.37%		99%
C23.99a Manufacture of bituminous products	0.07%	0.06%	0.04%	100%
C23.99b Graphite and carbon electrode manufacture			0.25%	84%
C24.1 Steel and iron foundries, ferroalloys	0.17%	0.06%	0.02%	99%
C24.42 Manufacture of aluminium		0.23%	0.11%	96%

Sector	First year costs % of annual turnover (incurred by % of companies continuing)			% of companies continuing
	Small	Medium	Large	
C24.45 Other non-ferrous metallurgy	3.06%	0.93%	0.78%	91%
C24.5 Casting of metals	0.36%	0.41%	0.25%	100%
D35.11 Coal fired power plants	1.90%	0.03%	0.02%	100%
E38.2 Waste incineration	0.04%	0.04%	0.01%	100%
E39 Soil remediation	0.70%	0.51%	0.42%	98%
F42.11 Road paving	0.17%	0.09%	0.03%	100%
F42.12 Welding of railroad tracks	0.50%	0.36%	0.14%	100%
G45.2 Motor vehicle maintenance and repairs	0.35%	0.07%	0.03%	100%
N81.22 Chimney sweeps	0.48%			100%
700 ng/m³				
C10.13 Meat and poultry smokehouses	0.05%	0.03%	0.01%	100%
C10.2 Seafood smokehouses	0.04%	0.03%	0.01%	100%
C16.1 Wood preservation (creosote)	0.67%	0.07%		100%
C19.1 Coking plants	0.09%	0.19%	0.15%	100%
C19.2 Petroleum refineries	0.03%	0.02%	0.002%	100%
C20.13 Manufacture of carbon black		0.02%	0.003%	100%
C20.14 Coal tar distillation		0.03%	0.01%	100%
C23.2 Manufacture of refractory products	0.32%	0.09%		100%
C23.99a Manufacture of bituminous products	0.03%	0.02%	0.01%	100%
C23.99b Graphite and carbon electrode manufacture			0.01%	100%
C24.1 Steel and iron foundries, ferroalloys	0.07%	0.02%	0.01%	100%
C24.42 Manufacture of aluminium		0.01%	0.003%	100%
C24.45 Other non-ferrous metallurgy	0.19%	0.06%	0.04%	100%
C24.5 Casting of metals	0.06%	0.05%	0.02%	100%
D35.11 Coal fired power plants	0.71%	0.01%	0.01%	100%
E38.2 Waste incineration	0.04%	0.03%	0.01%	100%
E39 Soil remediation	0.08%	0.06%	0.03%	100%
F42.11 Road paving	0.10%	0.05%	0.02%	100%
F42.12 Welding of railroad tracks	0.06%	0.04%	0.02%	100%

Sector	First year costs % of annual turnover (incurred by % of companies continuing)			% of companies continuing
	Small	Medium	Large	
G45.2 Motor vehicle maintenance and repairs	0.29%	0.06%	0.03%	100%
N81.22 Chimney sweeps	0.36%			100%
2000 ng/m³				
C10.13 Meat and poultry smokehouses	0.05%	0.03%	0.01%	100%
C10.2 Seafood smokehouses	0.04%	0.02%	0.01%	100%
C16.1 Wood preservation (creosote)	0.64%	0.06%		100%
C19.1 Coking plants	0.02%	0.06%	0.04%	100%
C19.2 Petroleum refineries	0.03%	0.01%	0.002%	100%
C20.13 Manufacture of carbon black		0.01%	0.003%	100%
C20.14 Coal tar distillation		0.01%	0.001%	100%
C23.2 Manufacture of refractory products	0.14%	0.03%		100%
C23.99a Manufacture of bituminous products	0.03%	0.02%	0.01%	100%
C23.99b Graphite and carbon electrode manufacture			0.01%	100%
C24.1 Steel and iron foundries, ferroalloys	0.06%	0.01%	0.01%	100%
C24.42 Manufacture of aluminium		0.01%	0.002%	100%
C24.45 Other non-ferrous metallurgy	0.04%	0.02%	0.005%	100%
C24.5 Casting of metals	0.06%	0.04%	0.02%	100%
D35.11 Coal fired power plants	0.69%	0.01%	0.005%	100%
E38.2 Waste incineration	0.03%	0.02%	0.01%	100%
E39 Soil remediation	0.08%	0.05%	0.03%	100%
F42.11 Road paving	0.09%	0.03%	0.02%	100%
F42.12 Welding of railroad tracks	0.04%	0.01%	0.01%	100%
G45.2 Motor vehicle maintenance and repairs	0.26%	0.04%	0.02%	100%
N81.22 Chimney sweeps	0.32%			100%

Source: Study team.

Note: Blank cells indicate that there are no companies with exposure, e.g. there are no medium and large companies predicted in N81.22 chimney sweeping.

The table presents percentages of companies continuing operation, i.e. the percentage of companies that have not discontinued. These figures do not represent the impacts on the wider sector and should be read with caution. For example, 100% of coking plants will have discontinued at 7 ng/m³ and therefore the costs may seem low as a percentage of turnover, but this is because no companies continue operation, and the remaining costs are due to the initial monitoring costs incurred by companies before closing. The figures should also be treated with

caution as discontinuation costs (which have been removed) also represent sectors with high compliance costs that would not realistically result in discontinuation but cannot be modelled.

Costs as a percentage of turnover does not take into account the profitability of the sectors, therefore the impact measured by the percentage of costs in relation to turnover will further differ depending on the sector. Table 8-9 shows first year approximate costs as a percentage of annual gross operating surplus (GOS) for the companies that continue to operate. High compliance costs in terms of upfront purchases are likely to act as a barrier for the entry of new companies as well as an indication of the ability of companies to absorb costs or pass them on to consumers. At higher OELs upfront costs are less severe and subsequently the barrier to entry is less prevalent. As indicated elsewhere, the figures do not take into account the level of discontinuations – for example, the costs as a percentage of GOS for coking plants (C19.1) are applicable to 0% of companies at the lowest policy option as 100% of companies discontinue. Also as indicated elsewhere, the numbers need to be treated with caution as discontinuation costs in some cases represent high compliance costs that cannot be easily modelled, and GOS values are taken from Eurostat and in some cases they do not represent the specific sub-NACE code being assessed.

At 7 ng/m³ the following sectors (and company sizes) would have significant (≥10%) first year costs as a percentage of annual GOS:

- C16.1 Wood preservation (small and medium companies);
- C19.2 Petroleum refineries (small and medium companies);
- C23.2 Manufacture of refractory products (small and medium companies);
- C23.99a Manufacture of bituminous products (small companies);
- C23.99b Graphite and carbon electrode manufacturers (large companies);
- C24.1 Steel and iron foundries, ferroalloys (small, medium and large companies);
- C24.42 Manufacture of aluminium (medium companies);
- C24.45 Other non-ferrous metallurgy (small, medium and large companies);
- C24.5 Casting of metals (small, medium and large companies);
- D35.11 Coal fired power plants (small companies);
- E39 soil Remediation (small, medium and large companies);
- F42.12 Welding of train tracks (small companies); and
- N81.22 Chimney sweeps (small companies).

At 70 ng/m³ the following sectors (and company sizes) would have significant first year costs (≥10%) as a percentage of annual operating surplus:

- C19.1 Coking plants (small, medium and large companies);
- C23.2 Manufacture of refractory products (small companies);
- C23.99b Graphite and carbon electrode manufacturers (large companies);
- C24.1 Steel and iron foundries, ferroalloys (small companies);
- C24.45 Other non-ferrous metallurgy (small, medium and large companies); and
- D35.11 Coal fired power plants (small companies).

Table 8-9 First year compliance costs (RMMs, monitoring and administrative burden) minus discontinuation) as a percentage of annual gross operating surplus, by policy options, sector and company size, and the proportion of companies expected to continue operations

Sector	First year costs % of gross operating surplus (incurred by % of companies continuing)			% of companies continuing
	Small	Medium	Large	
7 ng/m³				
C10.13 Meat and poultry smokehouses	3.76%	2.00%	2.56%	100%
C10.2 Seafood smokehouses	2.63%	2.57%	2.42%	100%
C16.1 Wood preservation (creosote)	180.19%	24.71%		100%
C19.1 Coking plants	-	-	-	0%
C19.2 Petroleum refineries	36.79%	24.31%	2.64%	40%
C20.13 Manufacture of carbon black		3.69%	1.71%	50%
C20.14 Coal tar distillation		13.27%	1.07%	38%
C23.2 Manufacture of refractory products	52.79%	19.61%		86%
C23.99a Manufacture of bituminous products	9.89%	7.53%	5.05%	100%
C23.99b Graphite and carbon electrode manufacture			508.38%	56%
C24.1 Steel and iron foundries, ferroalloys	97.85%	31.06%	11.03%	90%
C24.42 Manufacture of aluminium		10.64%	4.95%	70%
C24.45 Non-ferrous metallurgy	123.82%	32.40%	21.75%	56%
C24.5 Casting of metals	41.25%	40.74%	25.34%	98%
D35.11 Coal fired power plants	33.06%	1.24%	0.41%	60%
E38.2 Waste incineration	1.05%	0.63%	0.31%	97%
E39 Soil remediation	33.78%	22.68%	19.67%	79%
F42.11 Road paving	3.87%	2.34%	0.85%	100%
F42.12 Welding of railroad tracks	12.98%	4.44%	3.24%	45%
G45.2 Motor vehicle maintenance and repairs	4.17%	1.69%	1.13%	100%
N81.22 Chimney sweeps	126.00%			95%
70 ng/m³				
C10.13 Meat and poultry smokehouses	1.03%	0.61%	0.61%	100%
C10.2 Seafood smokehouses	0.92%	0.71%	0.62%	100%
C16.1 Wood preservation (creosote)	6.51%	0.73%		100%
C19.1 Coking plants	9.52%	27.10%	19.14%	55%
C19.2 Petroleum refineries	7.78%	3.68%	0.42%	97%
C20.13 Manufacture of carbon black		0.44%	0.14%	100%

Sector	First year costs % of gross operating surplus (incurred by % of companies continuing)			% of companies continuing
	Small	Medium	Large	
C20.14 Coal tar distillation		5.19%	0.91%	66%
C23.2 Manufacture of refractory products	14.01%	4.84%		99%
C23.99a Manufacture of bituminous products	1.18%	1.11%	0.66%	100%
C23.99b Graphite and carbon electrode manufacture			241.24%	84%
C24.1 Steel and iron foundries, ferroalloys	11.13%	3.79%	1.37%	99%
C24.42 Manufacture of aluminium		3.89%	1.93%	96%
C24.45 Other non-ferrous metallurgy	60.06%	18.36%	15.22%	91%
C24.5 Casting of metals	6.24%	7.05%	4.40%	100%
D35.11 Coal fired power plants	11.92%	0.21%	0.10%	100%
E38.2 Waste incineration	0.24%	0.20%	0.06%	100%
E39 Soil remediation	6.10%	4.44%	3.64%	98%
F42.11 Road paving	2.11%	1.08%	0.33%	100%
F42.12 Welding of railroad tracks	6.07%	4.39%	1.75%	100%
G45.2 Motor vehicle maintenance and repairs	1.76%	0.33%	0.14%	100%
N81.22 Chimney sweeps	3.45%			100%
700 ng/m³				
C10.13 Meat and poultry smokehouses	0.70%	0.39%	0.12%	100%
C10.2 Seafood smokehouses	0.65%	0.43%	0.16%	100%
C16.1 Wood preservation (creosote)	6.22%	0.65%		100%
C19.1 Coking plants	1.36%	2.97%	2.26%	100%
C19.2 Petroleum refineries	2.34%	1.18%	0.14%	100%
C20.13 Manufacture of carbon black		0.14%	0.03%	100%
C20.14 Coal tar distillation		0.38%	0.08%	100%
C23.2 Manufacture of refractory products	4.18%	1.12%		100%
C23.99a Manufacture of bituminous products	0.53%	0.40%	0.19%	100%
C23.99b Graphite and carbon electrode manufacture			7.11%	100%
C24.1 Steel and iron foundries, ferroalloys	4.95%	1.02%	0.48%	100%
C24.42 Manufacture of aluminium		0.13%	0.05%	100%
C24.45 Other non-ferrous metallurgy	3.71%	1.20%	0.84%	100%

Sector	First year costs % of gross operating surplus (incurred by % of companies continuing)			% of companies continuing
	Small	Medium	Large	
C24.5 Casting of metals	1.10%	0.91%	0.43%	100%
D35.11 Coal fired power plants	4.46%	0.06%	0.03%	100%
E38.2 Waste incineration	0.19%	0.16%	0.05%	100%
E39 Soil remediation	0.71%	0.48%	0.27%	100%
F42.11 Road paving	1.28%	0.58%	0.21%	100%
F42.12 Welding of railroad tracks	0.68%	0.53%	0.28%	100%
G45.2 Motor vehicle maintenance and repairs	1.44%	0.28%	0.13%	100%
N81.22 Chimney sweeps	2.59%			100%
2000 ng/m³				
C10.13 Meat and poultry smokehouses	0.69%	0.37%	0.12%	100%
C10.2 Seafood smokehouses	0.63%	0.40%	0.16%	100%
C16.1 Wood preservation (creosote)	5.95%	0.52%		100%
C19.1 Coking plants	0.35%	0.85%	0.55%	100%
C19.2 Petroleum refineries	2.11%	0.91%	0.14%	100%
C20.13 Manufacture of carbon black		0.09%	0.02%	100%
C20.14 Coal tar distillation		0.09%	0.01%	100%
C23.2 Manufacture of refractory products	1.80%	0.40%		100%
C23.99a Manufacture of bituminous products	0.51%	0.37%	0.18%	100%
C23.99b Graphite and carbon electrode manufacture			5.04%	100%
C24.1 Steel and iron foundries, ferroalloys	4.36%	0.77%	0.46%	100%
C24.42 Manufacture of aluminium		0.10%	0.04%	100%
C24.45 Other non-ferrous metallurgy	0.87%	0.30%	0.10%	100%
C24.5 Casting of metals	1.02%	0.75%	0.39%	100%
D35.11 Coal fired power plants	4.33%	0.04%	0.03%	100%
E38.2 Waste incineration	0.17%	0.11%	0.04%	100%
E39 Soil remediation	0.66%	0.40%	0.24%	100%
F42.11 Road paving	1.09%	0.41%	0.19%	100%
F42.12 Welding of railroad tracks	0.46%	0.16%	0.07%	100%
G45.2 Motor vehicle maintenance and repairs	1.28%	0.22%	0.11%	100%

Sector	First year costs % of gross operating surplus (incurred by % of companies continuing)			% of companies continuing
	Small	Medium	Large	
N81.22 Chimney sweeps	2.28%			100%

Source: Study team.

Note: Blank cells indicate that there are no companies with exposure, e.g. there are no medium and large companies predicted in N81.22 chimney sweeping.

The table presents percentages of companies continuing operation, i.e. the percentage of companies that have not discontinued. These figures do not represent the impacts on the wider sector and should be read with caution. For example, 100% of coking plants will have discontinued at 7 ng/m³ and therefore the costs may seem low as a percentage of turnover, but this is because no companies continue operation, and the remaining costs are due to the initial monitoring costs incurred by companies before closing. The figures should also be treated with caution as discontinuation costs (which have been removed) also represent sectors with high compliance costs that would not realistically result in discontinuation but cannot be modelled.

8.2 Research and innovation

Research and development (R&D) are key activities in an industry's capacity to develop new products and produce existing ones more efficiently and sustainably, in a way that protects the safety of workers. The ability of the different sectors to engage in R&D activities is likely to be affected by:

- The availability of financial resources to invest in R&D;
- The availability of human resources to conduct R&D activities; and
- The regulatory environment and whether it is conducive to invest in R&D activities.

Table 8-10 provides estimates of average R&D expenditures for small, medium and large companies in the sectors with workers exposed to PAH, based on Eurostat data. Clearly significant investment is being made in large enterprises across the different sectors.

Table 8-10 Average annual R&D expenditure per company, by company size, by sector (€ millions)

Sector	Average annual R&D expenditure per company (€ millions)		
	Small	Medium	Large
C10.13 Meat and poultry smokehouses	€ 0.01	€ 0.30	€ 3.19
C10.2 Seafood smokehouses	€ 0.03	€ 0.50	€ 3.60
C16.1 Wood preservation (creosote)	€ 0.01	€ 0.36	€ 3.44
C19.1 Coking plants	€ 0.10	€ 1.32	€ 2.54
C19.2 Petroleum refineries	€ 0.05	€ 1.29	€ 70.65
C20.13 Manufacture of carbon black	€ 0.03	€ 0.73	€ 9.24
C20.14 Coal tar distillation	€ 0.07	€ 1.67	€ 20.89
C23.2 Manufacture of refractory products	€ 0.02	€ 0.36	€ 2.39
C23.99a Manufacture of bituminous products	€ 0.04	€ 0.53	€ 2.73

Sector	Average annual R&D expenditure per company (€ millions)		
	Small	Medium	Large
C23.99b Graphite and carbon electrode manufacture	€ 0.04	€ 0.53	€ 2.73
C24.1 Steel and iron foundries, ferroalloys	€ 0.02	€ 0.96	€ 15.27
C24.42 Manufacture of aluminium	€ 0.04	€ 1.16	€ 8.03
C24.45 Other non-ferrous metallurgy	€ 0.01	€ 0.23	€ 1.61
C24.5 Casting of metals	€ 0.02	€ 0.26	€ 1.65
D35.11 Coal fired power plants	€ 0.0003	€ 0.07	€ 0.86
E38.2 Waste incineration	€ 0.01	€ 0.12	€ 1.14
E39 Soil remediation	€ 0.001	€ 0.01	€ 0.06
F42.11 Road paving	€ 0.0004	€ 0.01	€ 0.15
F42.12 Welding of railroad tracks	€ 0.001	€ 0.02	€ 0.31
G45.2 Motor vehicles maintenance and repairs	€ 0.0002	€ 0.01	€ 0.08
N81.22 Chimney sweeps	€ 0.0001	€ 0.003	€ 0.04

Source: Eurostat (2020)

Notes:

1. In most cases, R&D expenditure is not available at the level of the specific subsector in Eurostat. In these cases, the next level where data was available has been taken as a proxy for the sub-sector using PAH, and so may be under- or over-estimated.
2. Data gaps exist for some Member States. In these cases, the most recent data was used.
3. Data in Eurostat is not presented by company size. It is assumed that share of R&D expenditure between different sized companies is the same as the share for turnover (based on 2020 data)

Table 8-11 illustrates the modelled adjustment costs as a percentage of available R&D expenditure (based on Eurostat data). Better Regulation Tool #22 indicates that “All compliance costs divert resources from other purposes, potentially including research and innovation”. Therefore R&D funds are a likely source of finances to be used to meet the adjustment costs associated with an OEL/BLV and subsequently R&D may be negatively impacted. This table provides an overview of the most extreme option; which is assuming that enterprises would input 100% of their R&D expenditure into meeting adjustment costs. It is recognised that enterprises are not realistically going to place this level of R&D funding into meeting the costs. Such funding may be essential for the continuity of the business or alternatively enterprises may source the funds from elsewhere. This option should only be seen to be demonstrative of the extreme impact different OELs could have on funds available for R&D.

As shown in the table below, at 7 ng/m³ adjustment costs significantly outweigh the available R&D funding for most companies with a few exceptions: smokehouses, manufacture of bituminous products, and waste incineration. However, for most of these sectors, costs as a percentage of R&D expenditure (at 7 ng/m³) remain proportionally high.

To clarify, at this policy option level, meat and seafood smokehouses experience relatively low adjustment costs, and modelling estimates an overall cost saving for small meat smoke houses due

to a shift toward more cost effective RMMs. Wood preservation also displays a large cost saving due to a shift toward more efficient RMMs (which explains the high negative value in the table below).

Costs as a percentage of R&D are significantly lower at the 70 ng/m³ level, although R&D would still be significantly negatively impacted at this level. And at the 700 ng/m³ and 2000 ng/m³ levels compliance would be more achievable with the use of R&D funding.

Small and medium sized enterprises (which make up the bulk of enterprises) appear disproportionately impacted should compliance costs be sourced from R&D funding; however, these organisations are less likely to have substantial R&D programmes than estimated in this analysis. R&D is more likely to occur within large enterprises with significantly high funding available for research and may be able to absorb the costs without significantly impacting R&D.

The pressure on R&D expenditures may also be exacerbated by the fact that the regulatory environment is becoming stricter, and companies may be concerned about the future exposure and use of PAH at their facilities. Even if the final OEL/BLV implemented were at the mid to higher end of the range of the policy options, where fewer impacts are anticipated, the perception that other stricter limits might be imposed in the future could well emerge, leading to a lack of confidence in the future of the substance. This perception could then lead to a further reduction in R&D expenditures to develop new and more efficient products.

Alternatively, it is recognised that the need to comply with a new OEL may encourage existing companies to invest more into R&D in attempts to find alternative, more efficient, and effective means of complying. Although the study team cannot comment on the extent to which this may occur. Despite this it should also be recognised that companies must first secure their compliance to the OEL/BLV, and by extent, the continued operation of their facility. To do this, funds for initial investment must be sourced (possibly from R&D funds) suggesting that it is unlikely many will be able to increase R&D expenditure until after the OEL/BLV has been met by their facility. An increase in R&D expenditure is also more likely to occur for large companies as they have more R&D resources, existing investments to fulfil, and more generally lead industry in the development of novel methods.

Table 8-6 in the previous section outlines the percentage costs would be of enterprise gross operating surplus (GOS). GOS is defined as the profit of enterprises on goods and services after operational costs have been paid. GOS provides an alternative measure of source funding to comply with the policy option. Comparatively, costs as a percentage of GOS illustrate that more funding may be available to comply with an OEL/BLV than those dedicated for R&D alone. Despite this, Table 8-6 continues to show that costs at the 7ng/m³ level make up a significant proportion or exceed available GOS in all sectors apart from the following: smokehouses, manufacture of bituminous products, waste incineration, road paving, and motor vehicle repair and maintenance.

At the 70ng/m³ level costs as a percentage of GOS illustrates greater availability of funds for compliance in all sectors apart from coking plants, petroleum refineries, coal tar distillation, manufacture of refractory products, steel and iron foundries, other non-ferrous metallurgy, soil remediation, and the welding of railway tracks. Costs at the 700ng/m³ and 2000ng/m³ are minimal compared with estimated GOS.

Negative values in the below tables are due to companies selecting more cost effective RMMs over 40 years than currently installed.

Table 8-11 PV40 costs (additional to the baseline) for businesses implementing RMMs as a percentage of 40 years of R&D (discounted by 3% annually), by size

Sector	PV40 cost as a percentage of R&D expenditure		
	Small	Medium	Large
7 ng/m³			
C10.13 Meat and poultry smokehouses	3.35%	3.88%	1.31%
C10.2 Seafood smokehouses	3.34%	3.28%	1.12%
C16.1 Wood preservation (creosote)	-117.57%	-2.60%	
C19.1 Coking plants	363.00%	354.56%	27.35%
C19.2 Petroleum refineries	215.93%	219.19%	21.97%
C20.13 Manufacture of carbon black		181.90%	17.83%
C20.14 Coal tar distillation		434.46%	28.37%
C23.2 Manufacture of refractory products	46.50%	58.10%	
C23.99a Manufacture of bituminous products	2.74%	2.51%	1.98%
C23.99b Graphite and carbon electrode manufacture			17.80%
C24.1 Steel and iron foundries, ferroalloys	32.77%	37.50%	4.01%
C24.42 Manufacture of aluminium		130.01%	10.58%
C24.45 Other non-ferrous metallurgy	260.11%	253.34%	26.54%
C24.5 Casting of metals	25.76%	19.56%	6.53%
D35.11 Coal fired power plants	2113.56%	2552.04%	250.75%
E38.2 Waste incineration	30.16%	30.36%	2.36%
E39 Soil remediation	1896.60%	1785.67%	142.84%
F42.11 Road paving	124.55%	112.26%	101.42%
F42.12 Welding of railroad tracks	5906.76%	5900.87%	632.14%
G45.2 Motor vehicles maintenance and repairs	35.17%	16.76%	12.26%
N81.22 Chimney sweeps	1321.09%		
70 ng/m³			
C10.13 Meat and poultry smokehouses	0.14%	0.28%	0.17%
C10.2 Seafood smokehouses	0.19%	0.21%	0.15%
C16.1 Wood preservation (creosote)	-	-	
C19.1 Coking plants	164.27%	163.22%	14.67%
C19.2 Petroleum refineries	10.94%	11.02%	1.11%
C20.13 Manufacture of carbon black		0.08%	0.03%
C20.14 Coal tar distillation		215.90%	16.86%

Sector	PV40 cost as a percentage of R&D expenditure		
	Small	Medium	Large
C23.2 Manufacture of refractory products	4.32%	6.75%	
C23.99a Manufacture of bituminous products	0.14%	0.13%	0.11%
C23.99b Graphite and carbon electrode manufacture			7.00%
C24.1 Steel and iron foundries, ferroalloys	3.02%	3.70%	0.39%
C24.42 Manufacture of aluminium		0.61%	2.37%
C24.45 Other non-ferrous metallurgy	52.24%	53.13%	7.61%
C24.5 Casting of metals	0.73%	0.62%	0.11%
D35.11 Coal fired power plants	44.77%	0.44%	0.35%
E38.2 Waste incineration	-	-	-
E39 Soil remediation	161.82%	154.46%	-6.31%
F42.11 Road paving	17.11%	11.57%	7.21%
F42.12 Welding of railroad tracks	136.10%	120.11%	34.29%
G45.2 Motor vehicles maintenance and repairs	-	-	-
N81.22 Chimney sweeps	-		
700 ng/m³			
C10.13 Meat and poultry smokehouses	-	-	-
C10.2 Seafood smokehouses	-	-	-
C16.1 Wood preservation (creosote)	-	-	
C19.1 Coking plants	-0.01%	-0.23%	-0.08%
C19.2 Petroleum refineries	-	-	-
C20.13 Manufacture of carbon black		-	-
C20.14 Coal tar distillation		0.05%	0.02%
C23.2 Manufacture of refractory products	-0.01%	0.36%	
C23.99a Manufacture of bituminous products	-	-	-
C23.99b Graphite and carbon electrode manufacture			-
C24.1 Steel and iron foundries, ferroalloys	-	-	-
C24.42 Manufacture of aluminium		-	-
C24.45 Other non-ferrous metallurgy	0.21%	0.21%	0.16%
C24.5 Casting of metals	-	-	-
D35.11 Coal fired power plants	-	-	-
E38.2 Waste incineration	-	-	-

Sector	PV40 cost as a percentage of R&D expenditure		
	Small	Medium	Large
E39 Soil remediation	-	-	-
F42.11 Road paving	-	-	-
F42.12 Welding of railroad tracks	1.92%	1.52%	1.12%
G45.2 Motor vehicles maintenance and repairs	-	-	-
N81.22 Chimney sweeps	-		
2000 ng/m³			
C10.13 Meat and poultry smokehouses	-	-	-
C10.2 Seafood smokehouses	-	-	-
C16.1 Wood preservation (creosote)	-	-	
C19.1 Coking plants	-	-	-
C19.2 Petroleum refineries	-	-	-
C20.13 Manufacture of carbon black		-	-
C20.14 Coal tar distillation		-	-
C23.2 Manufacture of refractory products	-	-	
C23.99a Manufacture of bituminous products	-	-	-
C23.99b Graphite and carbon electrode manufacture			-
C24.1 Steel and iron foundries, ferroalloys	-	-	-
C24.42 Manufacture of aluminium		-	-
C24.45 Other non-ferrous metallurgy	-	-	-
C24.5 Casting of metals	-	-	-
D35.11 Coal fired power plants	-	-	-
E38.2 Waste incineration	-	-	-
E39 Soil remediation	-	-	-
F42.11 Road paving	-	-	-
F42.12 Welding of railroad tracks	-	-	-
G45.2 Motor vehicles maintenance and repairs	-	-	-
N81.22 Chimney sweeps	-		

Source: Study team on the basis of calculations performed in the study and Eurostat.

Note: ‘-’ refers to zero costs incurred by companies, blank cells refer to no companies with exposure.

8.3 Single market

8.3.1 Competition

Table 8-12 below includes the initial screening of impacts on competition in order to focus the analysis on those impacts likely to be the most significant. The most significant impacts are further explored in the following paragraphs.

The answers in the table are the overall assessment following by a more sector specific considerations.

Table 8-12 Screening of competition impacts

Impacts	Key questions	Yes/No
Existing firms	Additional costs?	Yes
	Scale of costs significant?	Yes
	Old firms affected more than new?	Yes
	Location influences?	No
	Some firms will exit the market?	Yes
	Are competitors limited in growth potential?	Unknown
	Increased collusion likely?	No
New entrants	Restrict entry?	Yes
Prices	Increased prices for consumers	Yes
Non-price impacts	Product quality/variety affected?	Yes
	Impact on innovation	Yes
Upstream and downstream market	Will OELs affect vertically integrated companies more or less than non-integrated ones?	Unknown
	Will OELs encourage greater integration and market barriers?	No
	Will OELs affect bargaining power of buyers or suppliers?	No

Source: Study team.

8.3.1.1 Existing firms

The analysis presented in the next section indicates that the absolute number of firms likely to exit the market in all sectors exposed to PAH is very high for lowest OEL policy option, and still relatively high at 70 ng/m³, although most companies will continue their operations at this level. This is because organisations in the sectors with the highest number of companies are already operating at lower levels of exposure, or because companies are financially or technically capable of implementing RMM that can help them achieve 70 ng/m³. Overall, policy options resulting in discontinuations would result in fewer companies operating in the EU market, and by definition, worse competition for existing firms.

Consultation feedback suggested that adapting existing large structures to be compliant with the most stringent OEL would not be achievable. Consultees continued to state that it would be cheaper and easier to install better RMMs when building a new plant from scratch than alter an existing site. This may make existing companies less competitive against new entrants.

Given the significant impact of costs and discontinuations upon small businesses, it is likely that some degree of market concentration will occur (other companies will take on this share of the market and workers of those discontinuing). This is more likely to occur in sectors where

alternative substances or process generating exposure to PAH are not viable (resulting in no option but discontinuation), and in sectors where there is capacity to do so. For already concentrated sectors such as coal tar distillation, refractory products and aluminium plants, with only seven, five and nine plants in total in the EU market, increased market concentration would not be possible.

8.3.1.2 *Firms leaving the market (discontinuations)*

At the lowest OEL policy option, modelling predicts high levels of discontinuation amongst companies resulting in 3,462 companies exiting the market. At the 70 ng/m³ policy option there is still a high level of discontinuations but less pronounced, with 146 companies in total exiting the market. In contrast, at the 700 and 2000 ng/m³ policy options there are no discontinuations.

In terms of the market significance of these discontinuations, Table 8-14 illustrates the share of companies discontinuing, representing both the total number of companies in the sector and of the number of companies with exposed workers. The estimates show that at an OEL of 7 ng/m³, all sectors except C16.1 wood preservation, C23.99a manufacture of bituminous products, and G45.2 motor vehicle maintenance and repair all experience discontinuations. The worst hit sectors at this level include:

- C19.1 Coking plants (100% discontinuing);
- C19.2 Petroleum refineries (60% discontinuing);
- C20.13 Manufacture of carbon black (50% discontinuing);
- C23.99b Graphite and carbon electrode manufacture (44% discontinuing);
- C24.45 Other non-ferrous metallurgy (44% discontinuing);
- D35.11 Coal fired powered plants (40% discontinuing); and
- F42.12 Welding of railroad tracks (55% discontinuing).

At 70 ng/m³ discontinuations still occur to a high degree, although the worst affected sectors only include C19.1 coking plants (45% discontinuing), C20.14 coal tar distillation (34% discontinuing), C23.99b graphite and carbon electrode (16.2%) and C24.45 Other non-ferrous metallurgy (8.8%).

The numbers reflect the difficulty that some operators would face in achieving the lower OELs; they would either have to discontinue or make significant investment (partially echoed in the discontinuation costs, see Table 7-16, since these are in some cases a reflection of costs to achieve compliance that cannot easily be modelled). In contrast, most other sectors show comparatively lower levels of discontinuation. However, these levels are still considered relatively high, suggesting that the moderate OEL policy options would still have severe negative impacts against businesses.

In contrast, there are no discontinuations at the 700 and 2000 ng/m³ options.

Trends for companies closing over the next 40 years as a result of EU policies (such as refineries, coal-powered plants and coking plants have been taken into account by modelling the trends into the baseline (see section 4.4.2).

There are some uncertainties and caution with regards to the interpretation of the calculations presented:

- Information regarding the capacity of other companies with PAH exposure to increase production and fill the potential gap in the market has not been identified during the study.

- However, with such high proportions of companies with PAH exposure discontinuing at lower levels, it would be more difficult for others to fill any gaps and impacts on prices and availability of certain products are likely to arise;
- In addition, the impacts resulting from compliance costs with a BLV have not been calculated and would likely result in increased discontinuations due to higher costs;
- The number of companies discontinuing and costs may be a reflection of: the difficulties companies face in achieving compliance, the high costs of implementing RMMs (particularly in large plants), certain lines or sites closing (as can be seen by less than whole integers in Table 8-13), and may not represent (entire) companies closing down closing. This is particularly true in refineries (C19.2) that operate with large turnovers and profits (in absolute numbers) and given the essential nature of the products provided (most private and public transport requires fuels generated from refineries) are likely to find a way to continue to operate rather than close;
- The figures for C23.99b graphite and carbon electrodes are thought to not accurately model the difficulties that companies in this sector would face to meet the two lowest policy options. The study team believes that a higher level of discontinuations would take place at the lowest two policy options, as indicated by costs as a percentage of GOS; and
- The only sector that can accommodate the use of alternatives is F42.11 road paving, where a warm mix asphalt technology is likely to replace the hot mix asphalt technology. This has been modelled in the cost estimates. The sector experiences a low level of discontinuations at the lowest policy option only. For other sectors either alternatives fundamentally change the technology so the sector is no longer viable (e.g. using renewable energy instead of coal fired power plants, or gas heating instead of fuel burning which requires chimney sweeping, or smoke flavouring that no longer requires the smoking of food products) or the available alternatives are not currently suitable (e.g. the use of petroleum pitch instead of coal tar pitch for the manufacture of electrodes, which results in the manufacture of electrodes that are less stable and unsuitable).

In conclusion, there are likely to be negative impacts on competition in some sectors, with the significant reductions in numbers leading to a concentration of the market as a result of significant increases in market shares of some firms. However, the number of discontinuations do not necessarily reflect the number of companies closing down and should be treated with caution.

Table 8-13 Estimates of companies or business units that will discontinue operation under different OEL policy options by sector and size of enterprise

Sector	Number of companies in sector			7 ng/m ³			70 ng/m ³			700 & 2000 ng/m ³		
	S	M	L	S	M	L	S	M	L	S	M	L
C10.13 Meat and poultry smokehouses	194	13	3	1 (0.5%)	0.07 (0.5%)	0.02 (0.5%)	-	-	-	-	-	-
C10.2 Seafood smokehouses	287	36	7	1.4 (0.5%)	0.2 (0.5%)	0.04 (0.5%)	-	-	-	-	-	-
C16.1 Wood preservation (creosote)	39	1		-	-		-	-		-	-	
C19.1 Coking plants	48	2	5	48 (100%)	2 (100%)	5 (100%)	21.6 (45%)	0.9 (1.88%)	2.3 (45%)	-	-	-
C19.2 Petroleum refineries	30	12	39	18 (60%)	7.2 (60%)	23.4 (60%)	0.9 (3%)	0.4 (1.2%)	1.2 (3%)	-	-	-
C20.13 Manufacture of carbon black		20	5		10 (50%)	2.5 (50%)		-	-		-	-
C20.14 Coal tar distillation		3	4		2.3 (77.2%)	2 (50.5%)		-	1.2 (30%)		-	-
C23.2 Manufacture of refractory products	4	1		0.6 (13.8%)	0.1 (13.8%)		0.05 (1.3%)	0.01 (0.3%)		-	-	
C23.99a Manufacture of bituminous products	1,057	99	24	-	-	-	-	-	-	-	-	-
C23.99b Graphite and carbon electrode manufacture			22			9.6 (43.7%)			3.6 (16.2%)			-
C24.1 Steel and iron foundries, ferroalloys	2,523	112	134	252.3 (10%)	11.2 (10%)	13.4 (10%)	25.2 (1%)	1.1 (0.04%)	1.3 (1%)	-	-	-
C24.42 Manufacture of aluminium		3	6		1.05 (35%)	1.7 (27.5%)		-	0.4 (5.8%)		-	-
C24.45 Other non-ferrous metallurgy	67	8	5	29.5 (44%)	3.5 (44%)	2.2 (44%)	5.9 (8.8%)	0.7 (1%)	0.4 (8.8%)	-	-	-
C24.5 Casting of metals	4,017	541	184	80.3 (2%)	10.8 (2%)	3.7 (2%)	-	-	-	-	-	-

Sector	Number of companies in sector			7 ng/m ³			70 ng/m ³			700 & 2000 ng/m ³		
	S	M	L	S	M	L	S	M	L	S	M	L
D35.11 Coal fired power plants	126	45	25	50.4 (40%)	18 (40%)	10 (40%)	-	-	-	-	-	-
E38.2 Waste incineration	597	43	10	17.9 (3%)	1.3 (3%)	0.3 (3%)	-	-	-	-	-	-
E39 Soil remediation	3,280	88	10	705.2 (21.5%)	18.9 (21.5%)	2.2 (21.5%)	65.6 (2%)	1.8 (0.05%)	0.2 (2%)	-	-	-
F42.11 Road paving	29,375	1,285	289	-	-	16.6 (5.8%)	-	-	-	-	-	-
F42.12 Welding of railroad tracks	1,914	83	19	1052.7 (55%)	45.7 (55%)	10.5 (55%)	9.6 (0.5%)	0.4 (0.02%)	0.1 (0.5%)	-	-	-
G45.2 Motor vehicle maintenance and repairs	373,527	606	50	-	-	-	-	-	-	-	-	-
N81.22 Chimney sweeps	19,381			969 (5%)			-			-		
Total	436,466	3,001	841	3,226 (1%)	132 (4%)	103 (12%)	129 (0.03%)	6 (0.2%)	11 (1%)	-	-	-

Source: Study team.

Table 8-14 Companies discontinuing at different OEL policy options by sector

Sector	Number of enterprises in EU (Eurostat)	Estimated enterprise with exposed workers in EU	No. of discontinuations	Discontinuations as a % of all enterprises	Discontinuations as a % of enterprises with exposed workers
7 ng/m³					
C10.13 Meat and poultry smokehouses	21,014	210	1	0.005%	0.5%
C10.2 Seafood smoke-houses	3,294	330	2	0.1%	0.5%
C16.1 Wood preservation (creosote)	32,000	40	0	0.0%	0.0%
C19.1 Coking plants	55	55	55	100.0%	100.0%
C19.2 Petroleum refineries	821	81	49	5.9%	60.0%
C20.13 Manufacture of carbon black	858	25	13	1.5%	50.0%
C20.14 Coal tar distillation	1,949	7	4	0.2%	61.9%
C23.2 Manufacture of refractory products	702	5	1	0.1%	13.8%
C23.99a Manufacture of bituminous products	2,360	1,180	0	0.0%	0.0%
C23.99b Graphite and carbon electrode manufacture	2,360	22	10	0.4%	43.7%
C24.1 Steel and iron foundries, ferroalloys	2,769	2,769	277	10.0%	10.0%
C24.42 Manufacture of aluminium	1,218	9	3	0.2%	30.0%
C24.45 Other non-ferrous metallurgy	522	80	35	6.7%	44.0%
C24.5 Casting of metals	4,742	4,742	95	2.0%	2.0%
D35.11 Coal fired power plants	145,912	196	78	0.1%	40.0%
E38.2 Waste incineration	7,728	650	20	0.3%	3.0%
E39 Soil remediation	4,223	3,378	726	17.2%	21.5%
F42.11 Road paving	36,411	30,949	17	0.05%	0.1%
F42.12 Welding of railroad tracks	2,520	2,016	1,109	44.0%	55.0%
G45.2 Motor vehicles maintenance and repairs	467,730	374,183	0	0.0%	0.0%
N81.22 Chimney sweeps	44,029	19,381	969	2.2%	5.0%
70 ng/m³					
C10.13 Meat and poultry smokehouses	21,014	210	0	0.0%	0.0%

Sector	Number of enterprises in EU (Eurostat)	Estimated enterprise with exposed workers in EU	No. of discontinuations	Discontinuations as a % of all enterprises	Discontinuations as a % of enterprises with exposed workers
C10.2 Seafood smoke-houses	3,294	330	0	0.0%	0.0%
C16.1 Wood preservation (creosote)	32,000	40	0	0.0%	0.0%
C19.1 Coking plants	55	55	25	45.0%	45.0%
C19.2 Petroleum refineries	821	81	2	0.3%	3.0%
C20.13 Manufacture of carbon black	858	25	0	0.0%	0.0%
C20.14 Coal tar distillation	1,949	7	2	0.1%	33.6%
C23.2 Manufacture of refractory products	702	5	0	0.009%	1.3%
C23.99a Manufacture of bituminous products	2,360	1,180	0	0.0%	0.0%
C23.99b Graphite and carbon electrode manufacture	2,360	22	4	0.15%	16.2%
C24.1 Steel and iron foundries, ferroalloys	2,769	2,769	28	1.0%	1.0%
C24.42 Manufacture of aluminium	1,218	9	0	0.0%	3.9%
C24.45 Other non-ferrous metallurgy	522	80	7	1.3%	8.8%
C24.5 Casting of metals	4,742	4,742	0	0.0%	0.0%
D35.11 Coal fired power plants	145,912	196	0	0.0%	0.0%
E38.2 Waste incineration	7,728	650	0	0.0%	0.0%
E39 Soil remediation	4,223	3,378	68	1.6%	2.0%
F42.11 Road paving	36,411	30,949	0	0.0%	0.0%
F42.12 Welding of railroad tracks	2,520	2,016	10	0.4%	0.5%
G45.2 Motor vehicles maintenance and repairs	467,730	374,183	0	0.0%	0.0%
N81.22 Chimney sweeps	44,029	19,381	0	0.0%	0.0%
700 ng/m³					
C10.13 Meat and poultry smokehouses	21,014	210	0	0.0%	0.0%
C10.2 Seafood smoke-houses	3,294	330	0	0.0%	0.0%
C16.1 Wood preservation (creosote)	32,000	40	0	0.0%	0.0%

Sector	Number of enterprises in EU (Eurostat)	Estimated enterprise with exposed workers in EU	No. of discontinuations	Discontinuations as a % of all enterprises	Discontinuations as a % of enterprises with exposed workers
C19.1 Coking plants	55	55	0	0.0%	0.0%
C19.2 Petroleum refineries	821	81	0	0.0%	0.0%
C20.13 Manufacture of carbon black	858	25	0	0.0%	0.0%
C20.14 Coal tar distillation	1,949	7	0	0.0%	0.0%
C23.2 Manufacture of refractory products	702	5	0	0.0%	0.0%
C23.99a Manufacture of bituminous products	2,360	1,180	0	0.0%	0.0%
C23.99b Graphite and carbon electrode manufacture	2,360	22	0	0.0%	0.0%
C24.1 Steel and iron foundries, ferroalloys	2,769	2,769	0	0.0%	0.0%
C24.42 Manufacture of aluminium	1,218	9	0	0.0%	0.0%
C24.45 Other non-ferrous metallurgy	522	80	0	0.0%	0.0%
C24.5 Casting of metals	4,742	4,742	0	0.0%	0.0%
D35.11 Coal fired power plants	145,912	196	0	0.0%	0.0%
E38.2 Waste incineration	7,728	650	0	0.0%	0.0%
E39 Soil remediation	4,223	3,378	0	0.0%	0.0%
F42.11 Road paving	36,411	30,949	0	0.0%	0.0%
F42.12 Welding of railroad tracks	2,520	2,016	0	0.0%	0.0%
G45.2 Motor vehicles maintenance and repairs	467,730	374,183	0	0.0%	0.0%
N81.22 Chimney sweeps	44,029	19,381	0	0.0%	0.0%
2000 ng/m³					
C10.13 Meat and poultry smokehouses	21,014	210	0	0.0%	0.0%
C10.2 Seafood smokehouses	3,294	330	0	0.0%	0.0%
C16.1 Wood preservation (creosote)	32,000	40	0	0.0%	0.0%
C19.1 Coking plants	55	55	0	0.0%	0.0%
C19.2 Petroleum refineries	821	81	0	0.0%	0.0%

Sector	Number of enterprises in EU (Eurostat)	Estimated enterprise with exposed workers in EU	No. of discontinuations	Discontinuations as a % of all enterprises	Discontinuations as a % of enterprises with exposed workers
C20.13 Manufacture of carbon black	858	25	0	0.0%	0.0%
C20.14 Coal tar distillation	1,949	7	0	0.0%	0.0%
C23.2 Manufacture of refractory products	702	5	0	0.0%	0.0%
C23.99a Manufacture of bituminous products	2,360	1,180	0	0.0%	0.0%
C23.99b Graphite and carbon electrode manufacture	2,360	22	0	0.0%	0.0%
C24.1 Steel and iron foundries, ferroalloys	2,769	2,769	0	0.0%	0.0%
C24.42 Manufacture of aluminium	1,218	9	0	0.0%	0.0%
C24.45 Other non-ferrous metallurgy	522	80	0	0.0%	0.0%
C24.5 Casting of metals	4,742	4,742	0	0.0%	0.0%
D35.11 Coal fired power plants	145,912	196	0	0.0%	0.0%
E38.2 Waste incineration	7,728	650	0	0.0%	0.0%
E39 Soil remediation	4,223	3,378	0	0.0%	0.0%
F42.11 Road paving	36,411	30,949	0	0.0%	0.0%

Source: Study team.

8.3.1.3 New entrants

The significant capital expenditures required for start-ups (to ensure that exposure to PAH is lower than the required OEL) represent a barrier to operation and trade for potential new entrants to the market. As OELs become lower, the investment required increases, making entry to the market more costly. This is particularly an issue in sectors where there is already a concentrated market dominated by large companies (for example, C19.2 petroleum refineries, C20.13 carbon black manufacturers, C20.14, coal tar distillation plants, C23.99b graphite and carbon electrode manufacture, and C24.42 manufacture of aluminium).

However, compliance costs as a proportion of turnover identified above are generally lower at OELs of 700 ng/m³ and above, and consequently it is not envisaged that the introduction OELs at of 700 ng/m³ or above will have a significant impact on new entrants compared with existing firms.

Table 8-8 illustrates that at 7 ng/m³ the following sectors (and company sizes) would have significant first year costs as a percentage of annual operating surplus. Companies in these sectors may struggle to cope with upfront investment costs and subsequently there may be less competition from new entrants as a result:

- C16.1 Wood preservation (small and medium companies);
- C23.2 Refractory product manufacturers (small and medium companies);
- C24.1 Steel and iron foundries, including ferroalloys (small companies);
- C24.45 Other non-ferrous metallurgy (small, medium and large companies);
- C24.5 Casting of metals (small, medium and large companies);
- D35.11 Coal fired power plants (small companies);
- E39 Soil remediation (small, medium and large companies);
- F42.12 Welding of train tracks (small companies); and
- N81.22 Chimney sweeps (small companies)

Estimations of year 1 costs as a percentage of annual operating surplus may also underestimate the potential difficulties for new entrants as these modelled costs assume that companies are already established. New entrants are less likely to have established company/client relationships and may therefore have lower turnover for the first years of their operation.

At higher OELs upfront costs are less severe and subsequently the barrier to entry is less prevalent. At 70 ng/m³ the following sectors (and company sizes) would have significant first year costs as a percentage of annual operating surplus:

- C19.1 Coking plants (medium and large companies);
- C23.2 Refractory product manufacturers (small companies);
- C24.45 Other non-ferrous metallurgy (small and medium companies); and
- D35.11 Coal fired power plants (small companies).

It is understood that monitoring and related administrative costs would not act as a barrier for new companies as they would be required to undertake monitoring as part of their first years' risk assessments (i.e. monitoring to complying with an EU-wide OEL would not be an additional cost as it is already a requirement for new entrants, unlike for existing companies). However, it is possible that should the OEL result in the need for additional monitoring, for example due to the need for more sensitive and expensive analytical methods (as a result of the OEL), monitoring may become a barrier to entry. For example, the analytical methods to measure airborne exposures in refineries are not currently sensitive enough to determine concentrations applicable to the two lowest policy options; additional refinement of existing methods is needed. This is thought to be due to the relatively low exposure levels in some tasks, the relatively short duration of relevant tasks, and more generally due to the difficulties in achieving the theoretical Limit of Detection and Limit of Quantification in real life scenarios compared (Stakeholder consultation (2023) see section 3.8). Other stakeholders that have commented on the need to achieve more sensitive analytical methods are road paving (F42.12) and manufacturers of bitumen products (C23.99a).

Alternatively, as previously stated, feedback from industry suggests that the costs of amending an existing facility to meet a new OEL will likely exceed the costs of building a new facility from scratch. This is because existing facilities may experience substantial costs for altering large and complex processes within sites not previously intended for such changes. This may result in a competitive edge for new entrants as their facilities would be built purposely to meet the OEL.

8.3.2 Consumers

Figures presented in Table 3-105 illustrate that the sectors included in this study are primarily made up of mature markets. In theory mature markets may have more capacity to increase prices

for consumers. Sectors have either matured to the point of having a higher percentage of large companies (e.g. C19.2, C23.99b and C24.42), or they are sectors where large enterprises are not common and the nature of the sector implies large companies are less likely to exist despite the level of maturity (low proportions of large companies as seen for example in C10.2 and C10.13 smokehouses, F42.11 road paving, G45.2 automotive repair and maintenance and N81.22 chimney sweeps, see Table 3-105). For example, automotive repair and maintenance is a mature market but large firms are not common.

Despite the maturity of markets analysed, most enterprises are small or medium sized (99.1% and 0.7% respectively) and are unlikely to be able to fully absorb additional costs without impacting consumer prices. The study team anticipate a mixed scenario in which mature markets dominated by small and medium enterprises result in increased prices for consumers.

The lower policy options modelled predict significant discontinuations, particularly for smaller businesses that would be unable to meet the OELs and their compliance costs. As a result of these discontinuations, it is also likely that there would be significantly fewer companies operating within industry resulting in lesser capacity for demand to be filled, and subsequently a higher risk of price increases for consumers.

Sectors relating to infrastructural or essential services such as C16.1 wood preservation for railway sleepers and telegraph poles, E38.2 soil remediation, F42.11 road paving, F42.12 welding of rail-road tracks, and N81.22 chimney sweeps may be more likely to pass costs onto downstream users. Although these sectors are more closely linked to public services and not considered to be sectors with consumers, with the exception of chimney sweeps working in the private sector and in residential settings.

Due to the highly esoteric nature of the sectors under review in this report, the study team has not been able to fully assess the elasticities of demand in the sectors (there is limited information related to the sectors). From limited findings, some sectors may be more capable of passing costs onto consumers due to inelastic demand. This may include C19.2 petroleum refineries (short term), C24.42 manufacture of aluminium, and G45.2 motor vehicle repair. No further information could be found regarding the remaining sectors, however, it is possible that costs may be passed onto consumers due to their essential role in EU markets and infrastructure, particularly metallurgical sectors.

Sectors may be able to avoid costs, and thus avoid price increases for consumers if cheaper substitutes are available. However, this is currently only viable for F42.11 road paving. Other sectors that could technically implement a substitute would redefine the nature of the sector to the point that it no longer operated in the same sector. For example, smokehouses may technically be able to substitute smoking meats and fish for artificial smoke flavouring, however these businesses would no longer be smokehouses by definition. Substitution is therefore not expected to be viable for sectors with downstream consumers, and thus would not prevent price increases.

8.3.3 Internal market

At the time of writing there is a large degree of variation in existing legislation across Member States which may negatively affect the competition of the internal market. For example, the existing OEL in Member State are shown in Table 6-16 and Table 16-17 show the different OEL/BLV identified as being applicable in EU Member States, with a wide range of values and conditions under which they apply. Table 3-1 provides the range of minimum OELs currently applied in Member States. Existing minimum binding OELs with BaP as a marker range from 70 ng/m³ to 5,000

ng/m³. with a median of 2000 ng/m³. Note that the 70 ng/m³ is based on Germany's acceptable level but the country also operates at a tolerated level which is 700 ng/m³ BaP.

Table 16-16 shows that the majority of Member States operate at an OEL around the highest policy option (some have higher). The only Member States with OELs lower than this are: Bulgaria, Germany, Latvia, and The Netherlands.

The OEL options considered in this study are likely to have a positive impact on the simplification of the existing rules and the creation of a more level playing field in the internal market. The establishment of an EU OEL should reduce the diversity of national legislation identified in section 3.1 of this report. The resulting simplification would be particularly beneficial to companies operating in more than one Member State as they would be faced with a reduced range of requirements to which they would have to adhere. This would also reduce the need to research OEL requirements across the EU for companies wishing to operate in more than one Member State, saving on both research costs as well as design costs through facilitating the adoption of common solutions to reduce exposure across plants in different locations instead of having to design facilities to meet with different OEL requirements.

It is not possible to determine the number of companies operating in more than one Member State across the sectors where worker exposure to PAH takes place. However, Table 3-105 shows that a relatively high proportion of the companies in the sectors under review are small and medium sized. A higher proportion of large companies exist in C19.2 refineries (48%), C20.14 coal tar distillation (57%), C23.99b graphite and carbon electrode (100%), C24.42 aluminium (67%). However, the total number of enterprises in these sectors is also small (81 for C19.2, 25 for C20.13, 7 for C20.14, 22 for C23.99b and 9 for C24.42). Small companies are less likely to have multiple operations across the EU. On the other hand, where large companies exist in the identified sectors, there are likely to be several companies that will benefit greatly from the simplification of Member State regulations across the EU if this occurs as a result of the introduction of an EU OEL.

Table 8-15 Simplification/level playing field

Policy option	Number of MS currently at or below the policy option
7 ng/m ³	0
70 ng/m ³	1 [^]
700 ng/m ³	4
2000 ng/m ³	12

Source: Study team.

Notes: [^] = Germany has set its acceptable level at 70 ng/m³ but it also operates at a tolerated level which is 700 ng/m³ BaP

Some companies may already be operating at or below the policy option level that could be implemented. These companies will be at a competitive advantage over companies that are not already complying who incur compliance costs. Whilst a precise number of companies already meeting the OEL is not known, Table 7-2 presents the estimation number of companies against each exposure point used in this study and presents a possible distribution of complying companies. There are some limitations with the values in the table however:

- The modelling of companies against exposure levels has been performed on a statistical basis and may not fully reflect reality;

- Furthermore, the allocation of companies has been performed based on consultation data which may contain biases, and calculated median exposures obtained literature; medians do not account for the proportion of companies operating at higher or lower exposure levels; and
- The distribution of companies used in modelling may not present an accurate representation of the proportion of companies already complying with an OEL.

Subsequently the following paragraphs should be understood as a limited estimation rather than a known proportion for each sector.

At 2000 ng/m³ all companies are expected to already be compliant and there would not be any impacts regarding internal market competition. At 700 ng/m³ a small proportion of companies are not expected to already be compliant with the OEL and could potentially be at a disadvantage against those that are: C19.1 coking plants, C20.14 coal tar distillation, C24.45 non-ferrous metal-lurgy, and F42.12 welding of railroad tracks.

The 70 ng/m³ level produces the greatest variation of potential disadvantage across all sectors. Again, a small proportion of the following sectors are potentially at a disadvantage against those already complying: C10.13 meat and poultry smokehouses, C10.2 seafood smokehouses, C19.2 petroleum refineries, C20.13 manufacture of carbon black, C23.99a manufacture of bituminous products, C24.1 steel and iron foundries, D35.11 coal fired power plants, and F42.11 road paving. Sectors with a higher degree of competitive disadvantage include: C20.14 Coal tar distillation, C23.2 manufacture of refractory products, C23.99b graphite and carbon electrode manufacture, C24.42 manufacture of aluminium, C24.5 casting of metals, and E39 soil remediation.

However, the greatest impact of single market competition may occur at 7 ng/m³ where significantly more companies could be at a disadvantage, albeit in fewer sectors than at 70 ng/m³. This is primarily due to G45.2 skewing the analysis due to the high number of companies in that sector. A small proportion of companies in the E38.2 waste incineration may be at a disadvantage compared with those already complying with an OEL of 7 ng/m³. A larger proportion of companies may be at a disadvantage in the following sectors: C10.13 meat and poultry smokehouses, C10.2 seafood smokehouses, F42.11 road paving, and G45.2 motor vehicle repair and maintenance. Whilst competition impacts would vary according to the costs for individual companies, this is not possible to calculate at this level.

Overall, a more level playing field may result in better competition within the internal market. Although companies in some sectors would be at an advantage over their competitors due to their existing compliance with the legislation put in place.

8.4 Competitiveness of EU businesses

The introduction of harmonised OEL will have a significant impact on companies' cost competitiveness at the lower OEL policy options. As indicated previously, the increase in costs due to having to implement additional or better RMMs represents the burden of compliance on companies. This would make those companies incurring costs less competitive where they are competing with any companies already compliant at this level.

Due to the nature of PAH exposure and the sectors in which it occurs, it not thought to be possible for companies to operate in such a way that exposure to PAH does not take place without fundamentally changing their operations or output of the business. For example, a coal tar distillation plant may distil petroleum tar instead, but it would not be able to produce coal tar pitch which is a

key product used in several other sectors for which there are currently no alternatives (coal tar pitch has been subject to a REACH authorisation, and many uses no longer take place). Similarly, waste incineration plants have to perform activities (incineration) that result in the formation of PAH. As previously stated, this may result in a disadvantage for existing companies that would not be able to adjust their RMMs without substantial redesign of their facility. Comparably, new entrants may be at an advantage as designing a facility from scratch with the latest technological developments is likely to be more feasible.

8.4.1 Sectors affected

Based on the tables in section 8.1 some sectors systematically come up as experiencing severe negative financial impacts from the introduction of an OEL at the two lowest policy option: coking (C19.1), smaller refineries (C19.2), coal tar distillation (C20.14), the manufacture of refractory products (C23.2), graphite and carbon electrode manufacture (C23.99b), steel, iron and other ferroalloy foundries (C24.1), aluminium manufacturers (C24.42), non-ferrous metallurgy (C24.45), casting of metals (C24.5), small coal fired power plants (D35.11), soil remediation (E39), welding of railroad tracks (F42.12) and chimney sweeps (N81.22).

Adverse impacts on the manufacture of graphite and carbon electrodes has the potential to impact a large number of sectors down the supply chain (see Figure 3-3).

There is also scope for companies to experience some cost savings by switching to more effective RMM that have a higher initial capital investment but a lower cost over 40 years (discounted). The sector tends to benefit is in wood preservation (C16.1).

8.4.2 SME competitiveness

The compliance costs relative to the baseline over 40 years are greater for small and medium businesses, as expected (see Table 8-5). The majority of sectors have >80-90% small businesses with a few exceptions (refineries C19.2, carbon black manufacturers C20.13, coal tar distillation plants C20.14, graphite and carbon electrode manufacturers C23.99b, aluminium C24.42) (see Table 3-105).

The average cost of compliance as a percentage of turnover relative to the baseline at the 7 ng/m³ is 0.2% for small businesses, 0.6% for medium businesses and 0.2% for large businesses. The larger percentage for medium sized businesses is thought to be related to the fact that certain sectors do not have any or only a few small businesses and operate with closed systems where possible (manufacturers of carbon black C20.13, coal tar distillation plants C20.14, electrode manufacturers C23.99b, aluminium C24.42, are only medium and large companies, and refineries have a high percentage of large companies).

There is also scope for companies to experience some cost savings by switching to more effective RMM that have a higher initial capital investment but a lower cost over 40 years (discounted). The sector which may benefit tends to be wood preservation (C16.1).

Overall, SME's may be at a competitive disadvantage compared with large enterprises as costs make up a higher proportion of their turnover than large companies which are more likely to absorb the costs.

A similar pattern is seen at the 70 ng/m³ with averages of 0.02%, 0.05% and 0.01% discounted compliance costs relative to their turnover over 40 years for small, medium and large businesses, respectively. Coking (C19.1), refineries (C19.2), coal tar distillation plants (C20.14),

manufacturers of refractory products (C23.2), steel and iron foundries (C24.1), non-ferrous metallurgy (C24.45), coal fired power plants (D35.11), and soil remediation (E39.0) are particularly affected at this level.

In addition to the above, section 8.2 also outlines sectoral costs for SMEs as a percentage of R&D expenditure. The premise being that R&D may be used as a source of funding for RMM adjustments. Table 8-11 illustrates that R&D would be severely affected at the two lowest policy option levels for most companies (despite size), however, SMEs are more severely affected than large companies. This is because small and medium sized companies typically have lower R&D expenditure available compared with large companies. Overall, this may result in proportionally less R&D being performed by small and medium companies than large (albeit most companies would reduce their R&D regardless of their size). This may put SMEs at a disadvantage against large companies in the future; R&D is the means to develop novel methods to improve efficiency and reduce costs for companies.

8.4.3 Cost competitiveness

The introduction of harmonised OEL will have an impact on companies' cost competitiveness but will be more significant for the lower OEL policy options.

As indicated previously, the increase in costs due to having to implement additional or better RMMs represents the burden of compliance on companies. This would make companies incurring these costs less competitive where they are competing with companies already compliant at this level.

Due to the nature of the businesses under review, until alternatives are more developed, the study team believes that it is very challenging to provide the same service or (similar) products without incurring exposure to PAH due to the nature of the products and sectors. For example, distilling petroleum tar instead of coal tar, may result in the distillation of some similar products, but will not result in coal tar pitch that is currently needed in the manufacture of graphite and carbon electrodes that feed into several sectors, articles and businesses (see Figure 3-3).

In the Member State authority consultation, the results of which are in Table 7-14, approximately 70% Member States think that the highest OEL policy option would have no impact, 67% think that the middle two policy options would have a moderately negative impact on companies, while at the lowest policy option 57% of respondents think it will have a significantly negative impact, and 29% that it will have a moderately negative impact on companies.

At the 7 ng/m³ policy option, as shown in Table 8-6, the adjustment costs for business over 40 years to implement RMMs, conducting monitoring, health surveillance and administrative burden as a percentage of GOS identified the following sectors as being particularly at risk:

- C19.1 Coking plants;
- C19.2 Petroleum refineries;
- C20.13 Carbon black manufacturers;
- C20.14 Coal tar distillation plants;
- C23.2 Manufacture of refractory products;
- C24.45 Other non-ferrous metallurgy;
- C23.99b Graphite and carbon electrode manufacturers;
- C24.1 Steel and iron foundries, ferroalloys;

- C24.42 Manufacture of aluminium;
- C24.45 Other non-ferrous metallurgy;
- D35.11 Coal fired power plants;
- E39 Soil remediation;
- F42.12 Welding of railroad tracks; and
- N81.22 Chimney sweeps.

These companies would have more than 10% of the GOS diverted to ensure compliance; of note are C19.2 refineries and C23.99b graphite and carbon electrodes that will have >100% of GOS diverted, although C19.1 coking plants would also divert just under 100% of GOS.

At the 70 ng/m³ policy option, companies in the following sectors would be at a high risk, with 10-50% of the GOS diverted to ensure compliance:

- C19.1 Coking plants;
- C19.2 Petroleum refineries;
- C20.14 Coal tar distillation plants;
- C23.99b Graphite and carbon electrode manufacturers; and
- C24.45 Other non-ferrous metallurgy.

The metallurgical sectors (C24.1, C24.42, C24.45, including casting C24.5), coking (C19.1) and graphite and carbon electrodes (C23.99b) are already facing pressures from mounting energy costs, which are going to have a negative impact on cost-competitiveness and likely result in higher prices to their customers.

For these sectors it can reasonably be anticipated that running costs will increase and that these will be passed on to their customers.

This could also result in compounding effects, where a higher priced coal tar (from coking, C19.1) used as feedstock in coal tar distillation plants (C20.14), results in higher costs in manufacturing coal tar pitch high temperature, which is used in the manufacture of graphite and carbon electrodes (C23.99b). Electrodes (from C23.99b) are used in most metallurgical process.

8.4.4 Capacity to innovate

Potential impacts on companies' capacity to innovate have been outlined in Section 8.2 above. Primarily, the diversion of costs away from R&D may occur due to overall cost impacts of having to invest in RMMs to meet the prescribed OEL.

8.4.5 International competitiveness

If EU companies are required to comply with stricter OEL than those in effect in third countries where import/export takes place, they will be at a disadvantage when compared to their competitors from third countries with higher OEL who can operate without incurring capital and operating costs to meet more stringent OEL. Companies with existing plants in third countries that would need to make substantial investments to meet more stringent OEL, could choose to condense operations in third countries and therefore shift operations away from the EU.

As identified in Table 3-105, small companies represent 99% of companies analysed in this study. Such companies are more likely to operate on national scale and have fewer opportunity to transfer operations to existing plants outside the EU. However, as the majority of exposed workers are

in small companies in the road paving, soil remediation, vehicle repair sectors, and chimney sweep sectors, and since these cannot easily relocate, they have less risk of being disadvantaged against competitors outside the EU.

Sectors such as C24.1 steel and iron foundries, ferroalloys, C24.42 aluminium manufacturers, C24.45 other metallurgy, C24.5 casting of metal companies and C23.99b graphite and carbon electrode manufacturers already experience pressure from cheaper imports, particularly Asian countries (Stakeholder consultation 2023). An increase in operational costs, in addition to high energy costs experienced since 2021 and the EU drive to decarbonise, could push additional companies to close or relocate operations outside the EU. Similarly, carbon and graphite electrode manufacturers (C23.99b) face competition from neighbouring countries such as Russia as well as China (Stakeholder consultation 2023). Both of these countries do not have OEL in place for PAH (Table 8-16).

Table 8-16 below draws on information provided in Table 16-16 and Table 16-17.

Table 8-16 OELs in selected non-EU countries

Country	OEL [mg/m ³]	Specification of OEL
Australia		
Canada	0.000005	BaP, Carc
	0.0002	Particulate PAH – benzene soluble, Carc
China		
India		
Japan	0.0002	Coal tar, benzene soluble
Norway	0.00004	See The existing OELs in Member States are shown in Table 16-16.
Russia		
South Korea	0.0002	PAH - benzene soluble
Switzerland	0.000002	B[a]P, Carc, Repro, Sk
	0.0002	PAH from coal tar pitch, Carc
Turkey		
UK		
USA, ACGIH	0.0002	PAH - benzene soluble, Carc
USA, NIOSH	0.0001	PAH from coal tar pitch - cyclohexane soluble, Carc
USA, OSHA	0.0002	PAH - benzene soluble %, Carc

Source: Information presented in section 3.1.

Coking (C19.1) and the sectors that depend on its by-product coal tar, i.e. coal tar distillation plants (C20.14) and carbon and graphite electrode manufacturers (C23.99b), require additional analysis because several sectors further down the supply chain may be impacted. The links between coking, particularly its by-product coal tar and other sectors is illustrated in the diagram below – which is not a complete list of sectors that may be affected, these represent only a fraction of the markets in which graphite is used. For example, graphite is commonly used in breaks of cars as it acts as a solid state lubricant without the use of grease and has very good durability. Graphite is also used in batteries and fuel cells for the storage of energy generated from wind

turbines²⁵, it is used in electrolysis for the production of hydrogen and in key strategic technologies (European Commission 2020c, JRC 2023). As mentioned in section 3.11.8, there are many more applications. In addition, semiconductors, which rely on the use of silicon metal to make wafers, are used in virtually all appliances and semiconductors are needed in electric vehicles (EV). Coal tar distillation is thus seen as an enabling industry, the products of which ultimately feed into many other industries. The removal of coking may have wider implications and may result in additional international competitiveness than for the coking sector itself.

In the sector of graphite and carbon electrodes (C23.99b) companies in the EU compete with cheaper imports by producing high quality products. Increased pressure on demand of coal tar pitch through imports may have a negative effect on the purchasing ability and price competitiveness of the products in this sector.

Another important point is the relationship of EU MS with neighbouring Norway and the UK. The coal tar distillation plant in Denmark for example, works closely with aluminium plants in Norway to supply them with coal tar for the manufacture of electrodes used in pre-bake aluminium plants. The aluminium is then sold back into EU markets. Should Norway not be able to purchase coal tar pitch due to closures in Europe, there may be additional impacts to companies that rely on aluminium imports from Norway. Graphite and carbon electrode manufacturers in the EU Member States purchase all their calcinated petroleum coke (needle coke) from the UK. There are no known regulatory challenges in the UK on PAH at the time of writing the report, however there is a balance of trade between needle coke and carbon and graphite electrodes.

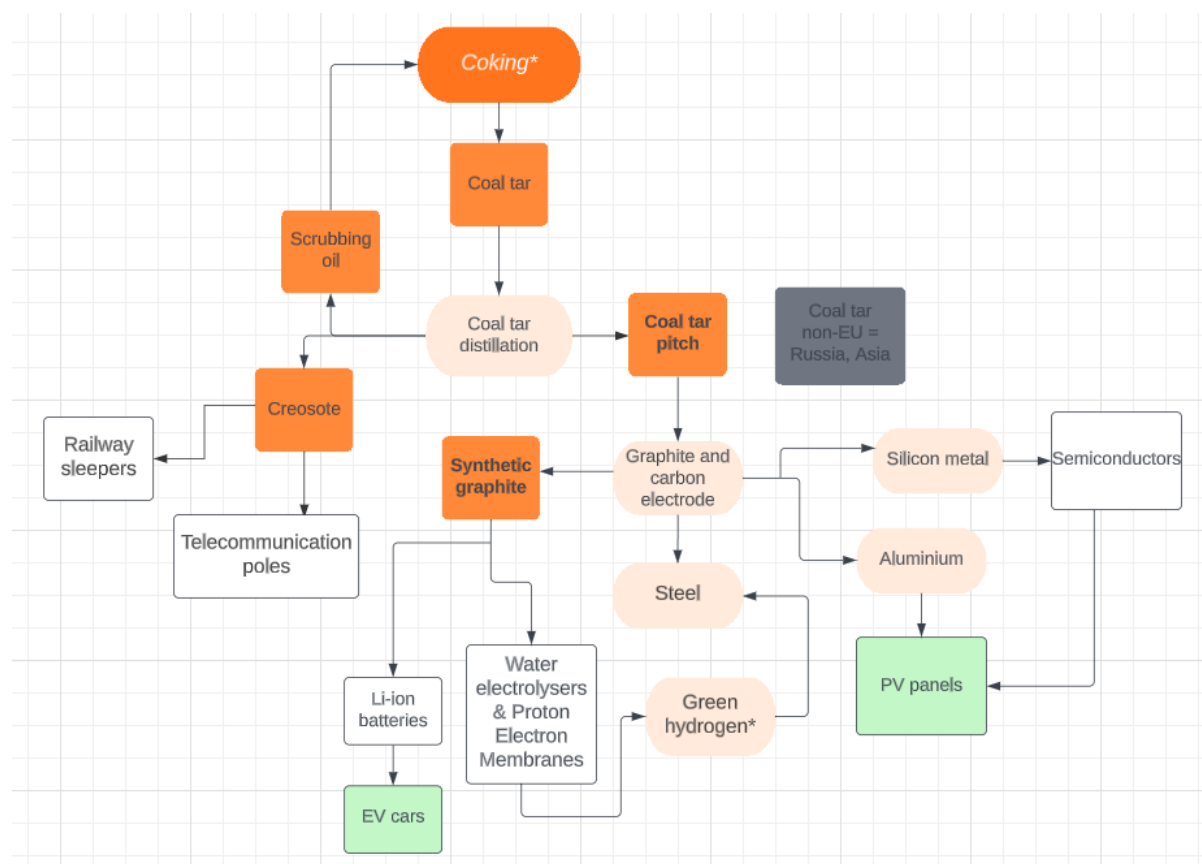


Figure 8-1: Relationship with coking, coal tar distillation, their products and other sectors

²⁵ See for example https://www.olmec.co.uk/wind_power_graphite/

Source: Study team

Note: EV = electric vehicles, PV = photovoltaic

Water electrolysis is an electricity-intensive process and it not currently the main form of hydrogen production.

Scrubbing oil or scrubber oil is made via the distillation of coal tar and is used in scrubbers of coking plants. Coal tar plants are said to use this oil as a bargaining chip to divert feedstock (coal tar) to the industry (as opposed to it going to e.g. carbon black).

Hydrogen is likely to become the reducing agent in steel plants (McKinsey & Company, 2020; FCHEA, 2022), and the move from coke as a reducing agent to hydrogen, may make coking plants obsolete – 68% of coking coal is destined for use in steel plants. Steel is also recycled through Electric Arc Furnaces (EAF), which require electrodes (which in turn are made with CTPht) to create the electric arc that melts the scrap material. Graphite electrodes are consumed at the rate of 1.5-3 Kg per tonne of steel. Coal tar pitch however is derived from coal tar, a by-product of coking. Silicon metal, needed in PV, semiconductors and electrolyzers are also manufactured with the use of electrodes. Similarly, aluminium is made with electrodes (aluminium is used in solar panels and cars) as well as many metallurgical processes (ferrous and non-ferrous).

In addition, the most efficient way of making hydrogen is through water electrolyzers (IEA, 2023), but today this is still an energy intensive and expensive way of making hydrogen. There are four main electrolyser technologies (European Commission, 2020c, JRC 2023) and it is unclear to the study team whether relevant electrolyzers can be made with both natural and synthetic graphite²⁶. Fuel cells, used to store energy and to power boats, forklifts, buses etc., also use graphite as a conductive material. There are clear synergies between hydrogen ironmaking supply chains and electrolyzers, wind power and solar PV (European Commission 2020c, and JRC 2023).

Coking is one of the sectors with the highest exposure levels, and one of the sectors that will be most adversely affected in terms of discontinuations and costs (see 8.3.1.2 and 8.3.1.1). International competitiveness of sectors that depend on coking by-products and their further processing is likely to have wider cross-sectorial implications.

8.5 Employment

Under the proposed policy options, employment conditions and workers health are expected to improve. This is covered in further detail regarding the benefits for each of the OEL policy options in section 6. The calculation of the social cost of unemployment has been performed on the application of 'valuing the social costs of job losses in applications for authorisation' by Dubourg (2016). See the Methodological Note for more information.

Employment impacts will result from companies forced to cease operations involving PAH if they cannot comply with the OEL/BLV. The numbers of workers potentially impacted at the different policy options are presented in Table 8-17 below.

Analysis carried out earlier in this report has indicated that approximately 440,308 companies have potential exposures to PAH. If an enterprise is unable to meet the prescribed policy options for those workers, the enterprise would be forced to close specific operations with PAH exposure and these workers could lose their jobs. The table below summarises the numbers of jobs that

²⁶ Pure graphite is manufactured, i.e. synthetic graphite, and it is used in fuel cells and proton exchange membranes, which are used in electrolyzers, e.g. <https://fuelcellstore.com/pemfc-graphite-flow-field-serpentine-5cm2-69000> Fuel cells can be used to generate electricity and hydrogen for the steel industry.

would potentially be lost at each OEL policy option and estimates the social costs of the impacts following the Dubourg (2016) method.

The study team recognises limitations in the calculations:

- The number of unemployed workers as a result of discontinuation may not fully reflect the reality that many employees may be retained in alternative roles or reemployed by competitors. This could result in an overestimation of unemployment figures and social costs;
- The model assumes that small and medium enterprises discontinuing the operations that involve exposure to the relevant substance would result in the entire company going out of business. The logic behind this is that small and medium sized organisations are more likely to experience closure if their sole or main operation becomes unfeasible. In contrast, large companies are more likely to discontinue divisions, lines or specific operations which would not result in the full closure of the business but the discontinuation of the line/process using the relevant substance. The assumption is that 10% of a large company would close. Overall, discontinuation figures are not a reflection of true company closures, but a reflection of difficulties companies face in achieving compliance. This could result in overestimations of unemployment figures and social costs; and
- The wider social costs of companies discontinuing such as the strategic costs of not competing, the impact on the overall market and the wider cost to a community of losing many jobs in one location (typical of large sites situated in small towns) are not included because the study team has no means of quantifying them. Nor is the study team capable of determining jobs lost throughout sectoral supply chains. This could result in an underestimation of unemployment figures and social costs, and a misrepresentation of impacts at a local level.

The study team is not able to quantify or comment on the proportion of jobs retained/reemployed, nor on the exact figure of companies discontinuing vs taking on high costs of compliance, nor on the impacts along the supply chain. Consequently, the figures in the table below represent a best estimate but with known inaccuracies.

The total number of discontinuations (3,426), number of unemployed workers (47,758) and social cost of unemployment (€ 4,028 million) are highest at the 7 ng/m³ policy option and decrease substantially at the 70 ng/m³ policy option (146 discontinuations, 2,275 workers unemployed and € 226 million social costs of unemployment). There are no discontinuations, unemployment and therefore social costs of unemployment at the 700 and 2000 ng/m³ policy options.

Table 8-17 Social cost (in € million) due to unemployment resulting from discontinuations

Sector	Discontinuations	Number of workers	Total social cost (€ millions)
7 ng/m³			
C10.13 Meat and poultry smokehouses	1	13	€ 0.77
C10.2 Seafood smokehouses	2	35	€ 1.99
C16.1 Wood preservation (creosote)	0	0	€ -

Sector	Discontinuations	Number of workers	Total social cost (€ millions)
C19.1 Coking plants	55	1,064	€ 42.90
C19.2 Petroleum refineries	49	5,739	€ 637.00
C20.13 Manufacture of carbon black	13	1,546	€ 266.00
C20.14 Coal tar distillation	4	804	€ 87.10
C23.2 Manufacture of refractory products	1	19	€ 1.67
C23.99a Manufacture of bituminous products	0	0	€ -
C23.99b Graphite and carbon electrode manufacture	10	507	€ 48.40
C24.1 Steel and iron foundries, ferroalloys	277	5,499	€ 559.00
C24.42 Manufacture of aluminium	3	362	€ 22.40
C24.45 Other non-ferrous metallurgy	35	356	€ 22.90
C24.5 Casting of metals	95	2,088	€ 164.00
D35.11 Coal fired power plants	78	2,368	€ 126.00
E38.2 Waste incineration	20	273	€ 21.50
E39 Soil remediation	726	5,490	€ 364.00
F42.11 Road paving	17	1,923	€ 168.00
F42.12 Welding of railroad tracks	1,109	17,735	€ 1,350.00
G45.2 Motor vehicles maintenance and repairs	0	0	€ -
N81.22 Chimney sweeps	969	1,938	€ 144.00
Total	3,462	47,758	€ 4,027.63
70 ng/m³			
C10.13 Meat and poultry smokehouses	0	0	€ 0
C10.2 Seafood smokehouses	0	0	€ 0
C16.1 Wood preservation (creosote)	0	0	€ 0
C19.1 Coking plants	25	479	€ 19.30
C19.2 Petroleum refineries	2	287	€ 31.90
C20.13 Manufacture of carbon black	0	0	€ 0

Sector	Discontinuations	Number of workers	Total social cost (€ millions)
C20.14 Coal tar distillation	2	437	€ 47.30
C23.2 Manufacture of refractory products	0	2	€ 0.15
C23.99a Manufacture of bituminous products	0	0	€ 0
C23.99b Graphite and carbon electrode manufacture	4	188	€ 17.90
C24.1 Steel and iron foundries, ferroalloys	28	550	€ 55.90
C24.42 Manufacture of aluminium	0	40	€ 2.47
C24.45 Other non-ferrous metallurgy	7	71	€ 4.55
C24.5 Casting of metals	0	0	€ 0
D35.11 Coal fired power plants	0	0	€ 0
E38.2 Waste incineration	0	0	€ 0
E39 Soil remediation	68	511	€ 33.90
F42.11 Road paving	0	0	€ 0
F42.12 Welding of railroad tracks	10	161	€ 12.30
G45.2 Motor vehicles maintenance and repairs	0	0	€ 0
N81.22 Chimney sweeps	0	0	€ 0
Total	146	2,725	€ 225.67
700 ng/m³			
C10.13 Meat and poultry smokehouses	0	0	€ 0
C10.2 Seafood smokehouses	0	0	€ 0
C16.1 Wood preservation (creosote)	0	0	€ 0
C19.1 Coking plants	0	0	€ 0
C19.2 Petroleum refineries	0	0	€ 0
C20.13 Manufacture of carbon black	0	0	€ 0
C20.14 Coal tar distillation	0	0	€ 0
C23.2 Manufacture of refractory products	0	0	€ 0

Sector	Discontinuations	Number of workers	Total social cost (€ millions)
C23.99a Manufacture of bituminous products	0	0	€ 0
C23.99b Graphite and carbon electrode manufacture	0	0	€ 0
C24.1 Steel and iron foundries, ferroalloys	0	0	€ 0
C24.42 Manufacture of aluminium	0	0	€ 0
C24.45 Other non-ferrous metallurgy	0	0	€ 0
C24.5 Casting of metals	0	0	€ 0
D35.11 Coal fired power plants	0	0	€ 0
E38.2 Waste incineration	0	0	€ 0
E39 Soil remediation	0	0	€ 0
F42.11 Road paving	0	0	€ 0
F42.12 Welding of railroad tracks	0	0	€ 0
G45.2 Motor vehicles maintenance and repairs	0	0	€ 0
N81.22 Chimney sweeps	0	0	€ 0
Total	0	0	€ 0
2000 ng/m³			
C10.13 Meat and poultry smokehouses	0	0	€ 0
C10.2 Seafood smokehouses	0	0	€ 0
C16.1 Wood preservation (creosote)	0	0	€ 0
C19.1 Coking plants	0	0	€ 0
C19.2 Petroleum refineries	0	0	€ 0
C20.13 Manufacture of carbon black	0	0	€ 0
C20.14 Coal tar distillation	0	0	€ 0
C23.2 Manufacture of refractory products	0	0	€ 0
C23.99a Manufacture of bituminous products	0	0	€ 0
C23.99b Graphite and carbon electrode manufacture	0	0	€ 0
C24.1 Steel and iron foundries, ferroalloys	0	0	€ 0

Sector	Discontinuations	Number of workers	Total social cost (€ millions)
C24.42 Manufacture of aluminium	0	0	€ 0
C24.45 Other non-ferrous metallurgy	0	0	€ 0
C24.5 Casting of metals	0	0	€ 0
D35.11 Coal fired power plants	0	0	€ 0
E38.2 Waste incineration	0	0	€ 0
E39 Soil remediation	0	0	€ 0
F42.11 Road paving	0	0	€ 0
F42.12 Welding of railroad tracks	0	0	€ 0
G45.2 Motor vehicles maintenance and repairs	0	0	€ 0
N81.22 Chimney sweeps	0	0	€ 0
Total	0	0	€ 0

Source: Study team.

8.6 Summary of market effects

In summary, there is a stark difference in costs between the lowest two and highest two policy options. At the lowest, 7 ng/m³, significant costs and discontinuations are expected to be incurred by industry which is likely to result in significant unemployment, closure and/or relocations, and potential price increases for consumers. Similar impacts occur at the 70 ng/m³ level although they are far less severe.

There is a degree of uncertainty relating to the number of discontinuations and related costs:

- The potential for unemployment impacts throughout the supply chain;
- The capacity of existing or new players to fill the potential gap resulting from discontinuations; and
- The number of companies discontinuing and costs may be a reflection of: the difficulties companies face in achieving compliance, the high costs of implementing RMMs (particularly in large plants), certain lines or sites closing (as can be seen by less than whole integers in Table 8-13), and may not represent (entire) companies closing down closing. This is particularly true for refineries (C19.2).

Whilst the implementation of OELs would result in greater harmonisation of health and employment standards across the EU, it is possible that they could also create a disadvantage for established companies that would incur significant costs to restructure entire facilities. Low OELs may also create a barrier of entry for new enterprises due to the high costs associated with implementing more advanced RMMs.

SMEs may also be disadvantaged as costs are expected to be a substantial proportion of turnover/GOS at the lowest two policy option levels (see section 8.1). Alternatively, large enterprises may be able to absorb costs to a greater degree.

The modelled market impacts and discontinuations for C23.99b graphite and carbon electrodes are thought to not accurately the difficulties that companies in this sector would face to meet the two lowest policy options in reality. This is because, based on stakeholder consultation, there are many activities that require implementation of RMMs (as opposed to a few key activities), the plants cover a large surface area (resulting in large areas and high costs needed to implement exposure reduction measures) and alternatives are not currently available. Therefore, the costs to achieve compliance and the number discontinuations are expected to be higher than the ones currently modelled at the 7 and 70 ng/m³.

Table 8-18 Summary of market effects

Sector	7 ng/m ³			70 ng/m ³			700 ng/m ³			2000 ng/m ³		
	S	M	L	S	M	L	S	M	L	S	M	L
Discontinuations	3,226	132	103	129	6	11	-	-	-	-	-	-
Number unemployed	47,758			2,725			-			-		
Social cost of unemployment	€ 4,027.63			€ 225.67			-			-		
Number of MS currently at or below the OEL policy option	0			1*			4			12		

Source: Study team assessment

Notes: * Germany operates between an acceptable level of 70 ng/m³, and a tolerable level of 700 ng/m³. No other MS operates towards 70 ng/m³.

The number of MS does not add up to 27 as some MS do not currently have a limit value in place.

The total number of discontinuations in this table may slightly differ to those in Table 8-17 due to rounding when splitting the totals by company size. The sum total of discontinuations in Table 8-17 should be taken as the overall number of discontinuations.

9 ENVIRONMENTAL IMPACTS

This chapter comprises the following sections:

- Section 9.1: Potential environmental impacts;
- Section 9.2: Current environmental exposure to the substance;
- Section 9.3: Direct impact on the environment;
- Section 9.4: Indirect impacts on the environment and environmental legislation; and
- Section 9.5: Summary of environmental impacts.

9.1 *Potential environmental impacts*

The overall approach to the assessment of the environmental impacts, based on the Better Regulation (BR) Toolbox for environmental impacts (BR Tool #36) is described in the Methodological note. Initially the key questions listed in section 3.3. of the BR Tool #36 have been screened in order to identify which questions is relevant for the introduction of an OEL and should be answered in the impact assessment. From this screening the following potential environmental impacts are included in the assessment for PAH:

- Issues relating to the implementation and enforcement of existing environmental legislation – section 9.4;
- Climate change including impacts on climate neutrality objectives – section 9.4;
- Air, Water, Biodiversity and Soil – section 9.3;
- Waste – section 9.4;
- Zero pollution and toxicity – section 9.3;
- Efficient use of resources – section 9.4;
- Circular economy – section 9.4; and
- International environmental effects – section 9.4.

9.2 *Current environmental exposure to the substance*

9.2.1 Persistent, bio-accumulative, and toxic (PBT) screening

Table 9-1 outlines the persistent, bio-accumulative, and toxic (PBT) assessment status of PAH. To be classified as PBT, all three criteria must be fulfilled. The following table outlines the PBT status and harmonised classification for PAH in respect to the environment.

Table 9-1 PBT assessment and harmonised classification with regard to the environment for PAH

Substance	P	B	T	PBT	Harmonised classification (environment)	Notes
Benzo[k]fluoranthene	Y	Y	Y	Yes	Aquatic Chronic 1 (H400) Aquatic Acute 1 (H410)	Also a Persistent Organic Pollutant (POP) substance according to Regulation (EU) 2019/1021
Chrysene	Y	Y	Y	Yes	Aquatic Chronic 1 (H400) Aquatic Acute 1 (H410)	
Benzo[a]pyrene	Y	Y	Y	Yes	Aquatic Chronic 1 (H400) Aquatic Acute 1 (H410)	Also a Persistent Organic Pollutant (POP) substance according to Regulation (EU) 2019/1021
Benzo[e]acephenanthrylene	Y	N	Y	No	Aquatic Chronic 1 (H400) Aquatic Acute 1 (H410)	PBT assessment based on limited data (RAC, 2022c) Also a Persistent Organic Pollutant (POP) substance according to Regulation (EU) 2019/1021
Benzo[a]anthracene	Y	Y	Y	Yes	Aquatic Chronic 1 (H400) Aquatic Acute 1 (H410)	
Benzo[e]pyrene				No	Aquatic Chronic 1 (H400) Aquatic Acute 1 (H410)	PBT assessment not conducted
Benzo[j]fluoranthene				No	Aquatic Chronic 1 (H400) Aquatic Acute 1 (H410)	PBT assessment not conducted
Dibenz[a,h]anthracene	N	Y	Y	No	Aquatic Chronic 1 (H400) Aquatic Acute 1 (H410)	PBT assessment based on limited data (RAC, 2022c)
Dibenzo[b,def]chrysene; dibenzo[a,h]pyrene				No	None	PBT assessment not conducted
Benzo[r,s,t]pentaphene				No	None	PBT assessment not conducted

PBT: Persistent, Bio-accumulative and Toxic.

Sources: ECHA Registration Dossiers and CLP.

9.2.2 Current environmental exposure

9.2.2.1 Sources

In general PAH main release to the environment occurs via the incomplete combustion of organic materials via both natural and anthropogenic sources. It is report in RAC (2022a) that the majority of emissions to the environment therefore occur due to anthropogenic sources. This could be expected as it is relatively uncommon for combustion to occur naturally in the environment, with the

exception of wildfires. Generally atmospheric emissions of PAH are significantly higher than that of emissions to water however once in the atmosphere, deposition on surfaces will occur and run-off following rainfall may lead to emissions to water (DEFRA, 2019). In DEFRA (2019), it is estimated that approximately 3% of total atmospheric emissions of PAH are attributed to industrial activities whilst 84% can be attributed to domestic combustion activities. Road traffic emissions are also a major source and are emitted at approximately the same proportion as industrial emissions.

When specifically considering the EU situation the European Pollutant Releases and Transfer Register (E-PRTR) estimates releases of PAH to air in 2021 of approximately 39,300kg with metal manufacture consistently producing among the highest proportion of emissions (EEA, 2023b). When considering direct emissions to water data since 2009 have not exceeded 5,000kg per year with a gradual decline observed since 2007 (EEA, 2023c). Recent data from 2021 however indicate releases of approximately 109,200kg. As this data point is so far beyond all the other report data it is likely this data is an anomaly and the realistic releases to water in the EU are <5,000kg per year. When accidental releases are considered the main emitter of PAH to water is again the metal manufacturing industry. Accidental releases however are in much smaller magnitude and have not exceeded 200kg since 2007 (EEA, 2023c).

9.2.2.2 Background exposure

Background concentrations of PAH in the UK have been estimated in a report by Ricardo Energy & Environment (2020). This report highlighted that in the UK background concentrations of Benzo[a]pyrene (BaP) were found to range between 0.01ng/m³ and 0.84ng/m³. In relation to this Guerreiro et al. (2016) combined observable concentrations and modelling to estimate ambient air concentrations of BaP across approximately 60% of the European population. It was found that 20% of the European population are exposed to ambient air levels of BaP above 1ng/m³ whilst 93% of the European population are exposed to concentrations above 0.12ng/m³ (determined in this study as the acceptable risk level) (Guerreiro et al., 2016).

In a broader study in the European context observations from European Monitoring and Evaluation Programme (EMEP) stations found the sum of PAH background concentrations in the range of 2ng/m³ and 418ng/m³ (Pribylova et al., 2012). In contrast to this a year previously, Halse et al. (2011) found PAH background concentrations at EMEP stations in the range 0.2ng/m³ to 35ng/m³. Pribylova et al., (2012) attributes the difference in this background level to the inclusion of sampling over winter periods when greater levels of combustion are likely to be occurring (increased car traffic or heating for example). Overall, these findings estimate the background exposures to PAH may vary significantly and so environmental and human health risks associated with the baseline may be hard to quantify for the EU in total.

In water a study conducted by Montuori et al. (2022) in Southern Italy, concentrations of USEPA listed 16 priority PAH were found to be in the range of 10.1-567.2ng/L in surface water to 121.2-654.4ng/L in suspended sediments. In an additional study conducted in Portugal concentrations of the same 16 PAH were found to have a mean value of 45.5ng/L (Raposo et al., 2022). It can therefore be expected that PAH concentrations in surface water in Europe may be in the range of 0-1,000ng/L although this would need verification with more sources of data to confirm.

9.2.2.3 Environmental levels in relation to hazard data

All data observed from background concentrations gathered in the UK were below the European Commission target value of 1ng/m³ as set out in the relevant Directive (2004/107/EC) under the Air Quality Framework Directive (Directive 96/62/EC). This data could be seen as applicable and transferable to other western European countries and provides the most recent dataset on

Benzo[a]pyrene ambient air concentrations. However, in Guerreiro et al. (2016) one of the most important sources of BaP is cited as coal and wood burning which typically occurs less in Western Europe than in Eastern and Central Europe. As such the exceedance of the 0.12ng/m³ WHO reference level resulting in human health/environmental risk from ambient air concentrations may be hard to predict for present day Europe due to limited data.

When considering the findings from Halse et al. (2011) and Pribylova et al. (2012) these cannot be compared to the target value of 1ng/m³ or the 0.12ng/m³ value as data from these studies relates to the sum of PAH not specifically the concentrations of BaP.

For water the current EU standard for drinking water based on the sum of PAH is equal to 100ng/L, which when compared to the surface water values found in Montuori et al. (2022) indicates that some waterbodies in Europe may be above safe levels for human drinking water. This is likely addressed however during drinking water treatment to ensure levels of PAH contamination do not constitute a human health risk. The findings of Montouri et al. (2022) highlight that in some cases environmental threshold effect levels are exceeded and presence of carcinogenic PAH results in carcinogenic risks being realised in this water body.

In relation to environmental hazards the Scientific Committee on Health, Environment and Emerging Risks (SCHEER) recently adopted the opinion that concentrations of BaP should not exceed the Annual Average EQS for freshwater or saltwater of 22ng/L and that BaP is a suitable indicator for all PAH (SCHEER, 2023). Based on data gathered in Asia and assuming this is transferable to the EU situation this EQS is not expected to be exceeded (Bukowska et al., 2022) however as reported above (Montouri et al., 2022) other/total PAH concentrations may still pose risks to the environment.

9.2.2.4 Summary of current environmental impact of PAH

PAH are very seldom generated via naturally occurring processes and are mainly sourced from anthropogenic activities, namely incomplete combustion of organic materials. As such current background exposure levels of PAH in the land, air and water are likely as a result of releases from activities such as burning of wood/coal, transport emissions and industrial emissions. Literature cites that domestic burning is the most major source of PAH. Exposure levels in the EU are expected to show high variability depending on the region with the majority of the EU population exposed to atmospheric levels of BaP above the WHO reference level of 0.12ng/m³. This finding however is based on data from 2012 and so may not be reflective of the current situation. Given the levels of PAH reported in both air and water in Europe it is expected that background air concentrations may be high enough to pose slight risks to human health whilst measured PAH exposure in drinking water is likely relatively controlled. Environmental risks to water are likely realised in specific waterbodies throughout Europe although based on data from Asia as a proxy this is likely not as a result of BaP levels, despite this frequently being used as a marker for other PAH.

9.3 Direct impact on the environment

Given the above information regarding the aquatic toxicity of PAH and the potential for environmental releases it is important to consider the potential impact OELs might have on direct emissions and by proxy the natural environment and ecosystems. In response to OELs industry will likely change the RMMs currently used which in turn will impact potential for environmental releases. Table 9-2 below assesses the alternative RMMs available for each of the primary RMMs used currently and draws conclusions on the broad impacts a switch to these alternatives might have on the environment.

Table 9-2 Primary and alternative RMMs for each OEL policy option, together with the broad environmental impact

Primary RMM	Alternative primary RMM for each policy option				Broad environmental impacts
	7 ng/m ³	70 ng/m ³	700 ng/m ³	2000 ng/m ³	
Closed systems	Discontinuation	Discontinuation	N/A	N/A	Reduction in PAH emissions
Partially closed systems	Closed system	Closed system	Closed system	Closed system	Reduction in PAH emissions
	Discontinuation	Discontinuation			
Open hoods over equipment or local extraction ventilation	Closed system	Closed system	Closed System	Closed System	Reduction in PAH emissions
	Discontinuation	Discontinuation			
HEPA filter based RPE	Self-contained breathing apparatus (with bottled air) or airline respirators (air supplied by hose)	Self-contained breathing apparatus (with bottled air) or airline respirators (air supplied by hose)	Self-contained breathing apparatus (with bottled air) or airline respirators (air supplied by hose)	Self-contained breathing apparatus (with bottled air) or airline respirators (air supplied by hose)	No impact
General dilution ventilation	Closed system	Closed system	Closed system	Closed system	Increased/Reduction in PAH emissions
	Partially Closed System	Partially Closed System	Partially Closed System	Partially Closed System	
	Open hoods over equipment or local extraction ventilation	Open hoods over equipment or local extraction ventilation	Open hoods over equipment or local extraction ventilation	Open hoods over equipment or local extraction ventilation	
	Discontinuation	Discontinuation			
No ventilation	General dilution ventilation	General dilution ventilation	General dilution ventilation	General dilution ventilation	Increased/Reduction in PAH emissions
	Closed system	Closed system	Closed system	Closed system	
	Partially Closed System	Partially Closed System	Partially Closed System	Partially Closed System	
	Open hoods over equipment or local extraction ventilation	Open hoods over equipment or local extraction ventilation	Open hoods over equipment or local extraction ventilation	Open hoods over equipment or local extraction ventilation	
	Discontinuation	Discontinuation			

Source: Study team.

Based on the RMMs suggested as alternatives to the primary RMMs existing across industries with PAH exposure, it can be expected that the introduction of OELs at any policy option will likely improve the direct environmental impacts of the various sectors. This is because the majority of alternative RMMs to be implemented result in increased enclosure of processes and as such mean lower levels of PAH emissions to the air. In the cases where discontinuations occur this would result in a total reduction of direct PAH emissions, whilst for closed and partially closed systems fugitive emissions and emissions during maintenance/filling/sampling operations may still occur.

It is difficult to predict if the above changes will impact direct emissions to water. Emissions to waterbodies via atmospheric deposition however will be influenced by changing OELs and so it can be expected that the increase in enclosure due to protection of workers will have wider environmental benefits.

In cases where existing measures are being replaced by general dilution ventilation or open hoods/local exhaust ventilation, this may conversely impact environmental PAH emissions. This is due to the fact that these RMMs reduce the exposure in the local vicinity via extraction/diffusion of fresh air although in doing so this can lead to increased releases of PAH to external air. When compared to RMMs resulting in enclosure and subsequent reduction of PAH emissions it could be expected that this reduction would outweigh the increase in PAH emissions from exhaust ventilation/diffusion and give overall positive environmental impacts from OEL introduction. It is also possible that in the case of local exhaust ventilation carbon filters will be used before extracted air is returned to the environment, further reducing the environmental risk.

9.4 Indirect impacts on the environment and environmental legislation

9.4.1 EU Green Deal

In 2019 the European Commission announced the European Green Deal to encourage future policies to be developed in line with minimal adverse impacts on the environment and to support efforts to move to sustainable practices (European Commission, 2019). This section reviews the implementation of OELs for PAH in the context of the key elements of the green deal. This is also in line with the approach described in chapter 36 of the better regulation toolbox.

Table 9-3 outlines the key elements put forward in the EU Green Deal and contains a short overview of the expected impact (positive or negative) of introducing OELs for PAH on the progress towards each of these elements. A short explanation is given to indicate the justification for the expected impact.

Table 9-3 Potential for OELs to impact benefits of the EU Green Deal

Elements of the EU Green Deal	OELs impact (Yes/No)	Comment
Increasing the EU's climate ambition for 2030 and 2050	Yes	See 9.4.2 on the European Climate Law
Supplying clean affordable and secure energy	Yes	PAH are present in the supply chain for important base materials such as steel, aluminium and silicon which are used for the manufacture of PV solar panels. Should OELs cause a loss of production of green infrastructure may be compromised and targets made harder to meet.
Mobilising industry for a clean and circular economy	Yes	PAH are present in the manufacture of electrodes used for the recycling of metals such as aluminium. Should OELs cause a loss of production of these electrodes the ability to construct new recycling facilities may be compromised.
Building and renovating in an energy and resource efficient way	Yes	As above, impacts on the availability of steel would likely have knock on impacts for the continued construction of energy efficient buildings and utilisation of recycled materials.
Accelerating the shift to sustainable and smart mobility	Yes	The manufacture of key metals such as aluminium and steel will be required to allow the

Elements of the EU Green Deal	OELs impact (Yes/No)	Comment
		continued manufacture of EVs and other sustainable forms of transport. Should OELs disrupt metal production in the EU the ability to continue manufacturing sustainable transport may be compromised.
Designing a fair, healthy and environmentally-friendly food system	No	Introduction of OELs is not expected to impact food safety or sustainability.
Preserving and restoring ecosystems and biodiversity	Yes	Less PAH emissions as a result of better RMMs to meet OELs will improve air/water quality which will in turn help to restore ecosystems and biodiversity in heavily polluted areas.
Zero pollution ambition for a toxic-free environment	Yes	Same comment as above.

Source: Study team

9.4.2 European Climate Law

The European climate law was introduced in 2021 and sets out legally binding targets for emissions reductions proposed by the EU Green Deal. The main target proposed is to ensure that the European economy and society become climate neutral by 2050, with an intermediate goal to reduce greenhouse gas emissions 55% by 2030, compared to 1990 levels. It is therefore important that any implementation of OELs for PAH should support the drive to climate neutrality and not contradict the objectives set out in this legislation.

In relation to these objectives the introduction of OELs at a level which will disrupt supply chains for the metal industry could have indirect impacts on the EU ability to meet the climate targets as set out in the European Climate Law. In order to achieve climate neutrality in 2050 technical infrastructure is required to reduce reliance on the current systems with high emissions of greenhouse gases (GHG). This transition includes the upscaling of electric vehicles, development of renewable energy technologies and increasing the energy efficiency of buildings. Each of these sectors are reliant on metal products (which are produced in supply chains with exposure to PAH) and as such any disruption to industry may affect the market availability of products to manufacture solar panels, electric vehicles and energy efficient buildings. Based on the findings of this report the introduction of an OEL at 7ng/m³ or 70ng/m³ discontinuations will occur at metallurgy and aluminium manufacturer sites, whilst steel and iron foundries will have discontinuations at the lowest OEL.

Table 8-13 shows the discontinuations of the three identified sectors (steel and iron foundries (C24.1), manufacture of aluminium (C24.42), and other non-ferrous metallurgy (C24.45)). For C24.1, discontinuations are approximately 10 times higher, for C24.42 discontinuations are approximately five times higher, and for C24.45 discontinuations are approximately three times higher at 7 ng/m³ than at 70 ng/m³. Overall, the large extent of discontinuations at 7 ng/m³ may result in fewer products or materials essential for the green transition to be available in the EU, increase dependency on third country sources for supply.

Additionally, the PAH supply chain relates to electrodes used in the manufacture of silicon, which is a crucial component in the manufacture of solar panels. Under the lowest OEL around 22% of manufacturers will discontinue operations and cause disruption to the supply chain. This in turn may impact the solar market and cause delays in the EU plans to meet GHG emission reduction targets as set out in the European Climate Law. Limited availability of silicon for solar panels may

also increase market price for the raw materials resulting in higher costs of development for new solar projects and thus countering the aims of delivering cost effective renewable energy.

9.4.3 Waste management and disposal

Given that PAH exposure may occur as a result of waste management processes (NACE: E38.2) it can be expected that the implementation of EU OEL at the lowest policy option would likely reduce the potential generation of PAH at the waste incineration stage, subsequently reducing environmental emissions. As very few products intentionally contain PAH, instead releasing them during the lifetime of the product or when combusted as waste, the environmental impacts at the waste and disposal stage will largely be attributed to the waste incineration as described above. Wastes which are landfilled however do have potential for leaching of PAH in run-off into groundwater following aerobic and anaerobic decomposition (Ates and Argun, 2021). The introduction of OELs however would likely not impact this emissions stream and as such leachate may continue to contain similar levels of PAH under any of the policy options.

9.4.4 Resource consumption and circular economy

The introduction of OELs for PAH may result in disruption to the graphite and carbon electrode manufacturing sector (C23.99b) either in the form of discontinuations or significant cost as a result of implementing RMMs. Graphite and carbon electrodes are important for electrolysis processes and are involved in both the manufacture and recycling of metals such as aluminium. The disruption caused to the supply chain by introducing an OEL at the lowest level, may result in limited availability of electrodes for metal recycling which is counter intuitive to goals set out in establishing a circular economy.

9.4.5 Global impacts

Given that OELs introduced at the lowest policy option may cause approximately 3,500 companies to exit the market, it is highly likely that a number of these companies may, if financially feasible, move operations to outside the EU. Other countries with successful manufacturing economies such as China, India and Australia do not currently have OELs in place for PAH and so relocation or redistribution of supply chains to source products from these economies may be a possibility as a direct result of the introduction of strict OELs in the EU. This would result in increased globalisation of supply chains which in turn contributes more GHG emissions via international transit. This movement of industry may also reduce direct emissions of PAH within Europe but in reality this will simply transfer these emissions to other global regions and ecosystems with potentially less environmental protections than in the EU.

9.4.6 Green initiatives

No green initiatives introduced by companies with PAH exposure are expected to be impacted as a result of the introduction of OELs. In some cases the discontinuation of companies may result in the loss of green initiatives although this will also be paired with a greater reduction in PAH emissions and energy consumption.

9.5 Summary of environmental impacts

The introduction of OELs are likely to have both direct and indirect impacts on environmental legislations and the environment itself. Some PAH pose significant environmental hazards based on their classification as Persistent, Bio-accumulative and Toxic (PBT) and their hazard classifications for aquatic toxicity from short- and long-term exposure. The change in risk regulation measures (RMMs) relating to the introduction of OELs at the lowest three policy option could result in environmental benefits via greater levels of encapsulation reducing PAH emissions to air. As PAH contamination of soil and water is often attributable to atmospheric deposition then this reduction of

air emissions would benefit all environmental compartments. Conversely the introduction of increased ventilation may result in increased environmental PAH emissions over the baseline however this is not perceived to be as significant a change as reduction from encapsulation and so the introduction of OELs would still result in a net benefit for direct emissions to the environment.

The impacts on the supply chains relating to sectors with PAH exposure however could result in challenges to realise goals set out in environmental policies/legislation. A key product sector that PAH influence is the manufacture of basic metals such as iron, steel and aluminium, as well as silicon metal. It has been noted in this impact assessment that OELs introduced at 7 ng/m³ or 70 ng/m³ may result in discontinuations in these sectors, potentially resulting in a market shortage. Aluminium, iron and steel, as well as silicon metal indirectly, are essential products in the manufacture of green infrastructure and so disruption to this supply chain may limit progress towards environmental goals reliant on this infrastructure. As particular examples, solar panel production, refurbishment of buildings to improve energy efficiency and use in the electric car manufacturing sector are all sectors which may be impacted by the discontinuations occurring as a result of the lower OELs for PAH. Additionally, some recycling of metals is dependent on carbon and graphite electrodes which would be disrupted by introduction of OELs.

Shortages of metal products in the market may also result in increased market prices for final products which oppose the general aims of environmental legislations to make environmentally beneficial products more economically attractive. It is also likely that this loss of market capacity will result in increasing imports of products from other economies where PAH OELs are not in force. This means environmental issues associated with PAH release may simply be transferred to other global areas, as opposed to the problems being addressed. A more globalised supply chain also results in higher GHG emissions which again counter acts climate targets and poses issues in the fairness of the burden of responsibility.

The above impacts are most likely realised at the lowest policy options which would result in the highest number of discontinuations or extensive works to manufacturing facilities. These responses to policy options would result in the most disruption to supply chains for metallic products and would therefore have the greatest impacts on environmental policies due to disruption. The greatest disruption would occur at the lowest policy option where it is estimated 3,461 companies would have to discontinue operations whilst at the highest two policy options, no discontinuations would likely occur.

At the second lowest policy option, 70 ng/m³ OEL, high discontinuations in coking, coal tar distillation, graphite and carbon electrodes and to some extent also in non-ferrous metallurgy may result in market disruptions. And for already concentrated sectors such as coal tar distillation and aluminium plants, with only seven and nine plants in total in the EU market, high costs and/or closures are more likely to result in supply chain disruptions. As explained in section 8.4.5 in more detail, the products of these industries are critical raw materials (European Commission 2020c) and/or feed into key strategic technologies (JRC 2023).

There are also conflicting forces: on one hand the closures and additional RMMs will result in a reduction of PAH emissions (and likely carbon emissions), but on the other there could be an inadvertent disruption to the supply chain of goods essential in the provision of green infrastructure. The scale of the disruption that may be experienced is difficult to quantify as it will depend on the response of industry and the ability of wider markets outside of the EU to fill demand whilst the European industry responds to the introduction of OELs. This disruption could therefore be mitigated by transitional measures.

10 OTHER IMPACTS

This chapter comprises the following sections:

- Section 10.1: Impacts on EU Strategic Goals;
- Section 10.2: Impacts on fundamental rights, including equality;
- Section 10.3: Impacts on digitalisation;
- Section 10.4: Contributions to the UN sustainable development goals; and
- Section 10.5: Summary of other impacts.

10.1 Impacts on EU Strategic Goals

In June 2019, the European Council agreed the EU's agenda for the next five years, setting out the priority areas for the European Council and establishing guidance for the work programmes of all parts of the EU (Council of the European Union, 2019).

It focuses on four priorities:

- Protecting citizens and freedoms;
- Developing a strong and vibrant economic base;
- Building a climate-neutral, green, fair and social Europe; and
- Promoting European interests and values on the global stage.

The first priority of the EU strategic goals is protecting citizens and freedoms, which includes access to affordable energy, and while coal fired power plants may be negatively impacted at the lowest policy options, the sector is already in declining (see section 3.10.7).

The second priority of the EU strategic goals is the development of a strong economic basis, therefore negative impacts on competitiveness at the lowest policy options, particularly in markets where there is already pressures from high energy prices and non-EU competition (mostly metallurgical) will be at disadvantage (see section 8.4.3). SMEs form the majority of companies in the sectors under review (99.8%) who are at a competitive disadvantage compared with large enterprises as costs make up a higher proportion of their turnover than large companies which are more likely to absorb the costs.

Adjustment costs as a percentage of research and development (R&D) expenditure are proportionally high at the lowest policy for manufacture of bituminous products, graphite and carbon electrode manufacture, steel and iron foundries, casting of metals, and waste incineration. Costs as a percentage of R&D are significantly lower at the second lowest policy option, although R&D would still be significantly negatively impacted at this level. Therefore it can be anticipated that there would be some adverse effects on innovation.

The third priority of the EU strategic goals is building a climate-neutral, green, fair and social Europe, and a reduction of PAH emissions will have a positive impact on reducing environmental

loads of Persistent, Bioaccumulative and Toxic (PBT), and Persistent Organic Polluting (POP) substances (see section 9). However, graphite (natural and synthetic) makes up around 50% of batteries in electric vehicles (EVs), it is an essential component of fuel cells, and is a critical raw material in smart mobility, while polycrystalline silicon wafers (made with silicon metal in C24.45) are used in photovoltaic (PV) solar panels. In addition, recycling of metal such as steel, requires the use of electrodes made by graphite and carbon electrode manufacturers (C23.99b).

Additionally, consideration has been given to the EU Commission priority areas for 2019-2024. These are assessed in Table 10-1 below.

Table 10-1 Potential for OELs to impact benefits of the EU Commission Priority areas

EU Commission Priority Areas 2019-2024	OELs impact (Yes/No)	Comment
A European Green Deal	Yes	See section 9.4.1
A Europe Fit for the Digital Age	Yes	See section 10.3
An Economy that Works for People	Yes	The introduction of OELs will affect SMEs due to the higher proportion of businesses being SMEs and due to higher costs in relation to turnover at the two lowest policy options.
A Stronger Europe in the World	Yes	The introduction of OELs will help to affirm the EU's reputation of delivering safe workplaces and respecting the fundamental rights of EU workforce. If OELs are set at a disproportionately low level however this could compromise the attractiveness of EU to international business and so to meet this priority area a balance should be found. This is particularly true for businesses operating in C23.99b graphite and carbon electrode manufacturers and the metallurgical sectors (C24.1, C24.42 and C24.45) which are already facing pressures from high energy costs and cheaper non-European imports.
Promoting our European Way of Life	Yes	The introduction of EU Binding OELs will mean all Member States are subject to the same regulation of hazardous substances set out in the CMRD. EU OELs therefore support an equal approach to chemical risk management and a united Europe when dealing with external markets.
A New Push for European Democracy	No	The introduction of OELs for PAH does not impact the push for a maintained and renewed European democracy.

Source: Study team

10.2 Impacts on fundamental rights, including equality

Article 31.1 of the Charter of Fundamental Rights of the European Union states that "Every worker has the right to working conditions which respect his or her health, safety and dignity." (European Commission, 2012). The lowest three policy options lead to an improvement in air quality or skin protection for at least some European workers that are currently exposed to PAH.

Benzo[a]pyrene has both reproductive toxicity in men (reduced sperm count) and developmental toxicity in women (during pregnancies) and the DRRs for both have thresholds in comparable ranges (see section 2.2.3.2). Men and women would be equally protected at the policy options under review.

Article 21.1 prohibits discrimination on the grounds of sex. It has not been a subject of this study to elucidate the relationship between setting protective limit values and gender equality.

10.3 Impacts on digitalisation

The Commission has in its 2030 Digital Compass Communication set out a vision, targets and avenues for a successful digital transformation of Europe by 2030 (European Commission, 2023b). To support this process, the Commission committed to assess how the options under consideration reflect the 'digital by default' principle and contribute to the digital transformation.

Digitalisation may be negatively impacted due to the products related sectors and how they feed into digitalisation: silicon metal (made in C24.45) is used to make high purity silicon, which ultimately makes wafers. Speciality graphite and graphene (C23.99b) are also used in semiconductors and if companies are not able to meet the OEL (particularly in C24.45 plants using Soderberg anodes, which are manufactured by players in C23.99b) this could have a negative impact on digitalisation.

Table 8-13 shows the discontinuations of the two identified sections (C24.45 and C23.99b). For both sectors discontinuations are approximately three times higher at 7 ng/m³ than at 70 ng/m³. At 700 and 2000 ng/m³ discontinuations do not occur. The high discontinuations suggest the difficulties the sector may have in achieving the two lowest policy options. It is possible that discontinuations may decrease the availability of EU sourced products required for digitalisation.

Overall, negative impacts on metal silicon manufacturers (C24.45) and graphite manufacturers (C23.99b), which feed into the manufacture of semiconductors, have the potential to disrupt the supply chain and the target under the Chips Act to double the production share of semiconductors, as part of the action plan in the Digital Decade targets and Digital Compass Communication. Collectively the difficulties of silicon and graphite production sector to meet costs at the two lowest policy options may result in negative impacts on digitalisation through increased material costs or greater reliance upon imports from third countries (primarily China).

10.4 Contributions to the UN sustainable development goals

The third UN sustainable development goal <https://www.undp.org/sustainable-development-goals>, which calls for "*good health and wellbeing - improved worker and family health*" is directly relevant to the setting of limit values for PAH. The lowest three policy options led to an improvement in air quality and skin protection for at least some European workers that are currently exposed to PAH.

The following UN sustainable development goals have been identified as being relevant:

- 3. Good health and wellbeing: the lowest three policy options achieve improved worker and family health outcomes. The more stringent the OEL, the higher the level of good health and wellbeing is achieved;
- 7. Affordable and clean energy: coal fired power plants will experience additional drive to either convert to biomass where possible or may be forced to close at the lowest policy, forcing a move to alternative energy sources;

- 8.8 Protecting labour rights and promoting safe and secure working environments for all workers, including migrant workers, in particular women migrants, and those in precarious employment; and
- 14 and 15. Life below water and Life on land: several PAH are PBT or POP (see section 9.2.1). By reducing the amount of PAH that are released, so will the burden of environmentally damaging chemicals.

10.5 Summary of other impacts

Table 10-2 below summarises other impacts in relation to EU strategic goals, fundamental rights, digitalisation and UN sustainable development goals.

Table 10-2 Summary of other impacts

Other impacts	Impacts
EU Strategic goals	Pressure on markets already squeezed by high energy prices (metallurgy, including electrode manufacturers), and SMEs (99.8% of companies investigated) may result in competitive disadvantage at the two lowest policy options. A reduction of PAH emissions will have a positive impact on reducing environmental loads of PBT and POP substances.
Fundamental rights	Positive impact on health and safety. Increased monitoring will help to ensure that future exposures remain controlled and worker risk remains low.
Digitalisation	Digitalisation and building a climate-neutral, green society may be impacted by high costs to silicon metal (C24.45) and graphite manufacturers (C23.99b, used in semiconductor manufacturing, fuel cells, PV solar panels and EV batteries).
UN Sustainable Development Goals – Goal 3	Positive. The more stringent the OEL, the higher the level of good health and wellbeing is achieved.
UN Sustainable Development Goals – Goal 7	At the lowest policy option, closure of coal fired power plants are anticipated.
UN Sustainable Development Goals – Goal 8	Secured health and wellbeing in the workplace, particularly for female workers.
UN Sustainable Development Goals – Goal 14 and 15	Positive. The lowest three policy options will reduce the environmental emissions of PBT and POP substances.

11 DISTRIBUTION OF THE IMPACTS (OEL ONLY)

This chapter comprises the following sections:

- Section 11.1: Businesses;
- Section 11.2: SMEs;
- Section 11.3: Workers;
- Section 11.4: Consumers;
- Section 11.5: Taxpayers/public authorities;
- Section 11.6: Specific Member States/regions; and
- Section 11.7: Summary of distribution of the impacts.

Please note that figures in this section only refer to the impacts of implementing an OEL and not of both an OEL and BLV. Due to the costs of monitoring and implementing a BLV (see sections 7.2.10 and 7.2.11), the distribution of impacts can be expected to increase in severity in comparison to an OEL only option.

11.1 Businesses

The total costs and benefits for businesses (relative to the baseline) are summarised in Table 11-1 for the different policy options. Benefits are shown as negative costs and represent a cost saving (usually due to model predicting companies will choose to invest in a more efficient risk management measure (RMM), with usually a higher capital expenditure but that over 40 years will result in cost savings). The impact on businesses should be read together with:

- The total PV40 compliance costs, disaggregated by policy option and sector are shown in Table 7-33 & Table 7-34;
- The number of companies predicted to discontinue, presented in Table 8-13 and the estimated cost of discontinuations in Table 7-17; and
- The benefits for employers, including public authorities as employers of firefighters, which are based upon the reduced cost of having an employee become ill with lung cancer or developmental toxicity effects, and are presented in sections 6.4.1 and 6.5.1.

The average benefits per enterprise for companies that continue in business are shown in Table 11-1 below. The benefits are based on workforce with a turnover of 5%, which effectively means that on average workers spend 20 years working in an environment with PAH compounds. Costs and benefits in this table exclude those for firefighters as they are dependents of a public agency (non-business). Figures for firefighters are included in section 11.5.

A comparison of costs and benefits to employers in the table below indicates that that RMM compliance, monitoring costs and administrative burden over a period of 40 years are significantly higher than the value of benefits returned to an enterprise in each OEL policy option. The majority of costs are attributable to recurrent adjustment costs, which are considerably higher at the lowest

policy option, and are still high at the second lowest policy option and small at the second highest policy option and none at the highest policy option (see Table 7-49).

Table 11-1 Costs and benefits to EMPLOYERS (PV over 40 years, policy options relative to the baseline)

	7 ng/m ³	70 ng/m ³	700 ng/m ³	2000 ng/m ³
Total benefits for employers (avoided disruption)	€ 290,921.97	€ 133,284.12	€ 8,499.99	€ -
Total RMM adjustment, monitoring, and administrative costs	€ 37,659.87	€ 3,023.87	€ 225.50	€ 148.45
Number of companies minus those discontinuing	437,604	440,920	441,066	441,066
Benefits (avoided disruption) per enterprise	€ 0.66	€ 0.30	€ 0.02	€ -
Adjustment, monitoring and admin costs per enterprise	€ 0.09	€ 0.01	€ 0.001	€ 0.0003

Source: Study team.

According to Table 8-8, at the lowest policy option companies will generally experience high costs as a percentage of turnover in their first year. Whilst this table does not provide percentages for the full cost of companies continuing over 40 years, these percentages are suggestive of sectors where costs associated with the policy options could be problematic in general. As shown, for companies that continue operating in the following sectors, costs make up a significant proportion of their turnover: C16.1 wood preservation, C23.2 manufacture of refractory product, C24.1 steel and iron foundries, C24.45 non-ferrous metallurgy, C24.5 casting of metals, D35.11 coal fired power plants, E39 soil remediation, F42.12 welding of railroads, and N81.22 chimney sweeps.

At 70 ng/m³ costs are significant for C23.2 manufacture of refractory products, C24.45 other non-ferrous metallurgy, and D35.11 coal fired power plants. Costs at the lowest two policy options are negligible.

11.2 SMEs

The assessment of the impact on SMEs are done following the principles of the SME test; see BR Tool #23. The SME test includes the following steps:

- Identification of affected business
- Consultation of SME stakeholders
- Assessment the impacts on SMEs
- Minimising the negative impacts on SMEs

Table 11-2 Summary of the SME test

SME test	Summary assessment
Identification of affected businesses	
	99.1% of the affected companies are small companies and 0.7% are medium sized companies.
	The majority of sectors under review in the study are primarily made up of SMEs (>90% of all companies are SMEs) with the exception of the following sectors: C19.2 (refineries

SME test	Summary assessment
	approximately half are SMEs), C20.13 (manufacturer of carbon black – around 80% are SMEs), C20.14 (coal tar distillation – approximately 45% are SMEs), C23.99b (graphite and carbon electrode manufacture – all are large enterprises), C24.42 (manufacture of aluminium – approximately one third are SMEs), and D35.11 (coal fired power plants – approximately 85% are SMEs). All of these sectors have a low number of operating enterprises in the EU indicating that the higher percentage of large companies refers to a small number overall.
Consultation with SME stakeholders	
	SMEs have been consulted as part of stakeholder consultation. The share of SME respondents is 38% in the stakeholder survey conducted for this study. SME responses were only provided in regard to C19.2 (refineries), C20.13 (manufacture of carbon black), C20.14 (coal tar distillation), C24.42 (manufacture of aluminium), C24.5 (casting of metals), F42.11 (road paving) and may not provide a robust representation of these sectors.
	SME respondents unilaterally believed that the most stringent policy options (7 and 70 ng/m³) would have negative impact on EU competition. At 700 ng/m³ SME respondents were split as to whether EU competition would be impacted (this was felt to be negative for C20.13 (approximately half of SME sector respondents) and C20.14. the remaining sectors believed there would be limited/no impact at this level. At 2000 ng/m³ one respondent believed there to be negative impacts in C20.14, and one believed there to be positive impacts for EU competition in F42.11. All respondents believed 7 and 70 ng/m³ would have negative impacts on global competition. At 700 ng/m³ approximately half of the respondents believed there would be limited/no impact. Those that believed there would be negative impacts were in C20.13 and C20.14. At 2000 ng/m³ the majority of respondents believed there to be limited/no impacts to global competitiveness. One believed there to be negative impacts in C20.14 and one believed there to be positive impacts in F42.11. However, these results should be read with caution as they are not a representative sample of the sectors.
Assessing the impacts on SMEs	
	One indicator for assessing the impacts on SMEs is the share of first year costs in annual turnover. This information is visible in Table 8-8 for the companies that are expected to continue operation at each policy option level. These percentages do not take account of high proportions of companies discontinuing in each sector. As shown in the market effects (section 8, particularly Table 8 8), at the lowest policy option, in approximately half the sectors, small and medium sized enterprises will experience high costs as a percentage of turnover. Sectors with high percentages for SMEs include C16.1 wood preservation, C19.2 petroleum refineries, C20.14 coal tar distillation, C23.2 manufacture of refractor products, C23.99a manufacture of bituminous products, C24.1 steel and iron foundries, C24.45 other non-ferrous metallurgy, C24.5 casting of metals, D35.11 coal fired power plants, E39 soil remediation, F42.12 welding of railroad tracks, and N81.22 chimney sweeps. Also coking plants (C19.1) are heavily impacted at this level due to 100% of companies discontinuing. At the 70 ng/m³ policy option SMEs are potentially disadvantaged, albeit to a lesser extent than at ng/m³ in the following sectors: C16.1 wood preservation, C19.1 coking plants, C19.2 petroleum refineries, C23.2 manufacture of refractory products, C24.1 steel

SME test	Summary assessment
	and iron foundries, C24.45 other non-ferrous metallurgy, C24.5 casting of metals, D35.11 coal fired power plants, E39 soil remediation, and F42.12 welding of railroad tracks. At 700 ng/m³ and 2000 ng/m³ SMEs may also have high costs as a percentage of operating surplus in C16.1 wood preservation, C23.2 manufacture of refractory products, C24.1 steel and iron foundries, and D35.11 coal fired power plants. In terms of R&D, the introduction of OELs this may result in proportionally less R&D being performed by small and medium companies than large (albeit most companies would reduce their R&D regardless of their size) at the two lowest policy options. This may put SMEs at a disadvantage against large companies in the future; R&D is the means to develop novel methods to improve efficiency and reduce costs for companies. Overall SME's may be at a competitive disadvantage compared with large enterprises as costs make up a higher proportion of their turnover than large companies which are more likely to absorb the costs.
Minimising the negative impacts on SMEs	
	The option proposed by the ACSH with a transitional period of 6 years before the option of the OEL 70 ng/m³ will be introduced allows companies to plan and finance their investments in RMMs over the six-year period. This will be particularly important for SMEs. Based on first year costs as a percentage of turnover for sectors with a transitional period, C19.1 and C20.14 are sectors with high first year costs for remaining SMEs, and a high proportion of discontinuations at 7ng/m³. For C19.1 the majority of the sector is estimated to be made up of SMEs, and for C20.14 approximately half of all companies are SMEs. The transitional period is expected to reduce the number of SMEs discontinuing (and therefore unemployment) for SMEs in these sectors. For the remaining transitioning sectors (except C24.1 which has low exposure concentrations), high exposure concentrations (far greater than 140 ng/m³) and associated high compliance costs may indicate little reduction in cost for SMEs (particularly C23.2, C24.1, C24.45, C24.5, and F42.12).

The numbers of small, medium and large enterprises likely to have workers exposed to PAHs in the EU are estimated in Table 3-105 in Section 3.10.4.3.10.3

The table below indicates that medium companies have comparatively higher costs relative to turnover at the lowest policy options (0.6% of turnover on average, vs 0.2% for small and large companies), and small and medium enterprises on average have similar share (0.5% of turnover) at the second lowest policy option.

Table 11-3 Costs for EMPLOYERS by size of company (PV over 40 years, constant discount rate, OEL policy options relative to the baseline) (€ millions)

Sector	Small	Medium	Large
Number of companies	436,466	3,001	841
7 ng/m³			
Total RMM adjustment costs, air monitoring costs, and administrative burden	€ 6,998	€ 9,210	€ 21,451

Sector	Small	Medium	Large
Average cost per company	€ 0.02	€ 3.07	€ 25.51
Average cost per company as a percentage of average turnover per company	0.23%	0.62%	0.2%
Discontinuations	3,226	132	103
70 ng/m³			
Total RMM adjustment costs, air monitoring costs, and administrative burden	€ 737.89	€ 698.28	€ 1,587.91
Average cost per company	€ 0.002	€ 0.23	€ 1.89
Average cost per company as a percentage of average turnover per company	0.02%	0.05%	0.01%
Discontinuations	129	6	11
700 ng/m³			
Total RMM adjustment costs, air monitoring costs, and administrative burden	€ 192.84	€ 21.23	€ 11.42
Average cost per company	€ 0.0004	€ 0.007	€ 0.01
Average cost per company as a percentage of average turnover per company	0.006%	0.001%	0.0001%
Discontinuations	0	0	0
2000 ng/m³			
Total RMM adjustment costs, air monitoring costs, and administrative burden	€ 131.58	€ 11.75	€ 5.13
Average cost per company	€ 0.0003	€ 0.004	€ 0.006
Average cost per company as a percentage of average turnover per company	0.004%	0.001%	0.00005%
Discontinuations	0	0	0

Source: Study team.

11.3 Workers

The costs and benefits for workers and their families (relative to the baseline) are summarised below for the different policy options. The benefits are the avoided costs of ill health. At the most severe policy option it is estimated that a substantial number of companies would close down, resulting in job losses. From the perspective of the cost to the EU, these people would, however, be available for employment elsewhere and in time, may find other equivalent employment. However, the impacts associated with the potentially temporary loss of employment cannot be estimated.

Table 11-4 presents the costs and benefits for workers (relative to the baseline) for Method 1 and 2, for the different OEL policy options. The benefits are the avoided costs of ill health (see section 6.3), and the costs are the distress burden of unemployment (see section 8.5).

There are substantial benefits at the two lowest policy options overall, but there are also substantial costs related to unemployment that are higher. At the second highest policy option there are some benefits from avoided ill health and no costs of unemployment. While the highest policy option has neither costs due to unemployment nor benefits from avoided ill health.

Whilst modelling estimates numbers of job losses, a number of employees may be retained in different roles (in the case of large companies with partial closures), or to be reemployed by competitors. Although it is not currently possible to model these.

These values represent workers as a whole and include those employed by companies and public authorities as firefighters. Cost of unemployment distress exclude firefighters as it would not be suitable for discontinuations in this sector.

Table 11-4 Comparison of the costs and benefits to WORKERS & THEIR FAMILIES (PV over 40 years, policy options, relative to the baseline) (€ millions)

Methods	7 ng/m ³	70 ng/m ³	700 ng/m ³	2000 ng/m ³
Number of workers	1,284,052	1,284,052	1,284,052	1,284,052
Benefits (avoided ill health) (M1)	€ 187.38	€ 101.06	€ 15.85	€ -
Benefits (avoided ill health) (M2)	€ 64.48	€ 20.06	€ 1.97	€ -
Costs (unemployment distress)	€ 4,028	€ 226	€ -	€ -
Benefits (avoided ill health) per worker (M1)	€ 0.0001	€ 0.0001	€ 0.00001	€ -
Benefits (avoided ill health) per worker (M2)	€ 0.0001	€ 0.00002	€ 0.000002	€ -
Costs (unemployment distress) per worker	€ 0.005	€ 0.0003	€ -	€ -

Source: Study team.

Notes: Only additional costs and benefits (i.e. relative to the baseline) are presented in this table.

As indicated in section 3.3.4.14 employment in the coal sector (mines and power plants) is most concentrated in Bulgaria, Czech Republic, Germany, Greece, Poland and Romania, while Germany has a large number of power plants, and therefore closures are most likely to be felt in these countries. However, the main driver for closures of coal powered plants is adherence to the 2016 Paris Agreement and the objective for the EU to achieve climate neutrality by 2050. Therefore, the closures and job losses will take place regardless of any OEL set for PAH.

The estimated geographic distribution of companies is shown in Table 3-107, and the number of enterprises discontinuing in each sector and the number of workers potentially made unemployed as a result is shown in Table 8-17. Analysis of these tables suggest exposed workers are heavily split across Member States, however workers are typically more prominent in Germany, Spain, France, Italy, and Poland.

Sectors with a high level of companies discontinuing at 7 ng/m³ include C19.1 coking plants (100%), C19.2 petroleum refineries (60%), C20.13 manufacture of carbon black (50%), C20.14 coal tar distillation (62%), C23.99b graphite and carbon electrode manufacture (44%), C24.42 manufacture of aluminium (30%), C24.45 other non-ferrous metallurgy (44%), D35.11 coal fired power plants (40%), E39 soil remediation (22%), and F42.12 welding of railroad tracks (55%).

At 70 ng/m³ companies discontinuing is severe for C19.1 (45%), C20.14 (34%), C23.99b (16%) and C23.35 (9%). Again, cross examination of sectoral discontinuations at 70 ng/m³ against the distribution of workers potentially made unemployed suggests disproportionate impacts would occur in the countries listed above.

The distribution of exposed workers by sector and EU Member State can also be found in Table 16-20. This information has been used to assess the severity of discontinuations on workers by Member State. Please note that the distribution of impacts by Member State has been performed on the basis of Eurostat data which may not accurately reflect the location of companies (due to issues regarding NACE code data reflecting larger sectors than those included in this study). Any analysis by EU Member State should be read with caution.

Modelling does not predict in which Member States discontinuations are expected to occur however, cross examining the discontinuations and unemployment costs against the distribution of enterprises by Member State in Table 3-107 and consultation feedback, the social costs of unemployment may be incurred to a greater extent in the following sectors and Member States:

- C19.1 Coking plants: Poland, Czech Republic, Hungary, Greece, Spain, Italy, and Romania;
- C19.2 Petroleum refineries: Italy, Spain, Poland, Sweden, Belgium and Greece;
- C20.13 Manufacture of carbon black: France, Poland, Germany, and Italy;
- C23.99b Graphite and carbon electrode manufacture: France, Poland, Germany, Austria, Spain, Italy, Romania, and Slovakia;
- C24.1 Steel and iron foundries: Germany, Italy, France, Poland and Austria, but also Sweden, Spain, Slovakia and Czech Republic;
- C24.45 Other non-ferrous metallurgy: Germany, France, Austria, and Italy;
- C24.5 Casting of metals: Germany, Italy, France, Spain, Czech Republic, and Poland;
- D35.11 Coal fired powerplants: Bulgaria, Czech Republic, Germany, and Poland;
- E38.2 Waste incineration: Germany, France, Spain, Italy, and Poland;
- E39 Soil remediation: France, Germany, Italy, Poland, and Romania;
- F42.11 Road paving: France, Germany, Netherlands, Romania, Poland, and Italy;
- F42.12 Welding of railroads: Poland, Germany, Spain, Italy, Hungary, and Sweden;
- G45.2 Motor vehicle repair: Germany, Spain, France, Italy, Poland, and Czech Republic; and
- N81.22 Chimney sweeps: Italy, Germany, France, Poland, Netherlands, and Belgium.

The above list should be treated with caution because the distribution of companies using PAH across EU Member States has been modelled based on Eurostat data and so may have a level of uncertainty relating to the true distribution. As such any analysis of impacts on specific Member States would pose a level of uncertainty and may lead to inaccurate conclusions, except for C20.14 and C23.99b, or C19.1, C24.1, and C24.5 because the information on MS split has been taken from industry or because the study team has taken 100% of the sector as relevant. In the latter category, the data should still be interpreted with caution since the Eurostat distribution may still

not reflect where businesses operate in reality. This may be due to the fact that for example the same type of industry may validly fall under two NACE codes.

As expected, significant unemployment costs are incurred at the first and second policy option levels, whereas no discontinuations and therefore no job losses are incurred at the third or fourth levels.

Overall, costs of unemployment are most likely to occur in France, Germany, Italy, Poland, and Spain than other Member States. However, this is not an indication of the severity of impacts in these Member States as smaller costs in other countries may represent a greater share of the sector in said country, although the extent of this is not known.

11.4 Consumers

As indicated in section 8.3.2, despite the maturity of markets analysed in this study, most enterprises are small or medium sized and are unlikely to be able to fully absorb additional costs without impacting consumer prices (e.g. road paving, motor vehicle repair, chimney sweeps). Overall, the lowest two policy options modelled predict significant discontinuations, particularly for smaller businesses that would be unable to meet the OELs and their compliance costs. As a result of these discontinuations, it is also likely that there would be significantly fewer companies operating within industry resulting in lesser capacity for demand to be filled, and subsequently a higher risk of price increases for consumers.

Sectors such as, but not limited to, carbon black manufacturers (C20.13), coking (C19.1), coal tar distillation (C20.14), graphite and carbon electrode (C23.99b), other metallurgy (C24.45) do not have products that enter the consumers' market directly. These sectors enable the manufacture of products that are used by consumers. The capacity for absorbing costs in these sectors appears to be limited based on the compliance costs as a percentage of gross operating surplus (GOS) at the two lowest policy options, see Table 8-9. This also seems to be the case generally for the metallurgical industry (under C24) where products can be sold directly to consumers. Pressure from non-EU imports may help reduce consumer costs in these markets.

Sectors such as smokehouses (C10.13, C10.2), automotive repair (G45.2) and chimney sweeps (N81.22) may sell their products/services directly to the public. However, the Member State split of activities has been taken from Eurostat data for these sectors and so may have a level of uncertainty relating to the true distribution. Taking into account the level of uncertainty, it may still be possible to conclude that based on the number of companies exiting the market as a proportion of total number of companies in the EU, that manufacturers of smoked foods (C10.13, C10.2) in Germany, Spain, France, Italy and Poland may increase consumer prices at the two lowest policy options; automotive garages (G45.2) in Italy, Poland and France may be more adversely affected and increase consumer prices; chimney sweeps (N81.22) in Germany, France, the Netherlands, Poland and Belgium may also need to pass costs on to consumers.

As already indicated in section 8.3.2, sectors relating to infrastructural or essential services such as C16.1 wood preservation for railway sleepers and telegraph poles, E38.2 soil remediation, F42.11 road paving, F42.12 welding of railroad tracks, G45.2 automotive repair and maintenance, and N81.22 chimney sweeps may be more likely to pass costs onto downstream users.

11.5 Taxpayers/public authorities

The costs and benefits for the public sector (relative to the baseline) are summarised in Table 11-5 for the different policy options. These impacts are in addition to the compliance, monitoring and administrative costs related to firefighters in Section 7.4.1.

The benefits of the avoided costs of ill health relative to the baseline to the public sector are composed of cost of treatment and tax revenue, as summarised in the table below. These costs include healthcare treatment costs, which assume that the costs are borne by the public sector. In addition, the avoided costs of healthcare include the benefits of avoided healthcare costs incurred by firefighter employers which are government agencies. For this same reason there are direct adjustment, monitoring and administrative costs for taxpayers and public authorities to allow firefighters to comply with OEL. There are also indirect costs due to lower tax revenues if the company's profitability is reduced or they employ fewer staff, albeit temporary until employment is regained.

The costs (transposition and firefighter compliance costs) and benefits (avoided costs) for the public sector (relative to the baseline) are summarised in Table 11-5 below for the different OEL policy options. The benefits of avoided healthcare costs and loss of tax revenue are in section 6.5. Indirect benefits from avoiding the cost of implementing an OEL are presented in section 6.5.2, the costs for public administrations (transposition costs and adjustment and monitoring costs for firefighters) are in section 7.4. As can be seen from the table below, the vast majority of costs are related to adjustment, monitoring and administrative costs for firefighters.

Table 11-5 Comparison of the costs and benefits to the PUBLIC SECTOR (PV over 40 years, policy options relative to the baseline) (€ millions)

Cost elements	7 ng/m ³	70 ng/m ³	700 ng/m ³	7 ng/m ³
Benefits				
Avoided costs of healthcare and avoided loss of tax revenue	€ 5.50	€ 3.87	€ 0.69	€ -
Avoided costs of implementing OEL	€ 1.80	€ 1.75	€ 1.60	€ 1.20
Total benefits	€ 7.30	€ 5.62	€ 2.29	€ 1.20
Costs				
Adjustment costs (firefighters)	€ 5,872.02	€ 62.58	€ -	€ -
Air monitoring (firefighters)	€ 0.87	€ 0.39	€ 0.24	€ 0.18
Biomonitoring (firefighters)	€ 9,509.88	€ 1,574.89	€ 524.28	€ 524.28
Administrative costs of air monitoring (firefighters)	€ 0.18	€ 0.09	€ 0.05	€ 0.04
Administrative costs of biomonitoring (firefighters)	€ 16.83	€ 16.83	€ 10.95	€ 10.95
Transposition costs	€ 1.27	€ 1.24	€ 1.24	€ 1.24
Total costs	€ 15,401.05	€ 1,656.02	€ 536.76	€ 536.69

Source: Study team.

Notes: Only additional costs and benefits (i.e. relative to the baseline) are presented in this table. Totals have been presented as two scenarios, '(OEL)' including first year and recurring adjustment costs, air monitoring, and

administrative burden. Alternatively, '(OEL & BLV)' also includes the costs of biomonitoring and health surveillance and its associated administrative burden). Health surveillance is expected to already be undertaken by firefighters and has not been factored in as an additional cost in the above calculations. Total rows present alternative scenarios and should be read independently of each other (they should not be read together as additional costs).

11.6 Specific Member States/regions

Of the 27 EU Member States, research carried out for this study has confirmed that 12 have an OEL for benzo(a)pyrene (BaP) as a marker for PAH. The following Member States have no OEL or STEL of any kind for PAH: Belgium, Croatia, France, Ireland, Italy, Luxembourg, Malta, Portugal, Poland. Companies in Member States where OELs already meet the different policy options will benefit the most, as will not incur the additional costs relative to their baseline (mentioned in 8.3.3), particularly when they are selling cross border. For example, setting an OEL at 700 ng/m³ would be the most advantageous for Germany, Denmark, Latvia and the Netherlands (15% of MS). Germany has two occupational exposure limit equivalent levels: an acceptable level at 70 ng/m³ and a tolerable level at 700 ng/m³. Companies in Germany must strive to achieve the more stringent, acceptable, limit, but can operate within the tolerable level. Some companies in Germany may be at an advantage if an OEL of 70 ng/m³ is selected. No Member State operates at the lowest OEL policy option, while 15 Member States (56%) already operate at the highest policy option.

Table 11-6 Member States that would need to introduce or alter legislation (OEL)

OEL	Member States that would need to introduce or alter legislation	% of MS who would need to introduce or alter legislation	No. of MS required to introduce or alter legislation	Notes
7 ng/m ³	AU, BE, BG, CY, CZ, DE, DK, EE, EL, ES, FI, FR, HR, HU, IE, IT, LT, LU, LV, MT, NL, PL, PT, RO, SE, SI, SK	100%	27	
70 ng/m ³	AU, BE, BG, CY, CZ, DK, EE, EL, ES, FI, FR, HR, HU, IE, IT, LT, LU, LV, MT, NL, PL, PT, RO, SE, SI, SK	96%	26	Germany has 70 ng/m ³ as the acceptable limit
700 ng/m ³	AU, BE, CY, CZ, DK, EE, EL, ES, FI, FR, HR, HU, IE, IT, LT, LU, MT, PL, PT, RO, SE, SI, SK	85%	23	Germany has 700 ng/m ³ as the tolerable limit
2000 ng/m ³	BE, CY, CZ, DK, EL, ES, FI, FR, HR, IE, IT, LU, MT, PT, RO	56%	15	

Source: Study team on the basis of information in section 3.1.

Only two Member States have a BLV based on 3-hydroxybenzo(a)pyrene (3-OHBP): France and Germany, but 4 have a BLV based on 1-hydroxypyrene (1-OHP).

No detailed quantitative analysis of direct impacts on Member States can be derived from this assessment. This is because the distribution of companies using PAH across EU Member States has been modelled based on Eurostat data and so may have a level of uncertainty relating to the true distribution. As such any analysis of impacts on specific Member States would pose a level of uncertainty and may lead to inaccurate conclusions, except for C20.14 and C23.99b, or C19.1, C24.1, and C24.5 because the information on Member State split has been taken from industry or

because the study team has taken 100% of the sector as relevant. In the latter category, the data should still be interpreted with caution since the Eurostat distribution may still not reflect where businesses operate in reality. This may be due to the fact that for example the same type of industry may validly fall under two NACE codes.

Based on data presented in Table 3-106, Table 3-107 and the discontinuations in Table 8-13, at the 7 ng/m³ the effects from closure of coking plants (100% discontinuation) may be most felt in Czech Republic (22% of plants), followed by Poland (19%), Romania (17%) and Greece and Spain (both 11%). A similar pattern should be observed at the 70 ng/m³ with 45% closures.

A high level of discontinuations in coal tar plants (62% at 7 ng/m³ and 34% at 70 ng/m³) may be most disruptive in Spain, followed by the remainder of Member States with plants: Belgium, Czech Republic, Denmark, Germany and Poland. The outputs from this sector however feed into many industries, therefore industries that are related to coal tar distillation plants (see Figure 8-1) will be negatively affected, regardless of the Member State in which the plants are located.

In casting of metals (C24.5, 100% of the sector taken from Eurostat), up to 2% discontinuations are predicted at the lowest policy option, which will affect Czech Republic and Italy the most.

The discontinuations in graphite and carbon electrode manufacturers (C23.99b) at the 7 and 70 ng/m³ policy options (44% and 16% discontinuations respectively), may be felt mostly in France (25%), Poland and Germany (both 20%), Spain and Austria (both 10%).

There is no information on the size of the market share in any particular Member State when looking at discontinuations per Member State.

11.7 Summary of distribution of the impacts

The key points on the distribution of impacts are presented below:

- A comparison of costs and benefits to employers indicates that that risk management measure (RMM) compliance, monitoring costs and administrative burden over a period of 40 years are significantly higher than the value of benefits returned to an enterprise in each OEL policy option;
- Sectors with the highest costs, generally speaking, are coking, refineries, manufacturers of carbon black, coal tar distillation, steel and iron foundries and ferroalloys, metal casters, coal power plants, soil remediation, train track welders, motor vehicle maintenance and chimney sweeps. This is based in absolute terms, not taking into account number of companies or turnover;
- Across all sectors, 99.1% are small companies, 0.7% are medium and 0.2% are large. When measured by the number of enterprises thus, the majority of enterprises that would need to comply with a new or stricter OEL would primarily consist of SMEs;
- Medium companies have comparatively higher costs relative to turnover at the lowest policy option (0.6% of turnover on average), while small and large have a similar share of costs (0.2% of turnover on average). At the second lowest policy option, medium companies have on average the highest costs as a percentage of turnover (0.05%) but on average have a similar share compared to small and large (0.02% and 0.01% respectively). At the

two highest policy options, small companies are more disadvantaged in comparison to medium and large companies but all are $\leq 0.001\%$ of turnover on average;

- There are substantial benefits from avoided ill health at the two lowest policy options overall (€65-187 million and €20-101 million), but there are also substantial costs related to unemployment that are higher (€4,028 and €226 million). At the second highest policy option there are some benefits from avoided ill health (€2-16 million) and no costs of unemployment. While the highest policy option has neither costs due to unemployment nor benefits from avoided ill health;
- Despite the maturity of markets analysed in this study, most enterprises are small or medium sized and are unlikely to be able to fully absorb additional costs without impacting consumer prices. This is particularly true for sectors selling directly to consumers, such as smoked foods (C10.13, C10.2) in Germany, Spain, France, Italy and Poland in particular. Automotive repair and maintenance garages (G45.2) in Italy, Poland and France may be more adversely affected and increase consumer prices; while chimney sweeps (N81.22) in Germany, France, the Netherlands, Poland and Belgium may also need to pass costs on to consumers;
- As a result of discontinuations, it is also likely that there would be significantly fewer companies operating within industry resulting in lesser capacity for demand to be filled, and subsequently a higher risk of price increases for consumers;
- Of the 27 EU Member States, 12 have an OEL for BaP as a marker for PAH, whereas 9 MS have no OEL at all. None have an OEL at the lowest policy option, only Germany has a tolerable level at 70 ng/m³ meaning that some companies may already be complying with that level, while Germany, Denmark, Latvia and the Netherlands (15% of MS) have an OEL at or lower than the second highest policy option (700 ng/m³) and would be at an advantage compared to other MS;
- The Czech Republic is estimated to have 22% of all coking plants (C19.1) – a sector with risk of closures, and 18% of metal casters (C24.5) – a sector with high costs. Coking plant closure particularly affect: Romania, Czech, Poland, Greece and Spain. But the numbers need to be treated with caution as often the spread of businesses in Member State is taken for a more general NACE code in Eurostat and may not reflect current spread; and
- The discontinuations in graphite and carbon electrode manufacturers (C23.99b) at the 7 and 70 ng/m³ policy options (44% and 16% discontinuations respectively), will be felt mostly in France (25%), Poland and Germany (both 20%), Spain and Austria (both 10%).

12 SUMMARY OF ECONOMIC, SOCIAL AND ENVIRONMENTAL IMPACTS

This chapter comprises the following sections:

- Section 12.1: Economic impacts;
- Section 12.2: Social impacts; and
- Section 12.3: Environmental impacts.

12.1 Economic impacts

The economic impacts relate to the direct and indirect costs that fall on companies that need to comply with the policy options are shown in Table 12-1.

Table 12-1 Aggregated PV costs and benefits for companies discounted over 40 years by policy options, € millions

Cost or benefit	7 ng/m ³ & 0.2 nmol/mol creatinine	70 ng/m ³ & 0.3 nmol/mol creatinine	700 ng/m ³ & 1.5 nmol/mol creatinine	2000 ng/m ³ & 3.8 nmol/mol creatinine
Cost (OEL)	€ 43,532.94	€ 3,086.93	€ 225.79	€ 148.67
Cost (OEL & BLV)	€ 54,808.13	€ 5,690.24	€ 1,380.13	€ 1,299.49
M1 Benefit (avoided cost)	€ 187.38	€ 101.06	€ 15.85	€ -
M2 Benefit (avoided cost)	€ 64.48	€ 20.06	€ 1.97	€ -

Source: Study team

Notes:

M1= Method 1, a methodology that relies on “willingness to pay” values

M2 = Method 2, a methodology that relies on monetised Disability Adjusted Life Years

Costs have been presented as two scenarios, ‘(OEL)’ including first year and recurring adjustment costs, air monitoring, and administrative burden. Alternatively, ‘(OEL & BLV)’ also includes the costs of biomonitoring and health surveillance and associated administrative burden. Health surveillance is expected to already be undertaken by firefighters and has not been factored in as an additional cost in the above calculations. Total rows present alternative scenarios and should be read independently of each other (they should not be read together as additional costs).

€ - refers to no cost/benefit incurred.

The costs outlined in the above table represent two scenarios, policy options for only an OEL and policy options for an OEL and BLV. The scenario for only an OEL includes costs associated with RMM adjustment costs, the cost of air monitoring, as well as administrative burden. Costs associated with an OEL and BLV include all of those for exclusively an OEL, but also biomonitoring, health surveillance and their associated administrative burden. Costs are inclusive of those for both industrial sectors, and cost for public authorities (related to firefighters). Similarly, the benefits are related to both companies and public authorities (including firefighters).

Costs at the lowest two policy options make up significant proportions of estimated company turnover and gross operating surplus suggesting these levels may not be economically (or technically) achievable for a lot of companies. Again, most companies in the sectors under review are estimated to be small and medium sized and are less likely to have capital available to absorb the compliance costs at these levels. It is therefore probable that they would pass costs onto consumers, resulting in an overall price increase in goods and services. For metallurgical sectors and the coal tar distillation sector, high costs and technical infeasibility at the lowest two policy options

may have downstream impacts on the supply of raw materials for other sectors, notably sectors reliant upon steel, aluminium, and electrodes.

Sectors in the EU may be at a competitive disadvantage against international competitors that do not require compliance (e.g. China, India or Russia do not have OELs in place, see Table 8-16) and potentially offer more cost attractive solutions to EU enterprises. This is particularly true at the two lowest OEL policy options, and not so relevant at the higher two OEL policy options. Although this would effectively leak ill health effects associated with sectoral PAH exposure outside of the EU upon third countries. The transfer of operations outside of the EU would primarily affect medium and large multinational enterprises, although this proportion of the market is thought to be relatively small and related to sectors such as C19.1, C19.2, C20.13, C20.14, C23.99b, C24.1, C24.42, C24.45 and C24.5. As the majority of the exposed sectors are small enterprises international competitiveness may not be significantly impacted. This is particularly true for sectors which are linked to in-situ industries, such as E39, F42.11, F42.12, G45.2, N81.22 and O84.25.

Costs make up a significant proportion of research and development (R&D) expenditure at the lowest policy option levels and suggest that R&D, and by extension innovation research, would be severely negatively impacted at these levels for most sectors. Although R&D amongst large companies appears to be affected to a lesser extent.

Discontinuations are significantly higher at the lowest policy option (representing a total of 3,457 enterprises) and occur to a lesser extent at the second lowest (representing a total of 142 enterprises) and do not occur at the remaining policy option levels. High levels of discontinuations at 7 ng/m³ and to a lesser extent 70 ng/m³ are anticipated to produce high unemployment costs, although the proportion of workers being retained in alternative roles or reemployed by competitors has not been taken into account. Costs are presented as a worst-case scenario.

Relatively few (four) Member States currently possess and OEL at or below 700 ng/m³ and even fewer (two) possess and equivalent BLV at this level. The application of an OEL and/or BLV at the EU level is likely to result in positive impacts in terms of harmonisation across the EU.

The two sectors where alternatives are possible in future: F42.12 road paving with the use of Warm Mix Asphalt (WMA) instead of Hot Mix Asphalt (HMA) reduces the temperature at which bitumen is laid, thereby reducing PAH exposure. However only customers (local authorities) in non-EU MS (Norway) have moved forward with this option. Steel plants are likely to move to hydrogen as a reducing agent, removing the need for coking coal (C19.1). However the by-products of coking coal, particularly coal tar, are required in other sectors. To note is that coal tar pitch is used in graphite and carbon electrodes manufacturing, which feed into many other sectors, including steel plants with electric arc furnaces (used in recycling of steel as well as hydrogen-based direct reduction). There are sectors that are entirely based on coal and petroleum and their derivatives (e.g. refineries, coal fired power plants, coking etc.), but also services such as chimney sweeping, for which alternatives exist for their products but entail a restructure of the sector with complete or partial discontinuations (e.g. electric or biofuel cars instead of internal combustion engines that use refinery products, renewable energy instead of coal generated power, heat pumps instead of solid fuel burners). Natural graphite can be used in most cases instead of synthetic graphite, but natural graphite has been identified a critical raw material.

12.2 Social impacts

The social impacts relate to the benefits and costs that fall on workers and public administrations, are shown in Table 12-2.

Table 12-2 Aggregated PV costs and benefits for workers and public administrations discounted over 40 years by policy options, € millions

Cost or benefit	7 ng/m ³ & 0.2 nmol/mol creatinine	70 ng/m ³ & 0.3 nmol/mol creatinine	700 ng/m ³ & 1.5 nmol/mol creatinine	2000 ng/m ³ & 3.8 nmol/mol creatinine
Workers				
Cost	€ 4,027.63	€ 225.67	€ -	€ -
Benefit (avoided cost) M1	€ 130.25	€ 97.23	€ 15.17	€ -
Benefit (avoided cost) M2	€ 33.10	€ 16.22	€ 1.29	€ -
Public administrations				
Transposition costs	€ 1.27	€ 1.24	€ 1.24	€ 1.24
Cost to public enterprises (OEL)	€ 5,873.07	€ 63.06	€ 0.29	€ 0.22
Cost to public enterprises (OEL & BLV)	€ 16,293.93	€ 1,788.90	€ 535.52	€ 535.45
Benefit (avoided cost) M1 (firefighters)	€ 51.35	€ -	€ -	€ -
Benefit (avoided cost) M2 (firefighters)	€ 26.26	€ -	€ -	€ -
Benefit (indirect)	€ 1.80	€ 1.75	€ 1.60	€ 1.20

Source: Study team

Notes: M1= Method 1, a methodology that relies on "willingness to pay" values

M2= Method 2, a methodology that relies on monetised Disability Adjusted Life Years

‘€ -’ refers to no costs/benefits incurred.

The social cost for workers refers to the social cost of unemployment. As illustrated in the table above and in section 8.5, modelling estimates that the first policy option would result in 49,344 workers made unemployed, and at the second policy option 2,610 workers would be made unemployed as a result of discontinuations (no discontinuations at the third and fourth policy options). This results in substantial costs at the first and second policy option levels. Whilst proportionally lower, three policy options produce benefits for workers in terms of avoided ill health, although they do not outweigh the social cost of unemployment monetarily.

The study team recognises limitations in the calculations:

- The number of unemployed workers as a result of discontinuation does not take into account that employees may be retained in alternative roles or reemployed by competitors;
- Modelling assumes that large companies are more likely to discontinue divisions, lines or specific operations which would not result in the full closure of the business but the discontinuation of the line/process using the relevant substance. The assumption is that 10% of a large company would close.
- Overall, discontinuation figures are not a reflection of true company closures, but a reflection of difficulties companies face in achieving compliance; and
- The wider social costs of companies discontinuing such as the strategic costs of not competing, the impact on the overall market and the wider cost to a community of losing many

jobs in one location (typical of large sites situated in small towns) are not included because the study team has no means of quantifying them. Nor is the study team capable of determining jobs lost throughout sectoral supply chains.

Costs that are incurred by public administrations include those spent on transposing or introducing an EU OEL/BLV in national legislation. This results in increased costs at lower policy options as some Member States already have existing national OELs/BLV which would not need to be amended at higher policy options. In general, few Member States have existing OELs/BLVs at the first two policy option levels.

In addition to this, public authorities incur costs related to the compliance of firefighters to the proposed OEL/BLV. For public authorities, compliance costs are substantial due to the number of firefighters requiring risk management measure (RMM) adjustments and health monitoring campaigns. The bulk of costs to public enterprises consist of the biomonitoring and health surveillance of all firefighters (including volunteers). It is recognised this may not be a realistic scenario and alternative calculations have been provided in section 13.2 (sensitivity analysis).

The indirect benefits which are listed in Table 12-2 relate to avoided costs of introducing a new national OEL/BLV as the background and scoping work would already have been conducted for the EU OEL/BLV. These costs would only be avoided in the case where a Member State is wanting to introduce a national OEL/BLV for PAH. In this study the assumption has been made that all Member States would eventually want to introduce an OEL/BLV for PAH.

Health benefits are only present at the first policy option as modelling does not estimate exposures above this level. At this level the costs (primarily associated with biomonitoring and health surveillance) far outweigh the benefits.

12.3 Environmental impacts

As previously outlined, PAH have varied environmental impacts and implications for EU environmental policy agendas. Environmental exposure to PAH are primarily due to the combustion of anthropogenic materials, leading to atmospheric emissions. Emissions to water are less severe, although atmospheric emissions result in deposition to land and water run-off. Assessment of PAH identifies the following substances classified as aquatic chronic 1 (H400) and aquatic acute 1 (H410): benzo[k]fluoranthene, chrysene, benzo[a]pyrene, benzo[e]acephenanthrylene, benzo[a]anthracene. In addition, benzo[k]fluoranthene, chrysene, benzo[a]pyrene and benzo[a]anthracene are classified as Persistent, Bioaccumulative and Toxic (PBT) and benzo[k]fluoranthene, benzo[a]pyrene and benzo[e]acephenanthrylene are Persistent Organic Pollutants (POPs).

In response to the proposed policy options, industries are more likely to install forms of local exhaust ventilation (e.g. closed and partially closed systems) which would result in lower atmospheric and water emissions. However, as shown in section 7, costs related to RMM adjustments are not anticipated at 2000 ng/m³ and as such, emissions are not expected to be reduced at that level. Other policy options are likely to result in reduced emissions.

The introduction of OELs/BLVs may have further implications for the elements of the EU Green Deal as PAH relate to sectors essential for the decarbonisation of energy, for example steel, aluminium, and silicon, as well graphite which is used in li-ion batteries, fuel cells and other technologies associated with the green industry (JRC 2023). The same sectors are also key for the production of electric vehicles, which may face supply chain shortages at the lowest policy options.

PAH are also emitted during the manufacture of graphite and carbon electrodes, whilst the electrodes are needed in the recycling of metals (electric arc furnaces). Similarly, policy options negatively impacting steel production may have further implications on energy efficient construction of buildings. For further information please see section 0.

13 LIMITATIONS & SENSITIVITY ANALYSIS

This chapter presents the limitations and uncertainties of this study, and comprises the following sections:

- Section 13.1: Overview of limitations and uncertainties; and
- Section 13.2: Key limitations and uncertainties.

13.1 Overview of limitations and uncertainties

This section presents an overview of the limitations and uncertainties of this study and considers their potential impact on the conclusions. Table 13-1 provides a summarised overview of each element and assesses their significance for the results of this study. A more detailed assessment of some of these limitations and uncertainties is provided in section 13.2.

Table 13-1 Overview of the key limitations/uncertainties and their significance

Limitation or uncertainty	Explanation	Estimates in this study are likely U (underestimates) or O (overestimates)	
		Costs	Benefits
Cost assessment – biomonitoring firefighters	Public authorities may not undertake biomonitoring and health surveillance for volunteer firefighters due to irregular (<1% of time) and low exposure. The cost is modelled based on professional and volunteer firefighters being subject to biomonitoring. Firefighters, professional and volunteers, make up the majority of workers in this study. Health surveillance is not costed since it is believed that all firefighters are subject to routine medical checks and health surveillance in their occupation.	O*	-
Cost assessment – health surveillance	In some Member States, e.g. Germany and France, there is already a requirement to undertake health surveillance when workers have the potential to be exposed to carcinogen, regardless of the exposure concentration. PAH are known carcinogens, so it is likely that some companies undertake health surveillance in these countries. However, the rate of compliance is not known and importantly, the distribution of workers per MS is often based on Eurostat for which data may not be reliable. In addition, there is no clear picture for which countries health surveillance is required and it is anticipated that the rate of health surveillance will increase when a BLV is enforced. The costs for health surveillance are therefore likely to be overestimated.	O	-
Exposed workforce	For some sectors there was little feedback from stakeholders and the study team made some assumptions on the number of workers based on literature and expert knowledge. For refractory products C23.2, it is known that binders with a lower benzo[a]pyrene (BaP) content are used but no data are available on the level of exposure or the number of workers. Generally, however, the cost and benefits based on the number of workers could be under or overestimated. The endpoint is not considered further in this sensitivity assessment. In addition to the above limitation on the exposed workforce, the study team have less certainty regarding the split of male and female workers in the reviewed sectors. This is problematic because both developmental toxicity (miscarriage) and reproductive toxicity (male infertility) are sex specific endpoints. Despite this, the study team expect the majority of sectors to be male dominated and the modelled split to be broadly correct. Due to uncertainty in the split, it is possible for both	-	U/O

Limitation or uncertainty	Explanation	Estimates in this study are likely U (underestimates) or O (overestimates)	
		Costs	Benefits
	endpoints to be either over/underestimating the number of cases.		
Number of pregnancies	Calculations on the number of pregnant workers in the EU27 have been made on the basis of a crude rate of pregnancy per EU female. However, there is limited data on the number of annual pregnancies due to issues related to under reporting and birthing outside of the EU. The study team used Eurostat figures on the number of livebirths as a proxy for the number of known pregnancies to calculate the impacts of developmental toxicity. However, this endpoint specifically refers to failed pregnancies and by definition would not be captured in live-birth figures, meaning that calculations underestimate the number of pregnancies in the EU27. The study team obtained two sources suggesting a proportion of pregnancies that may result in miscarriage and still birth. These figures have been used to assess the impacts of increased pregnancies upon the benefits in a sensitivity analysis below. However, this analysis resulted in little increase in cases of developmental toxicity due to the male dominated nature of the sectors in question. As a result of this little impact, the study team continued to use livebirths as a proxy for the crude rate due to higher levels of confidence in the figures. Also as previously identified in section 2.2.3.3 calculation of exposed pregnant workers may be overestimated due to the possibility that workers may be removed from exposure environments in their final trimester. This is dependent on employment scenarios (e.g. labour intensive roles are more likely to be replaced in the final trimester, although less intensive roles with exposure may continue until the final day of work). It is not possible to calculate the window of exposure during the nine months of pregnancy. Furthermore, sensitivity analysis increasing the number of pregnancies did not yield significant changes to the overall results, and by extent neither would reducing the pregnancy period. For this reason a sensitivity analysis of pregnancy periods has not been performed.	-	U/O
Exposure values	Several data points were below the limit of quantification. In accordance with work done in previous OEL impact assessments, and what is done in peer reviewed literature, a default value of LOQ/2 is taken. Since the measurements cannot be established and BaP is a non-threshold carcinogen, the benefits could be under or over-estimated. Similarly, the costs to achieve an OEL could be under or over-estimated. The endpoint is not considered further in this sensitivity analysis.	U/O	U/O
Workforce turnover	The workforce turnover rate does not have a significant impact on the estimated benefits. A higher workforce turnover will lead to an increased number of cases for reproductive and developmental toxicity as the latency period is 0, but the total cases for developmental toxicity will remain low in any case. The impacts of monetised health impacts are limited and no specific scenario is assessed.	-	-
Additional health endpoints – skin cancer	Skin cancer has also been definitively linked to PAH exposure but there are no quantifiable data on which to develop an impact assessment. The health impacts cannot be monetised and no specific scenario is assessed.	-	U*
Additional health	In the opinion on OEL, RAC considered the evidence for	-	U

Limitation or uncertainty	Explanation	Estimates in this study are likely U (underestimates) or O (overestimates)	
		Costs	Benefits
endpoints – bladder cancer	bladder cancer to be unequivocal: an increased risk was not observed in all studies or processes and confounding by the presence of established bladder carcinogens (e.g. aromatic amines) could not be excluded in all cases. An ERR has not been derived for bladder cancer linked to PAH exposure, although assuming no confounders RAC calculated the maximum influence from not considering possible bladder cancer risks to be a factor of 1.7. The potential for bladder cancer on benefits has been modelled in the sensitivity analysis.		
Additional health benefits from the introduction of a BLV	The main routes for occupational exposure to PAH are inhalation and skin contact. Both uptake routes will result in increased metabolite concentrations that can be monitored through the introduction of a BLV. PAH are known to conclusively cause skin cancer but there are no quantitative data on skin cancer to conclude on an exposure risk relationship. The introduction of a BLV is particularly beneficial in sectors where dermal exposure is the prevalent route of exposure (e.g. wood preservation), but also in sectors where significant dermal exposure is anticipated in addition to airborne exposure (e.g. coking, firefighters). However, it is not possible to quantify benefits because the presence of a substance in a biological matrix does not necessarily mean that it will result in adverse effects, while the absence does not necessarily indicate that an individual was not exposed. There is no ERR to link metabolite concentration to effects and the health benefits of introducing a BLV cannot be quantified. The benefits are likely underestimated, but the health impacts cannot be monetised and no specific scenario is assessed.	-	U*
DRRs – animal data	Although there is supportive information from human studies, transferring experimental animal data quantitatively to the human situation always includes relevant uncertainties. Furthermore, only a low number of concentration-effect points are available from the experimental studies to determine the DRRs. A further uncertainty with regard to the effects on fertility (sperm motility in males) is that from the animal studies it cannot be concluded whether the effects on fertility are reversible or not. In order to avoid overestimating the effects in humans, for the modelling it was assumed that they are permanent, which in this case produces a lower number of cases than assuming reversibility (with the possibility of producing the same effect again in the same exposed individual).	-	U/O*
The latency period for cancer	For lung cancer a latency period of 30 years has been used for the estimation of future cancer cases. This period has been selected in past impact assessments as the most likely period. The endpoint is not considered further in this sensitivity assessment.	-	O/U
Future trends	There is a high level of uncertainty in the future trends. A lower rate of phase out of refineries and coal power plants means that both costs and benefits are underestimated while a faster phase out means an overestimation. Conversely, the rates for increased production of aluminium and silicon metal could be under or overestimated impacting both the cost and benefits. In addition, the demand for natural and synthetic graphite has	O/U	O/U

Limitation or uncertainty	Explanation	Estimates in this study are likely U (underestimates) or O (overestimates)	
		Costs	Benefits
	been estimated to be 7.8-8.91% year-on-year (8.3% average, see section 4.4.2), but this does not take into account imports, difference in demand between natural and synthetic and future potential for recycling. Conversely, the study team is not able to model the effects of trends on costs due to modelling complexities. The study team modelled benefits associated with an average yearly trend of 8.3%, and found that M1 benefits increased by € 3.1m at 7 ng/m³ and €2.6m at 70 ng/m³, and M2 benefits by € 1.07 at 7 ng/m³, and € 0.84m at 70 ng/m³ (no change to M1 or M2 benefits at 700 ng/m³ or 2000 ng/m³). Overall, these are relatively minor changes to the overall calculated benefits. Considering the low impact of trends to benefits overall, the low levels of confidence in trend accuracy, the study team has not further considered this trend for sensitivity analysis.		
Discount rate	At the time of writing, standard discount rates of 3% may not represent reality. Alternative discount rates have been provided to best draw out cost and benefit scenarios.	O*/U*	O*
Positive biases in reported data	It is possible that there has been some self-selection among companies that provided the data collected through consultation for this study, with worse-performing companies less likely to report their exposure concentrations. The study team has integrated literature data with consultation data to minimise bias. This may underestimate both costs and benefits and has not been further assessed.	U	U
RMMs in place	The assumptions about RMMs in place impact on the costs since it is costlier for a company that already has RMMs in place to make improvements. To mitigate a potential positive bias in the reported data, the model inputs assume lower proportions of companies with RMMs than the data reported through consultation but at the same time also assumes that older data would be subject to the same level of RPE as today. The endpoint is not considered further in this sensitivity assessment.	U	U
Assessment period	The reference period of 40 years for this study was selected both to be consistent with previous Commission impact assessment. The estimation of costs and benefits take latency periods etc into account to the length on the period is not affecting the results. The endpoint is not considered further in this sensitivity assessment.	-	-

Source: Study team.

Notes: * refers to significant over/underestimations. The absence of an asterisk indicates lesser impacts of the over/underestimations.

13.2 Key limitations and uncertainties

13.2.1 Cost estimates and sensitivity scenarios

13.2.1.1 Cost estimates without biomonitoring for voluntary firefighters

The cost of biomonitoring makes up a substantial proportion of the overall costs and are based on the number of enterprises and exposed workers. O84.25 firefighters includes the potential for up to approximately 4.4 million professional and volunteers to require such biomonitoring. However,

there is uncertainty as to whether public authorities would require volunteers to be subject to this biomonitoring and the extent to which it would be undertaken. Biomonitoring would typically only be undertaken after exposure to PAH occurs during training exercises or responding to fire related incidents. Consultation feedback suggest exposures are not frequent and may occur few times a year and even less for volunteers. For these reasons Table 13-2 provides a sensitivity analysis as to whether or not biomonitoring would be undertaken for voluntary firefighters.

'Standard costs and benefits (all sectors)' refer to the general costs and benefits of this study, unaffected by sensitivity changes. 'Without biomonitoring for voluntary firefighters (all sectors)' removes the cost of biomonitoring for volunteers but includes the costs of all other sectors. 'Standard costs and benefits (public authorities only)' extracts the costs and benefits related to firefighters but is unaffected by sensitivity changes (this includes volunteer biomonitoring). Finally, 'without biomonitoring for voluntary firefighters (public authorities only)' provides the costs and benefits for public authorities related to firefighters only, with biomonitoring for volunteers removed.

As shown in the table below, cost benefit ratios remain relatively high despite the extraction of biomonitoring for volunteer firefighters. For public authorities there are no benefits at the 70, 700, and 2000 ng/m³ levels as exposures levels are expected to be lower than these policy option levels. At the 7 ng/m³ level costs for public firefighters are 21% lower without biomonitoring for volunteers, and the CBR improve by roughly a third. Comparatively, at 70 and 700 ng/m³ costs are 46% and 86% lower, respectively, and CBR improve by roughly half and two thirds, respectively, without biomonitoring for volunteers.

When only an OEL is implemented, there are no changes in costs and CBR.

Table 13-2 Sensitivity analysis: cost estimates without biomonitoring for voluntary firefighters

Sensitivity scenario	7 ng/m ³ & 0.2 nmol/mol creatinine	70 ng/m ³ & 0.3 nmol/mol creatinine	700 ng/m ³ & 1.5 nmol/mol creatinine	2000 ng/m ³ & 3.8 nmol/mol creatinine
Standard costs and benefits (all sectors)				
Benefits M1	€ 187.38	€ 101.06	€ 15.85	€ -
Benefits M2	€ 64.48	€ 20.06	€ 1.97	€ -
Costs (OEL & BLV)	€ 54,809	€ 5,691	€ 1,381	€ 776
CBR M1 (OEL & BLV)	293	56	87	-
CBR M2 (OEL & BLV)	850	284	701	-
Without biomonitoring for voluntary firefighters (all sectors)				
Benefits M1	€ 187.38	€ 101.06	€ 15.85	€ -
Benefits M2	€ 64.48	€ 20.06	€ 1.97	€ -
Costs (OEL & BLV)	€ 37,310	€ 2,766	€ 399	€ 274
CBR M1 (OEL & BLV)	199	27	25	-
CBR M2 (OEL & BLV)	579	138	202	-
Standard costs and benefits (public authorities only)				
Benefits M1	€ 52.44	€ -	€ -	€ -

Sensitivity scenario	7 ng/m ³ & 0.2 nmol/mol creatinine	70 ng/m ³ & 0.3 nmol/mol creatinine	700 ng/m ³ & 1.5 nmol/mol creatinine	2000 ng/m ³ & 3.8 nmol/mol creatinine
Benefits M2	€ 27.35	€ -	€ -	€ -
Costs (OEL & BLV)	€ 15,400	€ 1,655	€ 536	€ 535
CBR M1 (OEL & BLV)	294	-	-	-
CBR M2 (OEL & BLV)	570	-	-	-
Without biomonitoring for voluntary firefighters (public authorities only)				
Benefits M1	€ 52.44	€ -	€ -	€ -
Benefits M2	€ 27.35	€ -	€ -	€ -
Costs (OEL & BLV)	€ 6,650	€ 207	€ 54	€ 54
CBR M1 (OEL & BLV)	127	-	-	-
CBR M2 (OEL & BLV)	243	-	-	-

Source: Study team.

13.2.2 Benefit assessment and sensitivity scenarios

13.2.2.1 Bladder cancer

There is a non-conclusive link between bladder cancer and PAH exposure in humans (see section 2.1.3.1). However, in the meta-analysis studies the sectors under review resulted in co-exposure to other chemicals known to cause bladder cancer. RAC's sensitivity analysis calculations indicate that assuming no confounding by other factors, bladder cancer would at maximum influence the ERR by a factor of 1.7. Therefore the ERR calculated for lung cancer can be adapted to achieve 70% of bladder cancer cases. The sensitivity analysis presents the costs and benefits should bladder cancer be considered a definite health impact from exposure to PAH.

As shown in Table 13-3 below, the increased number of cancer cases resulted in an increase in benefits and no change in costs. At the most stringent policy option M1 increased by only € 56.52 (30% to €244 million and M2 by € 29.64 million (46% to €94 million). Subsequently CBRs for OEL only option, are improved by 23% and 31% respectively. Again, at 70 ng/m³ M1 benefits increased by €14.21 million (14% to €115 million) and M2 by €7.36 million (37% to €27 million). While the CBRs improved by 13% and 27%, respectively.

At the 700 ng/m³ policy option, the improvement in avoided costs is decreased less, where avoided costs increase by 6% and 24% in M1 and M2, respectively. While the CBRs improved by 0% and 19%, respectively.

These are slight increases which do not change the order of magnitude of impacts. Coupled with the lack of scientific certainty with the exposure risk relationship (ERR) for this endpoint, the study team has not considered bladder cancer further.

Table 13-3 Sensitivity analysis of bladder cancer (€ millions)

Sensitivity scenario	7 ng/m ³ & 0.2 nmol/mol creatinine	70 ng/m ³ & 0.3 nmol/mol creatinine	700 ng/m ³ & 1.5 nmol/mol creatinine	2000 ng/m ³ & 3.8 nmol/mol creatinine
Standard discount rate (3% discounted annually over 40 years for costs and benefits)				
Benefits M1	€ 187.38	€ 101.06	€ 15.85	€ -
Benefits M2	€ 64.48	€ 20.06	€ 1.97	€ -
Costs (OEL)	€ 43,534	€ 3,088	€ 227	€ 150
CBR M1 (OEL)	232	31	14	-
CBR M2 (OEL)	675	154	115	-
Costs (OEL & BLV)	€ 54,809	€ 5,691	€ 1,381	€ 776
CBR M1 (OEL & BLV)	293	56	87	-
CBR M2 (OEL & BLV)	850	284	701	-
Inclusive of benefits related to bladder cancer				
Benefits M1	€ 243.90	€ 115.27	€ 16.76	€ -
Benefits M2	€ 94.12	€ 27.42	€ 2.44	€ -
Costs (OEL)	€ 43,534	€ 3,088	€ 227	€ 150
CBR M1 (OEL)	178	27	14	-
CBR M2 (OEL)	463	113	93	-
Costs (OEL & BLV)	€ 54,809	€ 5,691	€ 1,381	€ 776
CBR M1 (OEL & BLV)	225	49	82	-
CBR M2 (OEL & BLV)	582	208	566	-

Source: Study team.

13.2.2.2 Number of pregnancies

For all calculated benefits related to developmental toxicity previously outlined in this report, the study team has used a method based on a calculated crude rate of pregnancy (0.017791) per female of the EU27 population in 2021. To calculate this rate, the study team divided the female population of EU Member States against the recorded number of live births (4,070,000) published on Eurostat in the same year (2021). As developmental toxicity refers to the failed pregnancies (both in terms of miscarriage and stillbirth) the number of live births used as a basis for known pregnancies underestimates how many annual pregnancies might occur. However, an accurate number of annual pregnancies (inclusive of those resulting in miscarriage and stillbirth) in the EU is not known, for example, because miscarriage/stillbirth are underreported due them taking place in a home setting etc, and potentially due to births happening outside of the EU.

Two additional sources of information may provide insight into the additional number of pregnancies not recorded in the 4,070,000. First a paper by Dugas et al. (2022) estimates that as many as 26% of pregnancies end in miscarriage. And the European Perinatal Health Report (2022) estimates that between 2015-2019 stillbirths occurred in 32 European countries at rates of 1.8-4.7 cases per 1,000 births (median of 2.9). The study team have used these figures to recalculate a

potential number of annual pregnancies (5,506,398) and a revised crude rate of pregnancies per female worker of 0.0241. This is a substantial increase in the number of pregnancies.

Despite this, the study team has opted to include these calculations as a sensitivity analysis instead of including in the overall core analysis. This is because the study team does not have strong confidence in the robustness of the data used in calculations. Furthermore, due to the low DRR, calculations relating to developmental toxicity calculations do not produce a significant increase in the overall benefits, as shown in Table 13-4 below. For example, at the most stringent policy option M1 increased by only € 0.61 (million) and M2 by € 0.76 (million). Subsequently CBRs are relatively unaffected. This issue has not been considered further.

Table 13-4 Sensitivity analysis related to the number of pregnancies (€ millions)

Sensitivity scenario	7 ng/m ³ & 0.2 nmol/mol creatinine	70 ng/m ³ & 0.3 nmol/mol creatinine	700 ng/m ³ & 1.5 nmol/mol creatinine	2000 ng/m ³ & 3.8 nmol/mol creatinine
Standard discount rate (3% discounted annually over 40 years for costs and benefits)				
Benefits M1	€ 187.38	€ 101.06	€ 15.85	€ -
Benefits M2	€ 64.48	€ 20.06	€ 1.97	€ -
Costs (OEL)	€ 43,534	€ 3,088	€ 227	€ 150
CBR M1 (OEL)	232	31	14	-
CBR M2 (OEL)	675	154	115	-
Costs (OEL & BLV)	€ 54,809	€ 5,691	€ 1,381	€ 776
CBR M1 (OEL & BLV)	293	56	87	-
CBR M2 (OEL & BLV)	850	284	701	-
Inclusive of benefits related increased number of pregnancies				
Benefits M1	€ 187.99	€ 101.83	€ 15.98	€ -
Benefits M2	€ 65.24	€ 20.31	€ 2.00	€ -
Costs (OEL)	€ 43,534	€ 3,088	€ 227	€ 150
CBR M1 (OEL)	232	30	14	-
CBR M2 (OEL)	667	152	114	-
Costs (OEL & BLV)	€ 54,809	€ 5,691	€ 1,381	€ 776
CBR M1 (OEL & BLV)	292	56	86	-
CBR M2 (OEL & BLV)	840	280	691	-

Source: Study team.

13.2.3 Discount rate

Given the current global economic climate the standard discount rates of 3% may no longer reflect reality. Therefore, the study team has provided two alternative discount rates scenarios. In Table 13-5 'Standard discount rate' refers to the general costs and benefits unaffected by any sensitivity changes (discounted by a static 3% annually over 40 years). 'Differential rate' refers to costs modelling performed at a static 3% annually over 40 years, and benefit modelling performed at a static 1.5% annually over 40 years. Finally, a 'declining discount rate' has been added at 3% annually for 20 years, and 2% annually for 20 years.

Table 13-5 Sensitivity analysis of discount rates (€ millions)

Sensitivity scenario	7 ng/m ³ & 0.2 nmol/mol creatinine	70 ng/m ³ & 0.3 nmol/mol creatinine	700 ng/m ³ & 1.5 nmol/mol creatinine	2000 ng/m ³ & 3.8 nmol/mol creatinine
Standard discount rate (3% discounted annually over 40 years for costs and benefits)				
Benefits M1	€ 187.38	€ 101.06	€ 15.85	€ -
Benefits M2	€ 64.48	€ 20.06	€ 1.97	€ -
Costs (OEL)	€ 43,534	€ 3,088	€ 227	€ 150
CBR M1 (OEL)	232	31	14	-
CBR M2 (OEL)	675	154	115	-
Costs (OEL & BLV)	€ 54,809	€ 5,691	€ 1,381	€ 776
CBR M1 (OEL & BLV)	293	56	87	-
CBR M2 (OEL & BLV)	850	284	701	-
Differential rate (costs discounted at 3% and benefits at 1.5% annually over 40 years)				
Benefits M1	€ 331.51	€ 145.63	€ 20.15	€ -
Benefits M2	€ 134.34	€ 38.01	€ 3.22	€ -
Costs (OEL)	€ 43,534	€ 3,088	€ 227	€ 150
CBR M1 (OEL)	131	21	11	-
CBR M2 (OEL)	324	81	71	-
Costs (OEL & BLV)	€ 54,809	€ 5,691	€ 1,381	€ 776
CBR M1 (OEL & BLV)	165	39	69	-
CBR M2 (OEL & BLV)	408	150	429	-
Declining discount rate (3% for 0-20 years and 2% for 21-40 years, annually)				
Benefits M1	€ 230.09	€ 112.25	€ 16.63	€ -
Benefits M2	€ 86.83	€ 25.64	€ 2.33	€ -
Costs (OEL)	€ 28,304.06	€ 2,321.21	€ 228.72	€ 151.49
CBR M1 (OEL)	123	21	14	-
CBR M2 (OEL)	326	91	98	-
Costs (OEL & BLV)	€ 33,994.61	€ 4,581.18	€ 1,435.29	€ 1,354.53
CBR M1 (OEL & BLV)	148	41	86	-
CBR M2 (OEL & BLV)	392	179	616	-

Source: Study team

In the differential rate scenario, costs are unaffected while benefits increase significantly compared to the standard scenario (between 27-77% increase in M1, and 63-108% in M2, where the highest increases are in the lowest policy scenarios). Consequently the CBRs also improve (between 21-44% in M1, and 38-52% in M2, where the highest increases are in the lowest policy options).

In the declining rate scenario, despite the change in discount rates, costs are lower than the standard scenario due to increased costs of RMMs as a result of discount rate changes. There is a high degree of existing RMMs being discounted from the modelling, particularly at the lowest policy option level. Subsequently, lower discount rates produce higher values for RMMs being replaced by alternative measures. This results in CBRs improving in the lowest policy option when considering an OEL only (by 36% and 42% when looking at M1 and M2 benefit calculations, respectively), while the CBRs decrease in the 70 ng/m³ policy option when considering the OEL only (by -32% and -16% when looking at M1 and M2 benefit calculations, respectively). At the 700 ng/m³ the CBRs decrease even further (by -514% and -436% when looking at M1 and M2 benefit calculations, respectively).

13.2.4 Combined effect of alternative assumptions

The study team have compiled the cost benefit ratios from the above sensitivity assessments to draw a direct comparison of impacts upon the standard model CBR. This is presented in the following table and figure.

Table 13-6 Combined cost/benefit ratios of all sensitivity analyses

Sensitivities	7 ng/m ³ & 0.2 nmol/mol creatinine		70 ng/m ³ & 0.3 nmol/mol creatinine		700 ng/m ³ & 1.5 nmol/mol creatinine		2000 ng/m ³ & 3.8 nmol/mol creatinine	
	M1	M2	M1	M2	M1	M2	M1	M2
Standard costs and benefits (all sectors) (OEL)	232	675	31	154	14	115	-	-
Standard costs and benefits (all sectors) (OEL & BLV)	293	850	56	284	87	701	-	-
Without biomonitoring for voluntary firefighters (all sectors) (OEL)	232	675	31	154	14	115	-	-
Without biomonitoring for voluntary firefighters (all sectors) (OEL & BLV)	199	579	27	138	25	202	-	-
Standard costs and benefits (public authorities only) (OEL)	112	217	-	-	-	-	-	-
Standard costs and benefits (public authorities only) (OEL & BLV)	294	570	-	-	-	-	-	-
Without biomonitoring for voluntary firefighters (public authorities only) (OEL)	112	217	-	-	-	-	-	-
Without biomonitoring for voluntary firefighters (public authorities only) (OEL & BLV)	127	243	-	-	-	-	-	-
Inclusive of bladder cancer (OEL)	178	463	27	113	14	93	-	-
Inclusive of bladder cancer (OEL & BLV)	225	582	49	208	82	566	-	-
With increased number of pregnancies (OEL)	232	667	30	152	14	114	-	-
With increased number of pregnancies (OEL & BLV)	292	840	56	280	86	691	-	-

Sensitivities	7 ng/m ³ & 0.2 nmol/mol creatinine		70 ng/m ³ & 0.3 nmol/mol creatinine		700 ng/m ³ & 1.5 nmol/mol creatinine		2000 ng/m ³ & 3.8 nmol/mol creatinine	
	M1	M2	M1	M2	M1	M2	M1	M2
Differential rate (costs discounted at 3% and benefits at 1.5% annually over 40 years (OEL))	131	324	21	81	11	71	-	-
Differential rate (costs discounted at 3% and benefits at 1.5% annually over 40 years (OEL & BLV))	165	408	39	150	69	429	-	-
Declining discount rate (3% for 0-20 years and 2% for 21-40 years, annually) (OEL)	123	326	21	91	14	98	-	-
Declining discount rate (3% for 0-20 years and 2% for 21-40 years, annually) (OEL & BLV)	148	392	41	179	86	616	-	-

Source: Study team.

As can be seen in the above table, at 7 ng/m³, 70 ng/m³ and 700 ng/m³ levels the standard costs and benefits ratios are improved significantly, particularly at the lowest policy option, and the improvement decreases as the OEL increases. However overall, the pattern remains the same, with 700 ng/m³ having the best ratios, and the ratios remaining high in almost all scenarios.

14 OVERVIEW OF THE IMPACTS

This chapter has the following sections:

- Section 14.1: Cost-benefit assessment (CBA);
- Section 14.2: Multi-criteria analysis (MCA);
- Section 14.3: Practical implications of establishing an OEL
- Section 14.4: Compliance with the subsidiarity and proportionality principles;
- Section 14.5: Highlighted issues; and
- Section 14.6: Summary for the option suggested by the ACSH.

This chapter summarises the estimates presented in the previous chapters by means of a Cost-benefit assessment (CBA), a Multi-criteria (MCA) analyses and analyses of effectiveness, efficiency and coherence of the policy options. All the costs and benefits presented in this chapter are Present value (PV) over 40 years and additional to the baseline scenario.

14.1 Cost-benefit assessment (CBA)

14.1.1 Overview of the benefits for the policy options

The benefits (relative to the baseline) estimated in this report for the different policy options are summarised in the tables below. The benefits include the direct, the indirect and the intangible benefits as described in Section 6.

Table 14-1 Overview of the benefits (PV cost savings due to reduced ill health and avoided costs) per OEL policy option (€ millions)

Impact	Stakeholders affected	Policy options			
		7 ng/m ³	70 ng/m ³	700 ng/m ³	2000 ng/m ³
Direct benefits – improved well-being – health					
Reduced cases of ill health (Lung cancer)	Workers & families	141	35	2	-
Reduced cases of ill health (Developmental toxicity)	Workers & families	38	38	7	-
Reduced cases of ill health (Male infertility)	Workers & families	3,157	3,230	608	-
Ill health avoided, incl. intangible costs (M1 to M2)	Workers & families	€180 - €59	€97 - €16	€15 - €1	€ -
Avoided costs	Companies	€ 0	€ 0	€ 0	€ -
Avoided costs	Public sector	€ 6	€ 4	€ 1	€ -
EU policy agenda	All	Improvements in workers fundamental rights and contribution towards Green Deal: Chemical Strategy towards a toxic-free environment			
Direct benefits – improved well-being – environmental					
Environmental releases	All	Increased reduction in PAH emissions at all levels except 2000 ng/m ³ where no RMM adjustments are anticipated.			
Direct benefits – market efficiency					
Level playing field	Companies	A harmonised OEL at EU level would help to ensure a level playing field between companies operating in different EU Member States.			
Indirect benefits					
Administrative simplification	Companies	Should all Member States have a harmonised OEL/BLV this would reduce the administrative burden for enterprises with operations across multiple Member States. However, the majority of enterprises under review are small and are unlikely to have multinational operations and be unaffected by this simplification. Sectors with the highest costs (in section 8) are typically medium and large enterprises which may benefit from such an administrative simplification.			

Impact	Stakeholders affected	Policy options			
		7 ng/m ³	70 ng/m ³	700 ng/m ³	2000 ng/m ³
Synergy	Companies	Synergies in terms of exposure reduction for other chemical substances used in production sectors may occur. The specific substances will vary between the sectors. The level of synergy to be harnessed will also depend on the RMMs applied in each enterprise.			
Corporate Social Responsibility	Companies	Work with PAH may be less perceived as a risky line of work associated with health issues. As a result of such an improvement in the public image, companies may find it easier to recruit and retain staff, reducing the cost of recruitment and increasing the productivity of workers.			
Avoided cost of setting an OEL	Public sector	€ 2	€ 2	€ 2	€ 1
Avoided cost of setting an OEL & BLV	Public sector	€ 4	€ 4	€ 4	€ 4

Source: Study team

Notes: May not sum to total due to rounding.

14.1.2 Overview of the costs for the policy options

The estimated direct and indirect costs are presented in Table 14-2. The costs are for the present value (PV) over 40 years with a static discount rate of 3%.

Table 14-2 Overview of the costs (incremental to the baseline, PV in € million over 40 years)

Impact	Stakeholders affected	Policy options			
		7 ng/m³ & 0.2 nmol/mol creatinine	70 ng/m³ & 0.3 nmol/mol creatinine	700 ng/m³ & 1.5 nmol/mol creatinine	2000 ng/m³ & 3.8 nmol/mol creatinine
Direct costs – adjustment					
Risk management measures (first year and recurrent) and discontinuation costs	Companies Public authorities	€ 43,000	€ 2,700	€ 3	€ -
Air monitoring (sampling and analysis)	Companies Public authorities	€ 550	€ 290	€ 180	€ 120
Biomonitoring and health surveillance	Companies Public authorities	€ 11,000	€ 1,900	€ 630	€ 100
Transposition costs	Public sector	€ 1	€ 1	€ 1	€ 1
Total compliance costs (OEL)	Companies Public authorities	€ 43,000	€ 3,000	€ 190	€ 120
Total compliance costs (OEL & BLV)	Companies Public authorities	€ 54,000	€ 4,900	€ 810	€ 220
Direct costs – administrative					
Air monitoring (administrative burden) (OEL)	Companies Public authorities	€120	€66	€41	€27
Biomonitoring and health surveillance (administrative burden) (BLV)	Companies Public authorities	€690	€690	€520	€520
Total administrative costs (OEL & BLV)	Companies Public authorities	€810	€760	€570	€550
Direct compliance costs – total					
Adjustment, air monitoring, and administrative burden costs per company (OEL)	Companies Public authorities	€ 44,000	€ 3,100	€ 230	€ 150

Impact	Stakeholders affected	Policy options			
		7 ng/m³ & 0.2 nmol/mol creatinine	70 ng/m³ & 0.3 nmol/mol creatinine	700 ng/m³ & 1.5 nmol/mol creatinine	2000 ng/m³ & 3.8 nmol/mol creatinine
Compliance, air monitoring, biomonitoring and health surveillance and their associated administrative burden costs per company (OEL & BLV)	Companies Public authorities	€ 54,800	€ 5,700	€ 1,400	€ 780
Direct costs - enforcement costs					
Enforcement costs except transposition	Public sector	Enforcement costs may arise as a result of ensuring compliance with new OELs however these costs are not estimated as they are specific to Member States individual inspection regime.			
Indirect costs – other					
Firms exiting the market - No. of company closures	Companies	3,462	146	-	-
Employment – Jobs lost	Workers & families	47,758	2,725	-	-
Employment – Social cost	Workers & families	€ 4,000	€ 230	€ -	€ -
International competitiveness	Companies	Several sectors (for example, metallurgical sectors) are in price sensitive competitive markets with many competitors outside the EU. Sectors that are geographically bound such as chimney sweeps, road paving, soil remediation, welding of train tracks, automotive repair and firefighters would not be affected.			
Consumers	Consumers	Costs for enterprises make up a significant proportion of turnover/GOS and the study team expects costs to be passed onto consumers through increased prices. Costs at 700 ng/m³ and 2000 ng/m³ are less substantial and may not result in as significant price increases for consumers.			
Internal market (Lowest to highest OEL)	Companies	1 : 1	1 : 1	1 : 10	1 : 28.6
Specific MSs/regions - MSs that would have to introduce or change OELs	Public sector	27 Member States: AU, BE, BG, CY, CZ, DE, DK, EE, EL, ES, FI, FR, HR, HU, IE, IT, LT, LU, LV, MT,	26 Member States: AU, BE, BG, CY, CZ, DK, EE, EL, ES, FI, FR, HR, HU, IE, IT, LT, LU, LV, MT, NL,	23 Member States: AU, BE, CY, CZ, DK, EE, EL, ES, FI, FR, HR, HU, IE, IT, LT, LU, MT, PL, PT, RO, SE, SI, SK	15 Member States: BE, CY, CZ, DK, EL, ES, FI, FR, HR, IE, IT, LU, MT, PT, RO

Impact	Stakeholders affected	Policy options			
		7 ng/m ³ & 0.2 nmol/mol creatinine	70 ng/m ³ & 0.3 nmol/mol creatinine	700 ng/m ³ & 1.5 nmol/mol creatinine	2000 ng/m ³ & 3.8 nmol/mol creatinine
		NL, PL, PT, RO, SE, SI, SK	PL, PT, RO, SE, SI, SK		
Specific MSs/regions - MSs that would have to introduce or change BLVs	Public sector	27 Member States: AU, BE, BG, CY, CZ, DE, DK, EE, EL, ES, FI, FR, HR, HU, IE, IT, LT, LU, LV, MT, NL, PL, PT, RO, SE, SI, SK	27 Member States: AU, BE, BG, CY, CZ, DE, DK, EE, EL, ES, FI, FR, HR, HU, IE, IT, LT, LU, LV, MT, NL, PL, PT, RO, SE, SI, SK	25 Member States: AU, BE, BG, CY, CZ, DK, EE, EL, ES, FI, HR, HU, IE, IT, LT, LU, LV, MT, NL, PL, PT, RO, SE, SI, SK	25 Member States: AU, BE, BG, CY, CZ, DK, EE, EL, ES, FI, HR, HU, IE, IT, LT, LU, LV, MT, NL, PL, PT, RO, SE, SI, SK
Regulation	Companies	A REACH Restriction on PAH in articles may be proposed by ECHA in future. EU Emissions Trading System (EU ETS) is driving steel plants to move to hydrogen as a reducing agent and the carbon border adjustment mechanism should help prevent cheaper imports.			

Source: Study team.

Notes: May not sum to total due to rounding. Totals have been presented as two scenarios, '(OEL)' including first year and recurring adjustment costs, air monitoring, and administrative burden. Alternatively, '(OEL & BLV)' also includes the costs of biomonitoring and health surveillance and its associated administrative burden). Health surveillance is expected to already be undertaken by firefighters and has not been factored in as an additional cost in the above calculations. Total rows present alternative scenarios and should be read independently of each other (they should not be read together as additional costs).

14.1.3 Impact of different timescales for costs and benefits

This section explores the impact of the proposed OEL and BLV over the modelled period of 40 years, outlining when and how costs and benefits are anticipated to occur. In short, and EU-wide OEL or BLV will not produce benefits or costs until it is ratified. Prior to this date, benefits cannot be actualised as there will be no changes to the regulation, however during this period some companies may opt to implement lower OELs/BLVs pre-emptively. These companies are not considered in this section as it is not possible to identify or quantify them.

The benefits of the proposed OEL/BLV start to occur as soon as compliance is made mandatory with benefits continuing annually as outlined in section 6. However, some RMMs require substantial upfront implementation costs which are modelled on a first- and twenty-year basis. For example, the implementation of local extraction ventilation has an anticipated lifespan of 20 years requiring upfront costs at the first year (year of regulatory change), and, on average, twenty years later. This is also true for all extraction and ventilation RMMs. These RMMs also incur a continued operational cost each year.

In contrast RPE and occupation health measures do not require upfront capital expenditure, however, they have a substantial recurring annual cost in terms of respiratory protective equipment (RPE) parts (filters), upkeep and staff training.

The impacts of transition periods for sectors that would struggle to comply with certain policy options are outlined in section 7.5. In summary, transition periods for eight sectors (primarily metallurgical) will only affect companies should the lowest two policy options be selected (an OEL of 7 ng/m³ or 70 ng/m³). This assumes that the transitional period is six years and the transitional OEL is 140 ng/m³. Overall, companies in these sectors would be required to meet a less stringent OEL (140 ng/m³) suggesting their costs would be lower for the first six years. This may help companies adjust to the compliance levels required. However, as shown in section 14.6, the difference in overall costs to comply are not significant despite the lower transitional period/levels. The difficulties for these sectors may therefore be due to technical limitations to comply rather than economic ones.

14.1.4 CBA for the policy options

The overall costs and benefits of the policy options are shown in Table 14-3. As shown in the table, modelled costs outweigh the calculated benefits at all policy option levels.

At the 7 ng/m³ level approximately € 10.6 billion are due to biomonitoring and health surveillance and administration costs, and approximately € 44 billion are due to discontinuation and RMM compliance costs (approximately 99% of total costs when implementing only an OEL, and 79% for an OEL & BLV). At this level the compliance costs outweigh the cost of biomonitoring due to a large volume of companies discontinuing. At other policy option levels however, biomonitoring and health surveillance constitutes a significant proportion of costs. At 70 ng/m³ biomonitoring and health surveillance costs attribute approximately 39% of the OEL & BLV costs, and at 700 ng/m³ and 2000 ng/m³ they account for approximately 77% and 46% of costs, respectively.

There are no health benefits at the fourth policy option level, although significant costs remain due to the requirement to undertake air monitoring, biomonitoring and health surveillance.

Table 14-3 Summary of monetised costs and benefits (static discount rate, additional to the baseline) (€ millions)

Policy option	7 ng/m ³ & 0.2 nmol/mol creatinine	70 ng/m ³ & 0.3 nmol/mol creatinine	700 ng/m ³ & 1.5 nmol/mol creatinine	2000 ng/m ³ & 3.8 nmol/mol creatinine
Total benefits M1	€ 190	€ 100	€ 16	€ -
Total benefits M2	€ 64	€ 20	€ 2	€ -
Total costs (OEL)	€ 44,000	€ 3,100	€ 230	€ 150
Cost benefit ratio M1 (OEL)	232	31	14	-
Cost benefit ratio M2 (OEL)	675	154	115	-
Total costs (OEL & BLV)	€ 55,000	€ 5,700	€ 1,400	€ 780
Cost benefit ratio M1 (OEL & BLV)	293	56	87	-
Cost benefit ratio M2 (OEL & BLV)	850	284	701	-

Notes: Values relate to method 1 - method 2.

Source: Study team.

Notes: May not sum to total due to rounding Costs have been presented as two scenarios, '(OEL)' including first year and recurring adjustment costs, air monitoring, and administrative burden. Alternatively, '(OEL & BLV)' also includes the costs of biomonitoring and health surveillance and its associated administrative burden). Health surveillance is expected to already be undertaken by firefighters and has not been factored in as an additional cost in the above calculations. Total rows present alternative scenarios and should be read independently of each other (they should not be read together as additional costs).

14.2 Multi-criteria analysis (MCA)

Table 14-4 summarises both the monetised and qualitative impacts.

The MCA includes the monetised health benefits and the quantifying compliance costs. Other effects including market effects are described only qualitatively.

The sensitivity assessment presented in the previous section indicates the uncertainty related to the monetised and quantified values. The sensitivity assessment points to the fact that benefits and costs could be of the same order of magnitude, the number presented below suggests that costs exceed benefits.

Table 14-4 Multi-criteria analysis (all impacts over 40 years and additional to the baseline) per OEL option (€ millions, and total n (companies/employees))

Impact	Stakeholders affected	7 ng/m ³ & 0.2 nmol/mol creatinine	70 ng/m ³ & 0.3 nmol/mol creatinine	Transitional period option **	700 ng/m ³ & 1.5 nmol/mol creatinine	2000 ng/m ³ & 3.8 nmol/mol creatinine
Direct costs – adjustment						
Risk management measures - first year	Companies	€ 1,700	€ 220	Cannot be monetised	€ 5	€ 0
Risk management measures – recurrent	Companies	€ 2,900	€ 200	Cannot be monetised	-€ 1	€ 0
Risk management measures - discontinuation	Companies	€ 32,000	€ 2,200	Cannot be monetised	€ 0	€ 0
Risk management measures total	Companies	€ 37,000	€ 2,700	€ 2,500	€ 3	€ 0
Risk management measures total per company	Companies	€ 0	€ 0	€ 0	€ 0	€ 0
Monitoring (sampling and analysis)	Companies	€ 550	€ 290	€ 290	€ 180	€ 120
Risk management measures - first year	Public sector	€ 540	€ 16	€ 16	€ 0	€ 0
Risk management measures – recurrent	Public sector	€ 5,300	€ 47	€ 47	€ 0	€ 0
Risk management measures - discontinuation	Public sector	€ 0	€ 0	€ 0	€ 0	€ 0
Risk management measures total	Public sector	€ 5,900	€ 63	€ 63	€ 0	€ 0
Risk management measures total per public authority	Public sector	€ 8	€ 0	€ 0	€ 0	€ 0
Monitoring (sampling and analysis)	Public sector	€ 1	€ 0	€ 0	€ 0	€ 0
Transposition costs	Public sector	€ 1	€ 1	€ 1	€ 1	€ 1
Direct costs - administrative						
Monitoring administrative burden	Companies	€ 120	€ 66	€ 65	€ 41	€ 27

Impact	Stakeholders af- fected	7 ng/m³ & 0.2 nmol/mol creati- nine	70 ng/m³ & 0.3 nmol/mol creati- nine	Transitional pe- riod option **	700 ng/m³ & 1.5 nmol/mol creati- nine	2000 ng/m³ & 3.8 nmol/mol creatinine
Monitoring administrative burden	Public sector	€ 0	€ 0	€ 0	€ 0	€ 0
Direct costs – total compliance						
Adjustment, monitoring and admin- istration burden costs (OEL only)	Companies	€ 38,000	€ 3,000	€ 2,900	€ 230	€ 150
Adjustment, monitoring and admin- istration burden costs per company (OEL only)	Companies	€ 0	€ 0	€ 0	€ 0	€ 0
Adjustment, monitoring and admin- istration burden costs (OEL only)	Public sector	€ 5,900	€ 63	€ 63	€ 0	€ 0
Adjustment, monitoring and admin- istration burden costs per public au- thority (OEL only)	Public sector	€ 8	€ 0	€ 0	€ 0	€ 0
Total compliance costs (OEL only)	Companies Public authorities	€ 44,000	€ 3,100	€ 2,900	€ 230	€ 150
Direct costs - enforcement costs						
Enforcement costs except transpo- sition	Public sector	Enforcement costs may arise as a result of ensuring compliance with new OELs however these costs are not estimated as they are specific to Member States individual inspection regime.				
Indirect costs - other						
Firms discontinuing at least a part of their business - No. of company closures	Companies	3,462	146	The number is likely to be lower than 146	-	-
Firms discontinuing at least a part of their business - %	Companies	0.79%*	0.03%*	The number is likely to be lower than 0.03%	-	-
Total compliance costs as % of turnover over 40 years (including discontinuations)	Companies	Up to 6.3% (C19.1 Coking plants – small & medium en- terprises)	Up to 2.9% (C19.1 Coking plants – small & medium enterprises)	Cannot be esti- mated	Up to 0.01% (sev- eral sectors and company sizes)	Up to 0.01% (sev- eral sectors and company sizes)

Impact	Stakeholders affected	7 ng/m ³ & 0.2 nmol/mol creatinine	70 ng/m ³ & 0.3 nmol/mol creatinine	Transitional period option **	700 ng/m ³ & 1.5 nmol/mol creatinine	2000 ng/m ³ & 3.8 nmol/mol creatinine
First year compliance costs as % of annual turnover (excluding discontinuations)	Companies	Up to 19% (C16.1 wood preservation – small enterprises)	Up to 3% (C24.45 other non-ferrous metallurgy – small enterprises)	Cannot be estimated	0.7% (several sectors – small enterprises)	0.7% (D35.11 coal fired power plants – small enterprises)
Employment – Jobs lost	Workers & families	47,758	2,725	Cannot be estimated – may be a reduction jobs lost due to fewer discontinuations	-	-
Employment – Social cost	Workers & families	€ 4,000	€ 230	Cannot be estimated – may be a reduction jobs lost due to fewer discontinuations	€ 0	€ 0
International competitiveness	Companies	Significantly negative impacts	Negative impacts	Negative impacts	No significant impacts	No significant impacts
Consumers	Consumers	Costs for enterprises at 7 ng/m³ and 70 ng/m³ make up a significant proportion of turnover/GOS and the study team expects costs to be passed onto consumers through increased prices; including C20.13 carbon black manufacturers, C19.1 coking, C24.45 other metallurgy, C10.13 and C10.2 smokehouses, G45.2 automotive repair, N81.22 chimney sweeps, C16.1 wood preservation, E38.2 soil remediation, F42.11 road paving, and F42.12 welding of railroad tracks. The impact of the second lowest policy option is likely to be more limited than under the lowest policy option. The transitional period will delay the increase in consumer prices, or allow for a gradual increase over 6 years, although the impact will be the same as 70 ng/m³.			Costs at 700 ng/m ³ and 2000 ng/m ³ are less substantial and may not result in as significant price increases for consumers.	
Internal market Lowest to highest OEL	Companies	1 : 1	1 : 1	1 : 1	1 : 10	1 : 28.6

Impact	Stakeholders affected	7 ng/m³ & 0.2 nmol/mol creatinine	70 ng/m³ & 0.3 nmol/mol creatinine	Transitional period option **	700 ng/m³ & 1.5 nmol/mol creatinine	2000 ng/m³ & 3.8 nmol/mol creatinine
Specific MSs/regions - MSs that would have to change OELs	Public sector	27 Member States: AU, BE, BG, CY, CZ, DE, DK, EE, EL, ES, FI, FR, HR, HU, IE, IT, LT, LU, LV, MT, NL, PL, PT, RO, SE, SI, SK	26 Member States: AU, BE, BG, CY, CZ, DK, EE, EL, ES, FI, FR, HR, HU, IE, IT, LT, LU, LV, MT, NL, PL, PT, RO, SE, SI, SK	26 Member States: AU, BE, BG, CY, CZ, DK, EE, EL, ES, FI, FR, HR, HU, IE, IT, LT, LU, LV, MT, NL, PL, PT, RO, SE, SI, SK	23 Member States: AU, BE, CY, CZ, DK, EE, EL, ES, FI, FR, HR, HU, IE, IT, LT, LU, MT, PL, PT, RO, SE, SI, SK	15 Member States: BE, CY, CZ, DK, EL, ES, FI, FR, HR, IE, IT, LU, MT, PT, RO
Regulation	Companies	A REACH Restriction on PAH in articles may be proposed by ECHA in future. EU Emissions Trading System (EU ETS) is driving steel plants to move to hydrogen as a reducing agent and the carbon border adjustment mechanism should help prevent cheaper imports.				
Direct benefits – improved well-being - health						
Reduced cases of ill health (lung cancer)	Workers & families	141	35	35	2	0
Reduced cases of ill health (developmental toxicity)	Workers & families	38	38	38	7	0
Reduced cases of ill health (male infertility)	Workers & families	3,157	3,157	3,157	608	0
Ill health avoided, incl. intangible costs (M1 to M2)	Workers & families	€ 180 - 59	€ 97 - 16	€ 89 - 15	€ 15 - 1	€ 0
Direct benefits – improved well-being - safety						
Avoided costs	Companies	€ 1	€ 0	€ 0	€ 0	€ 0
Avoided costs	Public sector	€ 5	€ 4	€ 4	€ 1	€ 0
EU policy agenda	All	Improvements in workers fundamental rights and contribution towards Green Deal: Chemical Strategy towards a toxic-free environment				
Direct benefits – improved well-being - environmental						
Environmental releases	All	Increased reduction in PAH emissions at all levels except 2000 ng/m³ where no RMM adjustments are anticipated. In some sectors environmental emissions are expected to reduce as OELs become more stringent. This is due to RMMs resulting in greater containment/abatement of emissions (e.g. through increased use of				

Impact	Stakeholders affected	7 ng/m³ & 0.2 nmol/mol creatinine	70 ng/m³ & 0.3 nmol/mol creatinine	Transitional period option **	700 ng/m³ & 1.5 nmol/mol creatinine	2000 ng/m³ & 3.8 nmol/mol creatinine
		closed systems or novel cleaner processes as they become available). It is unclear whether the use of alternatives would produce different levels of emissions and the extent to which this may occur, although as outlined in this report alternatives are not viable for most sectors. In the example of road paving where alternatives may be available, it is unknown whether emissions would be affected.				
Direct benefits – market efficiency						
Level playing field	Companies	A harmonised OEL at EU level would help to ensure a level playing field between companies operating in different EU Member States. As shown above ('Specific MSs/regions - MS that would have to change OELs'), at all policy option levels the introduction of an EU wide OEL would result in greater alignment of Member States.				
Indirect benefits						
Administrative simplification	Companies	Should all Member States have a harmonised OEL/BLV this would reduce the administrative burden for enterprises with operations across multiple Member States. However, the majority of enterprises under review are small and are unlikely to have multinational operations and be unaffected by this simplification. Sectors with the highest costs (in section 8) are typically medium and large enterprises which may benefit from such an administrative simplification.				
Synergy	Companies	Synergies in terms of exposure reduction for other chemical substances used in pro-duction sectors may occur. The specific substances will vary between the sectors. The level of synergy to be harnessed will also depend on the RMMs applied in each enterprise.				
Corporate Social Responsibility	Companies	Work with PAHs may be less perceived as a risky line of work associated with health issues. As a result of such an improvement in the public image, companies may find it easier to recruit and retain staff, reducing the cost of recruitment and increasing the productivity of workers.				
Avoided cost of setting an OEL	Public sector	€ 2	€ 2	No change	€ 2	€ 1
Other impacts						
Recycling – loss of business	Recycling companies	Metallurgical sectors may result in discontinuations at the lowest policy option levels, which in turn would result in less production of materials within the EU. However, the study team anticipate companies would continue to source materials from outside the EU to meet demand and subsequently materials available for recycling would be unaffected. However, metallurgical sectors also undertake secondary production (recycling) of metals which would also be subject to costs related to OELs/BLVs. At 7ng/m³ metallurgical sectors are expected to have significant discontinuations resulting in loss of EU capacity to recycle metals. At 70 ng/m³ the impacts to metallurgical				

Impact	Stakeholders affected	7 ng/m³ & 0.2 nmol/mol creatinine	70 ng/m³ & 0.3 nmol/mol creatinine	Transitional period option **	700 ng/m³ & 1.5 nmol/mol creatinine	2000 ng/m³ & 3.8 nmol/mol creatinine
		sectors are less significant in terms of discontinuations, thereby assuming capacity to recycle metals is maintained. Recycling is not considered to be impacted in other areas.				
European climate law		Discontinuations in three sectors steel and iron foundries (C24.1), manufacture of aluminium (C24.42), and other non-ferrous metallurgy (C24.45)) key for the green transition will be affected by the lowest two policy options. For C24.1, discontinuations are approximately 10 times higher, for C24.42 discontinuations are approximately five times higher, and for C24.45 discontinuations are approximately three times higher at 7 ng/m³ than at 70 ng/m³. Overall, the large extent of discontinuations at 7 ng/m³ may result in fewer products or materials essential for the green transition to be available in the EU, increase dependency on third country sources for supply. Transitional periods do not affect the production of relevant materials in these sectors.			No impacts	
Impacts on fundamental rights	All	Positive impact on health and safety. Increased monitoring will help to ensure that future exposures remain controlled and worker risk remains low.				
Impacts on digitalisation	Companies	Digitalisation may be impacted by high costs to silicon metal and graphite manufacturers (used in semiconductor manufacturing, fuel cells, PV solar panels and EV batteries). Costs and discontinuations related to silicon (C24.45) are estimated to be significantly negative at 7 ng/m³, negative at 70ng/m³, and negligible at 700 ng/m³ and 2,000 ng/m³ suggesting impacts on digitalisation would mainly be experienced at the most stringent policy option level. Regarding graphite production (C23.99b) modelling estimates significantly negative costs at 7 ng/m³ and negative costs at 70 ng/m³ indicating cost impacts on digitalisation at these levels (no impacts at 700 ng/m³ and 2,000 ng/m³). Synthetic graphite production is reliant upon C19.1 coking which also experiences significant costs at the lowest two policy options. Collectively the difficulties of silicon and graphite production sector to meet costs at the two lowest policy options may result in negative impacts on digitalisation through increased material costs or greater reliance upon imports from third countries (primarily China).				
Contributions to the UN sustainable development goals	All	Goal 3 – positive Goal 7 – positive Goal 8 – positive Goal 14 and 15 – positive				

Source: Study team.

Notes: May not sum to total due to rounding. * Please note the percentage of all companies discontinuing presented in these rows are significantly lower than the sectoral percentages presented in Table 8-13. This is due to D35.11 and G45.2 sectors with a significantly higher number of companies resulting in skewed total percentages.

*** Transitional period: 140 ng/m³ & 0.3 nmol/mol creatinine for six years and then 70 ng/m³ & 0.3 nmol/mol creatinine. Costs for transitioning sectors are not expected to increase or decrease as a result of changes to adjustments or complying with the OEL. However, the period in which costs are incurred will be delayed by 6 years and requires costs for transitional sectors to be reduced by 8% to more accurately reflect the present value. These reduced costs have been summed with totals for non-transitional sectors at 70ng/m³ to illustrate the impacts of the transitional period on the overall costs.*

Table 14-5 Multi-criteria analysis (all impacts over 40 years and additional to the baseline) per OEL+BLV option (€ millions, and total n (companies/employees))

Impact	Stakeholders affected	7 ng/m ³ & 0.2 nmol/mol creatinine	70 ng/m ³ & 0.3 nmol/mol creatinine	700 ng/m ³ & 1.5 nmol/mol creatinine	2000 ng/m ³ & 3.8 nmol/mol creatinine
Direct costs – adjustment					
Risk management measures - first year	Companies	€ 1,700	€ 220	€ 5	€ 0
Risk management measures – re-current	Companies	€ 2,900	€ 200	-€ 1	€ 0
Risk management measures - discontinuation	Companies	€ 32,000	€ 2,200	€ 0	€ 0
Risk management measures total	Companies	€ 37,000	€ 2,700	€ 3	€ 0
Risk management measures total per company	Companies	€ 0	€ 0	€ 0	€ 0
Air monitoring (sampling and analysis)	Companies	€ 540	€ 290	€ 180	€ 120
Biomonitoring and health surveillance	Companies	€ 1,100	€ 340	€ 100	€ 100
Risk management measures - first year	Public sector	€ 540	€ 16	€ 0	€ 0
Risk management measures – re-current	Public sector	€ 5,300	€ 47	€ 0	€ 0
Risk management measures - discontinuation	Public sector	€ 0	€ 0	€ 0	€ 0
Risk management measures total	Public sector	€ 5,900	€ 63	€ 0	€ 0

Impact	Stakeholders affected	7 ng/m ³ & 0.2 nmol/mol creatinine	70 ng/m ³ & 0.3 nmol/mol creatinine	700 ng/m ³ & 1.5 nmol/mol creatinine	2000 ng/m ³ & 3.8 nmol/mol creatinine
Risk management measures total per public authority	Public sector	€ 8	€ 0	€ 0	€ 0
Air monitoring (sampling and analysis)	Public sector	€ 1	€ 0	€ 0	€ 0
Biomonitoring and health surveillance	Public sector	€ 9,500	€ 1,600	€ 520	€ 520
Transposition costs	Public sector	€ 1	€ 1	€ 1	€ 1
Direct costs - administrative					
Air monitoring administrative burden	Companies	€ 120	€ 66	€ 41	€ 27
Biomonitoring and health surveillance administrative burden	Companies	€ 680	€ 670	€ 510	€ 510
Air monitoring administrative burden	Public sector	€ 0	€ 0	€ 0	€ 0
Biomonitoring administrative burden	Public sector	€ 17	€ 17	€ 11	€ 11
Direct costs – total compliance					
Adjustment, monitoring and administration burden costs (OEL & BLV)	Companies	€ 39,000	€ 4,000	€ 840	€ 770
Adjustment, monitoring and administration burden costs per company (OEL & BLV)	Companies	€ 0	€ 0	€ 0	€ 0
Adjustment, monitoring and administration burden costs (OEL & BLV)	Public sector	€ 15,000	€ 1,700	€ 540	€ 540
Adjustment, monitoring and administration burden costs per public authority (OEL & BLV)	Public sector	€ 20	€ 2	€ 1	€ 1

Impact	Stakeholders affected	7 ng/m³ & 0.2 nmol/mol creatinine	70 ng/m³ & 0.3 nmol/mol creatinine	700 ng/m³ & 1.5 nmol/mol creatinine	2000 ng/m³ & 3.8 nmol/mol creatinine
Total compliance costs (OEL & BLV)	Companies Public authorities	€ 55,000	€ 5,700	€ 1,400	€ 1,300
Direct costs - enforcement costs					
Enforcement costs except transposition	Public sector	Enforcement costs may arise as a result of ensuring compliance with new OELs however these costs are not estimated as they are specific to Member States individual inspection regime.			
Indirect costs - other					
Firms discontinuing at least a part of their business - No. of company closures	Companies	3,462	146	-	-
Firms discontinuing at least a part of their business - %	Companies	0.79%*	0.03%*	-	-
Total compliance costs as % of turnover over 40 years (including discontinuations)	Companies	Up to 6.3% (C19.1 Coking plants – small & medium enterprises)	Up to 2.9% (C19.1 Coking plants – small & medium enterprises)	Up to 0.01% (several sectors and company sizes)	Up to 0.01% (several sectors and company sizes)
First year compliance costs as % of annual turnover (excluding discontinuations)	Companies	Up to 19% (C16.1 wood preservation – small enterprises)	Up to 3% (C24.45 other non-ferrous metallurgy – small enterprises)	0.7% (several sectors – small enterprises)	0.7% (D35.11 coal fired power plants – small enterprises)
Employment – Jobs lost	Workers & families	47,758	2,725	-	-
Employment – Social cost	Workers & families	€ 4,000	€ 230	€ 0	€ 0
International competitiveness	Companies	Several sectors (for example, metallurgical sectors) are in price sensitive competitive markets with many competitors outside the EU. Sectors that are geographically bound such as chimney sweeps, road paving, soil remediation, welding of train tracks, automotive repair and firefighters would not be affected			
Consumers	Consumers	Costs for enterprises at 7 ng/m³ and 70 ng/m³ make up a significant proportion of turnover/GOS and the study team expects costs to be passed onto consumers through			

Impact	Stakeholders affected	7 ng/m³ & 0.2 nmol/mol creatinine	70 ng/m³ & 0.3 nmol/mol creatinine	700 ng/m³ & 1.5 nmol/mol creatinine	2000 ng/m³ & 3.8 nmol/mol creatinine
		increased prices. Costs at 700 ng/m³ and 2000 ng/m³ are less substantial and may not result in as significant price in-creses for consumers.			
Internal market Lowest to highest OEL	Companies	1 : 1	1 : 1	1 : 10	1 : 28.6
Specific MSs/regions - MSs that would have to change OELs	Public sector	27 Member States: AU, BE, BG, CY, CZ, DE, DK, EE, EL, ES, FI, FR, HR, HU, IE, IT, LT, LU, LV, MT, NL, PL, PT, RO, SE, SI, SK	26 Member States: AU, BE, BG, CY, CZ, DK, EE, EL, ES, FI, FR, HR, HU, IE, IT, LT, LU, LV, MT, NL, PL, PT, RO, SE, SI, SK	23 Member States: AU, BE, CY, CZ, DK, EE, EL, ES, FI, FR, HR, HU, IE, IT, LT, LU, MT, PL, PT, RO, SE, SI, SK	15 Member States: BE, CY, CZ, DK, EL, ES, FI, FR, HR, IE, IT, LU, MT, PT, RO
Specific MSs/regions - MSs that would have to change BLVs	Public sector	27 Member States: AU, BE, BG, CY, CZ, DE, DK, EE, EL, ES, FI, FR, HR, HU, IE, IT, LT, LU, LV, MT, NL, PL, PT, RO, SE, SI, SK	27 Member States: AU, BE, BG, CY, CZ, DE, DK, EE, EL, ES, FI, FR, HR, HU, IE, IT, LT, LU, LV, MT, NL, PL, PT, RO, SE, SI, SK	25 Member States: AU, BE, BG, CY, CZ, DK, EE, EL, ES, FI, HR, HU, IE, IT, LT, LU, LV, MT, NL, PL, PT, RO, SE, SI, SK	25 Member States: AU, BE, BG, CY, CZ, DK, EE, EL, ES, FI, HR, HU, IE, IT, LT, LU, LV, MT, NL, PL, PT, RO, SE, SI, SK
Regulation	Companies	A REACH Restriction on PAH in articles may be proposed by ECHA in future. EU Emissions Trading System (EU ETS) is driving steel plants to move to hydrogen as a reducing agent and the carbon border adjustment mechanism should help prevent cheaper imports.			
Direct benefits – improved well-being - health					
Reduced cases of ill health (lung cancer)	Workers & families	141	35	2	0
Reduced cases of ill health (developmental toxicity)	Workers & families	38	38	7	0
Reduced cases of ill health (male infertility)	Workers & families	3,157	3,157	608	0
Ill health avoided, incl. intangible costs (M1 to M2)	Workers & families	€ 180 - 59	€ 97 - 16	€ 15 - 1	€ 0
Direct benefits – improved well-being - safety					

Impact	Stakeholders affected	7 ng/m³ & 0.2 nmol/mol creatinine	70 ng/m³ & 0.3 nmol/mol creatinine	700 ng/m³ & 1.5 nmol/mol creatinine	2000 ng/m³ & 3.8 nmol/mol creatinine
Avoided costs	Companies	€ 1	€ 0	€ 0	€ 0
Avoided costs	Public sector	€ 5	€ 4	€ 1	€ 0
EU policy agenda	All	Improvements in workers fundamental rights and contribution towards Green Deal: Chemical Strategy towards a toxic-free environment			
Direct benefits – improved well-being - environmental					
Environmental releases	All	Increased reduction in PAH emissions at all levels except 2000 ng/m³ where no RMM adjustments are anticipated.			
Direct benefits – market efficiency					
Level playing field	Companies	A harmonised OEL at EU level would help to ensure a level playing field between companies operating in different EU Member States.			
Indirect benefits					
Administrative simplification	Companies	Should all Member States have a harmonised OEL/BLV this would reduce the administrative burden for enterprises with operations across multiple Member States. However, the majority of enterprises under review are small and are unlikely to have multinational operations and be unaffected by this simplification. Sectors with the highest costs (in section 8) are typically medium and large enterprises which may benefit from such an administrative simplification.			
Synergy	Companies	Synergies in terms of exposure reduction for other chemical substances used in production sectors may occur. The specific substances will vary between the sectors. The level of synergy to be harnessed will also depend on the RMMs applied in each enterprise.			
Corporate Social Responsibility	Companies	Work with PAH may be less perceived as a risky line of work associated with health issues. As a result of such an improvement in the public image, companies may find it easier to recruit and retain staff, reducing the cost of recruitment and increasing the productivity of workers.			
Avoided cost of setting an OEL	Public sector	€ 2	€ 2	€ 2	€ 1
Avoided cost of setting an OEL & BLV	Public sector	€ 4	€ 4	€ 4	€ 4
Other impacts					

Impact	Stakeholders affected	7 ng/m ³ & 0.2 nmol/mol creatinine	70 ng/m ³ & 0.3 nmol/mol creatinine	700 ng/m ³ & 1.5 nmol/mol creatinine	2000 ng/m ³ & 3.8 nmol/mol creatinine
Recycling – loss of business	Recycling companies	Metallurgical sectors may result in discontinuations at the lowest policy option levels, which in turn would result in less production of materials within the EU. However, the study team anticipate companies would continue to source materials from outside the EU to meet demand and subsequently materials available for recycling would be unaffected. However, metallurgical sectors also undertake secondary production (recycling) of metals which would also be subject to costs related to OELs/BLVs.			
Impacts on fundamental rights	All	Positive impact on health and safety. Increased monitoring will help to ensure that future exposures remain controlled and worker risk remains low.			
Impacts on digitalisation	Companies	Digitalisation may be impacted by high costs to silicon metal and graphite manufacturers (used in semiconductor manufacturing, fuel cells, PV solar panels and EV batteries).			
Contributions to the UN sustainable development goals	All	Goal 3 – positive Goal 7 – positive Goal 8 – positive Goal 14 and 15 – positive			

Source: Study team

Notes: Totals have been presented as two scenarios, '(OEL)' including first year and recurring adjustment costs, air monitoring, and administrative burden. Alternatively, '(OEL & BLV)' also includes the costs of biomonitoring and health surveillance and its associated administrative burden). Health surveillance is expected to already be undertaken by fire-fighters and has not been factored in as an additional cost in the above calculations. Total rows present alternative scenarios and should be read independently of each other (they should not be read together as additional costs).

* Please note the percentage of all companies discontinuing presented in these rows are significantly lower than the sectoral percentages presented in Table 8-13. This is due to D35.11 and G45.2 sectors with a significantly higher number of companies resulting in skewed total percentages.

14.3 Practical implications of establishing an OEL

The following table highlights practical considerations for citizens/consumers, businesses and administrations which should be considered under the introduction of an EU OEL/BLV for PAH.

Table 14-6 Practical implications of establishing an OEL/BLV for PAH

Citizens/Consumers	Businesses	Administrations
- Citizens/consumers may experience quantified cost changes to products/services as businesses may pass on increased costs (due to compliance) to consumers. - Employees have a duty to comply with requirements of their employers regarding the use of preventative and protective equipment and measures necessary to comply with the OSH legislation (e.g. OEL/BLV).	Businesses must comply with OSH legislated provisions (e.g. an OEL/BLV) which would have the following practical implications: - installation and continued operation of necessary risk management measures (RMMs) (such as forms of local exhaust ventilation and enclosed cabinets, personal protective equipment (PPE), respiratory protective equipment (RPE), organisational hygiene measures, general ventilation etc.) required to meet the OEL/BLV. - implementation of a sampling strategy for airborne concentration measurements as part of business risk assessment processes and effectiveness checks of existing measures to meet the OEL. - implementation of a sampling strategy for urine testing of exposed employees as part of the business risk assessment processes and effectiveness checks of existing measures to meet the BLV. - ensure that PAH are managed in line with the provisions of the carcinogens and mutagens national legislation. - ensure compliance with other provisions in the legislation (specific information and training to workers as regards the new working methods if such is the need in order to comply with the new OEL/BLV, collection of records, information to competent authorities, etc.).	Member States must transpose the amended Directive into national legislation: - assessment of the national scenario and potential impacts; - tripartite consultation of the proposal (workers, employers, authorities); - facilitate implementation of the national legislation by providing, among other measures, technical guidance to employers. These costs are minor in comparison to the overall costs of functioning incurred by the enforcement. Member States must also comply with the whole set of OSH national legislation provisions related to an OEL/BLV. For fire-fighting personnel this would require: - Implementation and continued operation of necessary RMMs suitable for this sector. For example, RPE, PPE, and organisational hygiene measures. - implementation of a sampling strategy for airborne concentration measurements as part of risk assessment processes and effectiveness checks of existing measures to meet the OEL. - implementation of a sampling strategy for urine testing of exposed firefighters as part of the risk assessment processes and effectiveness checks of existing measures to meet the BLV.

Citizens/Consumers	Businesses	Administrations
		- ensure that PAH are managed in line with the provisions of the carcinogens and mutagens national legislation. - ensure compliance with other provisions in the legislation (specific information and training to workers as regards the new working methods if such is the need in order to comply with the new OEL/BLV, collection of records, information to competent authorities, etc.).

Source: Study team.

14.4 Compliance with the subsidiarity and proportionality principles

Article 5.3 of the Treaty of Europe says “Under the principle of subsidiarity, in areas which do not fall within its exclusive competence, the Union shall act only if and in so far as the objectives of the proposed action cannot be sufficiently achieved by the Member States, either at central level or at regional and local level, but can rather, by reason of the scale or effects of the proposed action, be better achieved at Union level.”²⁷

Whilst Member States can and do set their own limit values, the analysis and decision making are more efficient and effective if the process of setting limit values is undertaken at the Union level. The introduction of limit values at Union level also ensures that there is not divergence of risk within industry operating across the Union. For these reasons the introduction of EU wide limit values can be seen as compliant with the principle of subsidiary.

Article 5.3 of the Treaty of Europe says “Under the principle of proportionality, the content and form of Union action shall not exceed what is necessary to achieve the objectives of the Treaties.”²⁸. It is often described as “not using a sledgehammer to crack a nut”.

For control of exposure to CMR substances it has been established that the inclusion in the CMRD and the subsequent introduction of limit values is an appropriate method of controlling exposure. PAH are already covered by the CMRD, therefore the Member States have already agreed that setting limit values through the process managed by the Advisory Committee for Safety and Health at Work (ACSH), Working Party on Chemicals (WPC) and DG EMPL is the appropriate and proportionate manner. By definition, Member States are obliged under the CMRD to continually work to reduce the exposure to PAH and this study provides all of the impacts, including the costs and benefits to the ACSH, WPC and DG EMPL enabling them to specify acceptable limit values. Given the structure and previous establishment of the above process, the introduction of EU wide limit values can be seen as compliant with the principle of proportionality.

²⁷ <https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:C:2008:115:0013:0045:en:PDF>

²⁸ <https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:C:2008:115:0013:0045:en:PDF>

14.5 Highlighted issues

Other issues to be considered in the decision-making process include:

14.5.1 Benzo[a]pyrene (BaP) as a marker

Benzo[a]pyrene is used as the sole indicator for exposure to a mixture. BaP is a very potent carcinogen and the Exposure Risk Relationship (ERR) has been derived from a large number of epidemiological studies (see section 2.2). It is generally accepted that BaP is a good proxy for exposure to PAH from different combustion and pyrolysis processes. However, BaP is not always present and as indicated by RAC, the exposure in some of the studies included in the Armstrong et al. (2014) analysis was sometimes poor and in some cases estimations from other workplaces in the same industries were used.

Based on the RAC recommendation (RAC, 2022a,b) the OEL policy options of this study are based on BaP exposure concentrations. One of the inclusion criteria for sectors in this study is based on exposure data with a P95 equivalent or greater than the lowest OEL policy option, i.e. 7 ng/m³ BaP. While exposure to other carcinogenic PAH cannot be excluded and in some cases does occur, it cannot be taken into account in the study to establish benefits or costs. However, it is assumed that protection from BaP in the PAH mixture will result in protection from other PAH in the mixture.

Examples of sectors or activities excluded for the purpose of this study, but where exposure to carcinogenic PAH other than BaP is documented are: mining, wildfire firefighting, roofing, tyre and rubber manufacturing and potentially many others. The study team has not undertaken a search of sectors with exposure to any PAH, but has focused on BaP. Exposure to lighter PAH (such as naphthalene) is far more widespread than the sectors analysed in this study, however these tend to also be less toxic. Naphthalene is a 2-ring PAH and often makes up the vast majority of the PAH found in the analysis, but it is classed as a carcinogen category 2 under the CLP Regulation (EC No 1272/2008) and is therefore outside of the scope of the CMRD. Would naphthalene be part of the CMRD, additional sectors would be included, e.g. paints and inks are manufactured with naphthalene.

Of the sectors under the scope of this study, the following have data on exposure to one or more carcinogenic PAH Cat. 1 that are under the scope of the CMRD (other than BaP, see Table 1-5 for a complete list of carcinogenic PAH):

- C10.13 and C10.20 Smokehouses (where data is available only for fish smokehouses but the process is understood to be similar);
- C16.1 Wood preservation with creosote;
- C19.1 Coking plant;
- C19.2 Petroleum refineries;
- C20.13 Manufacture of carbon black;
- C20.14 Coal tar distillation;
- C23.99b Manufacture of graphite and carbon electrodes;

- C24.1 Steel and iron foundries, ferroalloys;
- C24.42 Manufacture of aluminium;
- D35.11 Coal fired power plant;
- F42.12 Road paving;
- G45.2 Motor vehicle repair and maintenance; and
- O84.25 Firefighters.

In the remaining sectors, the study team anticipates that exposure to other carcinogenic PAH is also likely: C23.99a manufacture of bituminous products because they are found in road paving workers (who are exposed via the products made by C23.99a workers), C24.45 other metallurgical process since they use Soderberg anodes and manufacture according to methods that require the use of anodes and cathodes made using coal tar pitch; C24.5 casting since exposure to PAH is found in the casting areas of other metallurgical sectors; E39.0 soil remediation because exposure to other carcinogenic PAH can be expected if the contaminants being removed from the soil are coal or petroleum products; C23.2 refractory products and F42.12 welding of train tracks because these handle coal tar pitch and creosote, respectively, which contain and can lead to exposure to other carcinogenic PAH.

Therefore the scope of the assessment is somewhat limited by using BaP as an indicative substance, and there is the possibility that occupational exposure to other carcinogenic PAH takes place and is not monitored. As noted by RAC "In such settings it would be preferable to monitor exposure to a wider variety of PAH, e.g., the 16 EPA PAH, even if they were less carcinogenic than BaP. However, the available toxicological and epidemiological data does not allow deriving quantitative ERRs or other benchmarks for such an approach. Nevertheless, the exposure minimisation principle of CMRD should apply to any carcinogenic PAH."

14.5.2 3-hydroxybenzo[a]pyrene (3-OHBaP) as a biomarker

Similar remarks to using BaP as marker for the mixture can be made for using 3-OHBaP as a biomarker. In addition, the study team has noted that

- There is a lack of data on levels of 3-OHBaP in urine in many sectors. This means that it has not been possible to make meaningful comparisons of current metabolite concentrations to the proposed BLV options;
- The relationship between BaP and 3-OHBaP is said not to be accurate in the low exposure range and it is not possible to estimate exposure levels below urinary 3-OHBaP values below 0.1729 nmol/mol creatinine (0.41 µg/g creatinine), below which the corresponding air concentration would be negative (RAC 2022b). In addition, one expert indicated that samples should not be stored frozen, as the thawing process may cause the metabolite to be unstable and/or underestimate exposure levels, while another expert indicated that they should be analysed as soon as they are thawed – this is contradicting information from the experts the study team has interviewed;

- Confounding variables such as smoking, eating smoked foods or grilled food (particularly meats), and vicinity to fires burning solid fuels are known to increase PAH exposure and metabolite concentrations (see section 2.1.5). The urinary 1-OHP levels are about 2 to 3 times higher for smokers than for non-smokers (RAC, 2022a). For 1-OHP SCOEL has proposed a background level in urine of people not occupationally exposed to PAH that includes smokers (see section 1.2.3), while RAC proposed to set a BGV corresponding to the background level of the occupationally not PAH exposed, non-smoking general population. Background levels of 3-OHBaP have not been proposed. Consultees have expressed concern at the potential confounding factors and how these can be mitigated during biomonitoring campaigns, and that baseline values (i.e. no work-related exposure) will be different for each individual and may be a better starting point than a blanket threshold value;
- DFG (2013 as cited by RAC, 2022) indicates that the best sampling time is 16 h after last exposure, i.e. in the morning after the previous shift, due to excretion times. DFG as well as IARC (2023) indicate that 3-OHBaP (but not 1-OHP) is preferably metabolised and excreted in faeces; and
- Some respondents, as well as experts, have indicated that there is currently a lack of accredited laboratories to analyse for 3-OHBaP in Europe, especially with the new and more sensitive analytical method. It is anticipated that should a BLV with 3-OHBaP come into force, laboratories will adopt existing methods and offer the required analysis of 3-OHBaP. Although there may be a short-term capacity, this issue should resolve itself.

14.5.3 Other cancers and effects

The Exposure Risk Relationship (ERR) is derived for lung cancer. There is however conclusive evidence that PAH cause skin cancer but there are insufficient data to quantify effects and there is also indication that of elevated risk of bladder cancer, but inconclusive evidence due to confounding factors (RAC, 2022a,b). Sensitivity calculations done by RAC indicate that assuming no confounding by other factors, the risk of bladder cancer would at maximum influence the ERR by a factor of 1.7.

Other bodies have identified the possibility of other illnesses induced by exposure to PAH and RAC concluded that "There is some evidence that BaP can produce effects in the liver, kidney, cardiovascular system, and nervous system but overall this is less robust evidence than that for other endpoints and conclusions cannot be drawn."

It has not been possible to quantify the benefits from skin cancer and bladder cancer at the different policy options. However bladder cancer has been included in the sensitivity analysis.

Finally, BaP is a non-threshold carcinogen, meaning that exposure to any amount of BaP has the potential to cause effects.

14.5.4 Future trends

The study team has identified future trends for refineries (-6%), C24.42 aluminium manufacturing (+1%), C24.45 silicon metal manufacturing (+1.95%), D35.11 coal fired power plants (-2.5%). Related sectors may also be subject to trends, namely:

- C24.1 steel and iron foundries, and other ferroalloys, may be subject to similar trends. Steel is needed to construct many of the infrastructures that will be needed to achieve net zero emissions (e.g. wind turbines); and
- C23.99b manufacture of synthetic graphite is also expected to increase. Natural graphite has been identified as a critical raw material, the majority of which comes from China. The need for graphite in electric vehicles, fuel cells and other articles and processes needed to achieve net zero emissions are likely to increase demand and manufacture of synthetic graphite. A JRC (2023) report indicates that demand will increase on average by 8.36% yearly, but the demand does not take into account imports vs manufacture, natural vs synthetic and future potential for recycling. Therefore the trend for the sector has not been modelled.
- C19.1, the future of coking coal is very uncertain. Coking coal sites are generally integrated with steel plants where coke is currently used as a reducing agent in basic oxygen furnaces (BOF) in the manufacture of primary steel. It is anticipated that these will largely shift to hydrogen as a reducing agent, removing the need for coking coal. This will allow industry to adapt to the European Trading Scheme (ETS) and move the EU towards net zero, since a major by-product of BOF is CO₂. However, the by-product of coking is coal tar, which is then raw material for coal tar pitch. The latter is then currently needed in the manufacture of graphite and carbon electrodes that are essential in almost all metallurgical processes. And as indicated above, graphite is needed in other processes and articles.

14.5.5 DRRs based on animal studies and duration of effects

As indicated in the list of limitations and uncertainties (see section 13.1), the dose response relationship (DRR) data are based on experimental studies with animals rather than epidemiological studies and although there is supportive information from human studies, transferring experimental animal data quantitatively to the human situation always includes relevant uncertainties. Furthermore, only a low number of concentration-effect points are available from the experimental studies to determine the DRRs.

A further uncertainty with regard to the effects on fertility (sperm motility in males) is that from the animal studies it cannot be concluded whether the effects on fertility are reversible or not. In order to avoid overestimating the effects in humans, for the modelling it was assumed that they are permanent, which in this case produces a lower number of cases than assuming reversibility (with the possibility of producing the same effect again in the same exposed individual).

14.6 Summary for the option agreed by the ACSH

The ACSH agreed an OEL of 70 ng/m³ with a transitional period of up to six years with an OEL of 140 ng/m³ applicable to the following sectors:

- Coking plants;
- Coal tar distillation plants;
- Manufacture of refractory products;
- Graphite and carbon electrode manufacturers;
- Steel and iron foundries, including ferroalloys;
- Aluminium plants;

- Welding of train tracks;
- Casting of metals; and
- Other non-ferrous metallurgy

Further information on the impacts associated with this OEL can be found in 16.2 Annex 2.

The purpose of the transition period is to enable companies to comply in a controlled manner:

- Enabling them to implement major and expensive changes to RMMs;
- If possible, developing, finding and testing substitutes; and
- If possible, avoiding discontinuations and avoiding the associated disruption of supply chains; and
- Or, if possible, avoiding closure by focussing on other areas of business that do not use PAHs: this may lead to costs for retraining, retooling and redundancy payments.

The purpose of the transition period is not to reduce costs: these companies will still have high costs. It is likely that there will be fewer discontinuations as a result of the transitional period – this means that the transitional period has the potential to reduce the overall costs. However, even if the actual costs were reduced and/or there are fewer discontinuations and therefore less unemployment, the change in these costs and/or unemployment is impossible to calculate.

Therefore, the monetised impact on the costs and benefits is only due to the discount factor for the transitional period, which is shown in the Methodological Note section 8.4 to lead to a reduction in costs and benefits of approximately 8% for the sectors with a transitional period.

As both the costs and benefits reduce by 8%, the cost benefit ratios are unchanged.

Therefore, overall, the transitional period will delay impacts by an average of three years and reduce the value of costs and benefits by approximately 8% for all stakeholders, employers, workers and public administrations. The transitional periods for PAH are thus expected to delay and reduce the impacts for the following impact categories as shown below.

Table 14-7 Summary of impact of transitional period compared with no transitional period and OEL of 70 ng/m³ & 0.3 nmol/mol creatinine

Other impacts	Impacts
Social impacts	
Impact on workers (ill health cases and monetised health benefits including direct, indirect and intangible costs, and in particular healthcare costs.)	The benefits in terms of the reduced number of cases of ill-health be the same. The monetary value will decrease by around 8% as the benefits will be postponed by on average three years.
Impact on employment (job losses)	There may be fewer job losses if some companies can use the transitional period to avoid discontinuation.
Economic impacts	

Other impacts	Impacts
Impact on businesses, including SMEs (adjustment costs (one off and recurrent), number of discontinuations, air monitoring costs (one-off and recurrent), administrative burden (one-off and recurrent), cost savings from reduced ill health.	The total estimated costs will reduce by approximately 8% for all sizes of company. The costs of discontinuation are likely to be reduced, while the costs of RMMs might increase when companies are able to finance the investments in RMM instead of closing down. As previously outlined in section 11.2, C23.2, C24.1, C24.45, C24.5, and F42.12 are primarily made up of SMEs with low first year costs as a percentage of turnover at 70 ng/m³. This may suggest limited cost reductions for SMEs relating to the transitional period. Discontinuations are expected to reduce as a result of companies having additional time to implement compliant RMMs and processes to meet 70 ng/m³. The extent to which discontinuations reduce is not known. Of the remaining companies discontinuing in transitional sectors, the impacts are expected to reduce as company's should have more time available for a controlled closure of their sites (although this is not quantifiable). It might also be that the costs of RMMs will be reduced if companies can plan and do investments as part of investment in new production facilities and equipment.
Impact on competitiveness (cost and price competitiveness (incl. consumers), international competitiveness and capacity to innovate).	The transitional period will reduce some of the negative impact of the costs upon competitiveness as it allows companies to better plan and finance the necessary investments.
Impact on the single market (in particular better level playing field due to more harmonised legislations)	The transitional period will not affect the impacts on the single market. Introduction of the EU wide OEL for PAHs will lead to more level playing field across EU.
Impact on Member States (which MS are more expected to be impacted)	The expected fewer discontinuations as a result of the transitional period will benefit the Member States where the largest impacts are expected. This varies by sector and Member State: C19.1 Czechia, Greece, Poland, Romania and Spain C23.99b France, Germany, and Poland C24.1 Czechia, Germany, Italy, Slovakia, and Spain C24.45 German, and Italy C24.5 Czechia, France, Germany, Hungary, Italy, Netherlands, Poland, Portugal, Romania, and Spain F42.12 Germany, Italy, Netherlands, Poland, Spain, and Sweden

Other impacts	Impacts
	C20.14, C23.2, C24.42 Member States appear equally affected.
Impact on public authorities (transposition costs, avoided healthcare treatment costs, benefit) + for PAHs: adjustment costs (one-off and recurrent), air monitoring costs (one-off and recurrent), administrative burden (one-off and recurrent), cost savings from reduced ill health.	There are not significant changes to the estimated impacts on public authorities.
Impact on EU Strategic autonomy (where relevant)	The transitional period may decrease any negative impacts on EU strategic autonomy. The OEL might lead less discontinuation of facilities, supporting sustained supply of products (e.g. graphite which has further end uses in battery manufacturing etc.). The transitional period is likely to lead to overall more positive impacts on the EU Strategic autonomy. Furthermore, due to the 6 year delay for companies transitioning, international (and internal market) developments may result in alternative supply chains, novel technologies/alternatives, or strategic/political changes which relieve pressure against the EU's strategic autonomy.
Impact on digitalisation	Negative impacts to digitalisation and building a climate-neutral, green society may be reduced continued business operation in key sectors, for example silicon metal (C24.45) and graphite manufacturers (C23.99b, used in semiconductor manufacturing, fuel cells, PV solar panels and EV batteries).
Environmental impacts	
Direct impacts on environment (releases of substances in the air)	The transitional period is not expected to change the direct environmental impacts.
Indirect impacts on environment (EU Green Deal)	The potential reduction in discontinuations may support the continued operation of manufacturers of materials and products relevant to the EU's green transition.

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16 ANNEXES

16.1 Annex 1 - Stakeholder consultation – synopsis report

This section provides a summary of the stakeholder consultation exercises undertaken as part of this study ('Study on collecting the most recent information on substances to analyse health, socio-economic and environmental impacts in connection with possible amendments of Directive 2004/37/EC on the protection of workers from the risks related to exposure to carcinogens, mutagens or reprotoxic substances at work').

16.1.1 Outline of consultation strategy

The primary aim of the consultation activities is to identify information not available via desk-based research. For example, although information on current OELs, STELs, BLVs and notations is available, there is limited information on the specific concrete risk management measures already in place, as well as those that would need to be implemented, should the proposed measures be introduced into the CMRD. There may also, for example, be complications regarding the specificities of different sites and environments in which workers may be exposed. Consultation activities therefore formed a valuable part of this study.

The consultation activities conducted to date have included:

- Targeted questionnaires, these included: substance specific questionnaires, Member State Authorities, OSH Experts, Trade Unions and a further short questionnaire for welding²⁹;
- Interviews;
- Site visits; and
- Conversations (these consisted of email exchanges and online calls).

The study team have consulted a range of organisations whose activities are relevant to PAH. Information collected via consultation included the sectors and processes in which exposure to PAH occur, the size of companies that would be impacted, estimates of numbers of workers exposed currently, current air concentrations of substances concerned (both 8-hour time weighted averages (8-h TWA) and 15-minute reference periods), current biological limit values, as well as risk management measures currently in place, and risk management measures that would need to be implemented should the limits be introduced and the associated costs.

Consultation activities have been conducted by those with expertise; substance experts (those writing the substance-specific reports) and national experts (with knowledge of the situation in their Member State and native language competence) conducted the interviews with stakeholders. The substance and national experts in turn were also supported by experts in cost-benefit analysis and consultation via a consortium led by RPA which has worked on all five previous OELs studies.

Any contact made with stakeholders was logged so that progress can be monitored, and interview guides have been prepared for those conducting interviews to ensure that the approach to

²⁹ Questionnaires for MSA, Trade Unions and the further welding questionnaire were often accompanied by interviews. The aim of these interviews was to fill in the questionnaire and this formed the basis of the interview questions.

collecting data was thorough and consistent. These guides include information clarifying the objectives of the study, the study approach and provide detailed information on the measures being assessed. They also include information on the role of the national experts and the specific data that needs to be collected via consultation, as well as the privacy statement and the confidentiality options.

The following important aspects of the consultation exercise should be mentioned:

- There has been no public consultation conducted as part of this work, although the survey has – through its submission strategy – aimed to reach out widely;
- The consultation focused on generating *evidence* to directly support the analyses. Views and opinions have also been provided and are presented here as well, but the approach towards this has not been as systematic; and
- Much of the evidence gathered is of a confidential nature and is thus not presented here, however it has been used to support the calculations and assessments that result from the analyses.

The table below summarises the stakeholder groups targeted and the tools, interests and strategies applied:

Table 16-1 Consultation tools and strategies

Stakeholder type	Interests represented	Main consultation tools	Strategy
EU Associations and REACH Consortia	Industry	Online interviews Email requests	Our previous work demonstrated that EU Associations are the best instrument for reaching out to manufacturers/users. Upon request, the EU associations thus forwarded the questionnaires to national associations and companies. Supplementary information e.g. on number of companies, numbers of workers exposed, market situation, etc. was collected through email requests and online interviews with the associations and REACH consortia and statistics from Eurostat.
Member State Authorities	Member State authorities	Questionnaires Online interviews	Member State authorities were contacted with a questionnaire and responses were followed up with online interviews, where possible. Experience from supporting the OELs 3, OELs 4 and OELs 5 studies demonstrated that this is the most effective way of collecting the specific information across all Member States.
Manufacturers/users	Industry	Questionnaires Online interviews Email requests	Based on the experience from OELs 3, OELs 4 and OELs 5, questionnaires for manufacturers/users were mainly distributed via EU associations. The EU associations forwarded the questionnaire directly to companies or forwarded it to national industry associations which then forwarded it to their member companies. This strategy was deemed the most sensible as experience from the previous OELs studies shows that only a few companies answer the questionnaire unless encouraged to do so by either their

Stakeholder type	Interests represented	Main consultation tools	Strategy
			relevant EU association or their national industry associations. To increase the number of responses, questionnaires were refined and kept as short as possible, and focused on providing data on existing RMMs as well as RMMs (and costs) needed to comply with the various reference limits (options) Questionnaire responses were then, where possible/ necessary, followed up by interviews and site visits. Some companies have been also contacted directly (i.e. not via the associations) by phone by national experts who encouraged and assisted the companies in filling out the questionnaire and/or undertook telephone interviews. This additional approach was selected to ensure that answers are provided by companies situated in as many Member States as possible.
National industry associations	Industry	Online interviews Email requests	National industry associations were primarily contacted via the EU associations. Some national associations were contacted directly by phone by national experts and interviewed to collect information supplementary to the information from EU associations, and identify relevant national companies to be approached by the national experts.
Trade Unions	Workers	Online interviews Email requests WPC	Based on previous experience, this study focused on obtaining a few more targeted telephone interviews and email correspondence, as well as collecting information from worker association representatives of the WPC.
Occupational Health & Safety Professionals	Contacted to obtain scientific information	Questionnaire Online interviews	Occupational health and safety professionals were contacted with a questionnaire. This is considered the most efficient way to collect specific information across all Member States.
Working Party on Chemicals (WPC)	Industry Workers Member State Authorities	Participation in workshop	The study team presented draft results to the Working Party on Chemicals in May 2023. Previously, this has proved to be an effective means of receiving feedback from representatives of industry, employers' associations, workers' organisations and Member State authorities.
Laboratories	In communication to obtain information on sampling and analysis	Online interviews Email requests	In the study supporting OELs 3, a large number of laboratories were contacted via email requests. Limited information was obtained, and it was only obtained when the email requests were combined with telephone contact. For previous OELs studies and this study, the approach has been to contact a small number of laboratories

Stakeholder type	Interests represented	Main consultation tools	Strategy
			by phone and email using direct contacts, and to dedicate efforts to following-up on these, to obtain detailed information on methods applied, standards, limits of quantification and prices.

Source: Analysis by RPA Ltd and COWI

Some stakeholders could not be reached. Substance experts wanted to contact specific national institutes, companies and trade unions. Efforts were made to contact these stakeholders but there was no response.

16.1.2 Documentation of formal consultation activity

The questionnaires for PAH relevant to each stakeholder group can be found in:

- PAH Questionnaire: PAH Report Annex 3 ;
- MSA Questionnaire: Annex 2 (Methodological Note);
- OSH Questionnaire: Annex 3 (Methodological Note);
- Trade union questionnaire: Annex 4 (Methodological Note); and
- Welding short interview questionnaire: Annex 5 (Methodological Note).

16.1.3 Methodologies and tools to process data

The online questionnaires for this report were gathered using EU Survey. EU Survey allows for full control over the creation and design of the questionnaire and allows translations to be edited through the website tools. Once completed, the survey data was exported from EU Survey into Excel and cleaned to ensure that only genuine responses were analysed. Any test answers or irrelevant responses were removed. This was then analysed by substance experts, combined with information that had been obtained through internet research, interviews and other means.

A stakeholder log was also created to monitor and record contact with stakeholders. This included contact information, contact method, and survey completion.

All information was analysed by the PAH substance experts and, where considered robust and relevant, used as the basis for the substance-specific analyses in conjunction with information obtained via desk-based research.

16.1.4 Results of consultation activities

The consultation activities being conducted as part of this study are explained in greater detail in the subsections below.

16.1.5 Targeted online survey

The online targeted survey opened on 23 January 2023 and ran until 27 March 2023. The deadline was extended twice to allow for a broader range of stakeholders to respond and address low response rates for certain substances.

Stakeholders were initially contacted via email. The email provided an overview of the study and a link to the RPA webpage explaining the consultation activities, with links to each of the questionnaires, the privacy statement, and an introductory letter from the Commission. A link rather than an attachment was used to decrease the size of the email and reduce the number of emails automatically directed to junk folders. Five separate questionnaires were created for each of the substances for companies, three for the different stakeholder groups and an additional welding questionnaire:

- Companies - cobalt;
- Companies - PAH;
- Companies - isoprene;
- Companies - 1,4 – dioxane;
- Companies - welding fume;
- Member State Authorities;
- Occupational Safety and Health Experts;
- Trade Unions; and
- Welding short interview guide.

The questionnaires for companies were available as a link to EU Survey. The questionnaire for Member State authorities and occupational safety and health experts was available as a Word document which could be downloaded and sent to the study team using the designated OELs 6 email address. Trade Unions were also contacted by national experts and invited to interview for the questionnaire.

The questionnaires aimed to collect information on processes during which worker exposure to the substances in question is likely to occur, risk management measures that are already in place, current exposure concentrations, risk management measures that would need to be implemented should the limit be lowered, and any other impacts that could result from the introduction of EU-level limits. As mentioned above, the questionnaires were targeted, focusing on the evidence needed for the analyses. In that regard, particular focus was placed on risk management measures, as only limited information on these is available in the literature.

Translations of each of the substance questionnaires were available in German, French, Italian, Polish and Spanish and respondents also had the option to ask the study team for the questionnaire in a language of their choice. Translations were initially requested through EU Survey and were then checked and edited by the National Experts.

At the end of each questionnaire, respondents were given the opportunity to add any further comments and were asked if they were willing for a substance expert to ask potential follow-up questions and whether they would be willing to host a site visit. Follow-up interviews were very useful when there were gaps in a stakeholder's response and questions could be asked further to fill in missing information. Other consultation methods were used to probe further into respondents' answers and gain a more in-depth understanding of the topic and potential impacts.

National experts were used to contact MSAs for countries where a response from that country was not received.

The Commission and the WPC were provided the opportunity to comment on the drafts of each questionnaire before they were launched, to ensure that they were relevant and user-friendly.

Some stakeholders however expressed difficulty in responding to the questionnaire due to the complexity of the study. Discussions were held with key industry associations and these stakeholders were provided with the opportunity to respond to the questionnaire via interview, where explanation could be provided for each question. We also received responses from industry organisations.

Around **691** stakeholders were invited to take part in the surveys for all substance reports; many of the stakeholders contacted were relevant for multiple substances. However, the true number of stakeholders that were contacted is likely to be higher as many industry and EU associations were contacted and asked to distribute the survey to their members. Based on experience from previous studies, this has been a useful method to ensure a high response rate from companies. Efforts were also made during calls with industry associations to encourage their members to respond. Stakeholders were selected from the sectors that were identified as being relevant for each of the substances. The tables below provide a summary of the responses according to stakeholder type for all substance questionnaires.

Table 16-2 Summary of numbers of stakeholders directly contacted by questionnaire type

Stakeholder type		Number contacted
Companies	Companies	15.91% (110 out of 691)
	Industry associations	61.07% (422 out of 691)
Member State Authorities		20.69% (143 out of 691)
Occupational Health and Safety Experts		2.32% (16 out of 691)
Trade Unions*		3 contacted
Welding (short interviews)*		20 contacted

Source: Consultation. *These were accompanied by an interview and were undertaken in addition to the main questionnaires and thus are not included in the total number.

Four reminders were sent out to stakeholders to prompt them to respond and update them on the extension to the survey deadline. Stakeholders that had completed the survey or indicated to the study team that the substance was not relevant to them were removed from the mailing list.

Table 16-3 Breakdown of number of stakeholders directly contacted by questionnaire type

Stakeholder type	Number contacted
Company	15.63% (108 out of 691)
Education and Training	0.14% (1 out of 691)
Industry associations	59.62% (412 out of 691)
Laboratories	0.14% (1 out of 691)
Public authority	20.69% (143 out of 691)
NGO	1.45% (10 out of 691)

Stakeholder type	Number contacted
OSH Professional	2.32% (16 out of 691)
Trade Unions	0% (0 out of 691)

Source: Consultation

Table 16-4 below provides the number of responses submitted to questionnaires relevant to PAH. This number includes the number of responses that were able to be analysed after the initial cleaning process. Stakeholders were invited to share the questionnaire with wider relevant stakeholders in their network in an attempt to boost the data obtained. The number of responses in this table includes feedback from additional stakeholders than those initially invited (Table 16-3).

Most responses came from companies as this was the stakeholder group where there was the most engagement and requests for responses. At least one contact was approached for each Member State, however not all Member States provided a response to the targeted questionnaire. The study team used the national experts to conduct interviews with the Member State authorities that have not responded to the questionnaire, these were often accompanied by an interview based on the questions in the survey. National experts were also tasked with contacting and getting responses from trade unions.

Whilst information for the welding questionnaire was primarily intended for use in the welding report, the PAH report considered the inclusion of welding as a route of exposure (welding of railroad tracks was included in the analysis) and subsequently the analysis cross-referenced feedback to the welding questionnaire.

Table 16-4 Responses per questionnaire

Stakeholder type	Number of responses
Companies (PAH questionnaire)	71.91% (64 out of 89)
Member State Authorities	24.72% (22 out of 89)
Occupational Health and Safety Experts	3.37% (3 out of 89)
Trade Unions	2 responses
Welding (short questionnaire)	12 responses
Total	89

Source: Consultation

Table 16-5 splits responses submitted by companies by size. A total of 64 responses were submitted to the PAH questionnaire by companies.

Table 16-5 Number of responses submitted to the PAH questionnaire by companies, by size of company

Company size (employees)	PAH
Micro (<10)	1
Small (10-49)	10

Company size (employees)	PAH
Medium (50-249)	16
Large (250<)	37
Total	64

Source: Consultation

16.1.5.1 Online interviews

Online interviews were conducted with stakeholders whose activities are relevant to the five sub-stances. The aim of these interviews was to build upon the information provided in response to the questionnaires, to fill any information gaps. The study team aimed to obtain detailed information on processes, to pinpoint exactly where exposure is likely to occur, to investigate what types of risk management measures are already in place and how effective they are, as well as what risk management measures would be required if limits were lowered and other potential ramifications for the company, etc.

Interviews were obtained a variety of ways. At the end of the questionnaire, respondents were asked if they would be willing to take part in an interview. However, some online interviews were arranged through making direct contact with key industry associations.

Consultees were given the opportunity to respond in their native language. In cases where this was required, the interview was carried out by the national expert.

Each online interview lasted approximately one hour. At the end of the telephone interview, the study team ensured that the organisations/individuals are satisfied with the minutes of the interview. This either involves sending them the minutes by email and receiving confirmation or, if the interviewee was happy with this, a sign-off process at the end of the interview.

National experts and substance specific experts conducted interviews with relevant stakeholders. Some of the interviews were based on the responses to the questionnaire. The meeting notes were shared with the company after the interview, and that occasion was also used to ensure mutual agreement on the level of confidentiality required.

A summary of the number of interviews carried out is presented in the table below. A total of 26 interviews were carried out for the PAH report.

Table 16-6 Breakdown of interviews per stakeholder type

Stakeholder type	Interviews conducted
Laboratories	0% (0 out of 26)
EU industry association	61.54% (16 out of 26)
Companies	30.77% (8 out of 26)
Member State Authorities	0% (0 out of 26)
Trade Unions	0% (0 out of 26)
Occupational health and safety experts	0% (0 out of 26)

Stakeholder type	Interviews conducted
Other	7.69% (2 out of 26)
Total	26

Source: Consultation

16.1.5.2 Conversations

Email requests have also been used to collect information for the study. The purpose of email requests is similar to the interviews, with stakeholders being asked for further detail on their answers to the questionnaire, as well as making requests for additional information such as industry statistics.

PAH. For PAH, constructive conversations have been carried out via email with the following stakeholders:

- European Institute for Wood Preservation (WEI-IEO);
- Company, Germany;
- The European Steel Association (EUROFER);
- Fuels Europe;
- Community of European Railway and Infrastructure Companies (CER);
- European Salmon Smokers Association (ESSA);
- European Rubber Chemicals Association (ERCA);
- BWL Consulting (EAST) Limited;
- The Finnish Institute of Occupational Health (FIOH);
- European Construction Industry Federation (FIEC);
- Verband Chemiehandel e.V. (VHC);
- European Garage Equipment Association (EGEA);
- European Precious Metals Federation;
- Confederation of European Waste-to-Energy Plants (CEWEP);
- Timber Development UK;
- European Association of Research & Technology (EARTO);
- Wood Protection Association (WPA);
- Airports Council International Europe (ACI EUROPE);
- European Association for Coal and Lignite aisbl (Euracoal);
- The Voice of Europe's Independent Fuel Suppliers (UPEI);
- Airlines 4 Europe (A4E);
- Istituto nazionale Assicurazione Infortuni sul Lavoro (INAIL);
- International Carbon Black Association (ICBA);

- Federation of European Fire Officers association (FEU); and
- European Rail Infrastructure Managers (EIM).

16.1.5.3 Site visits

Companies whose activities are likely to be affected by the potential modifications to the CMRD were also asked whether they would be willing to welcome members of the study team for a site visit. Companies to be visited were identified via the questionnaire or via contact established via industry associations.

The purpose of the site visits was to gain a more operational understanding of the risk management measures currently in place to protect against exposure to the substances concerned, as well as of the risk management measures that would be needed should the CMRD be modified.

Detailed notes from each site visit were drafted and sent back to the company to ensure that the information recorded is accurate. This process enabled the company to add more detail and information to the study, where possible, and to confirm the level of confidentiality accorded to the information.

Site visits were undertaken during Spring and Summer 2023, once significant progress had been made with data collection. This ensured that site visits added more nuance to the data already collected and helped to fill remaining information gaps.

For PAH 3 site visits were carried out.

Table 16-7 Summary of site visits per substance and size of enterprise

Company size (enterprises)	PAH
Micro (< 10)	1
Small (10-49)	0
Medium (50-249)	0
Large (>250)	2
Total	3

Source: Consultation

16.1.5.4 Consultation results by substance

Specific information obtained from the stakeholder consultation on exposure levels, exposed workforce, applied RMMs, costs of compliance with reference OELs, etc. is included in the substance-specific reports.

16.1.5.5 Summary of consultation statistics

The following tables provide breakdowns of the questionnaire responses, interviews and site visits carried out by company size, stakeholder type and substance.

The breakdown of questionnaire responses, interviews and site visits by company size are provided below. They show that the majority of the responses were received from large or medium-sized enterprises, with fewer responses from small and very small enterprises.

Table 16-8 Breakdown of questionnaire responses, interviews and site visits per company size (only for consulted companies and laboratories)

Company size (employees)	Questionnaire responses	Interviews	Site visits
Micro (<10)	1.56% (1 out of 64)	0% (0 out of 8)	33.33% (1 out of 3)
Small (10-49)	15.63% (10 out of 64)	0% (0 out of 8)	0% (0 out of 3)
Medium (50-249)	25% (16 out of 64)	12.5% (1 out of 8)	0% (0 out of 3)
Large (250<)	57.81% (37 out of 64)	87.5% (7 out of 8)	66.66% (2 out of 3)

Source: Consultation

The breakdown of questionnaire responses, interviews and site visits per substance are provided below.

Table 16-9 Breakdown of questionnaire responses, interviews and site visits per substance (all stakeholders; companies, Member State authorities, trade associations, OSH (Occupational Safety and Health) specialists)

Substance	Questionnaire responses ³⁰	Interviews	Site visits
PAH	29.47% (89 out of 302)	44.83% (26 out of 58)	33.33% (3 out of 9)
Trade Unions	2 responses	n/a	n/a
Other	0% (0 out of 302)	3.45% (2 out of 58)	0% (0 out of 9)

Source: Consultation

The breakdown of questionnaire responses, interviews and site visits per Member State (specific to the PAH report) are provided in Table 16-10 below. These results show a high number of questionnaire responses were received from Germany and a high number of interviews were from Belgium. It is not clear why these countries received high responses but the high responses from these countries occurred across all substances.

In the substance reports, the potential impact of the high number of responses from Belgium and Germany is referred to if the study team thinks that the results could be biased by this. Germany in particular has already implemented regulations relating to welding and has relatively low existing OELs for PAH, cobalt and isoprene. Overall, the unbalanced breakdown of responses by Member States is taken into account by the study team, and the information is balanced by data from other stakeholders and sources, to ensure that the conclusions are not believed to be unduly influenced by the responses from Belgium and Germany.

Table 16-10 Breakdown of questionnaire responses, interviews and site visits per Member State (all stakeholders; companies, Member State authorities, trade associations, OSH (Occupational Safety and Health) specialists)

³⁰ The questionnaire responses are higher here as the MSA and OSH questionnaire had substance specific sections. Where these have been completed, they have been added as one response.

Country	Questionnaire responses	Interviews	Site visits
Inside the EU			
Austria	1.12% (1 out of 89)	0% (0 out of 26)	-
Belgium	3.37% (3 out of 89)	42.31% (11 out of 26)	-
Bulgaria	2.25% (2 out of 89)	0% (0 out of 26)	-
Croatia	1.12% (1 out of 89)	0% (0 out of 26)	-
Cyprus	0% (0 out of 89)	0% (0 out of 26)	-
Czechia	4.49% (4 out of 89)	0% (0 out of 26)	-
Denmark	2.25% (2 out of 89)	3.85% (1 out of 26)	-
Estonia	0% (0 out of 89)	0% (0 out of 26)	-
Finland	2.25% (2 out of 89)	3.85% (1 out of 26)	-
France	3.37% (3 out of 89)	0% (0 out of 26)	-
Germany	29.21% (26 out of 89)	19.23% (5 out of 26)	-
Greece	0% (0 out of 89)	0% (0 out of 26)	-
Hungary	1.12% (1 out of 89)	0% (0 out of 26)	-
Ireland	1.12% (1 out of 89)	0% (0 out of 26)	-
Italy	7.87% (7 out of 89)	3.85% (1 out of 26)	-
Latvia	1.12% (1 out of 89)	0% (0 out of 26)	-
Lithuania	0% (0 out of 89)	0% (0 out of 26)	-
Luxembourg	0% (0 out of 89)	0% (0 out of 26)	-
Malta	0% (0 out of 89)	0% (0 out of 26)	-
Netherlands	5.62% (5 out of 89)	3.85% (1 out of 26)	-
Poland	7.87% (7 out of 89)	0% (0 out of 26)	-
Portugal	0% (0 out of 89)	0% (0 out of 26)	-
Romania	1.12% (1 out of 89)	0% (0 out of 26)	-
Slovakia	1.12% (1 out of 89)	0% (0 out of 26)	-
Slovenia	1.12% (1 out of 89)	0% (0 out of 26)	-
Spain	7.87% (7 out of 89)	7.69% (2 out of 26)	-
Sweden	7.87% (7 out of 89)	3.85% (1 out of 26)	-
Multiple Member States	1.12% (1 out of 89)	0% (0 out of 26)	-
Other	1.12% (1 out of 89)	0% (0 out of 26)	-
Outside the EU			
Iceland	1.12% (1 out of 89)	0% (0 out of 26)	-
Norway	3.37% (3 out of 89)	0% (0 out of 26)	-
South Korea	0% (0 out of 89)	0% (0 out of 26)	-

Country	Questionnaire responses	Interviews	Site visits
Switzerland	0% (0 out of 89)	0% (0 out of 26)	-
UK	0% (0 out of 89)	11.54% (3 out of 26)	-
US	0% (0 out of 89)	0% (0 out of 26)	-
Total	89	26	3

Source: Consultation

Notes: In some cases, the input for location was given as several Member States or a list of companies for the same response. In order to not inflate the numbers presented, if this was given as an answer, it is recorded this under 'multiple Member States'.

Site visits have been carried out, but the location cannot be disclosed due to confidentiality and the small sample size.

16.1.6 How the information gathered has been taken into account

A large amount of information has been collected via consultation, particularly through means of the targeted online questionnaires, telephone interviews and email correspondence. Efforts have been made to contact a variety of relevant stakeholders in all of the Member States, for each of the relevant substances, from companies of varying sizes.

The information collected via consultation has enabled the study team to gain a more nuanced understanding of the likely impacts of modifying or introducing OELs, which could not have been obtained otherwise via desk-based research/literature reviews. Through the combination of desk-based research, questionnaire responses, interviews, and site visits, it has been possible to compile a significant amount of detailed information in relation to the potential impacts of introducing the proposed measures.

The table below summarises how the responses in each questionnaire section are used in each report. The majority of the analysis is undertaken and discussed in each of the substance specific reports.

Table 16-11 Questionnaire sections mapped to relevant section in each substance report

Questionnaires and sections	Report section
Companies	
B	Exposure concentrations Exposed workforce Current risk management measures (RMMs)
C	Lowest technically possible and economically feasible option
D	RMMs needed to achieve compliance
E	Voluntary industry initiatives
F	Other benefits
G	Impact of the implementation of other OELs
H	Other comments

Questionnaires and sections	Report section
Member State Authority	Existing national limits Costs for public administrations Costs Market effects Environmental impacts Indirect benefits Employment
Occupational Health & Safety Experts	Current risk management measures (RMMs) Existing national limits RMMs needed to achieve compliance
Trade Unions	Voluntary industry initiatives Exposed workforce Benefits
Welding	(Welding only- short interviews) Definition of the problem Benefits

Source: Study team

16.1.6.1 Information and issues raised by stakeholders

During the stakeholder consultation, the Cobalt Institute submitted three reports prepared specifically for the purpose of providing information for this study.

No similar reports specifically for this study were submitted for the other four substances.

16.2 Annex 2 - Who is affected and how?

The table below illustrates the calculated benefits for each stakeholder type. As shown, the majority of prevented cases refer to male infertility (a result of male dominated sectors) with most benefits related to the avoided ill health cost for workers & families.

Table 16-12 Overview of benefits (total for all provisions) – preferred option 70 ng/m³ € millions

Description	Amount €millions
Direct benefits	
Workers & families - Reduced cases of ill health (Lung cancer)	35
Workers & families - Reduced cases of ill health (Developmental toxicity)	38
Workers & families - Reduced cases of ill health (Male infertility)	3,230
Workers & families - Ill health avoided, incl. intangible costs (M1 to M2)	97.23 - 16.22
Companies - Avoided costs	0.13
Public sector - Avoided costs	3.87
Indirect benefits	
Public sector - Avoided cost of setting an OEL	1.75

Source: Study team

Notes: Benefits are PV discounted over 40 years

Table 16-13 and Table 16-14 give an overview of costs and apply the “one in, one out” approach for the preferred option. The costs are presented as present value costs discounted over 40 years and are not split between first year and recurrent costs. In the study, adjustment costs are presented as first year and recurrent costs. First year costs include recurrent costs incurred in the first year: this also applies to first year compliance (adjustment plus monitoring and administrative burden) costs.

Table 16-13 Overview of costs – Preferred option 70 ng/m³ € millions

	Businesses	Administration
Direct adjustment costs	€ 4,934.68	1.24
Direct administrative costs	€65.63	NA
Direct regulatory fees and charges	NA	NA
Direct enforcement costs		Not estimated
Indirect costs	NA	€225.67

Source: Study team

Notes: Costs are PV discounted over 40 years

Enforcement costs are not estimated as they are specific to Member States individual inspection regime.

Table 16-14 Application of the ‘one in, one out’ approach – Preferred option 70 ng/m³ € millions

	Total
Businesses	
New administrative burdens (INs)	€65.63
Removed administrative burdens (OUTs)	€0
Net administrative burdens	€65.63
Adjustment costs	€ 4,934.69
Total administrative burdens	€ 5,000.32

Source: Study team

Notes: recurrent costs are PV discounted over 40 years

Table 16-15 Overview of relevant Sustainable Development Goals – Preferred Option 70 ng/m³

Relevant SDG	Expected progress towards the Goal
SDG 8 Decent work & economic growth	The preferred policy option achieves improved worker and family health outcomes.
SDG 3 Good health and wellbeing	The preferred policy option achieves improved worker and family health outcomes. The more stringent the OEL, the higher the level of good health and wellbeing is achieved.

Relevant SDG	Expected progress towards the Goal
SDG 7 Affordable and clean energy	Coal fired power plants will experience additional drive to either convert to biomass where possible or may be forced to close at the preferred policy, forcing a move to alternative energy sources.
SDG 14 and 15 Life below water and Life on land	Several PAH are PBT or POP (see section 9.2.1). At the preferred policy option, the amount of PAH released, so will the burden of environmentally damaging chemicals.

Source: Study team

16.3 Annex 3 - Questionnaire

Questionnaire for companies: Polycyclic Aromatic Hydrocarbons

Fields marked with * are mandatory.

Questionnaire for companies: Polycyclic Aromatic Hydrocarbons (PAH)

This survey is part of a study to support a possible amendment of Directive 2004/37/EC on the protection of workers from exposure to carcinogens, mutagens or reprotoxic substances at work (the Carcinogens, Mutagens or Reprotoxic substances Directive, **CMRD**). Specifically, the study assesses the impacts of establishing new limit values for some substances or introducing a substance into Annex I.

The substances being considered are:

- **Polycyclic aromatic hydrocarbons (PAH)**
- **Cobalt and inorganic cobalt compounds**
- **Isoprene**
- **1,4-dioxane**
- **Welding fume**

New OELs are proposed for the first four substances above under the CMRD. In addition, biological limit values (BLV) are proposed for PAH and 1,4-dioxane, and a 15-minute short-term exposure limit value (STEL) is proposed for 1,4-dioxane. 'Skin sensitisation' and 'respiratory sensitisation' notations are also proposed for cobalt and inorganic cobalt compounds, and 'skin' notations are proposed for isoprene, PAHs and 1,4-dioxane.

An amendment to include welding fume in Annex I of the CMRD is also being considered.

This questionnaire is intended for all companies where exposure to **polycyclic aromatic hydrocarbons (PAH)** takes place.

The study is being undertaken by a consortium comprising RPA Risk & Policy Analysts (United Kingdom), RPA Europe (Italy), RPA Europe Prague (Czech Republic) COWI (Denmark), FoBiG Forschungs- und Beratungsinstitut Gefahrstoffe (Germany), EPRD (Poland) and Force Technology (Denmark) under a contract for the European Commission's Directorate-General for Employment, Social Affairs and Inclusion.

All responses to this questionnaire will be treated in the **strictest confidence** and will only be used for the purposes of this study. In preparing our report for the Commission (which, subsequently, may be published), care will be taken to ensure that specific responses cannot be linked to individual companies.

This questionnaire is intended for a **single facility**. If workers are exposed at multiple facilities, please complete the questionnaire several times or contact the study team.

It will take approximately 15–45 minutes to answer the questionnaire depending on data availability and detail.

The deadline for completion of the questionnaire is the 3 March 2023.

This questionnaire is available in English, French, German, Italian, Polish and Spanish. However, you are welcome to answer the questions in an official language of the European Union of your choice. If you prefer to be interviewed in your language or if you have questions about the survey, please contact: OELs6@rpaltd.co.uk

Abbreviations used in the questionnaire:

1-OHP - 1-hydroxypyrene

3-OHBaP - 3-hydroxybenzoapyrene

8 hour TWA - 8 hour Time-Weighted Average, measured in parts per million (ppm) or milligrams per cubic metre (mg/m³). The 8 hour TWA is an expression for the average exposure for a typical working day. It is calculated by summing up the concentrations (in ppm or mg/m³) during different periods of a day (usually 8 hours). Each concentration is multiplied by its relevant duration and the total is divided by the entire length of the working day (usually 8 hours) such as in this example:

$$8h\text{-TWA} = (2 \text{ hours} * 500 \text{ ppm} + 5 \text{ hours} * 100 \text{ ppm} + 1 \text{ hours} * 700 \text{ ppm}) / (2 + 5 + 1 \text{ hours}).$$

BaP - Benzo[a]pyrene

BLV - Biological Limit Value

CMRD - Carcinogens, Mutagens or Reprotoxic substances Directive

NACE - NACE Revision 2, statistical classification of economic activities in the European Community. See <https://ec.europa.eu/eurostat/documents/3859598/5902521/KS-RA-07-015-EN.PDF>, page 61 ff.

OEL - The term Occupational Exposure Limit value (OEL) refers to the limit of the time-weighted average (TWA) of the concentration in the air within the breathing zone of a worker, measured or calculated in relation to a reference period of eight hours.

PAH - Polycyclic Aromatic Hydrocarbons

ppb - Parts per billion

PPE - Personal Protective Equipment

ppm - Parts per million

RAC - The Committee for Risk Assessment (RAC) is a scientific committee of ECHA that prepares the opinions related to the risks of substances to human health and the environment.

RMM - Risk Management Measure

RPE - Respiratory protective equipment

Publication privacy settings

☐ By checking this box, I confirm that I have read the [Privacy Statement](#) and agree with the processing of my personal data for the purposes stated therein. I acknowledge that my views could be shared with the European Commission and published with information concerning the type of the organisation for which I submit information, to which I hereby give my consent.

A) About your company

A1) Please provide the following details about your company

*** Name of contact person**

*** Company**

*** Email address of contact person**

Telephone number of contact person

*** Country of facility**

- ☐ Austria
- ☐ Belgium
- ☐ Bulgaria
- ☐ Croatia
- ☐ Cyprus

- ☐ Czechia
- ☐ Denmark
- ☐ Estonia
- ☐ Finland
- ☐ France
- ☐ Germany
- ☐ Greece
- ☐ Hungary
- ☐ Ireland
- ☐ Italy
- ☐ Latvia
- ☐ Lithuania
- ☐ Luxembourg
- ☐ Malta
- ☐ Netherlands
- ☐ Poland
- ☐ Portugal
- ☐ Romania
- ☐ Slovak Republic
- ☐ Slovenia
- ☐ Spain
- ☐ Sweden
- ☐ Other

If other, please specify

A2) Please define the sector in which your company is active (if possible using a NACE code)

- ☐ A02.40 Support services to forestry (incl. forest fire fighting and protection)
- ☐ B05.10 Mining of hard coal
- ☐ B05.20 Mining of lignite
- ☐ B06.10 Extraction of crude petroleum
- ☐ B09.10 Support activities for petroleum and natural gas extraction (incl. exploration services, test drilling, oil and gas fire fighting services)
- ☐ C10.13 Production of meat and poultry meat products
- ☐ C10.20 Processing and preserving of fish, crustaceans and molluscs
- ☐ C16.10 Sawmilling and planing of wood
- ☐ C19.10 Manufacture of coke oven products
- ☐ C19.20 Manufacture of refined petroleum products
- ☐ C20.12 Manufacture of dyes and pigments
- ☐ C20.14 Manufacture of other organic basic chemicals
- ☐ C20.16 Manufacture of plastics in primary forms
- ☐ C20.17 Manufacture of synthetic rubber in primary forms
- ☐ C22.11 Manufacture of rubber tyres and tubes; retreading and rebuilding of rubber tyres
- ☐

- ☐ C22.19 Manufacture of other rubber products
- ☐ C22.2 Manufacture of plastic products
- ☐ C23.20 Manufacture of refractory products
- ☐ C23.99 Manufacture of other non-metallic mineral products n.e.c. (incl. manufacture of articles of asphalt or similar products, manufacture of carbon and graphite fibres and products (except electrodes and electrical applications))
- ☐ C24.10 Manufacture of basic iron and steel and of ferro-alloys
- ☐ C24.20 Manufacture of tubes, pipes, hollow profiles and related fittings, of steel
- ☐ C24.4 Manufacture of basic precious and other non-ferrous metals
- ☐ C24.42 Aluminium production
- ☐ C24.5 Casting of metals
- ☐ C25.62 Machining
- ☐ C27.9 Manufacture of other electrical equipment
- ☐ D32.30 Manufacture of sports goods
- ☐ D35.11 Production of electricity (incl. diesel)
- ☐ D35.21 Manufacture of gas (includes by carbonation of coal)
- ☐ E38.2 Waste treatment and disposal
- ☐ F41 Construction of buildings
- ☐ F42.11 Construction of roads and motorways
- ☐ F43.1 Demolition and site preparation
- ☐ F43.91 Roofing activities
- ☐ G45.20 Maintenance and repair of motor vehicles
- ☐ G45.40 Sale, maintenance and repair of motorcycles and related parts and accessories
- ☐ G47.30 Retail sale of automotive fuel in specialised stores
- ☐ H52.21 Service activities incidental to land transportation (incl. firefighters at airports)
- ☐ H52.22 Service activities incidental to water transportation (incl. operation of terminal facilities such as harbours and piers)
- ☐ H52.23 Service activities incidental to air transportation (incl. operation of terminal facilities, airport and air traffic control, ground service activities on air fields firefighters at airports)
- ☐ I56.10 Restaurants and mobile food service activities
- ☐ I56.21 Event catering activities
- ☐ I56.29 Other food service activities
- ☐ M72.1 Research and experimental development on natural sciences and engineering
- ☐ N81.22 Other building and industrial cleaning activities
- ☐ O84.25 Fire service activities
- ☐ S96.03 Funeral and related activities
- ☐ Other

If other, please specify

A3) Please describe your company's activities that involve PAHs within the scope of the study

A4) How many workers are employed in your company at this facility?

A5) How many of the workers employed in your company at this facility are exposed to PAH?

A6) Have you any experience of workers having health issues resulting from occupational exposure to PAH at the workplace?

A7) Have any workers left the company due to health issues associated with exposure to PAHs?

A8) What is the annual turnover in EUR at the facility for which you are filling out this questionnaire?

- ☐ < €2 million
- ☐ €2 – 10 million
- ☐ €10 – 50 million
- ☐ €50 – 100 million
- ☐ > €100 million

Please complete a separate questionnaire for each facility.

A9) Please give the name and address (incl. country) of the facility for which you are completing this questionnaire

B) Information about airborne and biological concentrations at your facility

Airborne concentrations

B1) Please specify the most important processes* during which exposure to the relevant substance can occur. You can specify a maximum of four processes.

*The most important processes in this context are those for which exposure to PAH gives you the most concern. This could be because the process has low levels of exposure but affects many people. Or because the process has high levels of exposure but for short periods. Or alternatively, a process where it is very difficult or expensive to reduce exposure at all.

Process 1

- ☐ PROC 1 Chemical production or refinery in closed process without likelihood of exposure or processes with equivalent containment conditions
- ☐ PROC 2 Chemical production or refinery in closed continuous process with occasional controlled exposure or processes with equivalent containment conditions
- ☐ PROC 3 Manufacture or formulation in the chemical industry in closed batch processes with occasional controlled exposure or processes with equivalent containment condition
- ☐ PROC 4 Chemical production where opportunity for exposure arises
- ☐ PROC 5 Mixing or blending in batch processes
- ☐ PROC 6 Calendering operations
- ☐ PROC 7 Industrial spraying
- ☐ PROC 8a Transfer of substance or mixture (charging and discharging) at non-dedicated facilities
- ☐ PROC 8b Transfer of substance or mixture (charging and discharging) at dedicated facilities
- ☐ PROC 9 Transfer of substance or mixture into small containers (dedicated filling line, including weighing)
- ☐ PROC 10 Roller application or brushing
- ☐ PROC 11 Non-industrial spraying
- ☐ PROC 12 Use of blowing agents in manufacture of foam
- ☐ PROC 13 Treatment of articles by dipping and pouring
- ☐ PROC 14 Tableting, compression, extrusion, pelletisation, granulation
- ☐ PROC 15 Use as laboratory reagent
- ☐ PROC 16 Use of fuels
- ☐ PROC 17 Lubrication at high energy conditions in metal working operations
- ☐ PROC 18 General greasing/lubrication at high kinetic energy conditions
- ☐ PROC 19 Manual activities involving hand contact
- ☐ PROC 20 Use of functional fluids in small devices
- ☐ PROC 21 Low energy manipulation of substances bound in materials and/or articles
- ☐ PROC 22 Manufacturing and processing of minerals and/or metals at substantially elevated temperature
- ☐ PROC 23 Open processing and transfer operations with minerals/metals at elevated temperature
- ☐ PROC 24 High (mechanical) energy work-up of substances bound in materials and/or articles
- ☐ PROC 25 Other hot work operations with metals
- ☐ PROC 26 Handling of solid inorganic substances at ambient temperature
- ☐ PROC 27a Production of metal powders (hot processes)
- ☐ PROC 27b Production of metal powders (wet processes)
- ☐ PROC 28 Manual maintenance (cleaning and repair) of machinery
- ☐ Other

Process 1: Please provide details about the activities within this PROC that lead to exposure to PAHs.

Process 2



PROC 1 Chemical production or refinery in closed process without likelihood of exposure or processes with equivalent containment conditions

- ☐ PROC 2 Chemical production or refinery in closed continuous process with occasional controlled exposure or processes with equivalent containment conditions
- ☐ PROC 3 Manufacture or formulation in the chemical industry in closed batch processes with occasional controlled exposure or processes with equivalent containment condition
- ☐ PROC 4 Chemical production where opportunity for exposure arises
- ☐ PROC 5 Mixing or blending in batch processes
- ☐ PROC 6 Calendering operations
- ☐ PROC 7 Industrial spraying
- ☐ PROC 8a Transfer of substance or mixture (charging and discharging) at non-dedicated facilities
- ☐ PROC 8b Transfer of substance or mixture (charging and discharging) at dedicated facilities
- ☐ PROC 9 Transfer of substance or mixture into small containers (dedicated filling line, including weighing)
- ☐ PROC 10 Roller application or brushing
- ☐ PROC 11 Non-industrial spraying
- ☐ PROC 12 Use of blowing agents in manufacture of foam
- ☐ PROC 13 Treatment of articles by dipping and pouring
- ☐ PROC 14 Tableting, compression, extrusion, pelletisation, granulation
- ☐ PROC 15 Use as laboratory reagent
- ☐ PROC 16 Use of fuels
- ☐ PROC 17 Lubrication at high energy conditions in metal working operations
- ☐ PROC 18 General greasing/lubrication at high kinetic energy conditions
- ☐ PROC 19 Manual activities involving hand contact
- ☐ PROC 20 Use of functional fluids in small devices
- ☐ PROC 21 Low energy manipulation of substances bound in materials and/or articles
- ☐ PROC 22 Manufacturing and processing of minerals and/or metals at substantially elevated temperature
- ☐ PROC 23 Open processing and transfer operations with minerals/metals at elevated temperature
- ☐ PROC 24 High (mechanical) energy work-up of substances bound in materials and/or articles
- ☐ PROC 25 Other hot work operations with metals
- ☐ PROC 26 Handling of solid inorganic substances at ambient temperature
- ☐ PROC 27a Production of metal powders (hot processes)
- ☐ PROC 27b Production of metal powders (wet processes)
- ☐ PROC 28 Manual maintenance (cleaning and repair) of machinery
- ☐ Other

Process 2: Please provide details about the activities within this PROC that lead to exposure to PAHs.

Process 3

- ☐ PROC 1 Chemical production or refinery in closed process without likelihood of exposure or processes with equivalent containment conditions
- ☐ PROC 2 Chemical production or refinery in closed continuous process with occasional controlled exposure or processes with equivalent containment conditions
- ☐ PROC 3 Manufacture or formulation in the chemical industry in closed batch processes with occasional controlled exposure or processes with equivalent containment condition
- ☐ PROC 4 Chemical production where opportunity for exposure arises

- ☐ PROC 5 Mixing or blending in batch processes
- ☐ PROC 6 Calendering operations
- ☐ PROC 7 Industrial spraying
- ☐ PROC 8a Transfer of substance or mixture (charging and discharging) at non-dedicated facilities
- ☐ PROC 8b Transfer of substance or mixture (charging and discharging) at dedicated facilities
- ☐ PROC 9 Transfer of substance or mixture into small containers (dedicated filling line, including weighing)
- ☐ PROC 10 Roller application or brushing
- ☐ PROC 11 Non-industrial spraying
- ☐ PROC 12 Use of blowing agents in manufacture of foam
- ☐ PROC 13 Treatment of articles by dipping and pouring
- ☐ PROC 14 Tableting, compression, extrusion, pelletisation, granulation
- ☐ PROC 15 Use as laboratory reagent
- ☐ PROC 16 Use of fuels
- ☐ PROC 17 Lubrication at high energy conditions in metal working operations
- ☐ PROC 18 General greasing/lubrication at high kinetic energy conditions
- ☐ PROC 19 Manual activities involving hand contact
- ☐ PROC 20 Use of functional fluids in small devices
- ☐ PROC 21 Low energy manipulation of substances bound in materials and/or articles
- ☐ PROC 22 Manufacturing and processing of minerals and/or metals at substantially elevated temperature
- ☐ PROC 23 Open processing and transfer operations with minerals/metals at elevated temperature
- ☐ PROC 24 High (mechanical) energy work-up of substances bound in materials and/or articles
- ☐ PROC 25 Other hot work operations with metals
- ☐ PROC 26 Handling of solid inorganic substances at ambient temperature
- ☐ PROC 27a Production of metal powders (hot processes)
- ☐ PROC 27b Production of metal powders (wet processes)
- ☐ PROC 28 Manual maintenance (cleaning and repair) of machinery
- ☐ Other

Process 3: Please provide details about the activities within this PROC that lead to exposure to PAHs.

Process 4

- ☐ PROC 1 Chemical production or refinery in closed process without likelihood of exposure or processes with equivalent containment conditions
- ☐ PROC 2 Chemical production or refinery in closed continuous process with occasional controlled exposure or processes with equivalent containment conditions
- ☐ PROC 3 Manufacture or formulation in the chemical industry in closed batch processes with occasional controlled exposure or processes with equivalent containment condition
- ☐ PROC 4 Chemical production where opportunity for exposure arises
- ☐ PROC 5 Mixing or blending in batch processes
- ☐ PROC 6 Calendering operations
- ☐ PROC 7 Industrial spraying
- ☐ PROC 8a Transfer of substance or mixture (charging and discharging) at non-dedicated facilities
- ☐ PROC 8b Transfer of substance or mixture (charging and discharging) at dedicated facilities
- ☐ PROC 9 Transfer of substance or mixture into small containers (dedicated filling line, including weighing)
- ☐ PROC 10 Roller application or brushing

- ☐ PROC 11 Non-industrial spraying
- ☐ PROC 12 Use of blowing agents in manufacture of foam
- ☐ PROC 13 Treatment of articles by dipping and pouring
- ☐ PROC 14 Tableting, compression, extrusion, pelletisation, granulation
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- ☐ PROC 18 General greasing/lubrication at high kinetic energy conditions
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- ☐ PROC 20 Use of functional fluids in small devices
- ☐ PROC 21 Low energy manipulation of substances bound in materials and/or articles
- ☐ PROC 22 Manufacturing and processing of minerals and/or metals at substantially elevated temperature
- ☐ PROC 23 Open processing and transfer operations with minerals/metals at elevated temperature
- ☐ PROC 24 High (mechanical) energy work-up of substances bound in materials and/or articles
- ☐ PROC 25 Other hot work operations with metals
- ☐ PROC 26 Handling of solid inorganic substances at ambient temperature
- ☐ PROC 27a Production of metal powders (hot processes)
- ☐ PROC 27b Production of metal powders (wet processes)
- ☐ PROC 28 Manual maintenance (cleaning and repair) of machinery
- ☐ Other

Process 4: Please provide details about the activities within this PROC that lead to exposure to PAHs.

B2) Please provide the number of workers exposed at all exposure levels during a typical working day

	Number of workers exposed
Process 1	
Process 2	
Process 3	
Process 4	

B3) Please provide your most recent airborne concentration data taken in accordance with an OEL (8-hour Time Weighted Averages).

Please confirm the relevant PAH airborne measurement that you are entering the data for.

Note that data on benzo(a)pyrene is the preferred data.

- ☐ Benzo[a]pyrene
- ☐ Total 16 PAH*
- ☐ Total 17 PAH**
- ☐ Total PAH other

* Total 16 PAH = US EPA 16 PAH: Naphthalene (CAS No. 91-20-3); Acenaphthene (CAS No.83-32-9); Acenaphthylene (CAS No. 208-96-8); Fluorene (CAS No. 86-73-7); Anthracene (CAS No. 120-12-7); Phenanthrene (CAS No. 85-01-8); Fluoranthene (CAS No. 206-44-0); Pyrene (CAS No. 129-00-0); Benzo

(a)anthracene (CAS No. 56-55-3); Chrysene (CAS No. 218-01-9); Benzo(b)fluoranthene (CAS No. 205-99-2); Benzo(k)fluoranthene (CAS No. 207-08-9); Benzo(a)pyrene (CAS No. 50-32-8); Indeno(1,2,3-cd)pyrene (CAS No. 193-39-5); Dibenzo(ah)anthracene (CAS No. 53-70-3); Benzo(ghi)perylene (CAS No. 191-24-2)

***Total 17 PAH = Naphthalene (CAS No. 91-20-3); Acenaphthene (CAS No.83-32-9); Acenaphthylene (CAS No. 208-96-8); Fluorene (CAS No. 86-73-7); Anthracene (CAS No. 120-12-7); Phenanthrene (CAS No. 85-01-8); Fluoranthene (CAS No. 206-44-0); Pyrene (CAS No. 129-00-0); Benz(a)anthracene (CAS No. 56-55-3); Chrysene (CAS No. 218-01-9); Benzo(b)fluoranthene (CAS No. 205-99-2); Benzo(k)fluoranthene (CAS No. 207-08-9); Benzo(a)pyrene (CAS No. 50-32-8); Indeno(1,2,3-cd)pyrene (CAS No. 193-39-5); Dibenzo(ah)anthracene (CAS No. 53-70-3); Benzo(ghi)perylene (CAS No. 191-24-2);perylene, (CAS No. 198-55-0)*

If you responded 'total PAH other' to the previous question, please specify the PAH(s) measured

Please confirm the unit for the data you are entering

- ☐ $\mu\text{g}/\text{m}^3$
- ☐ ng/m^3
- ☐ ppm
- ☐ ppb

Airborne concentration data

	Process 1	Process 2	Process 3	Process 4
Please select the sampling method followed	☐ Stationary sampling ☐ Personal sampling ☐ Personal sampling of inhalation air inside the RPE	☐ Stationary sampling ☐ Personal sampling ☐ Personal sampling of inhalation air inside the RPE	☐ Stationary sampling ☐ Personal sampling ☐ Personal sampling of inhalation air inside the RPE	☐ Stationary sampling ☐ Personal sampling ☐ Personal sampling of inhalation air inside the RPE
Lowest concentration (value)				
Highest concentration (value)				
Mean concentration (arithmetic mean; value)				
Median concentration (value)				
95th percentile concentration (value)				
Number of samples (n)				
Year of monitoring				
Are the workers wearing respiratory protective equipment (RPE) during the process?	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No
	☐	☐	☐	☐

Please confirm the analytical method followed	MétroPol Fiche 322 Hydrocarbures aromatiques polycycliques (HAP), 2018 ☐ IFA - Arbeitsmappe, Kennzahl 8408, 2018 ☐ DFG Method Nr 1, 2017 ☐ DFG Method Nr 2, 2002 ☐ DFG Method Nr 3, 2002 ☐ MTA/MA 039, 2000 ☐ NIOSH 5506, 1998 ☐ NIOSH 5515, 1994 ☐ Other	MétroPol Fiche 322 Hydrocarbures aromatiques polycycliques (HAP), 2018 ☐ IFA - Arbeitsmappe, Kennzahl 8408, 2018 ☐ DFG Method Nr 1, 2017 ☐ DFG Method Nr 2, 2002 ☐ DFG Method Nr 3, 2002 ☐ MTA/MA 039, 2000 ☐ NIOSH 5506, 1998 ☐ NIOSH 5515, 1994 ☐ Other	MétroPol Fiche 322 Hydrocarbures aromatiques polycycliques (HAP), 2018 ☐ IFA - Arbeitsmappe, Kennzahl 8408, 2018 ☐ DFG Method Nr 1, 2017 ☐ DFG Method Nr 2, 2002 ☐ DFG Method Nr 3, 2002 ☐ MTA/MA 039, 2000 ☐ NIOSH 5506, 1998 ☐ NIOSH 5515, 1994 ☐ Other	MétroPol Fiche 322 Hydrocarbures aromatiques polycycliques (HAP), 2018 ☐ IFA - Arbeitsmappe, Kennzahl 8408, 2018 ☐ DFG Method Nr 1, 2017 ☐ DFG Method Nr 2, 2002 ☐ DFG Method Nr 3, 2002 ☐ MTA/MA 039, 2000 ☐ NIOSH 5506, 1998 ☐ NIOSH 5515, 1994 ☐ Other
If you selected 'other' in answer to the above question, please specify the analytical method followed.				

B4) If you have indicated below limit of quantification (LoQ) and/or limit of detection (LoD) in the responses above, what was the LoQ or LoD?

	Value	Unit
Limit of quantification		
Limit of detection		

B5) Could actions related to covid-19 have artificially altered exposure levels? For example, greater use of PPE.

at most 1 choice(s)

- ☐ Yes, reduced exposure
- ☐ Yes, increased exposure
- ☐ No change
- ☐ Don't know

B6) Please provide a short explanation for your answer to B5

Biomonitoring

B7) Please specify the most important processes* during which exposure to the relevant substance can occur. You can specify a maximum of four processes.

This question is repeated for biomonitoring because biomonitoring may reflect additional dermal exposure in comparison to airborne exposure.

*The most important processes in this context are those for which exposure to PAH gives you the most concern. This could be because the process has low levels of exposure but affects many people. Or because the process has high levels of exposure but for short periods. Or alternatively, a process where it is very difficult or expensive to reduce exposure at all.

Process 1

- ☐ PROC 1 Chemical production or refinery in closed process without likelihood of exposure or processes with equivalent containment conditions
- ☐ PROC 2 Chemical production or refinery in closed continuous process with occasional controlled exposure or processes with equivalent containment conditions
- ☐ PROC 3 Manufacture or formulation in the chemical industry in closed batch processes with occasional controlled exposure or processes with equivalent containment condition

- ☐ PROC 4 Chemical production where opportunity for exposure arises
- ☐ PROC 5 Mixing or blending in batch processes
- ☐ PROC 6 Calendering operations
- ☐ PROC 7 Industrial spraying
- ☐ PROC 8a Transfer of substance or mixture (charging and discharging) at non-dedicated facilities
- ☐ PROC 8b Transfer of substance or mixture (charging and discharging) at dedicated facilities
- ☐ PROC 9 Transfer of substance or mixture into small containers (dedicated filling line, including weighing)
- ☐ PROC 10 Roller application or brushing
- ☐ PROC 11 Non-industrial spraying
- ☐ PROC 12 Use of blowing agents in manufacture of foam
- ☐ PROC 13 Treatment of articles by dipping and pouring
- ☐ PROC 14 Tableting, compression, extrusion, pelletisation, granulation
- ☐ PROC 15 Use as laboratory reagent
- ☐ PROC 16 Use of fuels
- ☐ PROC 17 Lubrication at high energy conditions in metal working operations
- ☐ PROC 18 General greasing/lubrication at high kinetic energy conditions
- ☐ PROC 19 Manual activities involving hand contact
- ☐ PROC 20 Use of functional fluids in small devices
- ☐ PROC 21 Low energy manipulation of substances bound in materials and/or articles
- ☐ PROC 22 Manufacturing and processing of minerals and/or metals at substantially elevated temperature
- ☐ PROC 23 Open processing and transfer operations with minerals/metals at elevated temperature
- ☐ PROC 24 High (mechanical) energy work-up of substances bound in materials and/or articles
- ☐ PROC 25 Other hot work operations with metals
- ☐ PROC 26 Handling of solid inorganic substances at ambient temperature
- ☐ PROC 27a Production of metal powders (hot processes)
- ☐ PROC 27b Production of metal powders (wet processes)
- ☐ PROC 28 Manual maintenance (cleaning and repair) of machinery
- ☐ Other

Process 1: Please provide details about the activities within this PROC that lead to exposure to PAHs.

Process 2

- ☐ PROC 1 Chemical production or refinery in closed process without likelihood of exposure or processes with equivalent containment conditions
- ☐ PROC 2 Chemical production or refinery in closed continuous process with occasional controlled exposure or processes with equivalent containment conditions
- ☐ PROC 3 Manufacture or formulation in the chemical industry in closed batch processes with occasional controlled exposure or processes with equivalent containment condition
- ☐ PROC 4 Chemical production where opportunity for exposure arises
- ☐ PROC 5 Mixing or blending in batch processes
- ☐ PROC 6 Calendering operations
- ☐ PROC 7 Industrial spraying
- ☐ PROC 8a Transfer of substance or mixture (charging and discharging) at non-dedicated facilities
- ☐ PROC 8b Transfer of substance or mixture (charging and discharging) at dedicated facilities
- ☐ PROC 9 Transfer of substance or mixture into small containers (dedicated filling line, including weighing)

- ☐ PROC 10 Roller application or brushing
- ☐ PROC 11 Non-industrial spraying
- ☐ PROC 12 Use of blowing agents in manufacture of foam
- ☐ PROC 13 Treatment of articles by dipping and pouring
- ☐ PROC 14 Tableting, compression, extrusion, pelletisation, granulation
- ☐ PROC 15 Use as laboratory reagent
- ☐ PROC 16 Use of fuels
- ☐ PROC 17 Lubrication at high energy conditions in metal working operations
- ☐ PROC 18 General greasing/lubrication at high kinetic energy conditions
- ☐ PROC 19 Manual activities involving hand contact
- ☐ PROC 20 Use of functional fluids in small devices
- ☐ PROC 21 Low energy manipulation of substances bound in materials and/or articles
- ☐ PROC 22 Manufacturing and processing of minerals and/or metals at substantially elevated temperature
- ☐ PROC 23 Open processing and transfer operations with minerals/metals at elevated temperature
- ☐ PROC 24 High (mechanical) energy work-up of substances bound in materials and/or articles
- ☐ PROC 25 Other hot work operations with metals
- ☐ PROC 26 Handling of solid inorganic substances at ambient temperature
- ☐ PROC 27a Production of metal powders (hot processes)
- ☐ PROC 27b Production of metal powders (wet processes)
- ☐ PROC 28 Manual maintenance (cleaning and repair) of machinery
- ☐ Other

Process 2: Please provide details about the activities within this PROC that lead to exposure to PAHs.

Process 3

- ☐ PROC 1 Chemical production or refinery in closed process without likelihood of exposure or processes with equivalent containment conditions
- ☐ PROC 2 Chemical production or refinery in closed continuous process with occasional controlled exposure or processes with equivalent containment conditions
- ☐ PROC 3 Manufacture or formulation in the chemical industry in closed batch processes with occasional controlled exposure or processes with equivalent containment condition
- ☐ PROC 4 Chemical production where opportunity for exposure arises
- ☐ PROC 5 Mixing or blending in batch processes
- ☐ PROC 6 Calendering operations
- ☐ PROC 7 Industrial spraying
- ☐ PROC 8a Transfer of substance or mixture (charging and discharging) at non-dedicated facilities
- ☐ PROC 8b Transfer of substance or mixture (charging and discharging) at dedicated facilities
- ☐ PROC 9 Transfer of substance or mixture into small containers (dedicated filling line, including weighing)
- ☐ PROC 10 Roller application or brushing
- ☐ PROC 11 Non-industrial spraying
- ☐ PROC 12 Use of blowing agents in manufacture of foam
- ☐ PROC 13 Treatment of articles by dipping and pouring
- ☐ PROC 14 Tableting, compression, extrusion, pelletisation, granulation
- ☐ PROC 15 Use as laboratory reagent
- ☐ PROC 16 Use of fuels

- PROC 17 Lubrication at high energy conditions in metal working operations
- PROC 18 General greasing/lubrication at high kinetic energy conditions
- PROC 19 Manual activities involving hand contact
- PROC 20 Use of functional fluids in small devices
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- PROC 25 Other hot work operations with metals
- PROC 26 Handling of solid inorganic substances at ambient temperature
- PROC 27a Production of metal powders (hot processes)
- PROC 27b Production of metal powders (wet processes)
- PROC 28 Manual maintenance (cleaning and repair) of machinery
- Other

Process 3: Please provide details about the activities within this PROC that lead to exposure to PAHs.

Process 4

- PROC 1 Chemical production or refinery in closed process without likelihood of exposure or processes with equivalent containment conditions
- PROC 2 Chemical production or refinery in closed continuous process with occasional controlled exposure or processes with equivalent containment conditions
- PROC 3 Manufacture or formulation in the chemical industry in closed batch processes with occasional controlled exposure or processes with equivalent containment condition
- PROC 4 Chemical production where opportunity for exposure arises
- PROC 5 Mixing or blending in batch processes
- PROC 6 Calendering operations
- PROC 7 Industrial spraying
- PROC 8a Transfer of substance or mixture (charging and discharging) at non-dedicated facilities
- PROC 8b Transfer of substance or mixture (charging and discharging) at dedicated facilities
- PROC 9 Transfer of substance or mixture into small containers (dedicated filling line, including weighing)
- PROC 10 Roller application or brushing
- PROC 11 Non-industrial spraying
- PROC 12 Use of blowing agents in manufacture of foam
- PROC 13 Treatment of articles by dipping and pouring
- PROC 14 Tableting, compression, extrusion, pelletisation, granulation
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- PROC 22 Manufacturing and processing of minerals and/or metals at substantially elevated temperature
- PROC 23 Open processing and transfer operations with minerals/metals at elevated temperature

- ☐ PROC 24 High (mechanical) energy work-up of substances bound in materials and/or articles
- ☐ PROC 25 Other hot work operations with metals
- ☐ PROC 26 Handling of solid inorganic substances at ambient temperature
- ☐ PROC 27a Production of metal powders (hot processes)
- ☐ PROC 27b Production of metal powders (wet processes)
- ☐ PROC 28 Manual maintenance (cleaning and repair) of machinery
- ☐ Other

Process 4: Please provide details about the activities within this PROC that lead to exposure to PAHs.

B8) Please provide the number of workers exposed at all exposure levels during a typical working day

	Number of workers exposed
Process 1	
Process 2	
Process 3	
Process 4	

B9) Please provide your most recent measured metabolite concentration data.

Please confirm the relevant metabolite that you are entering the data for.

Note that data on 3-OHBaP is the preferred data.

- ☐ 1-OHP
- ☐ 3-OHBaP

Please confirm the unit for the data you are entering

- ☐ nmol/mol creatinine
- ☐ ng/g creatinine
- ☐ µmol/mol creatinine
- ☐ µg/g creatinine

Please confirm when the samples were taken

- ☐ At the end of the shift.
- ☐ At the end of the shift and before the next shift.
- ☐ Other: please indicate

Please specify when the samples were taken.

Biomonitoring data

	Process 1	Process 2	Process 3	Process 4
Lowest concentration (value)				
Highest concentration (value)				
Mean concentration (arithmetic mean; value)				
Median concentration (value)				
95th percentile concentration (value)				
Number of samples (n)				
Year of monitoring				
Are the workers wearing respiratory protective equipment (RPE) during the process?	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No
	☐ 1-OHP (and OH-Phens) - HPLC /FLD; LC-MS/MS; GC-MS - Heudorf and Angerer 2001; Barbeau et al 2014 ☐ 3-OHBaP - HPLC/FLD - Barbeau et al 2011	☐ 1-OHP (and OH-Phens) - HPLC /FLD; LC-MS/MS; GC-MS - Heudorf and Angerer 2001; Barbeau et al 2014 ☐ 3-OHBaP - HPLC/FLD - Barbeau et al 2011	☐ 1-OHP (and OH-Phens) - HPLC /FLD; LC-MS/MS; GC-MS - Heudorf and Angerer 2001; Barbeau et al 2014 ☐ 3-OHBaP - HPLC/FLD - Barbeau et al 2011	☐ 1-OHP (and OH-Phens) - HPLC /FLD; LC-MS/MS; GC-MS - Heudorf and Angerer 2001; Barbeau et al 2014 ☐ 3-OHBaP - HPLC/FLD - Barbeau et al 2011

Please confirm the analytical method followed	☐ 3-OHBaP - GC-APLI-MS - Richter brockmann et al 2019 ☐ Tetraol-BaP - GC-NICI-MS/MS - Barbeau et al 2018 ☐ Tetraol-BaP - GC-MS - IPA Journal 1/2019 ☐ Other	☐ 3-OHBaP - GC-APLI-MS - Richter brockmann et al 2019 ☐ Tetraol-BaP - GC-NICI-MS/MS - Barbeau et al 2018 ☐ Tetraol-BaP - GC-MS - IPA Journal 1/2019 ☐ Other	☐ 3-OHBaP - GC-APLI-MS - Richter brockmann et al 2019 ☐ Tetraol-BaP - GC-NICI-MS/MS - Barbeau et al 2018 ☐ Tetraol-BaP - GC-MS - IPA Journal 1/2019 ☐ Other	☐ 3-OHBaP - GC-APLI-MS - Richter brockmann et al 2019 ☐ Tetraol-BaP - GC-NICI-MS/MS - Barbeau et al 2018 ☐ Tetraol-BaP - GC-MS - IPA Journal 1/2019 ☐ Other
If you selected 'other' in answer to the above question, please specify the analytical method followed.				

B10) Could actions related to covid-19 have artificially altered exposure levels? For example, greater use of PPE.

at most 1 choice(s)

- ☐ Yes, reduced exposure
- ☐ Yes, increased exposure
- ☐ No change
- ☐ Don't know

B11) Please provide a short explanation for your answer to B10

B12) If you have exposure data other than 8-hour Time Weighted Averages or biomonitoring data, please specify type of value and air exposure concentration. Please, for example, provide any dermal or short-term exposure data here.

	Process 1	Process 2	Process 3	Process 4
Type of exposure data, substance measured, type of value (median, 95th percentile, etc.)				
Value				
Please confirm the unit for the data you have just entered	☐ µg/m³ ☐ ng/m³ ☐ ppm ☐ ppb ☐ Other	☐ µg/m³ ☐ ng/m³ ☐ ppm ☐ ppb ☐ Other	☐ µg/m³ ☐ ng/m³ ☐ ppm ☐ ppb ☐ Other	☐ µg/m³ ☐ ng/m³ ☐ ppm ☐ ppb ☐ Other
If other, please specify				
Please confirm the sampling and analytical method followed				

B13) Do you have any other information on exposure to PAH at your facility?

If you are happy to provide more detailed information about numbers of workers exposed, exposure levels and/or further processes, please email OELs6@rpald.co.uk

Current Risk Management Measures

B14) Which Risk Management Measures are in place to control respiratory and dermal exposure to PAH in the different processes at this facility? Please tick all that you use.

Restructuring operations/processes

	Process 1	Process 2	Process 3	Process 4
Reduced amount of substance (generating PAH) used	☐	☐	☐	☐
Reduced number of workers exposed	☐	☐	☐	☐
Rotation of the workers exposed	☐	☐	☐	☐
Redesign of work processes	☐	☐	☐	☐

Ventilation and extraction

	Process 1	Process 2	Process 3	Process 4
Closed systems	☐	☐	☐	☐
Enclosure with extraction	☐	☐	☐	☐
Partially closed systems	☐	☐	☐	☐
Open hoods over equipment or local extraction ventilation	☐	☐	☐	☐
General ventilation	☐	☐	☐	☐
Pressurised or sealed control cabs	☐	☐	☐	☐
Simple enclosed control cabs	☐	☐	☐	☐

PPE (Personal Protective Equipment)

	Process 1	Process 2	Process 3	Process 4

PPE is essential regardless of the OEL	☐	☐	☐	☐
Self-contained breathing apparatus (with bottled air) or airline respirators (air supplied by hose)	☐	☐	☐	☐
Powered air-purifying respirators	☐	☐	☐	☐
Half and full facemasks (negative pressure respirators)	☐	☐	☐	☐
Disposable respirators (FFP masks)	☐	☐	☐	☐
Face screens, faceshields, visors	☐	☐	☐	☐
Safety spectacles, goggles	☐	☐	☐	☐
Gloves	☐	☐	☐	☐
Gloves with a cuff, gauntlets and sleeving that covers part or all of the arm	☐	☐	☐	☐
Safety boots and shoes	☐	☐	☐	☐
Rubber boots	☐	☐	☐	☐
Conventional or disposable overalls, boiler suits, aprons	☐	☐	☐	☐
Coveralls/hazardous materials suits	☐	☐	☐	☐

Organisational and hygiene measures

	Process 1	Process 2	Process 3	Process 4
Training and education	☐	☐	☐	☐
Cleaning	☐	☐	☐	☐
Provision of separate storage facilities for work clothes	☐	☐	☐	☐
Formal/external RPE cleaning and filter changing regime	☐	☐	☐	☐
Continuous measurement to detect unusual exposures	☐	☐	☐	☐
REACH Restriction training (future)	☐	☐	☐	☐

Substitution or discontinuation in the past

	Process 1	Process 2	Process 3	Process 4
Partial substitution or removal of substances that generate PAH in this process in the past	☐	☐	☐	☐

Discontinuation of part of the process generating release of PAH	☐	☐	☐	☐

Other measures

	Process 1	Process 2	Process 3	Process 4
Other (please specify)				

B15) Could there be co-exposure from both PAH and any of the following substances or processes at this facility? Please tick all that apply.

	Select
Cobalt substances under the CMRD	☐
Isoprene	☐
1,4-dioxane	☐
Perform welding	☐

B16) Is your company making any investments not directly related to exposure to PAHs that are likely to lead to a reduction in exposure to PAHs?

at most 1 answered row(s)

	Select
Investments are being made that will significantly reduce exposure to PAH	☐
Investments are being made that may reduce exposure to PAH	☐
No investments are planned that will reduce exposure to PAH	☐
Don't know	☐

B17) If any investments are being made in question B16, what are the investments for? Please tick all that apply.

	Select
Compliance with other OELs (please specify which)	☐
Improved risk management measures being implemented alongside other improvements to production facilities	☐
New or improved production facilities that will remove from or reduce exposure to worker	☐
Other, please specify	☐

Please specify the other OELs with which you will need to comply.

If you answered 'Other, please specify' to question B17, please provide further details of these investments.

B18) When will the reduction in worker exposure take effect?

at most 1 answered row(s)

	Select
By the end of 2024	☐
By the end of 2029	☐
By the end of 2034	☐

C) What are the lowest exposure levels that you could achieve

Airborne concentrations (8-hour TWA)

	Value	Unit
C1) What do you think is the lowest technically possible 8-hour OEL that can be achieved in this facility?		☐ $\mu\text{g}/\text{m}^3$ ☐ ng/m^3 ☐ ppm ☐ ppb
C2) What do you think is the lowest economically feasible 8-hour OEL that can be achieved in this facility?		☐ $\mu\text{g}/\text{m}^3$ ☐ ng/m^3 ☐ ppm ☐ ppb

C3) Do you have to comply with the European Workplace exposure standard EN 689?

- ☐ Yes
☐ No
☐ Don't know

C4) Any comments on above answers?

Biological Limit Value (BLV)

	Value	Unit
C5) What do you think is the lowest technically possible BLV that can be achieved in this facility?		☐ nmol 3-OHBaP /mol creatinine ☐ 3-OHBaP ng/g creatinine
C6) What do you think is the lowest economically feasible BLV that can be achieved in this facility?		☐ nmol 3-OHBaP /mol creatinine ☐ 3-OHBaP ng/g creatinine

C7) Any comments on above answers?

D) Compliance with a new OEL/BLV and Risk management measures

This section considers the Risk Management Measures (RMMs) that would have to be put in place to comply with a new OEL and Biological Limit Value (BLV) under the CMRD.

Benzo[a]pyrene (BaP) is used as a marker for exposure to complex mixtures of PAH. There is a correlation between measurements of BaP in air and measurements of 3-hydroxybenzo(a)pyrene (3-OHBaP) metabolites in urine post-shift, unless significant dermal exposure has taken place. On this basis, the impact of setting a BLV for the 3-OHBaP concentration equivalent to the air concentration of BaP as an OEL is currently being assessed.

The following limit values and air concentrations are the reference points for this questionnaire.		
Policy Option	OEL Policy Options (Inhalable fraction)	Equivalent BLV <u>post-shift</u> Policy Option
	BaP	3-OHBaP
1 (This is the mode and median level for EU MS that have an OEL, or equivalent)	2000 ng/m ³	3.8 nmol/mol creatinine
2 (equivalent to a lung cancer risk of 4 per 1,000)	700 ng/m ³	1.5 nmol/mol creatinine
3 (equivalent to a lung cancer risk of 4 per 10,000)	70 ng/m ³	0.3 nmol/mol creatinine
4 (equivalent to a lung cancer risk of 4 per 100,000)	7 ng/m ³	0.2 nmol/mol creatinine
All OELs or BLVs would be accompanied by a skin notation <i>Note:</i> To convert ng 3-OHBaP/g creatinine into nmol 3-OHBaP/mol creatinine, a factor of 2.37 can be used To convert nmol 3-OHBaP/mol creatinine into ng 3-OHBaP/g creatinine, a factor of 0.42 can be used		

The following table converts the OEL policy options from ng BaP/m³ to ppb, and the BLV reference values from nmol 3-OHBaP/nmol creatinine to ng/g.

Substance	MW [g/mol]	Exposure unit	OEL Policy Options and their conversions			
BaP	252.31	ng / m ³	7	70	700	2000
		Ppb	0.001	0.006	0.062	0.178
3-OHBaP	268.3 (3-OHBaP)	nmol/mol creatinine	0.2	0.30	1.5	3.8
	113.12 (creatinine)	ng/g creatinine	0.4	0.7	3.5	9.1

D1) If the OEL and BLV were 2000 ng/m³ and 3.8 nmol/mol creatinine, which *additional* RMMs would be the most important in helping you to achieve this?

All levels would be accompanied by a skin notation.

	Process 1	Process 2	Process 3	Process 4
No action required as OEL already achieved	☐	☐	☐	☐

Substitution or discontinuation

	Process 1	Process 2	Process 3	Process 4
Substitution of substances or materials generating PAH	☐	☐	☐	☐
Substitution of processes or activities generating PAH	☐	☐	☐	☐
Partial substitution of substances or materials generating PAH	☐	☐	☐	☐
Partial substitution of processes or activities generating PAH	☐	☐	☐	☐
Discontinuation of the activity generating PAH (shutdown business or part of business)	☐	☐	☐	☐

Restructuring operations/processes

	Process 1	Process 2	Process 3	Process 4
Reduced amount of substance-generating PAH used	☐	☐	☐	☐
Reduced the number of workers exposed	☐	☐	☐	☐
Rotation of workers exposed	☐	☐	☐	☐
Redesign of work processes	☐	☐	☐	☐

Ventilation and extraction

	Process 1	Process 2	Process 3	Process 4
Installing enclosure with extraction	☐	☐	☐	☐
Installing closed systems	☐	☐	☐	☐
Installing partially closed systems	☐	☐	☐	☐

Installing open hoods over equipment or local extraction	☐	☐	☐	☐
Installing general ventilation	☐	☐	☐	☐
Installing pressurised or sealed control cabs	☐	☐	☐	☐
Installing simple enclosed control cabs	☐	☐	☐	☐

PPE (Personal Protective Equipment)

	Process 1	Process 2	Process 3	Process 4
PPE is essential regardless of the OEL	☐	☐	☐	☐
Self-contained breathing apparatus (with bottled air) or airline respirators (air supplied by hose)	☐	☐	☐	☐
Powered air-purifying respirators	☐	☐	☐	☐
Half and full facemasks (negative pressure respirators)	☐	☐	☐	☐
Disposable respirators (FFP masks)	☐	☐	☐	☐
Face screens, faceshields, visors	☐	☐	☐	☐
Safety spectacles, goggles	☐	☐	☐	☐
Gloves	☐	☐	☐	☐
Gloves with a cuff, gauntlets and sleeving that covers part or all of the arm	☐	☐	☐	☐
Safety boots and shoes	☐	☐	☐	☐
Rubber boots	☐	☐	☐	☐
Conventional or disposable overalls, boiler suits, aprons	☐	☐	☐	☐
Coveralls/hazardous materials suits	☐	☐	☐	☐

Organisational and hygiene measures

	Process 1	Process 2	Process 3	Process 4
Further training and education	☐	☐	☐	☐
REACH restriction training (future)	☐	☐	☐	☐
Further cleaning	☐	☐	☐	☐
Provision of separate storage facilities for work clothes	☐	☐	☐	☐

Formal/external RPE cleaning and filter changing regime	☐	☐	☐	☐
Continuous measurement to detect unusual exposures	☐	☐	☐	☐

Other measures

	Process 1	Process 2	Process 3	Process 4
Other (please specify)				

D2) What is your estimated range of initial investment costs for additional RMMs required at this facility to achieve an OEL with 2000 ng/m³ and BLV of 3.8 nmol/mol creatinine?

at most 1 answered row(s)

	Select
< €10,000	☐
€10,000 - €100,000	☐
€100,000 - €1 million	☐
€1 -10 million	☐
€10 - 100 million	☐
€100 - 1 billion	☐
Over €1 billion	☐
Don't know	☐

D2a) What proportion of these initial investment costs would be attributed *solely* to risk management measures required to meet the BLV?

- ☐ Less than 5%
- ☐ 5-10%
- ☐ 10-20%
- ☐ 20-30%
- ☐ 30-40%
- ☐ 40-50%
- ☐ 50-60%
- ☐ 60-70%
- ☐ 70-80%
- ☐ 80-90%
- ☐ 90-100%

D2b) Please explain your answer to the previous question detailing where there may be differences across the different processes, or due to different levels of inhalation/dermal exposure.

D3) What is your estimated range of annual recurrent costs for additional RMMs required at this facility to achieve an OEL with 2000 ng/m³ and BLV of 3.8 nmol/mol creatinine?

at most 1 answered row(s)

	Select
< €1,000	☐

€1,000 - €10,000	☐
€10,000 - €100,000	☐
€100,000 - 1 million	☐
€1 - 10 million	☐
€10 - 100 million	☐
Over €100 million	☐
Don't know	☐

D3a) What proportion of these recurrent costs would be attributed solely to risk management measures required to meet the BLV?

- ☐ Less than 5%
- ☐ 5-10%
- ☐ 10-20%
- ☐ 20-30%
- ☐ 30-40%
- ☐ 40-50%
- ☐ 50-60%
- ☐ 60-70%
- ☐ 70-80%
- ☐ 80-90%
- ☐ 90-100%

D3b) Please explain your answer to the previous question detailing where there may be differences across the different processes, or due to different levels of inhalation/dermal exposure.

D4) If the OEL and BLV were 700 ng/m³ and 1.5 nmol/mol creatinine, which *additional* RMMs would be the most important in helping you to achieve this?

All levels would be accompanied by a skin notation.

	Process 1	Process 2	Process 3	Process 4
No action required as OEL already achieved	☐	☐	☐	☐

Substitution or discontinuation

	Process 1	Process 2	Process 3	Process 4

Substitution of substances or materials generating PAH	☐	☐	☐	☐
Substitution of processes or activities generating PAH	☐	☐	☐	☐
Partial substitution of substances or materials generating PAH	☐	☐	☐	☐
Partial substitution of processes or activities generating PAH	☐	☐	☐	☐
Discontinuation of the activity generating PAH (shutdown business or part of business)	☐	☐	☐	☐

Restructuring operations/processes

	Process 1	Process 2	Process 3	Process 4
Reduced amount of substance-generating PAH used	☐	☐	☐	☐
Reduced the number of workers exposed	☐	☐	☐	☐
Rotation of workers exposed	☐	☐	☐	☐
Redesign of work processes	☐	☐	☐	☐

Ventilation and extraction

	Process 1	Process 2	Process 3	Process 4
Installing enclosure with extraction	☐	☐	☐	☐
Installing closed systems	☐	☐	☐	☐
Installing partially closed systems	☐	☐	☐	☐
Installing open hoods over equipment or local extraction	☐	☐	☐	☐
Installing general ventilation	☐	☐	☐	☐
Installing pressurised or sealed control cabs	☐	☐	☐	☐
Installing simple enclosed control cabs	☐	☐	☐	☐

PPE (Personal Protective Equipment)

	Process 1	Process 2	Process 3	Process 4
PPE is essential regardless of the OEL	☐	☐	☐	☐
Self-contained breathing apparatus (with bottled air) or airline respirators (air supplied by hose)	☐	☐	☐	☐

Powered air-purifying respirators	☐	☐	☐	☐
Half and full facemasks (negative pressure respirators)	☐	☐	☐	☐
Disposable respirators (FFP masks)	☐	☐	☐	☐
Face screens, faceshields, visors	☐	☐	☐	☐
Safety spectacles, goggles	☐	☐	☐	☐
Gloves	☐	☐	☐	☐
Gloves with a cuff, gauntlets and sleeving that covers part or all of the arm	☐	☐	☐	☐
Safety boots and shoes	☐	☐	☐	☐
Rubber boots	☐	☐	☐	☐
Conventional or disposable overalls, boiler suits, aprons	☐	☐	☐	☐
Coveralls/hazardous materials suits	☐	☐	☐	☐

Organisational and hygiene measures

	Process 1	Process 2	Process 3	Process 4
Further training and education	☐	☐	☐	☐
REACH restriction training (future)	☐	☐	☐	☐
Further cleaning	☐	☐	☐	☐
Provision of separate storage facilities for work clothes	☐	☐	☐	☐
Formal/external RPE cleaning and filter changing regime	☐	☐	☐	☐
Continuous measurement to detect unusual exposures	☐	☐	☐	☐

Other measures

	Process 1	Process 2	Process 3	Process 4
Other (please specify)				

D5) What is your estimated range of *initial investment costs* for additional RMMs required at this facility to achieve an OEL with 700 ng/m³ and BLV of 1.5 nmol/mol creatinine?

at most 1 answered row(s)

	Select
< €10,000	☐
€10,000 - €100,000	☐
€100,000 - €1 million	☐
€1 -10 million	☐
€10 - 100 million	☐
€100 - 1 billion	☐
Over €1 billion	☐
Don't know	☐

D5a) What proportion of these initial investment costs would be attributed solely to risk management measures required to meet the BLV?

- ☐ Less than 5%
- ☐ 5-10%
- ☐ 10-20%
- ☐ 20-30%
- ☐ 30-40%
- ☐ 40-50%
- ☐ 50-60%
- ☐ 60-70%
- ☐ 70-80%
- ☐ 80-90%
- ☐ 90-100%

D5b) Please explain your answer to the previous question detailing where there may be differences across the different processes, or due to different levels of inhalation/dermal exposure.

D6) What is your estimated range of annual recurrent costs for additional RMMs required at this facility to achieve an OEL with 700 ng/m³ and BLV of 1.5 nmol/mol creatinine?

at most 1 answered row(s)

	Select
< €1,000	☐

€1,000 - €10,000	☐
€10,000 - €100,000	☐
€100,000 - 1 million	☐
€1 - 10 million	☐
€10 - 100 million	☐
Over €100 million	☐
Don't know	☐

D6a) What proportion of these recurrent costs would be attributed solely to risk management measures required to meet the BLV?

- ☐ Less than 5%
- ☐ 5-10%
- ☐ 10-20%
- ☐ 20-30%
- ☐ 30-40%
- ☐ 40-50%
- ☐ 50-60%
- ☐ 60-70%
- ☐ 70-80%
- ☐ 80-90%
- ☐ 90-100%

D6b) Please explain your answer to the previous question detailing where there may be differences across the different processes, or due to different levels of inhalation/dermal exposure.

D7) If the OEL and BLV were 70 ng/m³ and 0.3 nmol/mol creatinine, which *additional* RMMs would be the most important in helping you to achieve this?

All levels would be accompanied by a skin notation.

	Process 1	Process 2	Process 3	Process 4
No action required as OEL already achieved	☐	☐	☐	☐

Substitution or discontinuation

	Process 1	Process 2	Process 3	Process 4

Substitution of substances or materials generating PAH	☐	☐	☐	☐
Substitution of processes or activities generating PAH	☐	☐	☐	☐
Partial substitution of substances or materials generating PAH	☐	☐	☐	☐
Partial substitution of processes or activities generating PAH	☐	☐	☐	☐
Discontinuation of the activity generating PAH (shutdown business or part of business)	☐	☐	☐	☐

Restructuring operations/processes

	Process 1	Process 2	Process 3	Process 4
Reduced amount of substance-generating PAH used	☐	☐	☐	☐
Reduced the number of workers exposed	☐	☐	☐	☐
Rotation of workers exposed	☐	☐	☐	☐
Redesign of work processes	☐	☐	☐	☐

Ventilation and extraction

	Process 1	Process 2	Process 3	Process 4
Installing enclosure with extraction	☐	☐	☐	☐
Installing closed systems	☐	☐	☐	☐
Installing partially closed systems	☐	☐	☐	☐
Installing open hoods over equipment or local extraction	☐	☐	☐	☐
Installing general ventilation	☐	☐	☐	☐
Installing pressurised or sealed control cabs	☐	☐	☐	☐
Installing simple enclosed control cabs	☐	☐	☐	☐

PPE (Personal Protective Equipment)

	Process 1	Process 2	Process 3	Process 4
PPE is essential regardless of the OEL	☐	☐	☐	☐
Self-contained breathing apparatus (with bottled air) or airline respirators (air supplied by hose)	☐	☐	☐	☐

Powered air-purifying respirators	☐	☐	☐	☐
Half and full facemasks (negative pressure respirators)	☐	☐	☐	☐
Disposable respirators (FFP masks)	☐	☐	☐	☐
Face screens, faceshields, visors	☐	☐	☐	☐
Safety spectacles, goggles	☐	☐	☐	☐
Gloves	☐	☐	☐	☐
Gloves with a cuff, gauntlets and sleeving that covers part or all of the arm	☐	☐	☐	☐
Safety boots and shoes	☐	☐	☐	☐
Rubber boots	☐	☐	☐	☐
Conventional or disposable overalls, boiler suits, aprons	☐	☐	☐	☐
Coveralls/hazardous materials suits	☐	☐	☐	☐

Organisational and hygiene measures

	Process 1	Process 2	Process 3	Process 4
Further training and education	☐	☐	☐	☐
REACH restriction training (future)	☐	☐	☐	☐
Further cleaning	☐	☐	☐	☐
Provision of separate storage facilities for work clothes	☐	☐	☐	☐
Formal/external RPE cleaning and filter changing regime	☐	☐	☐	☐
Continuous measurement to detect unusual exposures	☐	☐	☐	☐

Other measures

	Process 1	Process 2	Process 3	Process 4
Other (please specify)				

D8) What is your estimated range of initial investment costs for additional RMMs required at this facility to achieve an OEL with 70 ng/m³ and BLV of 0.3 nmol/mol creatinine?

at most 1 answered row(s)

	Select
< €10,000	☐
€10,000 - €100,000	☐
€100,000 - €1 million	☐
€1 -10 million	☐
€10 - 100 million	☐
€100 - 1 billion	☐
Over €1 billion	☐
Don't know	☐

D8a) What proportion of these initial investment costs would be attributed solely to risk management measures required to meet the BLV?

- ☐ Less than 5%
- ☐ 5-10%
- ☐ 10-20%
- ☐ 20-30%
- ☐ 30-40%
- ☐ 40-50%
- ☐ 50-60%
- ☐ 60-70%
- ☐ 70-80%
- ☐ 80-90%
- ☐ 90-100%

D8b) Please explain your answer to the previous question detailing where there may be differences across the different processes, or due to different levels of inhalation/dermal exposure.

D9) What is your estimated range of annual recurrent costs for additional RMMs required at this facility to achieve an OEL with 70 ng/m³ and BLV of 0.3 nmol/mol creatinine?

at most 1 answered row(s)

	Select
< €1,000	☐

€1,000 - €10,000	☐
€10,000 - €100,000	☐
€100,000 - 1 million	☐
€1 - 10 million	☐
€10 - 100 million	☐
Over €100 million	☐
Don't know	☐

D9a) What proportion of these recurrent costs would be attributed solely to risk management measures required to meet the BLV?

- ☐ Less than 5%
- ☐ 5-10%
- ☐ 10-20%
- ☐ 20-30%
- ☐ 30-40%
- ☐ 40-50%
- ☐ 50-60%
- ☐ 60-70%
- ☐ 70-80%
- ☐ 80-90%
- ☐ 90-100%

D9b) Please explain your answer to the previous question detailing where there may be differences across the different processes, or due to different levels of inhalation/dermal exposure.

D10) If the OEL and BLV were 7 ng/m³ and 0.2 nmol/mol creatinine, which *additional* RMMs would be the most important in helping you to achieve this?

All levels would be accompanied by a skin notation.

	Process 1	Process 2	Process 3	Process 4
No action required as OEL already achieved	☐	☐	☐	☐

Substitution or discontinuation

	Process 1	Process 2	Process 3	Process 4

Substitution of substances or materials generating PAH	☐	☐	☐	☐
Substitution of processes or activities generating PAH	☐	☐	☐	☐
Partial substitution of substances or materials generating PAH	☐	☐	☐	☐
Partial substitution of processes or activities generating PAH	☐	☐	☐	☐
Discontinuation of the activity generating PAH (shutdown business or part of business)	☐	☐	☐	☐

Restructuring operations/processes

	Process 1	Process 2	Process 3	Process 4
Reduced amount of substance-generating PAH used	☐	☐	☐	☐
Reduced the number of workers exposed	☐	☐	☐	☐
Rotation of workers exposed	☐	☐	☐	☐
Redesign of work processes	☐	☐	☐	☐

Ventilation and extraction

	Process 1	Process 2	Process 3	Process 4
Installing enclosure with extraction	☐	☐	☐	☐
Installing closed systems	☐	☐	☐	☐
Installing partially closed systems	☐	☐	☐	☐
Installing open hoods over equipment or local extraction	☐	☐	☐	☐
Installing general ventilation	☐	☐	☐	☐
Installing pressurised or sealed control cabs	☐	☐	☐	☐
Installing simple enclosed control cabs	☐	☐	☐	☐

PPE (Personal Protective Equipment)

	Process 1	Process 2	Process 3	Process 4
PPE is essential regardless of the OEL	☐	☐	☐	☐
Self-contained breathing apparatus (with bottled air) or airline respirators (air supplied by hose)	☐	☐	☐	☐

Powered air-purifying respirators	☐	☐	☐	☐
Half and full facemasks (negative pressure respirators)	☐	☐	☐	☐
Disposable respirators (FFP masks)	☐	☐	☐	☐
Face screens, faceshields, visors	☐	☐	☐	☐
Safety spectacles, goggles	☐	☐	☐	☐
Gloves	☐	☐	☐	☐
Gloves with a cuff, gauntlets and sleeving that covers part or all of the arm	☐	☐	☐	☐
Safety boots and shoes	☐	☐	☐	☐
Rubber boots	☐	☐	☐	☐
Conventional or disposable overalls, boiler suits, aprons	☐	☐	☐	☐
Coveralls/hazardous materials suits	☐	☐	☐	☐

Organisational and hygiene measures

	Process 1	Process 2	Process 3	Process 4
Further training and education	☐	☐	☐	☐
REACH restriction training (future)	☐	☐	☐	☐
Further cleaning	☐	☐	☐	☐
Provision of separate storage facilities for work clothes	☐	☐	☐	☐
Formal/external RPE cleaning and filter changing regime	☐	☐	☐	☐
Continuous measurement to detect unusual exposures	☐	☐	☐	☐

Other measures

	Process 1	Process 2	Process 3	Process 4
Other (please specify)				

D11) What is your estimated range of initial investment costs for additional RMMs required at this facility to achieve an OEL with 7 ng/m³ and BLV of 0.2 nmol/mol creatinine?

at most 1 answered row(s)

	Select
< €10,000	☐
€10,000 - €100,000	☐
€100,000 - €1 million	☐
€1 -10 million	☐
€10 - 100 million	☐
€100 - 1 billion	☐
Over €1 billion	☐
Don't know	☐

D11a) What proportion of these initial investment costs would be attributed solely to risk management measures required to meet the BLV?

- ☐ Less than 5%
- ☐ 5-10%
- ☐ 10-20%
- ☐ 20-30%
- ☐ 30-40%
- ☐ 40-50%
- ☐ 50-60%
- ☐ 60-70%
- ☐ 70-80%
- ☐ 80-90%
- ☐ 90-100%

D11b) Please explain your answer to the previous question detailing where there may be differences across the different processes, or due to different levels of inhalation/dermal exposure.

D12) What is your estimated range of annual recurrent costs for additional RMMs required at this facility to achieve an OEL with 7 ng/m³ and BLV of 0.2 nmol/mol creatinine?

at most 1 answered row(s)

	Select
< €1,000	☐

€1,000 - €10,000	☐
€10,000 - €100,000	☐
€100,000 - 1 million	☐
€1 - 10 million	☐
€10 - 100 million	☐
Over €100 million	☐
Don't know	☐

D12a) What proportion of these recurrent costs would be attributed solely to risk management measures required to meet the BLV?

- ☐ Less than 5%
- ☐ 5-10%
- ☐ 10-20%
- ☐ 20-30%
- ☐ 30-40%
- ☐ 40-50%
- ☐ 50-60%
- ☐ 60-70%
- ☐ 70-80%
- ☐ 80-90%
- ☐ 90-100%

D12b) Please explain your answer to the previous question detailing where there may be differences across the different processes, or due to different levels of inhalation/dermal exposure.

D13) How would the OEL and equivalent BLV reference values impact the competitiveness of your company...

8 h TWA OEL	7 ng BaP/m ³	70 ng BaP/m ³	700 ng BaP/m ³	2000 ng BaP/m ³
BLV nmol 3-OHBaP / mol creatinine	0.2 nmol 3-OHBaP	0.3 nmol 3-OHBaP	1.5 nmol 3-OHBaP	3.8 nmol 3-OHBaP
versus competitors in EU	☐ Significant positive impact ☐ Moderate positive impact ☐ Limited/no impact ☐ Moderate negative impact ☐ Significant negative impact	☐ Significant positive impact ☐ Moderate positive impact ☐ Limited/no impact ☐ Moderate negative impact ☐ Significant negative impact	☐ Significant positive impact ☐ Moderate positive impact ☐ Limited/no impact ☐ Moderate negative impact ☐ Significant negative impact	☐ Significant positive impact ☐ Moderate positive impact ☐ Limited/no impact ☐ Moderate negative impact ☐ Significant negative impact
versus competitors outside of EU	☐ Significant positive impact ☐ Moderate positive impact ☐ Limited/no impact ☐ Moderate negative impact ☐ Significant negative impact	☐ Significant positive impact ☐ Moderate positive impact ☐ Limited/no impact ☐ Moderate negative impact ☐ Significant negative impact	☐ Significant positive impact ☐ Moderate positive impact ☐ Limited/no impact ☐ Moderate negative impact ☐ Significant negative impact	☐ Significant positive impact ☐ Moderate positive impact ☐ Limited/no impact ☐ Moderate negative impact ☐ Significant negative impact

D14) Are the following future REACH Restrictions likely to have an impact on exposure concentrations at your facility?

REACH Restriction	
<u>Substances containing PAH in clay targets for shooting?</u>	☐ Yes ☐ No
<u>Creosote and creosote related substances to treat wood, use and re-use of</u>	☐ Yes ☐ No
<u>Substances in single-use baby diapers</u>	☐ Yes ☐ No
Any other REACH initiative not listed above?	☐ Yes ☐ No

D15) If you answered 'yes' to any of the questions in D14, please describe the likely impact in reference to OEL and BLV Reference values 1, 2, 3 and 4.

E) Is your company working towards voluntary industry targets?

Voluntary industry targets

	Response
E1) Is your company trying to meet voluntary industry targets? If yes, please specify the targets (concentration, units)	
E2) What are the main challenges in meeting the voluntary targets?	
E3) Have you made any assessment of the possible costs of meeting the voluntary targets? If yes, please provide information on costs and cost structure.	

F) Indirect benefits

This question aims to capture indirect benefits that may arise for your company, should an EU-wide OEL be introduced for PAH.

F1) Do you think your company will benefit from any of these indirect benefits if an EU-wide OEL for PAH is introduced? Please tick all that apply.

	Select
Healthier staff	☐
Increased productivity of workers	☐
Improved public image	☐
Easier to recruit staff	☐
Easier to retain staff	☐
Reduced cost of recruitment	☐
Easier monitoring of exposure	☐
Savings because company currently has multiple locations in different Member States with different regulations or OELs	☐
Level playing field with EU competitors	☐
Other indirect benefits, please specify	☐
There will be no indirect benefits	☐

Please specify

G) Would compliance with newly introduced OELs for other substances influence the exposure to PAHs?

In order to comply with newly introduced OELs for other carcinogenic substances, you may have planned further implementation of RMMs, which may also lead to reduced exposure to PAH in processes where they are released and/or generated.

G1) Are newly introduced OELs expected to result in reduced exposure to PAHs as compared to the exposure concentrations reported in this questionnaire

Diesel engine exhaust emissions	☐ Yes, exposure is expected to be reduced by more than 50% ☐ Yes, exposure is expected to be reduced by less than 50%

	☐ No
Benzene	☐ Yes, exposure is expected to be reduced by more than 50% ☐ Yes, exposure is expected to be reduced by less than 50% ☐ No
Mineral oils that have been used before in internal combustion engines to lubricate and cool the moving parts within the engine	☐ Yes, exposure is expected to be reduced by more than 50% ☐ Yes, exposure is expected to be reduced by less than 50% ☐ No
Other	☐ Yes, exposure is expected to be reduced by more than 50% ☐ Yes, exposure is expected to be reduced by less than 50% ☐ No
Please specify	

H) Any other comments

H1) Do you have any other comments relevant to this study that you would like to make?

I) Further communication

I1) Please tick if you are happy for the study team to contact you for further clarification or discussion about your responses?

- ☐ Yes
☐ No

I2) Please tick if you would be willing to host a site visit for the study team at this facility. This can be carried out under a non-disclosure agreement.

- ☐ Yes
☐ No

I3) If you prefer this contact to be via a different email or phone number from those you provided at the start of the questionnaire, please provide the details here.

Thank you for your answers!

16.4 Annex 4 - Overview of limit values in Member States

Table 16-16 Current OELs and STELs in EU Member States and selected non-EU countries for PAH (status: April 2023)

Member State	OEL [mg/m ³]	Specification of OEL	STEL [mg/m ³]	Specification of STEL
Austria ^{1,2,3}	0.002	- B[a]P, TRK value [#] , Carc, Sd, Sk	0.008	- B[a]P, TRK value [#] , Carc, Sd, Sk
Belgium ^{1,4}	-	- PAH mixtures, particularly those containing B[a]P, which are carcinogens within the meaning of 2004/37 Directive Carc, Sk	-	
Bulgaria ⁵	0.00015 **	- B[a]P - PAH mixtures, particularly those containing B[a]P, which are carcinogens within the meaning of 2004/37 Directive, Sk	-	
Croatia ⁶	-	- PAH mixtures, particularly those containing B[a]P, which are carcinogens within the meaning of 2004/37 Directive, Sk	-	
Cyprus ⁷	-		-	
Czech Republic ⁸	0.005 *	- B[a]P, Carc, Repro, S, Sk	0.025 *	- B[a]P, Carc, Repro, S, Sk
Denmark ^{1,2,9}	0.2 ^{1,2} ** - ⁹	- PAH - benzene soluble, Carc, Sk ^{1,2} - PAH mixtures, particularly those containing B[a]P, Sk ⁹	0.4 ^{1,2}	- PAH - benzene soluble, 15 min average value, Carc, Sk ^{1,2}
Estonia ¹⁰	0.002 * -	- B[a]P, Carc, Repro, Sk - PAH mixtures, particularly those containing B[a]P, Carc, Sk	0.02 *	- B[a]P, Carc, Repro, Sk
Finland ^{1,2,11}	0.01 ^^ -	- B[a]P, Sk - PAH mixtures, Sk	-	
France ^{1,12}	-	- PAH mixtures, particularly those containing B[a]P, Carc, Sk	-	

Member State	OEL [mg/m ³]	Specification of OEL	STEL [mg/m ³]	Specification of STEL
Germany ^{1,2,13}	0.0007 (I) § * 0.00007 (I) §	- B[a]P as key component in defined PAH-mixtures, Sk	0.0056 (I) § *	- B[a]P as key component in defined PAH-mixtures, 15 min average value, Sk
Greece ¹⁴	0.005 *	- B[a]P	-	
Hungary ^{1,2,15}	0.002 *	- B[a]P, Carc	-	
Ireland ¹⁶	-	- PAH mixtures, particularly those containing B[a]P, Carc, Sk	-	
Italy ^{1,17}	-	- PAH mixtures, particularly those containing B[a]P, which are carcinogens within the meaning of 2004/37 Directive, Sk	-	
Latvia ^{1,2,18}	0.00015 **	- B[a]P* +	-	
Lithuania ¹⁹	0.002 *	- B[a]P ##, Carc, S, Repro, Sk	0.02 *	- B[a]P ##, 15 min average value, Carc, Repro, S, Sk
Luxembourg ²⁰	-		-	
Malta ²¹	-		-	
Netherlands ^{1,2,22}	0.00055 **	- B[a]P, same value also applies for PAH derived from coal (as B[a]P), Sk	-	
Poland ^{1,2,23}	0.002 ** 0.002 **	- B[a]P, Sk - For 9 carcinogenic PAH***+23, same value applies for PAH-benzene soluble ^{1,2} , Sk	-	
Portugal ²⁴	-		-	
Romania ^{1,2,25}	0.2 ^{1,2*} - 25	- PAH - benzene soluble ^{1,2} - PAH mixtures, particularly those containing B[a]P, Carc ²⁵	-	
Slovakia ²⁷	0.002 ** -	- Ba[a]P, TRK value [#] , Carc, Sk & - PAH mixtures, particularly those containing	0.008 **	- Ba[a]P, TRK value [#] , Carc, Sk &

Member State	OEL [mg/m ³]	Specification of OEL	STEL [mg/m ³]	Specification of STEL
		B[a]P, which are carcinogens, Sk		
Slovenia ²⁷	0.002 **	- Ba[a]P, TRK value [#] , Carc, Repro ^{&}	0.008 **	- Ba[a]P, TRK value [#] , Carc, Repro ^{&}
Spain ²⁸	0.2*	- Coal tar, benzene soluble, Carc, Repro ^{&}	-	
Sweden ^{1,2,29}	0.002 **	- B[a]P, Carc, Repro, Sk	0.02 ^^	- B[a]P, 15 min maximum value, Carc, Repro, Sk
European Union ³⁰	-	- IOELV, Sk	-	
RAC ²	-	- Sk	-	
Non-EU countries				
Australia ³¹	-		-	
Brazil ³²	-		-	
Canada, Ontario ^{1,33}	-		-	
Canada, Québec ^{1,34}	0.005 *** 0.2 ***	- B[a]P, Carc - particulate PAH - benzene soluble, Carc	-	
China	-		-	
India ³⁵	-		-	
Japan, MHLW ³⁶	0.2 ***	- Coal tar, benzene soluble	-	
Japan, JOSH ³⁷	-	- Carc	-	
Norway ^{1,2,38}	0.04 ^^	- For sum of 21 PAH***** collected as particulates ³⁸ , same value applies for PAH-benzene soluble ^{1,2} , Carc, Sk	-	
Russia ³⁹	-		-	
South Korea ¹	0.2 %	- PAH - benzene soluble	-	
Switzerland ^{1,2,40}	0.002 * 0.2 (I) *	- B[a]P, Carc, Repro, Sk - PAH from coal tar pitch, Carc	-	

Member State	OEL [mg/m ³]	Specification of OEL	STEL [mg/m ³]	Specification of STEL
Turkey ⁴¹	-		-	
United Kingdom ⁴²	-		-	
USA, ACGIH ⁴³	0.2 ^	- PAH - benzene soluble, Carc	-	
USA, NIOSH ^{44,\$\$}	0.1 ^	- PAH from coal tar pitch - cyclohexane soluble, Carc	-	
USA, OSHA ^{1,45}	0.2 *	- PAH - benzene soluble %, Carc	-	

Notes:

RAC = Committee for Risk Assessment

MHLW = Ministry of Health, Labour and Welfare

JSOH = Japan Society for Occupational Health

ACGIH = American Conference of Governmental Industrial Hygienists

NIOSH = National Institute for Occupational Safety and Health

OSHA = Occupational Safety and Health Administration

(I) = inhalable fraction/aerosol

* Binding value according to country-specific source

** Binding value according to reply of Member State authority on questionnaire

*** Binding value according to the Final report for OEL/STEL deriving systems from 2018 (Available at: <https://bit.ly/3PKDhbS>, accessed on 05.07.2023). Status was not checked since 2018.

^ Indicative value according to country-specific source

^^ Indicative value according to reply of Member State authority on questionnaire

^^^ Indicative value according to the Final report for OEL/STEL deriving systems from 2018 (Available at: <https://bit.ly/3PKDhbS>, accessed on 05.07.2023). Status was not checked since 2018.

% According to (country-specific source) unclear if value is binding or indicative

& Information according to reply of Member State authority on questionnaire

Carc = notation for carcinogenicity

Repro = notation for reproductive toxicity

Sk = skin notation assigned or danger of skin absorption

Member State	OEL [mg/m ³]	Specification of OEL	STEL [mg/m ³]	Specification of STEL

S = notation for sensitisation assigned. Where a more detailed notation for sensitisation was given, the following notations were reported:

Sd = skin/dermal sensitisation

- no value available

TRK value ("Technische Richtkonzentration", Technical Guidance Concentration), based on technical feasibility

B[a]P can be present together with other polycyclic aromatic hydrocarbons in smoke, dust or mist, such as from bitumen and asphalt, and in some oils and combustion products

§ Workplace exposure concentration corresponding to the proposed tolerable cancer risk

\$ Workplace exposure concentration corresponding to the proposed preliminary acceptable cancer risk

\$\$ For NIOSH recommended exposure limits (RELs), "TWA" indicates a time-weighted average concentration for up to a 10-hour workday during a 40-hour workweek."; Online: <https://www.cdc.gov/niosh/npg/pgintrod.html>, accessed December 2022

*** Additional OELs are derived for coal tar and pitch sublimates with an average content of benzo[a]pyrene (CAS No. 50-32-8): less than 0.075% an OEL of 0.2 mg/m³; 0.075-0.15 % an OEL of 0.1 mg/m³, and 0.15-0.3% an OEL of 0.05 mg/m³.*

***** The nine PAH are dibenzo[a,h]anthracene, benzo[a]pyrene, benzo[a]anthracene, benzo[b]fluoranthene, benzo[k]fluoranthene, indeno[1,2,3-c,d]pyrene, anthracene, benzo[g,h,i]perylene, and chrysene*

****** Sum of the following 21 PAH compounds: Anthracene, benz[a]anthracene, benzo[a]fluorene, benzo[b]fluorene, benzo[b]fluoranthene, benzo[j]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, benzo[e]pyrene, benzo[ghi]perylene, dibenzo[a,h]anthracene, dibenzo[a,e]pyrene, dibenzo[a,h]pyrene, dibenzo[a,i]pyrene, dibenzo[a,l]pyrene, phenanthrene, fluoranthene, indeno[(1,2,3-cd)pyrene, chrysene, pyrene, and triphenylene.*

\$\$ OSHA defines "coal tar pitch volatiles" as the fused polycyclic hydrocarbons that volatilize from the distillation residues of coal, petroleum (excluding asphalt), wood, and other organic matter and includes substances such as anthracene, benzo(a)pyrene (BaP), phenanthrene, acridine, chrysene, pyrene, etc

Sources:

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2: RAC, Committee for Risk Assessment (2022) ANNEX 1 in support of the Committee for Risk Assessment (RAC) for evaluation of limit values for polycyclic aromatic hydrocarbons at the workplace. European Chemicals Agency (ECHA), Helsinki, Finland. Available at: https://echa.europa.eu/documents/10162/7937606/annex1_rac_opi_oel_pah_en.pdf/8222f456-ee7f-bf3b-66b2-aebf39693bb9?t=1675065114197, accessed on 05.01.2023

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Member State	OEL [mg/m ³]	Specification of OEL	STEL [mg/m ³]	Specification of STEL
4: Belgium (2021) List of limit values (Titel 1. – Chemische agentia. and Titel 2. – Kankerverwekkende, mutagene en reprotoxische agentia). Available at: https://werk.belgie.be/nl/themas/welzijn-op-het-werk/algemene-beginselen/codex-over-het-welzijn-op-het-werk , accessed on 02.12.2022				
5: Bulgaria (2021) List of limit values and list of carcinogenic/mutagenic/reprotoxic substances. Available at: https://www.lex.bg/laws/ldoc/2135477597 and https://www.lex.bg/bg/mobile/ldoc/2135473243 , accessed on 05.12.2022				
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7: Cyprus (2021) Legislation on chemical agents and legislation on carcinogenic-mutagenic agents. Available at: https://www.mlsi.gov.cy/mlsi/dli/dliup.nsf/All/E3237CC15BD91575C2257E030029E9FF?OpenDocument and https://www.mlsi.gov.cy/mlsi/dli/dliup.nsf/All/D74ACEE6A814B7EAC2257E03002A76C9?OpenDocument , accessed on 05.12.2022				
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9: Denmark (2022) List of limit values. Available at: https://www.retsinformation.dk/eli/lt/2022/1054 , accessed on 05.12.2022				
10: Estonia (2022) List of limit values. Available at: https://www.riigiteataja.ee/ak-tilisa/1120/3202/2025/VV_30m_lisa.pdf# , accessed on 05.12.2022				
11: Finland (2020) List of limit values. Available at: https://julkaisut.valtioneuvosto.fi/handle/10024/162457 , accessed on 05.12.2022				
12: France (2022) List of limit values. Available at: https://www.inrs.fr/media.html?reflNRS=outil65 , accessed on 05.12.2022				
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15: Hungary (2022) List of limit values. Available at: https://net.jogtar.hu/jogszabaly?docid=a2000005.itm , accessed on 05.12.2022				
16: Ireland (2021) List of limit values. Available at: https://www.hsa.ie/eng/publications_and_forms/publications/chemical_and_hazardous_substances/2021-code-of-practice-for-the-chemical-agents-and-carcinogens-regulations.pdf , accessed on 05.12.2022				
17: Italy (2022) List of limit values and amendments. Available at: https://www.ispettorato.gov.it/it-it/strumenti-e-servizi/Documents/TU-81-08-Ed.-Agosto-2022.pdf , accessed on 06.12.2022				
18: Latvia (2022) List of limit values. Available at: https://likumi.lv/doc.php?id=157382&from=off , accessed on 06.12.2022				
19: Lithuania (2022) List of limit values. Available at: https://www.e-tar.lt/portal/lt/legalAct/TAR.8012ED3EA143/asr , accessed on 06.12.2022				

Member State	OEL [mg/m ³]	Specification of OEL	STEL [mg/m ³]	Specification of STEL
20: Luxembourg (2020)	List of limit values (2018) and list of carcinogens and mutagens (2020). Available at: http://legilux.public.lu/eli/etat/leg/rgd/2018/07/20/a684/jo and http://legilux.public.lu/eli/etat/leg/rgd/2020/01/24/a37/jo , accessed on 06.12.2022			
21: Malta (2021)	List of limit values. Available at: https://legislation.mt/eli/sl/424.24/eng/pdf , accessed on 06.12.2022			
22: Netherlands (2022)	List of limit values. Available at: https://wetten.overheid.nl/BWBR0008587/2022-07-01#BijlageXIII , accessed on 06.12.2022			
23: Poland (2021)	List of limit values from 2018 and amendments in 2020 and 2021. Available at: https://isap.sejm.gov.pl/isap.nsf/download.xsp/WDU20180001286/O/D20181286.pdf , http://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20200000061 , and https://isap.sejm.gov.pl/isap.nsf/download.xsp/WDU20210000325/O/D20210325.pdf , accessed on 06.12.2022			
24: Portugal (2022)	List of limit values. Available at: https://dre.pt/dre/legislacao-consolidada/decreto-lei/2012-115495237 , accessed on 07.12.2022			
25: Romania (2021)	List of limit values. Available at: https://legislatie.just.ro/Public/DetaliuDocument/75978 , accessed on 07.12.2022			
26: Slovakia (2020)	List of limit values. Available at: https://www.epi.sk/zz/2006-355 , accessed on 07.12.2022 and https://www.slov-lex.sk/pravne-predpisy/prilohy/SK/ZZ/2006/356/20201001_5255550-2.pdf , accessed on 05.07.2023			
27: Slovenia (2021)	List of limit values. Available at: http://www.pisrs.si/Pis.web/pregledPredpisa?id=PRAV14252 , accessed on 07.12.2022 and https://www.uradni-list.si/files/RS_-2007-053-02834-OB~P001-0000.PDF , accessed on 05.07.2023			
28: Spain (2022)	List of limit values. Available at: https://www.insst.es/el-instituto-al-dia/limites-de-exposicion-profesional-para-agentes-quimicos-2022 , accessed on 07.12.2022			
29: Sweden (2022)	List of limit values and amendments. Available at: https://www.av.se/arbetsmiljoarbete-och-inspektioner/publikationer/foreskrifter/hygieniska-gransvarden-afs-20181-foreskrifter/ , accessed on 07.12.2022			
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31: Australia (2022)	List of limit values. Available at: https://www.safeworkaustralia.gov.au/doc/workplace-exposure-standards-airborne-contaminants-2022 , accessed on 07.12.2022			
32: Brazil (2021)	List of limit values. Available at: https://www.guiatrabalhista.com.br/legislacao/nr/nr-15-anexo-11.pdf , accessed on 07.12.2022			
33: Canada, Ontario (2020)	List of limit values. Available at: https://www.ontario.ca/laws/regulation/900833 , accessed on 07.12.2022			
34: Canada, Québec (2022)	List of limit values. Available at: https://www.legisquebec.gouv.qc.ca/en/document/cr/S-2.1,%20r.%2013 , accessed on 07.12.2022			
35: India (2007)	List of limit values. Available at: https://dgtasli.gov.in/en/book-page/permissible-levels-certain-chemical-substances-in-work-environment , accessed on 08.12.2022			

Member State	OEL [mg/m ³]	Specification of OEL	STEL [mg/m ³]	Specification of STEL
36: Japan (2022)	List of limit values. Available at: https://www.nite.go.jp/en/chem/chrip/chrip_search/intSrh-SpcLst?sllIdxNm=&slScNm=RJ_04_061&slScCtNm=&slScRgNm=&ltCatFl=&slMdDplt=0&ltPgCt=200&stMd , accessed on 12.12.2022			
37: Japan - JOSH (2022)	List of limit values. Available at: https://www.sanei.or.jp/english/files/topics/oels/oel_en.pdf , accessed on 08.12.2022			
38: Norway (2022)	List of limit values. Available at: https://lovdata.no/dokument/SF/forskrift/2011-12-06-1358#KAPITTEL_8 , accessed on 10.12.2022			
39: Russia (2021)	List of limit values. Available at: http://publication.pravo.gov.ru/Document/View/0001202102030022 , accessed on 10.12.2022			
40: Switzerland (2022)	List of limit values. Available at: https://www.suva.ch/de-ch/services/grenzwerte#gnw-location=%2F , accessed on 10.12.2022			
41: Turkey (2013)	List of limit values. Available at: https://www.resmigazete.gov.tr/eskiler/2013/08/20130812-1.htm , accessed on 10.12.2022			
42: United Kingdom (2020)	List of limit values. Available at: https://www.hse.gov.uk/pubns/priced/eh40.pdf , accessed on 10.12.2022			
43: ACGIH, American Conference of Governmental Industrial Hygienists (2022)	TLVs and BEIs Based on the Documentation of the Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices.			
44: USA, NIOSH (2022)	List of limit values. Available at: https://www.cdc.gov/niosh/index.htm , accessed on 10.12.2022			
45: USA, OSHA (2022)	List of limit values. Available at: https://www.osha.gov/dsg/annotated-pels/tablez-1.html , accessed on 10.12.2022			

According to RAC, no legally binding BLVs for PAH metabolites are established (RAC, 2022b). The following table shows the reference values established in several countries.

Table 16-17 Current BLV in EU Member States and selected non-EU countries for PAH (status: April 2023)

Country	PAH in urine	Specification
Finland ^{1,2}	12 nmol µg 1-hydroxypyrene/l (ca. 2.3 µg 1-hydroxypyrene/g creatinine)	Biological limit value derived by FIOH; Parameter analysed 3-hydroxybenzo[a]pyrene in urine; corrected to the average relative density of the urine of Finnish workers of 1.021 g/ml; Sampling time: post shift
France ³	0.83 ng 3-hydroxybenzo[a]pyrene/g creatinine, following a B[a]P exposure of 150 ng/m ³	Threshold value proposed by INRS; Parameter analysed 3-hydroxybenzo[a]pyrene in urine; Sampling time: post shift
Germany ^{1,4}	Range of values starting from a value of 0.7 ng 3-hydroxybenzo[a]pyrene/g creatinine	Exposure equivalents for carcinogenic substances (EKA value, correlation between external and internal exposure)

Country	PAH in urine	Specification
	an external concentration of 0.07 µg/m ³ in air up to 7 ng/g creatinine for 1.5 µg/m ³	proposed by DFG (not legally binding); Parameter analysed 3-hydroxybenzo[a]pyrene in urine (by hydrolysis); Sampling time: for the long-term exposure: at the end of the working shift after several shifts
Greece ⁵	2.5 µg 1-hydroxypyrene/l	Parameter analysed 1-Hydroxypyrene (1-OHP) in urine (by hydrolysis), Adjusted for the pyrene to benzo(a)pyrene ratio of the PAH mixture to which workers are exposed; Sampling time: end of shift at end of workweek.
Ireland ^{1,6}	4 µmol 1-hydroxypyrene/mol creatinine	Parameter analysed 1-Hydroxypyrene; Sampling time: post shift
Slovakia ⁷	1.95 µmol 1-hydroxypyrene/mol creatinine	Polycyclic aromatic hydrocarbons (Carcinogen categories 1A and 1B); Parameter analysed 1-Hydroxypyrene; Sampling time: end of exposure or work shift
Non-EU countries		
United Kingdom ^{1,8}	4 µmol 1-hydroxypyrene/mol creatinine	Sampling time: post shift
USA, ACGIH ⁹	2.5 µg 1-hydroxypyrene/l	Biological Exposure Index (BEI®) recommended by ACGIH, Parameter analysed 1-Hydroxypyrene (1-HP) in urine (by hydrolysis), Adjusted for the pyrene to benzo(a)pyrene ratio of the PAH mixture to which workers are exposed; Sampling time: end of shift at end of workweek.

FIOH = Finnish Institute of Occupational Health

INRS = French National Research and Safety Institute for the Prevention of Occupational Accidents and Diseases

DFG = German Research Foundation, Permanent Senate Commission for the Investigation of Health Hazards of Chemical Compounds in the Work Area

ACGIH = American Conference of Governmental Industrial Hygienists

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4: Germany (2022) List of MAK and BAT values. Available at: https://doi.org/10.34865/mbwl_2022_eng, accessed on 14.02.2023

5: Greece (2019) List of limit values. Available at: https://www.elinyae.gr/sites/default/files/2019-10/oriakes%20times%202019_L_0.pdf, accessed on 05.12.2022

Country	PAH in urine	Specification
6: Ireland (2011) Biological Monitoring Guidelines. Available at: https://www.hsa.ie/eng/Publications_and_Forms/Publications/Chemical_and_Hazardous_Substances/Biological_Monitoring_Guidelines.pdf , accessed on 05.12.2022		
7: Slovakia (2020) List of limit values. Available at: https://www.epi.sk/zz/2006-355 , accessed on 07.12.2022		
8: United Kingdom (2020) List of limit values. Available at: https://www.hse.gov.uk/pubns/priced/eh40.pdf , accessed on 10.12.2022		
9: ACGIH, American Conference of Governmental Industrial Hygienists (2022), TLVs and BEIs Based on the Documentation of the Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices.		

16.5 Annex 5 - Selection procedure of relevant compounds in substance groups

Substances within the scope of the study

Substances within the scope of the Directive are substances that meet the criteria for classification as category 1A or 1B carcinogen, mutagen or reproductive toxicant as set out in Annex I to Regulation (EC) No 1272/2008 of the European Parliament and of the Council (the CLP). Substances that meet the criteria may either have a harmonised classification and listed in Annex VI to the CLP or they may have been classified by the manufacturer or importers' self-classification.

PAH occur almost always in mixtures of several PAH and are formed during incomplete pyrolysis processes of organic materials. Therefore, PAH are process-generated and/or are released unintentionally during use. The whole mixture is within the scope of the Directive.

16.5.1 Harmonised classification

Ten PAH have a harmonised classification under the CLP that indicates they are carcinogenic (Carc. 1B); of these, one is further classified reprotoxic (Repr. 1B).

Table 16-18 Harmonised classification of ten PAH classified as carcinogenic according to Annex VI to the CLP

EC No	Chemical name	CAS No	Hazard class and category	Hazard statement code
205-916-6	Benzo[k]fluoranthene	207-08-9	Carc. 1B Aquatic Acute 1 Aquatic Chronic 1	H350 H400 H410
205-923-4	Chrysene	218-01-9	Muta. 2 Carc. 1B Aquatic Acute 1 Aquatic Chronic 1	H431 H350 H400 H410
200-028-5	Benzo[a]pyrene	50-32-8	Skin Sens. 1 Muta. 1B Carc. 1B* Repro. 1B Aquatic Acute 1 Aquatic Chronic 1	H317 H340 H350 H360FD H400 H410

EC No	Chemical name	CAS No	Hazard class and category	Hazard statement code
205-911-9	Benzo[e]acephenanthrylene	205-99-2	Carc. 1B Aquatic Acute 1 Aquatic Chronic 1	H350 H400 H410
200-280-6	Benz[a]anthracene	56-55-3	Carc. 1B Aquatic Acute 1** Aquatic Chronic 1	H350 H400 H410
205-892-7	Benzo[e]pyrene	192-97-2	Carc. 1B (H350) Aquatic Acute 1 Aquatic Chronic 1	H350 H400 H410
205-910-3	Benzo[j]fluoranthene	205-82-3	Carc. 1B Aquatic Acute 1 Aquatic Chronic 1	H350 H400 H410
200-181-8	Dibenz[a,h]anthracene	53-70-3	Carc. 1B* Aquatic Acute 1** Aquatic Chronic 1	H350 H400 H410
205-878-0	Dibenzo[b,def]chrysene; dibenzo[a,h]pyrene	189-64-0	Muta. 2 Carc. 1B	H341 H350
205-877-5	Benzo[r,s,t]pentaphene	189-55-9	Muta. 2 Carc. 1B	H341 H350

Notes: in bold are the harmonised classification endpoints that make the substances within scope of the CMRD. * Specific Concentration Limit: C ≥ 0.01%

** M-factor: M=100

16.6 Annex 6 - Relevant sectors

Table 16-19 Analysed sectors with risk of exposure to PAH

NACE code	NACE definition	Refined short name for relevant sub-sector	Description of activity
C10.13, C10.20	Production of meat and poultry meat products; Processing and preserving of fish, crustaceans and molluscs	Fish and meat smoke houses	Smoking of fish and meat for preservation purposes
C16.1	Sawmilling and planing of wood	Wood preservation (creo-sote)	Impregnation of wood with creosote
C19.10	Manufacture of coke oven products	Coking plants	Carbonation of coal
C19.2	Manufacture of refined petroleum products	Petroleum refineries	Refining of crude oil
C20.13	Manufacture of other inorganic basic chemicals	Manufacture of carbon black	Reaction of aromatic compounds to manufacture carbon black
C20.14	Manufacture of other organic basic chemicals	Coal tar distillation	Refining of coal tar

NACE code	NACE definition	Refined short name for relevant sub-sector	Description of activity
C23.2	Manufacture of refractory products	Manufacture of refractory products	Manufacture of refractory products with coal tar pitch high-temperature (CTPht)
C23.99a	Manufacture of other non-metallic mineral products n.e.c	Manufacture of bituminous products	Use of bitumen to manufacture road paving and roofing products
C23.99b		Graphite and carbon electrodes manufacture	Use of carbon solids and binding agents such as CTPht to manufacture graphite and carbon electrodes, via baking, impregnation, shaping and graphitisation at high temperatures
C24.1	Manufacture of basic iron and steel and of ferro-alloys	Steel and iron foundries, ferroalloys	Use of coal, coal powders and graphite electrodes to manufacture iron and steel
C24.45	Other non-ferrous metal production	Other non-ferrous metallurgical processes	Use of Søderberg electrodes, briquettes or paste at high temperature to manufacture non-ferrous metals and products
C24.42	Aluminium production	Manufacture of aluminium	Use of carbon and graphite electrodes to manufacture aluminium
C24.5	Casting of metals	Casting of metals	Casting of metals in sand moulds
D35.11	Production of electricity	Coal fired power plants	Use of coal to generate electricity
E38.2	Waste treatment and disposal	Waste incineration	Incineration of municipal or hazardous waste
E39	Remediation activities and other waste management services	Soil remediation	Thermal soil remediation of soil contaminated with PAH, may include excavation
F42.11	Construction of roads and motorways	Road paving	Paving of roads with bitumen
F42.12	Construction of railways and underground railways	Welding of train tracks	Welding of train tracks impregnated with creosote oil
G45.2	Maintenance and repair of motor vehicles	Motor vehicle maintenance and repairs	Maintenance and repair of motorised vehicles
N81.22	Other building and industrial cleaning activities	Chimney sweeps	Cleaning of chimneys
O84.25	Fire service activities	Firefighters	Extinguishing and monitoring fires

16.7 Annex 7 - Consistency and synergies of establishing OELs under the CMRD

PAH currently are regulated in the EU under multiple other forms of legislation including:

- REACH – Authorisation (CTPht and anthracene oil), Restriction (Extender oils, rubber or plastic in article for general public, toys and childcare articles, granules or mulches in sport applications);
- Existing/future OELs – Diesel engine exhaust emissions (DEEE) and Benzene;
- Cosmetics products regulation (EC) No 1223/2009 – Specific PAH are prohibited in cosmetics products; and
- Persistent Organic Pollutants Regulation (POPs, EU) 2019/2021 – PAH listed in annex III part B – substances subject to release reduction provisions.

OELs for PAH therefore need to ensure consistency with the above regulation of PAH via other routes of legislation. In the case of REACH Authorisation and Restriction these have been assessed by the current study and would result in more specific controls of PAH exposure often tailored to specific products or sectors, e.g. anthracene oil, or exposure specifically via dermal/oral routes from consumer products. Introduction of OELs at the preferred policy option would therefore act as an extension of protection above what is currently delivered under REACH.

In terms of current/future OELs for DEEE and Benzene, the findings of this study indicate a high degree of uncertainty as to whether these OELs would influence PAH exposure. This derived from mixed responses as part of the consultation efforts and in the case of DEEE the majority of exposure occurring before the engine emissions stage. OELs at the preferred policy option for PAH in general therefore will increase worker protection from PAH where these other OELs may fail to do so.

Considering the prohibition of specific PAH under the Cosmetics Regulation (EC) 1223/2009, this currently prohibits eight specific PAH, anthracene oil and mixtures including benzo[a]pyrene >0.005% w/w. The introduction of the preferred policy option would ensure that manufacturers of cosmetic products would also be protected as well as consumers. This policy option may also relate to decreases in concentrations of PAH in cosmetic product outside of those currently prohibited in the Cosmetics Regulation.

Finally considering the POPs Regulation, the implementation of the preferred policy option will likely result in process changes to large numbers of industry members. This in turn will likely help to reduce environmental releases of PAH to the environment helping to further the targets set out in Annex III part B of this regulation.

Overall, the introduction of the preferred policy option does not provide major inconsistencies with existing EU regulations relating to PAH exposure and in many cases may be used to help further improve worker safety via increasing the scope over existing regulations.

16.8 Annex 8 - PAH – DEVELOPMENTAL TOXICITY

Benchmark Dose Modelling: Report

European Food Safety Authority (EFSA)

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Data Description

The endpoint to be analyzed is: Survival.

Data used for analysis:

Conc	Survival	SEMsurviv	size
0	98.9	1.1	10
25	78.3	4.1	10
75	38.0	2.1	10
100	33.8	1.3	10

Information pertaining to this endpoint.

Selection of the BMR

The BMR (benchmark response) used is a 10% change in mean response compared to the controls. The BMD (benchmark dose) is the dose corresponding with the BMR of interest.

A 90% confidence interval around the BMD will be estimated, the lower bound is reported by BMDL and the upper bound by BMDU.

Software Used

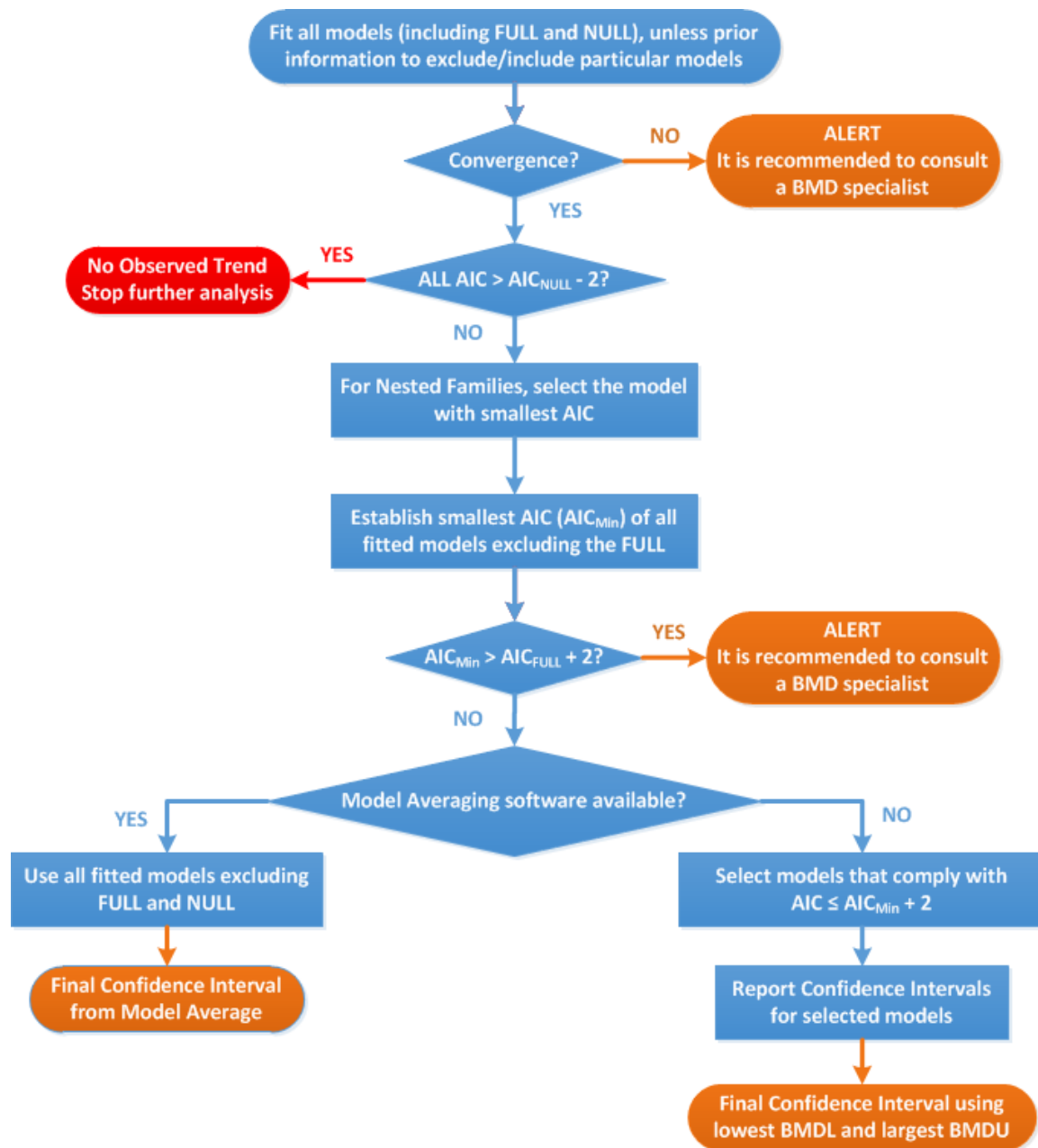
Results are obtained using the EFSA web-tool for BMD analysis, which uses the R-package PROAST, version 70.0, for the underlying calculations.

Specification of Deviations from Default Assumptions

Default set of fitted models:

Model	Number of parameters	Formula
Null	1	$y = a$
Full	no. of groups	$y = \text{group mean}$
Exp model 3	3	$y = a \cdot \exp(bx^d)$
Exp model 4	4	$y = a \cdot (c - (c - 1)\exp(-bx^d))$
Hill model 3	3	$y = a \cdot \left(1 - \frac{x^d}{b^d + x^d}\right)$
Hill model 4	4	$y = a \cdot \left(1 - \frac{(c - 1) \cdot x^d}{b^d + x^d}\right)$
Inverse Exponential	4	$y = a \cdot (1 + (c - 1)\exp(-bx^{-d}))$
Log-Normal Family	4	$y = a \cdot (1 + (c - 1)\Phi(\ln b + d \ln x))$

Procedure for selection of BMDL



Flowchart for selection of BMDL

Results

Response variable: Survival

Fitted Models

model	converged	loglik	npar	AIC
full model	yes	25.41	5	-40.82
null model	yes	-27.29	2	58.58
Expon. m3-	yes	20.76	4	-33.52
Expon. m5-	yes	25.41	5	-40.82

model	converged	loglik	npar	AIC
Hill m3-	yes	20.81	4	-33.62
Hill m5-	yes	25.41	5	-40.82
Inv.Expon. m3-	yes	22.05	4	-36.10
Inv.Expon. m5-	yes	23.37	5	-36.74
LN m3-	yes	21.52	4	-35.04
LN m5-	yes	24.27	5	-38.54

Estimated Model Parameters

EXP

estimate for var- : 0.01644

estimate for a- : 98.84

estimate for CED- : 15.47

estimate for c- : 0.3294

estimate for d- : 1.922

HILL

estimate for var- : 0.01644

estimate for a- : 98.84

estimate for CED- : 16.91

estimate for c- : 0.2988

estimate for d- : 2.522

INVEXP

estimate for var- : 0.0182

estimate for a- : 99.95

estimate for CED- : 13.35

estimate for c- : 0.01157

estimate for d- : 0.5

LOGN

estimate for var- : 0.0174

estimate for a- : 100

estimate for CED- : 14.08

estimate for c- : 0.1844

estimate for d- : 1

Weights for Model Averaging

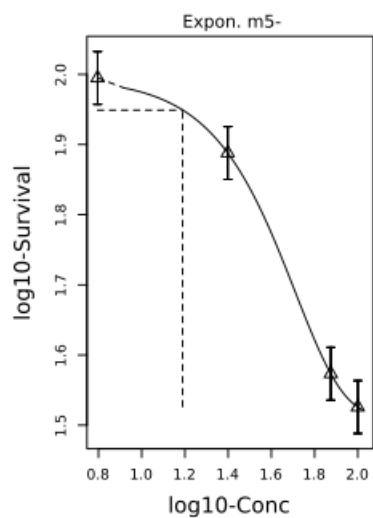
EXP	HILL	INVEXP	LOGN
0.41	0.41	0.05	0.13

Final BMD Values

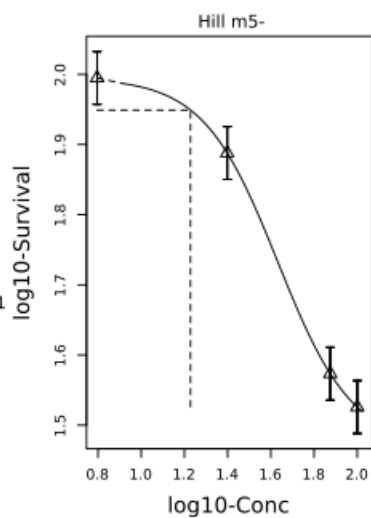
endpoint	subgroup	BMDL	BMDU
Survival	all	9.29	20.9

Confidence intervals for the BMD are based on 1000 bootstrap data sets.

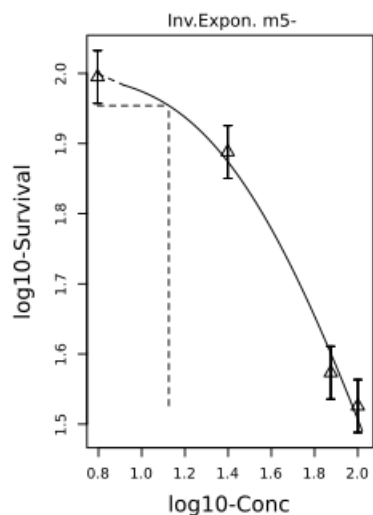
Visualization



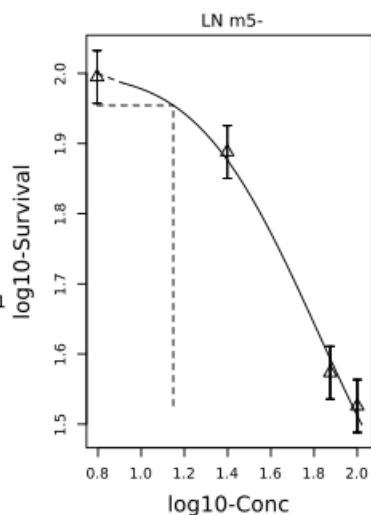
version: 70.0
loglik 25.41
AIC -40.82
var- 0.01644
a- 98.84
CED- 15.47
c- 0.3294
d- 1.922
CES -0.1
CEDL 10.6
CEDU 21.3
b: 51.32
conv : 1
scaling factor on x : 1
dtype : 10



version: 70.0
loglik 25.41
AIC -40.82
var- 0.01644
a- 98.84
CED- 16.91
c- 0.2988
d- 2.522
CES -0.1
CEDL 11.6
CEDU 22
b: 42.89
conv : 1
scaling factor on x : 1
dtype : 10

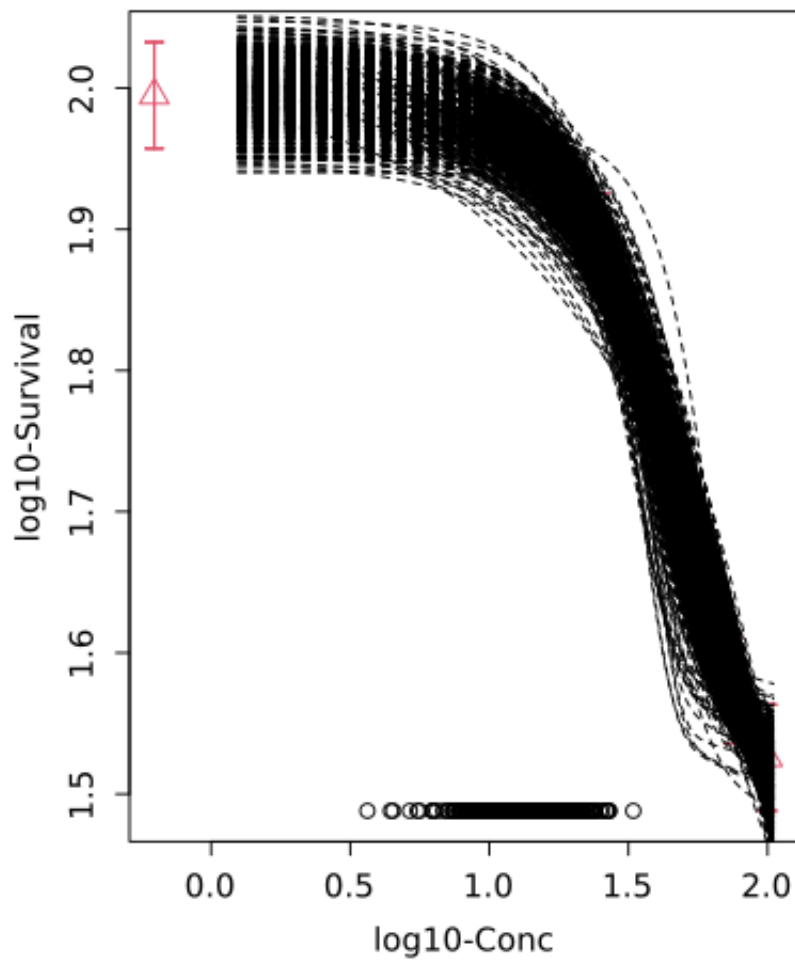


version: 70.0
loglik 23.37
AIC -36.74
var- 0.0182
a- 99.95
CED- 13.35
c- 0.01157
d- 0.5
CES -0.1
CEDL 9.39
CEDU 17.5
b: 187.2
conv : 1
scaling factor on x : 1
dtype : 10



version: 70.0
loglik 24.27
AIC -38.54
var- 0.0174
a- 100
CED- 14.08
c- 0.1844
d- 1
CES -0.1
CEDL 10.7
CEDU 17.6
b: 0.01529
conv : 1
scaling factor on x : 1
dtype : 10

bootstrap curves based on model averaging



version: 70.0
model averaging results
dtype 10
selected all
dose scaling: 1
conf level: 0.9
number of runs: 1000
CES -0.1
BMD CI
9.3 20.9

16.9 Annex 9 - Additional tables

Table 16-20 Percentile distribution of exposed workers in each sector by EU Member State (values = %)

EU 27	% of EU population 2021	Sector (percentage of exposed workers in MS)																					
		C10.13	C10.2	C16.1	C19.1	C19.2	C20.13	C20.14	C23.2	C23.99a	C23.99b	C24.1	C24.42	C24.45	C24.5	D35.11	E38.2	E39	F42.11	F42.12	G45.2	N81.22	O84.25
BE	2.6	1.3	1.2	0.9		6.9	3	14.3	1.2	1.5		3.8		2.6	1.2		2.2	2.5	2.3	1.3	1.5	4.5	2.4
BG	1.5	1.4	1.4	2.2		1.7	1.1		1.2	2.6		0.5			1.5	5.6	1.3	1	2.6	1.6	1.5	0.9	1.6
CZ	2.4	1.8	0.7	3.4	21.7			14.3	12.8	4		5.5		0.5	6.4	12.8	1.4	2.6			3.7		2.6
DK	1.3	0.8	2.8	0.4			0.5	14.3		4.6		0.8			0.7	2	1.1	0.8	0.5	1.6	1.4	1.8	1.5
DE	18.3	34.9	7.2	13.2	3.2		22.2	14.3	26.7	25.9	20	26.4	33.3	54.1	34.6	30.6	24.8	17.5	15.9	17.8	20.2	24.3	20.9
EE	0.3	0.6	1.3	2.3			0.1										0.3	0.3	0.5	0.5	0.4	3	0.3
IE	1.1	1.1	2.2	0.5		1.7	0.3			0.8		0.3			0.1	0.5	1	1	0.6	0.1	1	2.8	1.2
EL	2.4	0.8	1.4	0.5	0.3	6.9	0.3		1.2	2		0.7	11.1	0.2	0.4	1.5	0.6	1	1.5	0.6	2.4	0.7	2
ES	10.6	10.8	22.5	3	2.7	19	6.8	28.6	9.3	8.1	10	6.8	11.1	1.9	6.7	3.6	14.4	4.8	5.7	12.3	10	3.1	10
FR	15.1	9.1	11.9	8.3			33.7		3.5	6.2	25	8	22.2	10.2	8.4	3.1	17	29.1	24.4	3.3	11.1	16.8	14
HR	0.9	1.1	1.3	3.4		5.2	0.1			0.9					1.2	0.5	0.5	1	1.5	0.3	0.8	0.4	0.8
IT	13.2	6.6	5.9	4.1	9.3	27.6	8.2		8.1	10.1	5	14.1		8.4	11.1	3.6	10.6	15.1	5.3	12	15.3	15.9	11.4
CY	0.2	0.1															0.1	0.2	0.1		0.4	0.1	0.2

EU 27	% of EU popula- tion 2021	Sector (percentage of exposed workers in MS)																					
		C10.13	C10.2	C16.1	C19.1	C19.2	C20.13	C20.14	C23.2	C23.99a	C23.99b	C24.1	C24.42	C24.45	C24.5	D35.11	E38.2	E39	F42.11	F42.12	G45.2	N81.22	O84.25
LV	0.4	0.6	2.5	5.1	0.1					0.1		0.1					0.2	0.3	1	0.3	0.7	0.5	0.4
LT	0.6	0.7	5.4	2.8		1.7	0.1			0.3				0.1			1.1	0.6	1.1	0.3	1.2	1.2	0.7
LU	0.1									0.2		0.1					0.1	0.1	0.6	0.2	0.1	0.9	0.2
HU	2.2	2.1	0.3	1.6	21.1	5.2	0.9		2.3	4		1.6			3.5	1.5	3.7	1.1	2.6	4.7	2.1	0.9	2.3
MA	0.1									0.1							0.1	0.1			0.1	0.1	0.1
NL	3.9	1.7	2.8	0.8			3.6		3.5	2.8		1.7		1.8	1.4	2	3.1	2.4	4	5.5	1.9	4.8	4.7
AU	2.0	2.5	0.1	5.2		1.7	1.4		8.1	1.6	10	7.1		14.4	3.1		1.2	1.1	3.6	1.4	2.2	1.6	2.2
PL	8.4	11.5	17	16.7	40.8	8.6	8.7	14.3	11.6	10.8	20	7.2		1.1	9.6	21.9	6.3	6.3	13.1	18.9	9.6	8.6	8.4
PT	2.3	1.5	7.8	2			0.4		1.2	1.6		0.4			1.6		3.4	1.8	1.8	1.6	3.3	1.8	2.4
RO	4.3	5	1.2	9.9	0.9		4.5		1.2	2.5	5	2.7	11.1	1.8	1.9	4.1	1.6	5.4	7.2	3.6	3.5	1.3	3.9
SI	0.5	0.3	0.1	1.2			0.4		1.2	1.7		0.9			2.4	1	0.5	0.5	0.7	0.5	0.6	0.3	0.5
SK	1.2	0.6	0.3	4.4		1.7			3.5	2.5	5	3.7		0.8	1.9	2	1.7	0.5	0.9	1.1	1.2	0.4	1.3
FI	1.2	2	1	2.7		3.4	2.2			1.2		2.7		1.9	0.8	3.6	0.9	0.8	0.8	3.3	1.4	0.9	1.3
SE	2.3	1	1.7	5.3		8.6	1.4		1.2	3.8		4.7	11.1	0.2	1.4		0.8	2.1	1.7	7.4	2.3	2.5	2.6

EU 27	% of EU popula- tion 2021	Sector (percentage of exposed workers in MS)																					
		C10.13	C10.2	C16.1	C19.1	C19.2	C20.13	C20.14	C23.2	C23.99a	C23.99b	C24.1	C24.42	C24.45	C24.5	D35.11	E38.2	E39	F42.11	F42.12	G45.2	N81.22	O84.25
Total work ers	100%	713	1,62 6	1,00 0	2,51 6	20,2 66	1,02 0	750	86	5,80 0	1,00 1	95,7 52	626	616	68,1 09	18,0 01	1,88 8	10,5 50	6,43 7	6,43 7	371, 532	24,5 00	438, 506

Source: Study team calculations on the basis of Eurostat and consultation data.

Notes: Blank cells reference the absence of a sector within a Member State. Percentages are estimates and there is uncertainties on their accuracy due to the classifications of relevant sectors in Eurostat data. Shading has been applied to the above table to highlight sectors with >10% of workers in each Member State.

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