ISPRA
Istituto Superiore per la Protezione
e la Ricerca Ambientale

Sistema Nazionale
per la Protezione
dell'Ambiente

Efficiency and decarbonization indicators in Italy and in the biggest European Countries

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There may be reports with only one author but no reports without a hidden crowd. Behind anyone, many others are always concealed. I would like to express my gratitude to every single colleague I worked with, for their helpfulness to provide data. Special thanks to Antonella Bernetti who supplied detailed data on transport, and to Emanuele Peschi for his mindful reading of draft and stimulating exchange of ideas.
Any errors remain responsibility of the author.

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"Plato, upon the discourse of the state of human bodies and those of beasts, says: «I should know that what I have said is truth, had I the confirmation of an oracle; but this I will affirm, that what I have said is the most likely to be true of any thing I could say.»"

Michel de Montaigne, *The Essays, Apology for Raymond Sebond*, 1576.

"Countries do their best to apply the standardized concepts and methods established by the United Nations and other international organizations, but national accounting is not, and never will be, an exact science."
Thomas Piketty, *Capital in the Twenty-First Century*, 2013.

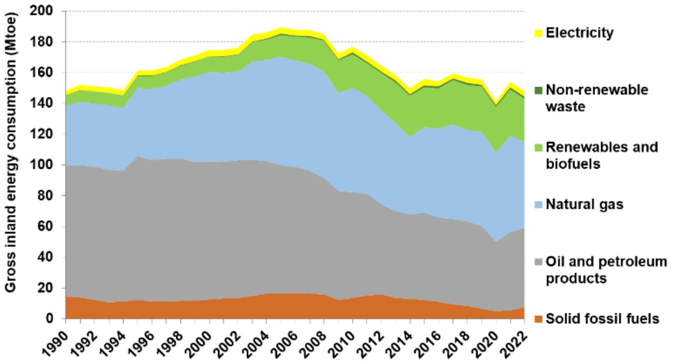
INDEX

EXECUTIVE SUMMARY

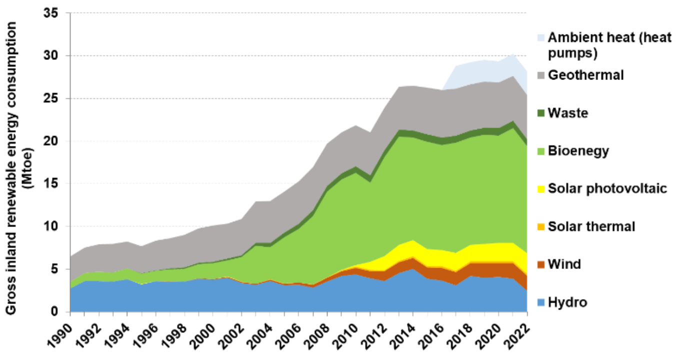
NATIONAL DATA

Italian energy consumption and GHGs

Gross inland energy consumption in Italy shows an increasing trend from 1990 until 2005 when it peaked at 189.4 Mtoe, then there was a reduction, accelerated by the economic crisis started in 2008, with the minimum value of 149.8 Mtoe reached in 2014 and a recovery in the following years. After the fall occurred in 2020 due to SARS-CoV-2 pandemic in 2021 a rebound of consumption has been recorded (+8.8% higher than 2020), with 154 ktoe, followed by further setback in 2022 (-3.9% lower than 2021).



Fossil fuels are the main energy carriers in the national energy system. From 1990 to 2007, the average ratio of fossil fuels over the gross domestic consumption was more than 90%, although with a slight decline. After 2007 the share of fossil energy has been severely reduced. From 1990 to 2022 the share of fossil energy decreased from 93.6% to 78.5%, with the lowest value in 2020 (77.3%). The decline has become particularly steep since 2007. The national fuel mix has changed considerably since the 1990s. Oil products accounted for the predominant component with 57.3% of gross domestic consumption in 1990. The share of oil products has steadily decreased to 31.7% in 2020, with a rebound in the following years (34.8% in 2022). The share of natural gas follows a specular trend with constant increase since 1990 up to 2020 (from 26.3% to 41.2%), followed by a decreasing trend (37.9% in 2022). The share of solid fuels, after a decreasing trend since 2012 up to 2021 (from 9.6% to 3.6%), recorded a rebound to 5% in 2022.

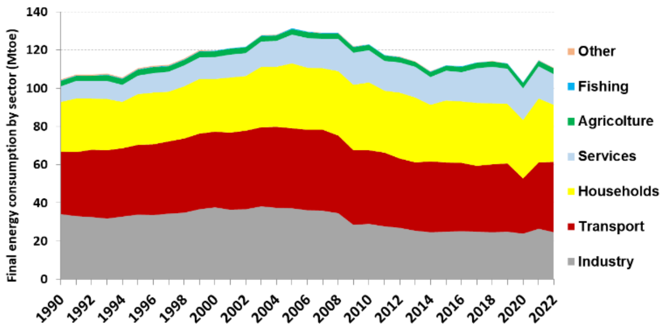


The share of energy from renewable sources is complementary to that observed for fossil fuels. From 1990 to 2007 there was a steady increase in the share of such sources from 4.4% to 9%. After 2007 the share accelerated to 20.7% of gross inland consumption in 2020, followed by a setback in the last years (19.6% in 2021 and 19% in 2022). Renewable gross inland consumption has more than quadrupled from 6.5 Mtoe in 1990 to 29.3 Mtoe in 2022.

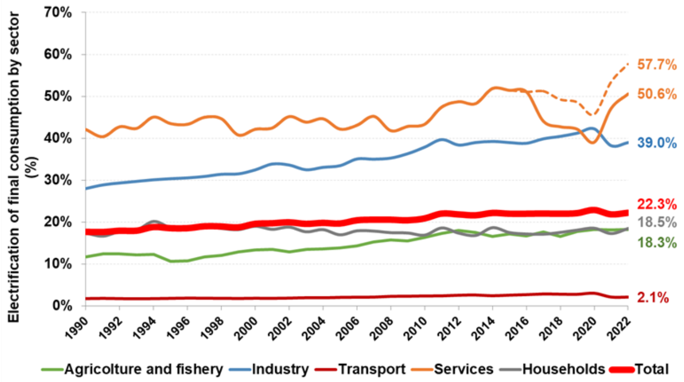
Up to 2000 the main sources of renewable energy have been geothermal and hydro, which accounted for more than 80% of gross inland consumption of renewable energy. The remaining share was mainly met by biomass and renewable wastes (bioenergy). Since 2000, the bioenergy has shown a considerable growth, reaching the peak of time series in 2008, with a share of 50.9%. In 2022, the share of bioenergy is 44.4%. In recent years, solar (thermal and photovoltaic) and wind energy have also assumed significant role and together represent 15.8% of renewable energy consumption. Since 2017 the heat pumps energy has been recorded by Italy in the Eurostat budget. Such item in 2022 was 9.8% of renewable gross inland consumption.

The final energy consumption per sector shows structural peculiarities for each sector and different sensitivities to the contingency, such as economic crisis since 2008 or 2020 lockdown which have mainly affected the productive branches. The final energy consumption of industry decreased by 27.8% from 1990 to 2022, while the services increased by 97.4%. The trend of final consumption in the households is quite variable depending upon different climatic conditions that affect the consumption. The consumption of residential sector in 2022 is 15.3% over the 1990 level. The overall trend for transport, including international aviation, increased by 12.2% from 1990 to 2022, after the fall in 2020 due to the lockdown measures.

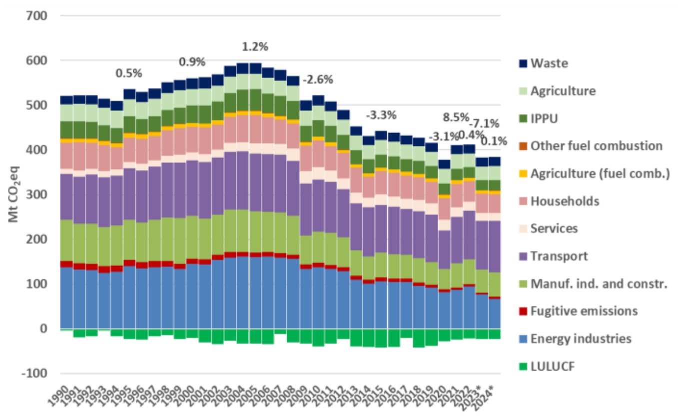
Since the 1990s, the structure of sectors in terms of energy consumption has changed considerably. Services account for an increasingly share of final consumption from 7.8% in 1990 to 14.6% in 2022, while industry reduces its share of energy consumption from 32.6% to 22.2% over the same period. Consumption in the households shows a growing trend until 2010 followed by slight decrease with large fluctuations mainly due to the average temperature. The average share of consumption in the other sectors, mainly agriculture and fisheries, is about 3%.



The electrification of final consumption is a key strategy to curb GHGs if pursued in parallel with the spread of renewable energy for electricity production. The share of electricity in final energy consumption increased since 1990 and in 2022 is 22.3%. The sectoral electrification level of final consumptions is quite different. Services show the highest share of electricity consumption, with more than 50% of the sector's final consumption. The rate of electrification of final consumption in industry has been steadily increasing since 1990, with 39% of electricity in the final consumption in 2022. The wide oscillations recorded in the last years for services and industry are also due to significant change in the countability methodology. The electrification of households and transport sectors shows no significant increase and in 2022 were 18.5% and 2.1% respectively. Agriculture and fisheries show an increase of electrification, similarly to industry, and in 2022 the level was 18.3%.



GHGs show an increasing trend until 2005, followed by decrease also because of the economic crisis. In 2020 GHGs (379.1 Mt CO_{2eq}) was heavily affected by lockdown measure to contain SARS-CoV-2 pandemic. GHGs fell by 27.4% in 2020 compared to 1990 and by 36.4% compared to 2005. All sectors reduced the emissions, albeit at different rates. In 2021 and 2022 the GHGs rebounded, although to level below the 2019 level. The 2022 GHGs fell by 20.9% compared to 1990 and by 30.7% compared to 2005. ISPRA's preliminary estimates for 2023 show that GHGs are well below the level of the previous year (-7.1%), mainly for the reduction recorded in energy industries. Preliminary estimates for 2024 show that the emissions should be as in the previous year.



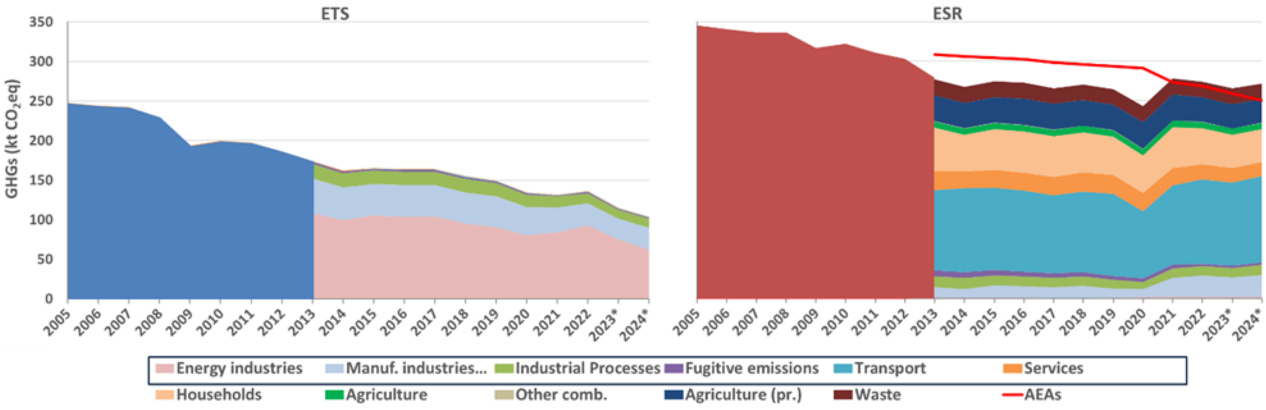
Emissions from manufacturing and construction decreased by 40.7% from 2005 to 2022. Transports increased steadily with a reversal of the trend only after 2007 and the sharp decrease in 2020; emissions in 2022 are 14.5% lower than 2005, but still over 1990 level (+7.4%). Households reduced the emissions by 21.6% compared to 1990, while the sector of services increased of 64.2%.

GHGs per capita increased from 9.2 t CO_{2eq} in 1990 to 10.3 t CO_{2eq} in 2004, in the following years there was a rapid decline up to 6.4 t CO_{2eq} in 2020. In 2022 the level is 7 t CO_{2eq}. The GHGs per capita decreased from 2005 to 2022 with an average annual rate of -2.2% (-0.9% since 1990).

GHGs from ETS and ESR

To monitor the achievement of emissions reduction targets the GHGs must be allocated in the two compartments: ETS (EU Emissions Trading System, EU ETS) and ESR (Effort Sharing Regulation), defined according to the European legislation.

ETS covers 33% of national GHGs in 2022. The share of such emissions steeply decreased from 2005, when it was 42%. The ESR scope from 2021 to 2030 remains substantially unchanged compared to the previous period up to 2020, but since 2021 only CO_2 from domestic aviation is not included in the ESR sector, no longer NF3, as until 2020. ESR accounts for 66.4% of total GHGs in 2022 with an increasing share since 2005, when it was almost 58%. GHGs decreased both in ETS and in ESR from 2005 to 2022, even though in ETS with a double rate than in ESR, -44.5% and -20.1% respectively. Moreover, since 2021 GHGs show a vigorous rebound in ESR (+12.3% in 2022 compared to 2020), while in ETS the increase is quite modest (+1.4%).



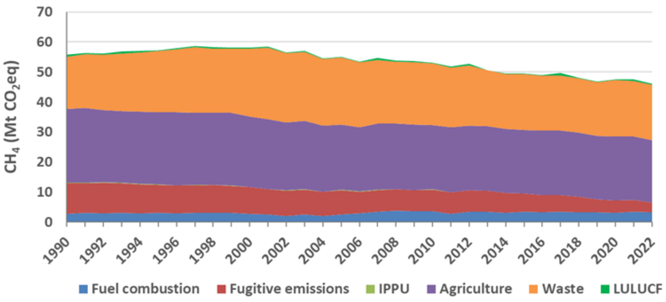
On the ETS side the dominant role is played by energy industries (68.1% of ETS GHGs in 2022) whose emissions are almost totally included in ETS (about 98% of sector's emissions), only a marginal share is in ESR. In the latter compartment the dominant role is played by transport with 38.8% of GHGs in 2022, the tiny share in ETS for such sector is utterly due to pipeline transport. GHGs from manufacturing industries and construction, together with industrial procesess, account for 29.8% in ETS and 14% in ESR. The fugitive emissions in ETS concern only CO_2 from flaring in refineries, while all other sources and GHGs are in ESR. GHGs from services are almost totally in ESR (about 98%) and represent 7% of compartment's GHGs. GHGs from households, agriculture (both combustion and processes), and waste are totally in ESR with shares of 16.5%, 14.1%, and 7.3% respectively. Sectors with higher share of GHGs should be the priority targets of policies and measures directed to achieve the GHGs reduction goal set for ESR emissions.

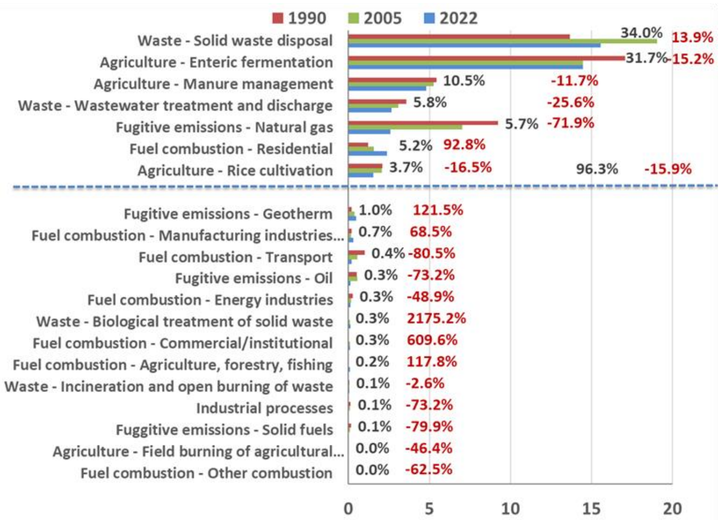
Methane emissions

Methane is a powerful greenhouse gas, second only to carbon dioxide in terms of its contribution to global warming (IPCC, 2021). Methane has a Global Warming Potential (GWP) about 85 times that of CO_2 over a period of 20 years, although CO_2 has an atmospheric lifetime of thousands of years, while methane disappears in about 10-15 years. The rapid decay of methane and its high impact on atmospheric temperature make it a primary target to curb in a timely and effective manner the climate change.

According to the recent report of the International Energy Agency (IEA, 2024) and IPCC (2022) reducing anthropogenic methane emissions is one of the most effective strategies, including in economic terms, to rapidly reduce the rate of warming and contribute significantly to efforts to limit the increasing global temperature.

National methane emissions, without the contribution of natural sources, represent on average 10.6%±0.8% of total emissions from 1990 to 2022. Methane emissions without LULUCF decreased from 55 to 45.7 Mt CO_2eq from 1990 to 2022 (-16.8%). The reduction of methane emissions is lower than the reduction of total GHGs (-20.9%). Moreover, GHGs other than methane reduced by 21.3% from 1990. These rates show the need to achieve methane emissions reduction from the main sources.





Among the main sources, methane emissions from wastes in 2022 were higher than 1990 levels (+6.3%), although the trend is descending from 2005 (-17.4%). Since 1990 agriculture decreased by 15.4% and fugitive emissions by 68%. Considering only methane emissions, agriculture contributes with 45.6% in 2022, while the waste sector accounts for 40.3%. Fugitive emissions make up 7.1%, and unburned methane in the energy sector accounts for 7%.

By far the most important source of the agricultural sector is represented by enteric fermentation, or the digestive processes of farm animals. This source represents 69.5% of methane emissions from the agriculture in 2022, followed by manure management with 23% and rice cultivation with 7.4%. Emissions due to the combustion of agricultural residues in the open field represent <0.05%.

In the waste sector, the dominant source of methane emissions is represented by the disposal of solid waste, responsible for 84.6% of sector's methane emissions in 2022, the next source is represented by wastewater treatment, with 14.5%. The remaining two sources, biological treatment of solid waste and incineration and open field burning, account for a share lower than 1%.

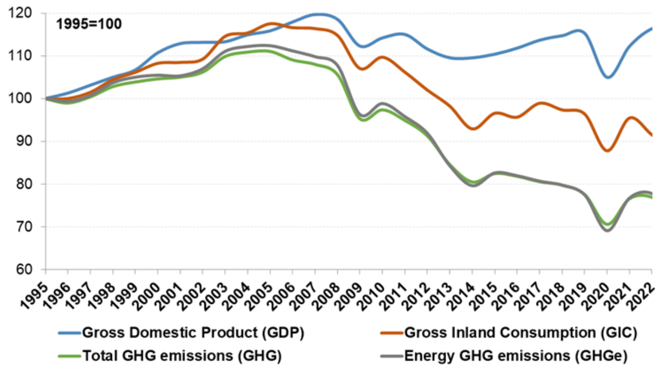
Most of the fugitive methane emissions are due to the natural gas supply chain (production, transport, and distribution) which in 2022 accounts for 80.1% of total fugitive methane emissions with a share that has decreased significantly since 1990, when it was 91.2%. Oil and natural gas supply chains have recorded reductions in methane emissions of more than 72% since 1990.

Unburned methane emissions in the energy sector are mainly due to the dominant source of the civil sector (mainly residential) with 79.8% of methane emissions in the energy sector in 2022, followed by manufacturing and construction industries with 9.9%, transport with 6.2% and energy industries with 4.1%.

Arranging in descending order the methane emissions from each source recorded in 2022 it can be noted that 96.3% of methane emissions come from seven key sources that emit 44 Mt CO_2eq. Emissions from key sources decreased by 15.9% since 1990. Minor sources, which are cumulatively responsible for 3.7% of emissions, are 35.4% lower than 1990 level. The disposal of municipal solid waste is the first key source with 34% of total methane emissions, followed by enteric fermentation with 31.7%. The first two sources are responsible for almost two-thirds of methane emissions.

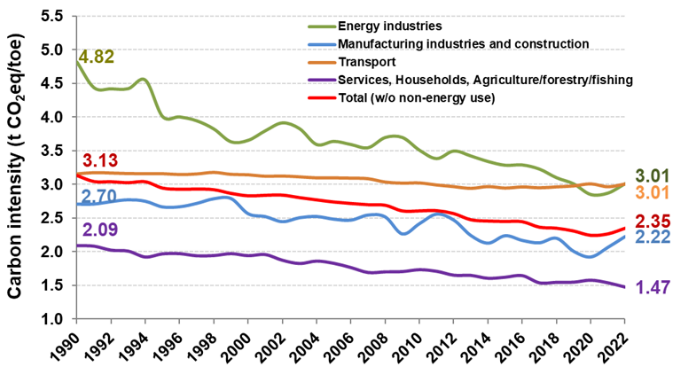
Energy intensity and decarbonization indicators

To assess the relationship between energy, economy and GHGs the trends of gross inland energy consumption (GIC), gross domestic product (GDP) and GHG emissions are analysed. GDP and GIC had parallel trends up to 2005. Then the two parameters begun to diverge showing an increasingly decoupling. GHGs grew slower than GDP until 2005, highlighting a relative decoupling. After 2005, the divergence between the two parameters became wider showing even absolute decoupling when the GDP increased and GHGs decreased (2015-2019).



Decoupling is also evident from the decreasing trend in the ratio of GIC to GDP since 2005. The decreasing trend in energy GHGs per primary energy consumption is mainly due to the replacement of higher carbon fuels with natural gas, mostly in power sector and industry, and to the increase of renewable share. The same decreasing trends are confirmed for final energy consumption (net of non-energy uses) per GDP and for GHGs per final energy consumed.

In the period 1995-2022 the GIC per GDP decreased from 107.5 toe/M€ to 83.5 toe/M€ (-22.3%). Over the same period, GHGs per GDP fell by 34.9%, from 357.8 t CO_2eq / M€ to 233 t CO_2eq/M€, while energy emissions per primary energy goes from 2.81 t CO_2eq/toe to 2.34 t CO_2eq/toe, with a reduction of 16.8%. Since 2005 there has been an acceleration in the decrease of energy intensity (on the economy side) and decarbonization of the national economy up to 2019/2020, once again highlighting the growing decoupling of economic activity, energy consumption and emissions. The causes of such decoupling are manifold and among the main ones there is the contraction of industrial activities, which are more energetic intensive as compared to services characterized by lower energy intensity and higher value added. GHGs per energy consumed (primary and final) decreased rapidly since 2005 mainly because of the increasing share of renewable energy since 2007. After 2020 the indicators show an upward trend due to the increasing share of oil fuels (2021 and 2022) and solid fuels (2022).

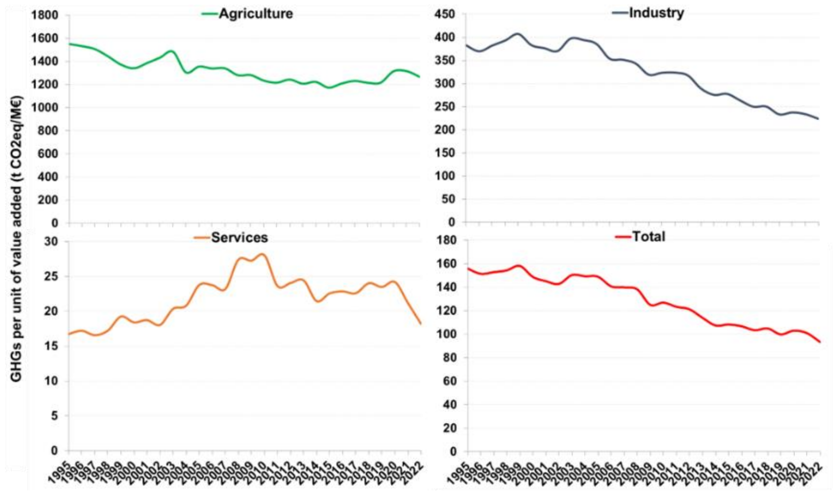


Decarbonization at sectoral level can be assessed by energy emissions and energy consumption by sector. The carbon intensity by energy is the ratio between GHGs and energy consumption. The average carbon intensity by sector is very different among sectors, depending upon the different deployment of renewable sources and electrification of final energy consumption. The carbon intensity of energy industries decreases by 37.5% in 2022 compared to 1990, from 4.82 t CO_2eq/toe to 3.01 t CO_2eq/toe. The carbon intensity of manufacturing industry in 2022 is 2.22 t CO_2eq/toe. decreasing by 17.8% compared to 1990 level. The carbon intensity for transport is 3.01 t CO_2eq/toe (-4.8% compared to 1990) and shows the highest value in the last years with the slowest decreasing slope since 1990 among sectors. The carbon intensity in the civil sector is 1.47 t CO_2eq/toe, 29.5% down compared to 1990 value. All declining trends of these indicators are statistically significant to Mann-Kendall test ($p<0.001$). Overall, the carbon intensity for the energy consumption considered, accounting by 93.6%±1.2% of gross energy inland consumption from 1990 to 2022, is 2.35 tCO_2eq/toe in 2022 (-25.1% compared to 1990 level).

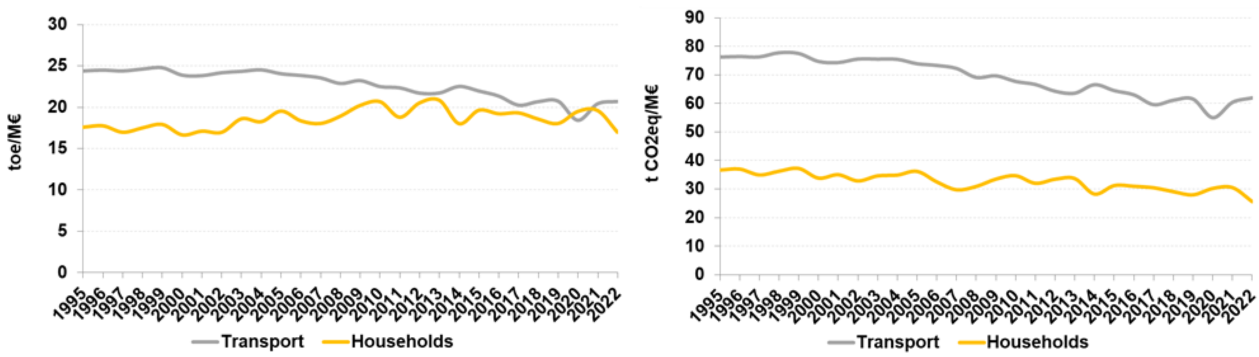
Energy and economy indicators at sectoral level

The carbon and energy intensity indicators by sector are calculated matching the GHGs by sector with respective energy consumption and value added or GDP for households and transports. Emissions by sector include only direct emissions and emissions from electricity self-production in industry. Indirect emissions, due to electricity consumption from the grid, are not considered, since they are allocated in the energy industries. GHGs from the three sectors (agriculture, industry, services) represent on average 34.5±0.8% of total GHGs.

Overall, emissions from the three sectors fell by 27.5% in 2022 compared to 1995. Combustion and process emissions decreased by 27.7% and 27.1%, respectively. In 2022 the energy intensity (toe/M€) of industry is well below the 1995 level (-31.4%), while services are higher (+28.8%) although in the last years the sector intensity decreased significantly. As for agriculture, after a downward trend from 2003 to 2015 the intensity increased but 2022 level is -3.5% compared to 1995. Aggregate energy intensity for the three sectors decreased by 22.2% over the period 1995-2022. Carbon intensity, the ratio between GHGs and value added, decreases because of the increasing share of renewable energy and fuels with lower carbon content, such as natural gas. The carbon intensities per value added are very different among sectors. Agriculture has the highest values, while services recorded the lowest ones. In 2022 the agriculture intensity is 18.3% below the 1995 level, while services are 8.7% over. Industry shows a robust downward trend (-41.6% in 2022 compared to 1995) which heavily determine the aggregate trend (-40% in 2022).



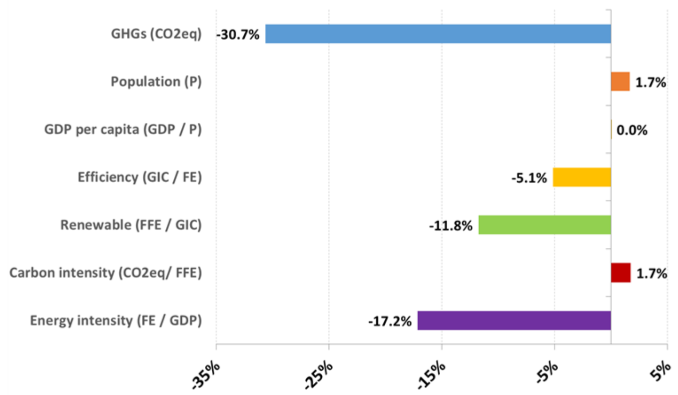
Energy and carbon intensities by economy for transport and households are calculated considering the GDP. The energy intensity of households fluctuates around an average without a clear tendency downward or upward (18.6±1.2 toe/M€), while the carbon intensity shows a downward trend since 1995 (from 36.7 t CO_2eq/M€ in 1995 to 25.6 t CO_2eq/M€ in 2022; -30.3%). The trend of GHGs emissions by GDP witnesses the sector's change of energy mix in the final consumption, with increasing contribution of biomass leading to lower carbon intensity but not reducing energy intensity.



The energy intensity of transport decreased by 15.2%, from 24.4 toe/M€ to 20.7 toe/M€ from 1995 to 2022. A quite parallel decreasing trend was observed for carbon intensity with a reduction by 19.4%, from 77.2 t CO_2eq/M€ to 62.2 t CO_2eq/M€ from 1995 to 2022, showing some decarbonization also in this sector. However, an in-depth analysis shows that for transport there is no real decoupling between energy and carbon intensities. Households' carbon and energy intensities by GDP show a growing distance since 2005, due to the decrease of GHGs compared to energy consumption.

Kaya identity and decomposition analysis

Decomposition analysis is a technique for studying the variation of an indicator in each time interval in relation to the variation of its driving factors. In other words, the variation of a parameter is decomposed in the variation of the parameters that determine it. The starting point of the analysis is the construction of an identity equation, where the variable whose variation over time is to be studied is represented as the product of components considered as the causes of the observed variation. In the identity equation the examined variable is indicated as a product of the driving factors, expressed as ratios where the denominator of a factor is the numerator of the next one. This identity, called Kaya by the economist Yoichi Kaya, is provided *a priori,* and must be realized according to a conceptual model consistent with the physical constraints of the studied variable, in addition to the considerations related to the availability of data and the objectives of the analysis.

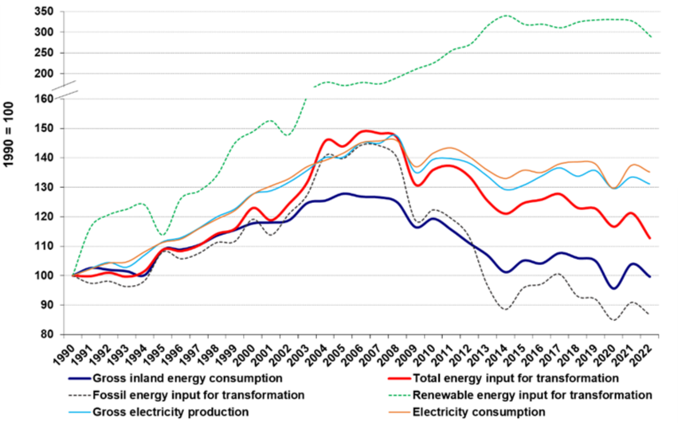


GHG emissions are decomposed in six driving factors: 1) population; 2) economic growth per capita; 3) efficiency; 4) renewable energy deployment; 5) carbon intensity from fossil fuels; 6) final energy intensity. The outcomes of decomposition analysis, carried out according *Logarithmic mean Divisia index* (Ang, 2005), shows that the effect of the factors that led to a reduction of emissions in the period 2005-2022 prevailed over the effect of the factors that led to an increase of emissions. The population and carbon intensity are the only driving factors that have contributed to the growth of emissions (both with +1.7%). The remaining factors have led to a reduction of emissions. The final energy intensity (final energy consumption / GDP) played the main role (-17.2%) followed by the share of renewable energy (fossil energy consumption / gross inland energy consumption; -11.8%) and the efficiency factor (gross inland consumption / final energy consumption; -3.9%). GDP per capita does not play any role in the period considered, because the GDP per capita in 2022 is quite the same as in 2005. The overall contribution of each factor leads to -30.7% of GHGs over the period 2005-2022.

Power sector

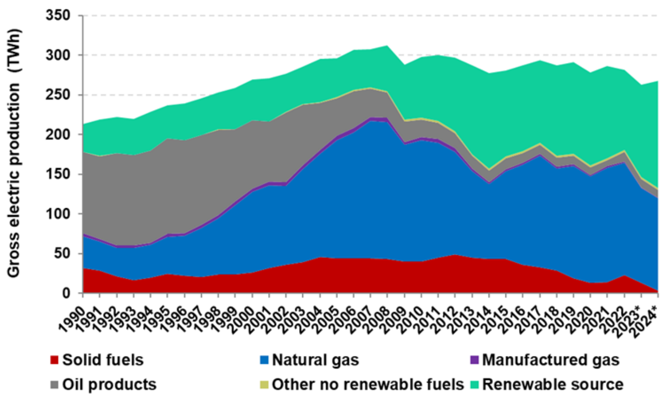
Thermoelectric and renewable electricity production

The growth of electricity consumption in the final energy consumptions makes this sector one of the main players in the national energy system. Since 2001 the energy consumption for electricity generation has increased at higher rates than gross inland energy consumption.



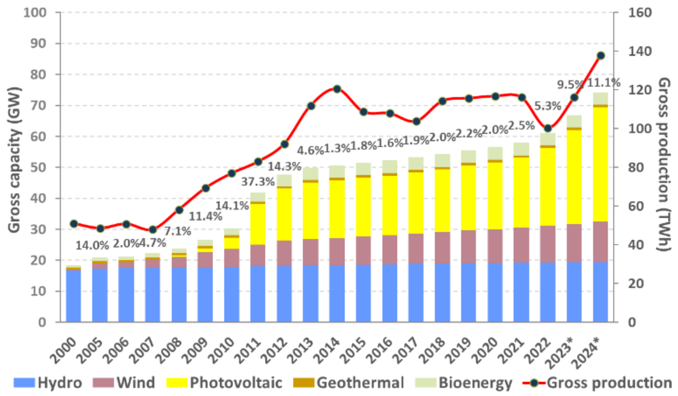
Gross electricity production rose from 216.6 TWh to 284 TWh from 1990 to 2022 (+31.1%). Electricity consumption increased from 218.8 TWh to 295.9 TWh over the same period (+35.2%). After a constant growth of gross electricity production and consumption, since 2007 there has been a downward trend also due to the economic crisis. In 2020 there has been a further downfall of electricity production and consumption, followed by the rebound in 2021. In 2022 the level of production was only 1.2% higher than 2020 level, while consumption was 4.2% higher, pushed by net import of electricity whose share in 2022, as well as in 2021, was over 14% of electricity consumption (14.2% and 14.5%, respectively in 2021 and 2022).

As regards the energy mix in power sector, natural gas increased steadily since 1990 at the expense of oil products (49.8% of electricity production from natural gas and about 4.5% from petroleum products in 2022, while in 1990 the two percentages were 18.3% and 47.4%, respectively). In 2022 an unprecedented increase of electricity production from petroleum product compared to the previous year has been recorded, from 2.7% to 4.5%. Also, solid fuels share displayed a relevant increase in 2022, from 4.9% in 2021 to 8% in 2022. The increase of oil products and solid fuels in 2022 should be read in the frame of Russian-Ukrainian war and the need to reduce the import of natural gas from Russia. Preliminary data for 2023 show a downward trend of natural gas share (≈45%), a slight decrease of oil products (≈4%) and a more consistent decrease of solid fuels (≈5%).



In 2005 the share of electricity from renewable sources accounted for only 16.4% of national production without production from pumped storage units. After 2007, renewable sources share increased significantly up to the top of 2014, when the share reached 43.4%. In 2022 the renewable share in electricity production is 35.6%, much below the level of the previous year (40.5%), due to the drastic fall of electricity from hydropower. Preliminary data show in 2023 a recovery of renewable production whose share on national electricity production should reach a new top, over 44%. The early data for 2024 show a massive recovery of hydro and increase of photovoltaic which should lead the share of renewable over the level of 2023, about 50%.

Total thermal power in 2022 is 62.4 GW with a sharp contraction since 2012, when the installed capacity reached the peak of 80.6 GW. Combined cycle plants, regardless of cogeneration or non-cogeneration production, show a significant increase in gross efficient power, from 7.9 GW in 2000 to a maximum of 43.4 GW in 2011-2012. Subsequently, these plants show a steady reduction in efficient power up to 40.5 GW in 2022.

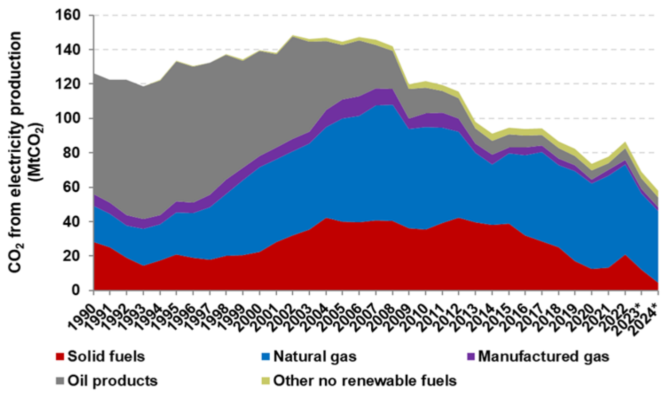


Since 2000 there has been a significant increase in installed renewable power capacity. In 2022 the renewable gross efficient power was 61.1 GW. The highest annual growth rate was recorded in 2011 when the new power compared to the previous year was 11.3 GW, of which 9.5 GW of PV plants and 1.1 GW of wind plants. After 2014 the additional new power per year was around 1 GW up to 2021. The additional power in 2022 was 3.1 GW (2.5 GW of PV). Preliminary data for 2023 show a further increase of new power over 5 GW, most by photovoltaic installations. Also considering preliminary data on installations of new PV plants up to July 2024 and estimating a comparable rate of new plants for rest of the year, the PV power should rise near 37 GW, while wind power should be around 13 GW. Total renewable power in 2024 should be about 74 GW.

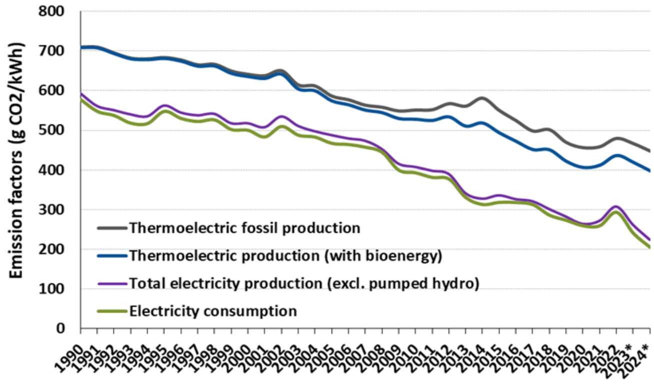
Plants powered by bioenergy recorded a rapid increase from 2008 to 2013 and the subsequent stabilization of gross efficient power with new installations of few MWs per year up to 2018 and a decrease in the last years. Biogas fuelled plants went from 0.37 GW in 2008 to 1.46 GW in 2022. The growth of plants fed with liquid biofuels in the period 2008-2013 is particularly rapid, from 0.12 GW to 1.04 GW, then decreased to 0.94 GW in 2022. Plants fuelled by solid biomass and waste increased from 1.07 GW in 2008 to 1.73 GW in 2018. Since 2018 the power of solid biomass plants shows a downward trend, while the power of waste plants increases. In 2022 the total power is 1.65 GW, of which 0.87 powered by wastes. Such trends can be explained by the reduction in incentives for bioenergy powered plants. The future development of such plants does not seem independent of some forms of subsidies.

CO_2 emissions and emission factors

The amount of CO_2 emitted from power sector in 2022 was 99.3 Mt (of which 86.7 Mt for electricity generation and 12.7 Mt for heat production), about 24% of national GHGs.



Until the first half of the 1990s, CO_2 from oil & oil products accounted for a significant share of total emissions from power sector. In 1995, the share of emissions from oil & oil products amounted to 61% of emissions. Later the share of CO_2 from these sources has steadily decreased to 9.6% in 2022, although in the last year there has been an increase of the share compared to 2021, as already seen for the electricity generation by source. Taking fuel oil alone, the CO_2 emissions decreased from 61% to 2.2% from 1995 to 2022 with a new increase in 2022 compared to the previous year, after the first one recorded in 2021 since many years of steady reduction. The share of natural gas emissions increased from 18.5% in 1995 to 61.5% in 2022, with a sensible decrease compared to 2021 (69.9%). The share of emissions from solid fuels, mainly coal, was constantly increasing up to 2014 when the peak of 37.2% was reached but in the following years was recorded a sharp reduction up to 14.7% in 2020 and 2021. A surge of solid fuels has been recorded in 2022, with the share reaching 21.5%. The preliminary estimates for 2023 show that the share of emissions by solid fuels should be around 18% and a massive decrease in 2024.

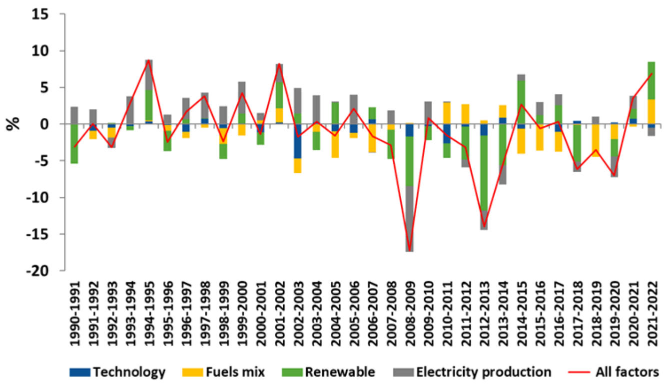


The emissions factor for national gross electricity generation by thermal plants decreases from 1990 to 2022 from 709 g CO_2/kWh to 436.8 g CO_2/kWh. A relevant increase of the emissions factor has been recorded in 2022 due to the increase of solid fuels and oil products in the fuel mix. The observed long-term decrease is mainly due to the increasing share of natural gas and the continuous reduction of the specific emissions factor of this fuel, which in turn is due to the increasing in the electrical conversion efficiency of plants. An important role is also played by bioenergy, with zero carbon balance, accounting for 8.8% of electricity generation by thermal plants. The difference between the emissions factor of the thermal electricity with or without the contribution of bioenergy shows the role of such sources in reducing the emissions factor. The difference becomes significant after 2000 because of the increasing amount of solid biomass and waste used for electricity production and the even greater increase in bioliquids and biogas observed after 2008. In the last years, starting from 2020, the share of bioenergy shows a downward trend.

The renewable sources reduce the emissions factor for electricity production since renewable sources have not CO_2 emissions. The emissions factor for electricity consumption is further reduced because of the share of electricity imported from abroad, whose emissions are released outside the national territory. Along with an increase of electricity production from 1990 to 2022 of 67.4 TWh, there was a decrease of CO_2 emissions of 39.7 Mt. The reduction of emissions factor for electricity generation from 2007 to 2014 was mainly due to the increase or renewable electricity production, while the decrease recorded since 2015 up to 2022 is also due to the increasing share of natural gas. The preliminary data show that in 2023 and 2024 should be recorded a notable decrease of CO_2 emissions from power sector.

Decomposition analysis

The change of GHGs from power sector is due to several factors such as electricity generation technology, the fossil mix, the renewable sources and electricity demand. Decomposition analysis was applied to assess the relative contribution of these components.



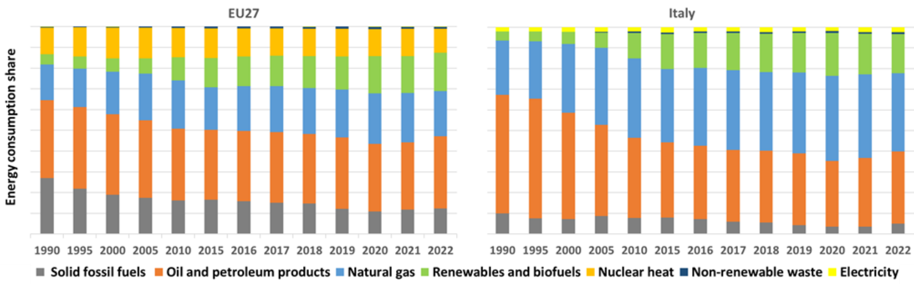
The factors considered in the analysis (technology, fuel mix, renewable sources) contribute to CO_2 emissions reduction where the increase in electricity production has the opposite effect. The results of the analysis show that technological, renewable sources, and fuel mix factors contribute to the reduction of CO_2 emissions from 1990 to 2022 respectively for 18.5%, 21.8% and 14.6%, while the increase in electricity production leads to an increase in emissions of 23.5%. The cumulative effect of the four factors led to a reduction in CO_2 emissions in 2022 of 31.4% compared to emissions observed in 1990 (-39.7 MtCO_2). In other words, the reduction due to the change in the technological factor (decrease of specific emission factors of fossil fuels) over the period 1990-2022 would have been 23.3 Mt CO_2 if the other factors had remained unchanged. The reduction due to the fuels mix change would have been 18.5 Mt CO_2, while the increasing renewable share would have led to a reduction in emissions of 27.6 Mt CO_2. These effects are offset by a net increase in electricity production which would have resulted in an increase in emissions of 29.7 Mt CO_2 without the contribution of the other factors.

Since 2007 the role of renewable sources became more relevant than the other factors. Moreover, it should be underlined that contingencies that depress the electricity demand, such as the economic crisis of 2008 or the pandemic in 2020, determine increasing share of renewable sources as result of the priority of dispatching renewable electricity.

ITALY AND THE BIGGEST EUROPEAN COUNTRIES

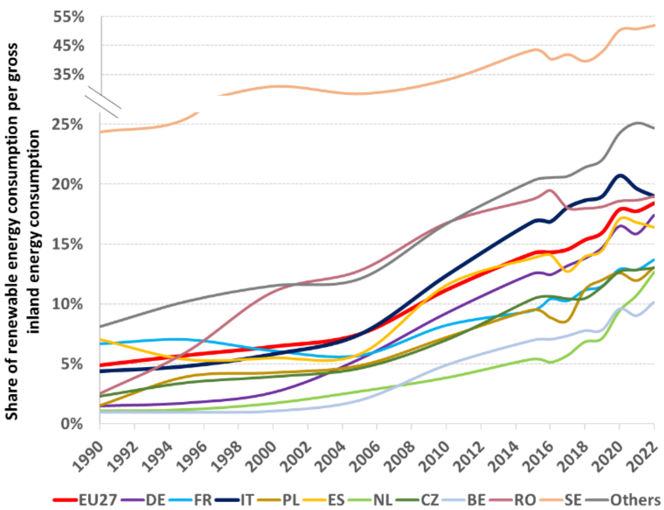
Efficiency and decarbonization indicators

Comparison among Italy and the largest European countries has been carried out for decarbonization and efficiency indicators. The EU Member States with more than 3% of EU27 GHG emissions or more than 3% of EU27 GDP in 2020 are considered for comparison. The countries examined (Germany, France, Italy, Spain, Poland, the Netherlands, Belgium, Romania, and Sweden) represented 81.5% of the population in EU27 in 2020, 81.6% of GHGs and 83.2% of GDP. The gross inland energy consumption accounted for 82.5% of the energy consumption of EU27.



Energy consumption and gross domestic product

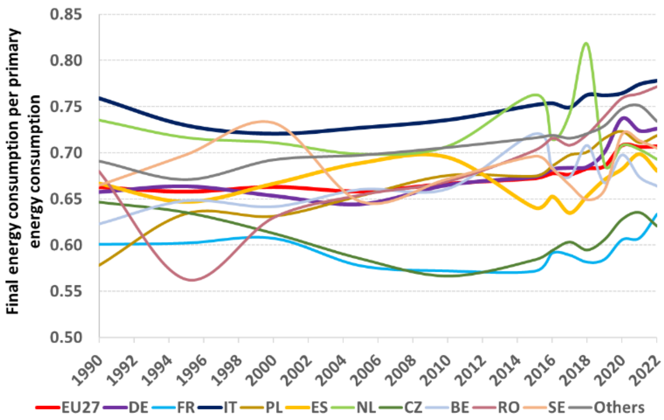
Since 1990, European environmental policies have led to a significant change of the energy mix in the Member States. The nuclear energy represented 11.5% of EU27 gross inland consumption in 2022, with a sensible reduction compared to the previous year, also due to the exit from nuclear power of Germany. Solid fuels energy faces significant contraction since 1990, even though in the last two years there was an increase compared to the lowest level reached in 2020. EU27 share in 2022 is 12%, while in 1990 it was 26.3%. There are still significant shares in some of the largest States such as Germany (19.7%), Poland (40.3%) and Czechia (32.1%). Oil and petroleum products, on the other hand, show a modest reduction at European level (from 38.3% in 1990 to 35.2% in 2022) with different trends among the States. Natural gas energy consumption shows a considerable increase in almost all States and at EU27 level increased from 17.1% in 1990 to 21.7% in 2022. The share in 2022 is quite lower than in 2021 and 2020 (23.9% and 24.4%, respectively). Renewable energy shows a significant increase in EU27 from 4.9% to 18.4% from 1990 to 2022.



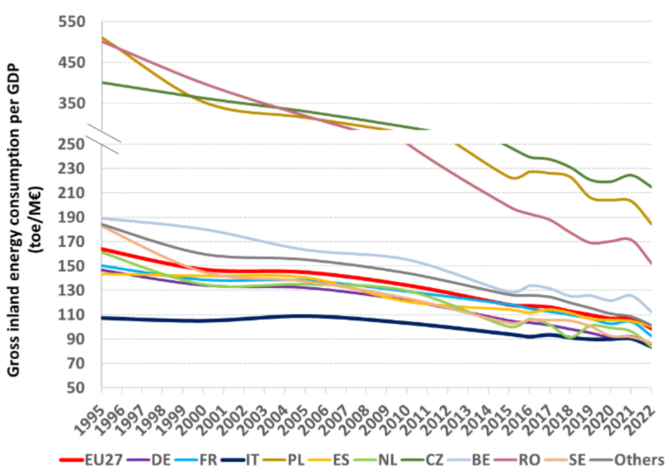
The Italian share of solid fuels, mainly coal, in gross inland consumption decreased from 9.9% in 1990 to 5% in 2022, higher than the previous year (3.6%). On the other hand, the share of natural gas goes from 26.3% to 37.9%, below the 2021 level (40.5%). The share of oil and petroleum products goes from 57.3% to 34.8% and renewable share grew from 4.4% to 19%, below the 2020 level of 20.7%. Italy's renewable share in gross inland consumption is among the highest in the countries examined, only Sweden's share is higher than the Italian one. However, the European target of renewable share in 2030 concerns the gross final consumption and Italy's overall share is well below the European average in 2022 (19.1% vs 23%).

The share of fossil fuels decreased significantly in almost all European countries, although the share in 2022 slightly grew up compared to 2021. The EU27 average decreased from 82% in 1990 to 70% in 2022. Among the examined countries, the Netherlands and Poland shares are still higher than 85%, respectively 86.1% and 87.1%.

The ratio between the final energy consumption (including non-energy uses) and gross inland consumption is an indicator of energy efficiency. Since 1990 this indicator has always been higher for Italy than for the European average. To evaluate energy transformation efficiency, it is useful to consider energy consumption without non-energy uses. In other words, the ratio between final energy consumption and primary energy. The Italian energy transformation efficiency is higher than any other Countries examined.



The gross inland energy consumption per gross domestic product (GDP) is an indicator of the country's economic and energy efficiency (energy intensity). Italy was one of the European countries with lowest energy intensity since 1995, then lost positions and in 2022 has the 6th lower values among the 27 countries. Among the biggest EU27 countries, Italy continues having one of the lowest energy intensities.

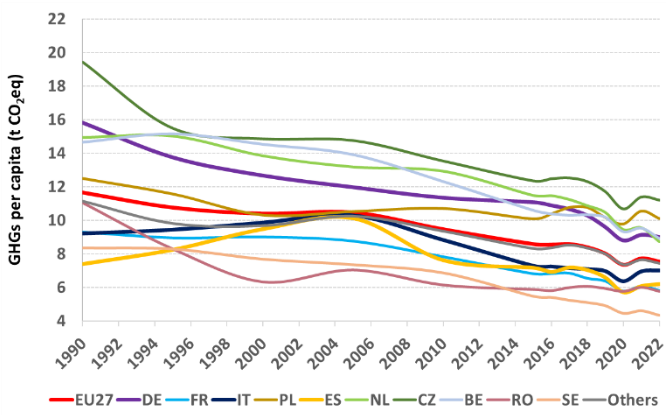


The final energy intensity (ratio between final energy consumption, including non-energy uses, and gross domestic product) follows similar trends of gross energy intensity with a sharp reduction in the European countries which, starting from higher levels than Italy, reach Italian figures and in some cases exceed them. Since 1995 Italy shows considerable energy and economic efficiency, the final energy intensity reduced by 18.1% from 1995 to 2022 considering chain linked volumes GDP, by 49.5% considering purchasing power standards GDP. Much higher reductions have occurred in the other European countries (EU27: -36.2% in EU27 with chain linked volumes GDP and -60.5% with purchasing power standards GDP). The reasons for the reduction in energy intensity observed are manifold such as the increase in building efficiency, industrial efficiency improvement, the electrification of final consumption and the shift of economy towards activities with high value added and low energy consumption as services to the detriment of industrial sectors.

European countries show a wide range of electrification of final energy consumption (energy uses only), ranging in 2022 from 14.5% in Latvia to 39.2% in Malta. Italy is just below the EU27 average with 22.3% *vs* 23%. Among the biggest countries, Sweden, France, and Spain have higher levels of electrification than Italy, respectively 33.8%, 26.9%, and 24.8%. At the lowest end there are Romania and Poland with 15.4% and 16.1% respectively.

At sectoral level, the Member States' electrification shows different figures although with a common growing trend. The electrification of industry in Italy is among the highest in Europe (39% in 2022) is the highest among the biggest countries and much higher than EU27 average (33.3%). Services show the highest percentages of electrification among sectors. The Italian share in 2022 is 50.6%, like the EU27 average, while the electrification of Italian households is much lower than the EU27 (18.5% *vs* 25.1%). The transport sector shows the lowest percentages of electrification. The EU27 average in 2022 is 2% and among the biggest countries the highest percentages are in Sweden (5.4%) and the Netherlands (3.1%). The Italian value is 2.1%.

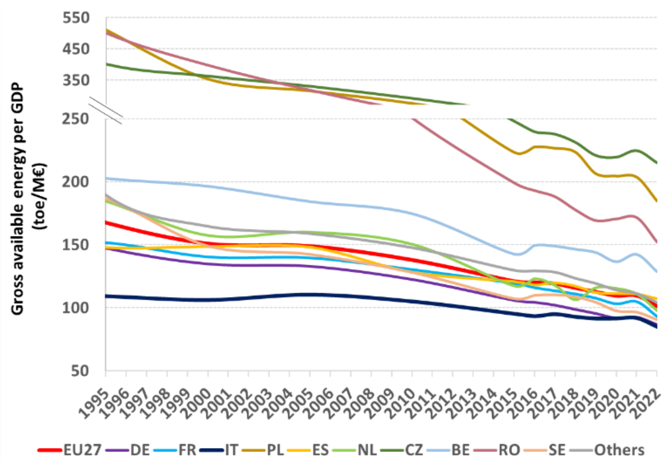
GHGs and energy consumption



Italy's average GHGs per capita from 1990 to 2022 is 8.8±1.2 t CO_2eq. Emissions per capita increased until 2004 when the maximum value of 10.3 t CO_2eq was reached, then a reduction up to 6.4 t CO_2eq was observed in 2020, followed by the increase up to 7 t CO_2eq in 2022. Italian GHGs per capita have always been below the European average (7.6 t CO_2eq in 2022).

GHGs by energy consumption decreased in all countries since 1990. Such indicator is sensible to the country's energy mix. Carbon intensity in Italy is higher than the European average, also for the contribute of nuclear power in many countries. By unbundling nuclear power from gross inland consumption, Italy's value is just below the EU27 average (2.79 t CO_2eq *vs* 2.82 t CO_2eq in 2022).

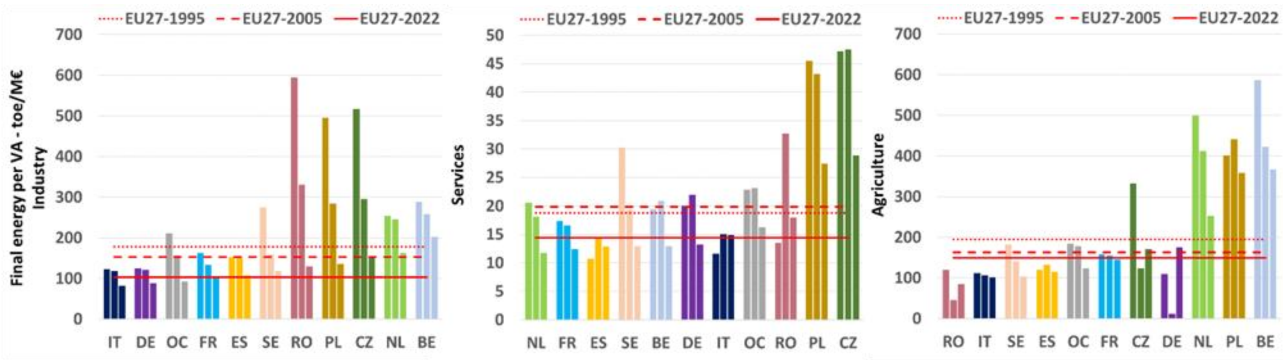
The ratio between GHGs and gross domestic product is the carbon intensity related to economy. Such indicator is sensible to the country's energy mix, as the carbon intensity related to energy, and even more sensible to economy structure: share of services and industry. Moreover, it should be considered that countries' GDP is also driven by activities linked to international bunkers, whose emissions are memo items in the emissions inventories submitted to UNFCCC and not included in sectoral or total emissions statistics. All European countries reduced the carbon intensity of economy and Italy's figures, considering chain linked volumes GDP, are below the EU27 average in 2022 (0.23 t CO_2eq/k€ *vs* 0.25 t CO_2eq/k€), as well as considering purchasing power standards GDP (0.19 t CO_2eq/k€ *vs* 0.21 t CO_2eq/k€). Sweden and France have the lowest values: 0.09 t CO_2eq/k€ and 0.17 t CO_2eq/k€, respectively (chain linked volumes). Poland and Czechia are at the upper end with 0.67 t CO_2eq/k€ and 0.6 t CO_2eq/k€, respectively (chain linked volumes).



The inclusion of the contribution of international bunkers in the elaboration of energy intensity and carbon intensity per unit of GDP shows that, among the biggest countries, Italy and Germany have the lowest energy intensities. The Italian carbon intensities are higher than France and Sweden, which benefit of nuclear contribute.

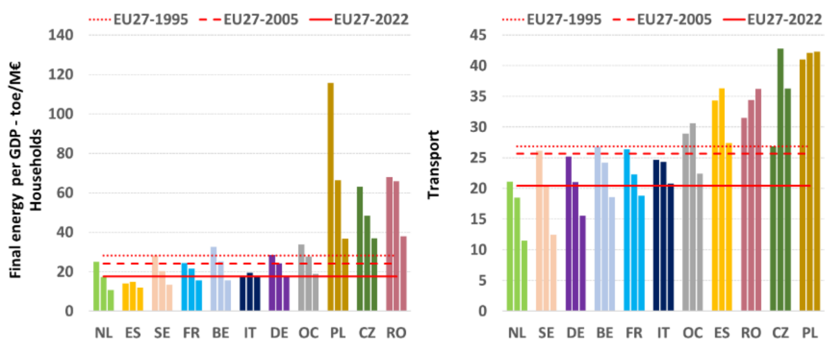
The comparison of efficiency and decarbonization indicators at sectoral level among Member States shows a rather heterogeneous portrait. As for industry in Italy, the ratio between final energy consumption and value added (final energy intensity) has always been the lowest among the biggest countries, with a decreasing trend. Among the European countries only Ireland, Denmark, Malta, and Estonia have lower industry energy intensities than Italy in 2022. Among the countries examined the Netherlands and Belgium show the highest energy intensities for industry. The average annual rate of the sector energy intensity from 2005 to 2022 decreased of -2.1% for Italy -2.3% for European average.

In commercial and public services Italy shows an intensity close to the European average, higher than Germany. Italy is the only State, among the biggest ones, whose energy intensity in this sector did not decrease so much since 2005. The outcome is also due to the accounting of energy consumed by heat



pumps whose data accounting for Italy started from 2017 in Eurostat database, although previously present. The average annual rate of energy intensity from 2005 to 2022 decreased by 0.1% in Italy against -1.9% in EU27.

The agriculture sector shows a general decrease of energy intensity in EU27. In 2022, among the considered countries, only Romania has lower energy intensity than Italy. The average annual rate of energy intensity from 2005 to 2022 decreased of -0.3% for Italy against -0.5% for European average.

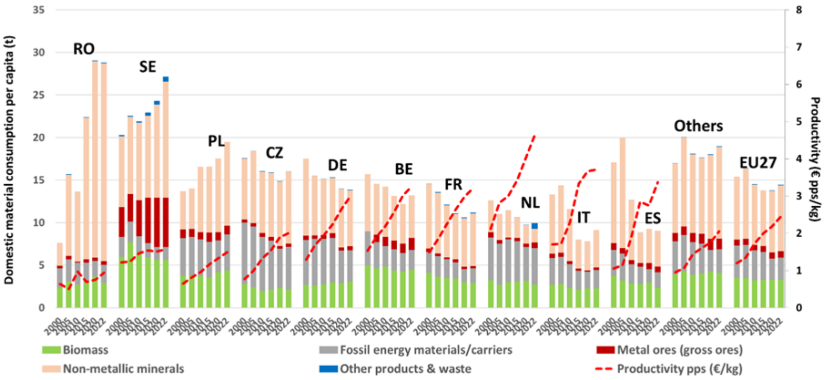


In the households, from 2005 to 2022 the biggest countries show significative reductions of energy consumption per GDP: from -0.8% per year in Italy to -3.4% per year in Poland. The energy intensity for transport in Italy is comparable to EU27 average in 2022. The ranking of the examined countries for households and transport shows that the Italian energy intensity is near the EU27 average. Transport performances in Italy have wide room for improvement if compared to Germany.

What is seen for energy intensity is reflected in the carbon intensity (t CO_2eq/M€). This indicator is more sensible to the role of renewable energies, nuclear power and electricity import in the countries' energy balance, because such sources do not produce GHGs. The Italian industry, as well as agriculture, in 2022 has carbon intensity higher only than those of Sweden among the biggest countries. The European average for industry is 10% higher than the Italian intensity, for agriculture the European average is 80.6% higher than Italy. On the other hand, services carbon intensity in Italy is 44.9% higher than EU27 average, only the carbon intensities of Romania, Poland, and Czechia are higher than the Italian one. Households and transport intensities in Italy are higher than the EU27 average (+19.5% for households, +6.2% for transport in 2022), showing an important GHGs reduction potential for the Country, especially considering that the households' electrification of final consumption in 2022 is much below the EU27 average (households: 18.5% *vs* 25.1%).

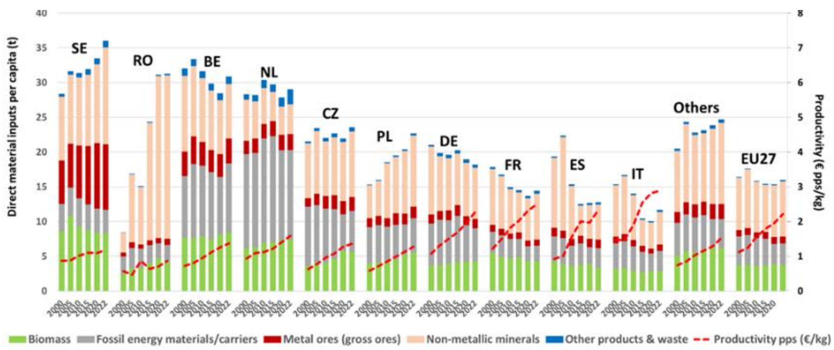
Material flow accounts

Indicators of *direct material inputs (DMI)* and *domestic material consumption (DMC)* describe, in aggregate terms, the direct use and provenance of natural resources and products. The first indicator includes all materials which have an economic value and are used for production and consumption activities and the indicator is calculated as the sum of internal extractions and imports. The second indicator represents domestic consumption of matter in the national economy net of exports and is calculated by subtracting from direct material inputs the share of physical exports.



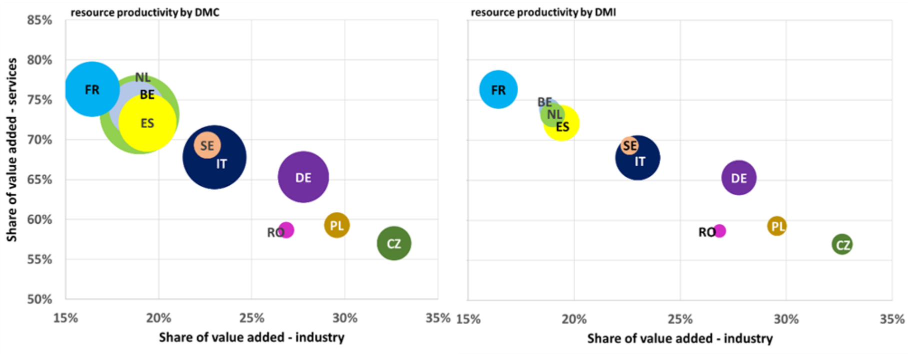
Since 2000, there has been a decrease of average DMC per capita in the European countries. In 2022 Spain has the lowest consumption per capita of matter among all EU27 countries followed by Italy and the Netherlands. As for resource productivity there is a general increase since 2000, although the absolute values of the countries are very different. The average annual growth rates among the biggest countries range from 1.2% for Sweden to 5.4% for Spain; Italy's annual rate is 3.6%. The Netherlands shows the highest value (4.6 €/kg in 2022), followed by Italy (3.7 €/kg). Germany and France productivities are 3 €/kg and 3.2 €/kg, respectively.

Direct material inputs (DMI) include all materials which are economically valued and are directly used in production and consumption activities. Such indicator is equal to the sum of internal extractions and imports. Since this indicator represents domestic consumption without exports, it is useful to assessing actual material consumption, including that not used in domestic production and consumption activities and addressed to exports. Sweden, Romania, Belgium, and the Netherlands have high share of fossil extraction, biomass, and metal ores destined to export and shows the highest DMI per capita among the biggest European countries, far above the European average. Italy recorded in 2022 the lowest value among all European countries (11.6 t per capita *vs* EU27 average of 16 t per capita).



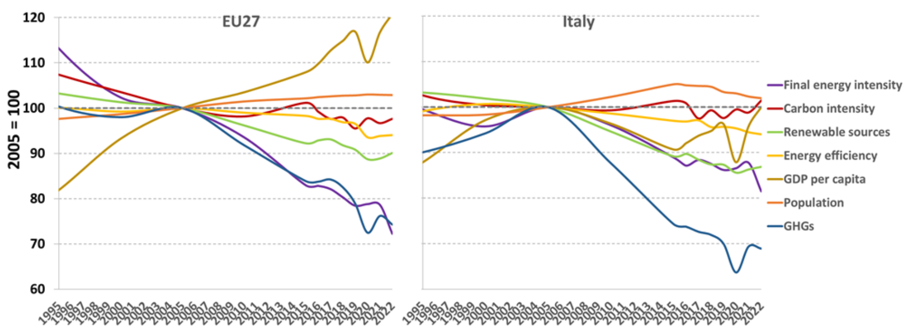
As for resource productivity Italy have the 2nd highest value among the European countries (2.9 €/kg), the 1st one is recorded for Ireland (3.1 €/kg). The productivity of the Netherlands for this indicator (1.6 €/kg) does not show high performance as for DMC.

The resource productivity for each country, considering the relative positioning of the countries' economy in the industry/service space, shows that Italy, despite having higher share of industrial value added than France and Spain, has higher productivity (DMC), a clear result of greater efficiency in the use of resources, mainly in the industry. This result is in line with what was seen for energy intensity indicators. Considering the DMI the resource productivity is significantly lower than for DMC. DMI productivity in the Netherlands falls by 65.7% compared to DMC productivity. For the other countries the gap ranges from 7.8% for Romania to 57.9% for Belgium, while Italy's DMI productivity is 22.1% lower than DMC productivity.



Kaya identity and decomposition analysis

The trend of *kaya identity* parameters for EU27 and Italy in the period 1995-2022 shows a quite different pattern for the driving factors in GHG reductions. Whereas in EU27 the most powerful factor is the final energy intensity, in Italy both renewable sources and final energy intensity (final energy consumed per GDP) are the driving factors. Moreover, in EU27 population and GDP increase, while in Italy such factors have downward trend. The GHGs change is the integrated result of the driving factors change. So, in EU27 is evident an absolute decoupling between economy and GHGs, while in Italy only a relative decoupling is recorded.



The outcomes of decomposition analysis show that in Italy the final energy efficiency played a less important role than in other countries because of the better performance of the indicator in Italy already in 2005. Moreover, unlike Italy, most countries recorded the sensible increase of GDP per capita since 2005.

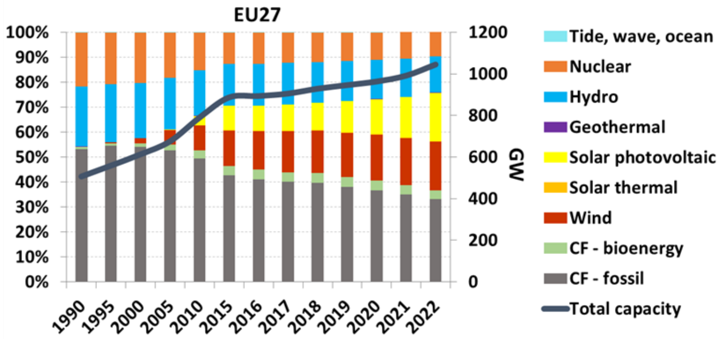
The decoupling does not necessarily correspond to emission reductions in line with the targets. Decomposition analysis focuses on the relative change of the parameters, without assigning any weight to the starting points. The economic and energy efficiency of the Italian system is among the highest in Europe. The last edition of the *International Energy Efficiency Scorecard*, issued by ACEEE in 2022, reported for Italy the drop of four ranks since the previous edition in 2018, mainly due to buildings section, but Italy managed to rank within the top five, after France, UK, Germany, and the Netherlands. The ACEEE International Energy Efficiency Scorecard evaluates the efficiency policies and performance of 25 of the most energy-consuming countries globally. ACEEE used 36 metrics, both policy and performance-oriented metrics, to score each country's efforts to save energy and reduce GHGs across four categories: buildings, industry, transportation, and overall national energy efficiency progress. "*Policy metrics highlight best practices in government actions and can be either qualitative or quantitative. Examples include national targets for energy efficiency, building and appliance labelling, and fuel economy standards for vehicles. The performance-oriented metrics are quantitative and measure energy use per unit of activity* *or service extracted. Examples include the efficiency of thermal power plants, energy intensities of buildings and industry, and average on-road vehicle fuel economy.*" (Subramanian *et al.*, 2022).

The efficiency improvement cannot be separated from the assessment of the potentials and cost effectiveness of the energy system change. Moreover, a mindful assessment of the countries' economy structure must be considered, especially concerning the role of services and industry which have very different energy intensities and carbon footprints.

Power sector

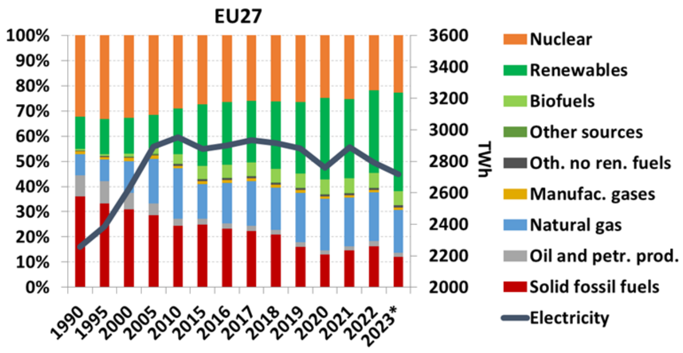
Power capacity and electricity production

The power sector is one of the main targets of measures aimed to decarbonize the economy, both for the amount of emissions and potential of renewable energy deployment. The countries examined for comparison with Italy account for 83.1% of EU27 gross electricity production in 2022.



The installed capacity in 1990 consisted mainly of thermoelectric plants (54% in EU27), nuclear (21.8%) and hydroelectric (24%). Wind and photovoltaic sources had marginal shares. In 2022 the thermoelectric capacity was 36.7%, 9.6% nuclear, 14.4% hydroelectric, 19.5% wind, and 19.4% photovoltaic. The total capacity has increased by 54.8% in 2022 compared to 2005, from 676 GW to 1,046 GW. The nuclear capacity is the only one with a relevant reduction, from 123 GW to 100 GW (-14.6%), mainly due to the downward trend in Germany, Sweden, and Belgium. It is also noteworthy the increase of bioenergy net capacity from 15.8 GW in 2005 to 36.9 GW in 2022, representing 9.6% of total thermoelectric capacity. All countries experienced considerable decreasing share of the thermoelectric capacity since 1990, as well as for nuclear capacity (except Czechia and Romania).

There is considerable heterogeneity of power capacity among countries. In Poland, there is a clear prevalence of thermoelectric plants with a minor role for bioenergy. The nuclear plants, which are not present in Italy and Poland among the considered countries, make up significant share of the capacity in France (41.3% in 2022), Sweden (14.4%), Belgium (18.2%), and Czechia (20.3%), although the shares of other countries are not negligible (from 0.9% in the Netherlands to 7.3% in Romania). Since 1990, hydroelectric capacity has accounted for a considerable proportion of traditional renewable sources in Romania, Spain, France, Italy and Sweden. In all the countries examined, the share of thermoelectric and nuclear capacity shows a considerable reduction. Wind power has increased in all countries since 2005. Photovoltaic plants begun to have significant shares only after 2010.



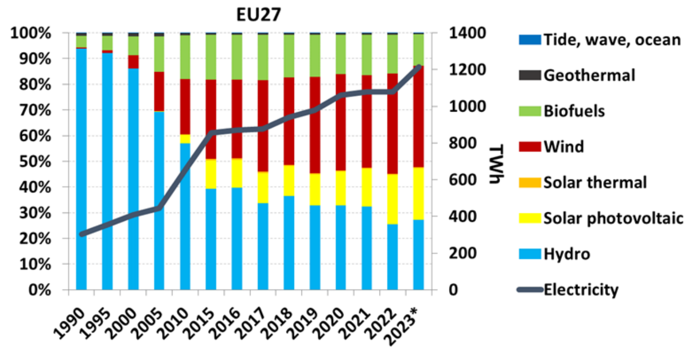
Gross electricity production in Europe increased from 1990 to 2015 with an annual average rate of 1%, in the following years up to 2019 wide oscillation was recorded and 2019 level is approximately the same of 2015. In 2020 the electricity fell, due to measures adopted to contain SARS-CoV-2 pandemic. In 2021 there was a recovery, followed by a new slowdown in 2022. From 2015 to 2022 the annual average rate has been -0.4%.

Preliminary data issued by Eurostat show a further decrease of electricity production in 2023.

The share of EU27 electricity production without pumping in 2022 is 16.3% from solid fuels and 19.4% from natural gas. and 19.4% from natural gas. Oil and petroleum products account for 2%. Nuclear source accounts for 21.8%, while 38.7% comes from renewable energy (renewables and biofuels). All considered countries increased the electricity production since 1990, from 4.9% in Germany to 90.4% in Spain, except Romania whose electricity production decreased by 13.5%.

The energy mix in the examined countries is quite heterogeneous, mainly as far as fossil fuels are concerned. In 2022, solid fuels make up 69.8% of electricity production in Poland, 44% in Czechia, and 31.3% in Germany. France has the highest share of electricity production from nuclear plants in Europe (62.8% in 2022), followed by Belgium (46.4%), Czechia (37%) and Sweden (30%). In the other biggest countries, the nuclear electricity ranges from 3.4% in the Netherlands to 19.9% in Romania. Poland and Italy do not have nuclear plants. At EU27 level, as already reported, the nuclear source provides 21.8% of electricity. Italy and the Netherlands have the highest share of electricity by natural gas in 2022, 50.1% and 39.2% respectively.

The renewable electricity share in EU27 has increased from 13.4% to 38.7% since 1990 to 2022. All countries recorded a notable increase of renewable electricity production with a strong acceleration since 2005. After 2015 the growth slowed down and has resumed in recent years, although with different rates among the States. Sweden has one of the highest renewable shares in Europe. According to preliminary data in 2023 the share of renewable electricity in EU27 should reach 44.6% with one of the highest annual rates ever recorded.



Efficiency of thermal power plants

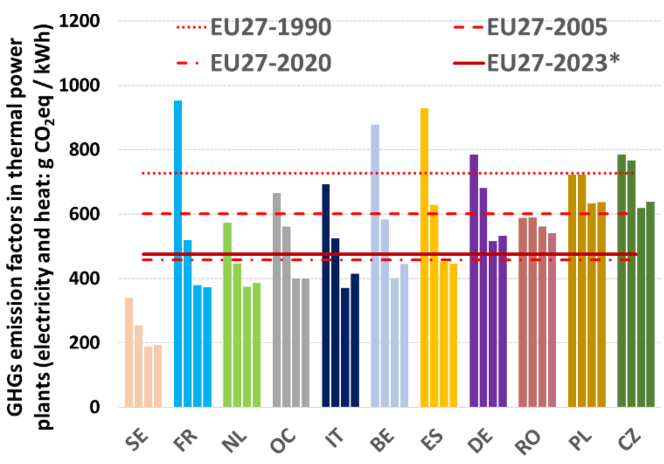
The most important parameter to assess the efficiency of power systems is the transformation efficiency of fuels to produce electricity and heat. The electrical efficiency of Italian non-cogeneration plants is just over the EU27 average (0.447 *vs* 0.429). As concerns the electrical efficiency of CHP plants, Spain shows the highest value among the main European countries in 2022 (0.646), far higher than the EU27 average (0.38). Italy's electrical efficiency is 0.457. The total efficiency, for electricity and heat production, of the Italian cogeneration plants (0.542) is below the EU27 average (0.625).

The Italian electrical efficiency for all power plants (CHP and electricity only) in 2022 is 0.452, exceeded by Spain, Belgium, and the Netherlands, from 0.461 to 0.486. Sweden has the lowest electrical efficiency among the examined countries (0.24), well below the EU27 average (0.404). The overall efficiency of Italian plants, for electricity and heat production, is 0.497, below the EU27 average (0.527). Sweden shows the highest value (0.808) due to the highest ratio between heat and electricity recorded in this Country in CHP plants (more than 2.4), followed by Czechia (1.56).

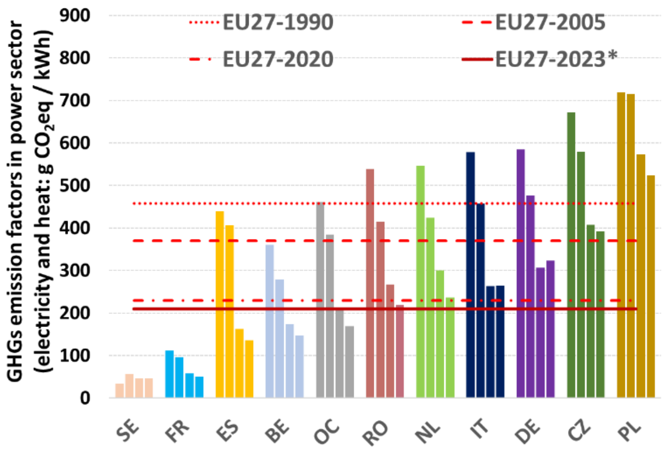
GHGs from the power sector

Since 1990 there has been a decoupling between electricity production and GHGs by power sector in almost all European countries, although emissions show a significant decrease only after 2005, with an increasing decoupling mainly due to the growing share of renewables.

GHG emissions factor for electricity and heat production due to fuel combustion in thermal power plants reduced since 1990. In 2023 the emissions factor in Italy, 413.8 g CO_2eq/kWh, is lower than EU27 average, 474.3 g CO_2eq/kWh. The average reduction since 2005 (-21% in EU27) ranges from -8.3% in Romania to -29% in Spain. Italy reduced the emissions factor by -21%.



The emissions factor for total electricity and heat production by the whole power sector, including renewable and nuclear power production, in Italy is higher than the European average (264.2 *vs* 210.3 g CO_2eq/kWh). All countries with lower emissions factor than Italy have relevant amount of electricity by nuclear plants or higher renewable share. The average EU27 emissions factor shows a reduction of 43.2%, compared to the 2005 level. Italy reduced the emissions factor by 42.2%. Spain recorded the highest reduction rate since 2005, -66.7%, on the other side Poland and Sweden have the lowest ones, -26.8% and -19.2% respectively, but Sweden has the lowest emissions factor. The emissions factor in Germany, which has the highest share of European GHGs by power sector, decreased by -32.2% since 2005.



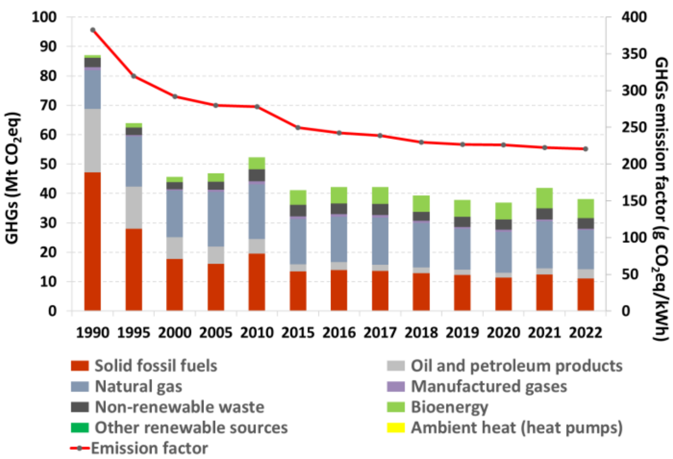
As concerns electricity production the outcomes allow to conclude that, among the biggest European countries, Italy's thermal power plants are in the lowest end of the GHGs emissions factor's range, apart France, the Netherlands, and Sweden which have much lower share of solid and oil fuels then Italy. Italy has the median position among all the European countries, well below the EU27 average. The Italian fuels mix, with greater share of natural gas than many other countries and the contribution of bioenergy, is a driving factor for the emissions factor in thermal power plants. On the other side, as for the whole power sector, therefore also considering the no thermal renewables and nuclear power plants, the Italian emissions factor loses positions compared to other countries and is higher than European average.

As concerns the power sector, Germany, Poland, and Italy are the three biggest emitters in Europe. Because of many factors (fuel mix shift, efficiency, share of renewables) Italy reduced the emissions factor for electricity production by -55.2% from 1990 to 2023 and by -45.9% since 2005. The reduction in Germany was -48.8% since 1990 and -34.5% since 2005, while the figures in Poland was -38.3% since 1990 and -31.6% since 2005. The three Countries account for almost 60% of EU27 GHGs from power sector.

Heat-only producers

Heat production accounts for a significant share of energy transformation processes. Plants dedicated to heat production for district heating and other uses (mainly for industry) consume an important share of the energy in the European balance. In 2022 the energy consumption of such plants in EU27 was 17.1 Mtoe of which 0.71 Mtoe from geothermal and solar thermal, and 0.27 Mtoe from heat pumps. The energy consumption of fuels was 16.2 Mtoe, of which 5.8 Mtoe from bioenergy.

Total energy consumption in 2022 is about 33% lower than 1990 level and a marked fuel shift occurred, with sensible decrease of solid and liquid fuels being replaced by natural gas and bioenergy. The contribution of other renewable sources (more than 90% from geothermal energy and the rest from solar thermal) and heat pumps recorded an increasing trend and in 2022 represent 5.7% of total consumption.



As a result of fuel shift and decreasing energy consumed (-33.4% in 2022 compared to 1990) and heat production (-24%), GHGs registered a sharp decrease by 56.2% since 1990. GHGs emissions factor decreased by 42.3%. At EU27 level the GHGs from these plants were 38.1 Mt CO_2eq in 2022. Since 2005 the emissions factor decreased by 21.1% in EU27 (from 279.7 to 220.7 g CO_2eq/kWh). Italy's emissions factor in 2022 is 18.2% lower than the EU27 average. The relevant solid fuels or non-renewable waste consumption in Poland and Germany results in higher emissions factor, respectively 95% and 45.7% higher than the Italian one.

CONCLUSIONS

The results show that Italy has one of the more efficient economies among the biggest countries in Europe. The figures show that energy intensity per GDP as well as resource productivity are among the lowest in Europe despite a relevant role of industry in the Italian economy. Low energy intensity often corresponds to more service-based economies with a minor role of industrial activities. EU27's carbon intensity per energy consumed is on average lower than Italian one, since in several countries is present a not negligible share of nuclear energy.

GHGs trends depend on many factors. The emission reductions in European countries are mainly due to the decreasing energy intensity and increasing renewable energy consumption. In 2020 the measures adopted to contain the diffusion of SARS-CoV-2 pandemic heavily affected the European economy and GHG emissions. Independently from contingencies there is a clear decoupling between GDP and GHGs in the European countries, although decoupling does not necessarily correspond to the emission reductions in line with the targets. The potential for reducing emissions must be assessed also considering the starting points of the driving factors and the costs to change the energy system, as well as the economy structure, especially concerning the services and industry assets.

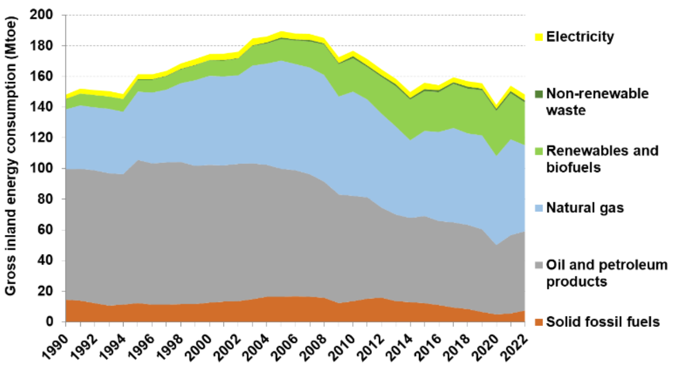
Sectoral decarbonization indicators in Italy show sectors such as industry and agriculture with energy and carbon intensities by GDP among the lowest in Europe and sectors such as households and transport showing wide room of improvement. The Italian electrification level in households is well below the European average and transport sector has wide room for reducing emissions, mainly in the segment of cars. Italian emissions per capita for such transport segment are over the European average: one of the highest values among the biggest countries. Such outcomes are consistent with the worrying distance of Italian GHGs projections from the target to be achieved in 2030. The targets are focused on the partition between biggest energy and manufacturing industries (subject to emissions trading system, ETS) and other sectors (ruled by Effort Sharing Regulation, ESR). The country's emission targets are set only for sectors not subject to the ETS, i.e. transport, services, households, agriculture, waste and small industry, while emissions from large plants as thermal power plants, refineries, cement plants, steel plants, etc. are in the European cap and trade system of emissions trading.

SOMMARIO (Italiano)

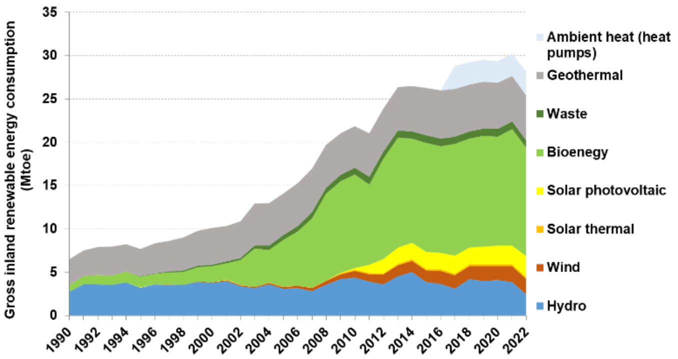
DATI NAZIONALI

Consumi di energia ed emissioni di gas serra

Il consumo interno lordo di energia in Italia è aumentato dal 1990 al 2005, con il picco di 189,4 Mtep. Successivamente si è registrata una riduzione, accelerata dalla crisi economica del 2008, con il valore minimo di 149,8 Mtep nel 2014 e la successiva ripresa. Dopo il calo del 2020, a causa della pandemia da SARS-CoV-2, nel 2021 si è registrato un rimbalzo dei consumi (+8,8% rispetto al 2020; 154 ktep), seguito da un'ulteriore battuta d'arresto nel 2022 (-3,9% rispetto al 2021).



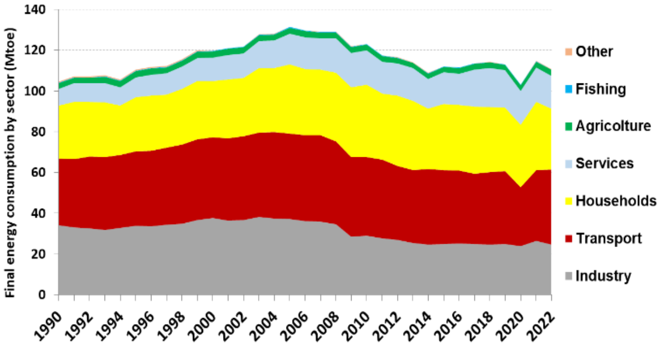
I combustibili fossili sono i principali vettori del sistema energetico nazionale. Dal 1990 al 2007, la quota media di combustibili fossili nel consumo interno lordo è stata superiore al 90%, anche se in lieve diminuzione. Dopo il 2007 la quota di energia fossile si è fortemente ridotta. Dal 1990 al 2022 la quota è scesa dal 93,6% al 78,5%, con il valore più basso nel 2020 (77,3%). La riduzione è diventata particolarmente marcata dal 2007. Il mix nazionale di combustibili è cambiato considerevolmente dagli anni '90. I prodotti petroliferi rappresentavano la componente predominante con il 57,3% del consumo interno lordo nel 1990. La quota di questi combustibili è costantemente diminuita fino al 31,7% nel 2020, con un rimbalzo negli anni successivi (34,8% nel 2022). La quota di gas naturale segue un andamento speculare con un aumento costante dal 1990 fino al 2020 (da 26,3% a 41,2%), seguito da un incremento (37,9% nel 2022). La quota dei combustibili solidi, dopo una costante riduzione dal 2012 al 2021 (da 9,6% a 3,6%), ha registrato un rimbalzo al 5% nel 2022.



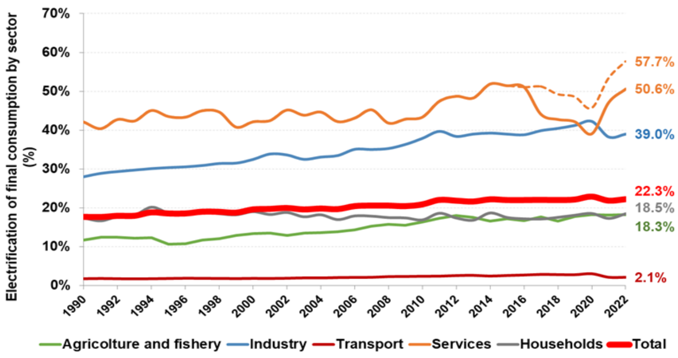
La quota di energia da fonti rinnovabili è complementare a quella osservata per i combustibili fossili. Dal 1990 al 2007 si è registrato un costante aumento della quota, passando da 4,4% a 9%. Dopo il 2007 la quota ha accelerato raggiungendo il 20,7% del consumo interno lordo nel 2020, seguita da una battuta d'arresto negli ultimi anni (19,6% nel 2021 e 19% nel 2022). Il consumo interno lordo di energia rinnovabile è più che quadruplicato dal 1990, passando da 6,5 Mtep a 29,3 Mtep nel 2022.

Fino al 2000 le principali fonti di energia rinnovabile sono state la geotermia e l'idroelettrico, che hanno rappresentato oltre l'80% del consumo interno lordo di energia rinnovabile. La quota rimanente era costituita principalmente da biomasse e rifiuti rinnovabili (bioenergia). Dal 2000 la bioenergia ha mostrato una crescita considerevole, raggiungendo il picco della serie storica nel 2008 con una quota del 50,9%. Nel 2022 la quota di bioenergia è pari al 44,4%. Negli ultimi anni anche l'energia solare (termica e fotovoltaica) ed eolica hanno assunto un ruolo significativo e insieme rappresentano il 15,8% del consumo di energia rinnovabile. Dal 2017 l'energia delle pompe di calore è registrata dall'Italia nel bilancio Eurostat. Tale voce nel 2022 rappresenta il 9,8% del consumo interno lordo di rinnovabili.

I consumi finali di energia mostrano peculiarità strutturali per ciascun settore, con diverse sensibilità a fattori contingenti, come la crisi economica dal 2008 o il lockdown del 2020 che hanno colpito soprattutto i settori produttivi. Dal 1990 al 2022 l'industria mostra un calo dei consumi finali di energia del 27,8%, mentre i servizi mostrano un aumento del 97,4%. L'andamento dei consumi finali nel settore domestico è molto variabile a seconda delle condizioni climatiche che influenzano i consumi. Il consumo del settore nel 2022 è del 15,3% rispetto al livello del 1990. Il consumo nei trasporti, compresa l'aviazione internazionale, è aumentato del 12,2% dal 1990 al 2022, dopo il calo del 2020 dovuto alle misure di confinamento per fermare la pandemia di SARS-CoV-2.

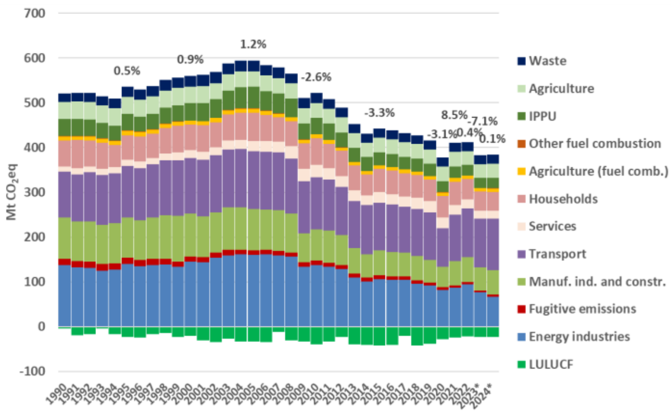


A partire dagli anni '90, la struttura dei settori in termini di consumo energetico è cambiata notevolmente. I servizi rappresentano una quota crescente dei consumi finali, passando da 7,8% nel 1990 a 14,6% nel 2022, mentre l'industria riduce la sua quota da 32,6% a 22,2% nello stesso periodo. I consumi nelle famiglie mostrano un andamento in crescita fino al 2010 seguito da una leggera diminuzione con forti oscillazioni dovute principalmente alla temperatura media. La quota media dei consumi negli altri settori, principalmente agricoltura e pesca, è circa il 3%.



L'elettrificazione dei consumi finali è una strategia fondamentale per ridurre i gas serra se perseguita parallelamente alla diffusione delle energie rinnovabili per la produzione di energia elettrica. La quota di energia elettrica nel consumo finale di energia è aumentata dal 1990 e nel 2022 è pari al 22,3%. Il livello di elettrificazione dei consumi finali dei settori è molto eterogeneo. I servizi presentano la quota più elevata, con oltre il 50% dei consumi finali del settore. Il tasso di elettrificazione nell'industria è in costante aumento dal 1990, con il 39% di elettricità del 2022. Le ampie oscillazioni registrate negli ultimi anni per i servizi e l'industria sono dovute anche a un significativo cambiamento nella metodologia di contabilizzazione dei consumi. L'elettrificazione dei settori domestico e dei trasporti non mostra aumenti significativi e nel 2022 è stata rispettivamente del 18,5% e 2,1%. L'agricoltura e la pesca mostrano un aumento dell'elettrificazione, analogamente all'industria, e nel 2022 il livello è stato del 18,3%.

Le emissioni totali di gas serra mostrano una tendenza all'aumento fino al 2005, seguita da una diminuzione accelerata dalla crisi economica del 2008. Nel 2020 le misure di lockdown per contenere la pandemia di SARS-CoV-2 hanno determinato la riduzione dei gas serra (379,1 Mt CO_2eq; -27,4% nel 2020 rispetto al 1990 e -36,4% rispetto al 2005). Tutti i settori hanno ridotto le emissioni, anche se con tassi diversi. Nel 2021 e nel 2022 i gas serra sono rimbalzati, anche se al di sotto del livello del 2019. Nel 2022 si registra una diminuzione del 20,9% rispetto al 1990 e del 30,7% rispetto al 2005. Le stime preliminari di ISPRA per il 2023 evidenziano che i gas serra sono ben al di sotto del livello dell'anno precedente (-7,1%), principalmente per la riduzione registrata nelle industrie energetiche. Le stime preliminari per il 2024 mostrano emissioni sullo stesso livello dell'anno precedente.



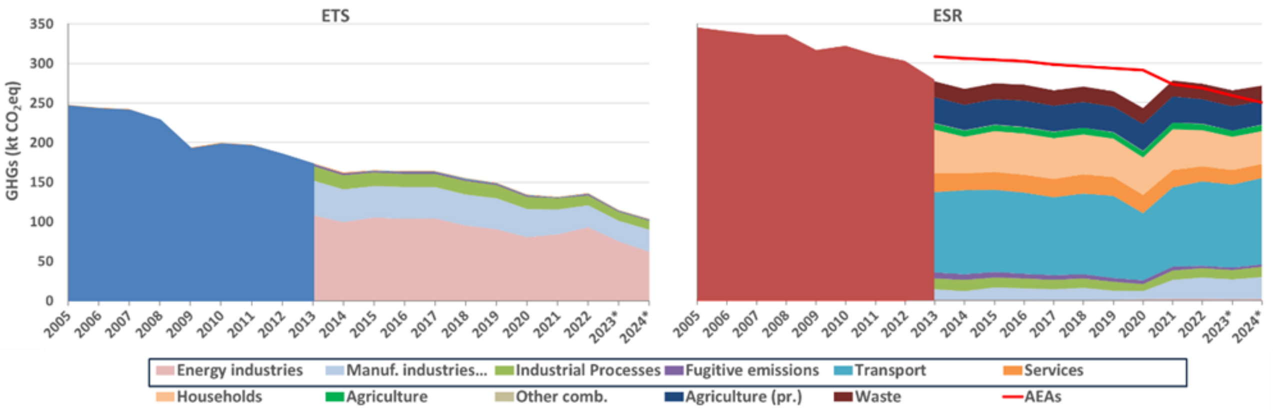
Le emissioni del settore manifatturiero e delle costruzioni sono diminuite del 40,7% dal 2005 al 2022. I trasporti sono aumentati costantemente con un'inversione di tendenza solo dopo il 2007 e il forte calo nel 2020; le emissioni del 2022 sono inferiori del 14,5% rispetto al 2005, ma ancora superiori al livello del 1990 (+7,4%). Il settore residenziale ha ridotto le emissioni del 21,6% rispetto al 1990, mentre nei servizi aumentano del 64,2%.

I gas serra pro-capite sono passati da 9,2 t CO_2eq nel 1990 a 10,3 t CO2eq nel 2004, negli anni successivi si è registrato un rapido calo fino a 6,4 t CO_2eq nel 2020. Nel 2022 il livello è di 7 t CO_2eq. I gas serra pro-capite sono diminuiti dal 2005 al 2022 con un tasso medio annuo del -2,2% (-0,9% dal 1990).

Gas serra da ETS and ESR

Per monitorare il raggiungimento degli obiettivi di riduzione i gas serra devono essere allocati nei due comparti: ETS (EU Emissions Trading System, EU ETS) e ESR (Effort Sharing Regulation), definiti secondo la normativa europea.

Nel 2022 l'ETS rappresenta il 33% dei gas serra nazionali. La quota di tali emissioni è diminuita dal 2005, quando era del 42%. L'ambito di applicazione dell'ESR rimane sostanzialmente invariato rispetto al periodo precedente fino al 2020, ma dal 2021 solo la CO_2 proveniente dall'aviazione nazionale è esclusa dal settore ESR, non più NF3, come fino al 2020. Nel 2022 le emissioni in ESR rappresentano il 66,4% delle emissioni nazionali; la quota è aumentata dal 2005, quando era quasi del 58%. Dal 2005 al 2022 i gas serra sono diminuiti sia in ETS che in ESR, anche se in ETS con un tasso doppio rispetto a ESR, rispettivamente -44,5% e -20,1%. Inoltre, negli ultimi anni, in particolare dal 2021, i gas serra mostrano un rimbalzo in ESR (+12,3% nel 2022 rispetto al 2020), mentre in ETS l'aumento è piuttosto modesto (+1,4%).



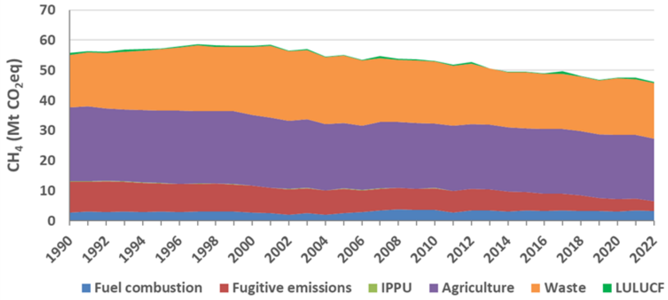
Sul versante ETS il ruolo dominante è svolto dalle industrie energetiche (68,1% dei gas serra del comparto nel 2022) le cui emissioni sono quasi totalmente incluse in ETS (circa il 98% delle emissioni del settore), solo una quota marginale è in ESR. In quest'ultimo comparto il ruolo dominante è svolto dai trasporti con il 38,8% dei gas serra nel 2022, la quota esigua in ETS per tale settore è interamente dovuta al trasporto via gasdotto/oleodotto. I gas serra delle industrie manifatturiere e delle costruzioni, insieme ai processi industriali, rappresentano il 29,8% in ETS e il 14% in ESR. Le emissioni fuggitive in ETS riguardano solo la CO_2 derivante dal flaring nelle raffinerie, mentre tutte le altre fonti e gli altri gas serra sono in ESR. I gas serra derivanti dai servizi sono quasi totalmente in ESR (circa il 98%) e rappresentano il 7% delle emissioni del comparto. I gas serra dei settori residenziale, agricoltura (sia da combustione che da processi) e rifiuti sono totalmente in ESR, con quote rispettivamente del 16,5%, 14,1% e 7,3%. I settori con quote elevate dovrebbero essere gli obiettivi prioritari delle politiche e misure volte a conseguire l'obiettivo di riduzione dei gas serra fissato per le emissioni di ESR.

Emissioni di metano

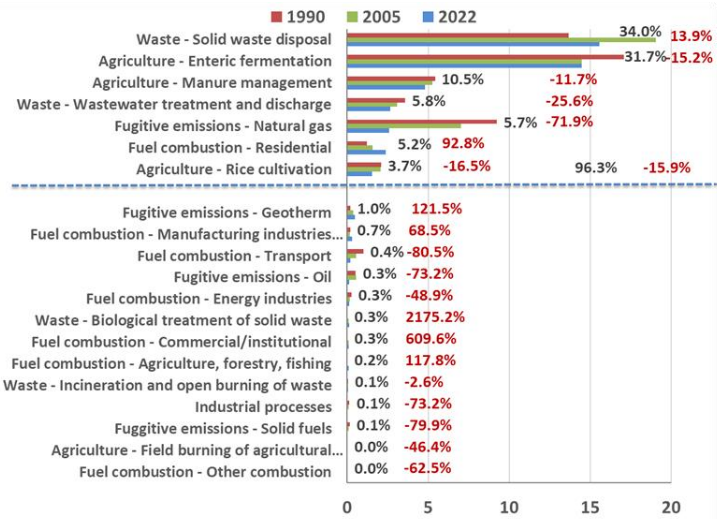
Il metano è un potente gas serra, secondo solo all'anidride carbonica in termini di contributo al riscaldamento globale (IPCC, 2021). Il metano ha un potenziale di riscaldamento globale (GWP) circa 85 volte superiore a quello della CO_2 in un periodo di 20 anni, sebbene la CO_2 abbia una vita in atmosfera di migliaia di anni, mentre il metano scompare in circa 10-15 anni. Il rapido decadimento del metano e il suo elevato impatto sulla temperatura atmosferica ne fanno un obiettivo primario per frenare in modo tempestivo ed efficace il cambiamento climatico.

Secondo il rapporto dell'Agenzia Internazionale dell'Energia (IEA, 2024) e dell'IPCC (2022) la riduzione delle emissioni antropogeniche di metano è una delle strategie più efficaci, anche in termini economici, per contribuire in modo significativo agli sforzi per limitare l'aumento della temperatura globale.

Le emissioni nazionali di metano, senza il contributo delle fonti naturali, rappresentano in media il 10,6%±0,8% delle emissioni totali dal 1990 al 2022. Le emissioni di metano senza LULUCF sono diminuite da 55 a 45,7 Mt CO_2eq dal 1990 al 2022 (-16,8%). La riduzione delle emissioni di metano è inferiore alla riduzione dei gas serra totali (-20,9%). Inoltre, i gas serra diversi dal metano si riducono del 21,3% rispetto al 1990. Questi tassi evidenziano la necessità di ridurre le emissioni di metano dalle principali fonti.



Tra le principali fonti, le emissioni di metano da rifiuti nel 2022 sono risultate superiori ai livelli del 1990 (+6,3%), anche se il trend è in netta discesa dal 2005 (-17,4%). Dal 1990 l'agricoltura è diminuita del 15,4% e le emissioni fuggitive del 68%. Considerando solo le emissioni di metano, l'agricoltura contribuisce con il 45,6% nel 2022, mentre il settore dei rifiuti rappresenta il 40,3%. Le emissioni fuggitive rappresentano il 7,1% e il metano incombusto nel settore energetico il 7%.



La fonte di gran lunga più importante del settore agricolo è rappresentata dalla fermentazione enterica, ovvero i processi digestivi degli animali da allevamento. Questa fonte rappresenta il 69,5% delle emissioni di metano dell'agricoltura nel 2022, seguita dalla gestione del letame con il 23% e dalla coltivazione del riso con il 7,4%. Le emissioni da combustione di residui agricoli in campo rappresentano il <0,05%.

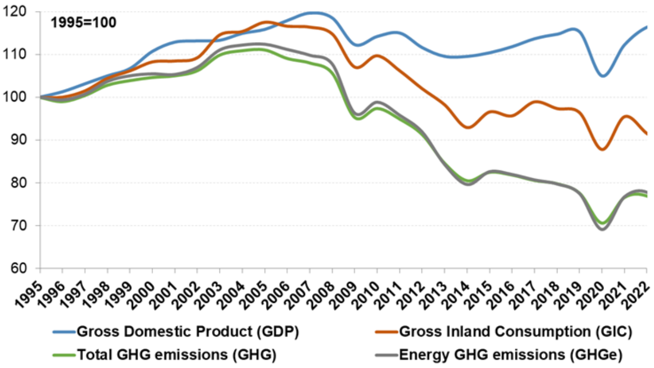
Nel settore dei rifiuti, la fonte dominante di metano è lo smaltimento dei rifiuti solidi, responsabili nel 2022 dell'84,6% delle emissioni di metano del settore, la fonte successiva è il trattamento delle acque reflue, con il 14,5%. Le altre due fonti, il trattamento biologico dei rifiuti solidi e l'incenerimento e la combustione in campo, rappresentano una quota inferiore all'1%.

La maggior parte delle emissioni fuggitive di metano sono dovute alla filiera del gas naturale (produzione, trasporto e distribuzione) che nel 2022 rappresenta l'80,1% delle emissioni fuggitive di metano con una quota che è diminuita significativamente dal 1990, quando era del 91,2%. Le filiere di approvvigionamento del petrolio e del gas naturale hanno registrato riduzioni delle emissioni di metano di oltre il 72% dal 1990.

Le emissioni di metano incombusto nel settore energetico sono dovute principalmente alla fonte dominante del settore civile (principalmente residenziale) con il 79,8% delle emissioni di metano del settore energetico nel 2022, seguito dall'industria manifatturiera e delle costruzioni con il 9,9%, dai trasporti con il 6,2% e dall'industria energetica con il 4,1%.

Disponendo in ordine decrescente le emissioni di metano del 2022 da tutte le fonti, si può notare che il 96,3% del metano proviene da sette fonti chiave che emettono 44 Mt CO_2eq. Le emissioni provenienti dalle principali fonti sono diminuite del 15,9% dal 1990. Le emissioni dalle fonti minori, che sono cumulativamente responsabili del 3,7% delle emissioni, sono inferiori del 35,4% rispetto al livello del 1990. Lo smaltimento dei rifiuti solidi urbani è la prima fonte chiave con il 34% delle emissioni totali di metano, seguito dalla fermentazione enterica con il 31,7%. Le prime due fonti sono responsabili di quasi due terzi delle emissioni di metano.

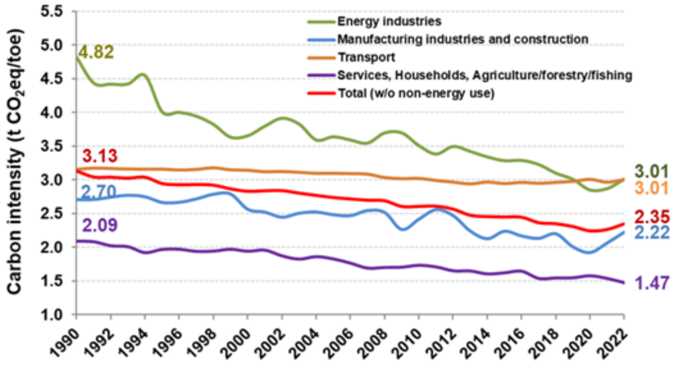
Intensità energetica e indicatori di decarbonizzazione



Per valutare le relazioni tra consumo energetico, economia ed emissioni di gas serra, sono state analizzati gli andamenti del consumo interno lordo di energia (GIC), del prodotto interno lordo (PIL) e delle emissioni. Il PIL e il GIC hanno andamenti paralleli fino al 2005. Successivamente i due parametri iniziano a divergere mostrando un disaccoppiamento sempre maggiore. La crescita delle emissioni di gas serra è stata più lenta di quella del PIL fino al 2005, evidenziando un relativo disaccoppiamento. Dopo il 2005, la divergenza tra i due parametri diventa sempre più marcata mostrando anche un disaccoppiamento assoluto quando il PIL è aumentato e i gas serra sono diminuiti (2015-2019).

Il disaccoppiamento è evidente anche dalla tendenza al ribasso del rapporto tra GIC e PIL dal 2005. La tendenza alla diminuzione delle emissioni di gas serra per unità di consumo di energia primaria è dovuta principalmente alla sostituzione di combustibili a più alto tenore di carbonio con gas naturale, principalmente nel settore energetico e nell'industria, e all'aumento della quota di energie rinnovabili. Le stesse tendenze sono confermate per il consumo finale di energia (al netto degli usi non energetici) per unità di PIL e per le emissioni di gas serra per unità di energia finale consumata.

Nel periodo 1995-2022 il consumo interno lordo di energia per PIL è sceso da 107,5 tep/M€ a 83,5 tep/M€ (-22,3%). Nello stesso periodo, i gas serra per PIL sono diminuiti del 34,9%, passando da 357,8 t CO_2eq/M€ a 233 t CO_2eq/M€, mentre le emissioni da combustione per consumo di energia primaria passano da 2,81 t CO_2eq/tep a 2,34 t CO_2eq/tep, con una riduzione del 16,8%. Dal 2005 si è registrata un'accelerazione del tasso di diminuzione di intensità energetica per unità di PIL e della decarbonizzazione dell'economia nazionale fino al 2019/2020, evidenziando ancora una volta il crescente disaccoppiamento tra attività economica, consumo di energia ed emissioni di gas serra. Le cause possono essere molteplici e tra le principali c'è la contrazione delle attività industriali, più energivore rispetto ai servizi caratterizzati da minore intensità energetica e maggiore valore aggiunto. I gas a effetto serra per energia consumata (primaria e finale) sono diminuiti rapidamente dal 2005, principalmente a causa dell'aumento della



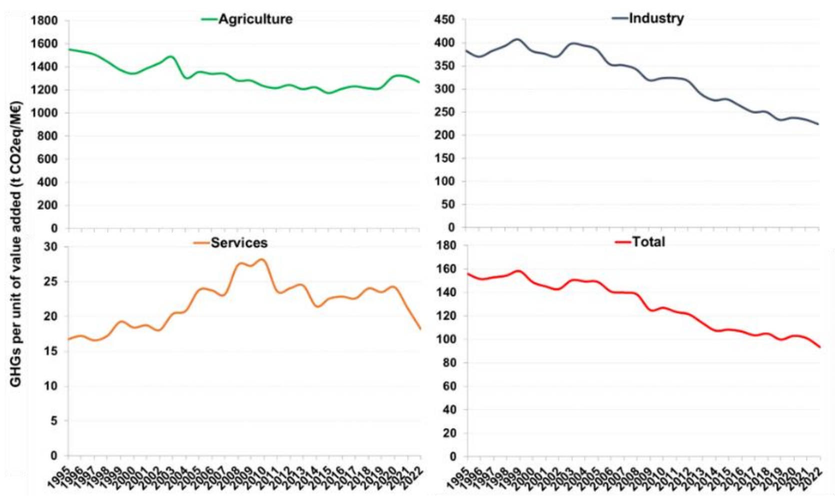
quota di energia rinnovabile dal 2007. Dopo il 2020 gli indicatori mostrano una tendenza al rialzo dovuta all'aumento dei combustibili petroliferi (2021 e 2022) e dei combustibili solidi (2022).

La decarbonizzazione a livello settoriale può essere valutata in base alle emissioni energetiche e al consumo di energia per settore. L'intensità di carbonio per energia è il rapporto tra i gas serra e il consumo di energia. L'intensità media di carbonio per settore varia notevolmente da un settore all'altro, a seconda della diversa diffusione delle fonti rinnovabili e dell'elettrificazione dei consumi finali. L'intensità di carbonio delle industrie energetiche diminuisce del 37,5% nel 2022 rispetto al 1990, passando da 4,82 t CO_2eq/tep a 3,01 t CO_2eq/tep. L'intensità di carbonio dell'industria manifatturiera nel 2022 è 2,22 t CO_2eq/tep, in calo del 17,8% rispetto al 1990. L'intensità di carbonio dei trasporti è 3,01 t CO_2eq/tep (-4,8% rispetto al 1990) e mostra il valore più alto degli ultimi anni tra i settori, con la pendenza decrescente più lenta dal 1990. L'intensità di carbonio nel settore civile è pari a 1,47 t CO_2eq/tep, in calo del 29,5% rispetto al 1990. La riduzione delle intensità di carbonio è statisticamente significativa per il test di Mann-Kendall ($p<0{,}001$). Complessivamente, l'intensità di carbonio per il consumo energetico considerato, pari al 93,6%±1,2% del consumo interno lordo di energia dal 1990 al 2022, è 2,35 tCO_2eq/tep nel 2022 (-25,1% rispetto al 1990).

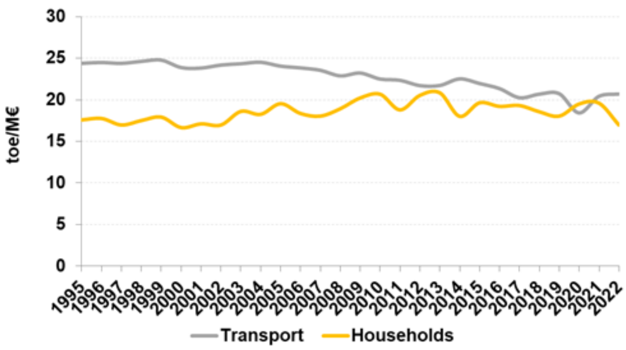
Indicatori dell'energia e dell'economia a livello settoriale

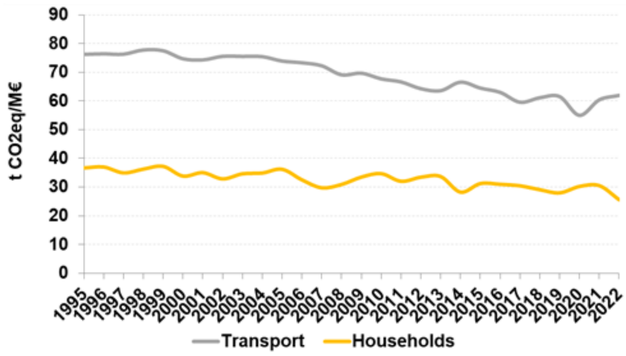
Gli indicatori di decarbonizzazione e di intensità energetica per settore sono stati calcolati confrontando i gas a effetto serra per settore con il rispettivo consumo di energia e valore aggiunto o PIL per i settori residenziale e trasporti. Le emissioni settoriali comprendono solo le emissioni dirette e le emissioni derivanti dall'autoproduzione di energia elettrica nell'industria manifatturiera. Le emissioni indirette dovute al consumo di energia elettrica prelevata dalla rete non sono considerate poiché comprese nelle industrie energetiche. I gas serra dei tre settori (agricoltura, industria, servizi)rappresentano in media il 34,5±0,8% dei gas serra totali.

Nel complesso, le emissioni sono diminuite del 27,5% nel 2022 rispetto al 1995. Le emissioni da combustione e da processi sono diminuite del 27,7% e del 27,1% rispettivamente. Nel 2022 l'intensità energetica (tep/M€) dell'industria è ben al di sotto del livello del 1995 (-31,4%), mentre i servizi sono più alti (+28,8%), anche se negli ultimi anni l'intensità del settore diminuisce in modo significativo. Per quanto riguarda l'agricoltura, dopo una tendenza al ribasso dal 2003 al 2015 l'intensità è aumentata ma il livello del 2022 è -3,5% rispetto al 1995. Nel periodo 1995-2022 l'intensità energetica aggregata dei tre settori è diminuita del 22,2%. L'intensità di carbonio, il rapporto tra gas serra e valore aggiunto, diminuisce a causa della crescente quota di energia rinnovabile e di combustibili a basso contenuto di carbonio, come il gas naturale. Le intensità di carbonio per valore aggiunto sono molto diverse da un settore all'altro. L'agricoltura ha i valori più alti, mentre i servizi registrano quelli più bassi. Nel 2022 l'intensità dell'agricoltura è inferiore del 18,3% rispetto al livello del 1995, mentre quella dei servizi è superiore dell'8,7%. L'industria mostra una forte diminuzione (-41,6% nel 2022 rispetto al 1995) che determina l'andamento dell'intensità aggregata (-40% nel 2022).



L'intensità energetica e l'intensità di carbonio dei trasporti e delle famiglie è stata calcolata considerando il PIL. L'intensità energetica delle famiglie oscilla intorno a una media senza una chiara tendenza (18,6±1,2 tep/M€), mentre l'intensità di carbonio mostra un andamento decrescente dal 1995 (da 36,7 t CO_2eq/M€ nel 1995 a 25,6 t CO_2eq/M€ nel 2022; -30,3%). L'andamento delle emissioni di gas serra rispetto al PIL testimonia il cambiamento del mix energetico nei consumi finali del settore, con un contributo crescente della biomassa che riduce l'intensità di carbonio ma non l'intensità energetica.

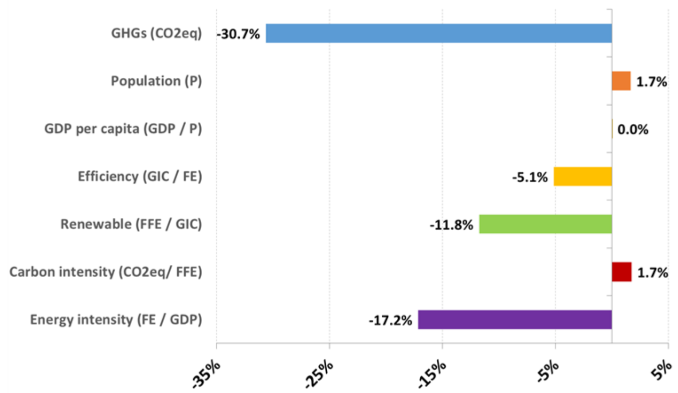




L'intensità energetica dei trasporti è diminuita del 15,2%, passando da 24,4 tep/M€ a 20,7 tep/M€ dal 1995 al 2022. Un trend decrescente parallelo è stato osservato per l'intensità di carbonio con una riduzione del 19,4%, da 77,2 t CO_2eq/M€ a 62,2 t CO_2eq/M€ dal 1995 al 2022, mostrando una certa decarbonizzazione anche in questo settore. Tuttavia, un'analisi più approfondita mostra che nei trasporti non c'è un vero e proprio disaccoppiamento tra consumi di energia e emissioni. Dal 2005 le due intensità, energetica e di carbonio, nel settore residenziale mostrano una distanza crescente, a causa della diminuzione dei gas a effetto serra rispetto al consumo di energia.

Identità di Kaya e analisi della decomposizione

L'analisi di decomposizione è una tecnica per studiare la variazione di un indicatore in ogni intervallo di tempo in relazione alla variazione dei suoi fattori determinanti. In altre parole, la variazione di un parametro viene scomposta nella variazione dei parametri che lo determinano. Il punto di partenza dell'analisi è la costruzione di un'equazione di identità, dove la variabile studiata è rappresentata come il prodotto di componenti considerate come le cause della variazione osservata. Per l'identità, i componenti devono essere rapporti, dove il denominatore di un componente è il numeratore del successivo. Questa identità, chiamata Kaya dall'economista Yoichi Kaya, è fornita *a priori*, e deve essere realizzata secondo un modello concettuale coerente con i vincoli fisici della variabile studiata, oltre alle considerazioni relative alla disponibilità dei dati e agli obiettivi dell'analisi.

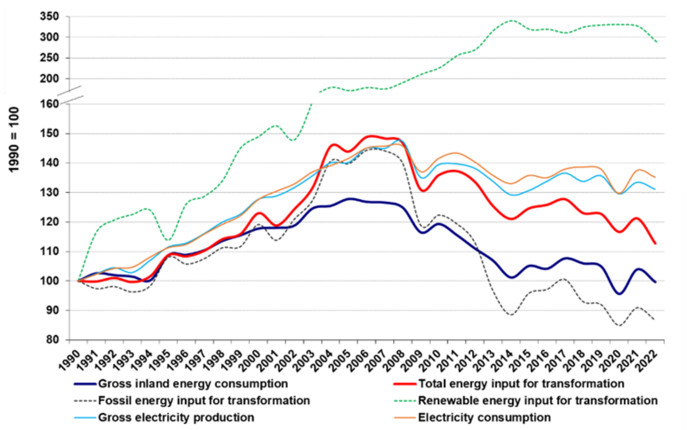


Le emissioni di gas serra sono state decomposte in sei fattori: 1) popolazione; 2) crescita economica *pro capite*; 3) efficienza; 4) energie rinnovabili; 5) intensità di carbonio da combustibili fossili; 6) intensità energetica finale. I risultati dell'analisi di decomposizione, effettuata secondo il *Logarithmic mean Divisia index* (Ang, 2005), mostrano che l'effetto dei fattori che hanno ridotto le emissioni nel periodo 2005-2022 ha prevalso sull'effetto dei fattori che hanno portato ad un aumento delle emissioni. La popolazione e l'intensità di carbonio sono gli unici fattori che hanno contribuito alla crescita delle emissioni (entrambe +1,7%). I restanti fattori hanno determinato la riduzione delle emissioni. L'intensità energetica finale (consumo finale di energia / PIL) ha svolto il ruolo principale

(-17,2%) seguita dalla quota di energia rinnovabile (consumo di energia fossile / consumo interno lordo di energia; -11,8%) e dall'efficienza (consumo interno lordo / consumo di energia finale; -3,9%). Il PIL pro capite non svolge alcun ruolo nell'intervallo considerato. Il contributo complessivo dei fattori determina la riduzione del 30,7% dei gas serra nel periodo 2005-2022.

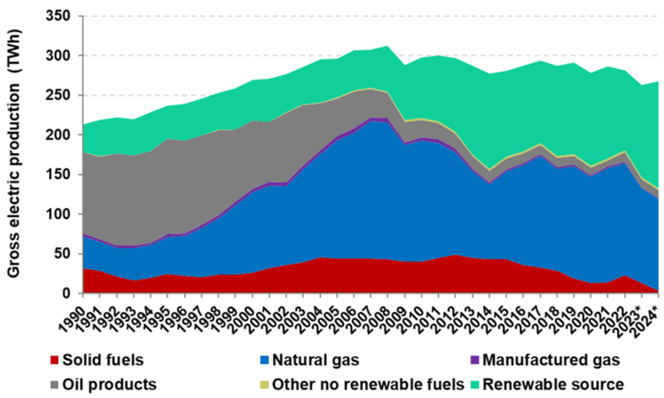
Settore elettrico

Produzione di energia termoelettrica e rinnovabile



La crescita dei consumi di energia elettrica nei consumi finali rende questo settore uno dei principali attori del sistema energetico nazionale. Dal 2001 il consumo di energia per la produzione di elettricità è aumentato a tassi superiori rispetto a quanto registrato per il consumo interno lordo di energia.

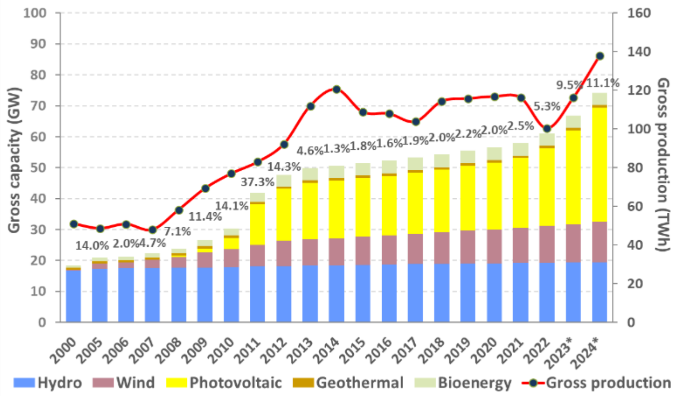
La produzione lorda di energia elettrica è passata da 216,6 TWh a 284 TWh dal 1990 al 2022 (+31,1%). Nello stesso periodo, i consumi sono passati da 218,8 TWh a 295,9 TWh (+35,2%). Dopo una crescita costante della produzione e del consumo, dal 2007 è stata registrata una diminuzione a causa della crisi economica. Nel 2020 c'è stato un ulteriore calo della produzione e del consumo, seguito dal rimbalzo nel 2021. Nel 2022 la produzione è stata superiore solo dell'1,2% rispetto al 2020, mentre il consumo è stato superiore del 4,2%, trainato dall'importazione netta di energia elettrica la cui quota nel 2022, così come nel 2021, è stata superiore al 14% del consumo (14,2% e 14,5%, rispettivamente nel 2021 e nel 2022).



Per quanto riguarda il mix energetico nel settore elettrico, il gas naturale è aumentato costantemente dal 1990 a scapito dei prodotti petroliferi (nel 2022 il 49,8% della produzione di energia elettrica da gas naturale e circa il 4,5% da prodotti petroliferi, mentre nel 1990 le due percentuali erano rispettivamente del 18,3% e del 47,4%). Nel 2022, dopo una costante diminuzione dal 1995, è stato registrato un aumento della produzione di energia elettrica da prodotti petroliferi rispetto all'anno precedente, passando dal 2,7% al 4,5%. Anche la quota dei combustibili solidi ha mostrato un rilevante incremento nell'ultimo anno, da 4,9% nel 2021 a 8% nel 2022. L'aumento dei prodotti petroliferi e dei combustibili solidi nel 2022 va letto nel quadro della guerra russo-ucraina e della necessità di ridurre l'importazione di gas naturale dalla Russia. Le stime preliminari per il 2023 mostrano una tendenza al ribasso della quota di gas naturale (≈45%), una lieve diminuzione dei prodotti petroliferi (≈4%) e la diminuzione più consistente dei combustibili solidi (≈5%).

Nel 2005 la quota di energia elettrica da fonti rinnovabili rispetto alla produzione totale rappresentava il 16,4%. Dopo il 2007 la quota di fonti rinnovabili è aumentata significativamente fino al massimo del 2014, quando ha raggiunto il 43,4%. Nel 2022 la quota rinnovabile è pari al 35,6%, molto al di sotto del livello dell'anno precedente (40,5%), a causa del drastico calo dell'idroelettrico. I dati preliminari per il 2023 mostrano una ripresa della produzione rinnovabile la cui quota sulla produzione elettrica nazionale dovrebbe raggiungere un nuovo massimo, intorno al 44%, dopo quello del 2014. I primi dati del 2024 mostrano una massiccia ripresa dell'idroelettrico e del fotovoltaico che dovrebbe portare la quota di rinnovabili oltre il livello stimato per il 2023 (circa il 50%).

La potenza termica totale nel 2022 è 62,4 GW con una forte contrazione dal 2012, quando la capacità installata raggiunse il picco di 80,6 GW. Gli impianti a ciclo combinato, indipendentemente dalla produzione cogenerativa o non cogenerativa, mostrano un significativo incremento della potenza efficiente lorda, passando da 7,9 GW nel 2000 ad un massimo di 43,4 GW nel 2011-2012. Successivamente, questi impianti mostrano una costante riduzione della potenza fino a 40,5 GW nel 2022.



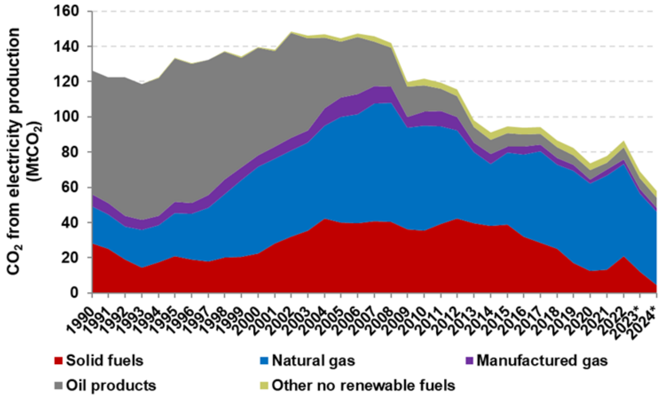
Dal 2000 è stato registrato un aumento significativo della capacità installata di energia rinnovabile. Nel 2022 la potenza efficiente lorda è stata 61,1 GW. Il tasso di crescita annuo più elevato è stato registrato nel 2011 quando la nuova potenza installata rispetto all'anno precedente è stata di 11,3 GW, di cui 9,5 GW di impianti fotovoltaici e 1,1 GW di impianti eolici. Dopo il 2014 la potenza aggiuntiva è stata di circa 1 GW all'anno fino al 2021. La potenza aggiuntiva nel 2022 è stata di 3,1 GW (2,5 GW di fotovoltaico). I dati preliminari del 2023 evidenziano un ulteriore aumento della nuova potenza, oltre i 5 GW, in gran parte da impianti fotovoltaici. Considerando anche i dati preliminari sulle installazioni di nuovi impianti fotovoltaici fino a luglio 2024 e stimando un tasso comparabile di nuovi impianti per il resto dell'anno, la potenza fotovoltaica totale dovrebbe salire fino a 37 GW, mentre l'eolico dovrebbe essere di quasi 13 GW. La potenza rinnovabile totale nel 2024 dovrebbe essere di circa 74 GW.

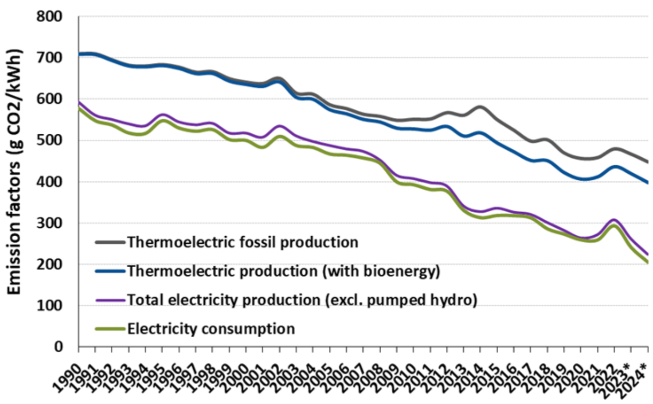
Per quanto riguarda gli impianti alimentati a bioenergia, va sottolineato il rapido aumento dal 2008 al 2013 e la successiva stabilizzazione della potenza lorda efficiente con nuove installazioni di pochi MW all'anno fino al 2018 e una diminuzione negli ultimi anni. Gli impianti alimentati a biogas sono passati da 0,37 GW nel 2008 a 1,46 GW nel 2022. La crescita degli impianti alimentati con bioliquidi nel periodo 2008-2013 è particolarmente rapida, passando da 0,12 GW a 1,04 GW, per poi ridursi a 0,94 GW nel 2022. Gli impianti alimentati da biomasse solide e rifiuti sono passati da 1,07 GW nel 2008 a 1,73 GW nel 2018. Dal 2018 la potenza degli impianti a biomasse solide mostra un decremento, mentre aumenta la potenza degli impianti a rifiuti. Nel 2022 la potenza complessiva è di 1,65 GW, di cui 0,87 alimentati da rifiuti. Tali tendenze si spiegano con la riduzione degli incentivi per gli impianti alimentati a bioenergia. Il futuro sviluppo di tali impianti non sembra indipendente da alcune forme di incentivazione.

Emissioni di CO_2 e fattori di emissione

La quantità di CO_2 emessa dal settore elettrico nel 2022 è stata di 99,3 Mt (di cui 86,7 Mt per la generazione di energia elettrica e 12,7 Mt per la produzione di calore), circa il 24% dei gas serra nazionali.

Fino alla prima metà degli anni '90, le emissioni di CO_2 derivanti dal petrolio e dai prodotti petroliferi rappresentavano una quota significativa delle emissioni totali del settore elettrico. Nel 1995, la quota di emissioni derivanti da prodotti petroliferi ammontava al 61% delle emissioni. Successivamente la quota di CO_2 proveniente da queste fonti è costantemente diminuita fino al 9,6% nel 2022, anche se nell'ultimo anno è stato registrato un aumento della quota rispetto al 2021, come già visto per la produzione elettrica. Considerando solo l'olio combustibile, le emissioni di CO_2 sono diminuite dal 61% al 2,2% dal 1995 al 2022 con un nuovo aumento nel 2022 rispetto all'anno precedente, dopo il primo registrato nel 2021 dopo molti anni di costante riduzione. La quota di emissioni di gas naturale è passata dal 18,5% del 1995 al 61,5% del 2022, con una sensibile diminuzione rispetto al 2021 (69,9%). La quota di emissioni da combustibili solidi, principalmente carbone, è stata in costante aumento fino al 2014 quando è stato raggiunto il picco del 37,2% ma negli anni successivi si registra una forte riduzione fino al 14,7% nel 2020 e nel 2021. Nel 2022 è stata osservata un'impennata dei combustibili solidi, con la quota che ha raggiunto il 21,5%. Le stime preliminari per il 2023 mostrano che la quota dovrebbe diminuire fino a circa il 18%, con un'ulteriore diminuzione nel 2024.



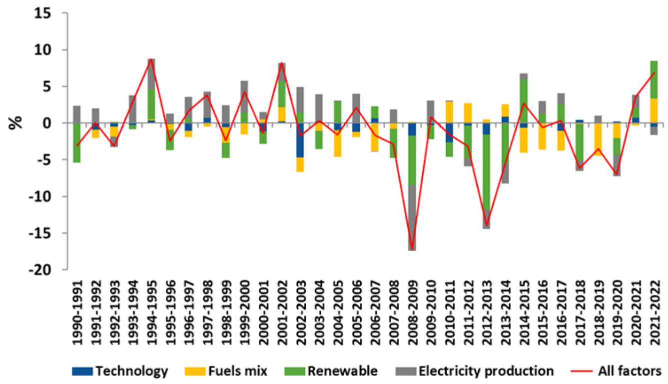


Dal 1990 al 2022 il fattore di emissione della produzione lorda nazionale di energia elettrica da centrali termiche diminuisce da 709 g CO_2/kWh a 436,8 g CO_2/kWh. Nel 2022 è stato registrato un rilevante incremento del fattore di emissione, dovuto all'aumento dei combustibili solidi e dei prodotti petroliferi nel mix energetico. La diminuzione osservata nel lungo periodo è dovuta principalmente all'aumento della quota di gas naturale e alla continua riduzione del fattore di emissione specifico di questo combustibile, a sua volta dovuto all'aumento dell'efficienza di conversione elettrica degli impianti. Un ruolo importante è svolto anche dalle bioenergie, con un bilancio emissivo pari a zero, che rappresentano l'8,8% della produzione elettrica di origine termica. La differenza tra il fattore di emissione da produzione termica con o senza il contributo delle bioenergie mostra il ruolo di tali fonti nella riduzione del fattore di emissione. La differenza diventa significativa dopo il 2000 a causa dell'aumento della quantità di biomassa solida e di rifiuti solidi urbani o assimilati utilizzati per la produzione elettrica e dell'aumento ancora maggiore dei bioliquidi e del biogas dopo il 2008. Negli ultimi anni, a partire dal 2020, la quota di bioenergie diminuisce.

La produzione elettrica da fonti rinnovabili riduce il fattore di emissione in quanto le fonti rinnovabili non hanno emissioni di CO_2. Il fattore di emissione per i consumi di energia elettrica è ulteriormente ridotto a causa della quota di energia elettrica importata dall'estero, le cui emissioni sono rilasciate al di fuori del territorio nazionale. All'aumento della produzione di energia elettrica dal 1990 al 2022 di 67,4 TWh corrisponde una diminuzione delle emissioni di CO_2 di 39,7 Mt. La riduzione del fattore di emissione per la produzione elettrica dal 2007 al 2014 è dovuta principalmente all'aumento delle fonti rinnovabili, mentre la diminuzione registrata dal 2015 al 2022 è dovuta anche alla crescente quota di gas naturale. I dati preliminari mostrano che nel 2023 e nel 2024 dovrebbe essere registrata una notevole diminuzione delle emissioni di CO_2 del settore elettrico.

Analisi di decomposizione

La variazione delle emissioni di gas serra derivanti dalla produzione termoelettrica è dovuta a diversi fattori come la tecnologia, i combustibili utilizzati, il contributo delle fonti rinnovabili e la domanda di elettricità. L'analisi di decomposizione è stata applicata per valutare il contributo relativo di questi fattori.



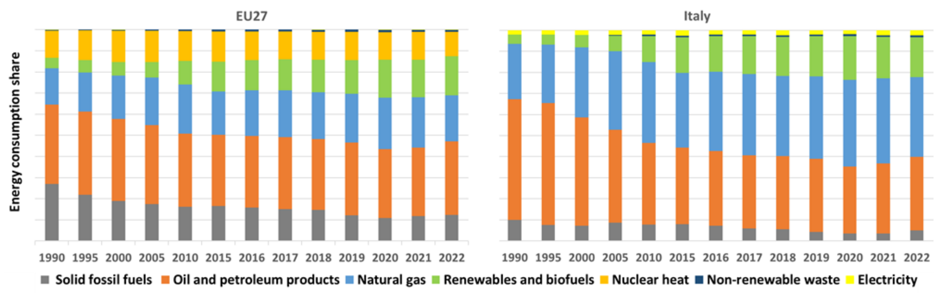
I fattori considerati nell'analisi (tecnologia, mix combustibile, fonti rinnovabili) contribuiscono alla riduzione delle emissioni di CO_2 laddove l'aumento della produzione di energia elettrica ha l'effetto opposto. I risultati dell'analisi mostrano che i fattori tecnologici, rinnovabili e mix energetico contribuiscono alla riduzione delle emissioni di CO_2 dal 1990 al 2022 rispettivamente per il 18,5%, il 21,8% e il 14,6%, mentre l'aumento della produzione di energia elettrica porta a un aumento delle emissioni del 23,5%. L'effetto cumulativo dei fattori ha portato a una riduzione delle emissioni di CO_2 nel 2022 del 31,4% rispetto alle emissioni del 1990 (-39,7 MtCO_2). In altre parole, la riduzione dovuta alla variazione del fattore tecnologico (diminuzione dei fattori di emissione specifici dei combustibili fossili) nel periodo 1990-2022 sarebbe stata di 23,3 Mt CO_2 se gli altri fattori fossero rimasti invariati. La riduzione dovuta alla variazione del mix di combustibili sarebbe stata di 18,5 Mt CO_2, mentre l'aumento della quota rinnovabile avrebbe portato a una riduzione delle emissioni di 27,6 Mt CO_2. Tali effetti sono stati compensati da un aumento netto della produzione di energia elettrica che avrebbe comportato un aumento delle emissioni di 29,7 Mt CO_2 senza il contributo degli altri fattori.

Dal 2007 il ruolo delle fonti rinnovabili diventa più rilevante rispetto agli altri fattori. Inoltre, va sottolineato che fattori che deprimono la domanda di elettricità, come la crisi economica del 2008 e la pandemia del 2020, determinano l'incremento della quota rinnovabile per effetto della priorità del dispacciamento dell'energia elettrica rinnovabile.

L'ITALIA E I PRINCIPALI PAESI EUROPEI

Indicatori di efficienza e decarbonizzazione

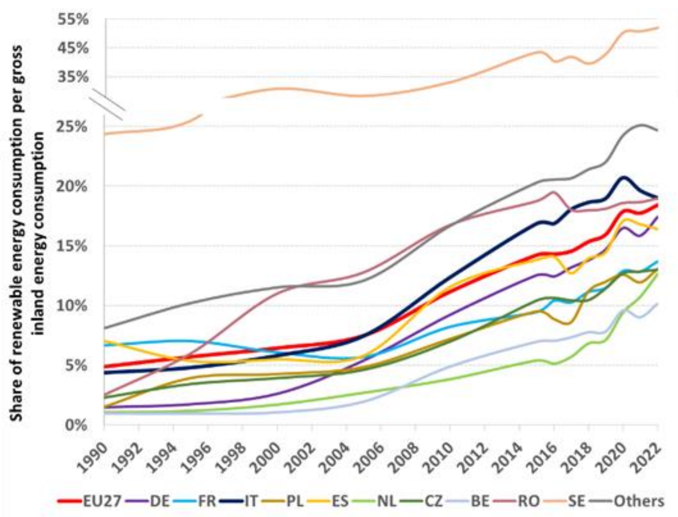
Sono stati confrontati gli indicatori di decarbonizzazione ed efficienza nazionali e dei principali Paesi europei. Per il confronto sono stati considerati gli Stati con più del 3% delle emissioni di gas serra dell'UE27 o più del 3% del PIL dell'UE27 nel 2020.



Gli Stati membri esaminati (Germania, Francia, Italia, Spagna, Polonia, Paesi Bassi, Belgio, Romania e Svezia) rappresentavano nel 2020 l'81,5 % della popolazione dell'UE27, l'81,6 % dei gas serra e l'83,2 % del PIL. Il consumo interno lordo di energia rappresentava l'82,5% del consumo energetico dell'UE27.

Consumo di energia e prodotto interno lordo

Dal 1990, le politiche ambientali europee hanno determinato una variazione del mix energetico negli Stati europei. L'energia nucleare rappresenta l'11,5% del consumo interno lordo dell'UE27 nel 2022, con una sensibile riduzione rispetto all'anno precedente, anche a causa dell'uscita della Germania dal nucleare. L'energia da combustibili solidi ha subito una contrazione significativa dal 1990, anche se negli ultimi due anni si è registrato un aumento rispetto al livello più basso raggiunto nel 2020. La quota dell'UE27 nel 2022 è del 12%, mentre nel 1990 era del 26,3%. Vi sono ancora quote significative di combustibili solidi in alcuni degli Stati più grandi come la Germania (19,7%), la Polonia (40,3%) e la Cechia (32,1%). Petrolio e prodotti petroliferi, invece, mostrano una modesta riduzione a livello europeo (dal 38,3% nel 1990 al 35,2% nel 2022) con andamenti diversi tra gli Stati. Il consumo di energia da gas naturale mostra un aumento considerevole in quasi tutti gli Stati e a livello europeo oscilla da 17,1% nel 1990 a 21,7% nel 2022, nettamente inferiore alla quota registrata nel 2021 e nel 2020 (rispettivamente 23,9% e 24,4%). L'energia rinnovabile in EU27 aumenta da 4,9% a 18,4% dal 1990 al 2022.

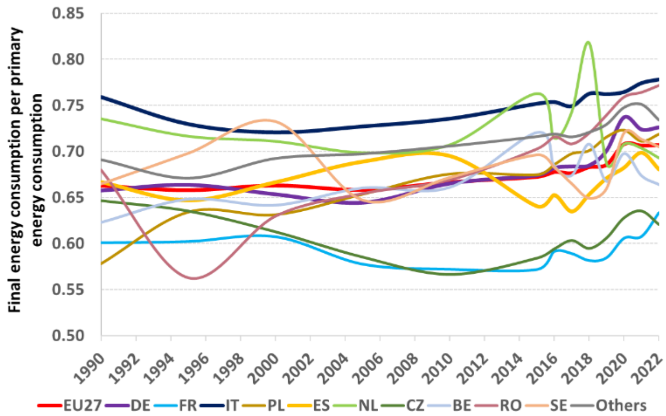


La quota italiana dei combustibili solidi, principalmente carbone, nel consumo interno lordo è scesa da 9,9% nel 1990 a 5% nel 2022, in aumento rispetto all'anno precedente (3,6%). La quota di gas naturale passa invece da 26,3% a 37,9%, ben al di sotto del livello del 2021 (40,5%). La quota di petrolio e prodotti petroliferi passa da 57,3% a 34,8% e la quota di rinnovabili aumenta da 4,4% a 19%, al di sotto del livello del 2020 (20,7%). In Italia la quota di rinnovabili sul consumo interno lordo è tra le più alte dei Paesi esaminati, solo la quota della Svezia è superiore a quella italiana. Tuttavia, l'obiettivo europeo al 2030 della quota di rinnovabili riguarda il consumo finale lordo e la quota dell'Italia è ben al di sotto della media europea nel 2022 (19,1% vs 23%).

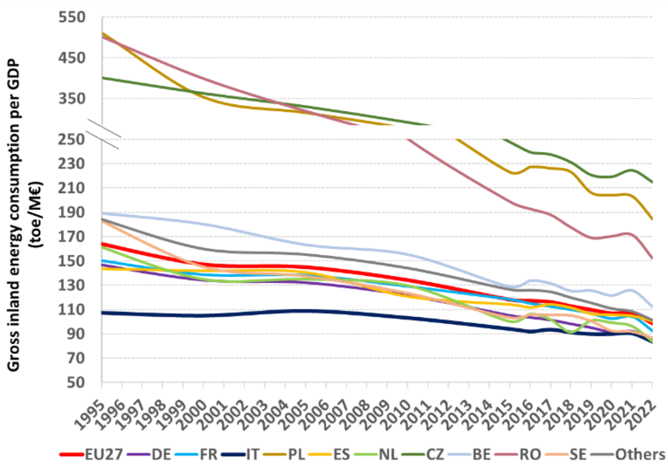
La quota di combustibili fossili è diminuita significativamente in quasi tutti i Paesi europei, anche se la quota nel 2022 è leggermente cresciuta rispetto al 2021. La media dell'UE27 è scesa da 82 % nel 1990 a

70% nel 2022. Tra i Paesi esaminati, le quote nei Paesi Bassi e Polonia sono ancora superiori all'85%, rispettivamente 86,1% e 87,1%.

Il rapporto tra consumo finale di energia (compresi gli usi non energetici) e consumo interno lordo è un indicatore dell'efficienza energetica. Dal 1990 questo indicatore è sempre stato più alto per l'Italia rispetto alla media europea. Per valutare l'efficienza della trasformazione dell'energia, è utile considerare il consumo di energia senza usi non energetici. In altre parole, il rapporto tra consumo di energia finale e di energia primaria. L'efficienza energetica italiana è superiore a quella degli altri Paesi esaminati.



Il consumo interno lordo di energia per unità di prodotto interno lordo (PIL) è un indicatore dell'efficienza economica ed energetica del Paese (intensità energetica). L'Italia è stata uno dei Paesi europei a più bassa intensità energetica fino al 1995, quando era dietro solo alla Danimarca, poi ha perso posizioni e nel 2022 ha il 6° valore più basso. Tra i maggiori Paesi dell'UE27, l'Italia continua ad essere tra i Paesi con la più bassa intensità energetica.

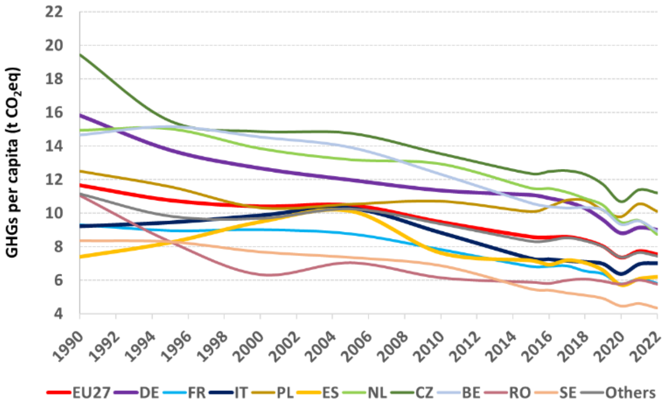


L'intensità energetica finale (rapporto tra consumi energetici finali, compresi gli usi non energetici, e PIL) segue andamenti analoghi all'intensità energetica lorda con una repentina riduzione nei Paesi europei che, partendo da livelli superiori a quelli italiani, raggiungono i valori italiani e in alcuni casi li superano. Dal 1995 l'Italia mostra una notevole efficienza energetica ed economica, l'intensità energetica finale si è ridotta del 18,1% dal 1995 al 2022, considerando il PIL a valori concatenati, e del 49,5% considerando il PIL a parità di potere d'acquisto. Negli altri Paesi europei si sono verificate riduzioni molto più elevate (-36,2% nell'UE27 con il PIL a valori concatenati e -60,5% con il PIL a parità di potere d'acquisto). Le ragioni della riduzione dell'intensità energetica osservata sono molteplici, come l'aumento dell'efficienza degli edifici, il miglioramento dell'efficienza industriale, l'elettrificazione dei consumi finali e lo spostamento dell'economia verso attività di servizi ad alto valore aggiunto e a basso consumo energetico a scapito dei settori industriali.

I Paesi europei mostrano un ampio intervallo di elettrificazione dei consumi finali di energia (solo usi energetici), che nel 2022 va da 14,5% in Lettonia a 39,2% in Malta. L'Italia è appena al di sotto della media UE27 con il 22,3% contro il 23%. Tra i Paesi considerati, Svezia, Francia e Spagna hanno livelli di elettrificazione più elevati dell'Italia, rispettivamente 33,8%, 26,9% e 24,8%. All'estremo inferiore ci sono Romania e Polonia, rispettivamente con 15,4% e 16,1%.

A livello settoriale, l'elettrificazione degli Stati membri mostra cifre diverse, anche se con una comune tendenza alla crescita. L'elettrificazione dell'industria italiana è tra le più alte in Europa (39% nel 2022), molto superiore alla media UE27 (33,3%). I servizi mostrano le quote più alte di elettrificazione tra i settori. La quota italiana nel 2022 è del 50,6%, in linea con la media UE27, mentre l'elettrificazione del settore residenziale in Italia è molto inferiore a quella dell'UE27 (18,5% vs 25,1%). Il settore dei trasporti mostra le percentuali più basse di elettrificazione. La media UE27 nel 2022 è del 2% e tra i principali Paesi le percentuali più alte si registrano in Svezia (5,4%) e Paesi Bassi (3,1%). Il dato nazionale è del 2,1%.

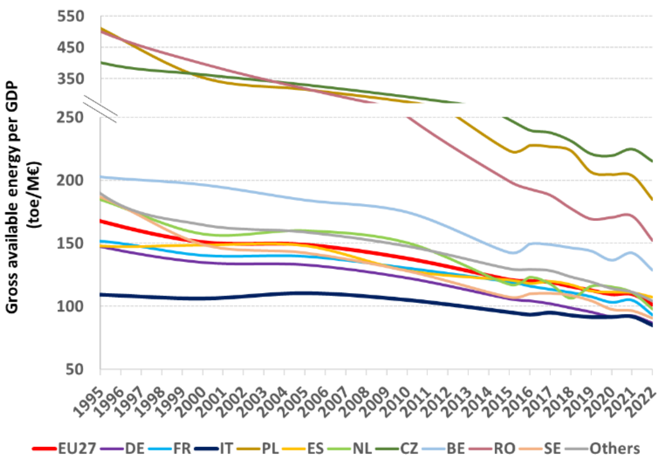
Emissioni di gas serra e consumo energetico



In Italia la media di gas serra pro capite dal 1990 al 2022 è pari a 8,8±1,2 t CO_2eq. Le emissioni pro capite sono aumentate fino al 2004 quando è stato raggiunto il picco di 10,3 t CO_2eq, seguito dalla riduzione fino a 6,4 t CO_2eq nel 2020, e dal successivo aumento fino a 7 t CO_2eq nel 2022. I gas serra pro capite italiani sono sempre stati al di sotto della media europea (7,6 t CO_2eq nel 2022).

Dal 1990 i gas serra per consumo energetico sono diminuiti in tutti i Paesi. Tale indicatore è sensibile al mix energetico del Paese. L'intensità di carbonio dell'Italia è superiore alla media europea, anche per il contributo dell'energia nucleare in molti Paesi. Separando l'energia nucleare dal consumo interno lordo, il valore dell'Italia è appena al di sotto della media europea (2,79 t CO_2eq *vs* 2,82 t CO_2eq nel 2022).

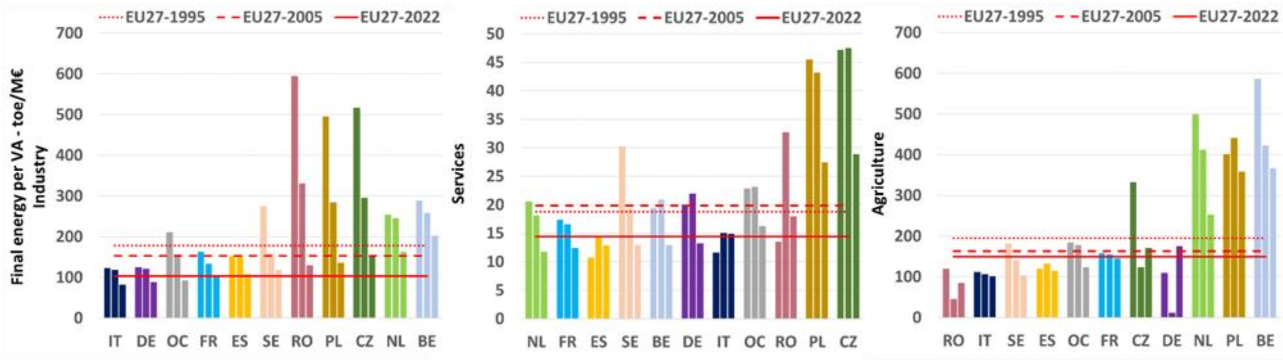
Il rapporto tra gas serra e PIL è l'intensità di carbonio correlata all'economia. Tale indicatore è sensibile al mix energetico del Paese, come l'intensità di carbonio relativa all'energia, e ancor più sensibile alla struttura dell'economia: quota di servizi e industria. Inoltre, va considerato che il PIL dei paesi è determinato anche da attività legate ai bunkeraggi internazionali, le cui emissioni sono voci "memo" negli inventari delle emissioni presentati all'UNFCCC e non considerate nelle statistiche nazionali sulle emissioni. Tutti i Paesi europei hanno ridotto l'intensità di carbonio dell'economia e i dati dell'Italia, considerando il PIL a valori concatenati, sono appena al di sotto della media UE27 nel 2022 (0,23 t CO_2eq/k€ vs 0,25 t CO_2eq/k€), mentre con il PIL a parità di potere di acquisto l'intensità in Italia è inferiore alla media Europea (0,19 t CO_2eq/k€ *vs* 0,21 t CO_2eq/k€). Svezia e Francia hanno i valori più bassi: rispettivamente 0,09 t CO_2eq/k€ e 0,17 t CO_2eq/k€ (a valori concatenati). Polonia e Cechia si collocano all'estremità superiore con 0,67 t CO_2eq/k€ e 0,6 t CO_2eq/k€ (a valori concatenati).



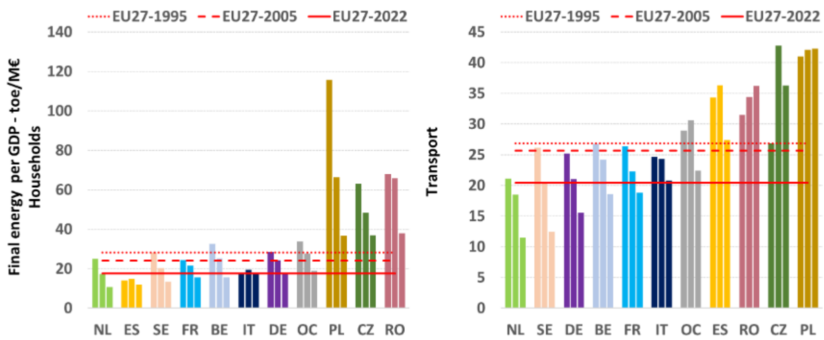
L'inclusione del contributo dei bunker internazionali nell'elaborazione dell'intensità energetica e dell'intensità di carbonio per unità di PIL dimostra che l'Italia e la Germania hanno le intensità energetiche più basse tra i principali Paesi. L'intensità di carbonio italiana è maggiore di quelle registrate in Francia e Svezia, che beneficiano del contributo dell'energia nucleare.

Il confronto degli indicatori di efficienza e decarbonizzazione a livello settoriale tra gli Stati membri mostra un quadro piuttosto eterogeneo. Per quanto riguarda l'industria in Italia, l'intensità energetica finale, rapporto tra consumi finali di energia e valore aggiunto, è sempre stata la più bassa tra i maggiori Paesi con un trend decrescente. Tra i Paesi europei solo Irlanda, Danimarca, Malta ed Estonia hanno un'intensità energetica industriale inferiore a quella dell'Italia nel 2022. Tra i Paesi esaminati, Paesi Bassi e Belgio mostrano le più alte intensità energetiche per l'industria. Il tasso medio annuo dell'intensità energetica del settore dal 2005 al 2022 è diminuito del -2,1% per l'Italia e -2,3% per la media europea.

Nei servizi l'Italia mostra un'intensità vicina alla media europea, superiore a quella della Germania. L'Italia è l'unico Paese, tra i più grandi, la cui intensità energetica in questo settore non è diminuita in maniera rilevante dal 2005. Il risultato è dovuto anche all'energia consumata dalle pompe di calore che l'Italia ha iniziato a contabilizzare dal 2017 nel database Eurostat, sebbene presenti anche in anni precedenti. L'intensità energetica italiana è diminuita con un tasso medio annuo dello 0,1% dal 2005 al 2022, contro una diminuzione media annua di -1,9% per EU27.



Il settore dell'agricoltura mostra una generale diminuzione dell'intensità energetica nell'UE27. Nel 2022, tra i Paesi considerati, solo la Romania ha un'intensità energetica inferiore a quella dell'Italia. L'intensità energetica italiana diminuisce con un tasso medio annuo di -0,3% dal 2005 al 2022 contro il -0,5% della media europea.



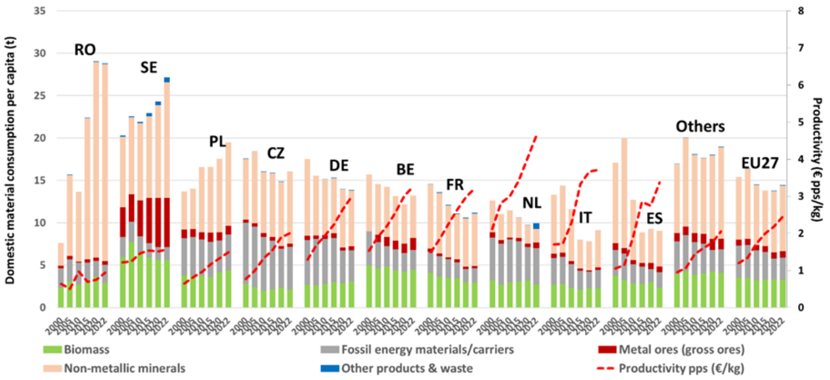
Nel settore domestico, dal 2005 al 2022 i principali Paesi mostrano significative riduzioni dei consumi energetici per unità di PIL: da -0,8% annuo in Italia a -3,4% annuo in Polonia. Per i trasporti l'intensità energetica in Italia è in linea con la media europea.

La classifica dei Paesi esaminati nei settori residenziale e trasporti mostra che l'intensità energetica italiana è vicina alla media UE27, con ampi margini di miglioramento delle performance dei trasporti se confrontate con la Germania.

Quanto detto per l'intensità energetica si riflette nell'intensità di carbonio (t CO_2eq/M€). Questo indicatore è più sensibile al ruolo delle energie rinnovabili, dell'energia nucleare e dell'importazione di energia elettrica nel bilancio energetico dei Paesi, perché tali fonti non generano gas serra. L'industria italiana, così come l'agricoltura, nel 2022 ha intensità di carbonio superiori solo a quelle della Svezia tra i principali Paesi. La media europea per industria e agricoltura è superiore all'intensità italiana del 10% e 80,6%, rispettivamente. D'altra parte, l'intensità di carbonio dei servizi in Italia è superiore del 44,9% alla media UE27, solo le intensità di carbonio di Romania, Polonia e Repubblica Ceca sono superiori a quella italiana. Le intensità nei settori residenziale e trasporti in Italia sono superiori alla media UE27 (+19,5% per il residenziale, +6,2% per i trasporti nel 2022), mostrando un importante potenziale di riduzione dei gas serra per il Paese, soprattutto considerando che l'elettrificazione dei consumi finali del residenziale nel 2022 è molto al di sotto della media UE27 (18,5% vs 25,1%).

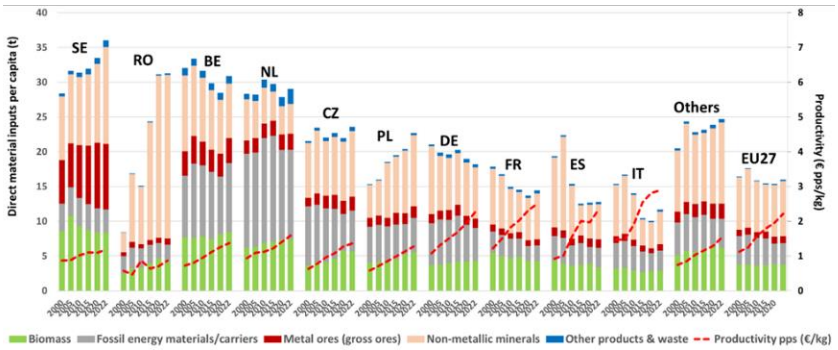
Flussi di materiali

Gli indicatori degli input diretti di materia (DMI) e del consumo interno di materia (DMC) descrivono, in termini aggregati, l'uso diretto e la provenienza delle risorse e dei prodotti naturali. Il primo indicatore comprende tutti i materiali che hanno un valore economico e sono utilizzati per attività di produzione e consumo; l'indicatore è calcolato come somma delle estrazioni interne e delle importazioni. Il secondo indicatore rappresenta il consumo interno di materia nell'economia nazionale al netto delle esportazioni ed è calcolato sottraendo dagli input materiali diretti la quota delle esportazioni fisiche.



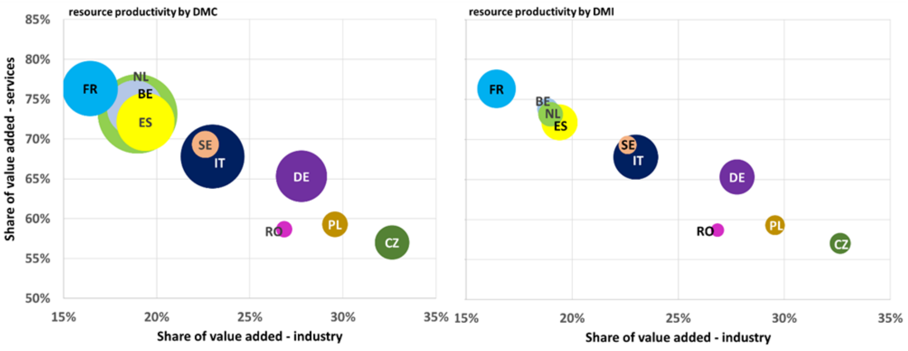
A partire dal 2000 è stata registrata la diminuzione della DMC media pro capite nei Paesi europei. Nel 2022 la Spagna ha il più basso consumo pro capite di materia tra i Paesi dell'UE27, seguita da Italia e Paesi Bassi. Per quanto riguarda la produttività delle risorse si registra un aumento generale a partire dal 2000, anche se i valori assoluti dei Paesi sono molto diversi. I tassi di crescita medi annui tra i Paesi esaminati vanno da 1,2% in Svezia a 5,4% in Spagna; il tasso annuo dell'Italia è 3,6%. I Paesi Bassi mostrano il valore più alto (4,6 €/kg nel 2022), seguiti dall'Italia (3,7 €/kg). La produttività in Germania e Francia è rispettivamente 3 €/kg e 3,2 €/kg.

Gli input diretti di materiali (DMI) comprendono tutti i materiali che hanno un valore economico e sono direttamente utilizzati nelle attività di produzione e consumo. Tale indicatore è la somma delle estrazioni interne e delle importazioni. Poiché questo indicatore rappresenta il consumo interno senza esportazioni, è utile per valutare il consumo effettivo di materiali, compresi quelli non utilizzati nelle attività di produzione e consumo interno e destinati alle esportazioni. Svezia, Romania, Belgio e Paesi Bassi hanno elevate quote di estrazione fossile, biomassa e minerali metallici destinati all'esportazione e mostrano il più alto DMI pro capite tra i principali Paesi europei, molto al di sopra della media europea. Tra i Paesi europei l'Italia ha il valore più basso nel 2022 (11,6 t pro capite *vs* media UE27 di 16 t pro capite).



Per quanto riguarda la produttività delle risorse, l'Italia ha il secondo valore più alto tra i Paesi europei (2,9 €/kg), il primo si registra per l'Irlanda (3,1 €/kg). La produttività dei Paesi Bassi per questo indicatore (1,6 €/kg) non mostra prestazioni elevate come per il DMC.

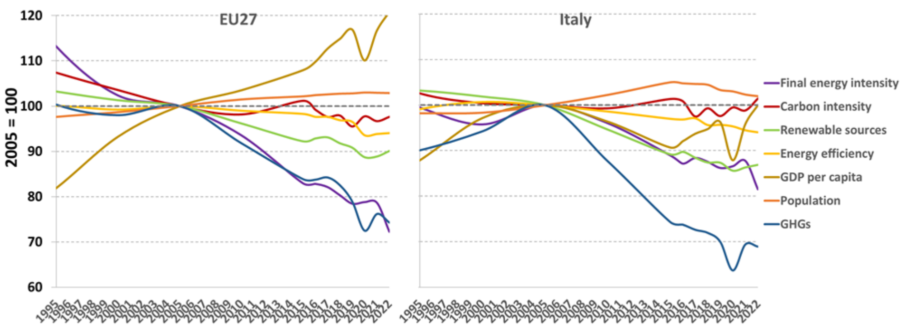
La produttività delle risorse per ciascun Paese, considerando il posizionamento relativo dell'economia dei Paesi nel spazio definito dal rapporto industria/servizi, mostra che l'Italia, pur avendo una quota di valore aggiunto industriale superiore a quella di Francia e Spagna, ha una maggiore produttività (DMC); un chiaro risultato della maggiore efficienza nell'uso delle risorse, principalmente nel settore industriale.



Questo risultato è in linea con quanto osservato per gli indicatori di intensità energetica. Considerando il DMI, la produttività delle risorse è significativamente inferiore rispetto al DMC. La produttività del DMI nei Paesi Bassi è inferiore del 65,7% rispetto alla produttività del DMC. Per gli altri Paesi l'intervallo va da 7,8% della Romania a 57,9% del Belgio, mentre la produttività del DMI italiano è inferiore del 22,1% rispetto alla produttività del DMC.

Identità di Kaya e analisi della decomposizione

I parametri dell'identità di Kaya per UE27 e Italia nel periodo 1995-2022 mostrano un andamento molto diverso per quanto riguarda i fattori determinanti la riduzione dei gas serra. Mentre nell'UE27 il fattore principale è l'intensità energetica finale, in Italia sia le fonti rinnovabili che l'intensità energetica finale (energia finale consumata per PIL) sono i fattori trainanti. Inoltre, in UE27 la popolazione e il PIL aumentano, mentre in Italia tali fattori hanno mostrato una tendenza al ribasso. La diminuzione dei gas serra è il risultato integrato della variazione dei fattori determinanti. Quindi, in UE27 è evidente un disaccoppiamento assoluto tra economia e gas serra, mentre in Italia si registra un disaccoppiamento relativo.



I risultati dell'analisi di decomposizione mostrano che in Italia l'efficienza energetica finale ha avuto un ruolo meno importante rispetto ad altri Paesi a causa della migliore performance dell'indicatore in Italia già nel 2005. Inoltre, a differenza dell'Italia, la maggior parte dei Paesi ha registrato un sensibile aumento del PIL pro capite a partire dal 2005.

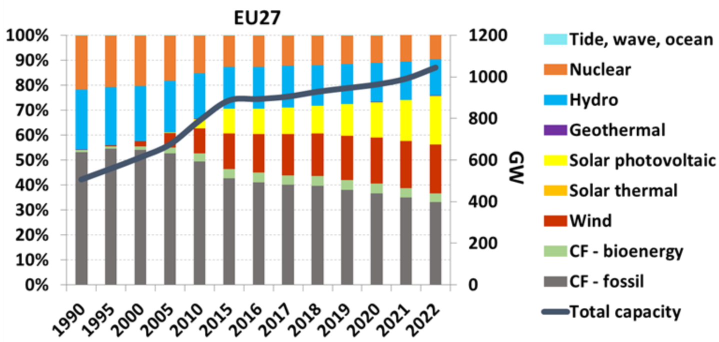
Il disaccoppiamento non corrisponde necessariamente a riduzioni delle emissioni in linea con gli obiettivi. L'analisi di decomposizione si concentra sulla variazione relativa dei parametri, senza assegnare alcun peso ai punti di partenza. L'efficienza economica ed energetica del sistema italiano è tra le più alte d'Europa. L'ultima edizione dell'International Energy Efficiency Scorecard, pubblicata da ACEEE nel 2022, ha segnalato per l'Italia il calo di quattro posizioni rispetto alla precedente edizione del 2018, principalmente a causa della sezione edifici, ma l'Italia è riuscita a posizionarsi tra i primi cinque Paesi, dopo Francia, Regno Unito, Germania e Paesi Bassi. L'International Energy Efficiency Scorecard valuta le politiche di efficienza e le prestazioni di 25 dei Paesi più energivori a livello globale. ACEEE ha utilizzato 36 metriche, sia politiche che orientate alle prestazioni, per valutare gli sforzi di ciascun Paese per risparmiare energia e ridurre le emissioni di gas serra in quattro categorie: edifici, industria, trasporti e progressi complessivi nell'efficienza energetica nazionale. "Le metriche politiche evidenziano le migliori pratiche nelle azioni governative e possono essere qualitative o quantitative. Ne sono un esempio gli obiettivi nazionali per l'efficienza energetica, l'etichettatura degli edifici e degli elettrodomestici e le norme sul risparmio di carburante per i veicoli. Le metriche orientate alle prestazioni sono quantitative e misurano il consumo di energia per unità di attività o servizio fornito. Ne sono un esempio l'efficienza delle centrali termiche, l'intensità energetica degli edifici e dell'industria e il risparmio medio di carburante dei veicoli su strada". (Subramanian et al., 2022).

Il miglioramento dell'efficienza non può prescindere dalla valutazione delle potenzialità e dell'efficacia in termini di costi del cambiamento del sistema energetico. Inoltre, è necessario valutare la struttura economica dei Paesi, in particolare per quanto riguarda il ruolo dei servizi e dell'industria, che hanno intensità energetiche e impronte di carbonio molto diverse.

Settore elettrico

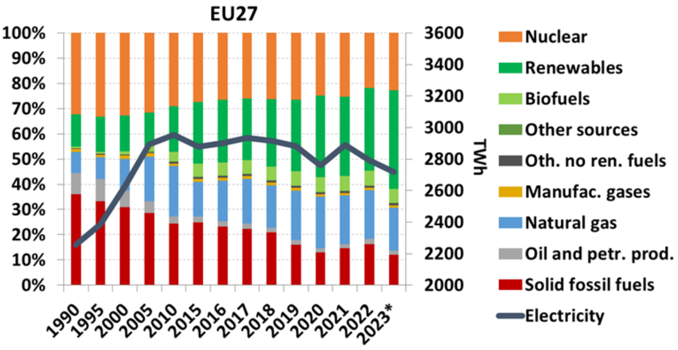
Capacità e produzione di energia elettrica

Il settore elettrico è uno dei principali obiettivi delle misure volte a decarbonizzare l'economia, sia per la quantità di emissioni provenienti dal settore che per il potenziale di diffusione delle energie rinnovabili. I Paesi presi in esame per il confronto con l'Italia rappresentano l'83,1% della produzione lorda di energia elettrica dell'UE27 nel 2022.



La potenza installata nel 1990 era costituita principalmente da impianti termoelettrici (54% nell'UE27), nucleari (21,8%) e idroelettrici (24%). L'eolico e il fotovoltaico avevano quote marginali. Nel 2022 la capacità termoelettrica è stata del 36,7%, quella nucleare del 9,6%, quella idroelettrica del 14,4%, quella eolica del 19,5% e quella fotovoltaica del 19,4%. La capacità totale è aumentata del 54,8% nel 2022 rispetto al 2005, passando da 676 GW a 1.046 GW. La capacità nucleare è l'unica con una significativa riduzione, da 123 GW a 100 GW (-14,6% dal 2005 al 2022), principalmente a causa della diminuzione in Germania, Svezia e Belgio. Da segnalare anche l'aumento della capacità netta di impianti alimentati da bioenergie da 15,8 GW nel 2005 a 36,9 GW nel 2022, pari al 9,6% della capacità termoelettrica totale. Tutti i Paesi hanno registrato una notevole diminuzione della quota di capacità termoelettrica dal 1990, così come per la capacità nucleare (ad eccezione di Cechia e Romania).

In relazione al sistema elettrico gli Stati Europei presentano una notevole eterogeneità. In Polonia c'è una netta prevalenza di centrali termoelettriche con un ruolo minore per le bioenergie. Le centrali nucleari, assenti in Italia e Polonia tra i Paesi considerati, costituiscono una quota significativa della capacità in Francia (41,3% nel 2022), Svezia (14,4%), Belgio (18,2%) e Repubblica Ceca (20,3%), sebbene le quote degli altri Paesi non siano trascurabili (da 0,9% nei Paesi Bassi a 7,3% in Romania). Dal 1990, la capacità idroelettrica ha rappresentato una parte considerevole delle fonti rinnovabili tradizionali in Romania, Spagna, Francia, Italia e Svezia. In tutti i Paesi esaminati, la quota termoelettrica e nucleare mostra una notevole riduzione. Dal 2005 la capacità eolica è aumentata in tutti i Paesi. Gli impianti fotovoltaici hanno iniziato ad avere quote significative solo dopo il 2010.

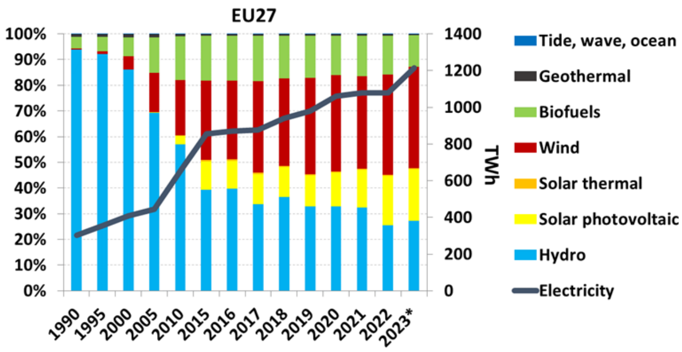


La produzione elettrica lorda in Europa è aumentata dal 1990 al 2015 con un tasso medio annuo dell'1%, negli anni successivi fino al 2019 è stata registrata un'ampia oscillazione e il livello del 2019 è approssimativamente lo stesso del 2015. Nel 2020 l'energia elettrica è diminuita, a causa delle misure adottate per contenere la pandemia da SARS-CoV-2. Nel 2021 c'è stata una ripresa, seguita da un nuovo rallentamento nel 2022. Dal 2015 al 2022 il tasso medio annuo è -0,4%. I dati preliminari del 2023 mostrano una ulteriore diminuzione dell'elettricità prodotta a livello europeo.

Nel 2022 il 16,3% della produzione di energia elettrica dell'UE27 senza pompaggio proviene da combustibili solidi e il 19,4% da gas naturale. Il petrolio e i prodotti petroliferi rappresentano il 2%. Il nucleare rappresenta il 21,8%, mentre il 38,7% proviene da energie rinnovabili. Tutti i Paesi considerati hanno aumentato la produzione di energia elettrica dal 1990, da 4,9% in Germania a 90,4% in Spagna, ad eccezione della Romania la cui produzione di energia elettrica è diminuita del 13,5%.

Il mix energetico nei Paesi esaminati è piuttosto eterogeneo, soprattutto per quanto riguarda i combustibili fossili. Nel 2022 i combustibili solidi determinano il 69,8% della produzione di energia elettrica in Polonia, il 44% in Cechia e il 31,3% in Germania. La Francia ha la quota più alta di produzione elettrica da centrali nucleari in Europa (62,8% nel 2022), seguita da Belgio (46,4%), Repubblica Ceca (37%) e Svezia (30%), tra i Paesi esaminati. Negli altri Paesi, la quota nucleare va da 3,4% nei Paesi Bassi a 19,9% in Romania. Polonia e Italia non hanno centrali nucleari. A livello europeo, la fonte nucleare fornisce il 21,8% dell'elettricità. L'Italia e i Paesi Bassi hanno la quota più alta di elettricità da gas naturale nel 2022, rispettivamente 50,1% e 39,2%.

La quota di energia elettrica rinnovabile in UE27 è aumentata da 13,4% a 38,7% dal 1990 al 2022. Tutti i Paesi hanno registrato un incremento della produzione elettrica da fonti rinnovabili con una forte accelerazione dal 2005. Dopo il 2015 la crescita ha rallentato ed è ripresa negli ultimi anni, anche se con tassi diversi tra gli Stati. La Svezia ha una delle quote più alte in Europa. Secondo i dati preliminari pubblicati da Eurostat nel 2023 l'elettricità rinnovabile dovrebbe raggiungere il 44.6% con uno dei più alti tassi di incremento annuale mai registrati.



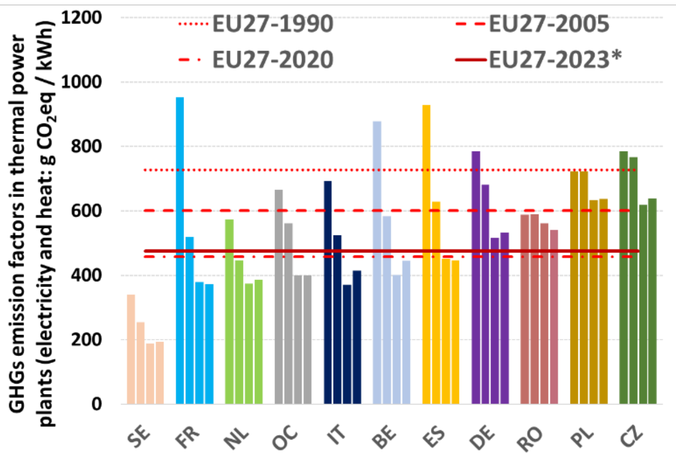
Efficienza delle centrali termiche

Il parametro più importante per valutare l'efficienza del settore elettrico è l'efficienza di trasformazione dei combustibili in elettricità e calore. Il rendimento elettrico degli impianti italiani non cogenerativi è di poco superiore alla media UE27 (0,447 vs 0,429). Per quanto riguarda l'efficienza elettrica degli impianti di cogenerazione, nel 2022 la Spagna ha il valore più alto tra i principali Paesi europei (0,646), di gran lunga superiore alla media UE27 (0,38). L'efficienza elettrica in Italia è 0,457. Il rendimento totale, per la produzione di energia elettrica e calore, degli impianti di cogenerazione italiani (0,542) è inferiore alla media UE27 (0,625).

Il rendimento elettrico italiano per tutte le centrali elettriche (cogenerative e non cogenerative) nel 2022 è 0,452, superato da Spagna, Belgio e Paesi Bassi: da 0,461 a 0,486. La Svezia ha l'efficienza elettrica più bassa tra i Paesi esaminati (0,24), al di sotto della media UE27 (0,404). L'efficienza totale degli impianti italiani è 0,497, inferiore alla media UE27 (0,527). La Svezia mostra il valore più alto (0,808) a causa del più alto rapporto tra calore ed elettricità registrato in questo Paese negli impianti di cogenerazione (oltre 2,4), seguita dalla Repubblica Ceca (1,56).

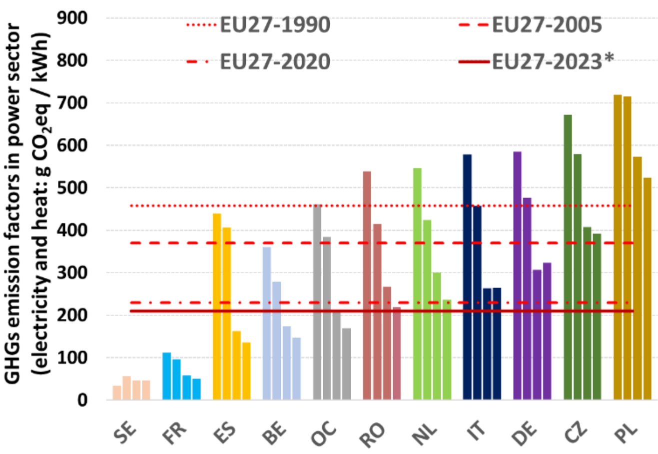
Gas serra nel settore elettrico

Dal 1990 si registra un disaccoppiamento tra produzione elettrica ed emissioni di gas serra nel settore elettrico di quasi tutti i Paesi europei, anche se le emissioni mostrano una significativa diminuzione solo dopo il 2005. Il disaccoppiamento è dovuto principalmente alla crescente quota di rinnovabili.



Il fattore di emissione di gas serra per la produzione di elettricità e calore nelle centrali termiche è diminuito dal 1990. Nel 2023 il fattore di emissione in Italia, 413,8 g CO_2eq/kWh, è inferiore alla media UE27, 474,3 g CO_2eq/kWh. La riduzione media dal 2005 (-21%) va da -8,3% in Romania a -29% in Spagna. L'Italia ha ridotto il proprio fattore del -21%.

Il fattore di emissione per la produzione totale di energia elettrica e calore dell'intero settore elettrico, inclusa quindi la produzione da fonti rinnovabili e nucleare, in Italia è superiore alla media europea (264,2 *vs* 210,3 g CO_2eq/kWh). I Paesi con fattore di emissione inferiore all'Italia hanno una rilevante quota nucleare o quote superiori di fonti rinnovabili. Il fattore di emissione medio in UE27 diminuisce del 43,2% rispetto al 2005 (-42,2% in Italia). In Spagna si registra il tasso di riduzione più alto dal 2005, -66,7%, mentre Polonia e Svezia hanno quelli più bassi, rispettivamente -26,8% e -19,2%, ma la Svezia ha il fattore di emissioni più basso. Il fattore di emissione in Germania, che ha la più alta quota di gas serra del settore elettrico in EU27, è diminuito del -32,2% dal 2005.



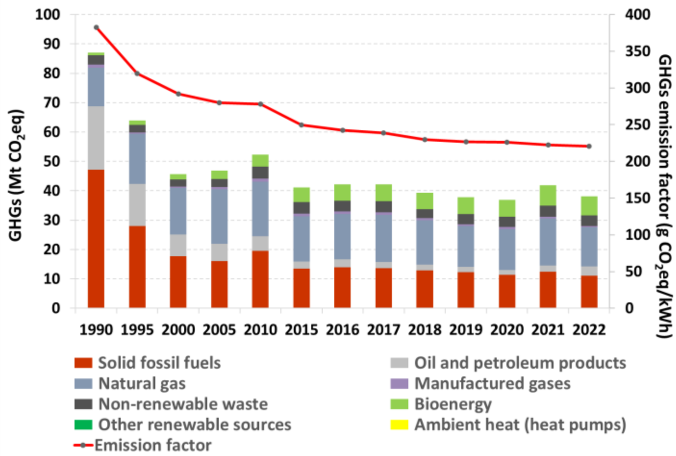
Le centrali termoelettriche italiane si trovano all'estremità più bassa dell'intervallo del fattore di emissione dei gas serra, ad eccezione di Francia, Paesi Bassi e Svezia che hanno una quota molto più bassa di combustibili solidi e petroliferi rispetto all'Italia. Il fattore di emissione italiano occupa la posizione mediana tra tutti i Paesi europei, ben al di sotto della media UE27. Il mix di combustibili italiano, con una quota di gas naturale maggiore rispetto a molti altri Paesi, e il contributo delle bioenergie sono fattori determinanti per il fattore di emissione nelle centrali termoelettriche. D'altra parte, per l'intero comparto elettrico, considerando quindi anche le rinnovabili non termiche e il nucleare, il fattore di emissione italiano perde posizioni rispetto agli altri Paesi ed è maggiore della media Europea.

Per quanto riguarda il settore elettrico, Germania, Polonia e Italia sono i tre maggiori emettitori in Europa. A causa di molti fattori (variazione del mix di combustibili, efficienza, rinnovabili) l'Italia ha ridotto il fattore di emissione per la produzione di energia elettrica del -55,2% dal 1990 al 2023 e del -45,9% dal 2005. La riduzione in Germania è stata del -48,8% dal 1990 e del -34,5% dal 2005, mentre i dati in Polonia sono stati del -38,3% dal 1990 e del -31,6% dal 2005. I tre Paesi rappresentano quasi il 60% dei gas serra dell'UE27 provenienti dal settore energetico.

Produttori di solo calore

La produzione di calore rappresenta una quota significativa dei consumi energetici nel comparto della trasformazione. Gli impianti dedicati alla produzione di calore per il teleriscaldamento e altri usi (principalmente per l'industria) consumano una quota importante dell'energia nel bilancio europeo. Nel 2022 il consumo di questi impianti in UE27 è stato di 17,1 Mtep, di cui 0,71 Mtep da geotermia e solare termico e 0,27 Mtep da pompe di calore. Il consumo energetico dei combustibili è stato di 16,2 Mtep, di cui 5,8 Mtep da bioenergia.

Il consumo totale nel 2022 è inferiore di circa il 33% rispetto a quello registrato nel 1990 e si è verificata una marcata variazione del mix con una sensibile diminuzione dei combustibili solidi e liquidi, sostituiti dal gas naturale e da bioenergia. Il contributo delle altre fonti rinnovabili (oltre il 90% dalla geotermia e il resto dal solare termico) e delle pompe di calore ha registrato una crescita e nel 2022 rappresenta il 5,7% dei consumi totali.



A seguito della variazione del mix energetico, della diminuzione dei consumi (-33,4%) e della produzione di calore (-24%), i gas serra hanno registrato una riduzione del 56,2% dal 1990. Il fattore di emissione di gas serra è diminuito del 42,3%. A livello europeo, nel 2022 le emissioni di gas serra di questi impianti sono state 38,1 Mt CO_2eq. Dal 2005 il fattore di emissione è diminuito del 21,1% nell'UE27 (da 279,7 a 220,7 g CO_2eq/kWh). Il fattore di emissioni dell'Italia nel 2022 è inferiore del 18,2% rispetto alla media UE27. Il rilevante consumo di combustibili solidi o rifiuti non rinnovabili in Polonia e Germania si traduce in un fattore di emissione più elevato, rispettivamente del 95% e del 45,7% superiore a quello italiano.

CONCLUSIONI

I risultati mostrano che l'Italia ha una delle economie più efficienti tra i principali Paesi europei. I dati mostrano che l'intensità energetica per PIL e la produttività delle risorse sono tra le più basse in Europa, nonostante un ruolo rilevante dell'industria nell'economia italiana. Una bassa intensità energetica corrisponde spesso a economie basate sui servizi, con un ruolo minore delle attività industriali. L'intensità di carbonio per energia consumata in EU27 è mediamente inferiore a quella italiana, anche per il contributo di una quota non trascurabile di energia nucleare in diversi Paesi.

L'andamento dei gas serra dipende da molti fattori. La riduzione delle emissioni nei Paesi europei è dovuta principalmente alla diminuzione dell'intensità energetica e all'aumento del consumo di energia rinnovabile. Nel 2020 le misure adottate per contenere la diffusione della pandemia da SARS-CoV-2 hanno inciso pesantemente sull'economia europea e sulle emissioni di gas serra. Indipendentemente dalle contingenze c'è un chiaro disaccoppiamento tra PIL ed emissioni serra nei Paesi europei, anche se al disaccoppiamento non corrispondono necessariamente riduzioni delle emissioni in linea con gli obiettivi. Il potenziale di riduzione delle emissioni deve essere valutato considerando anche i punti di partenza dei fattori determinanti e dei costi per modificare il sistema energetico, nonché la struttura economica, soprattutto per quanto riguarda il rapporto tra servizi e industria.

Gli indicatori settoriali di decarbonizzazione in Italia mostrano settori come l'industria e l'agricoltura con intensità energetiche e di carbonio in rapporto al PIL tra le più basse d'Europa e settori come residenziale e trasporti con ampi margini di miglioramento. Il livello di elettrificazione del settore residenziale in Italia è ben al di sotto della media europea e il settore dei trasporti ha ampi margini di riduzione delle emissioni, soprattutto nel segmento delle autovetture. Le emissioni italiane pro capite per questo segmento dei trasporti sono superiori alla media europea e tra le più alte tra i principali Paesi. Tali risultati sono coerenti con la preoccupante distanza delle proiezioni italiane dall'obiettivo di riduzione delle emissioni serra da raggiungere nel 2030. Gli obiettivi si concentrano sulla ripartizione tra le maggiori industrie energetiche e manifatturiere (soggette al sistema di scambio di quote di emissione, ETS) e altri settori (disciplinati dal regolamento sulla condivisione degli sforzi, ESR). Gli obiettivi di emissione del Paese sono fissati solo per i settori non soggetti a ETS, ovvero trasporti, servizi, residenziale, agricoltura, rifiuti e piccola industria, mentre le emissioni di grandi impianti, come centrali termoelettriche, raffinerie, cementifici, acciaierie, ecc. rientrano nel sistema europeo di scambio di quote di emissione.

INTRODUCTION

Country's greenhouse gas emissions (GHGs) depend on many factors related to the economic activities and citizens lifestyle. In European Union (EU27), energy emissions accounted for about 77% of total emissions in 2022, from 70% in France to 85% in Germany, among the biggest countries. Italian GHG emissions from the energy sector are 82%. The energy system underlying economic activities is therefore the main area of investigation to understand the driving factors for GHG emissions. The fuel mix, as well as energy efficiency, in terms of transformation of primary energy and economic output, are key factors. The economic activities themselves, which are also driven by the users' demands, are driving factors of GHGs, and the reduction of such activities inevitably leads to emissions reduction. While energy efficiency can be considered as intrinsic driving factors of the energy system, the demand for goods and services can be regarded as an extrinsic economic factor, although both energy and economy systems are intertwined and difficult to be treated as separate systems. The economic crisis that has affected the world's major economies, including Italy, since 2007-2008, has made the task of discerning the driving factors of GHG emissions even more difficult. After more than a decade Italy and Greece, among the EU countries, suffered the most significant impacts of the economic crisis. Even though Italy' economy recovered since 2015, up to 2019 was the only Country which had not yet filled the gap of GDP per capita loss in EU. Moreover in 2020 the SARS-CoV-2 pandemic caused a further decline of the economy in all the European countries. In 2021 the European economy experienced a marked recovery but the Russian-Ukrainian war that broke out in the first half of 2022 adversely affected the growth projections. Such events heavily impacted on GHG emissions and European climate policy.

Climate and energy policies are undergoing an in-depth review following what was agreed at COP21 in Paris in 2015, when the Parties decided to keep the rise of global average temperature well below 2°C and to do everything possible to limit the increase to 1.5°C above pre-industrial levels, a target that will be exceeded in 2030 according to the statement released in 2023 by Jim Skea (Chair of IPCC). The historic significance of the Paris Agreement lies in the key point that virtually all the States of the world have committed to reduce their GHGs by 2030, through mitigation plans. In the context of emissions mitigation policies, the EU has already played an important role since the ratification of the Kyoto Protocol, when it committed to reducing the GHGs, in the period 2008-2012, by 8% compared to 1990. This commitment was shared among the Member States and Italy was allocated a reduction by 6.5%. In 2012, an agreement was reached among the Parties on the continuation of the Kyoto Protocol through the Doha Amendment, which sets reduction commitments for the period 2013-2020. Italy ratified the Doha Amendment with Law of 3 May 2016. The Doha Amendment entered into force on 31 December 2020, with 148 countries.

In 2007, before what was agreed at the international level, the European Council had already expressed the need for the EU to initiate a transition towards a low-carbon economy through an integrated approach that included energy policies to curb climate change. In particular, the Council set binding targets to be achieved by 2020, such as 20% reduction of GHG emissions compared to 1990, the share for renewable energy consumption set to 20% of the EU energy consumption, the use of biofuels for 10% of the amount of fuel used in the transport sector and the indicative target of reducing energy consumption by 20% compared to the 2007 Reference Scenario projections for 2020. Following the Council's conclusions, the "Climate and Energy Package" was approved, i.e. a set of legislative measures aimed at implementing the commitments was put in place.

For 2030 the European reduction targets reflected the commitments made by the EU under the Paris Agreement: reduction of GHGs by at least 40% compared to 1990, achievement of at least 32% of energy consumption from renewables and the achievement of at least 32.5% increase in energy efficiency compared to projections of the expected energy used in 2030. Another target directly related to the electricity system is the achievement of 15% for electrical interconnections in 2030. This means that each country should have in place electricity cables that allow at least 15% of the electricity produced on its territory to be transported across its borders to neighbouring countries.

In such context, Italy issued its National Energy and Climate Plan in 2019 (AA.VV. 2019). The Plan established how the country should achieve or approach the national 2030 targets on energy efficiency, renewable sources and the reduction of GHG emissions.

With the European Green Deal, the European Commission proposed in September 2020 to raise the 2030 GHG emissions reduction target, including carbon removals from forestry activities, to at least 55% compared to 1990, with a view to achieving carbon neutrality by 2050 as established in the European Commission's Long-Term Strategy (2018a, 2018b). In this context, as required for each EU Member State by article 15 of the Regulation (UE) 2018/1999 (Governance Regulation), Italy adopted its National Long-Term Strategy on the reduction of GHGs (LTS) in January 2021 (AA.VV., 2021), identifying the possible pathways that could allow to achieve a condition of carbon neutrality by 2050, i.e. the balance between GHGs and CO_2 removals, with the possible use of geological capture and storage systems or CO_2 reuse.

On 14 July 2021 the European Commission presented a proposal for amending the Renewable Energy Directive increasing the target to at least 40% renewable energy sources in the EU's overall energy mix by 2030. Relevant actions are required across all sectors to achieve the new targets, including increased energy efficiency and renewable energy. Such actions were considered in the Italy's Recovery and Resilience Plan submitted in 2021 to European Commission in compliance with EU's extraordinary recovery effort, Next Generation EU: the plan agreed by EU leaders in July 2020 to overcome the economic and social impact of the pandemic facing the environmental, technological, and social challenges of our time.

The Commission started the process of making detailed legislative proposals by July 2021 (Fit-for-55 package) to implement and achieve the increased ambition that will enable EU to move towards a climate-neutral economy by 2050 – an economy with net-zero GHG emissions. Among other measures the Commission put forward a proposal for a recast directive on energy efficiency. The proposal raised the level of ambition of the EU energy efficiency target and makes it binding by requiring EU countries to collectively ensure a reduction in primary energy consumption of 9% compared to the reference trend established in the PRIMES 2020 scenario. Moreover, the Fit-for-55 package put forward several legislative proposals to translate the European hydrogen strategy into concrete European hydrogen policy framework.

In reaction to the Russian invasion of Ukraine since 24th February 2022, there was growing support across the European Parliament to increase the EU's 2030 renewable energy target ending the EU's dependence on Russian fossil fuels. Currently, just over 23% of Europe's energy final consumption comes from renewables. From the 40% renewable energy target by 2030 proposed by European Commissions in July 2021, the European Parliament set to push for the target to be increased to 45%. On 18 May 2022 European Commission presented the REPowerEU Plan to phase out EU dependency on Russian fossil fuels faster through energy savings, diversification of energy supplies, and accelerated deployment of renewable energy to replace fossil fuels in buildings, industry, and power generation. Moreover, as for the hydrogen the ambition is to produce 10 Mt and import 10 Mt of renewable hydrogen in the EU by 2030 (EC, 2022a).

At present, the European target of reducing net GHG emissions by at least 55% by 2030 compared to 1990 levels, as reported in the second NDC transmitted by the EU in compliance with the Paris Agreement and fit-for-55 package. The raise of the European target from the previous -40% to the current -55% of emissions compared to 1990 determined a radical increase of the effort in reducing emissions through all sectors.

The emission reduction target of ETS passed from -42% to -62% in 2030 compared to 2005 at European level, whereas the non ETS emission target, ruled by Effort Sharing Regulation, passed from -30% to -40% at European level. The new ETS target covers an expanded scope compared to the previous one. Beyond the emissions from power generation, energy-intensive industries, and aviation as previously legislated, the new structure will add carbon dioxide emissions from maritime transport from 2024, further extended to methane and nitrous oxide from 2026. Moreover, with Directive (EU) 2023/959 of 10 May 2023 amending Directive 2003/87/EC, a new emissions trading system will be established (ETS-2), for buildings, road transport and additional sectors, e.g. fuel combustion by industry not covered by the existing EU ETS. The ETS-2 is an upstream system regulating fuel suppliers rather than households and car users. It will become fully operational in 2027, while the monitoring and reporting of emissions will start in 2025. The cap is set to achieve an emission reduction of 42% by 2030 compared to 2005 levels. Emissions from sectors covered by the ETS-2 remain covered by Member States' emission reduction targets under the

Effort Sharing Regulation (ESR). This means that the ETS-2 complements national efforts to reduce emissions in the ESR sectors. It is estimated that by 2030, half of the ESR emissions will be covered under the ETS-2. The ETS-2 does not cover non-CO_2 emissions which are mainly from agriculture and waste management. (EEA, 2023). The carbon price set by the ETS-2 will provide a market incentive for investments in building renovations and low-emissions mobility.

Whereas the target for ETS is defined at European level, the GHG reduction targets for sectors included in the Effort Sharing Regulation (ESR) and the objectives for the LULUCF sector are on Member States with burden shared according to the different capacities of Member States to act by differentiating targets. Collective national targets result in a 2030 emission reduction at European level of 40% compared to 2005. This value was proposed by the European Commission and approved by the European Parliament on March 14, 2023. The target for Italy, determined in accordance with Article 4(3) of the Effort Sharing Regulation, is -43.7%. The European target of 55% emissions cut also includes the emissions and removals by LULUCF, ruled by Regulation (EU) 2018/841. The revision of the mentioned Regulation set the emissions neutrality by 2025 (2021-2025), and further removals target by 2030 of 310 $MtCO_2eq$. The Italian target is -35.8 $MtCO_2eq$ by 2030.

As for the renewable energy use, the European Parliament and the Council reached on 30 March 2023 a provisional agreement to raise the binding renewable energy target to at least 42.5% by 2030 but aiming for 45%. On the energy efficiency side, the EU concluded the revision of the Energy Efficiency Directive on 25 July 2023. The current legislation set new binding target of reducing EU final energy consumption by 11.7% by 2030, compared to the projected energy use for 2030 (based on the 2020 reference scenario).

The National Energy and Climate Plan (NECP) issued in 2019 has been recently updated (MASE, 2024) to embody the new targets set by European Commission. The updated NECP encompasses policies and measures addressed to achieve the European targets on GHGs emissions, renewable share, and efficiency.

Regardless any specific target the negotiating processes among EU countries cannot ignore the peculiarities of Member States energy systems as well as the technical and economic potentials to change their systems. The development of a country's productive structure involves not only technological aspects but also the economic and social ones affecting the daily lives of millions of people. The definition of climate targets must therefore consider several factors. If GDP is an essential factor, as an expression of a country's investment capacity, it is equally essential to consider other aspects of energy and economy systems, such as industry share, fuel mix used by each country and the cost effectiveness for changes. In other words, the inertia of any complex systems and the decreasing returns of investments aimed at changing a particular equilibrium state cannot be ignored. This does not mean that a given situation cannot be changed, but any country should be aware of both the resources needed and the consequences. As far as energy sources are concerned, there are different reduction potentials between countries with a significant share of high-carbon fuels and countries with a very small share of high carbon content fuels. It can be misleading to consider only GDP as the investment capacity, without looking at the different reduction potentials and the related costs.

This report does not aim to analyse energy and production systems but at the analysis of Italian performance indicators and the comparison with the largest European countries concerning energy consumption and climate-changing emissions. The analysis will not go into details on factors determining the energy needs of the countries, such as the geographical-climatic factor or demographic and social factors. No indicator is immune to criticism and weaknesses: the energy intensity (energy consumption per GDP) in the buildings sector is affected by climatic factors, not only by efficiency; the industry sector includes a wide range of activities with very different energy requirements, so the relative shares of activities is a crucial factor for sector's intensity. While aware of the role played by these factors on energy demand and efficiency, the target of the analysis is to examine at macroscopic level the main indicators of decarbonization and energy efficiency in the European countries *rebus sic stantibus*. If the former indicators provide information on GHGs emissions per unit of energy used or per unit of wealth produced, the latter ones provide information on how efficiently energy is used to produce wealth. The two families of indicators are strongly interlinked, because if the production of goods and services cannot be separated from energy consumption, the consumption of energy by fossil fuels in turn determines GHGs emissions. The economy decarbonization can be pursued by acting both on the energy sources used to produce commodities and on the efficiency of energy use, acting on both fronts is the most virtuous path that can be taken. Concerning the energy sources, useful strategies point to shift towards a fuel mix with lower carbon content, therefore mainly made up of natural gas, or increasing the renewable share of energy that are not without other environmental worries, e.g. the combustion of biomass and the consequent emission of atmospheric contaminants harmful to air quality or the consumption of soil by wind and photovoltaics power plants. On the energy efficiency side, the goal is obviously optimization, which consists in achieving more with less. In other words, to reduce as much as possible the losses and inefficiencies to produce commodities (e.g. buildings heating system, moving by vehicles, production of steel, cement, paper, textiles and so on).

In a highly interconnected system, the identification of the causes of a given phenomenon, such as GHG emissions, is a thorny issue, however it is possible to assess the role of the different driving factors according to a conceptual model that establishes coherent relationships between the factors considered. To assess the role of the factors behind the change in GHG emissions, Kaya analysis and decomposition analysis was applied to study the variation of a parameter in a time interval in relation to the variation of its driving factors.

The power sector is a key stone of any energy system. The electricity generation accounts for a significant share of the energy sector, around one third of European energy GHG emissions. The EU long-term strategy by 2050 (EC, 2018a, b) examines different development scenarios and highlights how electricity will become the main energy carrier, from 22% of final energy consumption in 2015, to 41%-53% in 2050. The growing role of the power sector requires an examination of electricity generation systems in the Member States. The analysis in the largest European countries was therefore carried out concerning the fuel mix, the transformation efficiency, and the GHGs emissions factors. The same analysis, although less detailed, was carried out for plants producing only heat that represent a significant share of energy consumption, especially in the countries of Northern Europe.

In this report the GHGs accounting follows the approach required to elaborate the national inventory reports of GHGs under the UNFCCC frame. Only emissions from fuel combustion occurring in the national territory are considered. As for the combustion of bioenergy, it is considered a net zero CO_2 emitting process; only CH_4 and N_2O are accounted. However, as already mentioned, the deployment of bioenergy is not without other environmental concerns (air quality, biodiversity, forest degradation, etc.) or serious troubles on agricultural land loss and food system. Even on the GHGs side IPCC (2022) reports that "the use of bioenergy can lead to either increased or reduced emissions, depending on the scale of deployment, conversion technology, fuel displaced, and how, and where, the biomass is produced."

1 NATIONAL DATA

Energy data of Italy have been downloaded from the Eurostat database in the complete energy balances section (https://ec.europa.eu/eurostat/data/database, last update 24 May 2024). The inventory of GHG emissions has been submitted by ISPRA to EU on 15 January 2024 and to UNFCCC on 30 April 2024. Data submitted to UNFCCC for Italy have been elaborated. For all other European countries data from Eurostat database (last update 18 April 2024) have been elaborated.

Preliminary estimates of fuel consumption in 2023 have been carried out by ISPRA, based on data by SNAM for the distribution of natural gas, MASE (Ministry of Environment and Energy Security) for coal and petroleum products consumptions updated to 31 December 2023. Preliminary data on electricity production in 2023 have been issued by Eurostat on 27 June 2024. Very early estimates of fuel consumption and electricity production in 2024 are also presented. The estimates for 2024 are based on data updated to the first seven months of the year in power sector (TERNA, Monthly Report on the electricity system, July 2024), and the most updated data by SNAM and MASE until the end of August.

The preliminary estimates are characterized by considerable uncertainty and will be revised with final data.

1.1 Energy consumption and GHGs

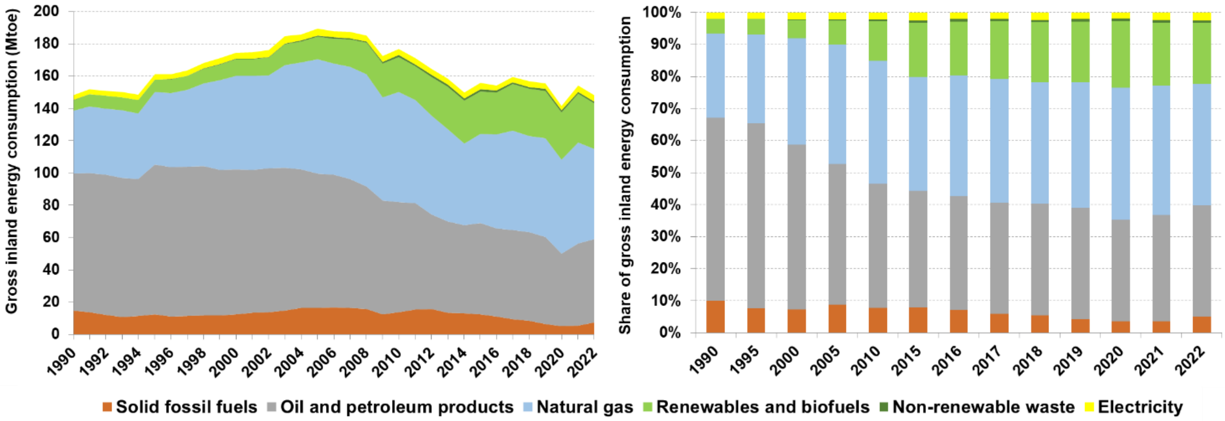
National gross inland energy consumption shows an increasing trend from 1990 to 2005, when it peaked at 189.4 Mtoe (toe: tonnes of oil equivalent), then there was a reduction accelerated by the economic crisis started in 2008, with the minimum value of 149.8 Mtoe reached in 2014 and a recovery in the following years. As shown in Table 1.1 and Figure 1.1, gross energy consumption in 2020 furtherly decreased as consequence of lockdown to contain SARS-CoV-2 pandemic (-8.9% lower than 2019 level and -4.4% lower than 1990 level). In 2021 it was recorded a rebound of consumption (+8.8% higher than 2020), with 154 ktoe, followed by further setback in 2022 (-3.9% lower than 2021). Preliminary estimates for 2023, although uncertain, show a further decrease of energy consumption, about -4% compared to 2022.

Table 1.1 – Gross inland energy consumption by energy source (Mtoe).

Energy source	1990	1995	2000	2005	2010	2015	2020	2021	2022	*2023**
Solid fossil fuels	14.6	12.3	12.6	16.5	13.7	12.3	5.1	5.5	7.4	*4.8*
Oil and petroleum products	84.9	93.2	89.9	83.3	68.4	56.7	44.9	51.0	51.5	*52.0*
Natural gas	39.0	44.7	57.9	70.7	68.1	55.3	58.3	62.4	56.1	*50.5*
Renewables and biofuels	6.5	7.7	10.1	14.1	21.9	26.3	29.3	30.3	28.2	*29.4*
Non-renewable waste	0.2	0.2	0.3	0.7	1.0	1.1	1.2	1.2	1.2	*1.2*
Electricity	3.0	3.2	3.8	4.2	3.8	4.0	2.8	3.7	3.7	*4.2*
Heat	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	*0.0*
Total	**148.1**	**161.2**	**174.5**	**189.4**	**176.8**	**155.7**	**141.6**	**154.1**	**148.1**	***142.0***

* Preliminary data.

Figure 1.1– Gross inland energy consumption and share by energy source.



Fossil fuels are the main carriers in the national energy system. From 1990 to 2005, the average ratio of fossil fuels over the gross domestic consumption was more than 90%, although with a slight decline. Later, the share of fossil energy is severely reduced. From 1990 to 2022 the share of fossil energy decreased from 93.6% to 78.5%, with the lowest value in 2020 (77.3%). The decline has become particularly steep since 2007. In 2022 it is worth noting the slight increase of fossil share compared to the previous year, mainly due to the contraction of hydro energy and increase of solid fuels share: the first factor due to drought, the second one to cope the natural gas contraction following the Russia-Ukraine war. The increase of hydro energy and the decrease of solid fuels in 2023 will lead the fossil share below the 2020 level. Moreover, preliminary data for 2024 records a further decrease of solid fuels and increase of hydro energy.

The fuel mix has changed since the 1990s. Oil products accounted for the predominant component, with 57.3% of gross domestic consumption in 1990. The share of oil products has steadily decreased to 31.7% in 2020, with a steady increase in the following years. In 2022 the share of oil products (34.8%) came back to the level of 2019 and preliminary data for 2023 and 2024 show that such fossil fuels are increasing their share. The share of natural gas follows a specular trend with constant increase since 1990 up to 2020 (from 26.3% to 41.2%), followed by a decreasing trend (37.9% in 2022) that should go on in 2023 and 2024. The share of solid fuels, after a decreasing trend since 2012 up to 2021 (from 9.6% to 3.6%), recorded a rebound to 5% in 2022 and a downward trend up to 2024.

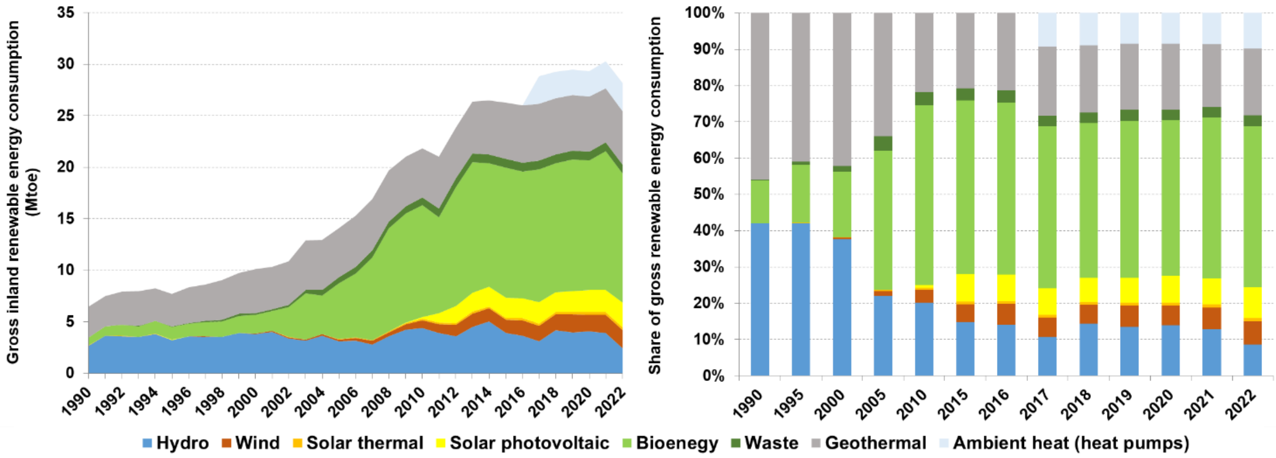
The share of renewable energy is complementary to that observed for fossil fuels. From 1990 to 2007 there was a steady increase in the share of renewable sources from 4.4% to 9%. After 2007 the share accelerated to 20.7% of gross inland consumption in 2020, followed by a setback in the last years (19.6% in 2021 and 19% in 2022). According to the preliminary estimate for 2023, the renewable share should come back over 20% with further increase in 2024.

Table 1.2 – Gross inland renewable energy consumption by energy source (Mtoe).

Energy source	1990	1995	2000	2005	2010	2015	2020	2021	2022	*2023**
Hydro	2.7	3.2	3.8	3.1	4.4	3.9	4.1	3.9	2.4	*3.5*
Wind	0.0	0.0	0.0	0.2	0.8	1.3	1.6	1.8	1.8	*2.0*
Solar thermal	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.2	0.3	*0.3*
Solar photovoltaic	0.0	0.0	0.0	0.0	0.2	2.0	2.1	2.2	2.4	*2.6*
Biomass	0.8	1.2	1.8	5.4	10.8	12.6	12.6	13.5	12.5	*12.6*
Waste	0.0	0.1	0.2	0.6	0.8	0.8	0.8	0.8	0.8	*0.8*
Geothermal	3.0	3.2	4.3	4.8	4.8	5.5	5.3	5.3	5.2	*5.1*
Heat pump	0.0	0.0	0.0	0.0	0.0	0.0	2.5	2.6	2.8	*2.6*
Total	**6.5**	**7.7**	**10.1**	**14.1**	**21.9**	**26.3**	**29.3**	**30.3**	**28.2**	***29.5***

* Preliminary data.

Figure 1.2 – Gross inland renewable energy consumption trend and share by energy source.



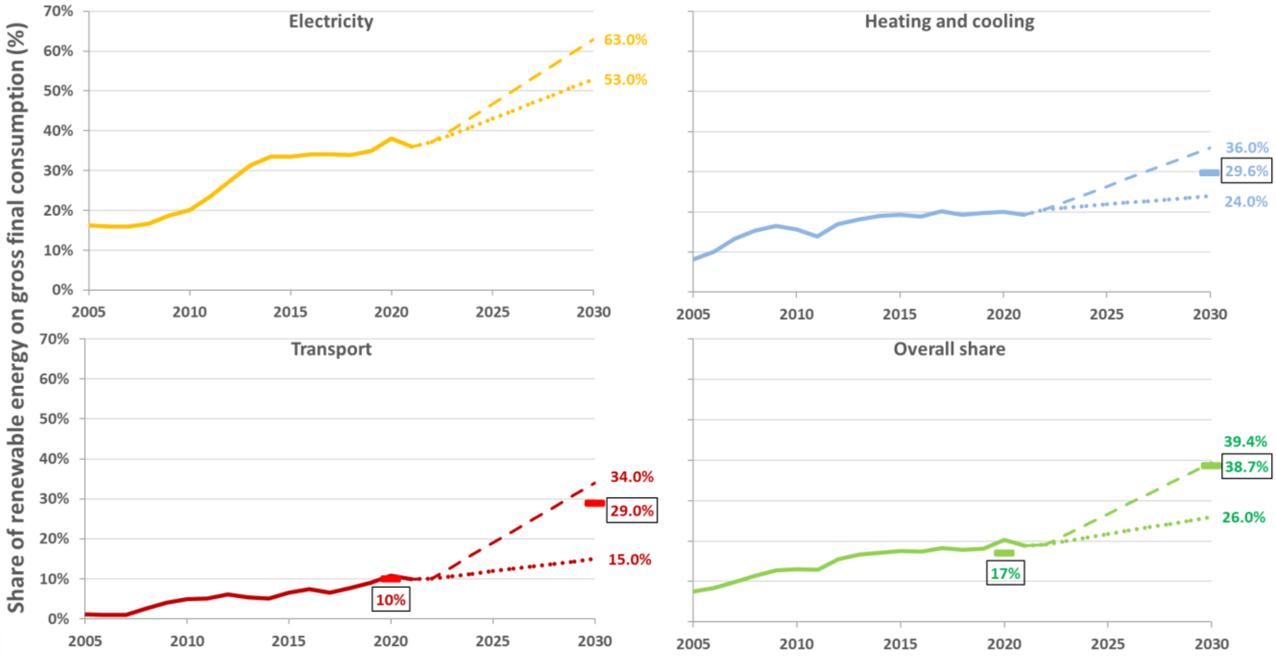
From 1990 to 2000 the main sources of renewable energy have been geothermal and hydro, which accounted for more than 80% of gross inland consumption of renewable energy. The remaining share was mainly met by biomass and wastes (bioenergy). Since 2000, the bioenergy has shown a considerable growth, reaching the peak of time series in 2008 with a share of 50.9% on renewable sources. After 2008 the share of bioenergy decreased (44.4% in 2022) in the aftermath of the increase of other sources, as solar (thermal and photovoltaic) and wind. Solar and wind sources have assumed significant role and together represent 15.8% of total renewable energy consumption in 2022. The energy by heat pumps has been recorded by Italy in the Eurostat budget since 2017. Such item in 2022 was 9.8% of renewable gross inland consumption.

As concerns the European renewable targets, Directive 2009/28/EC established the shares of energy from renewable sources on gross final consumption by 2020 for each country of the European Union; the target for Italy was 17% which was overachieved, with 20.4%. The fall of energy demand in 2020, due to COVID-19 pandemic, pushed up the renewable energy share. The level in 2022, calculated according to Directive (EU) 2018/2001, was 19.1%, showing a minor increase compared to 2021. The overall target to be achieved in 2030 for Italy, calculated according to the Directive (EU) 2023/2413 (so called RED III), is 38.7% (MASE, 2024). The policy scenario, issued with the National Energy and Climate Plan (MASE, 2024), shows that Italy should overachieve the target with 39.4%. Such result can be reached only with a robust acceleration of renewable energy final consumption. From 2005 to 2022 the share increased by 0.6 percentage points per annum (from 7.5% to 19.1%), while the increase should be 2.5 percentage points per annum since 2022 up to 2030 (from 19.1% to 39.4%).

Even more challenging is the achievement of the mandatory target for transport. The historical data show an average increase of 0.5 percentage points per year from 2005 to 2022, while the annual average increase required to achieve the mandatory target of 29% in 2030 must be 2.4 percentage points up to 2030 (3 points per year to reach the share of policy scenario of NECP). Even the renewable share for heating and cooling (H&C) must accelerate to achieve the mandatory target of 29.6%. The average increase of renewable share in such sector was 0.7 percentage points per year from 2005 to 2022, while the required rate to achieve the target must be 1.1 points per year (1.9 per year to reach the share of policy scenario of NECP). Renewable for electricity consumption have not a mandatory target but even for such sector is necessary to speed up the annual rate of the past. The annual average increase was 1.2 percentage points per year from 2005 to 2022. From 2010 to 2014 has been recorded the highest increase with an average of 3.3 points per year. The required rate per year to achieve the levels reported in the NECP should be 2 points for the reference scenario and 3.2 points for the policy scenario.

All sectors contribute to the achievement of the overall renewable target but should be also considered the share of each sector in the gross final consumption. Electricity, which recorded the highest rate of renewable development and will see the highest increase in the future according to the projections, accounted for about a quarter of gross final consumption in 2022, while transport and H&C accounted for about 30% and 45%, respectively showing the relevance of such final uses to achieve the overall target.

Figure 1.3 – Share of renewable energy gross final consumption by sector. Actual trends up to 2022 are shown and projections up to 2030 as reported in the NECP (dotted lines: reference scenario; dashed lines: policy scenario). The figures in the box are mandatory targets.



Primary energy is the gross inland energy consumption without non-energy consumption. Non-energy consumption from 1990 to 2022 represented an average of 5.2% of gross domestic consumption with a decreasing trend: from 7% in 1990 to 3.8% in 2022.

Final energy consumption, including non-energy uses, is on average 79.9% of primary energy in the period 1990-2022. Primary and final energy consumption peaked in 2005. A sharp reduction in energy consumption has been observed up to 2014 in the aftermath of the economic crisis started in 2008. The decline from 2005 to the lowest value in 2014 (142.7 Mtoe of primary energy and 116 Mtoe of final consumption) was 21.1% for primary energy and 17.2% for final consumption. After 2014 the final consumption increased with wide fluctuations and a drastic fall in 2020. In 2021 a rebound has been recorded (+9.8% compared to 2020), followed by a new setback in 2022 (-3.4%). Primary energy consumption in 2022 is -21.3% below the 2005 level, while final energy without no energy uses is -15.8% lower than 2005 level. No energy final consumption in 2022 recorded a reduction of 34.2% compared to 2005 level.

Table 1.3 – Primary energy consumption by energy source (Mtoe).

Energy source	1990	1995	2000	2005	2010	2015	2020	2021	2022
Solid fossil fuels	14.6	12.1	12.4	16.3	13.5	12.2	5.1	5.5	7.4
Oil and petroleum products	76.1	84.5	82.6	75.9	59.5	50.8	38.8	45.8	46.4
Natural gas	37.3	43.7	57.0	69.7	67.5	54.7	57.6	61.8	55.6
Renewables and biofuels	6.5	7.7	10.1	14.1	21.9	26.3	29.3	30.3	28.2
Non-renewable waste	0.2	0.2	0.3	0.7	1.0	1.1	1.2	1.2	1.2
Electricity	3.0	3.2	3.8	4.2	3.8	4.0	2.8	3.7	3.7
Primary energy	**137.7**	**151.4**	**166.1**	**180.8**	**167.3**	**149.1**	**134.8**	**148.2**	**142.4**
Primary energy (2020-2030)*	**137.7**	**151.4**	**166.1**	**180.8**	**167.3**	**149.1**	**132.3**	**145.6**	**139.6**

* This indicator monitors progress towards energy efficiency targets implemented by Directive 2012/27/EU on energy efficiency and Directive (EU) 2023/1791 on energy efficiency (recast). The indicator measures the level of energy consumption and distance to 2020/2030 targets.

Table 1.4 – Final energy consumption by energy source (Mtoe).

Energy source	1990	1995	2000	2005	2010	2015	2020	2021	2022
Solid fossil fuels	2.7	2.0	1.5	1.3	0.6	0.5	0.4	0.3	0.3
Oil and petroleum products	52.7	52.1	55.0	56.0	45.6	41.2	32.2	38.9	41.0
Manufactured gas	0.9	0.8	0.3	0.0	0.0	0.2	0.1	0.1	0.1
Natural gas	28.7	33.7	37.6	40.6	38.5	33.0	31.8	36.6	31.6
Renewables and biofuels	0.9	1.4	1.7	4.5	9.1	8.4	10.7	11.9	11.3
Non-renewable waste	0.1	0.1	0.1	0.1	0.2	0.3	23.7	25.1	24.7
Electricity	18.5	20.5	23.5	25.9	25.7	24.7	3.9	1.5	1.5
Heat	0.0	0.0	0.0	3.1	3.3	3.9	0.3	0.3	0.3
Final energy	**104.5**	**110.5**	**119.7**	**131.5**	**123.1**	**112.1**	**103.1**	**114.7**	**110.8**
No energy final consumption	**10.4**	**9.8**	**8.4**	**8.6**	**9.6**	**6.6**	**6.8**	**5.9**	**5.7**
Final energy (2020-2030)*	**107.8**	**114.7**	**124.8**	**137.2**	**128.5**	**116.2**	**102.7**	**114.8**	**111.7**

* This indicator monitors progress towards energy efficiency targets implemented by Directive 2012/27/EU on energy efficiency and Directive (EU) 2023/1791 on energy efficiency (recast). The indicator measures the level of energy consumption and distance to 2020/2030 targets.

Tables 1.3 and 1.4 show also the indicators to monitor the energy efficiency targets. Primary and final energy consumption in 2022, respectively 139.6 Mtoe and 111.7 Mtoe, should be compared with the targets to be achieved in 2030, set according to the Fit for 55 and REPower EU, respectively 111 Mtoe and 93 Mtoe (MASE, 2024). Such thresholds result in average reduction from 2022 to 2030 of -2.8% per year for primary energy consumption and -2.3% per year for final energy consumption. The average annual rate of energy consumption decreased since 2005 by -1.5% for primary energy and -1.2% for final energy up to 2022. According to the policy scenario issued in the National Energy and Climate Plan (MASE, 2024), Italy would not reduce the energy consumption as required by the target and the projected energy consumption in 2030 should be 123 Mtoe for primary energy and 102 Mtoe for final energy. The projected energy consumption should decrease with the same annual average rate recorded in the past, from 2005 to 2022 (Figure 1.3).

Figure 1.4 – Primary and final energy consumption. Actual trends up to 2022 are shown and projections up to 2030 as reported in the NECP (dotted lines: reference scenario; dashed lines: policy scenario).

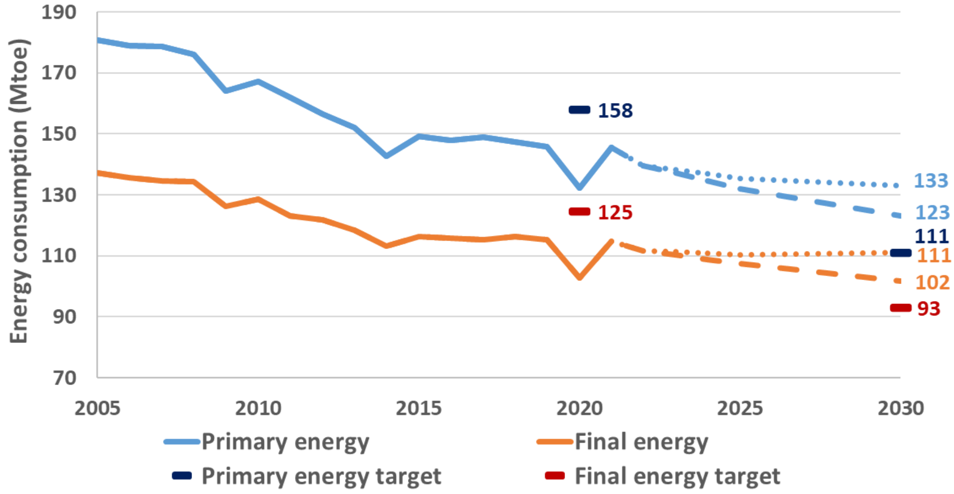
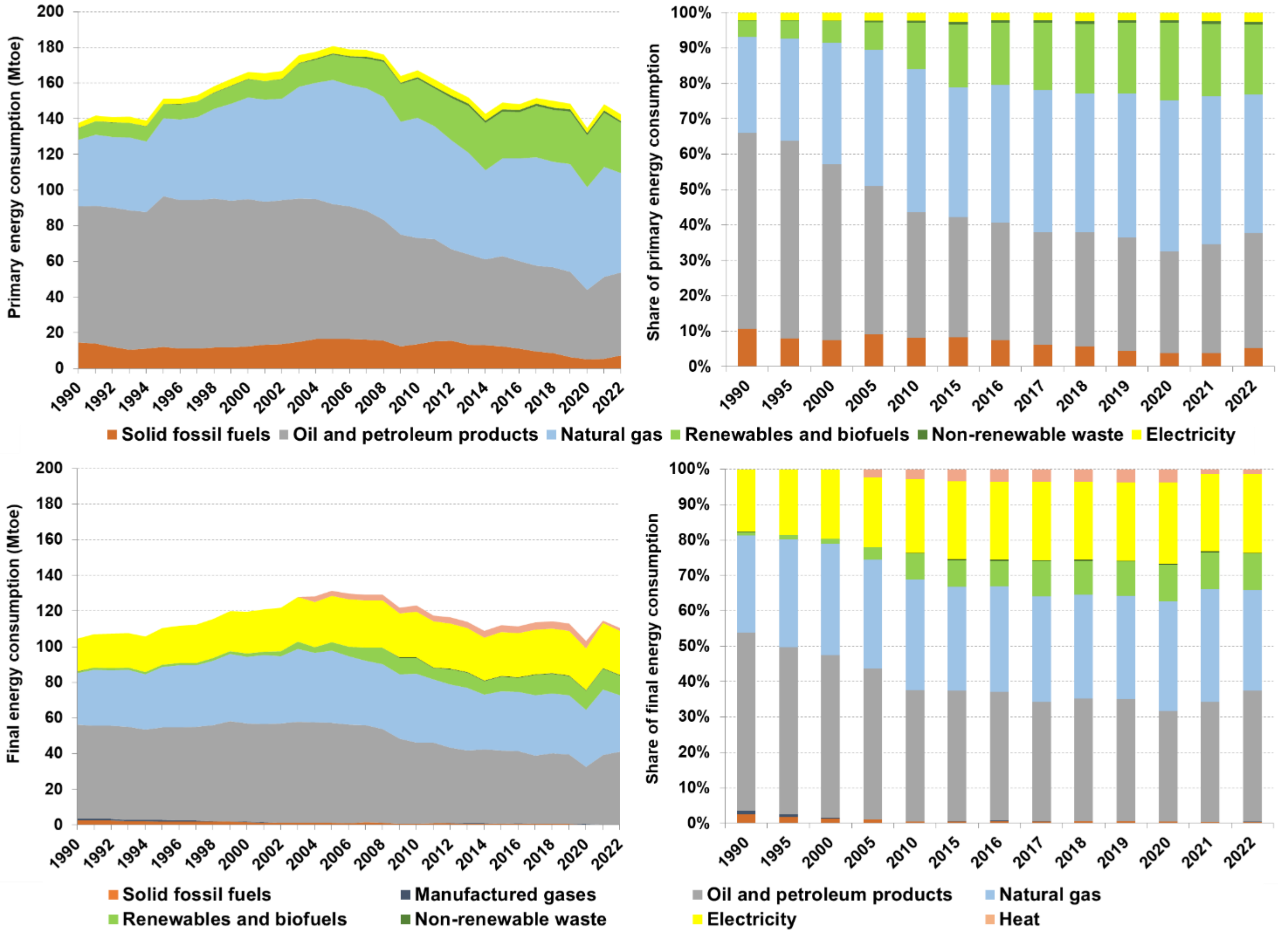


Figure 1.5 – Primary and final energy consumption trends by sources.



In Table 1.5 the gross inland energy consumption is split by final uses and transformation and losses energy.

Table 1.5 – Energy consumption by sector.

Settori	1990	1995	2000	2005	2010	2015	2020	2021	2022
Transformation & losses	31.5	38.4	42.9	46.9	41.9	34.9	30.8	32.1	33.2
Industry	34.1	33.9	37.6	37.2	29.0	24.9	23.9	26.4	24.6
Transport*	34.2	38.6	42.5	44.8	41.7	39.5	30.5	36.4	39.5
Households	26.1	26.3	27.6	33.9	35.4	32.5	30.7	33.4	30.0
Services	8.2	9.8	11.5	15.1	17.0	15.4	16.6	16.8	16.1
Agriculture	2.9	3.0	2.9	3.0	2.7	2.7	2.8	3.0	2.9
Fishing	0.2	0.2	0.3	0.3	0.2	0.2	0.2	0.2	0.2
Others	0.4	0.6	0.2	0.2	0.2	0.1	0.0	0.1	0.2
No energy final use	10.4	9.8	8.4	8.6	9.6	6.6	6.8	5.9	5.7
Statistical differences	0.1	0.5	0.6	-0.5	-0.9	-1.1	-0.6	-0.2	-4.4
Total	**148.1**	**161.2**	**174.5**	**189.4**	**176.8**	**155.7**	**141.6**	**154.1**	**148.1**

* Including international aviation

Figure 1.6 shows trends and shares of energy consumption by sector. Sectors with more than 20% share of consumption in 2022 are transformation and losses (22.4%), households (20.3%), and transport with international aviation (26.7%). Industry and services take 16.6% and 10.9%, respectively.

Figure 1.6 – Energy consumption trend and share for transformation and final users. Transport with international aviation.

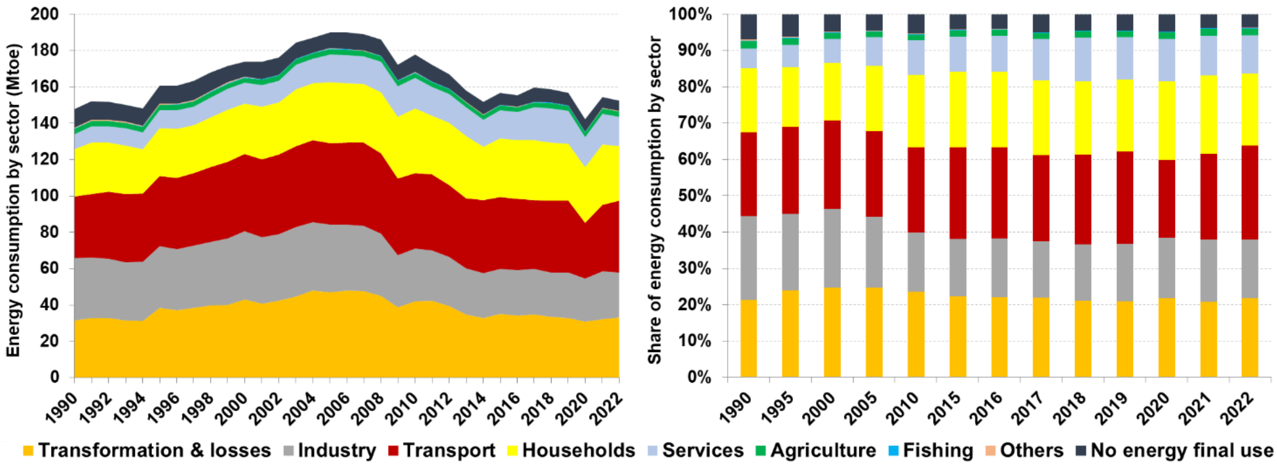
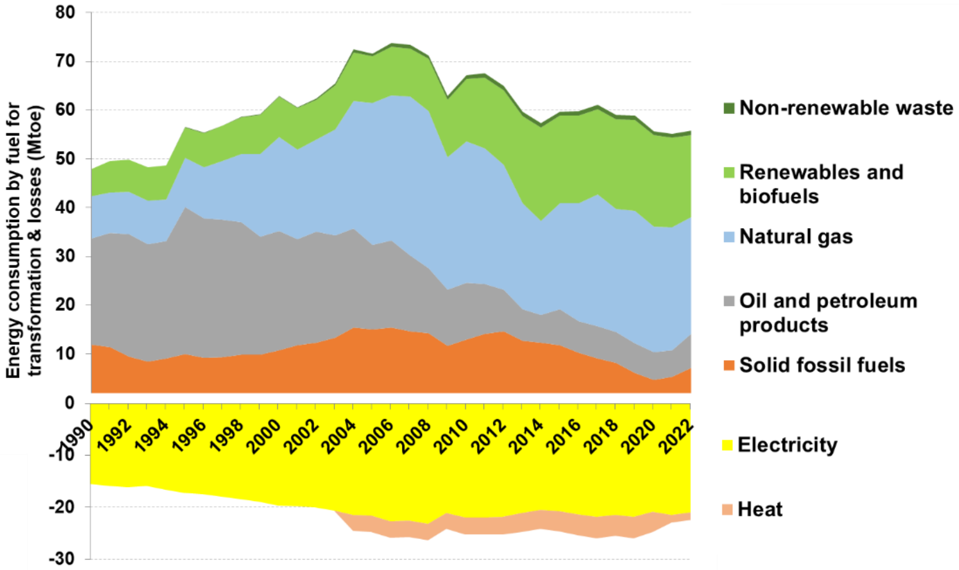


Figure 1.7 zooms in the transformation and losses and makes clear the shrinking of solid fossil fuels since 2012 and the rebound in 2021 and 2022. Even more clear is the decrease of oil & petroleum products and the corresponding increase of natural gas and the increasing share of renewable sources.

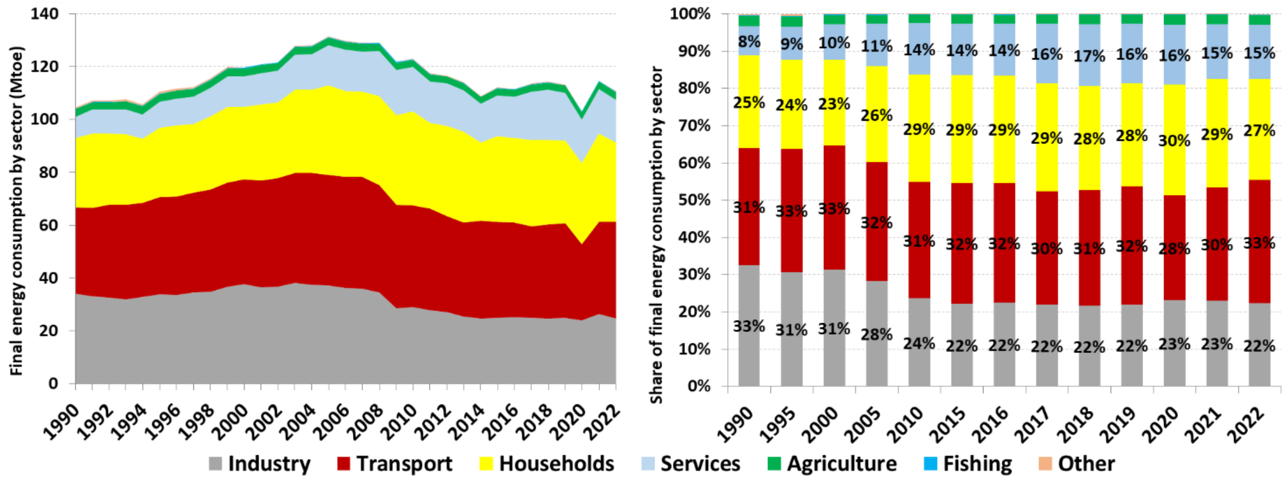
Figure 1.7 – Energy consumption trend by fuel for transformation and losses.



The final energy consumption by sector shows structural peculiarities for each sector and different sensitivities to contingent factors, such as economic crisis since 2008 or 2020 lockdown which have mainly affected the productive sectors. The final energy consumption of industry decreased by 27.8% from 1990 to 2022, while the final consumption of services in 2022 is almost twofold the 1990 level (+97.4%). The trend of final consumption in the households is quite swinging depending upon climatic conditions that affect the energy demand. The consumption of such sector in 2022 is 15.3% over the 1990 level. The overall trend for transport increased by 12.2% in 2022 compared to 1990, after the fall in 2020 due to the lockdown measures.

Since the 1990s, the structure of sectors in terms of energy demand has changed considerably. Services account for an increasingly share of final consumption from 7.8% in 1990 to 14.6% in 2022, while industry reduced the share from 32.6% to 22.2% over the same period. Consumption in the households shows a growing trend until 2010 followed by slight decrease with large fluctuations mainly due to the average temperature. The average share of energy consumption in the other sectors (mainly agriculture and fisheries) is around 3%.

Figure 1.8 – Final energy consumption trend and share by sector. Transport with international aviation.



The details of energy consumption by sources and sector show the peculiar consumption structure for each sector. Oil & petroleum products are the dominant energy source in transport (91.2% in 2022), which records a very small amount of electricity consumption (2.1%). Biofuels share for transport is 3.8%. Industry has more diversified energy sources, high level of electricity consumption (39%) and small renewable share (2.1%). Natural gas feed 41.3% of sector's energy demand. In the household's sector there is a growing share of renewable energy since 2000 (23.8% in 2022), mainly represented by solid biomass (85.7% of renewable energy in 2022). In the services the renewable energy use starts only since 2017 (13.6% in 2022), mainly because Italy begins to record energy consumption by heat pumps since 2017, as required by Eurostat. As for electricity consumption in 2022 the households share is 18.5%, while the services share is 50.7%. Natural gas feed 49.8% of household's demand and 31.1% of services' demand.

A relevant change of data reporting occurred for Italy with the current edition of Eurostat energy balance, even though the current data reporting has been required by Eurostat since many years. Data for 2021 and 2022 encompass the revision of reporting criteria concerning the energy needed for industrial heat auto producers. Up to the previous submission, all the energy for heat production was accounted in the transformation sector. Since the current submission only the energy to produce the heat transferred to third parties is accounted in transformation, while the energy consumed by industrial plants for heat self-production is accounted in industry. Such change determined an increase of the final energy consumption in industry and affects the electrification rate; the sharp decline in 2021 and 2022 of industry electrification is uniquely due to the reporting criteria. Moreover, electricity consumption reporting has been revised, mainly for services which in 2021 and 2022 contain the consumption for water supply, previously included in industry.

Figure 1.9 – Final energy consumption trend and share by energy source.

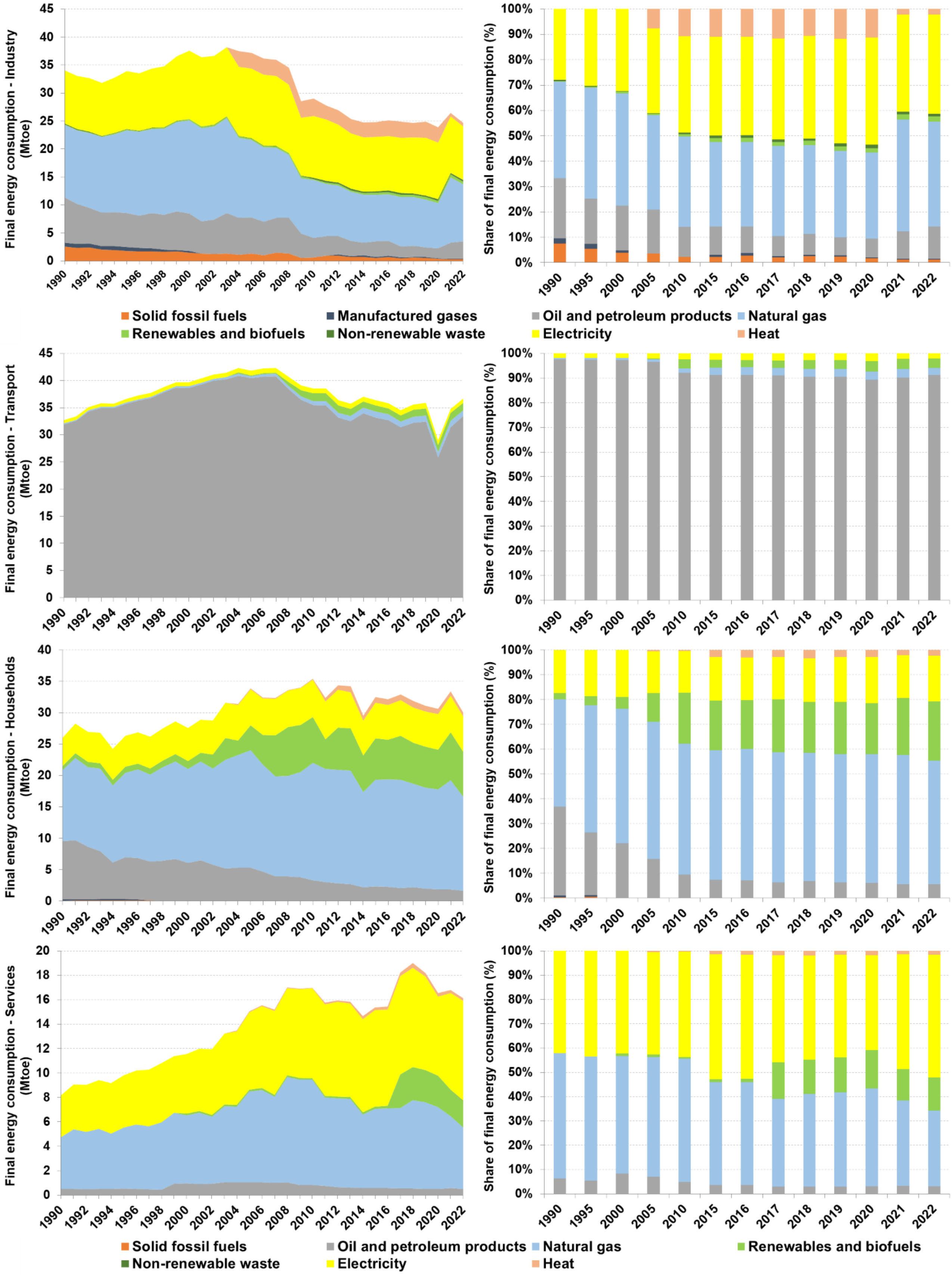
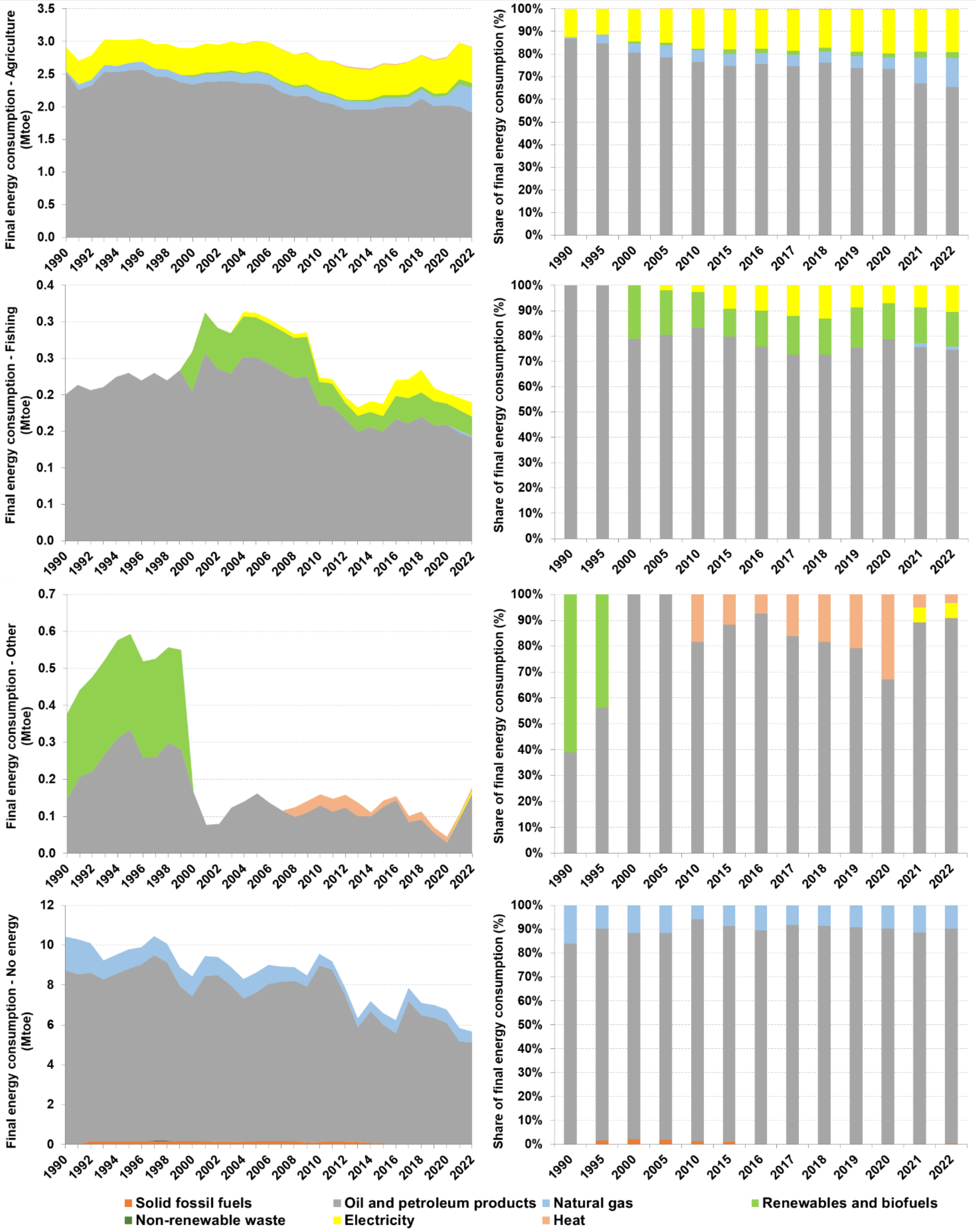


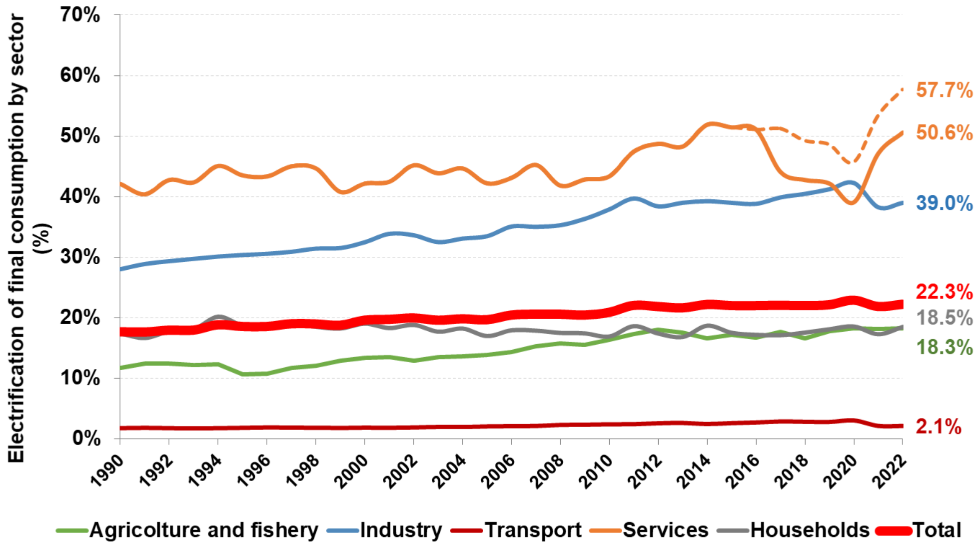
Figure 1.10 shows the energy consumption for sectors with lower energy consumption and no energy uses. All sectors have significant share of oil & petroleum products consumptions even though sectors as agriculture and fishing show a growing share of electricity. In the fishing sector, a relevant share of renewable energy is recorded since 2000.

Figure 1.10 – Final energy consumption trend and share by energy source.



The electrification of final energy consumption is a key strategy to mitigate GHG emissions if pursued in parallel with the spread of renewable energy for electricity production. The share of electricity in final energy consumption increased since 1990 and in 2022 is 22.3%. As seen in the previous graphs, the sectoral electrification is quite different. Services show the highest share of electricity consumption, with a significant increase from 2008, reaching more than 50% of the sector's final consumption in 2014 and 2015. Since 2017 the share decreased up to 2020 to grow again in the last years. The sharp decrease is mainly due to countability reason: Italy reported the final consumption of ambient heat from heat pumps since 2017, before such year such data did not appear in the national energy balance. Without such item, the electrification of the sector in 2022 is 57.7%. The sharp increase from 2021 is due to the allocation in this sector of water services, previously accounted in industry. The electrification in industry has been steadily increasing since 1990, with the rate clearly accelerating since 2005. In this sector, electricity consumption represents 39% in 2022. Even for this sector the setback recorded in 2021 and 2022 is due to countability reason, as previously reported. The electrification of households and transport shows no significant increases; in 2022 the electricity shares were respectively 18.5% and 2.1%. Agriculture and fisheries show a long-term increase of electrification, similarly to industry; in 2022 the share was 18.3%.

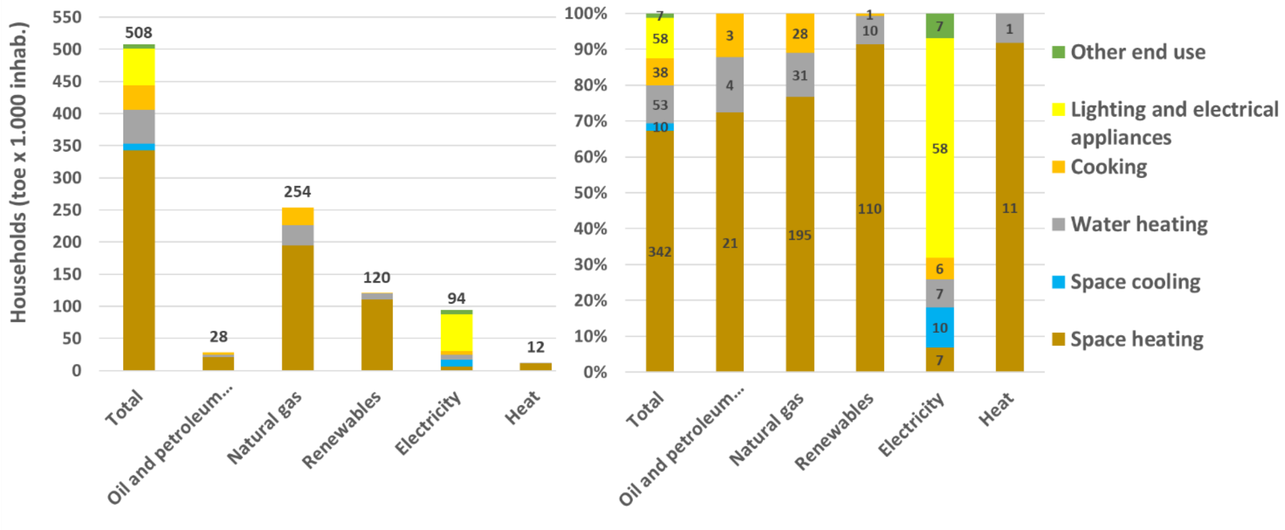
Figure 1.11 – Electrification of final energy consumption by sector. The dashed line refers to the energy consumption without the heat pumps.



Some detail on households' final energy uses is provided in Figure 1.12. The energy consumption in 2022 is 508 toe per 1.000 inhabitants, -13.2% below 2005 level but 10.7% over 1990 level. As already seen the natural gas is the main source of energy (49.8%), while electricity and heat account for 18.5% and 2.3% respectively. Renewable sources supply the 23.8% of final demand. Oil and petroleum products supply only 5.6% of energy, while solid fuels are not used in households. The renewable energy is represented by 85.7% of primary solid biofuels, while heat pumps represent 10.8% and solar thermal 2.9%.

Space heating is the main purpose of energy consumption (67.3%), pursued with natural gas for 56.8% and renewables for 32.1%. Natural gas is the main fuel also for water heating (the fuel covers 58.4% of use energy demand) and cooking (73.5%), which together account for 18% of final consumption of the sector. The electricity carrier covers totally only lighting & electrical appliances and space cooling which take respectively 11.3% and 2.1% of final consumption, while plays only a marginal role in space heating (1.9%). Electricity supplies 13.7% of water heating consumption and 15.1% of cooking. Heat supplies only space heating and water heating with marginal share, respectively 3.1% and 1.8%, compared to the other energy sources.

Figure 1.12 – Disaggregated final energy consumption in households by energy carrier and use. The labels on the bars of left-hand graph are the energy consumption per 1.000 inhabitants by energy carrier. The labels on the right-hand graph are the energy consumption per 1.000 inhabitants by energy carrier and use.



Data of national greenhouse gas emissions (GHGs) are reported in more detail in the National Inventory of greenhouse gas emissions that ISPRA submits annually to the competent authorities at national and international level (ISPRA, 2024a). GHGs are expressed in CO_2eq. Starting from the 2023 submission under the UNFCCC (*United Nations Framework Convention on Climate Change*), the GWP in use for the GHGs is established by the IPCC V *Assessment Report* (2013). For CH_4 the GWP is 28, while for N_2O is 265.

The methodology to esteem GHGs and emission factors for each sector and its sources are detailed in the National Inventory. The emissions examined in this report follow the same sectoral nomenclature used internationally for the reporting of emission estimates. Tables are organized according to the Common Reporting Format (CRF) for energy and process emissions.

Energy emissions of GHGs are due to the fuel combustion. In addition, fugitive emissions, i.e., emissions that occur along the fossil fuels chain, from production to final use, and methane emissions from geothermal sources are included in the energy emissions. Process emissions occur because of oxidation reactions other than combustion: other redox reactions, such as fermentation. Most methane emissions are due to the latter type of reactions.

Table 1.6 – GHG emissions by CRF source (MtCO_2eq.).

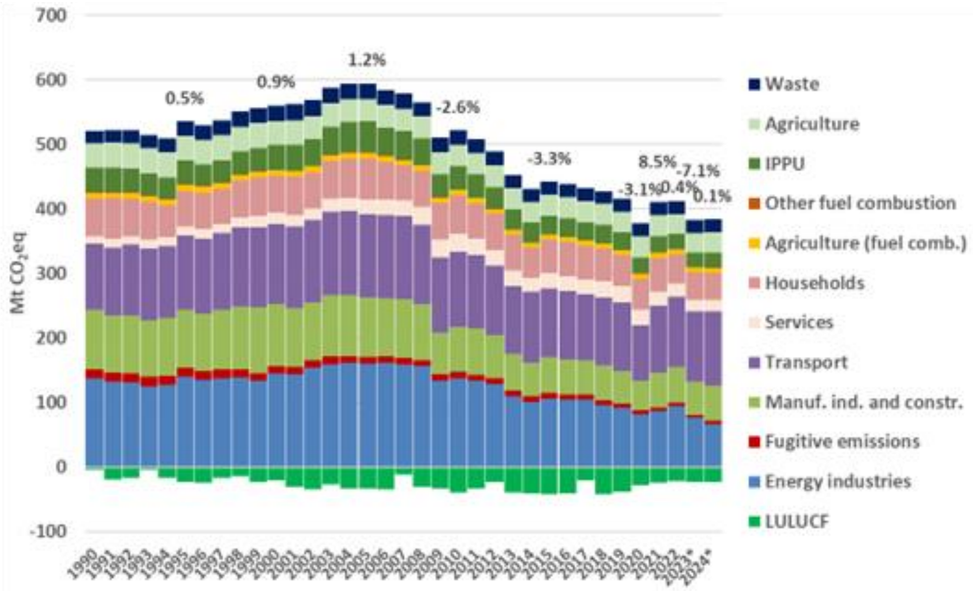
Source	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023*
Energy industries	137.6	140.6	144.9	159.9	137.5	106.1	81.6	86.4	94.9	*76.4*
Fugitive emissions	14.2	13.4	12.1	10.6	9.7	8.7	6.2	5.7	5.1	*4.6*
Manufacturing industries and construction	92.2	90.2	96.2	92.3	70.0	55.6	45.8	54.6	54.7	*51.6*
Transport	102.2	114.2	124.0	128.4	115.9	106.7	86.6	102.9	109.8	*108.2*
Services	57.8	55.0	56.2	62.9	59.4	51.7	47.5	52.0	45.3	*42.5*
Households	12.0	14.2	17.4	23.8	28.7	23.2	23.9	22.1	19.7	*18.5*
Agriculture (fuel combustion)	9.1	9.5	8.8	9.2	8.0	7.6	7.8	8.2	7.9	*7.4*
Other fuel combustion[1]	1.1	1.6	0.9	1.3	0.7	0.5	0.6	0.3	0.5	*0.4*
Industrial Processes and Product Use (IPPU)	37.9	36.3	38.2	47.1	36.6	29.1	24.3	25.3	23.6	*22.6*
Agriculture	38.0	38.3	37.4	35.0	32.6	32.5	33.5	32.9	30.8	*30.7*
Waste	19.0	22.0	24.1	24.1	22.4	20.3	20.5	20.2	20.1	*20.3*
LULUCF	-3.6	-23.4	-20.2	-33.7	-39.7	-41.9	-27.5	-24.8	-21.2	*-23.4*
Total w/o LULUCF	**522.4**	**536.5**	**561.3**	**595.6**	**522.4**	**442.6**	**379.1**	**411.3**	**413.0**	***383.9***
Total with LULUCF	**518.7**	**513.1**	**541.1**	**561.9**	**482.7**	**400.6**	**351.6**	**386.5**	**391.8**	***360.4***

[1] GHGs from military mobile activities; * Preliminary data.

Total GHGs show an increasing trend until 2005, followed by decline accelerated in the aftermath of the economic crisis from 2008 to 2014. In 2020 GHGs (379.1 Mt CO_2eq) was heavily affected by lockdown measures to contain SARS-CoV-2 pandemic. GHGs fell by 27.4% in 2020 compared to 1990 and by 36.4% compared to 2005. All sectors reduced the emissions, albeit at different rates. In 2021 and 2022 the GHGs rebounded, although to level below the 2019 level (416.5 Mt CO_2eq). The 2022 emissions fell by 20.9% compared to 1990 and by 30.7% compared to 2005. ISPRA's preliminary estimates for 2023 show that GHGs are below the level of the previous year (-7.1%), mainly for the reduction recorded in energy industries. Early estimates based on preliminary data of 2024 show that the emissions should remain on the same level of the previous year.

Emissions from manufacturing and construction decreased by 40.7% from 2005 to 2022. Transport sector shows steady growth with a reversal of the trend only after 2007 and the sharp decrease in 2020; 2022 emissions are 14.5% lower than 2005, but still over 1990 level (+7.4%). Households reduced the emissions by 21.6% compared to 1990, while the sector of services increased of 64.2%.

Figure 1.13 – GHGs trend by source.

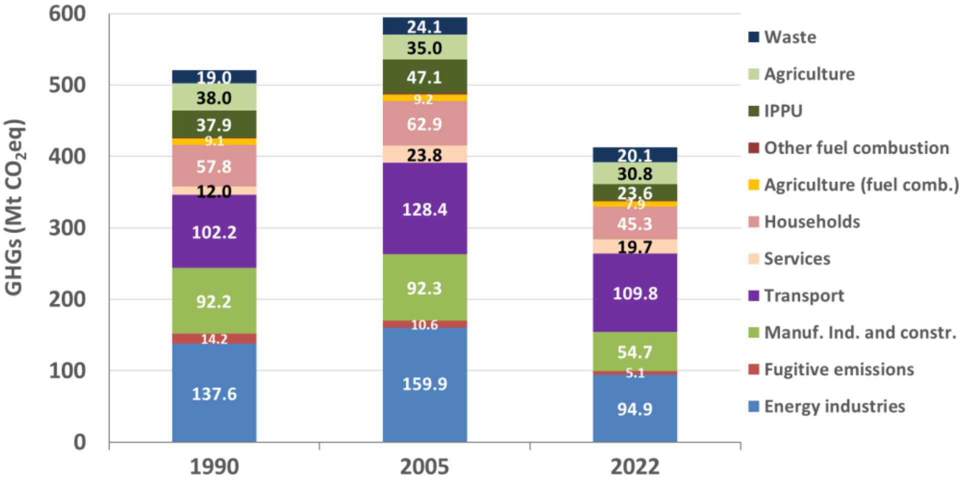


* Preliminary data.

In 2022 energy industries, together with fugitive emissions, have 24.2% of the GHGs share, followed by transport with 26.6%, households and services, that together account for 15.7%. The sectors mentioned, together with all other energy sectors, such as manufacturing and construction industries, combustion from agriculture and fisheries, account for 81.8% of total GHGs.

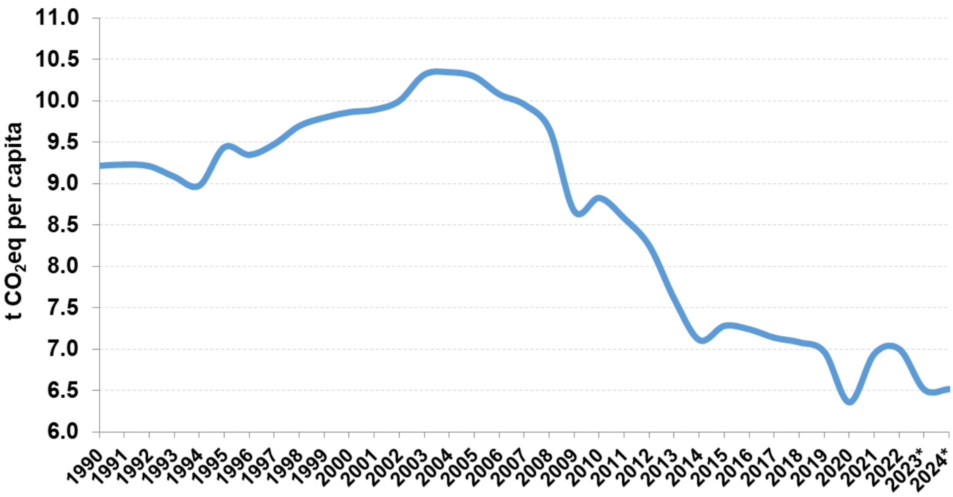
Figure 1.14 shows how each sector changed since 2005. All sectors reduced the emissions, but it is worth noting that some sectors, such as agriculture (processes emissions) or transport (energy emissions) appear harder to abate than other sectors, as energy industries or manufacture industries.

Figure 1.14 – GHGs by source in 1990, 2005, and 2022.



GHGs per capita increased from 9.2 t CO_{2eq} in 1990 to 10.3 t CO_{2eq} in 2004, in the following years there was a rapid decline up to 6.4 t CO_{2eq} in 2020, followed by a rebound in the next years. In 2022 the GHGs per capita was 7 t CO_{2eq}. The GHGs per capita decreased from 2005 to 2022 with an average annual rate of -2.2% (-0.9% since 1990). Preliminary data show a further decrease in the last years.

Figure 1.15 – Trend of per capita GHGs.



* Preliminary data.

1.1.1 GHGs from ETS and ESR

To monitor the achievement of GHGs reduction targets the GHGs must be allocated in the two compartments: ETS (EU Emissions Trading System, EU ETS) and ESR (Effort Sharing Regulation), defined according to the European legislation. EU ETS is one of the European Union's main policies to curb climate change and is an essential tool for cost-effective reductions in GHGs. It covers the emissions from power plants, big manufacturing industry and aviation within Europe. The Effort Sharing legislation covers GHGs from domestic transport (excluding CO_2 emissions from aviation), buildings, agriculture, small industry, and waste. The Effort Sharing legislation sets binding national targets to reduce emissions compared to 2005 levels, under the Effort Sharing Decision (ESD) for the period 2013-2020 and under the Effort Sharing Regulation (ESR) for the period 2021-2030. The analysis of the targets achievement has been carried by

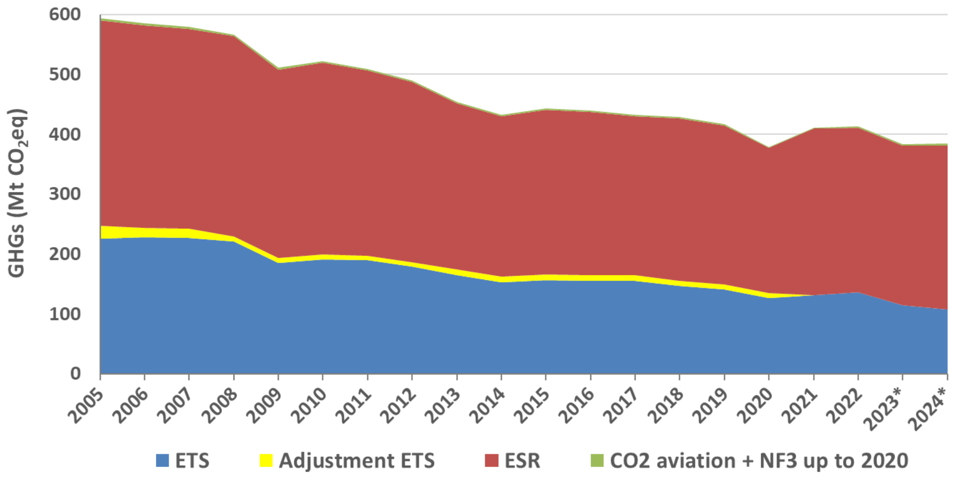
ISPRA (2024b) and goes beyond the purpose of this paper. Here only the emissions by sector will be focused for ETS and ESR compartments.

The EU ETS works on the ‘cap and trade’ principle. The cap, established at European level, is reduced annually in line with the EU’s climate target and within cap each company trades on the market of carbon allowances. If an installation or operator reduce the emissions, they can either keep the spare allowances to use in the future or sell them. The ETS emissions are regulated by market mechanisms and each operator is responsible of its own emissions. On the other hand, emissions not subject to the ETS fall within the scope of Regulation (EU) 2023/857 (Effort Sharing Regulation, ESR), on binding annual greenhouse gas emission reductions by Member States over the period 2021-2030 and which set an emissions reduction target for Italy by 2030 by 43.7% compared to 2005 levels. This target will have to be achieved on a reduction trajectory that will result in annual emission allowances (AEAs) for each year.

The recent revision of the legislation relating to the Fit for 55 set the emission reduction at European level for ETS from -42% to -62% and for no ETS emissions from -30% to -40%, both targets compared to 2005. The new ETS target covers an expanded scope: emissions from power generation, energy-intensive industries and aviation as previously legislated; adding carbon dioxide emissions from maritime transport from 2024, further extended to methane and nitrous oxide as of 2026. With the revision of the EU ETS Directive (Directive (EU) 2023/959), a new emissions trading system will be established (ETS-2), for buildings, road transport and additional sectors, e.g. fuel combustion by industry not covered by the existing EU ETS. Separate from the existing EU ETS, the ETS-2 is an upstream system regulating fuel suppliers rather than households and car users. It will come into operation in 2027, while the monitoring and reporting of emissions will start in 2025. The cap is set to achieve an emission reduction of 42% by 2030 compared to 2005 levels. Emissions from sectors covered by the ETS-2 remain covered by Member States' emission reduction targets under the Effort Sharing Regulation (ESR). This means that the ETS-2 will complement national efforts to bring down emissions in the ESR sectors. It is estimated that by 2030, half of the ESR emissions will be covered under the ETS-2. The ETS-2 does not cover non-CO_2 emissions which are mainly from agriculture and waste management. (EEA, 2023).

ETS covers 33% of national GHGs in 2022. The share of such emissions steeply decreased from 2005, when it was 42%. The ESR scope remains substantially unchanged compared to the previous period up to 2020, but since 2021 only CO_2 from domestic aviation is not included in the ESR sector, no longer NF3, as until 2020. ESR accounts for 66.4% of national GHGs in 2022 with an increasing share since 2005, when it was almost 58%. As shown in Figure 1.16 the ETS emissions, also considering the adjusted share to consider the current scope, decreased by 44.5% from 2005 to 2022, while the ESR emissions decreased by 20.1%. The last figure should be compared with the national target of emissions reduction of -43.7% in 2030 compared to 2005. Moreover, the reductions must accomplish annual thresholds and data in 2021 and 2022 show that such thresholds have been overcame: 4.6 MtCO_2eq in 2021, 5.5 MtCO_2eq in 2022 (ISPRA, 2024b). Preliminary data for 2023 show that the ESR emissions should be higher than the annual threshold by about 7 MtCO_2eq. In 2024 preliminary estimate of gap is over 20 MtCO_2eq with a wide uncertainty (Figure 1.17). According to the policy scenario in the National Energy and Climate Plan (MASE, 2024) the ESR emissions should decrease by 40.6% in 2030, not achieving the mandatory target, while the ETS emissions should decrease by 66% (Figure 1.19).

Figure 1.16 – Trends of GHGs from ETS and ESR (Mt CO_2eq). It is also shown the ETS adjustment for 2030 targets, as well the CO_2 emissions from domestic aviation and NF3. Since 2021 NF3 are included in ESR.

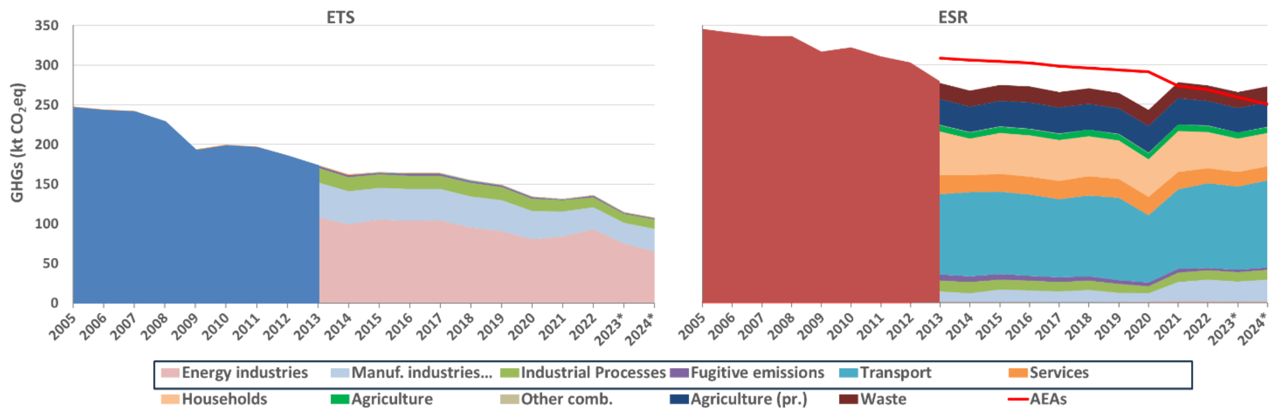


* Preliminary data.

Since 2013, the European Commission has required the reporting of ETS emissions allocated in the CRF sectors according with the implementing Regulation (EU) 749/2014 (art. 10, annex V pursuant to Regulation (EU) 525/2013) up to 2020, and according with the implementing regulation 2020/1208 (art. 14, annex XII pursuant to Regulation (EU) 2018/842) since 2021. By subtracting ETS emissions from the national emissions of the CRF sectors, ESR emissions by sector can be processed, without CO_2 from aviation in the transport. The adjusted ETS emissions are distributed in manufacturing industries & construction and industrial processes according to the weight of emissions recorded in the two sectors becouse the extension of ETS scope occurred in 2013 has only involved industrial installations, in particular manufacturing industries.

Figure 1.17 shows the trends of GHGs by CRF's sector since 2013 for ETS and ESR. Both compartments show long run downward trends, even though with a double rate in ETS than in ESR. Moreover, in the last years, particularly since 2021, GHGs show a vigorous rebound in ESR (+12.3% in 2022 compared to 2020), while in ETS the increase is quite modest (+1.4%). Preliminary data for 2023 and 2024 show, as already reported, further increase of ESR emissions.

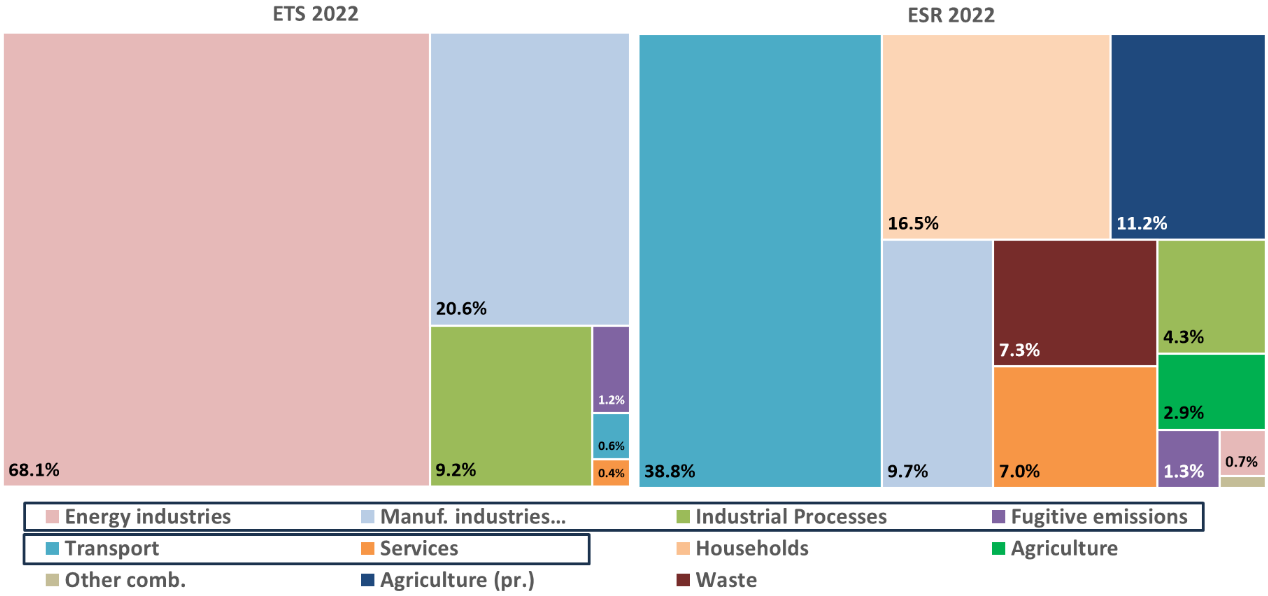
Figure 1.17 – Trends of GHGs from ETS and ESR by sector since 2013 (Mt CO_2eq). The sectors in the square are in ETS and ESR, while the other sectors are only in ESR. Annual emissions allowances (AEAs) are reported.



* Preliminary data.

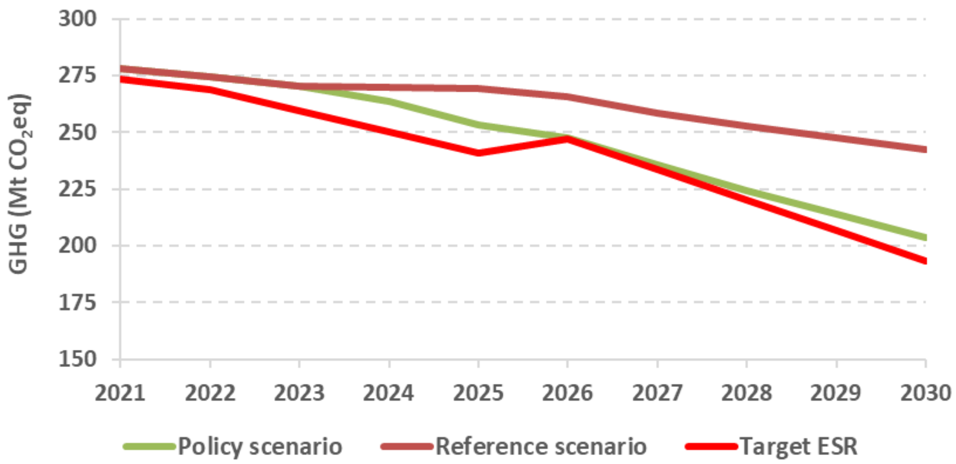
On the ETS side the dominant role is played by energy industries (68.1% of ETS GHGs in 2022) whose emissions are almost totally included in ETS (about 98% of sector's emissions), only a marginal share is in ESR. In the latter compartment the dominant role is played by transport with 38.8% of GHGs in 2022, the tiny share in ETS for such sector is utterly due to pipeline transport. GHGs from manufacturing industries and construction, together with industrial processess, account for 29.8% in ETS and 14% in ESR. The fugitive emissions in ETS concern only CO_2 from flaring in refineries, while all other sources and GHGs are in ESR. GHGs from services are almost totally in ESR (about 98%) and represent 7% of compartment's GHGs. GHGs from households, agriculture (both combustion and processes), and waste are totally in ESR with shares of 16.5%, 14.1%, and 7.3% respectively. Moreover, it should be considered that GHGs from agriculture processes and waste are mostly methane, that is utterly accounted in ESR. A focus on methane emissions is carried out in the next paragraph.

Figure 1.18 – Share of GHGs by sector from ETS and ESR in 2022 (Mt CO_2eq). The sectors in the square are both in ETS and ESR, while the other sectors are only in ESR.



Such quick glance is aimed to provide the current weight of each sector's emissions in ESR. Sectors with higher share of GHGs should be the priority targets for policies and measures directed to achieve the GHGs reduction goal. Figure 1.19 shows the projections of ESR emissions elaborated by ISPRA and reported in the NECP (MASE, 2024). The annual allowances from 2026 to 2030 will be provided by specific legal act to be adopted at European level. The current estimation was based on the criteria set out in Regulation (EU) 2023/857 on binding annual GHGs reductions by Member States from 2021 to 2030. The actual emissions in 2021 and 2022 are higher than the assigned annual allowances, as already stated. The emission projections show GHGs always higher than the annual allowances, both for reference and policy scenario.

Figure 1.19 – GHGs in ESR (Mt CO_2eq). Actual data up to 2022 are shown and projections up to 2030 as reported in the NECP.



1.1.2 Methane emissions

Methane is a powerful greenhouse gas, second only to carbon dioxide in terms of contribution to global warming (IPCC, 2021). Methane has a Global Warming Potential (GWP) about 85 times that of CO_2 over a period of 20 years, although CO_2 has an atmospheric lifetime of thousands of years, while methane disappears in about 10-15 years. The rapid decay of methane and its high impact on atmospheric temperature make it a primary objective to curb in a timely and effective way the climate change.

According to the recent reports of the International Energy Agency (IEA, 2024) and IPCC (2022), reducing anthropogenic methane emissions is one of the most effective strategies, including in economic terms, to rapidly reduce the rate of warming and contribute significantly to limit the increasing global temperature.

1.1.2.1 National methane emissions

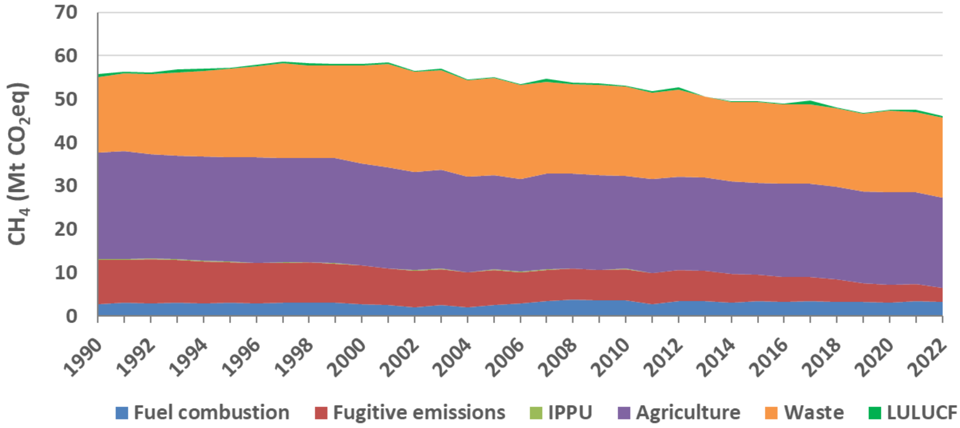
National methane emissions, without the contribution of natural sources, represent on average 10.6%±0.8% of total emissions from 1990 to 2022. Methane emissions without LULUCF decreased from 55 to 45.7 Mt CO_2eq, -16.8%. The reduction of methane is lower than the reduction of total GHGs (-20.9%). Moreover, GHGs other than methane reduced by 21.3% from 1990. These rates show the need to achieve methane emissions reduction from the main sources.

Table 1.7 – Methane emissions by source (Mt CO_2eq).

Source	1990	1995	2000	2005	2010	2015	2020	2021	2022
Combustion	2.7	3.0	2.8	2.6	3.5	3.4	3.1	3.4	3.2
Fugitive	10.1	9.4	8.8	8.0	7.3	6.1	4.1	3.8	3.2
IPPU	0.1	0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.0
Agriculture	24.6	24.1	23.5	21.8	21.5	21.2	21.4	21.2	20.8
Waste	17.3	20.4	22.5	22.3	20.5	18.6	18.8	18.5	18.4
Total	**55.0**	**57.0**	**57.7**	**54.8**	**52.9**	**49.4**	**47.4**	**47.0**	**45.7**

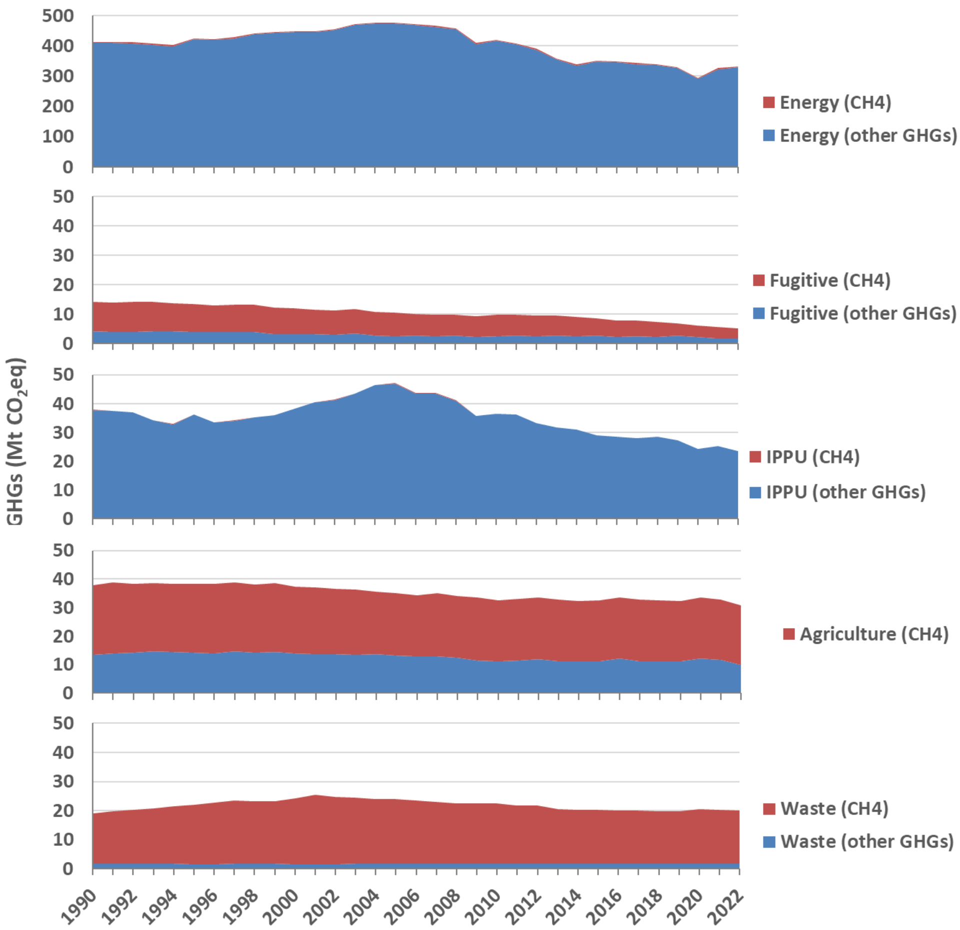
Figure 1.20 shows the decreasing trends of methane emissions by source and the dominant role of agriculture and waste sources.

Figure 1.20 – Trends of methane emissions by source (Mt CO_2eq).



The sources contribute differently to methane emissions. Some sector, as IPPU, emits a very marginal share of methane, while the GHGs by waste are almost entirely methane.

Figure 1.21 – Trends of methane and other GHGs by source (Mt CO_2eq).



Among the main sources, emissions by wastes in 2022 were higher than 1990 levels (+6.3%), although the trend is clearly descending from 2005 (-17.4%). Since 1990 agriculture decreased by 15.4% and fugitive emissions by 68%. Agriculture contributes with 45.6% of methane emissions in 2022, while wastes account for 40.3%. Fugitive emissions make up 7.1%, and unburned methane in the energy sector accounts for 7%.

By far the most important source of the agricultural sector is represented by enteric fermentation, or the digestive processes of farm animals, with 69.5% of methane emissions from the sector in 2022, followed by manure management with 23% and rice cultivation with 7.4%. Emissions due to the combustion of agricultural residues in the open field represent a marginal share, less than 0.05%.

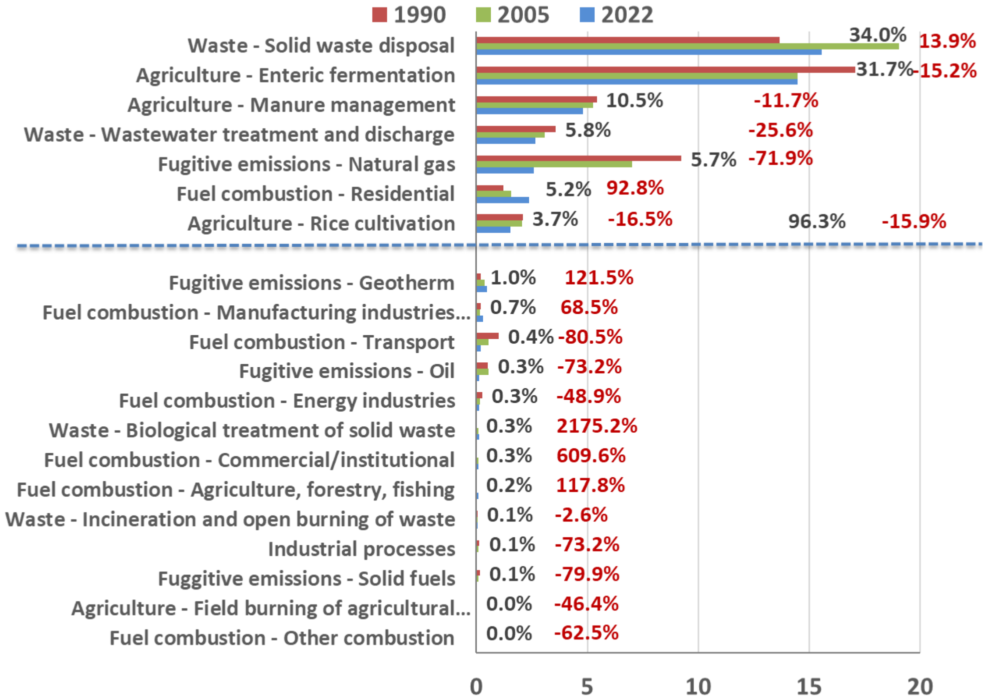
In the waste sector, the dominant source of methane emissions is represented by the disposal of solid waste, with 84.6% of sector's methane emissions in 2022, the next source is represented by wastewater treatment, with a share of 14.5%. The remaining two sources, biological treatment of solid waste and incineration and open field burning, account for a marginal share, lower than 1%.

Most of the fugitive methane emissions are due to the natural gas supply chain (production, transport, and distribution) which in 2022 accounts for 80.1% of total fugitive methane emissions with a share that has decreased significantly since 1990, when it was 91.2%. Oil and natural gas supply chains reduced methane emissions of 72% since 1990.

Unburned methane emissions in the energy sector are mainly due to the dominant source of the civil sectors (mainly by households) with 79.8% of methane emissions of the energy sector in 2022, followed by manufacturing and construction industries with 9.9%, transport with 6.2% and energy industries with 4.1%.

Arranging in descending order the methane emissions recorded in 2022 from all sources it can be noted that 96.3% of methane emissions come from seven key sources that emit 44 Mt CO_2eq (Figure 1.22). Emissions from key sources decreased by 15.9% since 1990. Minor sources, cumulatively responsible for 3.7% of emissions, are 35.4% lower than 1990 level. The disposal of municipal solid waste is the first key source with 34% of total methane emissions, followed by enteric fermentation with 31.7%. The first two sources are responsible for almost two-thirds of methane emissions.

Figure 1.22 – Methane emissions by source in 1990, 2005 and 2022 (Mt CO_2eq). Data in descending order of 2022 values. The black labels next to the bars are the 2022 share of emissions share by source, the red labels are the percentage change from 1990 to 2022. The values for the seven key sources are reported on the dotted line.



The waste sector has two key sources (MSW and disposal and wastewater treatment) with 39.9% of total methane emissions, while the agriculture has three sources (enteric fermentation, manure management and rice cultivation) with 45.6% of total methane emissions. The energy sector has one source for fugitive emissions (natural gas supply chain) and one for combustion (residential sector) which contribute 5.7% and 5.2% of total methane emissions respectively.

1.1.2.2 Agriculture

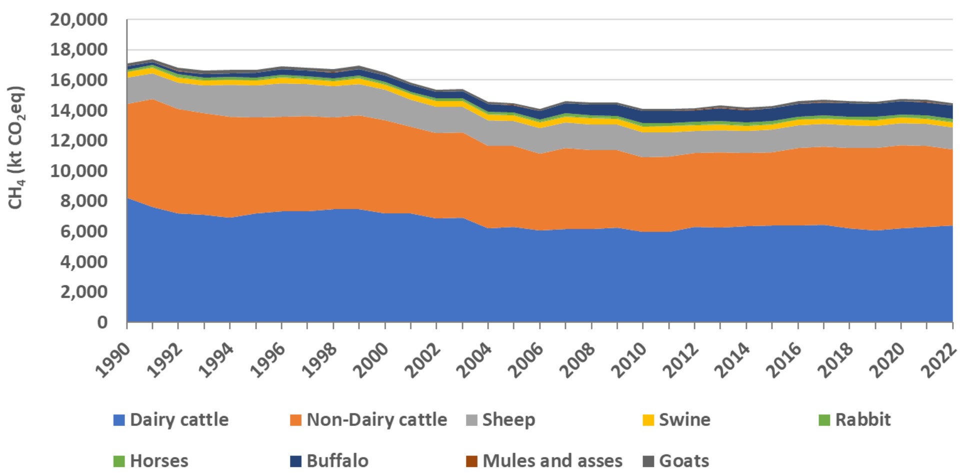
The sector accounts for 45.6% of national methane and the three main sources of agriculture represent almost 100% of methane emissions from the sector in 2022.

Table 1.8 – Methane emissions from the agriculture sources (Mt CO_2eq).

Source	1990	1995	2000	2005	2010	2015	2020	2021	2022
Enteric fermentation	17.1	16.7	16.5	14.5	14.1	14.3	14.8	14.7	14.5
Manure management	5.4	5.2	5.1	5.2	5.1	5.0	4.9	4.8	4.8
Rice cultivation	2.1	2.2	1.9	2.1	2.3	1.9	1.7	1.7	1.5
Field burning of agric. residuals	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	**24.6**	**24.1**	**23.5**	**21.8**	**21.5**	**21.2**	**21.4**	**21.2**	**20.8**

The top source of methane is the ***enteric fermentation*** of livestock, which in 2022 accounts for 69.5% of methane emissions from the agricultural sector. Number and mass of livestock are the main activity data for estimating emissions. To these parameters are added for the main animal categories parameters such as the production of milk, the percentage of fat in the milk, the percentage of grazing animals, the daily weight gain, the share of females that give birth, the quantity and quality of the diet and the coefficient of conversion into methane of the diet.

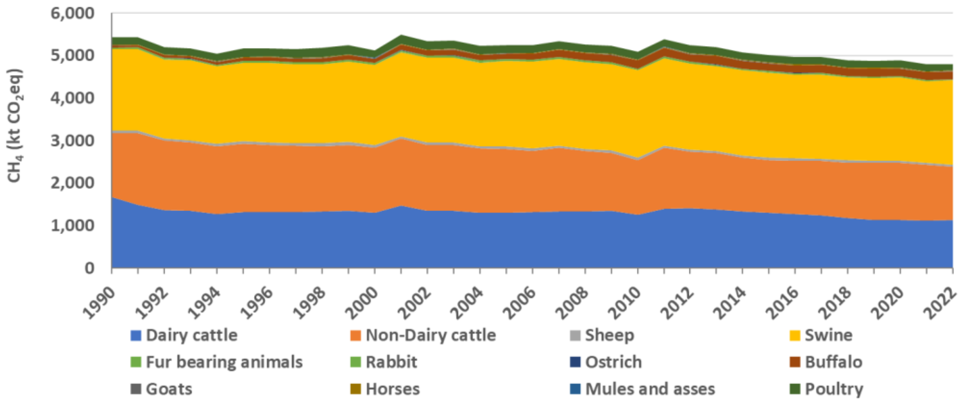
Figure 1.23 – Methane emissions trend from enteric fermentation by livestock.



Dairy and non-dairy cattle represent the main source of methane emissions from enteric fermentation (78.9% of methane emissions in 2022), followed by sheep (9.8%). Buffaloes record a constant increase in emissions in parallel with the increase in livestock bred and in 2022 they determine 6.1% of methane emissions from the source. Methane emissions from cattle and sheep decreased from 1990 to 2022, by just more than 20.6%, while for buffaloes there is an increase of a factor of about 4.5.

Manure management is the second largest source of methane emissions in the agriculture, with 23% of the sector's emissions. Such emissions are generated by the decomposition of organic matter under anaerobic conditions, during treatment and storage, and on pasture. The most relevant factors of the emissions are the amount of manure produced, which depends on the number of animals and the rate of manure production per animal, and the share of anaerobic treatment, which depends on the adopted manure management. The storage of non-palatable manure (liquid waste), which takes place in environments essentially devoid of oxygen, generates a significant amount of methane compared to the management of solid manure. The temperature and duration of storage also affect methane production.

Figure 1.24 – Methane emissions trend from manure management by livestock.



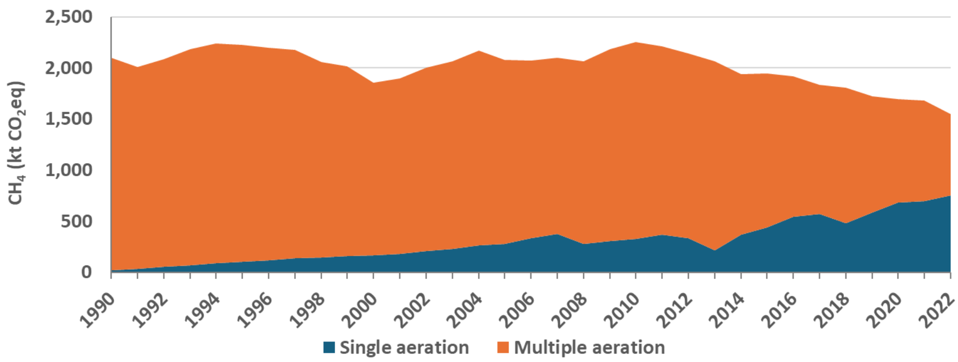
Dairy and non-dairy cattle represent the main source of methane emissions from manure management in 2022, accounting for 49.6% of the source's emissions, followed by swine, which contribute with more than 41.6%. In 1990, the share of cattle was about 58.6% and that of swine 35.2%.

In the estimation of methane emissions from manure management, fugitive methane losses of plants are also considered, which are equal to 1% of total biogas production. This percentage is calculated on all the biogas produced which derives not only from livestock waste, but also from all the other organic components that feed the digester. The amount of fugitive methane losses in 2022 are 325.6 kt CO_2eq.

Rice cultivation is the third source of methane emissions in the agriculture with 7.4% of sector's emissions. Emissions are generated by the decomposition of organic material by methanogenic microorganisms in rice fields submerged by the water. Emissions depend on the extent of the crops, the length of the growing period, the irrigation regimes and usage of organic and inorganic soil improvers. Soil type, temperature and cultivated variety also affect methane emissions.

In 2022 the source emitted 55.3 kt CH_4, with a reduction of 26.4% compared to 1990. Although the total harvested area has increased by 1.4%, there is a gradual spread of the cultivation technique in which the surface is submerged for less time than the traditional technique and therefore with less methane emission. The average weighted methane factor from 1990 to 2022 decreased by 27.4%. This reduction is mainly due to the increasing share of area cultivated with single aeration (in which the dry-seeded sowing technique is applied).

Figure 1.25 – Methane emissions trend from rice cultivation by cultivation technique.



1.1.2.3 Waste

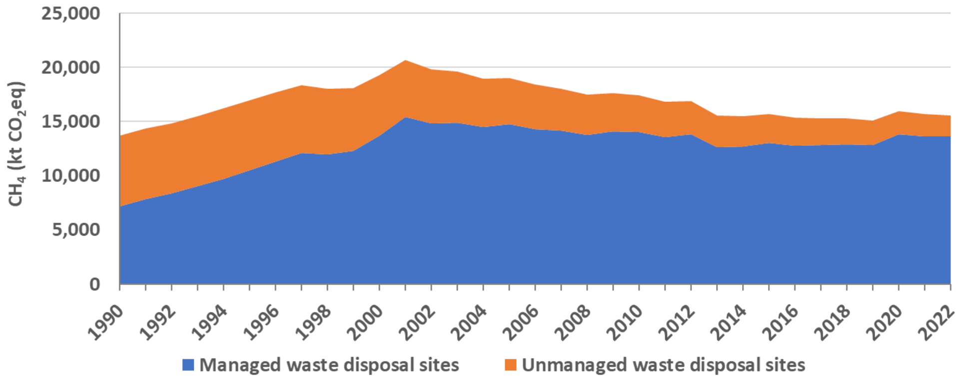
Waste sources emit 40.3% of national methane emissions. The disposal of solid waste is the dominant source, responsible in 2022 for 84.6% of the sector's methane emissions, the next source is represented by wastewater treatment and management with 14.5%.

Table 1.9 – Methane emissions from the waste sources (Mt CO_2eq).

Source	1990	1995	2000	2005	2010	2015	2020	2021	2022
Solid waste disposal	13.7	16.9	19.3	19.0	17.4	15.7	16.0	15.7	15.6
Biological treatment of solid waste	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Incineration and open burning of waste	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Wastewater treatment and discharge	3.6	3.4	3.2	3.1	2.9	2.7	2.7	2.7	2.7
Total	**17.3**	**20.4**	**22.5**	**22.3**	**20.5**	**18.6**	**18.8**	**18.5**	**18.4**

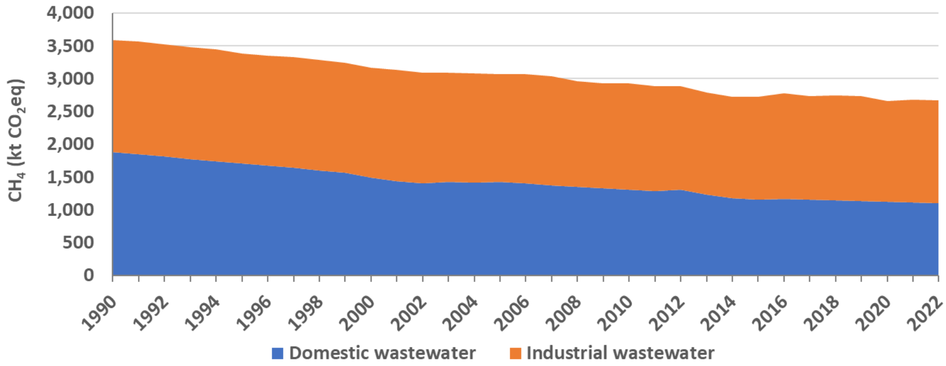
Solid waste disposal is a key category for methane, both for quantity and trend. The main parameters that affect the estimation of landfill emissions are, in addition to the quantity of waste disposed in landfills, the waste composition, the methane ratio in the biogas and the quantity collected and recovered. These parameters are strictly dependent on the waste management policies that start from the production and transport of waste, separate collection, treatment for volume reduction, stabilization, recycling, and energy recovery up to the deposition of the final residues in landfills. The disposal of solid waste in landfills contributes for about a third of methane national emissions in 2022 (34%). Between 1990 and 2022, methane emissions from this source increased by 19.9%, from 13.7 MtCO_2eq to 15.6 MtCO_2eq. The emissions trend shows an increase from 1990 to 2001 (+51.1%) followed by a decreasing trend up to 2022 (-24.7%), reflecting the steep downward trend of annual waste disposal in landfills.

Figure 1.26 – Methane emissions trend from waste disposal for managed and unmanaged sites.



Anaerobic conditions can also arise within ***wastewater management*** systems. In addition, the sewage sludge and the organic substance contained in the sewage can undergo anaerobic degradation if dispersed in the environment. Methane emissions are strictly connected to the characteristics of the wastewater and therefore to the quantity of organic substance present in the sewage, to the way in which they are managed as well as to the temperature. Methane emissions are estimated for both civil and industrial wastewater. Civil wastewater means mixed civil-industrial sewage deriving from strictly domestic activities and from commercial/industrial users operating in an urban context. Methane emissions from civil wastewater show a significant reduction from 1990 to 2022 (-41.7%) compared to an increase in the total organic load in treated wastewater of about 30% in the same period. As for industrial wastewater the methane emissions decreased by 7.7% in line with a decrease of the organic product of treated wastewater.

Figure 1.27 – Methane emissions trend from wastewater management for domestic and industrial wastewater.



1.1.2.4 Energy: fugitive emissions

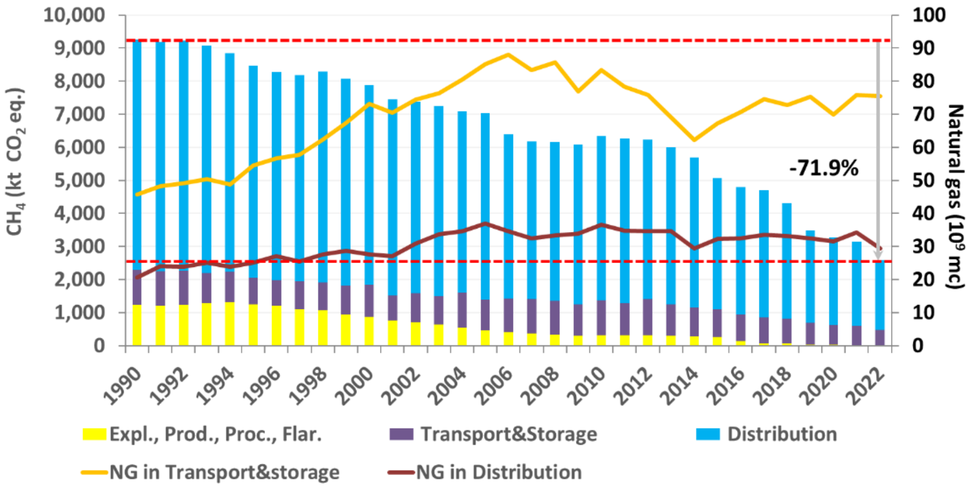
Fugitive emissions are 7.1% of national methane emissions. The ***natural gas supply chain*** accounts for 5.7% of national methane emissions and 80.1% of fugitive emissions in 2022. There has been a significant reduction in emissions since 1990 when represented 16.8% of national methane emissions and 91.2% of fugitive emissions.

Table 1.10 – Methane emissions from the fugitive sources (Mt CO_2eq).

Source	1990	1995	2000	2005	2010	2015	2020	2021	2022
Solid fuels	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0
Oil	0.5	0.6	0.5	0.5	0.4	0.4	0.2	0.2	0.1
Natural gas	9.3	8.5	7.9	7.0	6.3	5.1	3.3	3.1	2.6
Geothermal	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.5	0.5
Total	**10.1**	**9.4**	**8.8**	**8.0**	**7.3**	**6.1**	**4.1**	**3.8**	**3.2**

Transport, storage, and distribution of natural gas are the main sources of fugitive emissions with distribution in the dominant role. Fugitive emissions from the supply chain have been significantly reduced since 1990 because of many measures to improve the transport and distribution network performances. Since the 90s there has been the replacement in the distribution network from material characterized by high emissions factor (grey cast iron with hemp and lead joints) to materials characterized by fewer joints and lower emissions factor. In addition, the steel pipelines with cathodic protection for the corrosion prevention is increasingly extensive. Such improvements led to the methane emissions reduction of 71.9% from 1990 to 2022 compared to the increase of gas transported (+65%) and distributed (+42.9%) in the same period. Distributed natural gas meets the demand of users in the civil sector and small industry, while large industrial users are directly served by the transport network.

Figure 1.28 – Trend of methane emissions by source from the natural gas supply chain (left axis) and amount of natural gas transported and distributed (right axis). The dotted lines are the emission levels of 1990 and 2022.



The main sources transport-storage and distribution recorded emission reductions from 1990 to 2022 of 56.6% and 69.4%, respectively. Transport-storage source includes losses due to the transport, storage, and regasification of liquefied natural gas. The emissions factor shows a continuous decrease, because of the performance improvement of transport and distribution network. The emissions factor per gas volume in the transport-storage source recorded a reduction of 73.7% from 1990 to 2022, while distribution decreased by 78.6%. The emissions factor in the transport-storage source is about an order of magnitude lower than the emissions factor in the distribution and shows that the grid set-up for the satisfaction of natural gas demand is a crucial factor for the reduction of fugitive emissions in the natural gas supply chain. In addition, the relevance of emissions from distribution, 81.9% of methane emissions from natural gas supply chain, makes this source the main objective to furtherly reduce fugitive emissions.

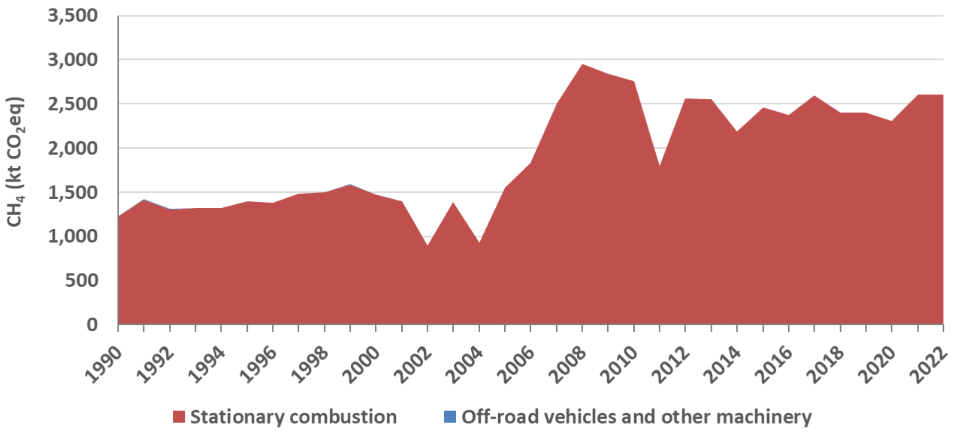
1.1.2.5 Energy: Combustion

Energy sector emits 7.2% of national methane emissions. The residential sector is the main source with a growing share from 1990, when it contributed to 44.8% of methane emissions by energy sectors, to 2022 with 74%. GHGs in the residential sector originate from the energy used directly in buildings, mainly for heating.

Table 1.11 – Methane emissions from the energy sources (Mt CO_2eq).

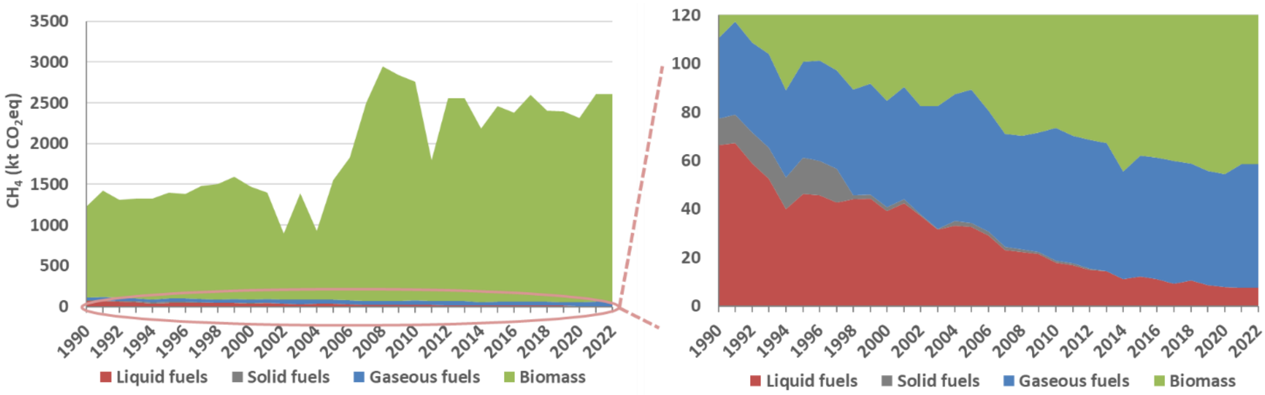
Source	1990	1995	2000	2005	2010	2015	2020	2021	2022
Energy industries	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1
Manuf. industries and construction	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3
Transport	1.0	1.1	0.9	0.6	0.3	0.2	0.2	0.2	0.2
Other: Commercial / institutional	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other: Residential	1.2	1.4	1.5	1.6	2.8	2.5	2.3	2.6	2.4
Other: Agriculture / forestry / fishing	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1
Other combustion	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	**2.7**	**3.0**	**2.8**	**2.6**	**3.5**	**3.4**	**3.1**	**3.4**	**3.2**

Figure 1.29 – Methane emissions trend from residential sector.



Methane emissions increased from 1990 to 2022 by 92.8% in the residential source compared to reduction in total GHGs in the sector by 21.6%. The decoupling is due to the increasing share of energy from biomass compared to other fuels. The sector's energy consumption oscillates around an average value without a particular trend, while the share of energy consumption from biomass has increased, going from an average of 14.2% in the 90s to an average of 25.8% in the last five years. Biomass essentially refers to the consumption of wood for heating.

Figure 1.30 – Methane emissions trend from residential sector by fuel.

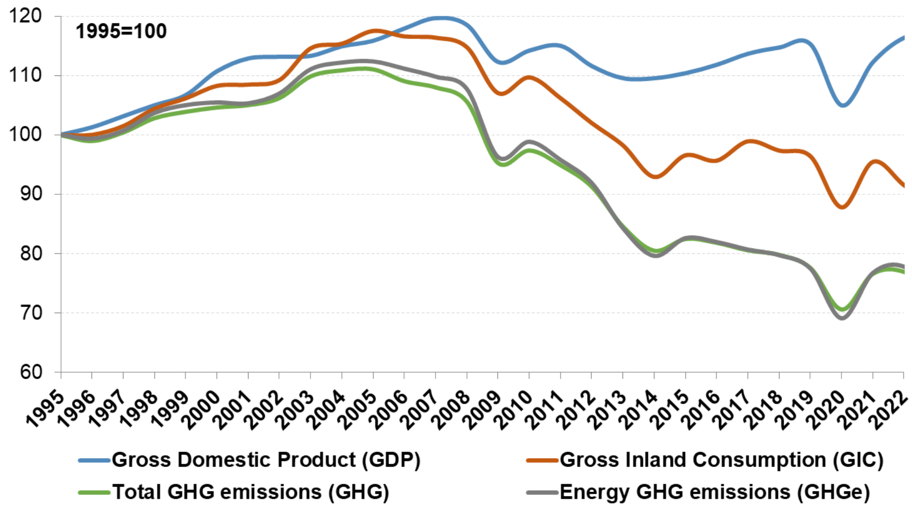


The share of methane emissions from biomass has always been prevalent but increased from 91% in 1990 to 97.9% in 2022. Other fuels contribute with fewer and fewer shares. The emission factors of methane and nitrous oxide from biomass for the entire time series examined are respectively 320 and 14 kg/TJ, much higher than those recorded for fossil fuels. However, the emission factors of biomass, expressed in CO_2eq, thus also considering the zero emissions of CO_2, are lower than those of fossil fuels.

1.2 Energy intensity and decarbonization indicators

To assess the relationship between energy consumption, economy and GHGs the trends of gross inland energy consumption (GIC), gross domestic product and GHGs are analysed. GDP and GIC had parallel trends up to 2005. Then the two parameters begun to diverge showing an increasingly decoupling. GHG emissions growth was slower than that of GDP until 2005, highlighting a relative decoupling. After 2005, the divergence between the two parameters became wider showing even absolute decoupling when the GDP increased and GHGs decreased (2015-2019).

Figure 1.31 – Indexed trend of gross inland energy consumption, GDP and GHGs.



Decoupling is also evident from the downward trend in the ratio of GIC to GDP since 2005. The decreasing trend in energy GHGs per primary energy consumption is mainly due to the replacement of higher carbon fuels with natural gas, mostly in power sector and industry, and to the increase of renewable share. The same decreasing trends are confirmed for final energy consumption (net of non-energy uses) per GDP and for GHGs per final energy consumed.

In the period 1995-2022 the GIC per GDP decreased from 107.5 toe/M€ to 83.5 toe/M€ (-22.3%). Over the same period, GHGs per GDP fell by 34.9%, from 357.8 t CO_2eq / M€ to 233 t CO_2eq/M€, while energy emissions per primary energy goes from 2.81 t CO_2eq/toe to 2.34 t CO_2eq/toe, with a reduction of 16.8%. All declining trends of the shown indicators are statistically significant to Mann-Kendall test ($p<0.001$). The preliminary estimates for 2023 show a further decrease of energy intensity and decarbonization indicators by GDP compared to the previous year. Even preliminary data for 2024 show a further decrease of energy intensity and decarbonization indicators.

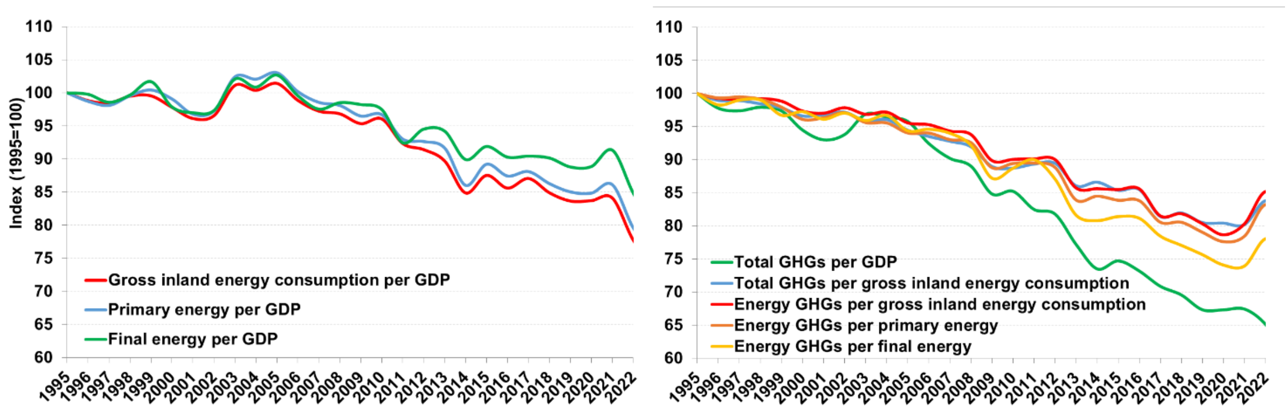
Table 1.12 – Energy intensity by economy and decarbonization indicators.

	Indicators	1995	2000	2005	2010	2015	2020	2021	2022	*2023**
Energy intensity	GIC per GDP (toe/M€)	107.5	105.1	109.0	103.3	94.1	90.0	90.4	83.5	*78.9*
	Primary energy per GDP (toe/M€)	101.0	100.0	104.1	97.7	90.1	85.7	87.0	80.3	*75.9*
	Final energy per GDP (toe/M€)	73.7	72.1	75.7	71.8	67.7	65.5	67.3	62.5	*58.4*
Decarbonization	Total GHGs per GDP (t CO_2eq/M€)	357.8	338.1	342.8	305.0	267.3	240.9	241.3	233.0	*214.6*
	Energy GHGs per GDP (t CO_2eq/M€)	283.7	270.1	274.9	245.4	212.2	186.7	191.6	187.8	*170.5*
	Total GHGs per GIC (t CO_2eq/toe)	3.33	3.22	3.14	2.95	2.84	2.68	2.67	2.79	*2.72*
	Primary energy emissions (t CO_2eq /toe)	2.81	2.70	2.64	2.51	2.36	2.18	2.20	2.34	*2.25*
	Final energy emissions (t CO_2eq/toe)	3.85	3.74	3.63	3.42	3.13	2.85	2.85	3.00	*2.92*

* Preliminary data.

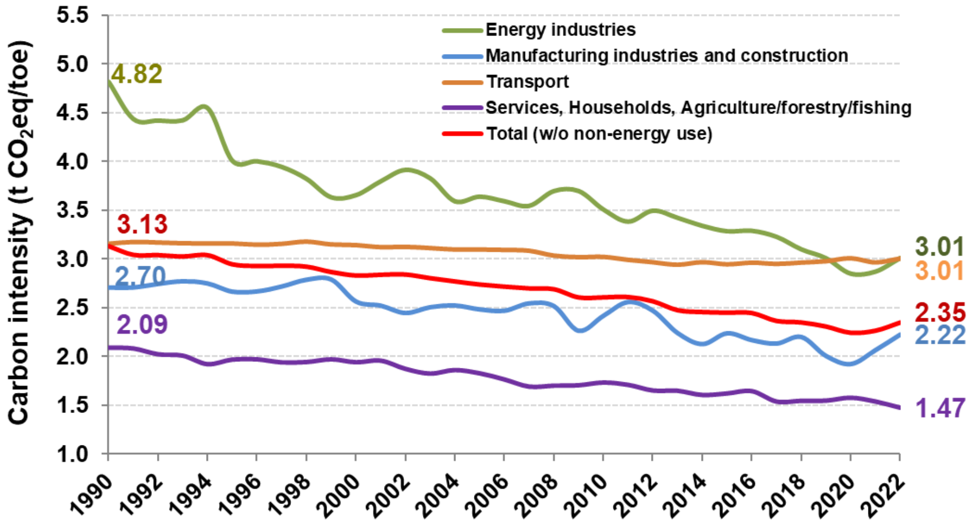
Since 2005 there has been an acceleration in the energy intensity decrease and decarbonization of the national economy up to 2019/2020, once again highlighting the growing decoupling of economy, energy and GHGs. The decoupling between energy consumption and GDP leads to a decreasing energy intensity of the national economic system. The causes can be manifold and among the main ones is the contraction of industrial activities, which are more energetic intensive as compared to services characterized by lower energy intensity and higher value added. GHGs per energy consumed (primary and final) decreased rapidly since 2005 mainly because of the increasing share of renewable energy since 2007. After 2020 the indicators show an upward trend due to the increase of share oil fuels (2021 and 2022) and solid fuels (2022).

Figure 1.32 – Energy intensity and decarbonization indexes.



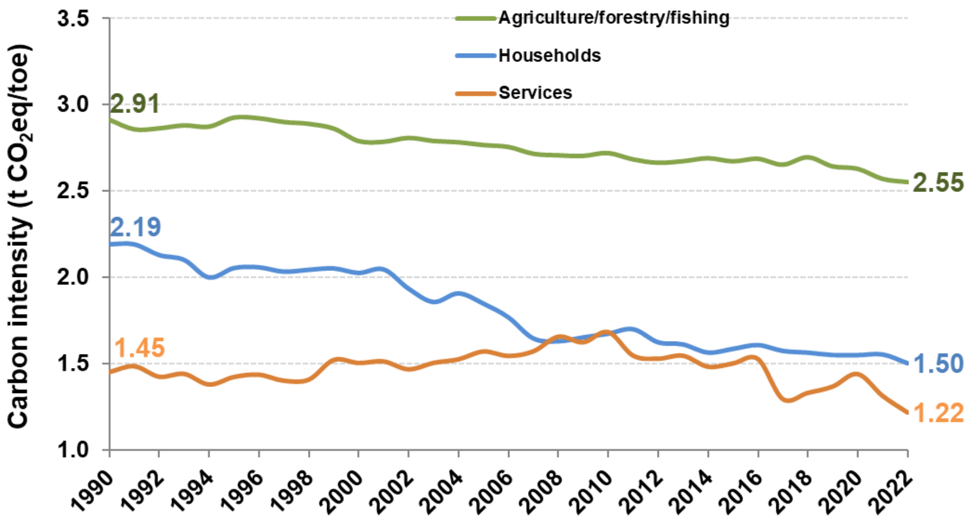
Decarbonization at sectoral level can be assessed by energy emissions and energy consumption by sector. The carbon intensity by energy is the ratio between GHGs and energy consumption. The average carbon intensity by sector is notable different among sectors, depending upon the different deployment of renewable sources and electrification of final energy consumption. The carbon intensity of energy industries decreases by 37.5% in 2022 compared to 1990, from 4.82 t CO_2eq/toe to 3.01 t CO_2eq/toe. The carbon intensity of manufacturing industry in 2022 is 2.22 t CO_2eq/toe. decreasing by 17.8% compared to 1990 level. The transport carbon intensity is 3.01 t CO_2eq/toe (-4.8% compared to 1990) and shows the highest value in the last years with the slowest decreasing slope since 1990 among sectors. The carbon intensity in the civil sector is 1.47 t CO_2eq/toe, 29.5% down compared to 1990 value. All declining trends of these indicators are statistically significant to Mann-Kendall test ($p<0.001$). Overall, the carbon intensity for the energy consumption considered, accounting by 93.6%±1.2% of gross energy inland consumption from 1990 to 2022, is 2.35 tCO_2eq/toe (-25.1% compared to 1990 level).

Figure 1.33 – Carbon intensity by sector.



Splitting the civil sector into its sub-sectors it emerges how services have the lowest intensity because of the high electrification of final consumption and the structural low energy demand of the sector. The households show the highest reduction from 1990 to 2022 (-31.5%), followed by services (-16.3%) and agriculture, forestry, and fishing (-12.4%). Moreover, it is noteworthy how households catch up services from 1990 to 2008, mainly because of the steep decrease of high carbon content fuels and parallel increase of renewable energy in the households' sub-sector, as seen in Figure 1.8.

Figure 1.34 – Carbon intensity in the civil sub-sectors.



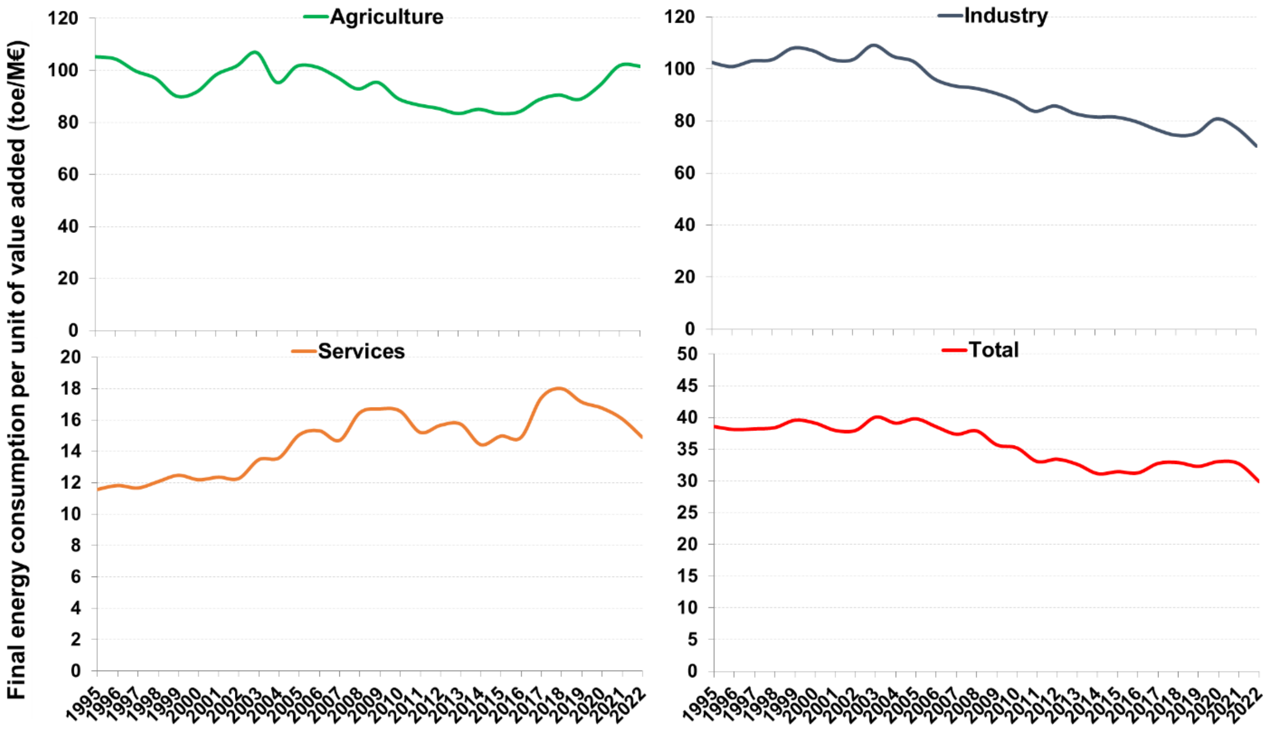
1.2.1 Energy and carbon intensities by economy

The carbon and energy intensity indicators by sector are calculated matching the GHGs by sector with respective value added or GDP for households and transports. Emissions by sector include only direct emissions and emissions from electricity self-production in industry. Indirect emissions due to electricity consumption from the grid are not considered, since they are allocated in the energy industries.

For agriculture, which includes fisheries and forestry, it is possible to establish a direct correspondence between GHGs, final energy consumption, and value added produced by the sector. For the services, value added was considered without the transport item, to compare sector's GHGs and value added. For industry, the items of value added from manufacture of coke and oil-petroleum products, electricity and water services are excluded to make comparable the industry value added with the GHGs of manufacturing and construction industries and relative energy consumption. For agriculture and industry both combustion and process emissions are considered.

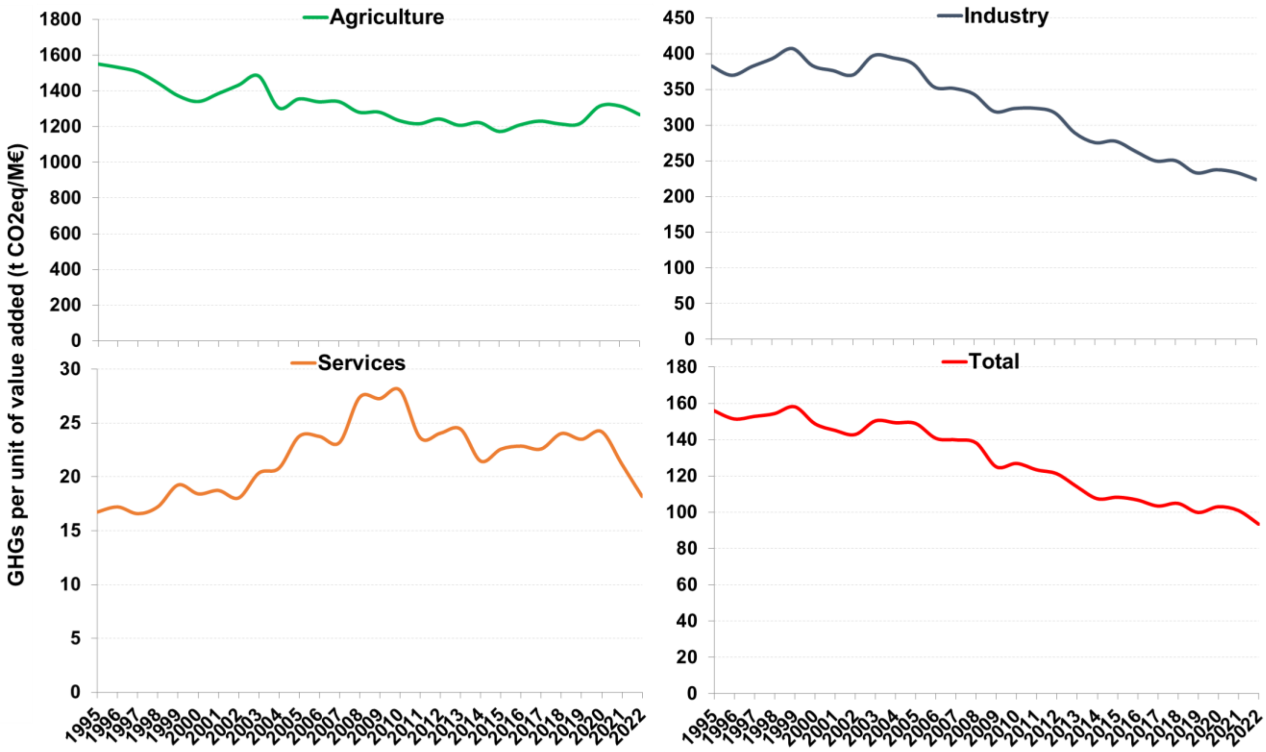
Overall, emissions from the three sectors (agriculture, industry, services) fell by 27.5% in 2022 compared to 1995. Combustion and process emissions are reduced by 27.7% and 27.1%, respectively. GHGs from the three sectors represent on average 34.5±0.8% of total GHGs in the period 1990-2022. In 2022 the energy intensity (toe/M€) of industry is well below the 1995 level (-31.4%), while services are higher (+28.8%) although in the last years the sector intensity decreases significantly. As for agriculture, after a downward trend from 2003 to 2015, the intensity shows increasing trend even though 2022 level is -3.5% compared to 1995. Aggregate energy intensity for the three sectors decreased by 22.2% over the period 1995-2022.

Figure 1.35 – Final energy intensity by value added.



The ratio between GHGs and value added, carbon intensity, decreases because of the increasing share of renewable energy and fuels with lower carbon content, as natural gas. The carbon intensities per value added are very different among sectors. Agriculture has the highest values, while services recorded the lowest ones. In 2022 the agriculture intensity is 18.3% below the 1995 level, while services' one is 8.7% over. In the latter sector the indicator increased until 2010, then followed by a decarbonization, particularly steep in the last years. Industry shows a robust downward trend (-41.6% in 2022 compared to 1995). The aggregate trend (-40% in 2022) is heavily driven by industry.

Figure 1.36 – Carbon intensity by value added.



1.2.1.1 Transport and households

GHGs in transport and households cannot be uniquely linked to a specific economic parameter, such as the value added for the sectors seen before. Energy and carbon intensities by economy for such sectors are calculated considering the GDP. Moreover, GHGs per capita (in transport) could provide useful insights about the sector's performance concerning carbon intensity. Furthermore, to consider the transport performance for unit of transported item, without the effect of increasing population and integrating the technology change of vehicles over time, the GHGs are compared to passenger-km (p-km) or tonne-km (t-km) for freight transport. One passenger-km represents the transport of one passenger over one kilometre, while one tonne-km represents the transport of one tonne of goods over one kilometre. So, the carbon intensities per p-km or t-km are the GHGs emitted to move one passenger or one tonne of goods over one kilometre. Passenger-km and tonne-km data are issued by Ministry of infrastructures and transport. For freight transport Eurostat data are considered because such source includes also transport below 50 km. For such metric the GHGs from heavy and light duty trucks are considered together. The sources of transport data (number of vehicles, p-km, and t-km) are Eurostat, Ministry of infrastructures and transport, ACI.

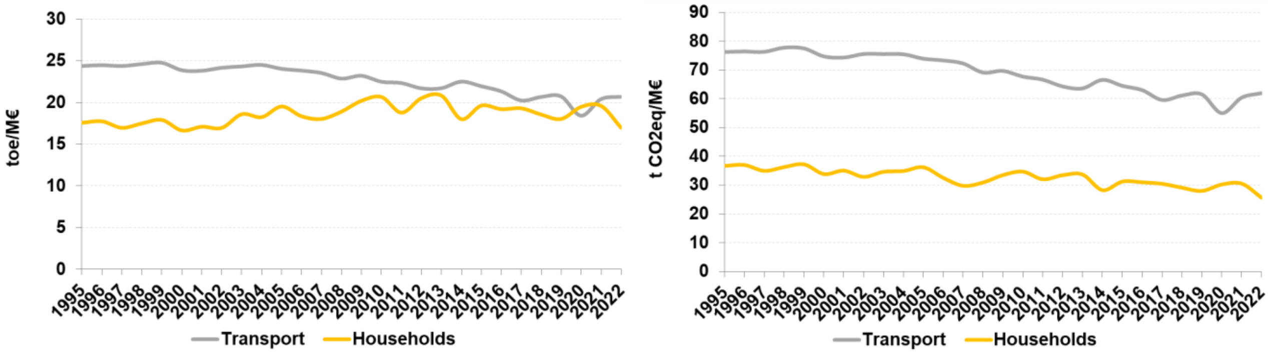
The GHGs from transport and households together show an increasing share, from 30.6% to 37.7% of total GHGs in the period 1990-2022. The increase is due to transport (from 19.8% to 26.7%), while the share of households does not show any specific tendency but fluctuates within the range 10%-12%.

Figure 1.37 shows the trend of energy and carbon intensities by GDP for the two sectors. The energy intensity of households fluctuates around an average without a clear tendency downward or upward (18.6±1.2 toe/M€), while the carbon intensity shows a downward trend since 1995 (from 36.7 t CO_2eq/M€ in 1995 to 25.6 t CO_2eq/M€ in 2022; -30.3%). The trend of GHGs emissions by GDP witnesses the sector's change of energy mix in the final consumption, with increasing contribution of biomass leading to lower carbon intensity but not reducing energy intensity.

As for transport the energy intensity decreased by 15.2%, from 24.4 toe/M€ to 20.7 toe/M€ from 1995 to 2022. A quite parallel decreasing trend was observed for carbon intensity with a reduction by 19.4%, from

77.2 t CO_2eq/M€ to 62.2 t CO_2eq/M€ from 1995 to 2022, showing some decarbonization also in this sector.

Figure 1.37 – Energy and carbon intensities by GDP for transport and households.



The GHGs per capita (Figure 1.38) shows a decreasing trend since 2005 for the two sectors (-16.6% transport, -29.4% households). It is noteworthy the relevant fall of emissions per capita recorded in 2020 for transport because of the pandemic and the rebound in the next year with emissions per capita even higher than the pre-pandemic values and an upward trend.

Figure 1.39 shows the decoupling among the considered indicators in the two sectors since 2005. As for transport there is no real decoupling between energy and carbon intensities, while GHGs per capita, as well as energy consumption per 1000 inhabitants show only small decoupling, even though in the last years all the indicators are very close.

As for households the two intensities by GDP show a growing distance since 2005, due to the decrease of GHGs compared to energy consumption. Even more distant from energy intensity are GHGs per capita. The relative closeness between energy intensity by GDP and energy consumption per 1000 inhabitants, confirms that it was the fuel mix the driving factor leading to less GHGs, followed by efficiency of energy final consumption in the dwellings. As already seen, the GHGs per capita decreased by 29.4%, whereas the energy per capita consumption decreased by 13.2% since 2005.

Figure 1.38 – GHGs per capita for transport and households.

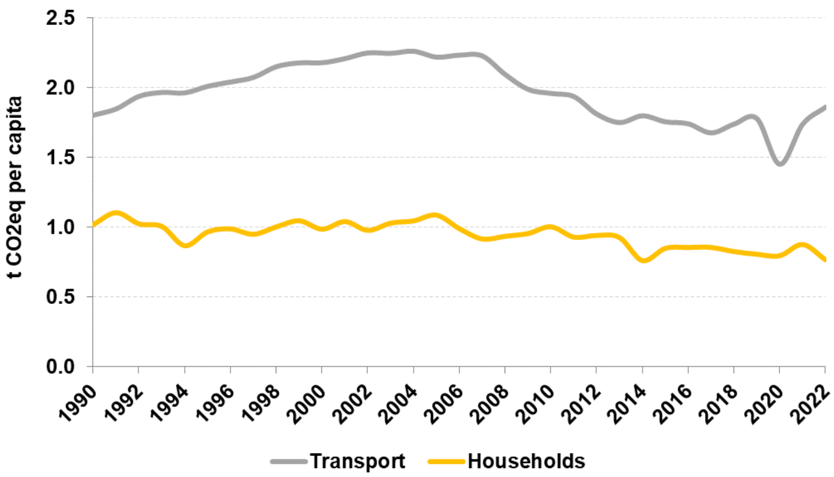
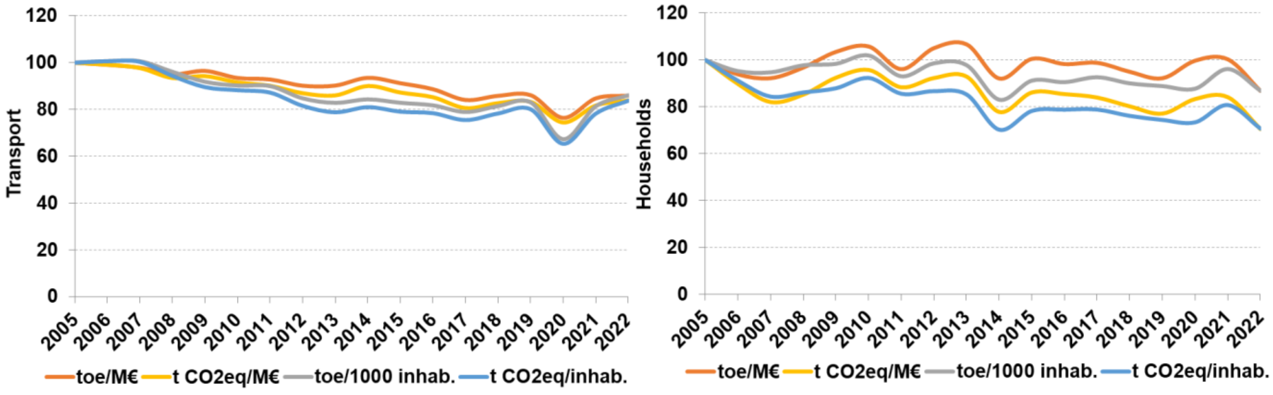


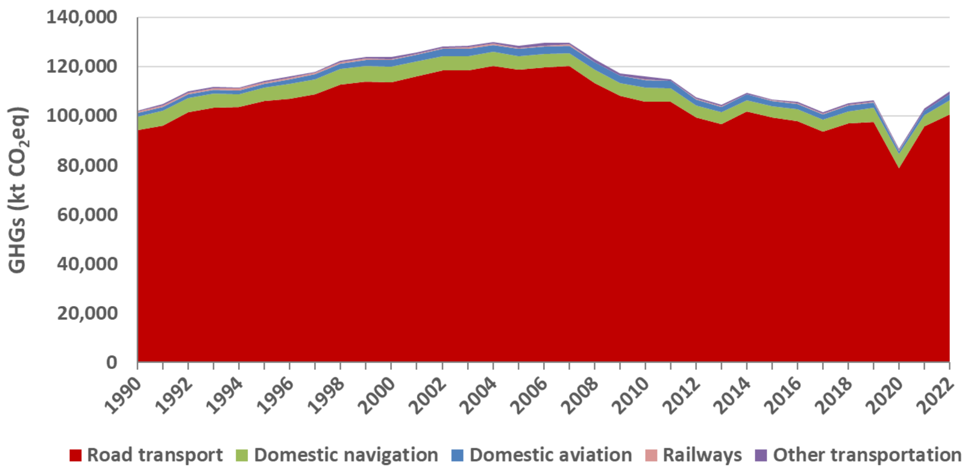
Figure 1.39 – Change since 2005 of energy and carbon intensities, and GHGs per capita for transport and households.



The relevance and complexity of transport sector deserve considering GHGs by different mobility segments, mainly for road transport. The passengers and freights mobility respond to very different driving factors. If the former segment, although not independent by country's wealth, satisfies the mobility demand without a direct link to economy, the freights transport is directly driven by economy. So, GHGs per capita indicator from freights' transport provides only limited information about the performance of segment, better described by the GDP driver. Considering the multiple sources of transport, it will be useful a focus on GHGs from such sector.

As shown in Figure 1.40, the GHGs from road transport represent almost the totality of the sector's GHGs (the average share since 1990 is 92.2%), followed by domestic navigation (4.8%), and domestic aviation (2%). The carbon intensity has been calculated only for the main source. Since 2005, when the peak of transport GHGs was reached, the road transport reduced the emissions by 15.3% even though the 2022 level is still over the 1990 level (+6.8%) and 2.9% over the pre-pandemic level of 2019.

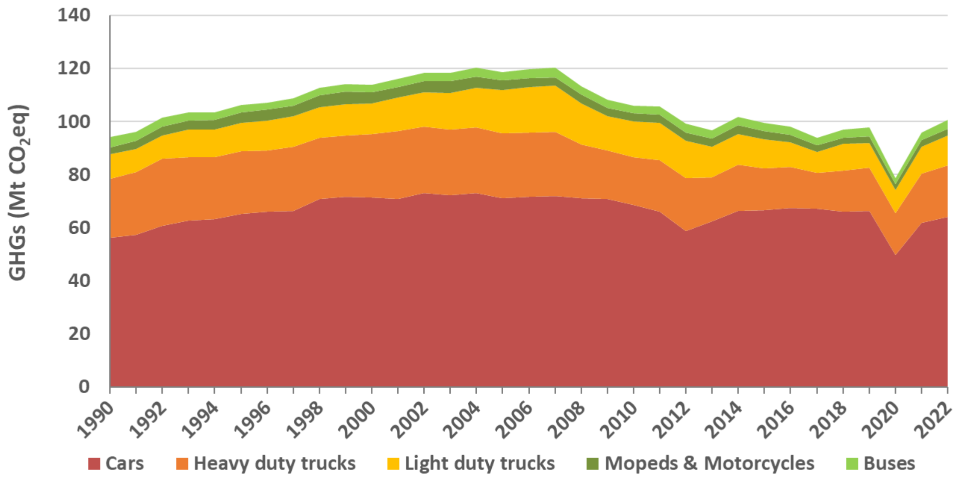
Figure 1.40 – GHGs from transport.



The road transport can be split into its components, according to the type of transport and vehicles. The mobility on cars produces about 63% of GHGs from road transport, heavy duty trucks around 20%, light duty trucks 11%, and mopeds & motorcycles (L-category) 3%, as well as buses. All categories reduced the GHGs since 2005, even though cars and light duty trucks are still over 1990 levels, respectively +14.6% and +23.9%. GHGs from cars decreased by 9.7% since 2005. Light duty trucks' emissions decreased by 30.6%, while heavy duty trucks decreased by 21.9%. GHGs from mopeds & motorcycles decreased by

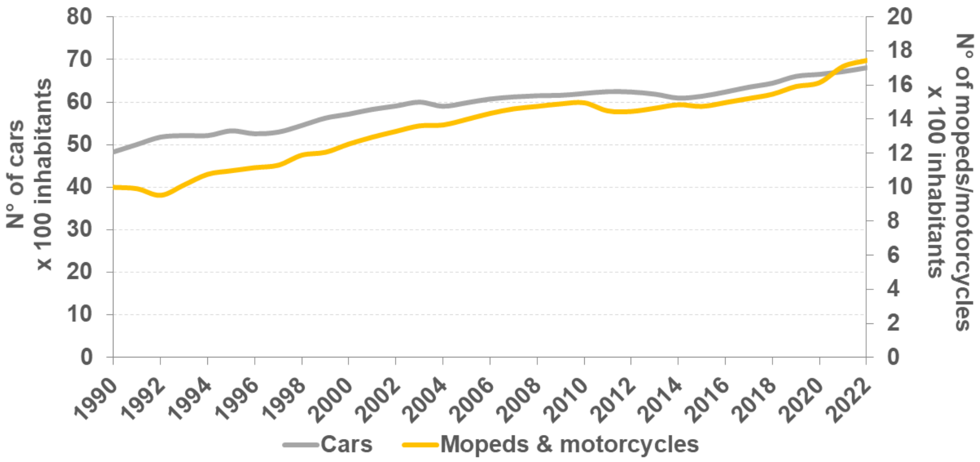
29.2%. GHGs from buses decreased since 1990 (-14.9%) but increased since 2005 (-7%). The comparison between the emissions before and after 2020 shows that the 2022 levels for cars and L-category vehicles are respectively 3.1% and 0.7% below the 2019 levels, while all other vehicles are over the 2019 levels (light duty trucks, +22.3%; heavy duty trucks, +16.7%; buses, +4.3%).

Figure 1.41 – GHGs from road transport.



The number of cars per 100 inhabitants increased by 40.9% since 1990 (+13.7% since 2005), while L-category vehicles increased by 74.8% since 1990 (+24.8 since 2005).

Figure 1.42 – Number of vehicles per 100 inhabitants.



GHGs per capita by cars are about 20 times higher than those by L-category vehicles. The emissions per capita by L-category vehicles decreased by 5.7% since 1990 and 30.6% since 2005. The trend is significantly decreasing since 1990 only for L-category vehicles, while for the other vehicles the emissions per capita decreased significantly only since 2005, even though the observed increase in the last years for buses weaken the significance of Mann-Kendall test.

Figure 1.43 – GHGs per capita for cars, buses, and mopeds & motorcycles.

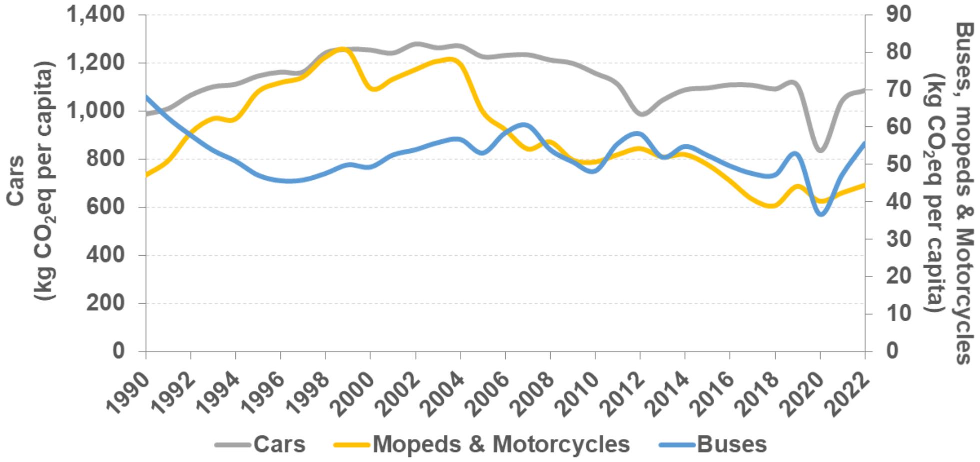
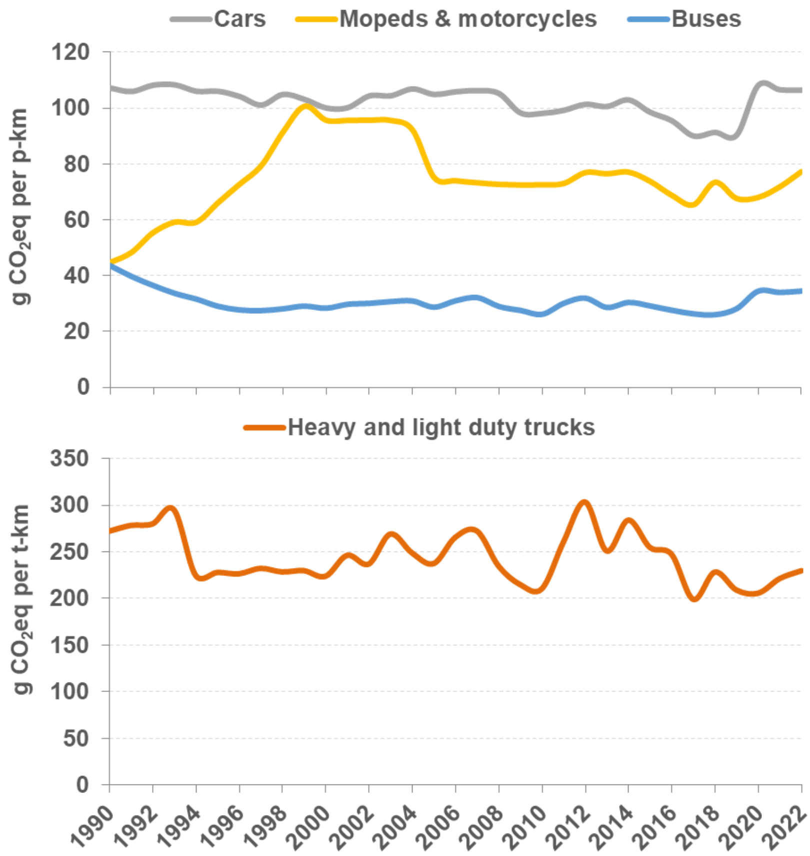


Figure 1.44 shows that the intensity of mobility with cars or L-category vehicles are much higher than mobility with buses and the mobility with car has the highest intensity. GHGs per p-km of cars in 2022 is only 0.7% below the 1990 level and 1.4% over 2005 level. The GHGs per p-km of the other segments of passenger transport in 2022 are over the 2005 level (+2.8% mopeds & motorcycles; +20.4% buses), while compared to 1990 level the intensities are 73.2% over for L-category vehicles and 21.1% below for buses.

As concerns the freight transport, up to 2012 the GHGs per t-km fluctuate around an average value, while after 2012 there is a downward trend which is not without wide oscillations. The 2022 level is 15.6% below the 1990 level and 3.2% below the 2005 level, showing slight improvement of the performances of road freight transport.

Figure 1.44 – GHGs per passenger-km and per t-km.



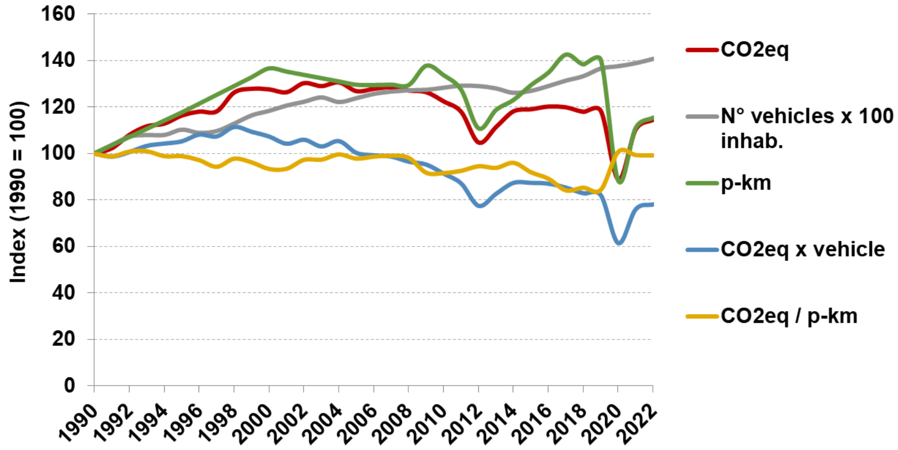
Just to complete the picture of transport sector, also GHGs per passenger-km for the other transport items have been elaborated. As shown in Table 1.13 navigation is the more carbon intensive transport, whereas mobility on railways is the lowest one.

Table 1.13 – GHGs per passenger-km (g CO_2eq/p-km); transport items in decreasing order of 2022 data.

Source	1990	1995	2000	2005	2010	2015	2020	2021	2022	Δ% 1990-2022
Domestic navigation	1920.0	1963.4	1566.6	1529.1	1412.5	1252.5	2004.1	1495.0	1548.2	-19.4%
Domestic aviation	234.6	225.3	263.8	223.4	189.6	122.7	200.9	187.9	134.2	-42.8%
Cars	107.1	106.0	100.0	104.9	98.1	98.5	108.0	106.5	106.4	-0.7%
Mopeds & motorcycles	44.5	66.0	95.6	75.0	72.4	73.7	67.9	71.7	77.2	73.2%
Buses	43.8	29.0	28.3	28.7	26.1	29.2	34.5	34.0	34.5	-21.1%
Railways	14.2	14.2	9.6	6.7	4.6	1.5	6.6	4.6	0.8	-94.0%

A summary for cars is provided in Figure 1.45 with indexed indicators showing that the technology improvement to reduce GHGs per vehicles is more than offset by the increasing number of vehicles. Moreover, total GHG emissions follow the mobility demand (p-km) which reached the top in 2017 (+42.5% compared to 1990); after the shock of 2020 there was a recovery of mobility demand, which is about 13% over the 1990 level. The vehicles which can drag downward the GHGs, as BEV and PHEV, still represent a marginal share of the mobility demand by vehicle (vehicle-km), around 0.3% and 1.3% respectively in 2022.

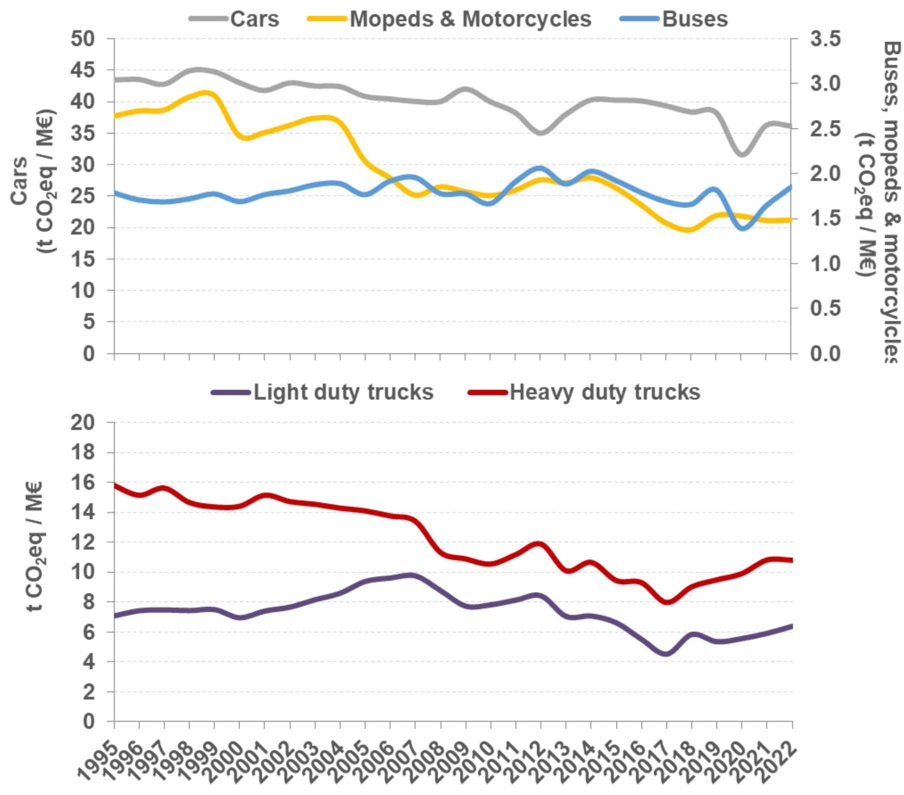
Figure 1.45 – Indexed indicators for cars.



The responsiveness to GDP of GHGs for passenger and freight mobility is shown in Figure 1.46 for the road transport items. Except for buses the carbon intensity by GDP recorded downward trend in all other mobility segments considered, even though the light duty trucks effectively reduce the intensity only since 2007. The carbon intensity of cars decreased by 16.7% since 1995, while for L-category vehicles the decrease is 43.7%. As for freights transport, heavy duty trucks reduced the intensity by 31.7%, while light duty trucks by 9.8% (34.6% since 2007). It is notable the parallel increase recorded for both trucks since 2017: +35.6% for heavy duty truck and +41.3% for light duty trucks.

All the segments, except buses, significantly decreased the carbon intensity by GDP since 1995 ($p<0.001$ for cars, L-category, heavy duty trucks; $p<0.05$ for light duty trucks), as well since 2005 ($p<0.01$).

Figure 1.46 – GHGs per GDP by vehicle categories.



1.2.2 Kaya identity and decomposition analysis

Decomposition analysis is a technique for studying the variation of an indicator in each time interval in relation to the variation of its determinants. In other words, the variation of a parameter is decomposed in the variation of the driving parameters. The starting point of the analysis is the construction of an identity equation, where the variable whose variation over time is to be studied is represented as the product of components considered as the causes of the observed variation. In the identity equation the examined variable is indicated as a product of the driving factors, expressed as ratios where the denominator of a factor is the numerator of the next one. This identity, called Kaya by the economist Yoichi Kaya, is provided *a priori,* and must be realized according to a conceptual model consistent with the physical constraints of the studied variable, in addition to the considerations related to the availability of data and the objectives of the analysis.

GHG emissions are decomposed in six driving factors: 1) population; 2) economic growth per capita; 3) efficiency; 4) renewable energy deployment; 5) carbon intensity from fossil fuels; 6) final energy intensity.

The analysis of decomposition makes it possible to evaluate the contribution of each determining factor. Identity is expressed in logarithmic form:

$$ln\left(CO_{2eq}\right) = ln(POP)\ x\ ln\left(\frac{GDP}{POP}\right)\ x\ ln\left(\frac{GIC}{FEC}\right)\ x\ ln\left(\frac{FFC}{CIL}\right)\ x\ ln\left(\frac{CO_{2eq}}{FFC}\right)\ x\ ln\left(\frac{FEC}{GDP}\right)$$

where:

CO_2eq: GHG emissions;

POP: population;

GDP/POP: Gross domestic product per capita – economy;

GIC/FEC: ratio between gross inland energy consumption and final energy consumption (included non-energy uses) - efficiency;

FFC/GIC: ratio between fossil energy consumption and gross inland energy consumption – renewable;

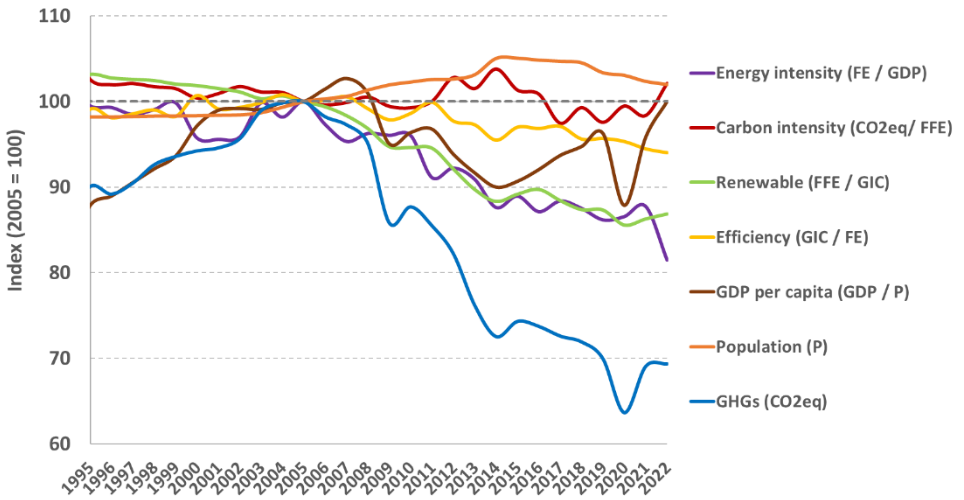
CO_2eq/FFC: ratio between CO_2eq emissions and fossil energy consumption – fossil fuel carbon intensity;

FEC/GDP: ratio between final energy consumption and gross inland consumption – final energy intensity.

The equation therefore allows to assess the effect of population, economic growth, efficiency, renewables, fossil fuel carbon intensity and energy intensity.

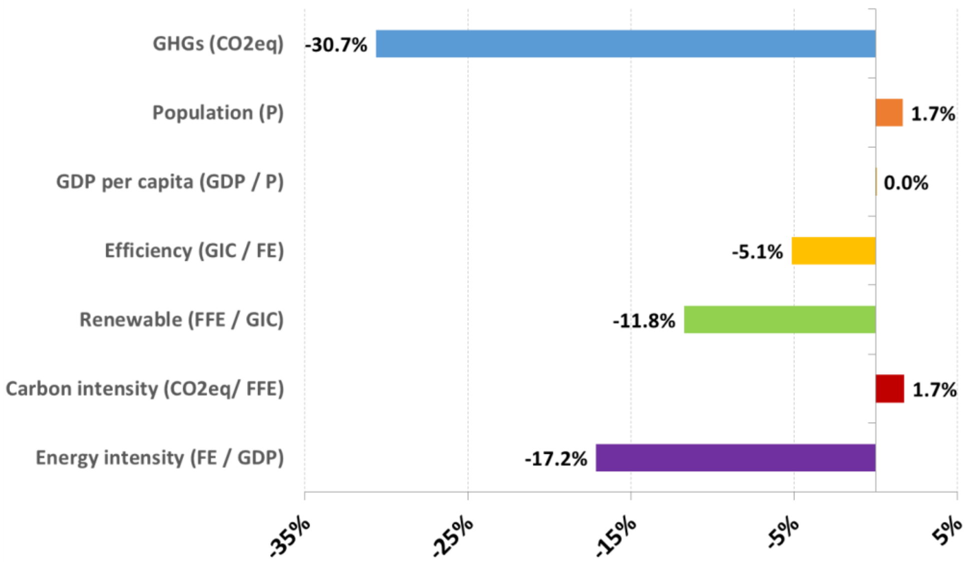
The trend of the Kaya Identity parameters in the period 1995-2022 is shown in Figure 1.47, with normalized values to 2005. The reduction of emissions since 2005 is determined by factors such as energy intensity, renewable sources, GDP per capita, efficiency. Carbon intensity and population are the only factor driving an increase in emissions in 2022 compared to 2005. GHGs reduction in 2020 has been mainly driven by economy contraction.

Figure 1.47 – Performance of the national parameters of the Kaya Identity. Normalised values for 2005.



The outcomes of decomposition analysis, carried out according *Logarithmic mean Divisia index* (Ang, 2005), shows that the effect of the factors that led to a reduction of emissions in the period 2005-2022 prevailed over the effect of the factors that led to an increase of emissions. The population and carbon intensity are the only driving factors that have contributed to the growth of emissions (both with +1.7%). The remaining factors have led to a reduction of emissions. The final energy intensity (final energy consumption / GDP) played the main role (-17.2%) followed by the share of renewable energy (fossil energy consumption / gross inland energy consumption; -11.8%) and the efficiency factor (gross inland consumption / final energy consumption; -3.9%). GDP per capita does not play any role in the period considered, because the GDP per capita in 2022 is quite the same as in 2005. The overall contribution of each factor leads to -30.7% of GHGs over the period 2005-2022.

Figure 1.48 – Decomposition of the change in GHGs emissions from 2005 to 2022.



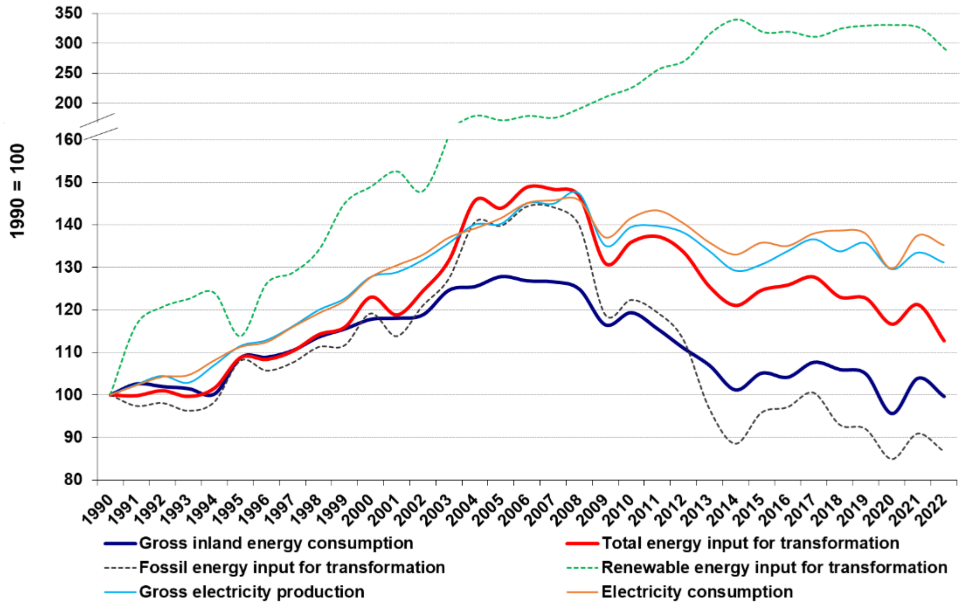
1.3 Power sector

The approach followed to estimate the GHGs in power sector is the same required to elaborate the national inventory reports of GHGs under the UNFCCC frame. GHGs in the power sector fall in the 1.A category of CRF (*Common Reporting Format*). Only emissions from fuel combustion occurring in the national territory have been considered. The generation of electricity imported does not provide GHGs in the importing country. As for the combustion of bioenergy, it is considered a net zero CO_2 emitting process; only CH_4 and N_2O are accounted.

1.3.1 Thermoelectric and renewable electricity production

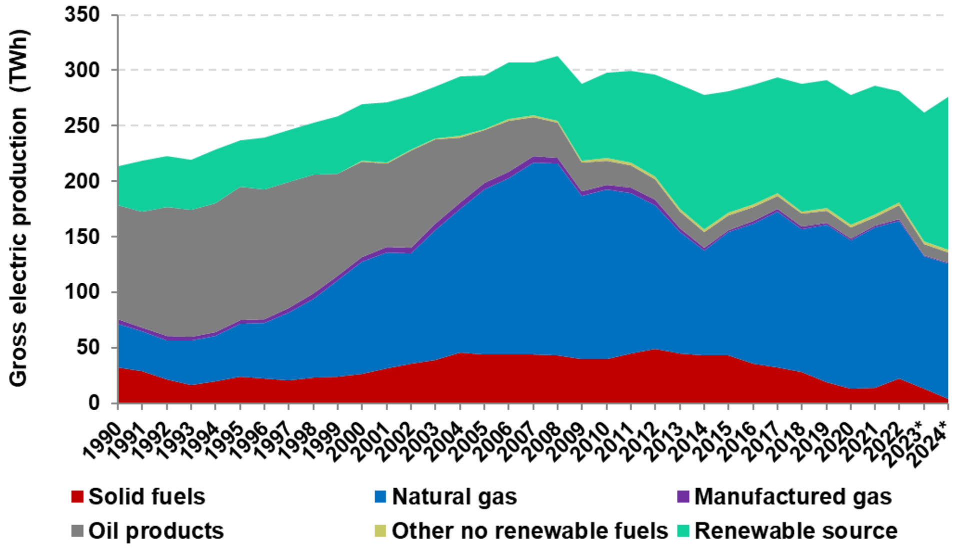
The growth of electricity consumption in the final energy consumptions makes this sector one of the main players in the national energy system. Since 2001 the energy consumption for electricity generation has increased at higher rates than gross inland energy consumption. The growth of consumption of renewable energy corresponds to the decrease of fossil energy.

Figure 1.49 – Indexed trends for gross inland energy consumption, energy consumption in the power sector to produce electricity and heat, electricity production and electricity.



Gross electricity production rose from 216.6 TWh to 284 TWh from 1990 to 2022 (+31.1%). Electricity consumption increased from 218.8 TWh to 295.9 TWh over the same period (+35.2%). After a constant growth of gross electricity production and consumption, since 2007 there has been a downward trend because of the economic crisis. A further downfall of electricity production and consumption occurred in 2020 due to lockdown measures to stop the SARS-CoV-2 pandemic. In 2021 both production and consumption of electricity recovered. In 2022 the level of production was only 1.2% higher than 2020 level, while consumption was 4.2% higher, pushed by net import of electricity whose share in 2022, as well as in 2021, was over 14% of electricity consumption (14.2% and 14.5%, respectively in 2021 and 2022). The average share of net import of electricity since 1990 is around 15% of electricity consumption with wide fluctuations and a sensible reduction from 2018 (14.5%) to 2020 (11.3%). Preliminary data of 2023 show that the import share should increase around 18%, while national gross production and consumptions fall respectively by 6.9% and 3.3%, compared to 2022.

Figure 1.50 – Gross electricity production by energy source.

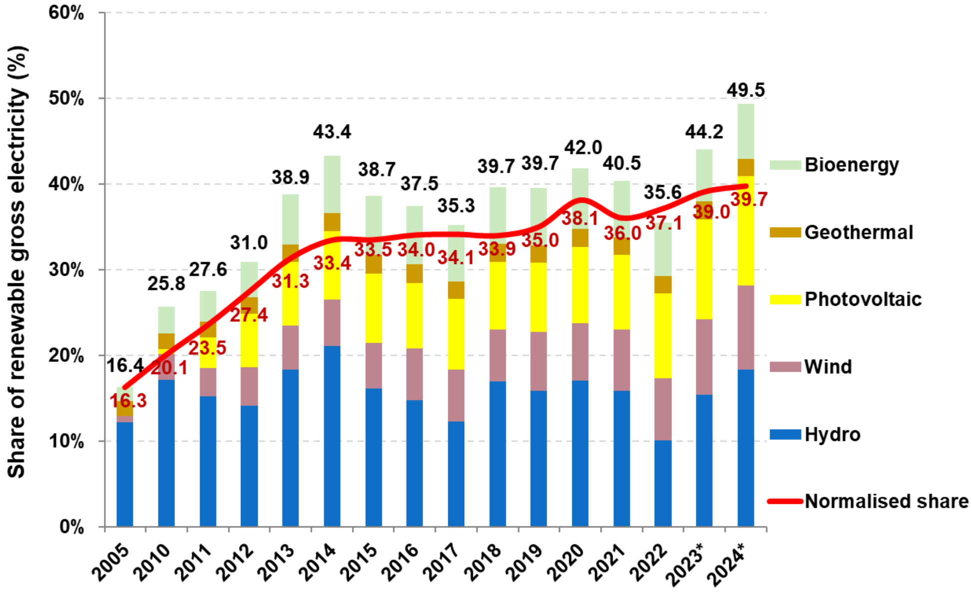


* Preliminary data.

As regards the energy mix in power sector, natural gas increased steadily its role since 1990 at the expense of oil products (49.8% of electricity production from natural gas and about 4.5% from petroleum products in 2022, while in 1990 the two percentages were 18.3% and 47.4%, respectively). However, in 2022 an unprecedented increase of electricity production share from petroleum product compared to the previous year has been recorded, from 2.7% to 4.5%. Solid fuels share showed a relevant increase in the last year passing from 4.9% in 2021 to 8% in 2022, the first annual increase after the steady decrease recorded since 2012 when the share reached the top of time series with 16.4%. The increase of oil products and solid fuels in 2022 should be read in the frame of Russian-Ukrainian war and the need to reduce the import of natural gas from Russia. Preliminary data for 2023 show a downward trend of natural gas share (around 45%) and a consistent decrease of solid fuels (around 5%), while petroleum products share should decrease (around 4%).

In 2005 the share of electricity from renewable sources accounted for only 16.4% of national production without production from pumped storage units. After 2007, renewable sources share skyrocketed significantly up to 2014, when the share reached 43.4%. In 2022 the renewable share in electricity production is 35.6%, much below the level of the previous year (40.5%) due to the drastic fall of electricity from hydropower. Preliminary data for 2023 show a recovery of renewable production whose share on national electricity production should reach a new top, around 44%, higher than that achieved in 2014. The early data for 2024 show a massive increase of hydro and photovoltaic which should lead the share of renewable over the level of 2023, about 50%.

Figure 1.51 – Share of renewable gross electricity production by energy source (black labels) and normalised share (red line and labels) according to Directive 2009/28/EC until 2020 and Directive (EU) 2018/2001 from 2021.



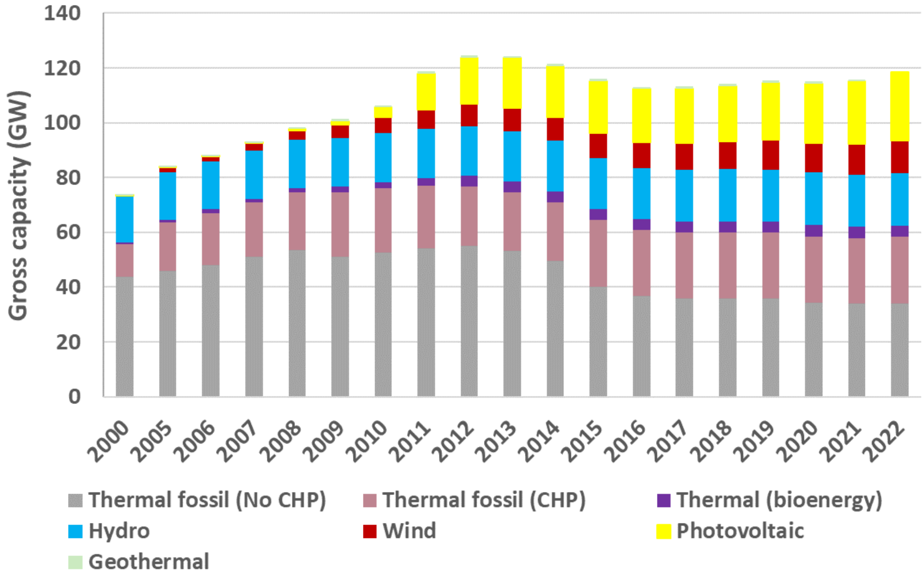
* Preliminary data.

According to methodology to monitor the European 2020 targets (Directive 2009/28/EC), the share of electricity from renewable sources compared to final gross consumption of electricity was 38.1% in 2020. In 2022 the share, calculated according to Directive (EU) 2018/2001, was 37.1%. Preliminary data for 2023 set the share around 39%, with further increase in 2024, around 40%.

1.3.1.1 Power capacity

Total thermal power in 2022 is 62.4 GW with a sharp contraction since 2012, when the installed capacity reached the peak of 80.6 GW. Combined cycle plants, regardless of cogeneration or only electricity production, show a significant increase in gross efficient power, from 7.9 GW in 2000 to a maximum of 43.4 GW in 2011-2012. Subsequently, these plants show a steady reduction up to 40.5 GW in 2022 but whereas the cogeneration power increased by 13.1% since 2012, the non-cogeneration plants decreased by 37.2% showing that almost all the new plants are CHP.

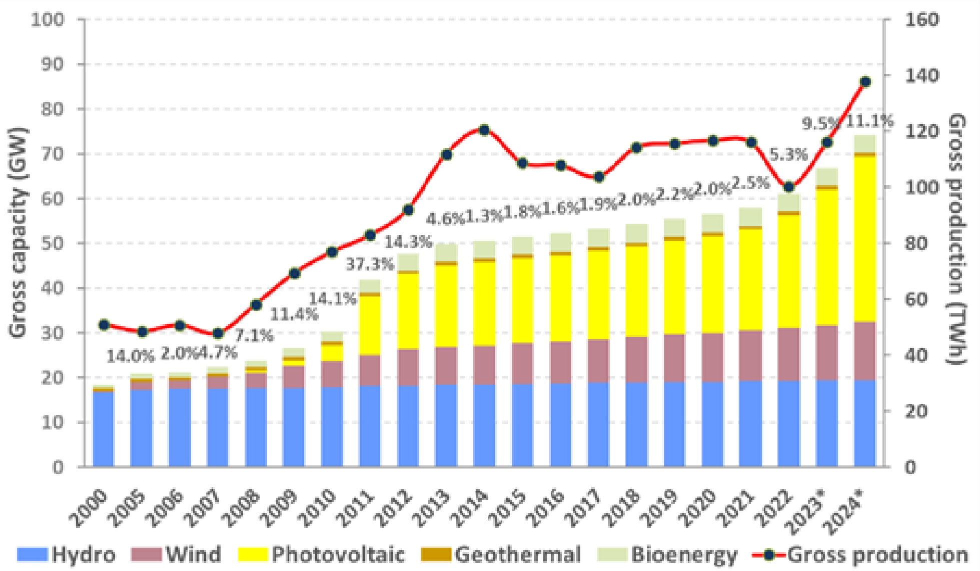
Figure 1.52 – Gross efficient capacity of power plants.



As for renewable power, a significant increase occurred since 2000. In 2022 the renewable gross efficient power was 61.1 GW. The highest annual growth rate was recorded in 2011 when the new power compared to the previous year was 11.3 GW, of which 9.5 GW of PV plants and 1.1 GW of wind plants. After 2014 the additional new power per year was around 1 GW up to 2021. The additional power in 2022 was 3.1 GW, of which 2.5 GW of PV plants. The total PV and wind power in 2022 are 25.1 GW and 11.9, respectively.

Preliminary data by TERNA show a further increase of new power over 5 GW in 2023, most by photovoltaic installations whose power is about 30 GW. Also considering preliminary data on installations of new PV plants up to July 2024 and estimating a comparable rate of new plants for rest of the year, the PV power should rise near 37 GW, while wind power should be almost 13 GW. Total renewable power in 2024 should be about 74 GW.

Figure 1.53 – Gross efficient capacity of plants from renewable sources (left axis) and gross electricity production (red line, right axis). The percentage increase in power compared to the previous year is also reported.



* Preliminary data.

About plants powered by bioenergy, it should be emphasized the rapid increase from 2008 to 2013 and the subsequent stabilization of gross efficient power with new installations of few MWs per year up to 2018 and a decrease in the last years. Plants fuelled by biogas went from 0.37 GW in 2008 to 1.46 GW in 2022. The growth of plants fed with liquid biofuels in the period 2008-2013 is particularly rapid, from 0.12 GW to 1.04 GW, then it is reduced to 0.94 GW in 2022. Plants fuelled by solid biomass and waste increased from 1.07 GW in 2008 to 1.73 GW in 2018. Since 2018 the power shows a downward trend. In 2022 the total power is 1.65 GW, of which 0.87 powered by wastes. Such trends can be explained by the reduction of incentives for bioenergy powered plants. The future development of such plants does not seem independent of some forms of subsidies.

The efficiency of power plants has been calculated from data issued by TERNA on fuel consumption and energy (electricity and heat) production. The amount of fuel used for electricity generation in CHP plants can be calculated by separating the share allocated to heat generation. The unbundling of fuels is processed by TERNA considering the consumption of an equivalent boiler that generates heat separately with an average efficiency that varies from year to year. For thermoelectric power plants and cogeneration plants, the total efficiency, electrical efficiency, and equivalent electrical efficiency are therefore calculated according to the following equations.

Total efficiency (εt) and electrical efficiency (εel) for all power plants and for CHP plants have been calculated with the following equations:

$$\varepsilon t = (H + E) / F$$

$$\varepsilon el = E / F$$

where H is the heat, E the electricity, and F the energy in the fuels.

The equivalent electrical efficiency, $\varepsilon' el$, is calculated with the equation:

$$\varepsilon' el = E / Fe$$

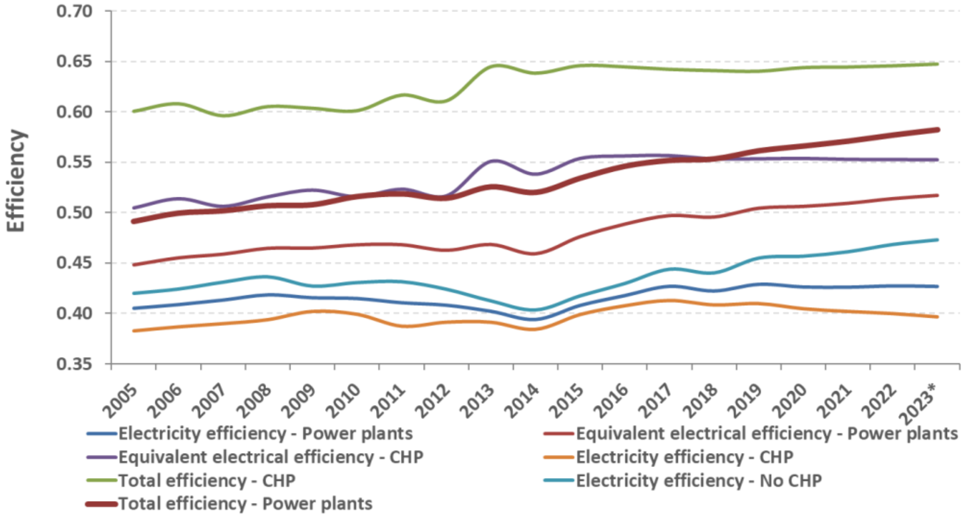
where Fe is the energy in the fuels used for the electricity production, calculated with the equation:

$$Fe = F - (Q / \eta t)$$

where Q is the heat produced and ηt is the reference thermal efficiency for a standard boiler. The average reference thermal efficiency calculated in 2022 is 0.888.

The efficiency of the thermoelectric plants has increased since 2005 mainly due to the contribution of cogeneration plants with greater efficiency than non-cogeneration plants. In 2022 the electrical efficiency of non-cogeneration plants was 46.8% while for cogeneration plants there was a total efficiency of 64.6% and an equivalent electrical efficiency of 55.3%. The total efficiency of the power plants is 57.7% with a steady upward trend since 2005.

Figure 1.54 – Efficiency of power plants.



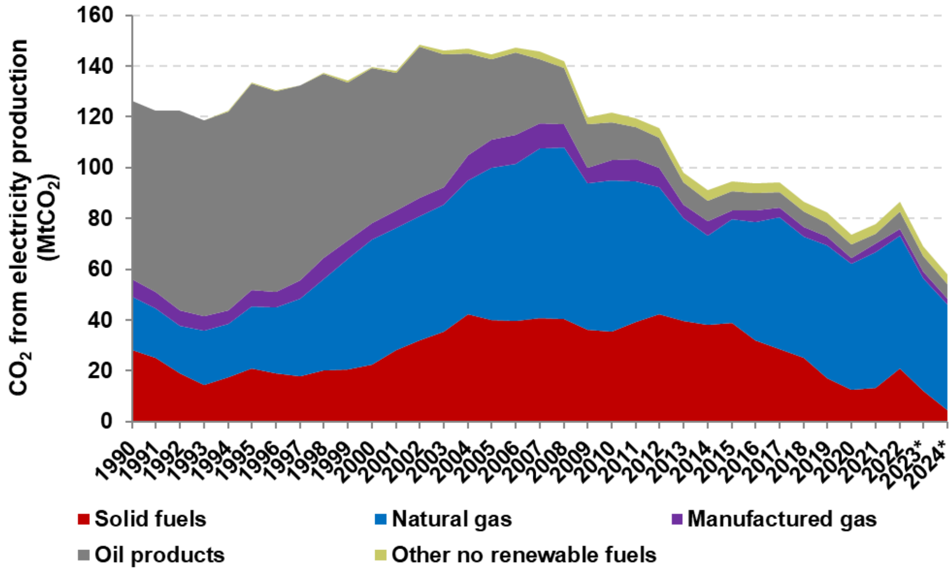
* Preliminary data.

1.3.2 CO_2 emissions and emission factors

The amount of CO_2 from power sector in 2022 was 99.4 Mt (of which 86.7 Mt for electricity generation and 12.7 Mt for heat production), around 24% of national GHGs.

Until the first half of the 1990s, CO_2 emissions from oil & oil products accounted for a significant share of total emissions from power sector. In 1995, the share of emissions from such fuels amounted to 61% of emissions. Later the share of CO_2 from these sources decreased up to 6.4% in 2021, while there has been an increase to 9.6% in 2022, as already seen for the electricity generation by source. Taking fuel oil alone, the CO_2 emissions decreased from 61% to 2.2% from 1995 to 2022, with a new increase in 2022 compared to the previous year, after the first one recorded in 2021 since many years of steady decrease. The share of natural gas emissions increased from 18.5% in 1995 to 61.4% in 2022, with a sensible decrease compared to 2021 (69.9%). The share of emissions from solid fuels, mainly bituminous coal, increased constantly up to 2014, when peaked to 37.2%, but in the following years was recorded a sharp reduction up to 14.5% in 2020 and 2021. A surge of solid fuels share has been recorded in 2022 (21.2%). The preliminary estimates for 2023 show that the share of emissions by solid fuels should decrease around 16%, while the share by oil product should slightly increase around 9.7%. As for emissions by natural gas, the share should slightly increase compared to 2022 (around 66%) but remaining below the highest level recorded in 2021. A further fall of CO_2 by power sector should be recorded in 2024 (about -9%), with a share of electricity generation by fossil fuels reaching the lowest value ever recorded (around 50%).

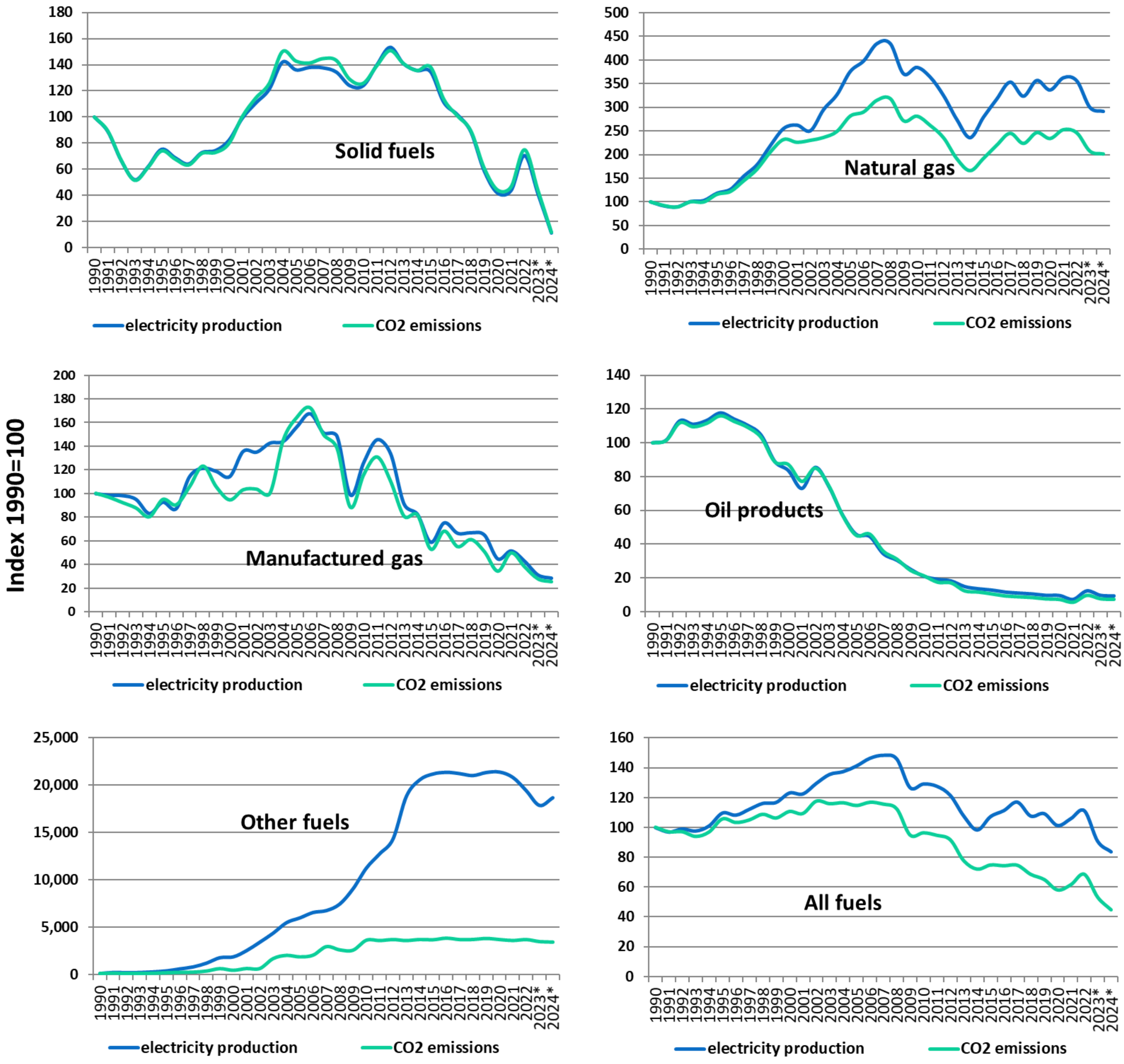
Figure 1.55 – Share of CO_2 emissions from power sector for by energy source.



* Preliminary data.

A relevant decoupling is recorded between electricity production and CO_2 emissions for natural gas, while for solid fuels, petroleum products and derived gases, there is substantial covariation of the two parameters. The overall decoupling is due to increasing efficiency of power plants fuelled with natural gas and increasing share of bioenergy.

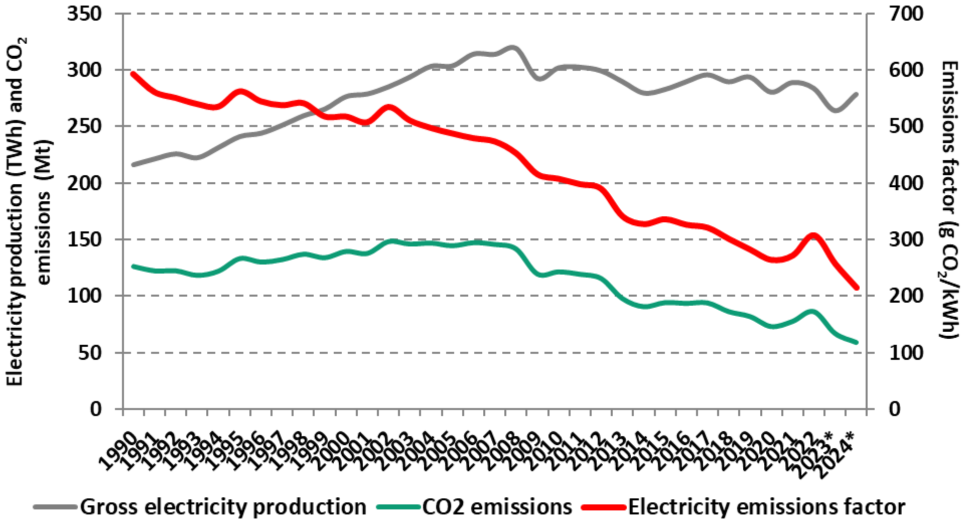
Figure 1.56 – Indexed change in thermoelectric production and CO_2 emissions per fuel (1990=100).



* Preliminary data.

CO_2 emissions for electricity generation reached the highest point in 2002, with an increase of 17.4% over 1990, while thermoelectric production showed an increase of 30.1% over the same period. Emissions fell slightly from 2002 to 2008. After 2008 there has been a significant reduction of electricity generation and CO_2 emissions because of the contraction of the economy triggered by the economic crisis. After 2014 is observed a recovery in electricity production with a sharp fall in 2020 because of the SARS-CoV-2 pandemic and a rebound in 2021 followed by further decrease in 2022. Since 1990 emissions for electricity generation decreased by 31.4% in 2022, compared with an increase in electricity production of 31.1%.

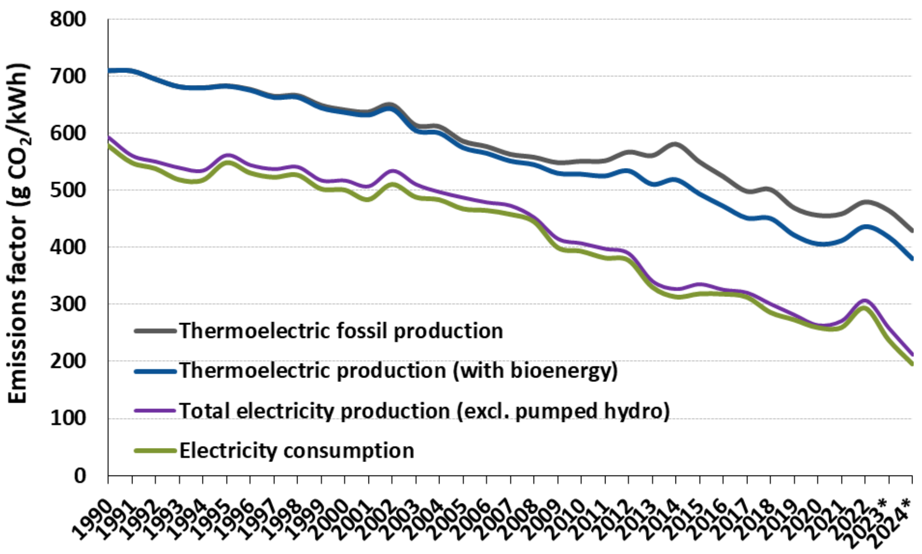
Figure 1.57 – Trends of gross electricity production, CO_2 emissions (left axis), and emissions factor (right axis).



* Preliminary data.

The emissions factor for national gross electricity generation by thermal plants decreased from 1990 to 2022 from 709 g CO_2/kWh to 436.8 g CO_2/kWh. A relevant increase of the emissions factor has been recorded in 2022 due to the increase of solid fuels and oil products in the fuel mix. The observed long-term decrease is mainly due to the increasing share of natural gas and the continuous reduction of the specific emissions factor of this fuel, which in turn is due to the increasing electrical efficiency of plants. An important role is also played by bioenergy which is considered a net zero CO_2 emitting process. Bioenergy accounts for 8.8% of electricity generation by thermal plants in 2022, lower than the shares recorded from 2014 to 2021 around 10%. The difference between the emissions factor of the thermal electricity with or without the contribution of bioenergy shows the role of such sources in reducing the emissions factor. The difference becomes relevant after 2000 because of the increase in the amount of solid biomass and municipal solid waste used for electricity production and the even greater increase in bioliquids and biogas observed after 2008. In the last years, starting from 2020, the share of bioenergy shows a downward trend.

Figure 1.58 – Trends emission factors in the power sector.



* Preliminary data.

The renewable sources reduce the emissions factor for electricity production since they have not CO_2 emissions according to the approach adopted in this report. The emissions factor for electricity consumption is further reduced because of the share of electricity imported from abroad, whose emissions are released outside the national territory. Moreover, the emissions factor for grid losses has been calculated applying the emissions factor for electricity production only to the share of electricity loss that is produced internally, since the imported share does not produce emissions.

Along with an increase of electricity production from 1990 to 2022 of 67.4 TWh, there was a decrease of CO_2 emissions of 39.7 Mt. The reduction of emissions factor for electricity generation from 2007 to 2014 was mainly due to the increase of renewable electricity production, while the decrease recorded since 2015 up to 2022 is also due to the increasing share of natural gas. The preliminary data show that in 2023 should be recorded a notable decrease of CO_2 emissions from power sector (about 78 Mt, of which 67 Mt for electricity production). A significant reduction of the emissions factor for gross electricity production is also expected following the increase of renewable production and decrease of solid fuels share. The early data on renewable electricity for 2024 allow to estimate a further decrease of the emissions factor for production and consumption (around -16% compared to the previous year).

Table 1.14 – Emissions factors in the power sector (g CO_2/kWh).

Year	Gross thermo-electricity production (only fossils)	Gross thermo-electricity production[1]	Gross electricity production[2]	Electricity consumption[3]	Grid losses[4]	Gross thermo-electricity and heat production[1,5]	Gross electricity and heat production[2,5]	Heat production[5]
1990	709.2	709.0	593.0	577.8	505.6	709.0	593.0	
1995	681.5	681.7	562.2	548.1	481.6	681.7	562.2	
2000	638.1	636.0	517.6	500.2	440.7	636.0	517.6	
2005	583.1	574.5	487.6	467.2	415.1	516.5	450.4	244.4
2010	548.7	528.1	407.4	392.8	352.9	473.3	382.3	249.0
2015	547.6	493.8	335.8	318.2	286.7	429.5	316.0	221.7
2016	521.7	472.4	326.0	317.6	287.6	413.9	308.1	223.6
2017	496.1	451.6	320.8	312.4	283.0	398.9	303.2	218.8
2018	499.3	450.9	300.8	285.5	259.7	394.7	285.8	213.4
2019	467.3	422.0	281.9	272.8	248.3	373.5	270.7	216.4
2020	454.4	406.3	263.7	258.8	235.5	359.1	255.2	215.0
2021	456.8	412.1	271.6	259.0	235.3	365.7	261.9	213.7
2022	477.4	436.8	307.4	293.1	265.4	389.5	293.4	223.9
*2023**	*460.0*	*416.3*	*256.6*	*235.6*	*213.4*	*369.4*	*250.3*	*217.4*

[1] Included electricity by bioenergy.

[2] Included renewable electricity, without production from pumped storage units.

[3] Included grid losses and imported electricity share.

[4] Emissions factor for electricity grid losses applied to the share of national production.

[5] Included CO_2 emissions for heat production.

* Preliminary data.

The development of renewable sources in the electricity sector has led to a reduction of GHGs. To assess the impact of renewables, the CO_2 emissions avoided each year has been calculated. These statistics are processed by GSE (2023) both for direct emissions and LCA emissions (Life Cycle Assessment). According to the methodology adopted by GSE the avoided emissions mainly depend on the marginal fossil mix replaced by renewable sources. The methodology adopted in this work, in line with that developed by EEA (2015), refers only to direct emissions, and calculates the emissions from electricity by fossil fuels mix offsetting renewable electricity if such electricity would not be produced. Therefore, the avoided emissions are calculated multiplying the electricity from renewable sources by the annual emissions factor from fossil fuels. The assumption underlying the two methodologies is that in the absence of renewable production, the same amount of electricity must be produced from the fossil fuel mix. The two approaches provide different values of avoided emissions, but it is not the purpose of this work to compare the two methodologies, but to adopt a homogeneous method to evaluate the impact of renewable sources in the electricity sector, independent of the influence of economic and contingent factors that can modify the marginal costs of electricity.

From 1990 to 2007, the average avoided emissions in the power sector due to renewable sources changed around an average value of 30.6 Mt CO_2, in parallel with the variability observed for hydroelectric production. Later the development of non-traditional sources led to a surge of the impact with a peak recorded in 2014, when 69.8 Mt CO_2 were not emitted thanks to renewable production. In the following years there was a decrease in the yearly avoided emissions, following the decrease in electricity production from renewable. The average value from 2015 to 2021 was 55 Mt CO_2 and in 2022 the value drops to 48 Mt CO_2, because of the lack of hydropower. According to the preliminary data the avoided emissions in 2023 should come back around 53 Mt CO_2 and around 59 Mt CO_2 in 2024.

The atmospheric emissions from power sector also involves other greenhouse gases than carbon dioxide, such as methane (CH_4) and nitrous oxide (N_2O). Although methane and nitrous oxide are emitted in extremely limited quantities compared to carbon dioxide, these gases are characterized by high global warming potentials (28 for methane and 265 for nitrous oxide). Methane and nitrous oxide emissions account from 0.4% to 0.7% of total GHGs from the power sector.

The power sector is also responsible for emissions of other atmospheric pollutants such as nitrogen oxides (NO_x), sulphur oxides (SO_x), non-methane volatile organic compounds (NMVOC), carbon monoxide (CO), ammonia (NH_3) and particulate matter (PM_{10}). All pollutants considered decreased the emissions in 2022 compared to 2005 levels, from -14.1% for CO to -90.9% for SO_x. Only NMVOC increased since 2005 (+61.4%).

Table 1.15 –GHGs in the power sector for electricity and heat production (Mt CO_2eq).

Gas	2005	2010	2015	2016	2017	2018	2019	2020	2021	2022	2023*
CO_2	157.85	135.72	107.69	107.51	107.67	99.36	95.36	86.21	90.27	99.39	*78.27*
CH_4	0.18	0.19	0.25	0.26	0.26	0.25	0.25	0.24	0.24	0.23	*0.20*
N_2O	0.44	0.46	0.50	0.50	0.47	0.45	0.42	0.39	0.37	0.40	*0.33*
GHGs	**158.46**	**136.37**	**108.44**	**108.27**	**108.40**	**100.06**	**96.03**	**86.85**	**90.88**	**100.02**	***78.80***

* Preliminary data.

Table 1.16 – Emissions factors of GHGs in the power sector for electricity and heat production (g CO_2eq/kWh).

Gas	2005	2010	2015	2016	2017	2018	2019	2020	2021	2022	*2023**
CO_2	450.39	382.27	315.96	308.06	303.23	285.83	270.70	255.16	261.91	293.41	*250.35*
CH_4	0.51	0.54	0.74	0.74	0.73	0.72	0.72	0.72	0.69	0.68	*0.65*
N_2O	1.24	1.29	1.47	1.42	1.32	1.29	1.18	1.16	1.08	1.17	*1.06*
GHGs	**452.14**	**384.11**	**318.17**	**310.23**	**305.27**	**287.84**	**272.59**	**257.04**	**263.68**	**295.27**	***252.05***

* Preliminary data.

Table 1.17 – Emissions of pollutants in the power sector for electricity and heat production (kt).

Pollutant	2005	2010	2015	2016	2017	2018	2019	2020	2021	2022
NOx	129.13	102.27	86.27	82.94	80.57	75.89	74.07	67.90	68.74	70.45
SOx	183.91	78.98	32.52	25.03	22.48	20.30	16.86	14.44	13.45	16.82
COVNM	17.86	25.26	27.46	29.89	29.99	29.67	30.83	30.29	29.53	28.83
CO	36.97	35.90	32.15	33.61	34.66	32.46	33.34	31.25	32.06	31.79
NH_3	0.23	0.23	0.24	0.21	0.19	0.17	0.13	0.11	0.11	0.14
PM_{10}	5.93	2.87	1.42	1.26	1.19	1.03	0.96	0.82	0.85	0.91

Table 1.18 – Emissions factors of atmospheric pollutants in the power sector for electricity and heat production (mg/kWh).

Pollutant	2005	2010	2015	2016	2017	2018	2019	2019	2021	2022
NOx	368.44	288.07	253.12	237.66	226.91	218.32	210.27	200.97	199.45	207.97
SOx	524.75	222.46	95.41	71.72	63.31	58.41	47.86	42.73	39.03	49.64
COVNM	50.95	71.14	80.57	85.65	84.45	85.34	87.53	89.65	85.57	85.07
CO	105.49	101.12	94.32	96.30	97.61	93.37	94.63	92.50	92.44	93.74
NH_3	0.66	0.65	0.71	0.60	0.54	0.50	0.37	0.32	0.30	0.41
PM_{10}	16.91	8.07	4.17	3.60	3.36	2.97	2.71	2.43	2.47	2.69

The emission of sulphur oxides is basically due to solid fuels which in recent years have been used by high-efficiency plants equipped with emission abatement systems. Abatement systems have also contributed to a significant reduction of PM_{10} emissions, -84.6% compared to 2005.

1.3.3 Decomposition analysis

The change of GHGs from power sector is due to several factors such as electricity generation technology, the fossil fuel used, the contribution of renewable sources and electricity demand. Decomposition analysis was applied to assess the relative contribution of these components. The Statistical Institute of Germany adopted decomposition analysis to assess the driving factors of carbon dioxide emissions (Seibel, 2003).

As already seen the starting point of decomposition analysis is the construction of an identity in which the examined variable is indicated as a product of the driving factors. The identity identified in this study is as follows:

$$CO_2 = \sum_{i=1}^{n} \frac{CO_{2i}}{E.E._i} \times \frac{E.E._i}{E.E._F} \times \frac{E.E._F}{E.E._T} \times E.E._T$$

Where:

CO_{2i} is the carbon dioxide emitted by the type of fossil fuel i;

$E.E._i$ is the electricity produced by the type of fossil fuel i;

E.E.F is the electricity produced from fossil fuels;

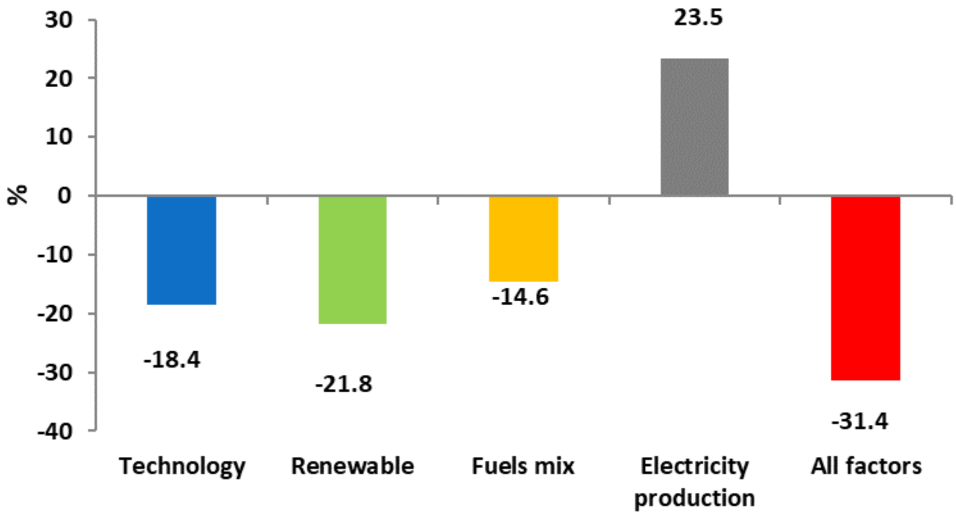
$E.E._T$ is the total electricity produced, including renewable sources.

The first factor of the equation evaluates the technological effect, in terms of the temporal variation of the emissions factors of the different types of fossil fuels. This variation is an indicator of the increase in efficiency of thermoelectric plants in the process of transformation of fossil fuels into electricity. In other words, it is assessed the effect of the variation of carbon intensity in electricity generation. The second factor considers the effect of the fuel mix, i.e., the variation in the relative frequency of different fuels with different carbon content and therefore different emissions factors. The third factor assesses the effect of electricity production from renewable sources by considering the variation in the ratio between fossil electricity and total electricity. Finally, the fourth factor considers the effect of the electricity produced.

According to the equation shown, emissions can be decomposed into different factors to evaluate the effect of the variation of one factor while leaving the other factors unchanged. In the decomposition analysis carried out, an independent contribution of the four factors to the variation of atmospheric emissions was assumed. The final effect shall be evaluated in additive terms for the factors considered. The *structural decomposition analysis* (SDA) approach has been applied (Seibel, 2003; APAT, 2007).

The driving factors considered in the analysis (technology, type of fuel, renewable sources) contribute to CO_2 emissions reduction where the increase in electricity production has the opposite effect. The results of the analysis show that technology, renewables, and fuel mix contribute to the reduction of CO_2 emissions from 1990 to 2022 respectively by 18.4%, 21.8% and 14.6%, while the increase of electricity production leads to an increase of emissions by 23.5%. The cumulative effect of the factors which reduce the emissions outweighed the production factor leading to a net reduction of CO_2 in 2022 by 31.4% compared to the value observed in 1990 (-39.7 $MtCO_2$).

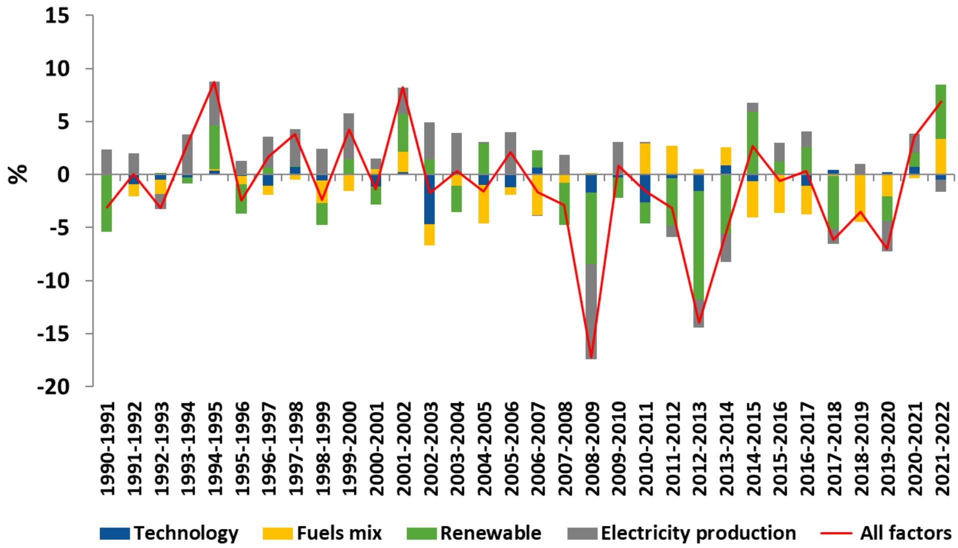
Figure 1.59 – Decomposition analysis of CO_2 emissions in the period 1990-2022 with the contribution to the emissions change for the four factors identified.



In other words, the reduction due the technological factor (decrease of the specific emission factors of fossil fuels) over the period 1990-2022 would have been 23.3 Mt CO_2 if the other factors had remained unchanged. The reduction due to the fuels mix change would have been 18.5 Mt CO_2, while the increasing renewable share would have led to a reduction in emissions of 27.6 Mt CO_2. These effects are offset by the increase of electricity production which would have resulted in an increase of emissions of 29.7 Mt CO_2 without the contribution of the other factors.

The year-by-year decomposition analysis (Figure 1.60) shows the role of each factor on a year basis. The renewable effect played the largest role from 2007 to 2014. The great variability observed for this factor reflects the uncertainty of the hydroelectricity production due to weather conditions. As concerns the technological factor the largest reduction of emissions was recorded in the period 2000-2003 when several combined cycle plants powered by synthesis gases and natural gas started the activity. Such plants are characterized by greater efficiency than traditional steam cycles. Regarding the fossil fuels shift over the whole period examined, the increase of natural gas and the corresponding decrease of petroleum products, leads to reduction in emissions in almost all years.

Figure 1.60 – Year by year decomposition analysis of CO_2 emissions in the period 1990-2022 with the contribution to the emissions change for the four factors identified.



Since 2007 the role of renewable sources became more relevant than the other factors. Moreover, it should be underlined that contingencies that depress the electricity demand, such as the economic crisis of 2008 or the pandemic in 2020, determine increasing share of renewable sources as result of the priority of dispatching renewable electricity.

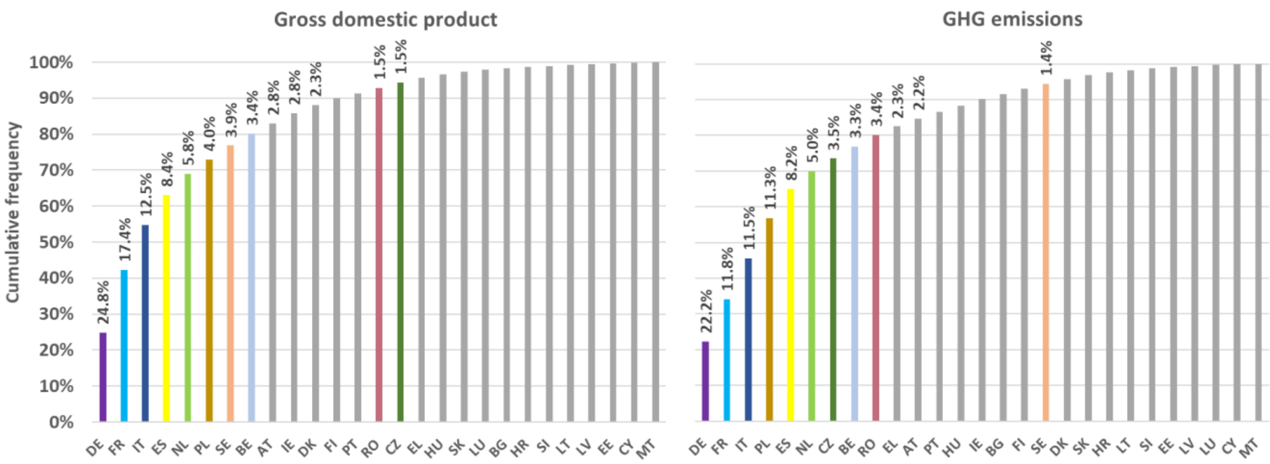
2 ITALY AND THE BIGGEST EUROPEAN COUNTRIES

This chapter will examine the trends of efficiency and decarbonization indicators in the biggest European Member States. The indicators are elaborated using data of energy balances from the Eurostat database (https://ec.europa.eu/eurostat/data/database, last update 24 May 2024). The renewable share by sector are from SHARES 2022, SHort Assessment of Renewable Energy Sources by Eurostat (https://ec.europa.eu/eurostat/web/energy/database/additional-data, last update 04 April 2024). GHG emissions submitted by EU countries to EU on 15 January 2024 are available in the Eurostat database, last update 18 April 2024. GHG emissions submitted by ISPRA to UNFCCC have been analysed for Italy. Preliminary data on electricity production by source in 2023 are available in the Eurostat database (last update 27 June 2024).

2.1 Efficiency and decarbonization indicators

Comparison of decarbonization and efficiency indicators is carried out among Italy and the EU Member States with more than 3% of EU27 GHGs or more than 3% of EU27 GDP in 2020. The Member States examined (Germany, France, Italy, Spain, Poland, the Netherlands, Belgium, Romania, Czechia, and Sweden) represented 81.5% of the population in EU27 in 2020, 81.6% of GHGs and 83.2% of GDP. The gross inland energy consumption accounted for 82.5% of the energy consumption of EU27.

Figure 2.1 – Cumulative frequencies for gross domestic product and GHGs in the EU27 countries (data 2020). Labels of selected countries or higher than 2% are reported.



2.1.1 Energy consumption and gross domestic product

Since 1990, European environmental policies have led to a significant change of the energy mix in the Member States. The nuclear energy represents 11.5% of EU27 gross inland consumption in 2022, with a sensible reduction compared to the previous year, also due to the exit from nuclear power of Germany. The nuclear share for this Country in 2022 (3.2%) is almost half the value recorded in the previous year. Fossil fuels have been grouped in macro categories (solids, oil & petroleum products, etc.; see Table 2.1). Solid fuels energy faces significant contraction in EU27 since 1990, even though in the last two years there was an increase compared to the lowest level reached in 2020 (10.8%). EU27 share in 2022 is 12.3%, while in 1990 it was 26.9%. There are still significant shares in some of the largest States, such as Germany (19.7% in 2022), Poland (40.3%), and Czechia (32.1%). Oil and petroleum products show a very modest reduction at European level (from 37.6% in 1990 to 34.9% in 2022) with different trends among the States. Natural gas energy consumption shows a considerable increase in almost all States and at EU27 level ranges from 17.1% in 1990 to 21.7% in 2022, quite lower than the share recorded in 2021 and 2020 (23.9% and 24.4%, respectively).

The share of fossil fuels in 2022 has been affected by Russian-Ukrainian war, started in February 2022, and the reduced supply of natural gas due to the sanctions on Russia established by the European Union. Renewable energy increased significantly in EU27, from 4.9% to 18.4% from 1990 to 2022.

Figure 2.2 – Trend of fuel energy share in gross inland consumption for EU27 and Italy.

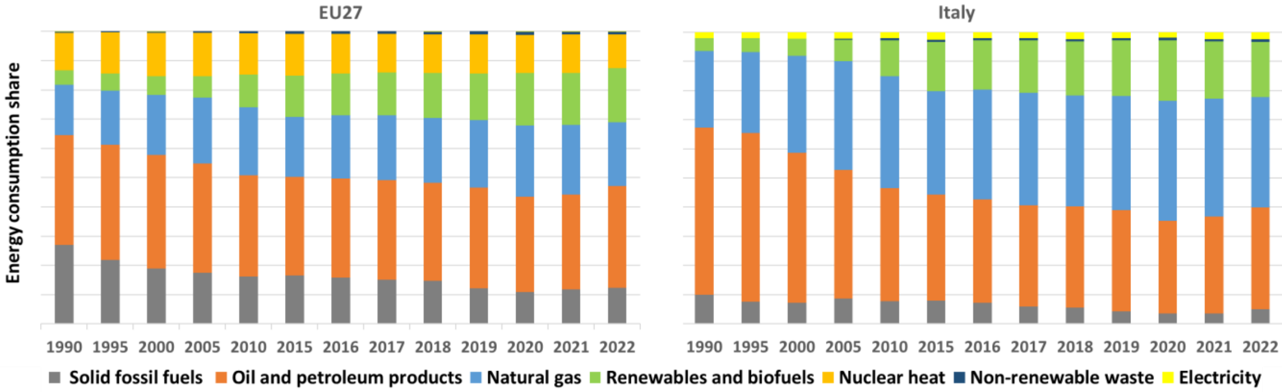
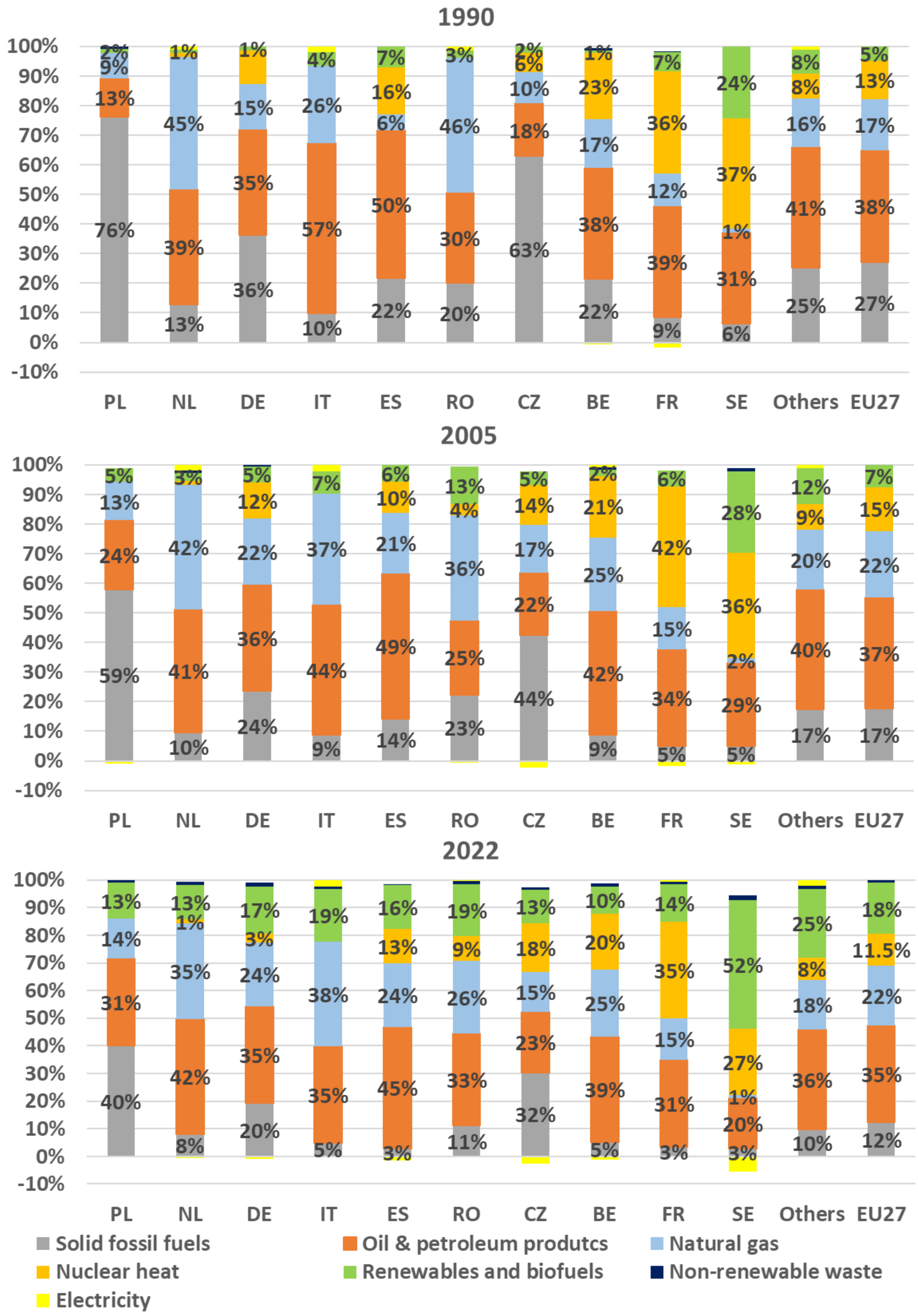


Figure 2.3 shows the fuel energy share in gross inland consumption for each country in 1990, 2005, and 2022. There is a great heterogeneity in the European countries' energy mix and a common shift toward renewable sources and fuels with lower carbon content, as natural gas.

The Italian share of solid fuels, mainly bituminous coal, decreased from 9.9% in 1990 to 5% in 2022, higher than the previous year (3.6%). On the other hand, the share of natural gas in the period 1990-2022 goes from 26.3% to 37.9%, quite below the 2021 level (40.5%). The share of oil and petroleum products goes from 57.3% to 34.8% (33.1% in 2021) and renewable share grew from 4.4% to 19%, with a decreasing trend since 2020, when the share reached its highest level (20.7%) also due to the contraction of energy demand following the pandemic. The contraction of renewables after 2020 concerned almost all European countries even though Italy recorded an extremely important fall of hydropower in 2022 which led to further reduction of renewable share. Despite all, Italy's renewable share in gross inland consumption in 2022 is one of the highest among the biggest countries, only Sweden has a share higher than Italy (Figure 2.3-2.5). However, the European target in 2030 of renewable share concerns the gross final consumption and as shown in Figure 2.15 Italy's overall share is well below the European average in 2022 (19.1% vs 23%) and behind countries as France, Germany, and Spain.

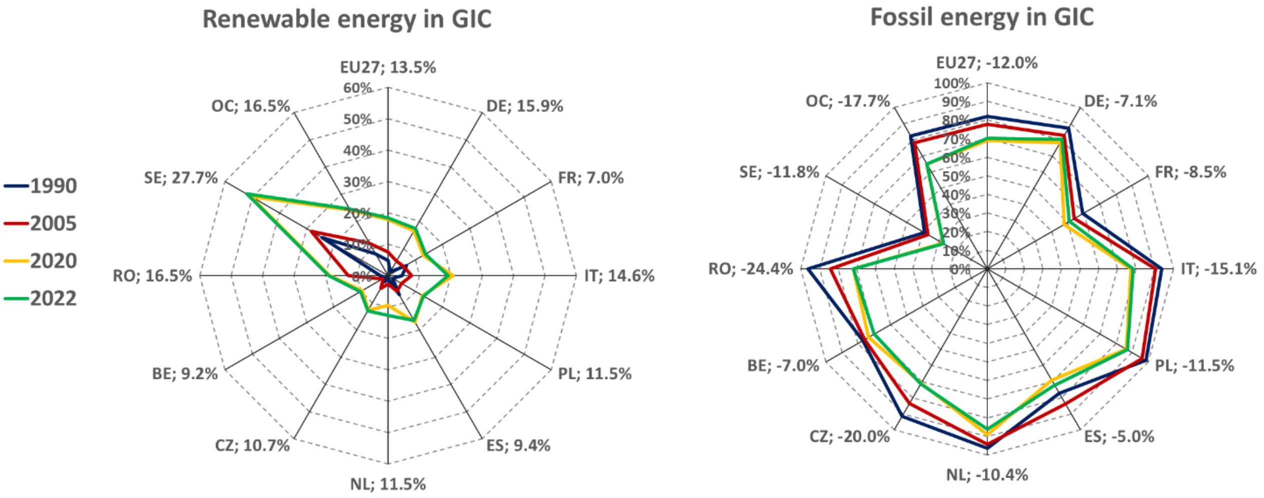
The share of fossil fuels decreased significantly in almost all European countries, although the share in 2022 slightly grew up compared to 2021. The EU27 average decreased from 82% in 1990 to 70% in 2022. Among the examined countries, the Netherlands and Poland shares are still higher than 85%, respectively 86.1% and 87.1%.

Figure 2.3 – Fuel energy share in gross inland consumption for EU27 and biggest countries in 1990, 2005, and 2022. Countries in decreasing order of 2022 fossil share (solid, liquid, and gaseous fuels).



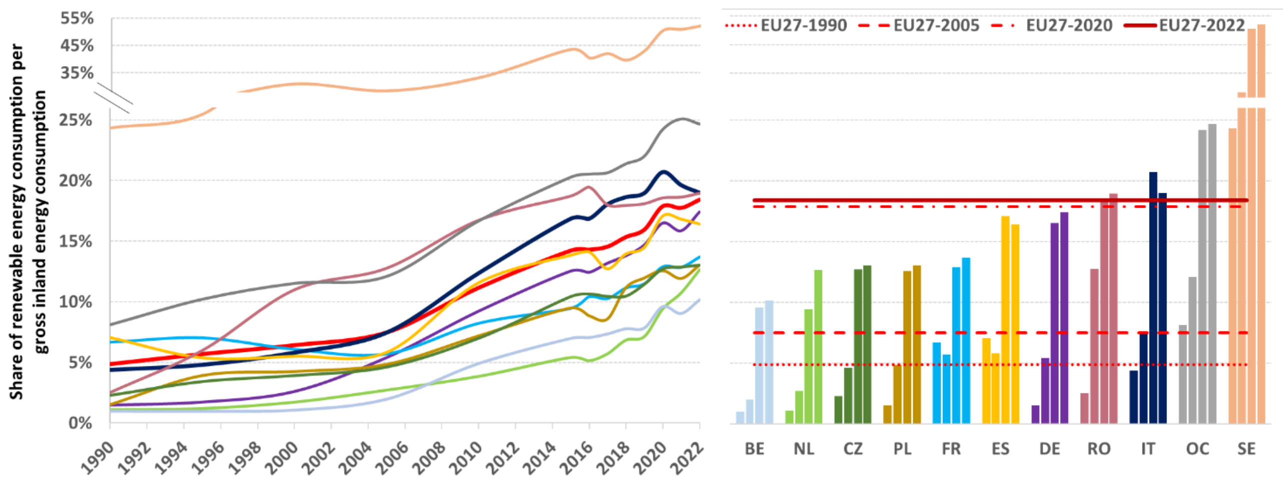
The countries' trends on the path of decarbonization of the energy mix can be summarized by the following graph showing the change of renewable and fossil shares from 1990 to 2022. The picture makes clear the widening area of renewable energy opposed to the shrinking area of fossil energy since 1990. As shown the increasing rate of renewable share and the decreasing rate for fossil share are very different for each country.

Figure 2.4 – Share of renewable and fossil energy in gross inland energy consumption. The labels show the percentage points range between the share in 2022 and 1990.



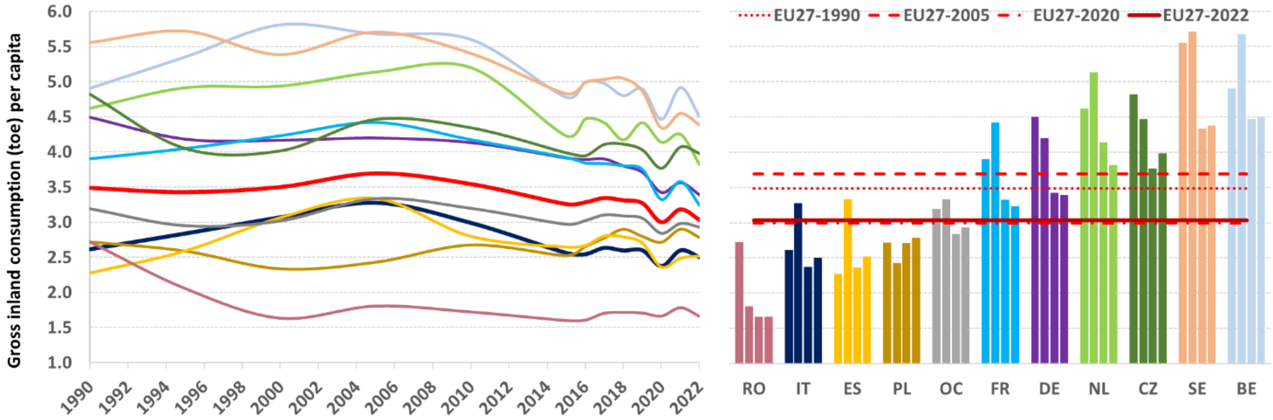
A detail for renewable sources is provided in the following graph with the trend for each examined country.

Figure 2.5 – Share of renewable energy in gross inland energy consumption. For each country the bars on the right graph refer to 1990, 2005, 2020, and 2022. Data in ascending order of 2022 value. OC – Other countries.



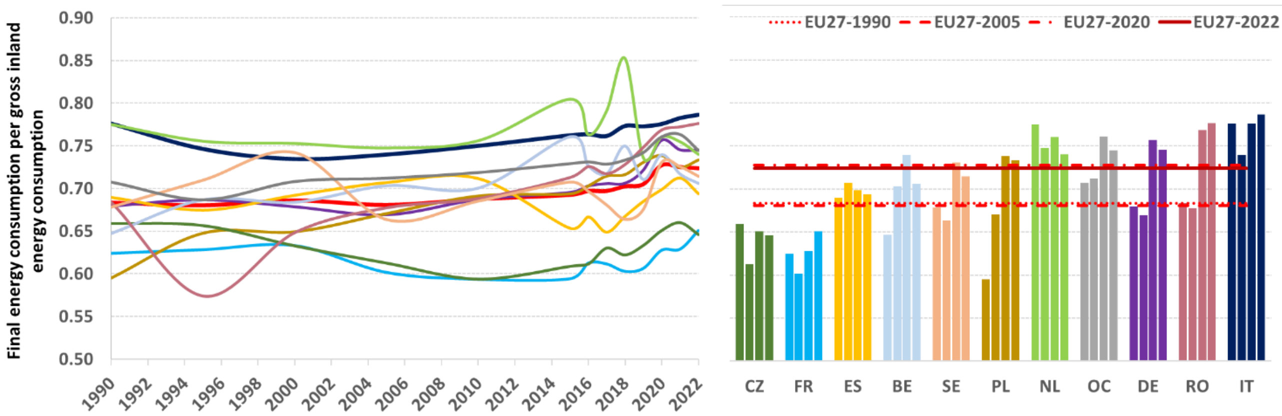
Gross inland energy consumption per capita is very different in the European countries. Italy is well below the European average (2.71 *vs* 3.33 toe per capita). The consume per capita in Italy increased from 2.61 toe in 1990 to 3.27 toe in 2005. After 2005 the consumption falls to 2.51 toe per capita in 2022, while in EU27 the consumption per capita was 3.48 in 1990, 3.69 in 2005, and 3.03 in 2022. In 2022 Italy has one of the lowest consumptions per capita among the countries examined, only Romania registered lower level: 1.66 toe per capita. Germany, France, Czechia, the Netherlands, Belgium, and Sweden have higher figures than EU27 averages. The countries' energy consumption decreased everywhere since 2005 with relevant fluctuations in the last years. In 2020 data was heavily affected by measures adopted by all countries to contain SARS-CoV-2 pandemic. France shows the highest rates of reduction from 2005 to 2022 (-26.6%), followed by the Netherlands (-25.6%), Spain (-24.5%), Italy (-23.4%), and Sweden (-23.3%) among the biggest countries. Germany reduced the consumption per capita by 19.3%. Poland is the only exception to the observed trend for the countries examined, with a 14.6% increase of energy consumption per capita from 2005 to 2022.

Figure 2.6 – Gross inland energy consumption per capita. For each country the bars on the right graph refer to 1990, 2005, 2020, and 2022. Data in ascending order of 2022 value. OC – Other countries.



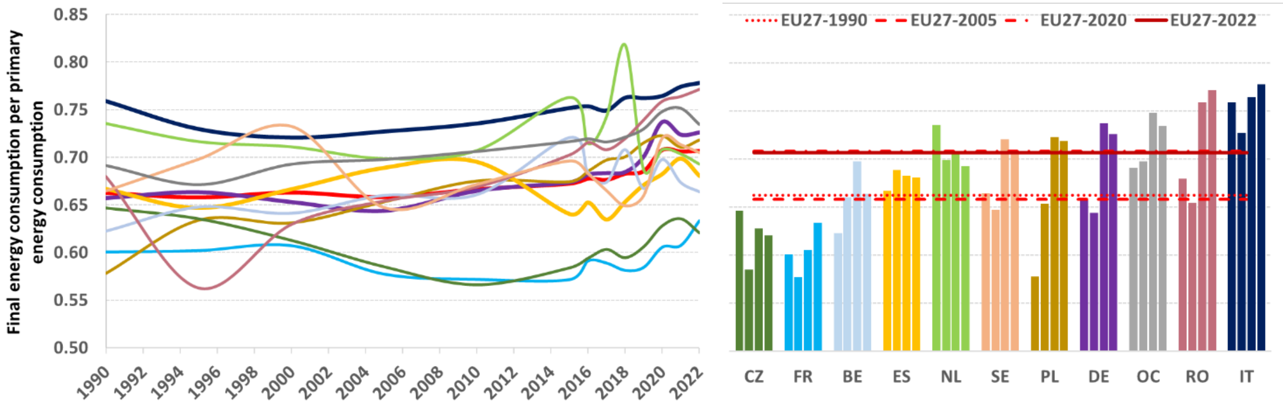
The ratio between the final energy consumption (including non-energy uses) and gross inland consumption is an indicator of energy efficiency. Since 1990 this indicator has always been higher for Italy than for the European average and shows values which, among the biggest countries, are comparable only with those of the Netherlands up to 2015. After this year the Netherlands efficiency shows wide fluctuations with a sensible decrease in the last years, while the Italian efficiency increased constantly. As concerns the other States, except France and Czechia which have the lowest values, the efficiency fluctuates around the European average since 2005. The lowest values for France and Czechia are also due to the low electrical conversion efficiency of nuclear power plants and the significant weight that such source has in the energy balance of these States (34.9% and 18.4% of gross inland consumption in 2022, respectively in France and Czechia). However, this is not the only factor because Sweden and Belgium, with respectively 27.1% and 20.5% of gross inland consumption by nuclear energy, have final energy efficiency much higher than France and Czechia. A sharp increase in efficiency made Poland reach and overcome the European average in recent years. It should be noted that, beyond the already mentioned countries, also Germany, Spain, the Netherlands, and Romania have some share of nuclear heat in their energy consumption in 2022 (from 1.4% in the Netherlands to 8.9% in Romania).

Figure 2.7 – Ratio between final energy consumption (including non-energy uses) and gross inland energy consumption. For each country the bars on the right graph refer to 1990, 2005, 2020, and 2022. Data in ascending order of 2022 value. OC – Other countries.



To evaluate energy transformation efficiency, it is useful to consider energy consumption without non-energy uses. In other words, the ratio between final energy consumption and primary energy. The Italian energy transformation efficiency is higher than any other countries examined. The trend of this indicator is like that of the previous one, although it highlights some difference among Member States concerning the share of non-energy uses. This indicator reveals that the value of the Netherlands' energy transformation efficiency is lower than in Italy. In the Netherlands, the average share of non-energy uses is more than 16% of gross inland consumption, while for Italy the average is less than 5% with a decreasing trend. The Netherlands' share of non-energy consumption in 2022 is the highest among the biggest countries (15.4%), followed by Belgium (12.5%). The EU27 average in 2022 is 5.8%.

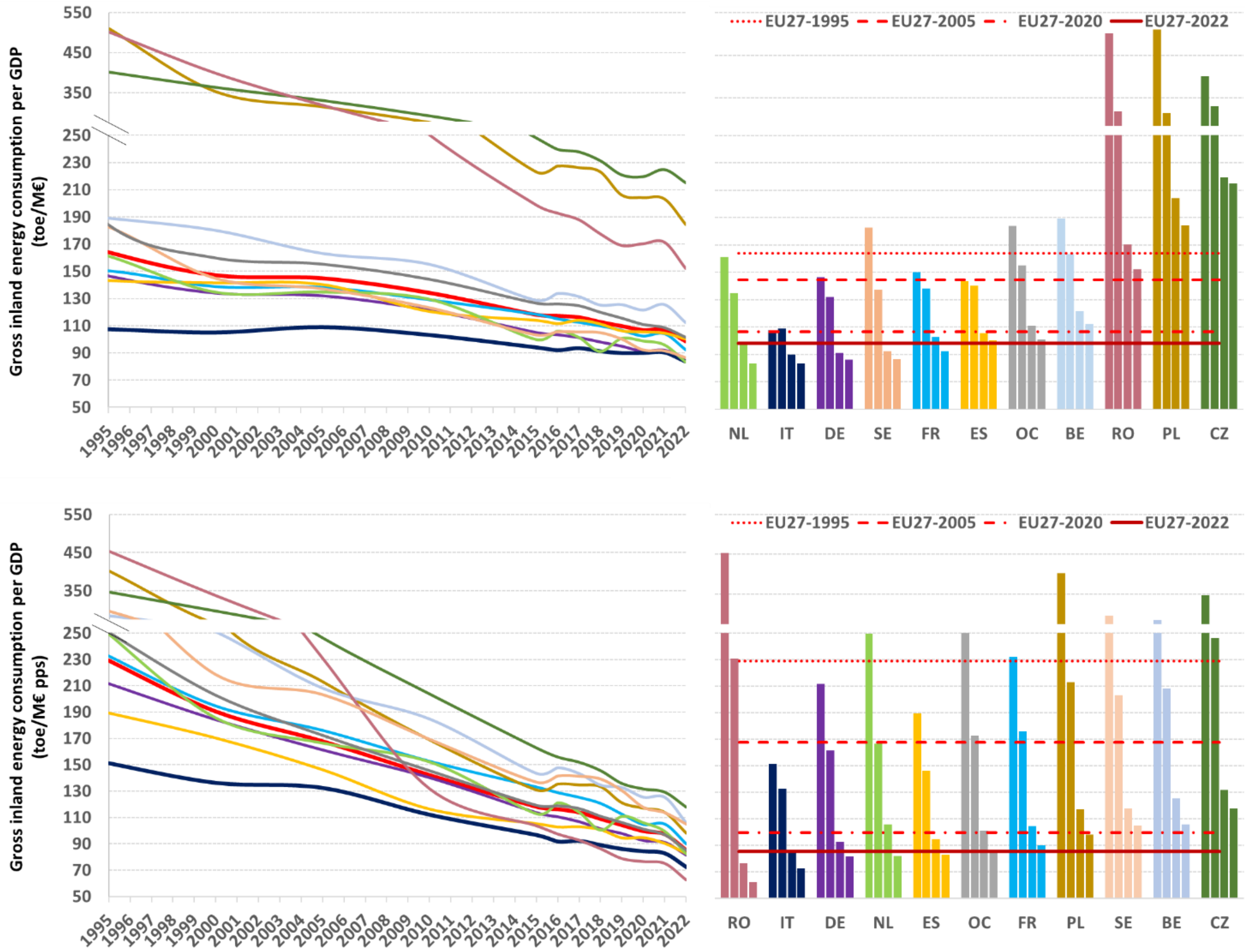
Figure 2.8 – Ratio between final energy (w/o non-energy uses) and primary energy consumption. For each country the bars on the right graph refer to 1990, 2005, 2020, and 2022. Data in ascending order of 2022 value. OC – Other countries.



The gross inland energy consumption per gross domestic product (GDP - chain linked volumes, reference year 2015 and current prices, purchasing power standards) is an indicator of the country's economic and energy efficiency (energy intensity). Such indicator is sensible to the country's energy mix and economy structure, in terms of industry and services share. An industry-based economy is more energy intensive than a service-based economy, even without considering the efficiency improvement. Moreover, the GDP is also determined by activities related to international bunkers, such as international maritime bunkers, whose energy consumption is not included in gross inland energy consumption. The role of international bunkers will be considered in the paragraph 2.1.2.1.

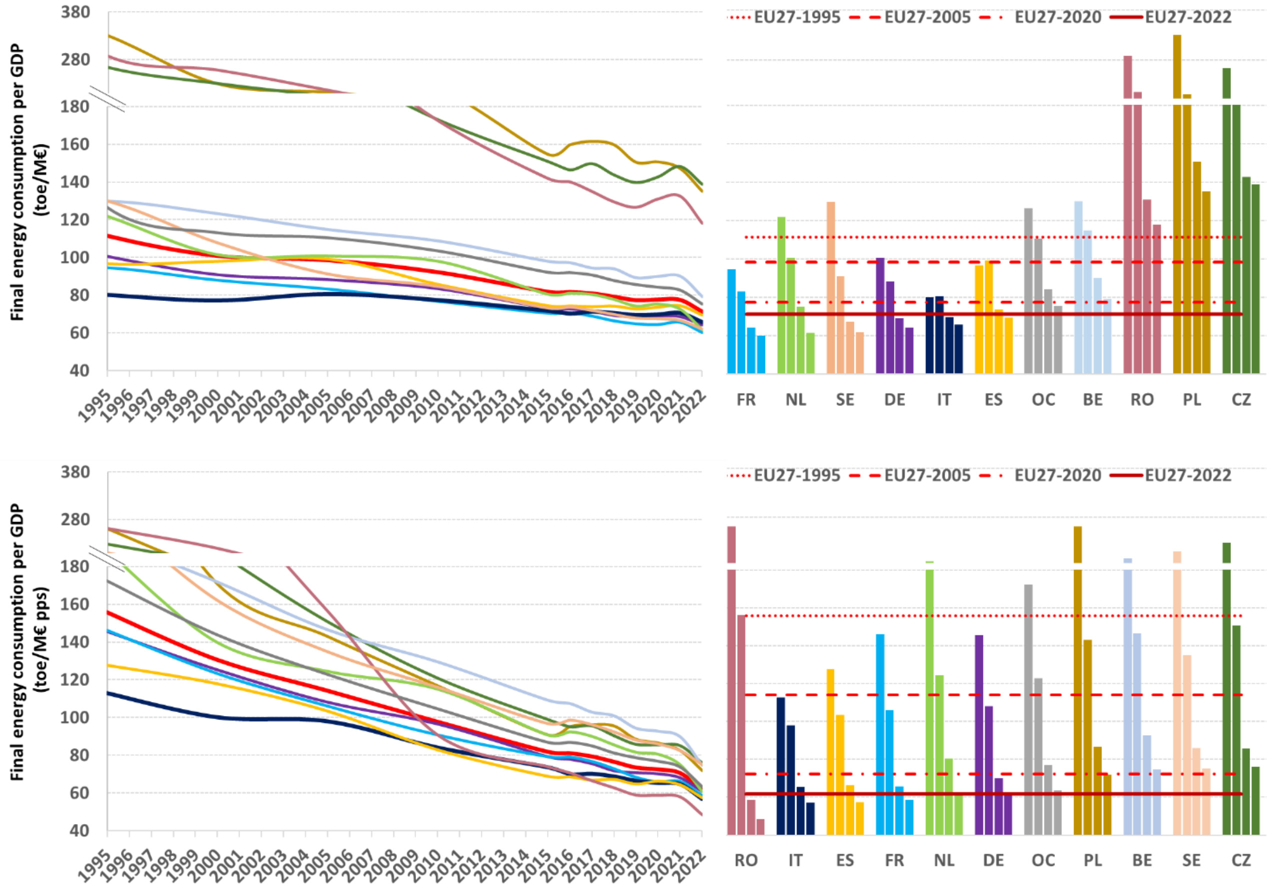
Italy was one of the European countries with lowest energy intensity since 1995, when it was second only to Denmark, then lost positions and in 2022 has the 6th lower values. Among the biggest EU27 countries, Italy continues having one of the lowest energy intensities.

Figure 2.9 – Gross inland energy consumption per GDP (chain linked volumes, reference year 2015, upper graphs; current prices, purchasing power standards, lower graphs). For each country the bars on the right graph refer to 1995, 2005, 2020, and 2022 values. Data in ascending order of 2022 value. OC – Other countries.



The final energy intensity (ratio between final energy consumption, including non-energy uses, and gross domestic product) follows similar trends of gross energy intensity with a sudden reduction in the European countries which, starting from higher levels than Italy, reached Italian figures and in some cases exceed them. Since 1995 Italy shows considerable energy and economic efficiency; the final energy intensity reduced by 18.1% from 1995 to 2022 considering chain linked volumes GDP, by 49.5% considering purchasing power standards GDP. Much higher reductions have occurred in the other European countries (EU27: -36.2% with chain linked volumes GDP and -60.5% with purchasing power standards GDP), whose "starting point" of energy intensity was much higher than the Italian one. The reasons for the observed reduction in energy intensity are manifold such as the increase in building efficiency, industrial efficiency improvement, electrification of final consumption, and shift of economy towards economic activities with high value added and low energy consumption as services to the detriment of industrial sectors. The last aspect is particularly relevant considering the long-term growth of GDP in the countries and the increasing share of the value added from services, which in EU27 represents 72.6% of the value added of all economic activities in 2022, while in1995 it represented 69.5%. On the other hand, the share of value added in industry (except construction), the most energy-intensive sector, was 28.3% in 1995 and 25.7% in 2022. Figure 2.10 shows that with the purchasing power standards GDP, Italy has one of the lowest final energy intensities among the considered countries.

Figure 2.10 – Final energy consumption per unit of GDP (chain linked volumes, reference year 2015, upper graphs; current prices, purchasing power standards, lower graphs). For each country the bars on the right graph refer to 1995, 2005, 2020, and 2022 values. Data in ascending order of 2022 value. OC – Other countries.



European countries show a wide range of electrification of final energy consumption (energy uses only), ranging from 14.5% in Latvia to 39.2% in Malta in 2022. Italy is just below the EU27 average with 22.3% *vs* 23%. Among the biggest countries, Sweden, France, and Spain have higher levels of electrification than Italy, respectively 33.8%, 26.9%, and 24.8%. At the lowest end there are Romania and Poland with 15.4% and 17.1% respectively.

Figure 2.11 – Share of final electricity consumption in total final energy consumption in EU27 countries (2022).

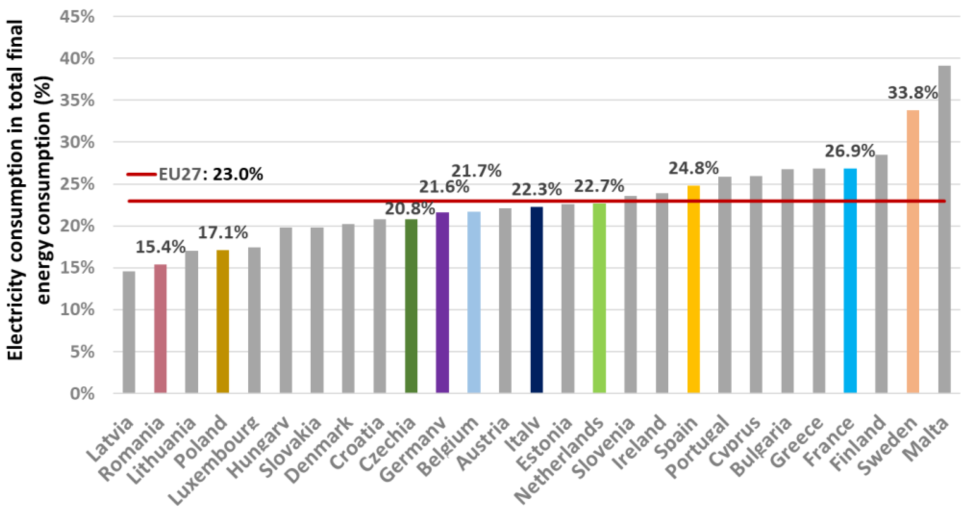
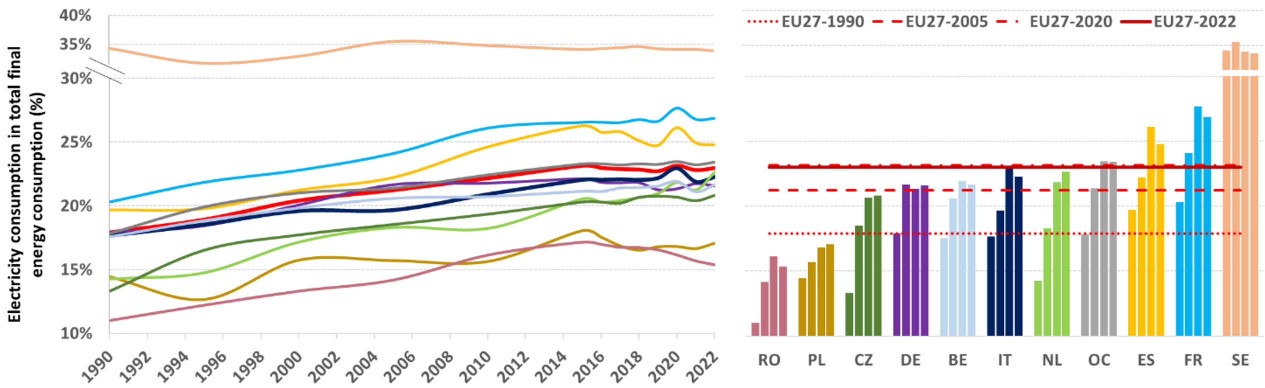


Figure 2.12 shows the increasing trends of electrification in almost all the European countries except Sweden whose highest level is quite constant.

Figure 2.12 – Trend of final electricity consumption share in total final energy consumption. For each country the bars on the right graph refer to 1990, 2005, 2020, and 2022. Data in ascending order of 2022 value. OC – Other countries.



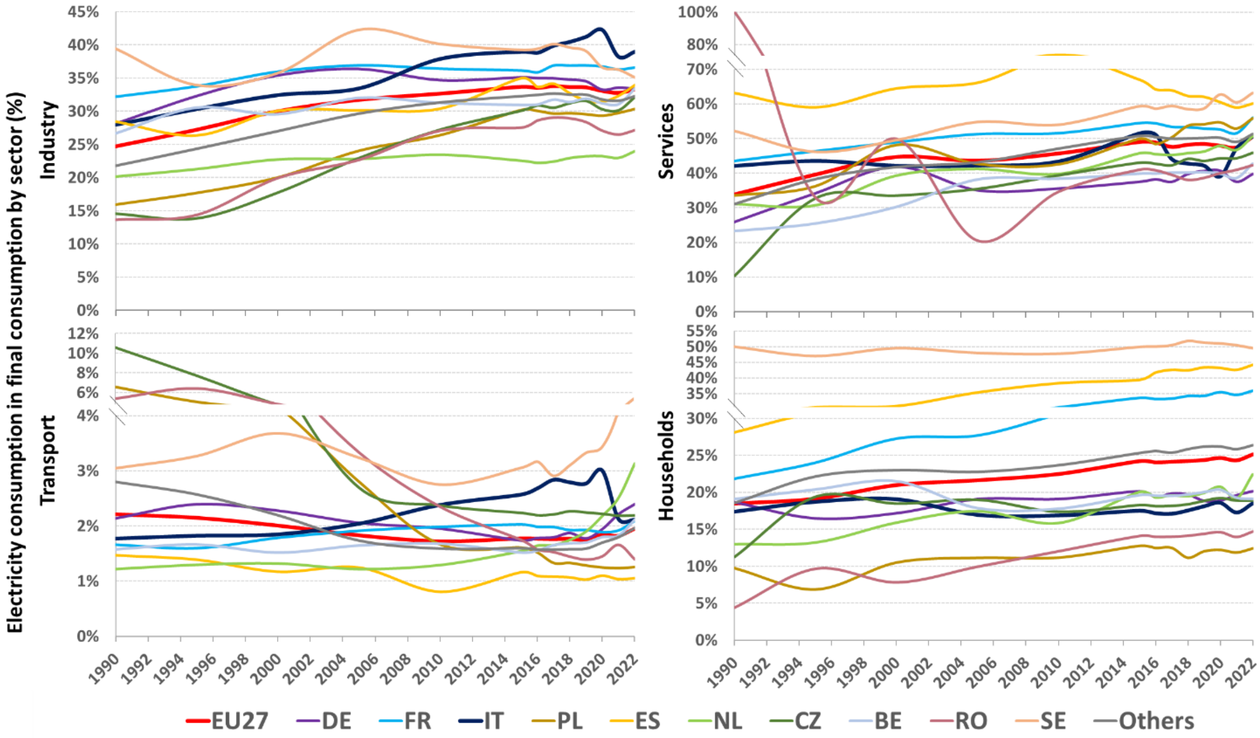
At sectoral level, the Member States' electrification shows different shares although with a common growing trend. The electrification of industry in Italy (39% in 2022) is the highest among the biggest countries and much higher than EU27 average (33.3%). The sharp boost of industry electrification recorded in Poland, Czechia, and Romania is particularly interesting. These countries are approaching the EU27 average. Equally notable is the reduction recorded in Germany from 36.4% in 2005 to 33.4% in 2022. The electrification of final consumption in the most emission intensive sector, such as industry, is an important strategy to mitigate GHG emissions if pursued with renewable electricity production.

Services show the highest percentages of electrification among sectors. The Italian share in 2022 is 50.6%, like the EU27 average. Among the largest countries, Sweden and Spain have the highest electrification shares in services, respectively 63.1% and 60.1% in 2022, although in Spain there has been a sudden reduction since 2010, when the share of electricity consumption was 73.8%. Germany, Romania, and Belgium are at the lower end with 39.7%, 42.3%, and 42.7% respectively.

The electrification of Italian households is much lower than the EU27 (18.5% *vs* 25.1%). Among the largest countries, Sweden (49.5%), Spain (44.2%), and France (35.9%) have the highest electrification shares in households. At the lowest end, after Italy, there are Romania (14.7%) and Poland (12.4%).

The transport sector shows the lowest percentages of electrification. The EU27 average in 2022 is 2% and among the biggest countries the highest percentages are in Sweden (5.4%) and the Netherlands (3.1%). The Italian value is 2.1%. Electricity consumption in the mobility sector has been limited so far to public transport (train, tram, metro), while for private mobility the electricity still plays a marginal role. The decline in the electrification rate in Poland, Czechia and Romania is explained by the strong growth of final consumptions in this sector, especially due to road transport, and decreasing consumptions of electricity as consequence of decrease of public transport demand.

Figure 2.13 – Trend of final electricity consumption share in total final energy consumption.



The share of electricity consumption by sector can provide indications on the emission mitigation performance of each sector reading the figures together with consumption of renewable energy by sector and above all with the role of renewable source for electricity production and consumption.

Figure 2.14 – Share of renewable electricity production in the EU27 countries (2022).

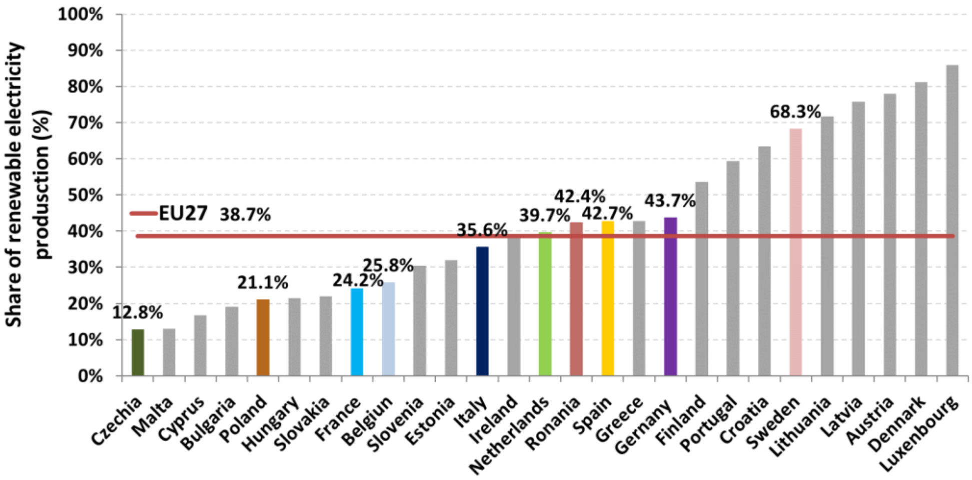
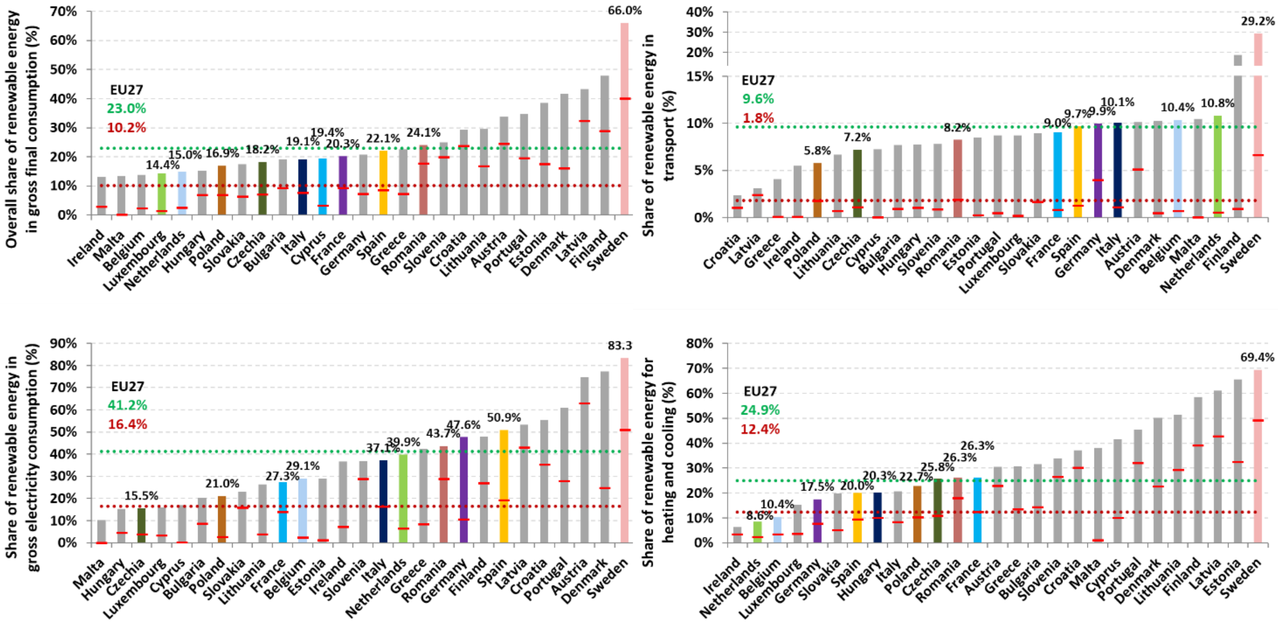


Figure 2.15 shows the overall and sectoral shares of renewable energy recorded in 2022 in the EU27 countries according to the Directive (EU) 2018/2001. The EU27 average share of renewable energy in gross final electricity consumption has more than doubled from 2005 to 2022 (16.4% *vs* 41.2%). Italy overall share is well below the European average in 2022 (19.1% vs 23%). This indicator is crucial to follow the achievement of European target of renewable share in 2030.

Figure 2.15 – Share of renewable energy in the EU27 countries (2022) according to Directive (EU) 2018/2001. The red dash on the bars is the country's 2005 level. The red and green dotted lines are the EU27 average respectively in 2005 and 2022.



The countries examined for comparison with Italy represent 83.1% of EU27 renewable energy in gross final electricity consumption in 2022. Such outcomes show clearly that the electrification of the final consumption in the biggest countries, such as Germany, France, Italy, Spain, and Sweden, involve a significant contribution to the mitigation of GHGs in Europe. The mentioned countries collectively account 66.4% of EU27 renewable electricity consumption.

2.1.2 GHGs and energy consumption

Italy's average GHGs per capita from 1990 to 2022 is 8.8±1.2 t CO_2eq (ISPRA, 2024a). Emissions per capita increased until 2004 when the maximum value of 10.3 t CO_2eq was reached, then decreased up to 6.4 t CO_2eq was observed in 2020, followed by the increase up to 7 t CO_2eq in 2022. Italian GHGs per capita have always been below the European average (7.6 t CO_2eq in 2022).

Apart for Italy and Spain, the trend of GHGs reductions in the other countries began as early as 1990. GHGs per capita in Spain increased with higher rate than in Italy until 2005, when the GHGs per capita of the two countries reached the same level. After 2005 a the downward trend is observed also for Italy and Spain. In recent years, GHGs in France, Spain, and Romania are very close. Sweden has the lowest GHGs per capita. All other examined countries have higher emissions than the EU27 average.

Figure 2.16 – GHGs per capita. For each country the bars on the right picture are 1990, 2005, 2020, and 2022 values. Data in ascending order of 2022 value. OC – Other countries.

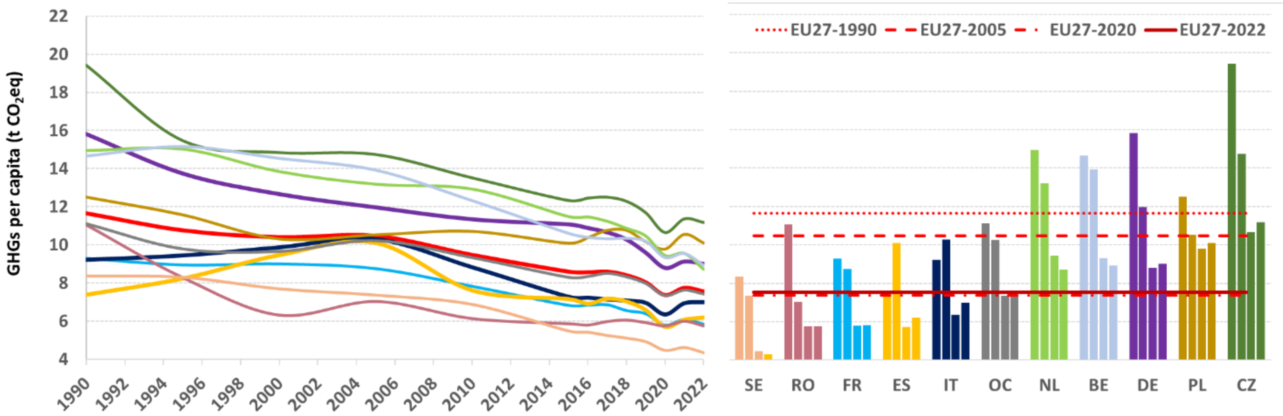
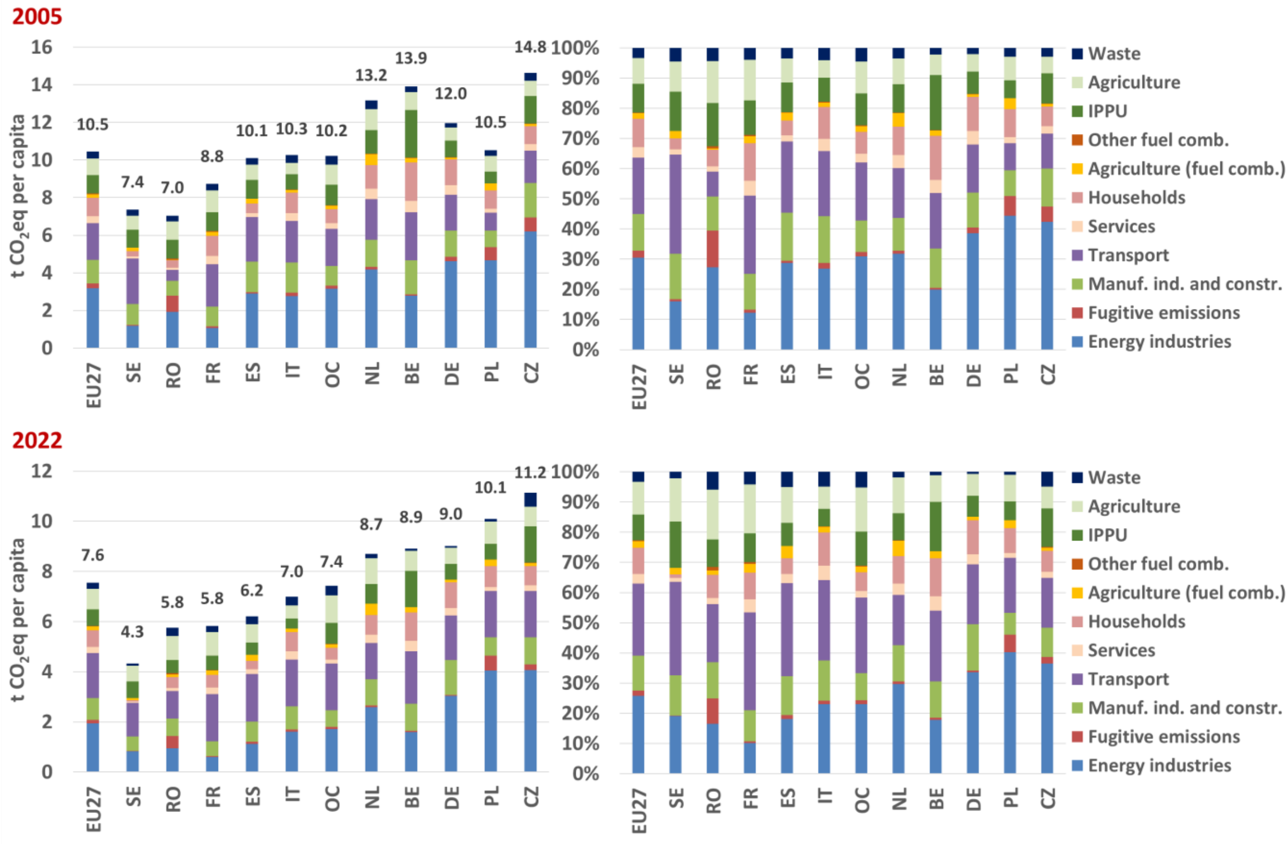


Figure 2.17 shows the GHGs per capita by sector in 2005 and 2022. The allocation by sector of countries' emissions is very heterogeneous depending upon the peculiarity of the energy system of each country, with its own ratio between energy consumed for transformation and final users. Energy industries and transport are the sectors with the highest shares in EU27 in 2022, 25.7% and 23.8% respectively. In 2005 the EU27 share of energy industries was 30.5%, while transport was 18.6%.

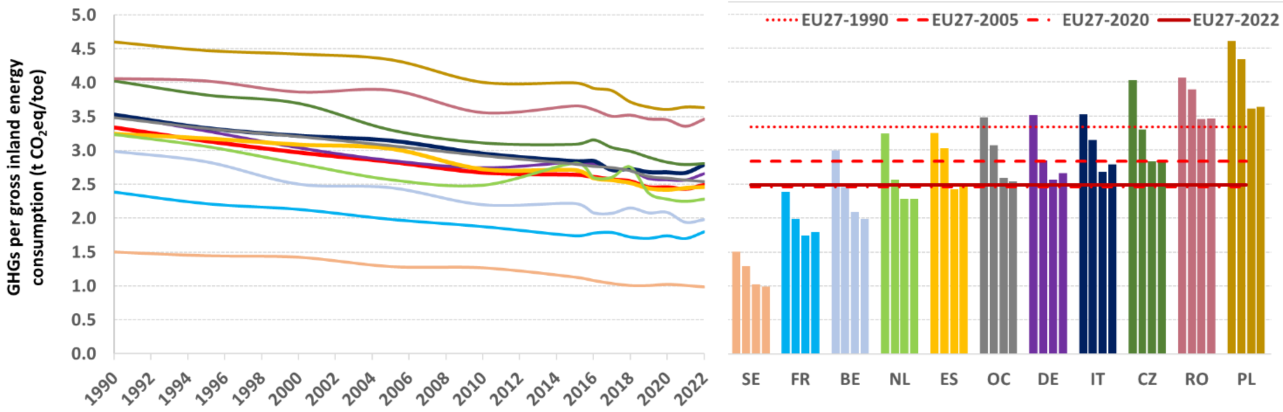
The range is very wide in the countries. The 2022 share of GHGs per capita by energy industries goes from 10.1% in France to 40.1% in Poland, while transport goes from 16.5% in Czechia to 32.3% in France.

Figure 2.17 – GHGs per capita by sector in 2005 and 2022 (left), and share (right). Data of MSs in ascending order of GHGs per capita in 2022. OC – Other countries.



GHGs by energy consumption, carbon intensity, decreased in all countries since 1990. Such indicator is sensible to the country's energy mix. It should be considered that sources of energy, as renewables and nuclear heat, do not contribute to GHG emissions, so countries with higher share of such sources are more likely to have low carbon intensity. Moreover, the share of net imported electricity plays a positive role in reducing the indicator because the emissions to generate such electricity are allocated to the countries which produce it. The country economy structure is another relevant factor to be considered to correctly interpret such indicator. The industry activities are more energy consuming than service activities, so the countries' economy structure is a relevant factor for such indicator. Carbon intensity of Italy is higher than the European average (Figure 2.18), also for the contribute of nuclear power in Europe. By unbundling nuclear power from gross inland consumption, Italy's value is just below the EU27 average (2.79 t CO_2eq *vs* 2.82 t CO_2eq in 2022).

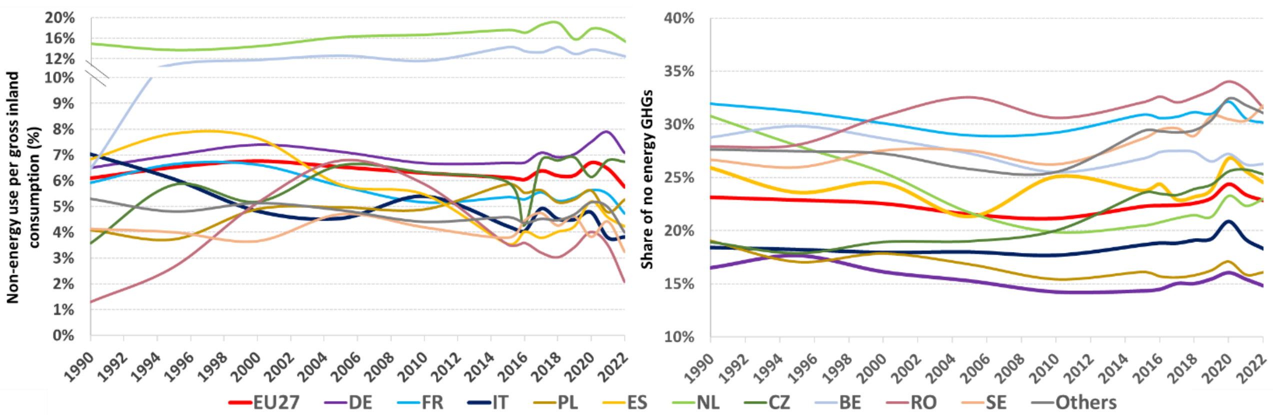
Figure 2.18 – GHGs per gross inland energy consumption. For each country the bars on the right picture are 1990, 2005, 2020, and 2022 values. Data in ascending order of 2022 value. OC – Other countries.



Countries with lower carbon intensity than Italy have higher share of renewable and nuclear energy with the only exception of the Netherlands, whose renewable share is lower than the Italian one (12.6% vs 19% in 2022). On the complementary side of the fossil share the only countries with higher values than Italy (78.5%) are Germany, Poland, and the Netherlands, respectively 80.2%, 87.1%, and 86.1%. It is worth noting that despite the lower fossil share in Czechia (71.3%) and Romania (71.8%) compared to Italy the two countries have higher carbon intensity due to higher shares of solid and liquid fuels in their fossil mix.

The carbon intensity in the Netherlands is in apparent contrast to what was previously said about the country's energy mix. To overcome the apparent contrast, Figure 2.18 should be read considering the role of non-energy consumption in the energy mix (Figure 2.19). The share of non-energy consumption in the Netherlands (15.4%) is significantly higher than in Italy (3.8%). While primary energy consumption has a direct relationship with GHGs, the same is not true for non-energy uses. These consumptions include industrial processes in sectors such as the petrochemical, pharmaceutical, etc., where oil and its products are not used as fuels, but for transformation into other products. Moreover, the role of no energy GHGs must be considered along with large source of GHGs, as waste and agriculture, not related to energy consumption. The GHGs from no energy sectors show a wide range in the European countries with an average for EU27 of 22.8% in 2022. Among the countries here considered the range goes from 14.8% in Germany to 31.8% in Sweden; the Italian share is 18.2%.

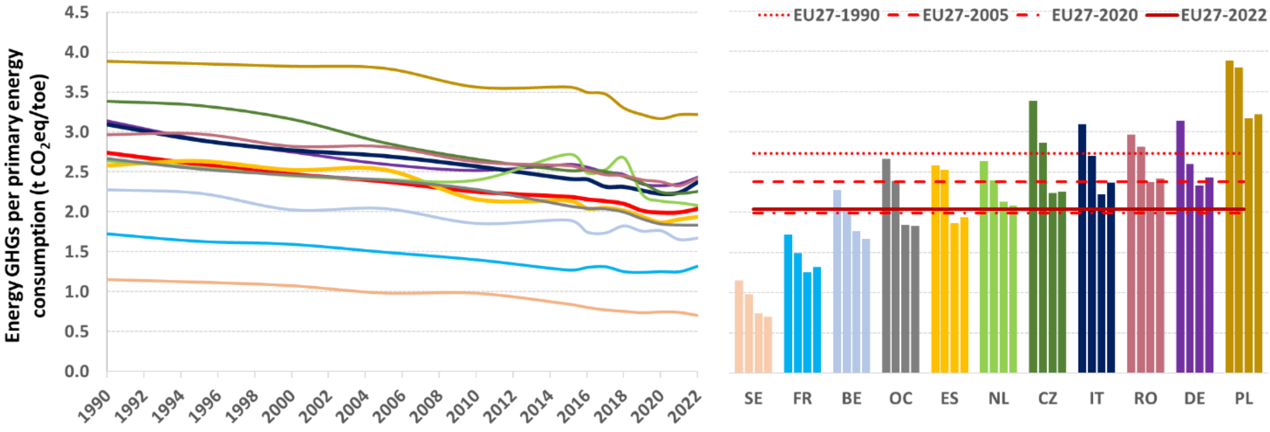
Figure 2.19 – Shares of no energy use per gross inland energy consumption and no energy GHGs.



The comparison of decarbonization indicators among countries with significantly different shares of no energy uses and no energy GHGs can be corrected by considering the energy GHGs per unit of primary energy consumption: primary energy carbon intensity. This indicator highlights the decarbonization of a

Country's energy sector. In general terms countries with higher shares of renewable or nuclear energy have lower primary energy carbon intensity. According to this indicator the intensities of the Netherlands and Italy are closer. The primary energy carbon intensity of Germany is higher than the Italian one also because of the lower share of no energy GHGs in Germany (14.8%) than in Italy (18.2%). As for the gross inland consumption of energy Czechia has higher carbon intensity than Italy, while as for primary energy there is a shift in the countries' position which can be explained by the higher share of no energy emissions in Czechia (25.3%) than Italy (18.2%).

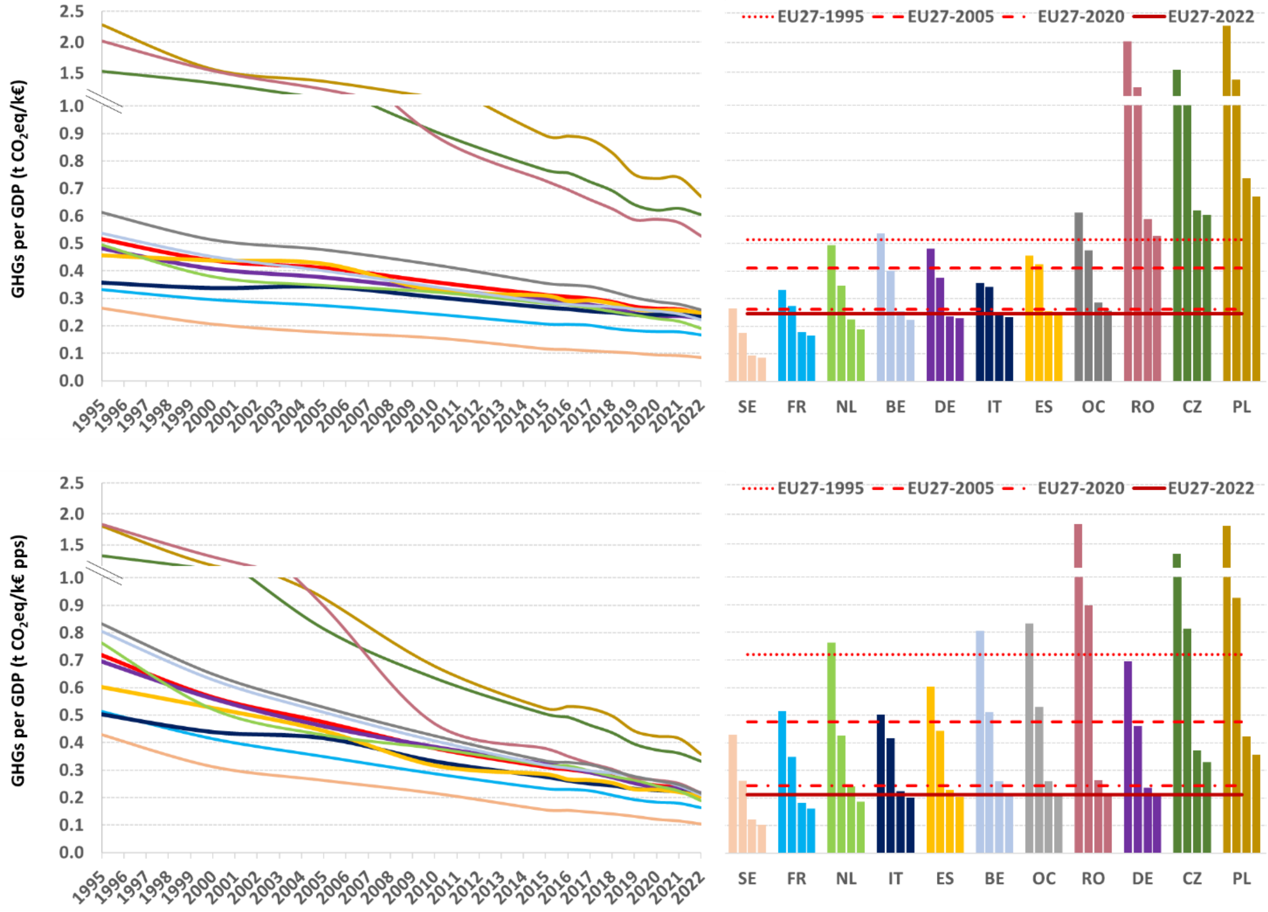
Figure 2.20 – Energy GHGs per primary energy consumption. For each country the bars on the right picture are 1990, 2005, 2020, and 2022 values. Data in ascending order of 2022 value. OC – Other countries.



The ratio between GHGs and gross domestic product is the carbon intensity of economy. Such indicator is sensible to the country's energy mix, like the carbon intensity of energy, and even more sensible to economy structure: share of services and industry. Moreover, it should be considered that countries' GDP is also driven by activities linked to international bunkers, whose emissions are memo items in the emissions inventories submitted to UNFCCC and not considered in the national emissions statistics. The following graphs (Figure 2.21-2.23) do not include memo items. The role of such items will be considered in the next paragraph. All European countries reduced the carbon intensity of economy and Italy's figures, considering chain linked volumes GDP, are below the EU27 average in 2022 (0.23 t CO_2eq/k€ *vs* 0.25 t CO_2eq/k€), as well as considering purchasing power standards GDP (0.19 t CO_2eq/k€ *vs* 0.21 t CO_2eq/k€). Sweden and France have the lowest values: 0.09 t CO_2eq/k€ and 0.17 t CO_2eq/k€, respectively (chain linked volumes). Poland and Czechia are at the upper end with 0.67 t CO_2eq/k€ and 0.6 t CO_2eq/k€, respectively (chain linked volumes).

The reduction since 1995 for EU27 is -52.4% and ranges from -34.9% for Italy to -73.9% for Romania with chain linked volumes, while considering purchasing power standards EU27 reduced by 70.5% spanning from -59.9% for Italy to -88.2% for Romania. The reasons of such reductions are manifold and concern both the common increase in efficiency of industry and the increasing share of value added from services, whose carbon intensity is far lower than those of manufacturing industries.

Figure 2.21 – GHGs per GDP (chain linked volumes, reference year 2015, upper graphs; current prices, purchasing power standards, lower graphs). For each country the bars on the right picture are 1995, 2005, 2020 and 2022 values. Data in ascending order of 2022 value. OC – Other countries.



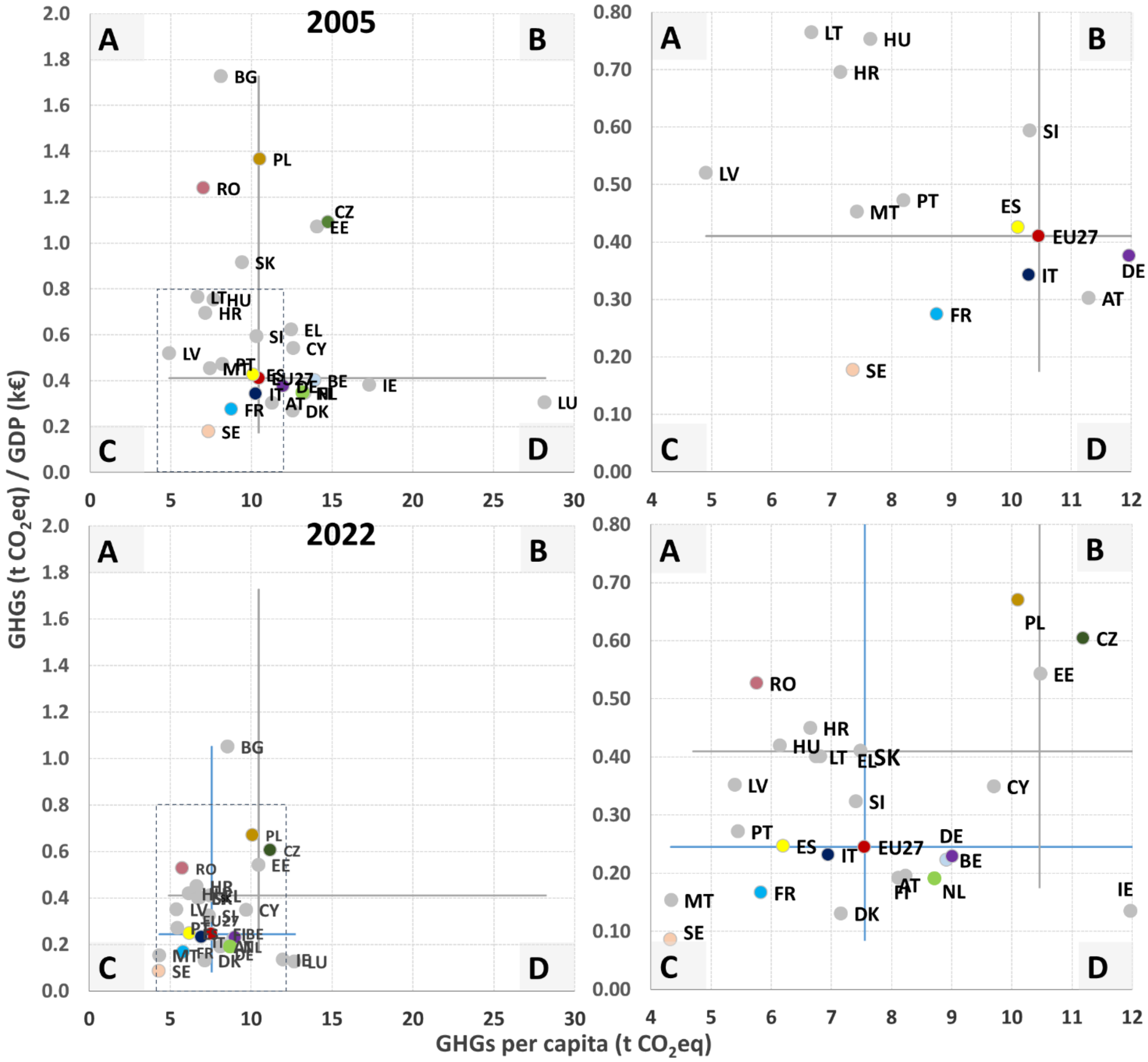
The following graphs show how the countries "moved" in the phase space defined by GHGs per capita and GHGs per unit of GDP from 2005 to 2022 (chain linked volumes, reference year 2015). EU27 average is the centroid of the countries' cloud. The crossed axes on EU27 value separate four quadrants with different performances. The pictures on the right are the zoomed box which inscribes the biggest Member States in 2022. In the quadrant C, at the bottom left corner, there are the best performing countries with lower GHGs per capita and lower GHGs per GDP than EU27 average, while in the quadrant B, at the upper left corner, there are the worst performing countries, with higher GHGs per capita and higher GHGs per GDP than EU27 average. The countries' cloud became more and more "concentrated" moving toward the bottom left corner. Italy, France, and Sweden were in the quadrant C since 2005 (Figure 2.22). In 2022 Spain is on the verge of quadrants A and C, while the Poland and Czechia are in the quadrant B both in 2005 and in 2022. Germany, Belgium, and the Netherlands are in the quadrant D, with higher GHGs per capita but lower GHGs per GDP than EU27 average.

The distance that each country travelled since 2005 in the phase space along the bottom left direction provides a measure of the progress made in the decarbonization process. The distance of two points in the two-dimension Euclidean space, P = (p_x , p_y) and Q = (q_x , q_y), is calculated as:

$$\sqrt{(p_x - q_x)^2 + (p_y - q_y)^2}$$

Among the examined countries, Belgium and the Netherlands travelled the longest distances, followed by Spain, Czechia, and Italy. Poland moved the shortest distance reducing only the GHGs per GDP without any relevant change of GHGs per capita.

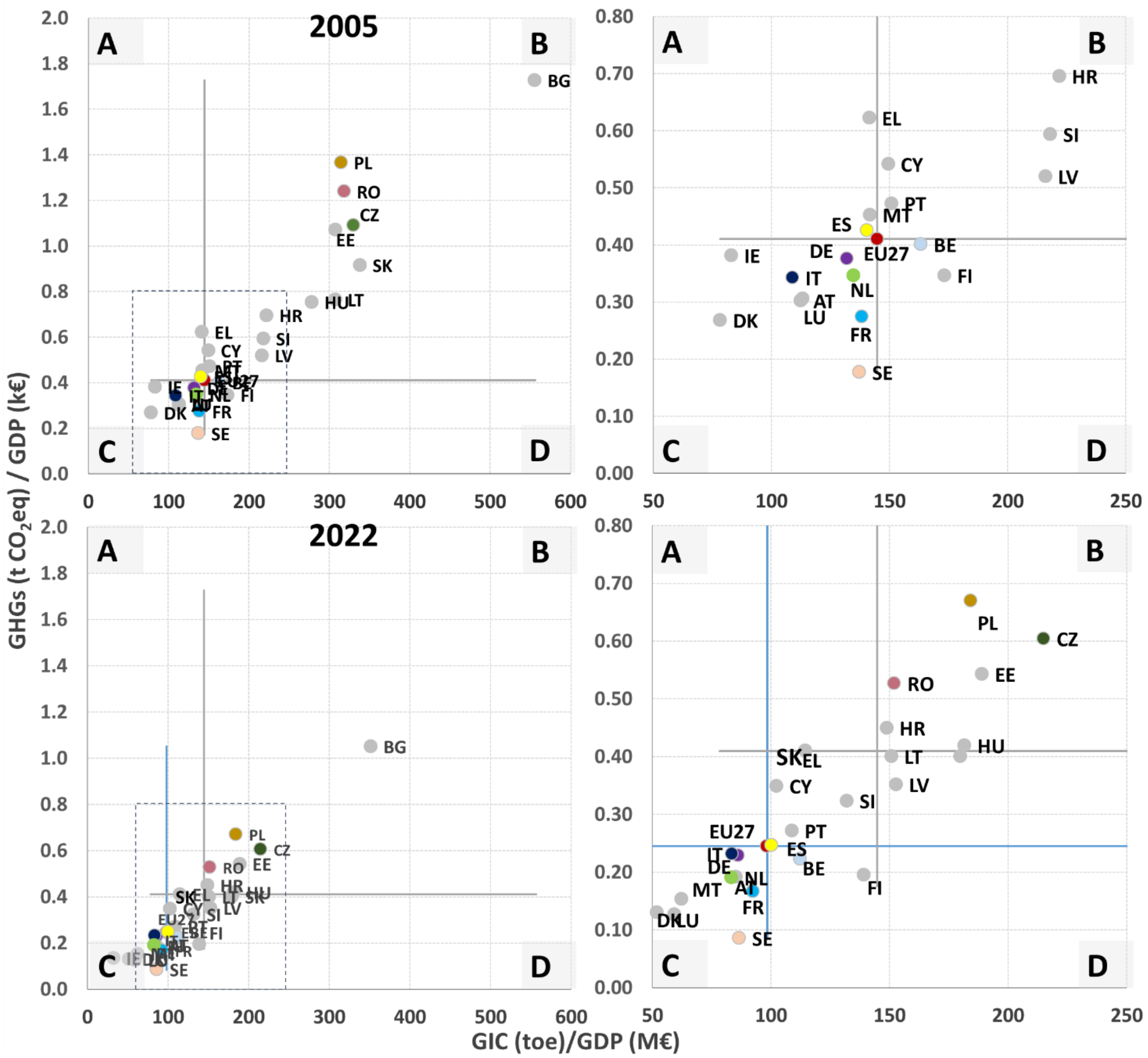
Figure 2.22 – In the phase space defined by emissions per capita (abscissa) and economy carbon intensity (ordinate) is shown the position for each Member State on the left. On the right it is shown the enlarged box that inscribes the biggest Member States in 2022. The grey axes in the bottom graphs are those plotted in 2005.



Even more interesting is the positioning of countries in the space defined by GHGs per GDP and gross inland energy consumption per GDP (Figure 2.23). In such picture both abscissa and ordinate report intensities indicators giving a portray of the efficiency and decarbonization of economy. Broadly speaking, the efficiency improves using less energy per GDP (moving on the left of x-axes), while decarbonization improves with less GHGs per GDP (moving on the bottom of y-axes).

Among the examined countries only Poland, Czechia, and Romania are still in the quadrant B with the worst performances in 2022, although travelling in this phase space longer distances than any other countries since 2005. On the other end Italy travelled the shortest distance. Such phase space makes clear how Germany and other countries, as Spain and the Netherlands, approached Italy from 2005 to 2022.

Figure 2.23 – In the phase space defined by economy energy intensity (abscissa) and economy carbon intensity (ordinate) is shown the position for each Member State on the left. On the right it is shown the enlarged box that inscribes the biggest Member States in 2022. The grey axes in the bottom graphs are those plotted in 2005.



GHGs per capita, energy and carbon intensities by economy show that Italy had some of the lowest values since 2005 and the biggest countries gradually moved toward the quadrant that Italy, together with few other countries, occupied already in 2005.

The comparison of indicators among Italy and the biggest EU27 countries shows that Italy has historically high energy efficiency with a significant share of renewable energy and natural gas in the energy mix, and GHGs per capita lower than EU27 average. The gross energy intensity per GDP in Italy is among the lowest in EU27, while carbon intensity per GDP is just below EU27 average and very close to values recorded in Germany and Spain, among the biggest countries. The carbon intensity per gross energy consumption is lower in EU27 than Italy because of the significant share of nuclear heat in many European countries. Many countries have improved their GHG emissions performance compared to GDP, sometimes achieving better results than Italy. GHGs per GDP need further details that will be examined in the next paragraph.

2.1.2.1 International bunkers

The decarbonization and efficiency indicators with GHGs from international bunkers (international flights and shipping) require a premise on the composition of national emission inventories and energy balance.

GHG emissions inventories submitted to the UNFCCC Secretariat include emissions from international aviation and maritime activities. Such emissions, although methodologically consistent with IPCC guidelines (2006), are reported as "memo" items and are not included in total national emissions.

Similarly, for energy consumption, the items that make up a country's gross inland energy consumption must be considered in relation to GHGs from international bunkers. In Eurostat's energy balance, gross inland energy consumption includes the consumption of international aviation but not those of international maritime activities.

In particular, the main items in the budget can be explained by the following equations:

GAE= PPRD + RCV_RCY + IMP – EXP + STK_CHG (1)

where

GAE: gross available energy;

PPRD: primary production;

RCV_RCY: recovered or recycled products;

IMP: import;

EXP: export;

STK_CHG: stock changes.

GIC = GAE – INTMARB (2)

where

GIC: gross inland energy consumption;

INTMARB: international maritime bunkers;

NRGSUP = GIC – INTAVI (3)

where

NRGSUP: total energy supply;

INTAVI: international aviation;

AFC = NRGSUP – (TI_E – TO) – NRG_E – DL (4)

AFC = FC_E + FC_NE (5)

where

AFC: energy available for final consumption;

TI_E: transformation input of energy:

TO: transformation output;

NRG_E: energy consumption in the energy sector;

DL: distribution losses;

FC_E: energy uses of final energy;

FC_NE: non-energy uses of final energy.

Equations (2) and (3) show that in the gross inland energy consumption is not considered the energy consumption by international maritime bunkers, while the consumption by international aviation is included. Therefore, a decarbonization indicator that considers total emissions reported in the inventories should be the ratio between GHGs to total energy supply (NRGSUP), as both terms are without international bunkers. Similarly, decarbonization indicators can be drawn up with gross inland energy consumption (GIC) or with gross available energy (GAE) considering the contribution of international aviation in the first case and of all international bunkers in the second case.

The energy available for final uses (AFC) includes energy and non-energy uses. The former component is directly related to GHGs from combustion, while the latter is involved in transformation processes not directly related to atmospheric emissions. Final uses consist of total energy without transformation losses, energy branch sector consumption and distribution losses.

This report has not the aim to examine in detail the components of gross domestic product, but in the first approximation it can be considered that GDP is also determined by activities related to international aviation and international navigation.

The biggest European countries have very different share of GHGs from international bunkers. The GHGs from such sectors are very notable in some countries: the EU27 average in total GHGs with bunkers in 2022 is 6.6%. For the biggest countries, it ranges from 0.3% in Romania to 22.9% in the Netherlands.

In the light of such different contributions, it is reasonable to investigate the dynamics of decarbonization and efficiency indicators considering the role of international bunkers. Carbon intensity per gross domestic product and carbon intensity per energy consumption will be considered. The GHGs in such indicators include the emissions by international bunkers. The first indicator is equal to the ratio between GHGs and gross domestic product (GDP). The second one is equal to the ratio between energy GHGs and gross available energy (GAE), without final consumption for non-energy uses (FC_NE): such measure can be defined as gross available primary energy. Regarding the efficiency indicator, carbon and energy intensities will be calculated through the ratio between gross available energy (GAE) and gross domestic product (GDP).

Figure 2.24 – Share of national GHGs in the inventories and international bunkers GHGs (2022 data). Countries in descending order of international bunkers GHGs share.

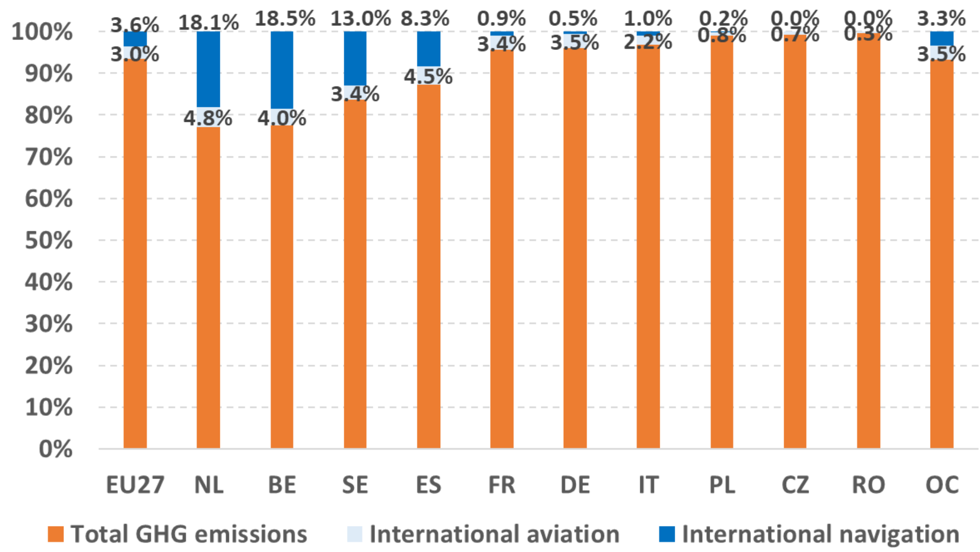
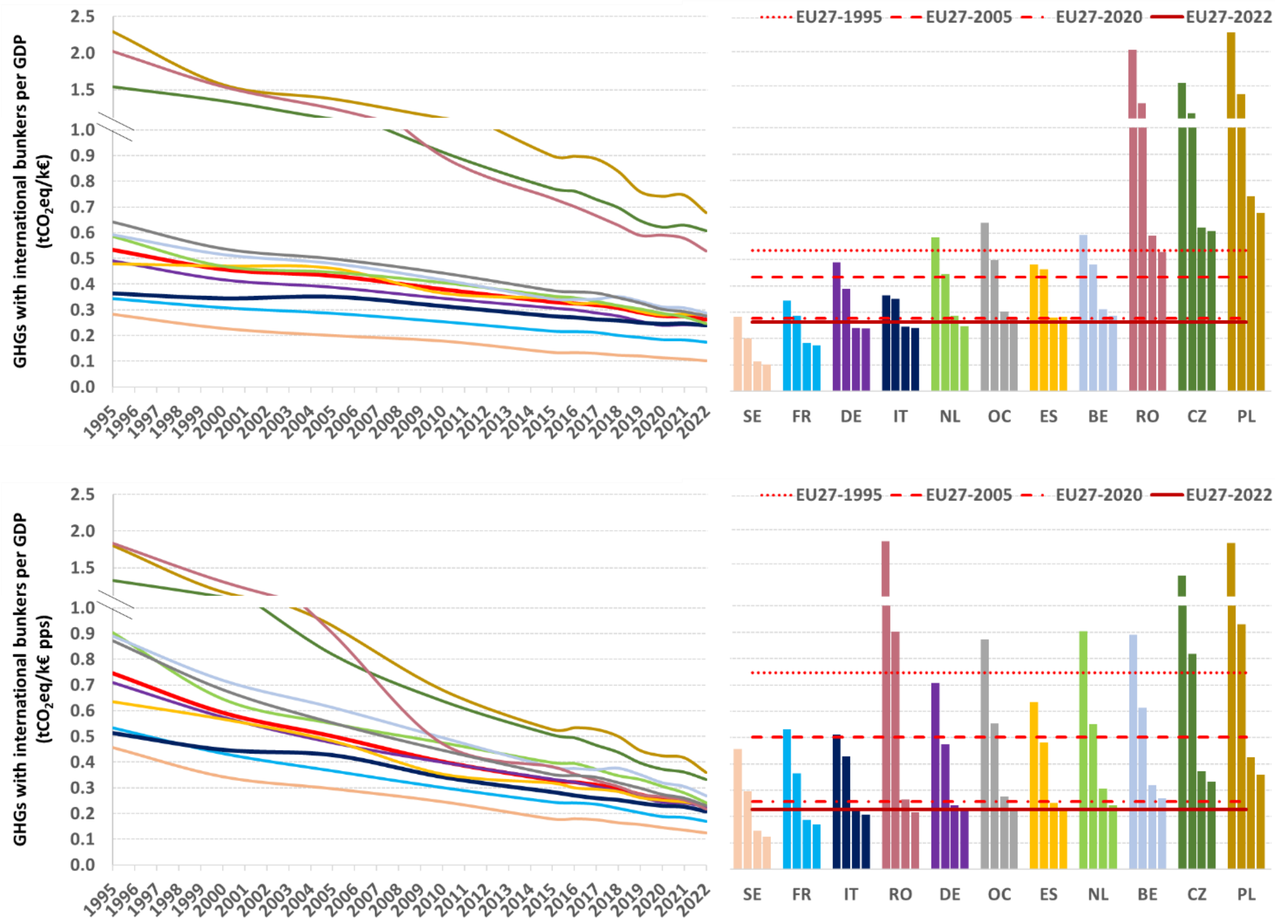


Figure 2.25 shows the GHGs per GDP and should be compared with Figure 2.21. The indicator highlights the role of international bunkers because where GHGs from such activities have a significant share, as in Belgium and the Netherlands, the carbon intensity is significantly higher than without such GHGs. Whereas in Figure 2.21 the intensities of Belgium and the Netherlands are quite below the EU27 average,

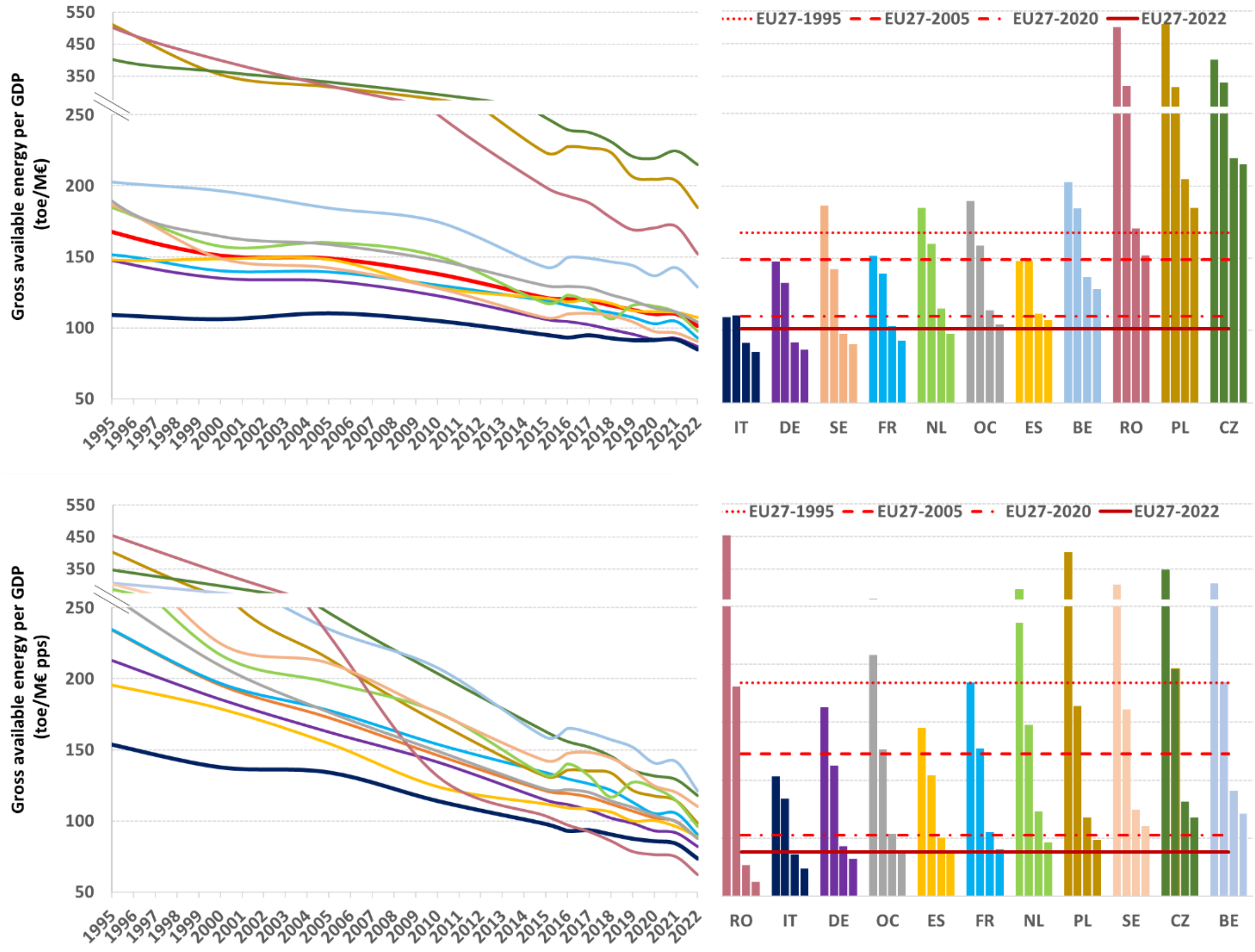
in Figure 2.25 the intensity of Belgium is higher than the European average and the intensity of the Netherlands is closer to the EU27 average. This indicator changes the countries' ranking. Italy is near to Germany considering chain linked volumes GDP. According to purchasing power standards GDP, Italy's carbon intensity is higher than those recorded in France and Sweden, where the role of energy with zero GHGs (nuclear energy in both countries and bioenergy in Sweden) is notable.

Figure 2.25 – GHGs with international bunkers per GDP (chain linked volumes, reference year 2015, upper graphs; current prices, purchasing power standards, lower graphs). For each country the bars on the right picture are 1995, 2005, 2020, and 2022 values. Data in ascending order of 2022 value. OC – Other countries.



The gross available energy per unit of GDP shown in Figure 2.26 (cf. Figure 2.9) confirms that Italy and Germany values are the lowest among the largest countries. The relevant amount of energy consumed by international bunkers in the Netherlands and Belgium moves the energy intensity per GDP of these countries towards higher values than that shown in Figure 2.9.

Figure 2.26 – Gross available energy per GDP (chain linked volumes, reference year 2015, upper graphs; current prices, purchasing power standards, lower graphs). For each country the bars on the right picture are 1995, 2005, 2020, and 2022 values. Data in ascending order of 2022 value. OC – Other countries.



2.1.2.2 Sectoral efficiency and decarbonization

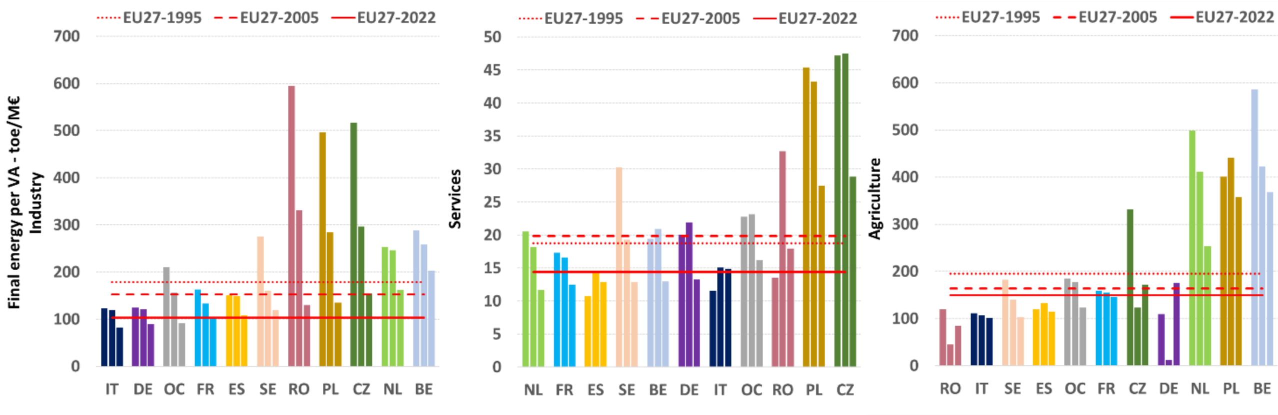
The comparison of efficiency and decarbonization indicators at sectoral level among Member States shows a rather heterogeneous picture. For the sectoral value added the chain linked volumes with reference year 2015 has been used. Figure 2.27 compares the final energy intensity in 1995, 2005, and 2022 in the examined countries for the industry, services, an agriculture.

The industry final energy intensity, ratio between final energy consumption and sector value added, in Italy has always been the lowest among the biggest countries, with a decreasing trend. Among the European countries only Ireland, Denmark, Malta, and Estonia have lower industry energy intensities than Italy in 2022. Among the countries examined the Netherlands and Belgium show the highest energy intensities for industry. The average annual rate of the sector energy intensity from 2005 to 2022 decreased of -2.1% for Italy and -2.3% for European average.

In commercial and public services Italy shows an intensity close to the European average, higher than Germany in 2022. Italy is the only country, among the biggest ones, whose energy intensity in this sector did not decrease so much since 2005. The outcome is also due to the accounting of energy consumed by heat pumps, whose data accounting in Eurostat started since 2017 for Italy, although previously present. The accounting of such item in 2005 would have set higher energy intensity. Countries as France and Germany regularly reported energy consumed by heat pumps since 2005. Anyway, with available data the average annual rate of energy intensity from 2005 to 2022 decreased by 0.1% in Italy against -1.9% in EU27.

The agriculture sector shows a general decrease of energy intensity in EU27. In 2022, among the considered countries, only Romania has lower energy intensity than Italy. The average annual rate of energy intensity from 2005 to 2022 decreased of -0.3% in Italy against -0.5% in EU27.

Figure 2.27 – Final energy consumption per value added in 1995, 2005 and 2022. Countries in ascending order of 2022 value. OC = other countries.

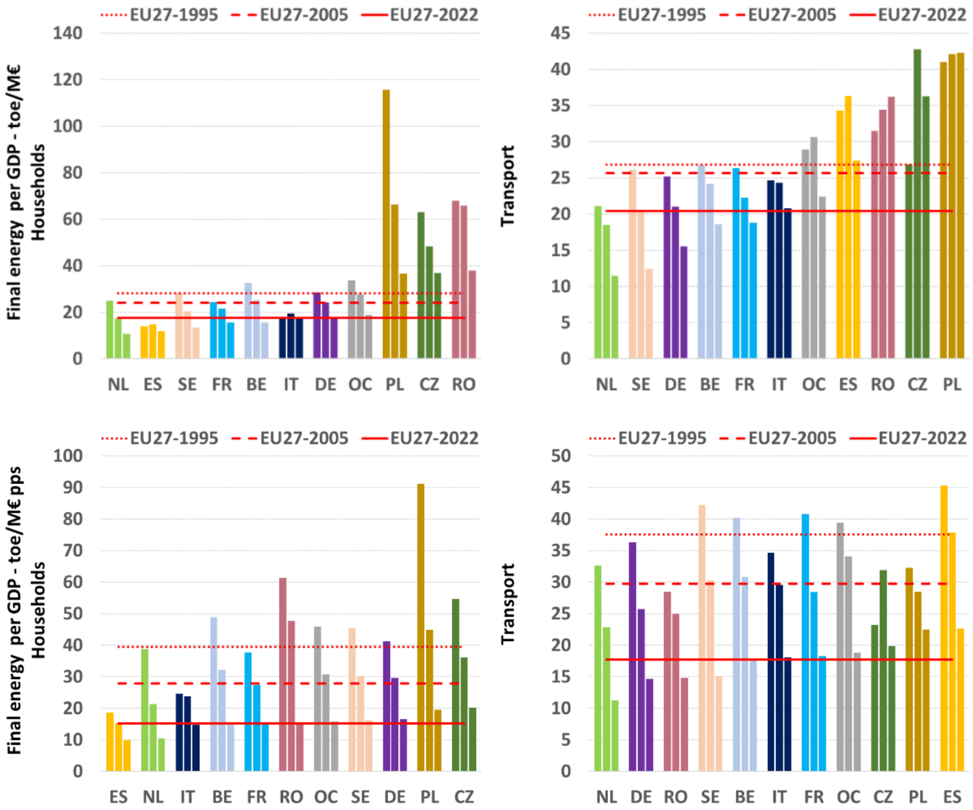


The GDP will be considered to assess the energy intensity of those sectors not directly linked to value added output, such as households and transport (Figure 2.28). In the households, from 2005 to 2022 the biggest countries reduced the energy consumption per GDP (chain linked volumes): from -0.8% per year in Italy to -3.4% per year in Poland.

The Italian energy intensity for transport in 2022 is comparable to EU27 average. The Italian reduction rate since 2005 is -0.9% per year, against -1.3% in EU27. The intensity in Germany and France is respectively 24.2% and 8% lower than EU27 average in 2022.

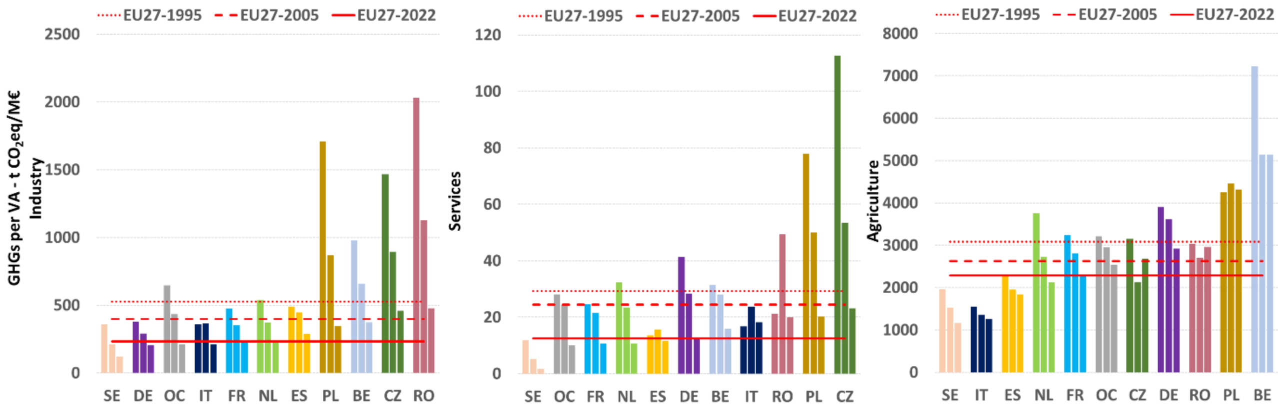
The ranking of the examined countries for households and transport shows that the Italian energy intensity is near the EU27 average. Moreover, transport performances in Italy have wide room for improvement if compared to Germany.

Figure 2.28 – Final energy consumption per GDP in 1995, 2005, and 2022 (chain linked volumes, reference year 2015, upper graphs; current prices, purchasing power standards, lower graphs). Countries are in ascending order of 2022 value. OC = other countries.



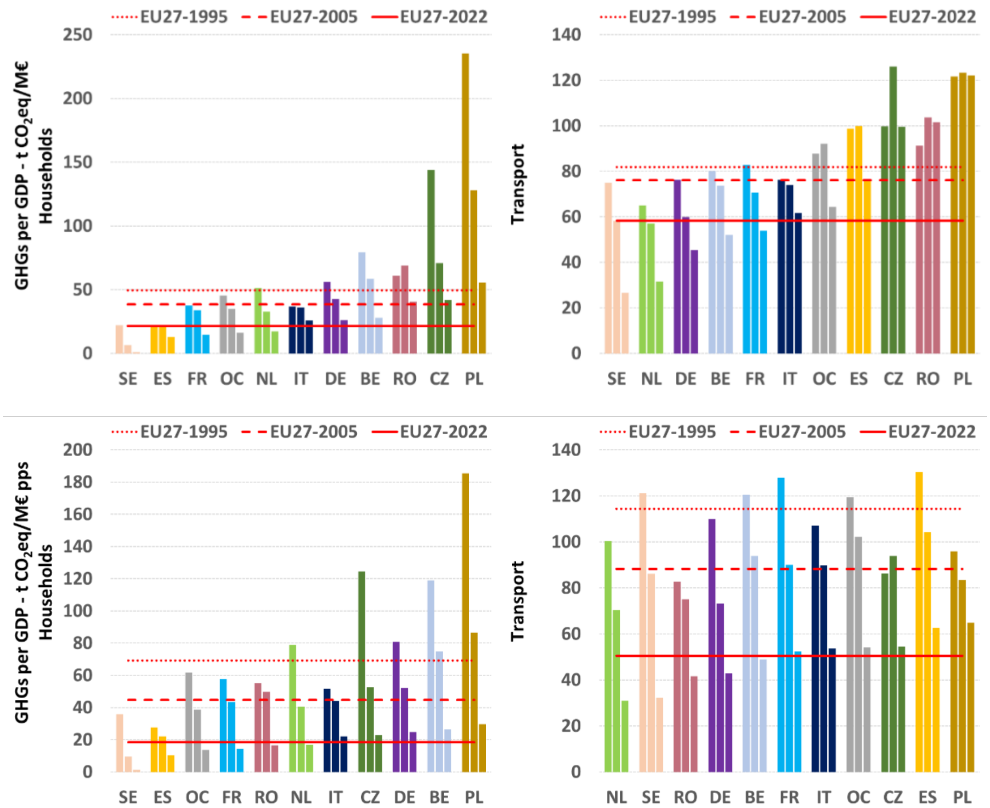
What is seen for energy intensity is reflected in the carbon intensity (t CO_2eq/M€), but this indicator is more sensible to the role of renewable energies, nuclear power and electricity import in the countries' energy balance, because such sources do not produce GHGs, even though the combustion of bioenergy produces CH_4 and N_2O. Although at the lower end the carbon intensity of Italian industry in 2022 is higher than those of Sweden and Germany, among the biggest countries. As for agriculture only Sweden has intensity lower than Italy. The Italian intensities for industry and agriculture are respectively 9.1% and 44.6% lower than EU27 average. On the other hand, services carbon intensity in Italy is 44.9% higher than EU27 average; only Romania, Poland, and Czechia have higher values than Italy. Such configuration deserves more details which are provided in the following pages (Figure 2.33-2.34).

Figure 2.29 – GHGs per value added in 1995, 2005, and 2022. Countries are in ascending order of 2022 value. OC = other countries.



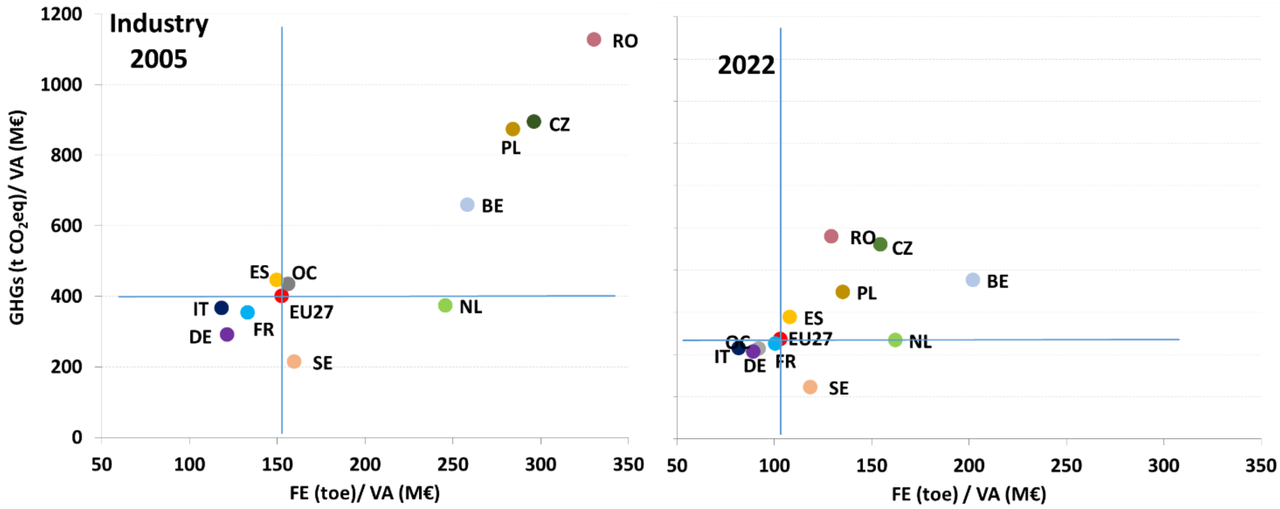
The carbon intensities of households and transport in Italy are higher than the EU27 average (+19.5% for households, +6.2% for transport in 2022; figures with GDP chain linked volumes), showing an important potential to reduce GHGs in households, especially considering that the electrification of final consumption in such sector is much below the EU27 average (18.5% *vs* 25.1% in 2022). Moreover, the district heating in Italy supplies only 2.3% of households' final consumption, whereas the UE27 average is 8.2%. As for transport a detail will be provided in the next pages, here it is enough to note, as done for energy intensity, that the ranking of carbon intensity in the examined countries shows that Italy has wide room for better performances in transport.

Figure 2.30 – GHGs per GDP in 1995, 2005, and 2022 (chain linked volumes, reference year 2015, upper graphs; current prices, purchasing power standards, lower graphs). Countries are in ascending order of 2022 value. OC = other countries.



The position of the biggest EU States in the space defined by the carbon and final energy intensities by sector added value has been investigated. For each sector, all countries move to the lower left corner from 2005 to 2022. Figure 2.31 shows the space for industry. It is evident that the countries are clustering around a narrow area with better performances. European industry reduced the energy intensity by 32.5% from 2005 to 2022, while carbon intensity decreased by 41.2%. Italy reduced the energy and carbon intensities by economy respectively by 30.8% and 41.6%.

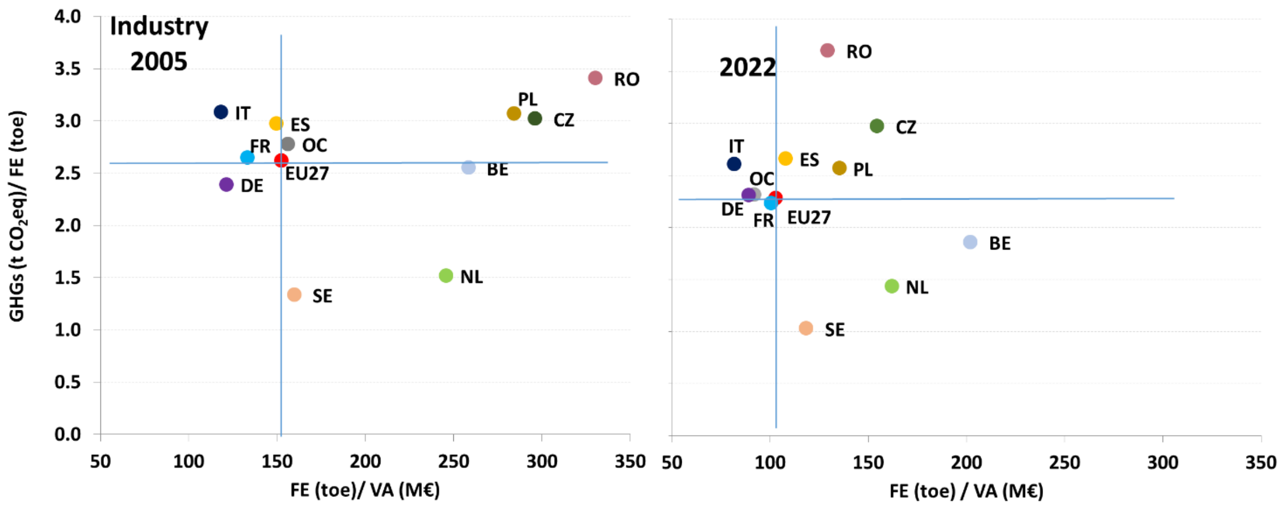
Figure 2.31 – Member States' position in the phase space defined by energy (abscissa) and carbon intensities (ordinate) per value added for the biggest European countries and the groups of other countries.



If the previous graph portrays the efficiency (x-axes) and decarbonization (y-axes) of the sector's economy, the next one depicts on the y-axes the decarbonization of the energy mix used in the final consumption (less GHGs per final energy consumption moving toward the bottom of y-axes). Such dimension is directly linked to the use of no GHGs' emitting sources, as renewables, or sources whose emissions occurred in the transformation sector, as electricity and heat.

In the space shown in the Figure 2.32 it is clear for Italy the increase of energy consumption with no direct emissions in the sector, as well as the room to improve such dimension if compared to Germany, where both renewables and heat play a major role in industry than in Italy. The carbon intensity by energy of Italy in 2005 was 29% higher than Germany and 17.9% higher than EU27, while in 2022 it is 12.9% higher than Germany and 14.3% higher than EU27.

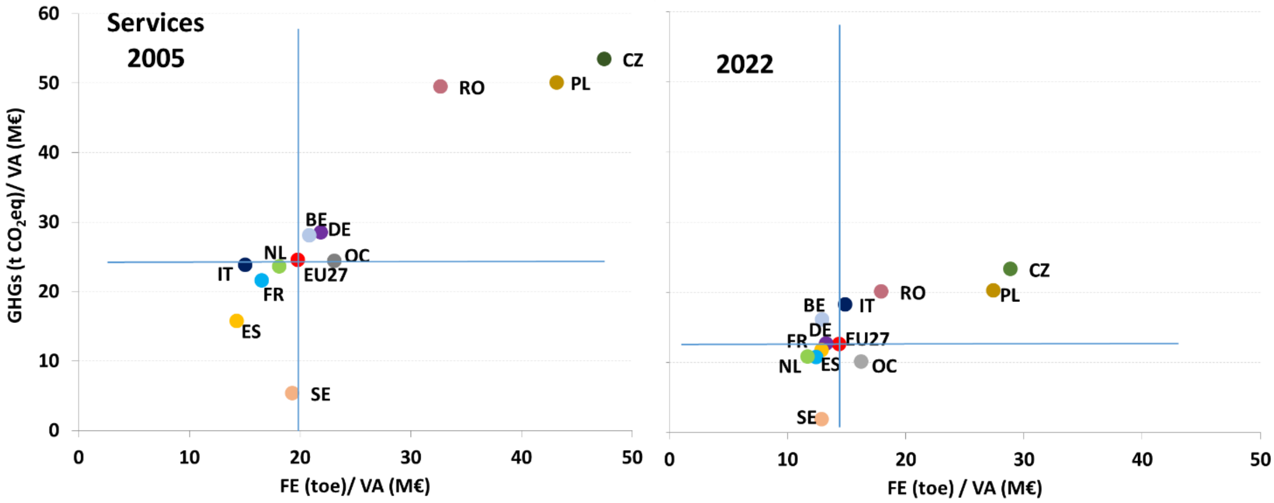
Figure 2.32 – Member States' position in the phase space defined by energy intensity by value added (abscissa) and carbon intensities per final energy (ordinate) for the biggest European countries and the groups of other countries.



Unlike industry, the intensity by economy for services shows that Italy has lost many positions if compared to other countries. Energy intensity did not change significantly (15.1 toe/M€ in 2005, 14.9 toe/M€ in 2022) and carbon intensity decreased from 23.8 t CO_2eq/M€ to 18.2 t CO_2eq/M€. All other countries and

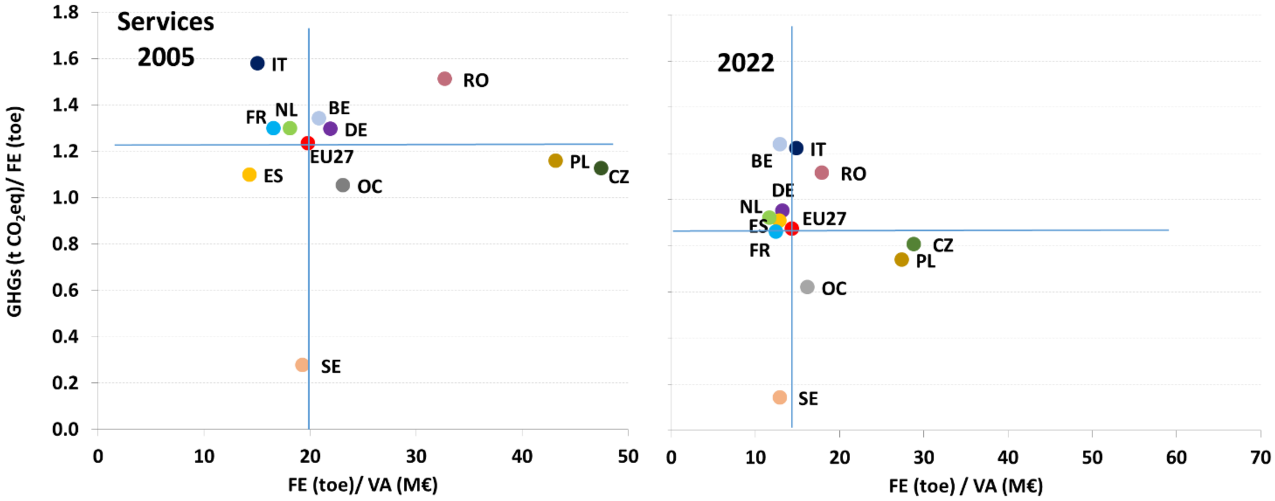
EU27 average show much larger decreases of energy and carbon intensity than Italy (energy intensity: -27.4% EU27 and -1% Italy; carbon intensity: -48.7% EU27 and -23.4% Italy).

Figure 2.33 – Member States' position in the phase space defined by energy (abscissa) and carbon intensities (ordinate) per value added for the biggest European countries and the groups of other countries.



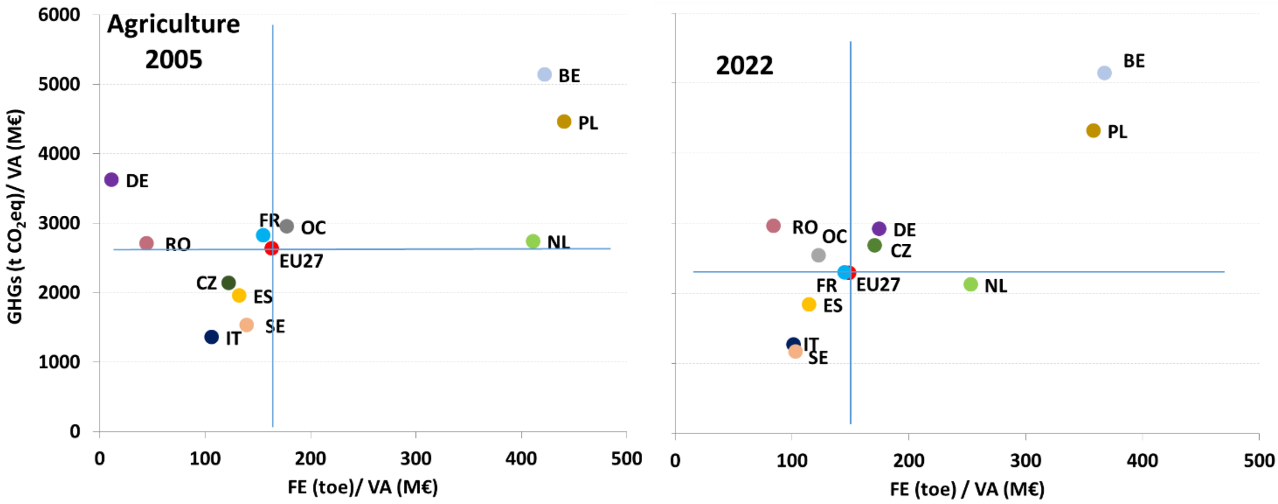
The following graph shows that services in Italy have the 2nd highest carbon intensity per energy as compared to the main European countries (+40% higher than EU27 average in 2022). Such configuration cannot be uniquely interpreted in terms of performance for Italy because it is mainly due to the allocation in this sector of GHG emissions by fossil waste burnt in incinerators with energy recovery. As stated in the National Inventory Report (ISPRA, 2024a): "Emissions from these plants are allocated in the commercial/institutional category because of the final use of heat and electricity production which is mainly used for district heating of commercial buildings or is auto consumed in the plant." Such approach makes incomparable the GHGs from services with the final energy consumption in energy balance, because the final fossil energy consumption in energy balance is significantly lower than the amount reported in CRF (Common Reporting Formats submitted to UNFCCC). The fossil energy consumption for services reported in the energy balance and CRF of Germany, France, and Spain are much closer than data of Italy. Adding the amount of energy by fossil waste considered in the CRF to the final consumption of energy balance, the Italian carbon intensity per energy would be lower by about 12%, with some improvement of the position in the space of phase approaching the EU27 average. Notwithstanding such correction the carbon intensity would remain +23% higher than EU27 average in 2022 showing some room of improvement in the sector's performances.

Figure 2.34 – Member States' position in the phase space defined by energy intensity by value added (abscissa) and carbon intensities per final energy (ordinate) for the biggest European countries and the groups of other countries.



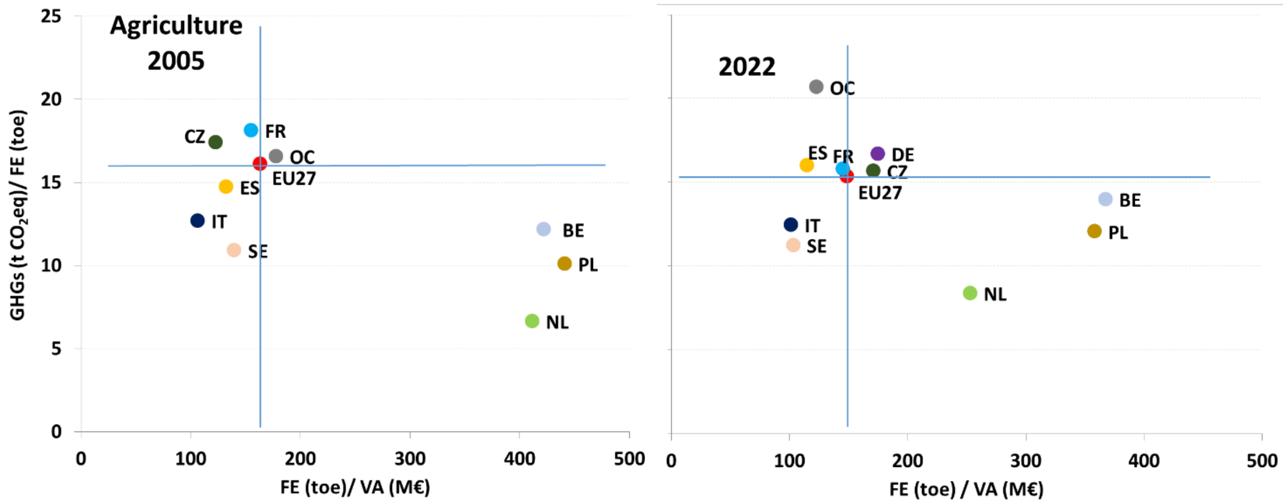
The agriculture is the sector with highest absolute intensities and the following graph shows that in 2022 Italy occupies the position at the lower left corner of the graph, together with Sweden.

Figure 2.35 – Member States' position in the phase space defined by energy (abscissa) and carbon intensities (ordinate) per value added for the biggest European countries and the groups of other countries.



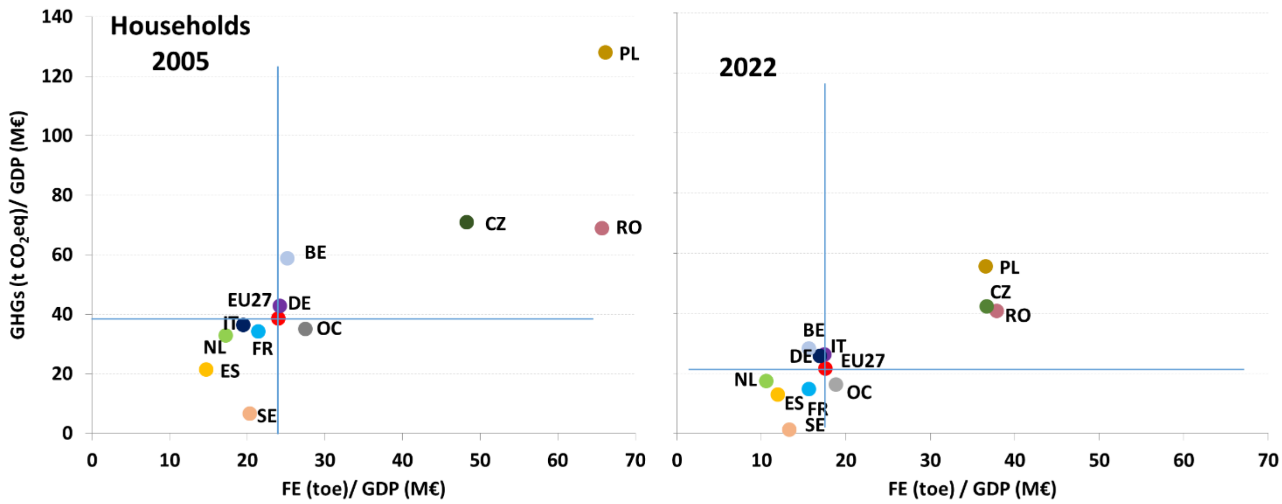
The good position of Italian agriculture is confirmed in Figure 2.36. Carbon intensity per energy of Germany in 2005 is out of the scale (309.3 t CO_2eq/toe).

Figure 2.36 – Member States' position in the phase space defined by energy intensity by value added (abscissa) and carbon intensities per final energy (ordinate) for the biggest European countries and the groups of other countries.



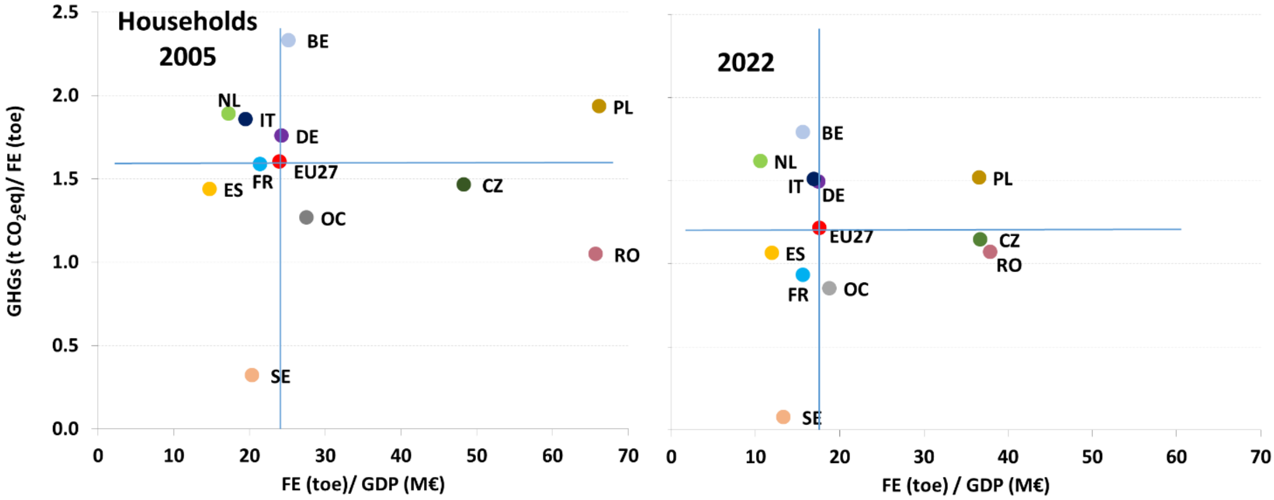
For households and transports, the intensities per GDP are reported in the following graphs. For the household sector, too, the Italian energy intensity has been overcome or reached by countries that had higher values in 2005, such as Germany and Belgium. Italy experienced the lowest improvement of energy and carbon intensities per GDP (Italy -13.2%; EU27 -26.7%). Data in 2022 show that Italy overlaps Germany.

Figure 2.37 – Member States' position in the phase space defined by energy (abscissa) and carbon intensities (ordinate) per GDP for the biggest European countries and the groups of other countries.



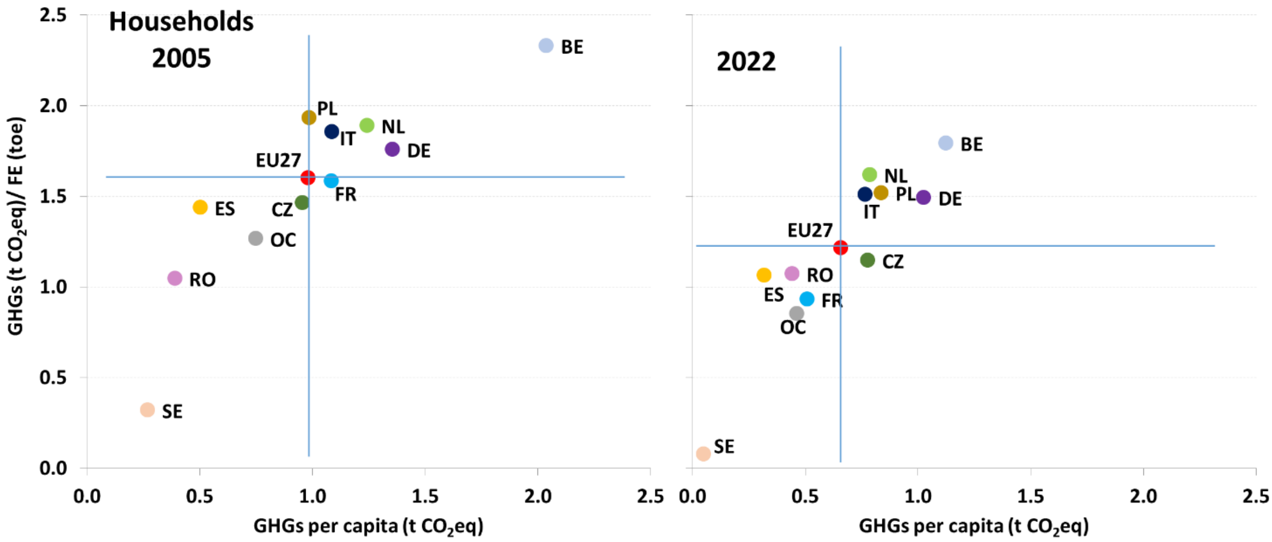
The Italian carbon intensity per final energy shown in Figure 2.38 is well over the European average and aligned to Germany in 2022. The electrification of final consumption is a key factor to reduce the carbon footprint of households and Figure 2.13 shows the gap between Italy and the European average for this sector.

Figure 2.38 – Member States' position in the phase space defined by energy intensity by value added (abscissa) and carbon intensities per final energy (ordinate) for the biggest European countries and the groups of other countries.



For the households another dimension which deserves attention is GHGs per capita. Together with carbon intensity per energy consumption such indicator provides further insights in the decarbonization process of the sector. Since 2005 the EU27 average moved toward the bottom left area, showing the reduction of the carbon footprint in the residential sector, notwithstanding a wide range among countries. Indeed, all countries, except Romania, reduced both carbon intensity and GHGs per capita compared to 2005. The "travel" length, as defined in paragraph 2.1.2, spanned from 0.1 for Romania which travelled the shortest distance, to 1.1 for Belgium, which run the longest one. Italy moved together to EU27 average along a quite similar distance (0.5).

Figure 2.39 – Member States' position in the phase space defined by GHGs per capita (abscissa) and carbon intensities per final energy (ordinate) for the biggest European countries and the groups of other countries.

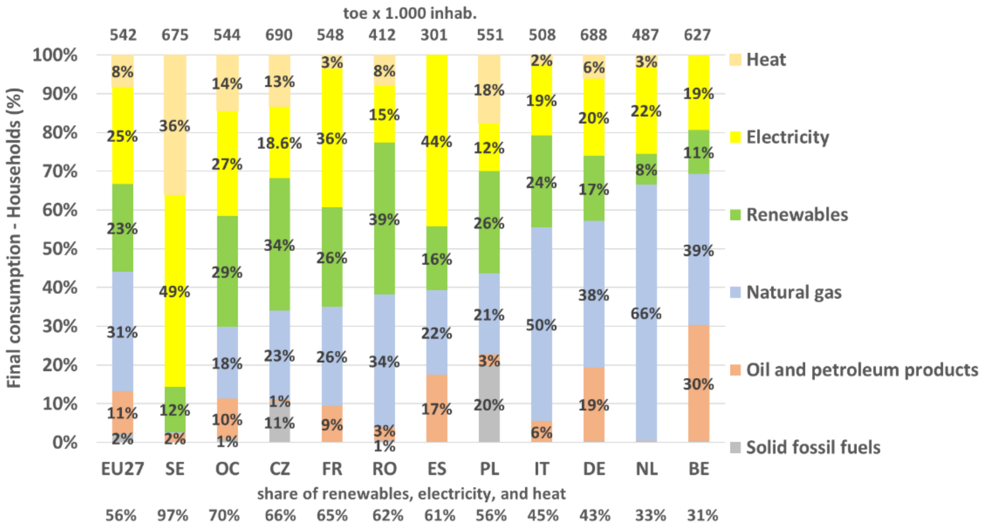


The details on households' final energy uses are provided in Figures 2.40-2.42. Figure 2.40 shows the share of energy consumption by energy carrier and the average energy consumption per 1.000 inhabitants.

The average energy consumption in EU27 in 2022 is 542 toe per 1.000 inhabitants, 7% above the Italian figure. The energy consumption per capita among the considered countries span from 690 toe per 1.000 inhabitants in Czechia to 301 toe per 1.000 inhabitants in Spain. Germany, the biggest country, recorded 688 toe per 1.000 inhabitants.

As shown in Figure 2.40, natural gas is the main source of energy in EU27 (30.9%), followed by electricity (25.1%) and renewables (22.6%). Oil and petroleum products supply 10.9% of energy, while solid fuels account for 2.4%. The heat provides 8.2% of final energy. It is noteworthy noting that the GHGs from electricity and heat consumed in households are accounted in the 1.A.1.a of CRF, while the combustion of bioenergy is considered a net zero CO_2 emitting process. Such items account for 55.9% in EU27. Sweden and the group of minor countries recorded in 2022 the highest share of no emitting items, respectively 97.3% and 70.1%. At the last end there are the Netherlands and Belgium with 33.4% and 30.7%.

Figure 2.40 – Share of final energy consumption in households by energy carrier in EU27 and biggest countries in 2022. Countries in descending order of share of renewables, electricity, and heat. OC = other countries.



As shown in Figure 2.41, the main purpose of energy consumption in EU27 is space heating (63.5% with 344.2 toe per 1.000 inhabitants out of 542.2 toe per 1.000 inhabitants), spanning from 39.5% in Spain to 71.3% in Belgium among the examined countries. The European average share of energy consumption for water heating is 14.9% (80.5 toe per 1.000 inhabitants), from 10.3% in France to 19.1% in Spain. Lighting and electrical appliances consumption accounts for 13.9% in EU27 (75.4 toe per 1.000 inhabitants, all by electricity), with the wider span recorded: from 7% in Czechia to 32.5% in Spain. The European share for cooking is 6.3% (34 toe per 1.000 inhabitants), from 1.8% in Belgium to 9.8% in Romania. Space cooling accounts only for 0.6% of energy consumption in EU27 (3.4 toe per 1.000 inhabitants, all by electricity), from no consumption in the Netherlands and Poland to 2.1% in Italy.

The electricity carrier is mainly used for lighting and electrical appliances (55.4%), although even other uses are satisfied by electricity: space heating (15.4%), water heating (11.5%), and cooking (12.6%). The mentioned figures must be compared with the shares of energy consumption by use in Italy: 61.1% for lighting and electrical appliances, 6.9% for space heating, 7.7% for water heating, 2.1% for space cooling. As for the latter item it must be emphasized that Italy has one of the highest energy consumptions (10.5 toe per 1.000 inhabitants *vs* 3.4 toe per 1.000 inhabitants in EU27); only four European countries have higher figures than Italy (42.3 in Cyprus, 33.6 in Malta, 14.5 in Greece, and 12 in Croatia).

Figure 2.41 – Disaggregated final energy consumption in households by energy carrier and use in EU27. The labels on the bars of left-hand graph are the energy consumption 1.000 inhabitants by energy carrier. The labels on the right-hand graph are the energy consumption 1.000 inhabitants by energy carrier and use.

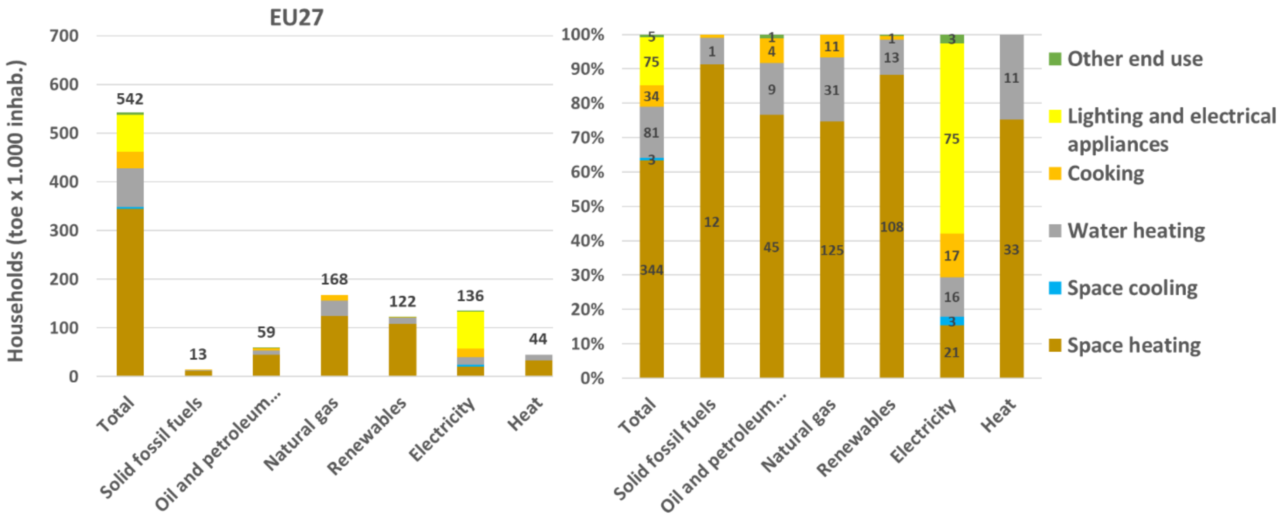
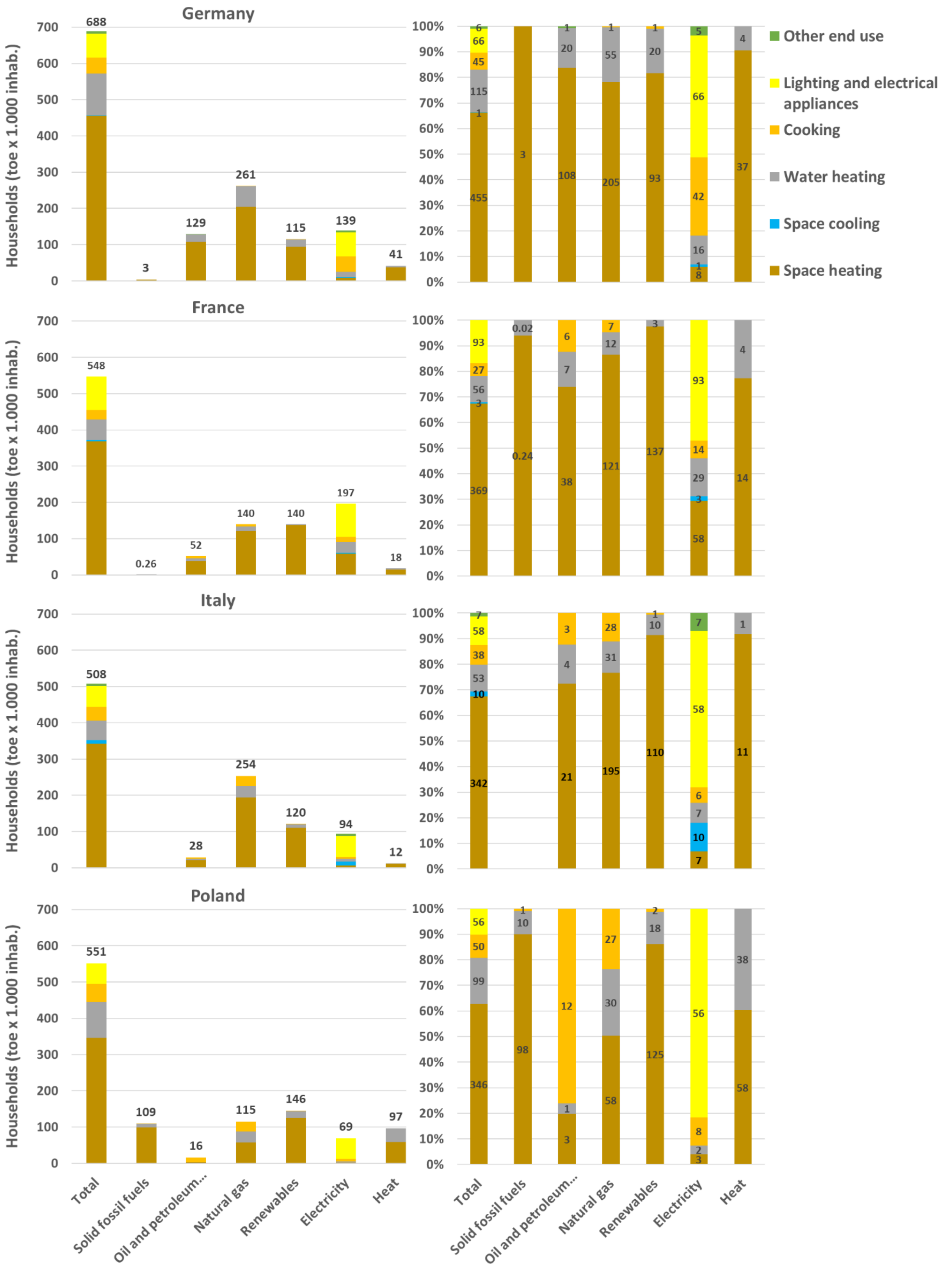


Figure 2.42 shows the details of households' final energy uses in the four European countries with the highest energy consumption and GHGs in the sector: Germany, France, Italy, and Poland. As already seen in Figure 2.40, among the four countries France has the highest share of energy consumption by sources whose GHGs are accounted in other sectors (GHGs from electricity and heat production are accounted in sector 1.A.1.a. of CRF) or do not occur at all (renewables). The country has the highest electricity consumption per 1.000 inhabitants among the considered countries: 196.8 toe against 68.6 toe in Poland, 94.2 toe in Italy, and 138.7 toe in Germany. Even the energy consumption by renewables in France is higher than the European average (140.3 toe per 1.000 inhabitants *vs* 122.4 toe per 1.000 inhabitants in EU27). Among the four biggest countries only Poland recorded higher consumption (145.5 toe per 1.000 inhabitants). Italy and Germany recorded respectively 120.4 and 114.5 toe per 1.000 inhabitants. As for heat consumption in Italy has the lowest share among the considered countries (2.3% against 3.4% in France, 5.9% in Germany, 17.5% in Poland). Italy has the lowest heat consumption per 1.000 inhabitants among the considered countries: 11.6 toe against 18.4 toe in France, 40.9 toe in Germany, 96.6 toe in Poland. The EU27 average consumption of heat is 44.3 toe per 1.000 inhabitants.

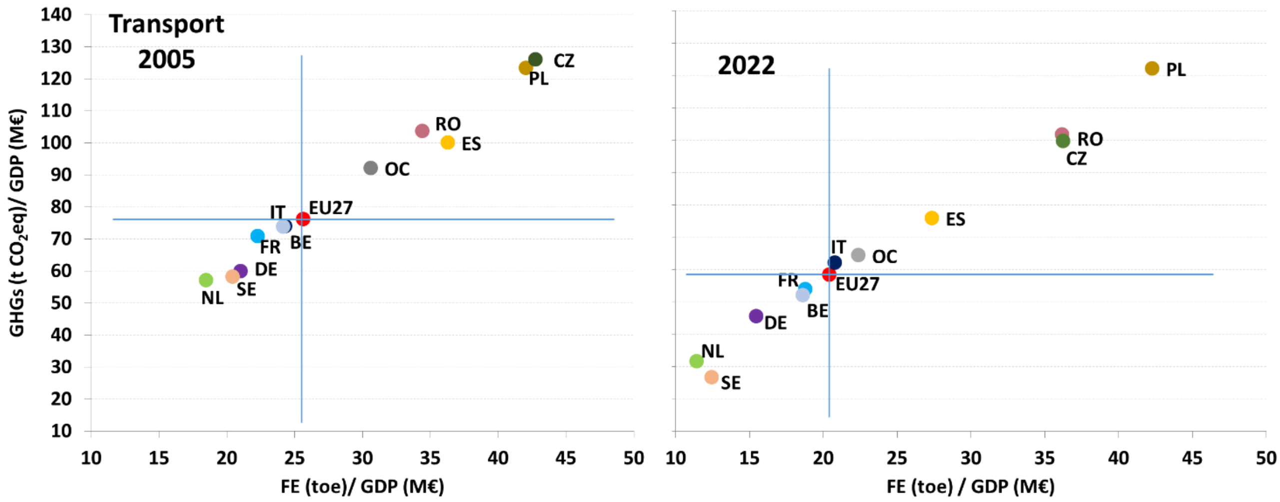
Such data make clear the room of improvement for Italy in the households, mainly on the side of electrification of final consumption and use of district heating.

Figure 2.42 – Disaggregated final energy consumption in households by energy carrier and use in Germany, France, Italy, and Spain (in decreasing order of energy consumption). The labels on the bars of left-hand graph are the energy consumption 1.000 inhabitants by energy carrier. The labels on the right-hand graph are the energy consumption 1.000 inhabitants by energy carrier and use.



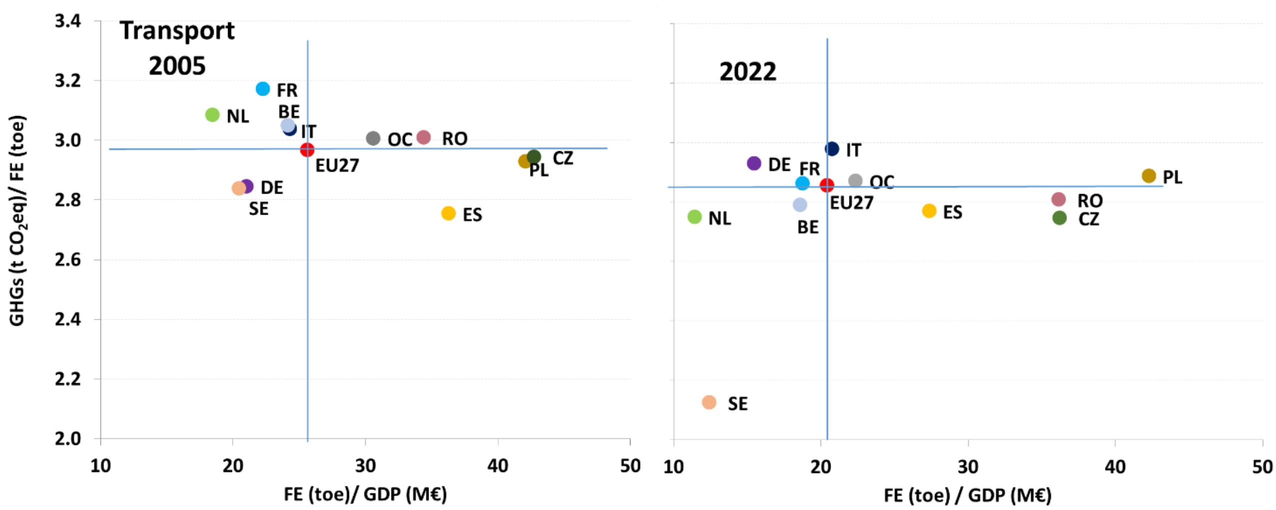
The sector of transport shows a linear correlation between GHGs and energy consumption, mainly made up of fossil fuels. For this sector too, it is clear the shift of countries towards lower intensities. The average decrease on the two dimensions shown in Figure 2.43 was about 20% for energy intensity and 23% for carbon intensity, respectively. On such dimensions Poland and Romania recorded marginal shift and among countries which reduced significantly their intensities Italy recorded the lower rate of reduction.

Figure 2.43 – Member States' position in the phase space defined by energy (abscissa) and carbon intensities (ordinate) by GDP for the biggest European countries and the groups of other countries.



The final energy intensity of Italy is very close the European average but the carbon intensity per energy consumption in 2022 (Figure 2.44) is the highest among the biggest country, followed by Germany which, with Spain, were the only countries whose carbon intensity increased: +3% in Germany and +0.5% in Spain. For all other countries the carbon intensity recorded some decrease with relevant differences among countries. Poland and Italy recorded the lower reduction: -1.4% and -2%, respectively, while at the highest end there are the Netherlands with -10.9%, France with -9.8%, and Sweden with -25.1%. EU27 reduced carbon intensity per energy consumption by -3.8%.

Figure 2.44 – Member States' position in the phase space defined by energy intensity by value added (abscissa) and carbon intensities per final energy (ordinate) for the biggest European countries and the groups of other countries.

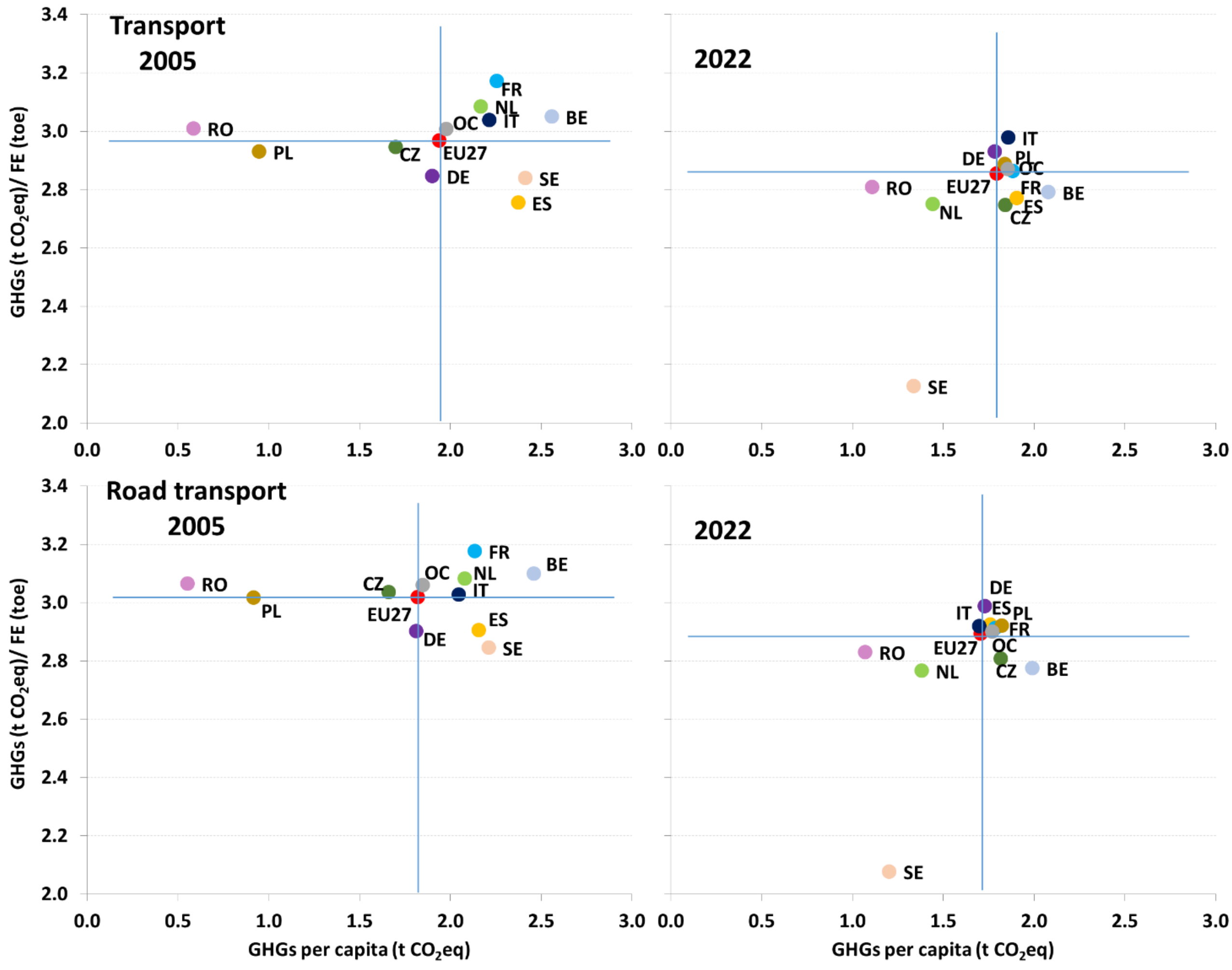


For transport, as well as for households, has been examined the positioning of countries in the phase space defined by GHGs per capita and carbon intensities per final energy consumption. Moreover, since road transport represents 95% of sector's European emissions in 2022, from 90% in Sweden to 99.1% in Poland, specific attention deserves such subsector. The no energy final consumption in the sector has been allocated in road transport according to the GHGs share.

GHGs per capita of the whole sector increased only in Czechia, Poland, and Romania, while all other countries decreased from -6.2% in Germany to -44.5% in Sweden; the European average is -7.4%. Italy recorded -16.2%. The increasing GHGs per capita in Czechia, Poland, and Romania cannot be read only in terms of performance. Such countries started from lower level of mobility compared to the other countries so the increase of GHGs per capita shows the alignment to European standard.

Considering only road transport there is a turnover at the top position of carbon intensity per energy in 2022, with Germany which recorded the highest value and many countries, with Italy among them, which approached the EU27 average. This outcome is explained by the role of other transport items in Italy. Even though such items have minor share, both on the energy consumption side (7%) and the GHGs side (8.5%), Italy's carbon intensity for transport other than road is the highest among the biggest countries, because of the higher share of GHGs from domestic navigation and domestic aviation compared to other countries and EU27 in 2022 (navigation: 2.2% in EU27 and 5.3% in Italy; aviation: 1.6% in EU27 and 2.3% in Italy), so the role of such items is crucial to place Italy at the top of carbon intensity per energy consumption in the sector of transport in 2022. Anyway, as already reported transport other than road accounts for 8.5% of GHGs from transport and any improvements of carbon intensity for this section would lead to minor effects for the whole sector.

Figure 2.45 – Member States' position in the phase space defined by GHGs per capita (abscissa) and carbon intensities per final energy (ordinate) for the biggest European countries and the groups of other countries.



In 2022 GHGs from cars account for 59.1% of EU27 emissions from road transport and 56.2% of emissions from the whole sector. GHGs from cars in Italy account 63.8% of road transport emissions and 58.4% of transport emissions. There is a wide range in the Member States with shares of emissions from cars on road emissions going from 46.3% in Greece to 67.9% in Croatia, but all road emissions in Finland are due to cars. So, it is important to delve in the segment of road transport and break up GHGs from cars and other vehicles.

The positioning of MSs in the phase space defined by GHGs per capita and carbon intensities per GDP has been examined for the two segments of road transport (Figure 2.46). The picture shows clearly that the carbon intensity per GDP reduced much more than emissions per capita in both segments. The GHGs per capita in EU27 in the period 2005-2022 reduced by 8.3% for cars and 3% for other vehicles, while the carbon intensity per GDP reduced by 24.1% and 19.8% respectively. In Italy, unlike the other countries, there is the same rate of change of population and GDP in 2022 compared to 2005, while in EU27 the GDP grew much more than population. So, in Italy GHGs per capita and GHGs per GDP reduced both by 11.4% for cars and 25.1% for other vehicles.

In the cars' segment the only countries, among the biggest ones, with higher GHGs per capita and carbon intensity in 2022 compared to 2005 are Czechia, Poland, and Romania. As for other vehicles, beyond the mentioned countries, also Germany increased the GHGs per capita, while as concerns carbon intensity only Poland increased GHGs per GDP.

The overall performance of cars' segment allows to conclude that, among the biggest countries (excluding Czechia, Poland, and Romania for the reasons already mentioned), Italy reduced emissions per capita and per GDP lesser than other countries, while as concerns the segment of other vehicles the improvement of the Italian performances is overcome only by the Netherlands and Sweeden. It must be stressed that the relative change of 2022 compared to 2005 overlooks the starting point. Germany is emblematic in this regard, because the country shows little change but had better performances since 2005.

In absolute terms the GHGs per capita and per GDP of Italian cars in 2022 are respectively 7.5% and 10.3% higher than EU27 average and only exceeded by Spain, among the biggest countries. The mobility behaviour of citizens, as well as policies which determine the share between public and private mobility, explain the observed frame. It goes beyond the aims of this report to furtherly delve into such tangle but surely the number of cars could give some insight in this regard. As shown in Figure 2.47 the number of cars in Italy is the highest in Europe after Luxembourg. Moreover, among the biggest countries the Italian share of oldest cars (>10 years) is higher than those recorded in France, the Netherlands, Sweeden, Germany, and Belgium.

Unlike the cars, for the other vehicles the GHGs per capita and per GDP in Italy are respectively 11.9% and 9.6% below the EU27 average. The Netherlands, Sweeden, and Romania have GHGs per capita lower than Italy. As for GHGs per GDP, Germany, the Netherlands, and Sweeden have better performance than Italy.

Figure 2.46 – Member States' position in the phase space defined by GHGs per capita (abscissa) and carbon intensities per GDP (ordinate) for the biggest European countries and the groups of other countries.

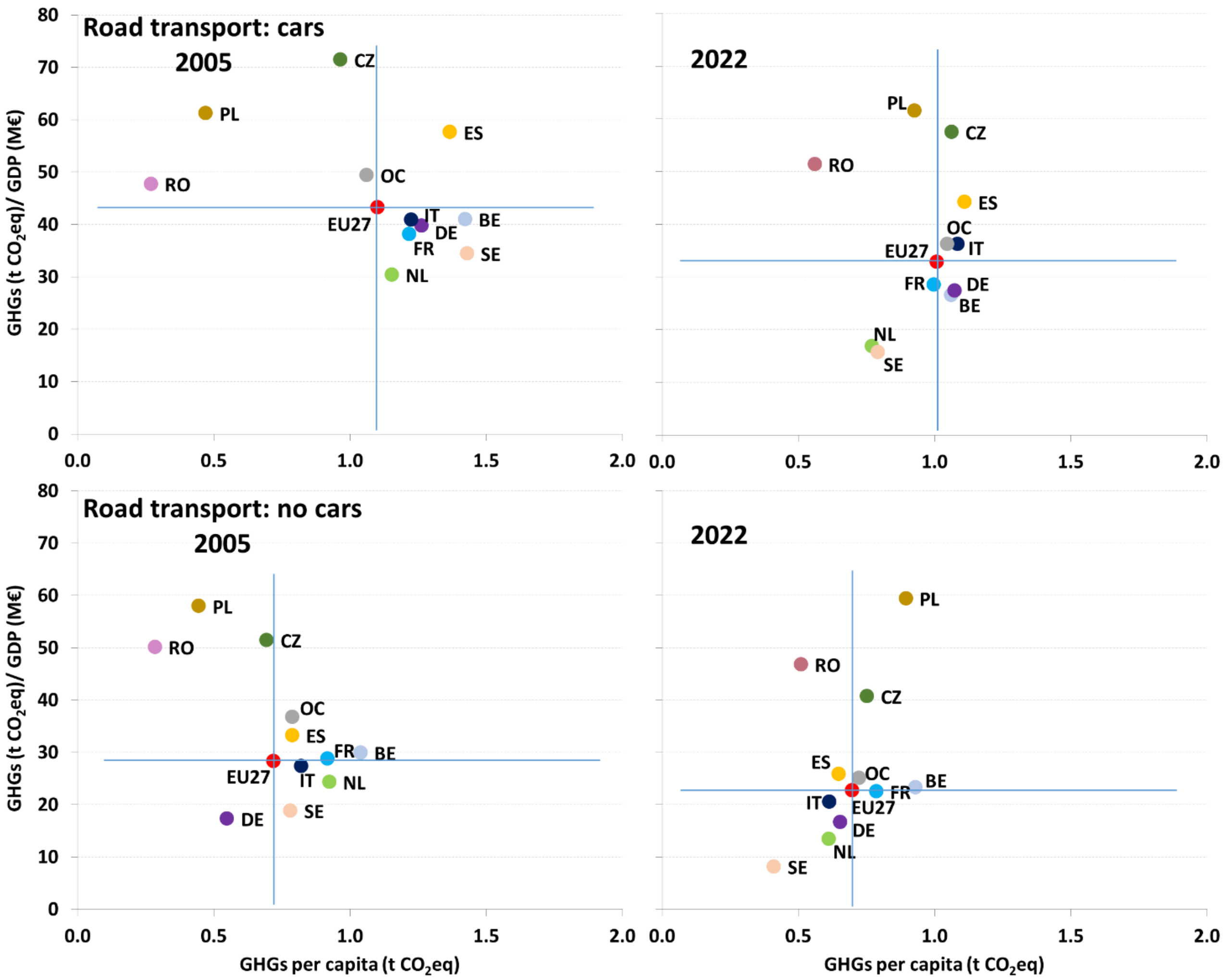


Figure 2.47 – Number of cars by age per 100 inhabitants. Dark grey, not available the age of cars.

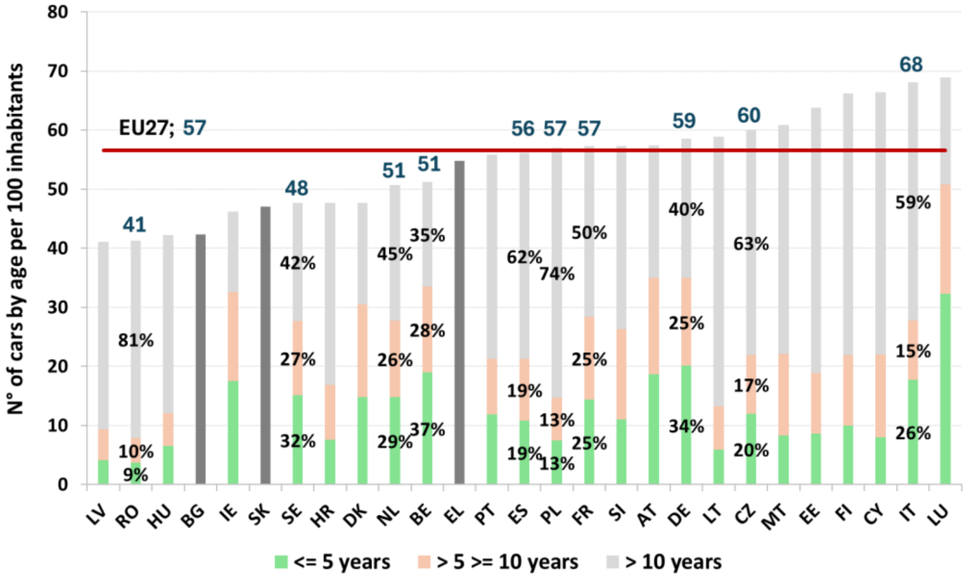
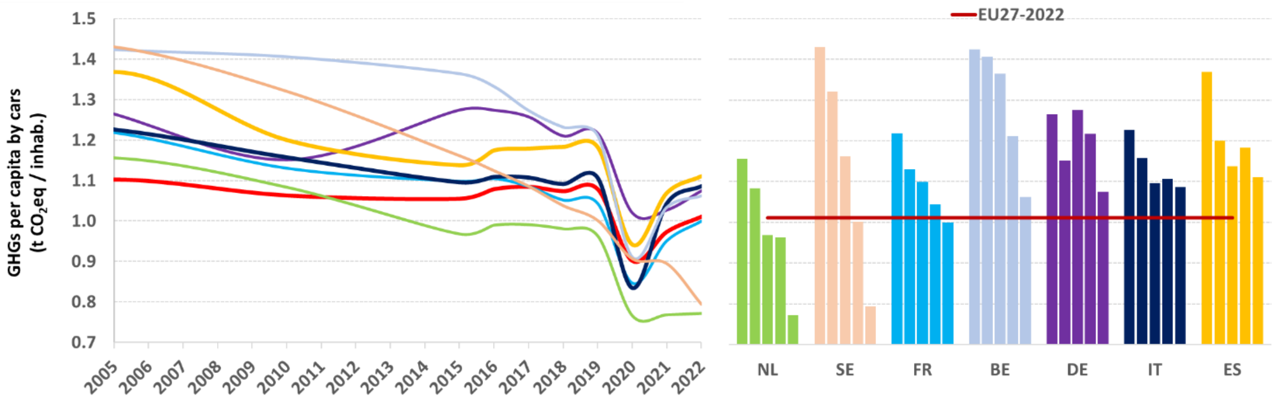


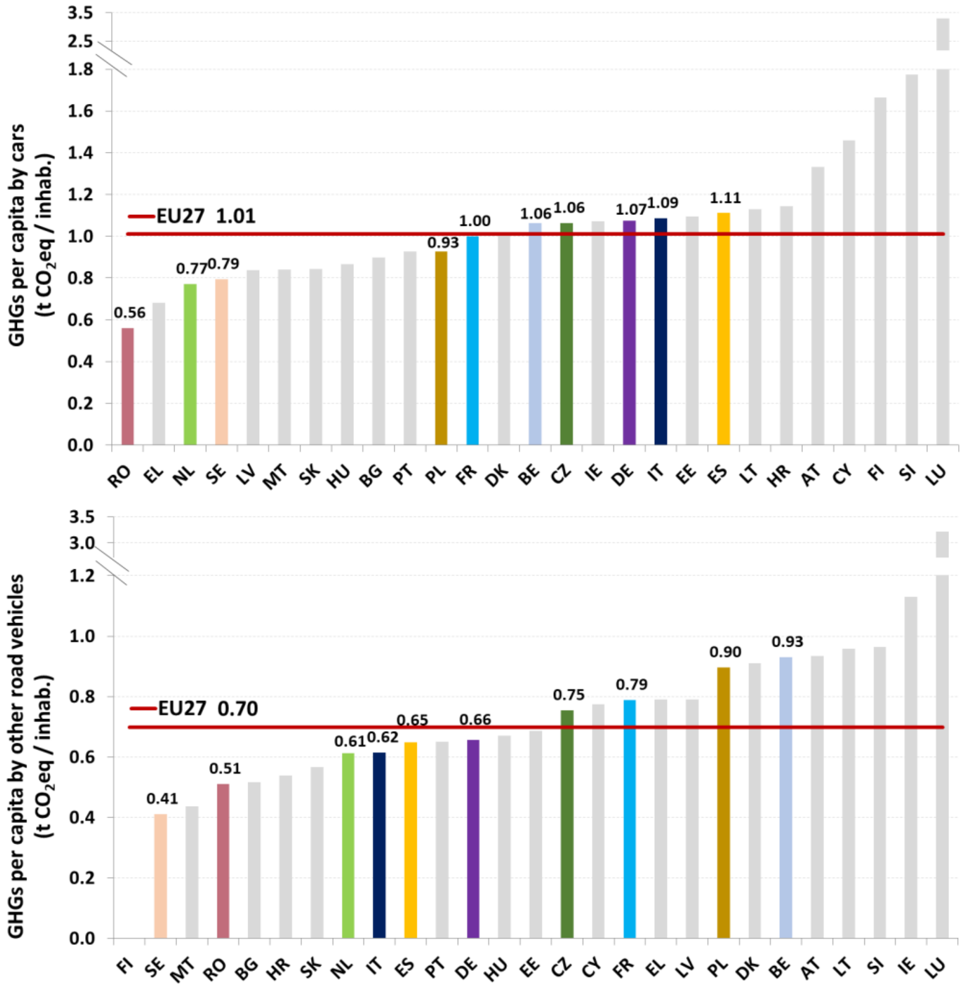
Figure 2.48 shows the trend of GHGs per capita since 2005 for the biggest European countries. Poland, Czechia, and Romania are not reported because, as already mentioned, for historical reasons had much lower values with an upward trend and cannot be compared with the considered countries for this indicator. The left-side graph shows that in 2020 the GHGs per capita fall in all countries because of the pandemic. Since 2021 a rebound has been recorded for most countries but while Italy came back to values just lower than the pre-pandemic values (2019), the other countries reduced significantly their GHGs per capita compared to pre-pandemic levels. Such outcome is more evident in the right-side of Figure 2.48, where the represented years do not include 2020.

Figure 2.48 – GHGs per capita from cars by country. The bars on the right-side graph represent 2005, 2010, 2015, 2019, 2022. Data in ascending order of 2022 value.



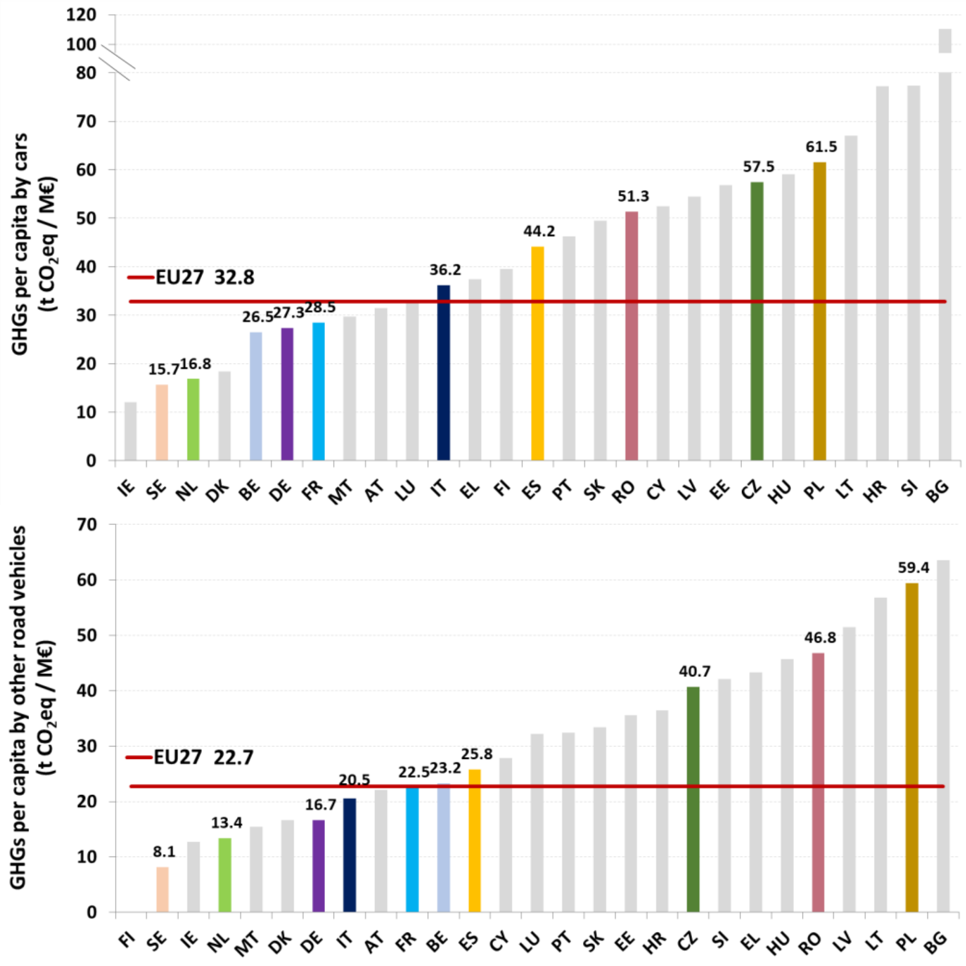
To sum up the situation for road transport Figure 2.49 shows the emissions per capita from cars and other vehicles in 2022 in all European countries. As for the cars, only Spain has higher emissions per capita than Italy among the biggest countries, while the ranking for other vehicles is quite different, and Italy is well below the European average.

Figure 2.49 – GHGs per capita from cars and other road vehicles by country in 2022. Data in ascending order.



Even emissions per GDP (Figure 2.50) place Italian cars over the European average and many positions after countries as Germany, France, and Belgium with better performances, while as concerns other road vehicles the emissions per GDP in Italy are lower than the European average and near, although higher, to Germany. The GDP used is expressed in chain linked volumes (reference year 2015), but the same picture for the mentioned countries is confirmed considering GDP with purchasing power standards.

Figure 2.50 – GHGs per GDP from cars and other road vehicles by country in 2022. Data in ascending order.



2.1.3 Material flow accounts

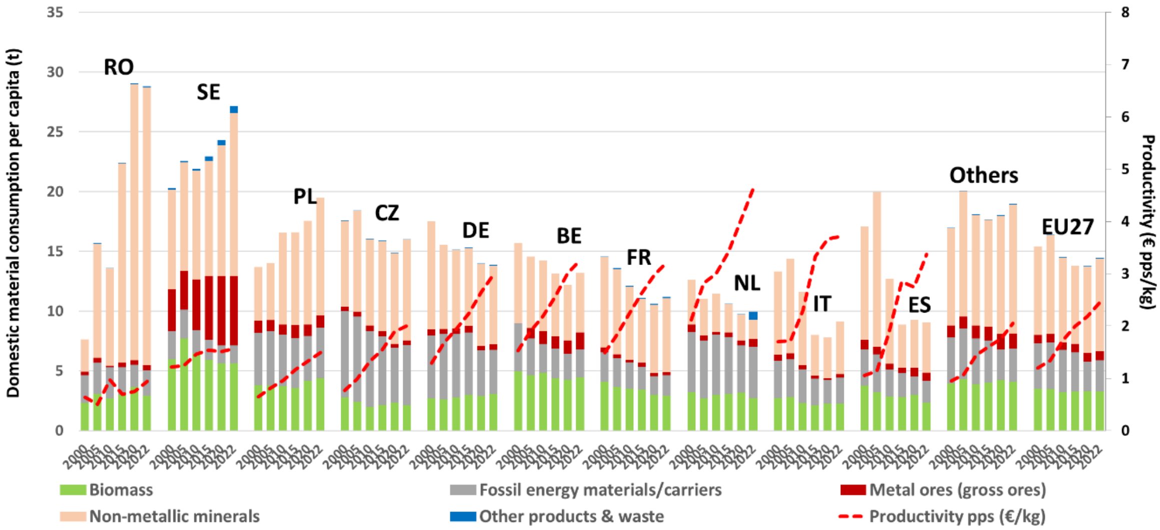
This paragraph compares material flow accounts among countries *(EW-MFA Economy Wide - Material flow Accounts)*. The material flows for Italy are processed by ISTAT and communicated to Eurostat in whose database the material flows of the other Member States are also available (last update: 26/09/2023). For Italy, the historical series is drawn up from 1990 to 2022 (provisional data). The availability of data from other countries allows comparison only from 2000.

The EW-MFA is an approach to measure the interactions between the environment and the anthropogenic system, that is, the exploitation of resources used in human activities. EW-MFA provides an aggregate measure (mass) of material flows in and out of an economic system. In Eurostat's EW-MFA material inputs to the economy cover extractions of natural resources (excluding water and air) from the natural environment and imports of material products (goods) from the rest of the world economy. Material outputs are disposals of materials to the natural environment and exports of material products and waste to the rest of the world. EW-MFA is a satellite account of national accounts prepared by ISTAT in accordance with the European Regulation 691/2011 on environmental accounting and is developed with harmonized methodologies at European and international level.

Indicators of *direct material inputs (DMI)* and *domestic material consumption (DMC)* describe, in aggregate terms, the direct use and provenance of natural resources and products. The first indicator includes all materials which have an economic value and are used for production and consumption activities and the indicator is calculated as the sum of internal extractions and imports. The second indicator represents domestic consumption of matter in the national economy net of exports and is calculated by subtracting from direct material inputs the share of physical exports. The indicators make possible to analyse the material aspects of socio-economic metabolism related to the environmental sustainability of production and consumption patterns, and - in conjunction with the traditional national accounts, with which they are consistent - allow economic activity to be dissociated from environmental pressures and the intensity/efficiency of resource use (Femia and Paolantoni, 2012; Paolantoni and Femia, 2016). One economic system which, with the same flow of matter, produces more wealth than another is a more efficient system.

Since 2000, the average DMC per capita decreased in the European countries. Spain has the lowest consumption per capita of matter among all EU27 countries in 2022, followed by Italy and the Netherlands. As for resource productivity there is a general increase since 2000, although the absolute values of the countries are very different. The average annual growth rates among the biggest countries range from 1.2% for Sweden to 5.4% for Spain; Italy's annual rate is 3.6%. The Netherlands shows the highest value (4.6 €/kg in 2022), followed by Italy (3.7 €/kg). Germany and France productivities are 3 €/kg and 3.2 €/kg, respectively.

Figure 2.51 – Domestic material consumption per capita by type of material and resource productivity at purchasing power standard. Countries sorted in descending order by DMC per capita in 2022.

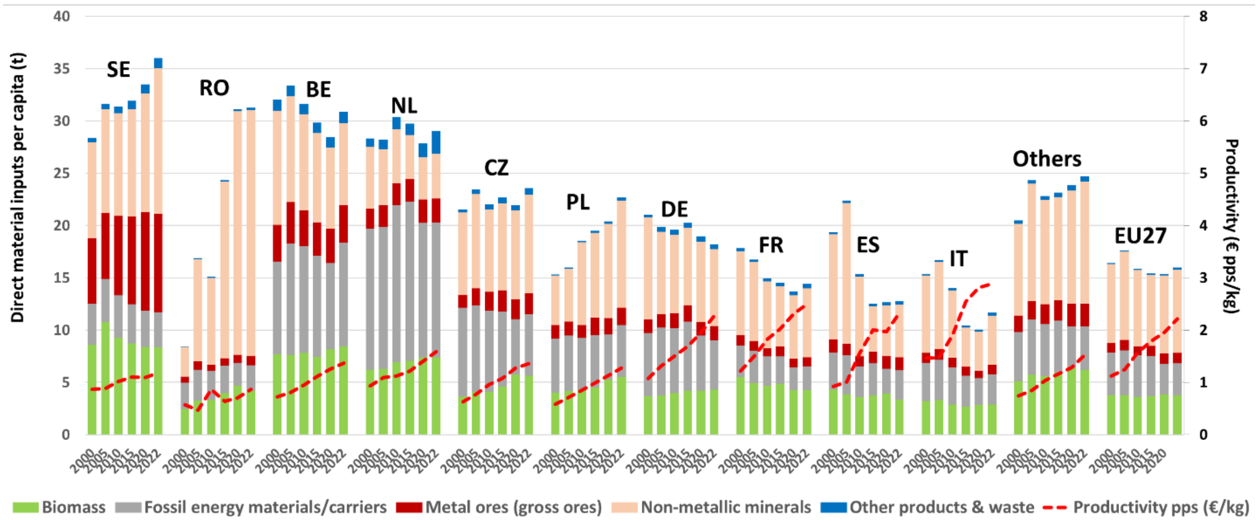


As already reported, direct material inputs (DMI) include all materials which are economically valued and are directly used in production and consumption activities. Such indicator is equal to the sum of internal extractions and imports. Since this indicator represents domestic consumption without exports, it is useful for assessing actual material consumption, including that not used in domestic production and consumption activities and addressed to exports.

The following graph, realized in the same way as the previous one, shows the direct material inputs per capita and the resource productivity. Sweden, Romania, Belgium, and the Netherlands have high share of fossil extraction, biomass, and metal ores destined for exports and shows the highest DMI per capita among the biggest European countries, far above the European average. It is also clear the increasing DMI per capita recorded in Romania. Italy recorded in 2022 the lowest value among all European countries (11.6 t per capita *vs* EU27 average of 16 t per capita).

As for resource productivity Italy have the 2nd highest value among the European countries (2.9 €/kg), the 1st one is recorded for Ireland (3.1 €/kg). The productivity of the Netherlands for this indicator (1.6 €/kg) does not show high performance as for DMC.

Figure 2.52 – Direct material inputs by type of material per capita and resource productivity at purchasing power standard. Countries sorted in descending order by DMI per capita in 2022.



The direct material inputs are far greater than the domestic material consumption due to the amount of material exported. The surplus percentage of DMI per capita compared to DMC per capita is on average 10.6% for EU27 in 2022, and ranges from 8.4% in Romania to 191.5% in the Netherlands. The share of export is quite relevant also for Belgium with a surplus of 137.7%. The Italian figure is 28.3%, in line with the other biggest countries (France 28.8%; Germany 31.9%; Spain 44.6%).

It should be noted that the reciprocal of productivity is an indicator of material intensity (Fischer-Kowalski *et al.*, 2011), *i.e.*, a measure of the exploitation of material resources. The countries with the lowest productivity are therefore the countries with the greatest pressure on their material reserves.

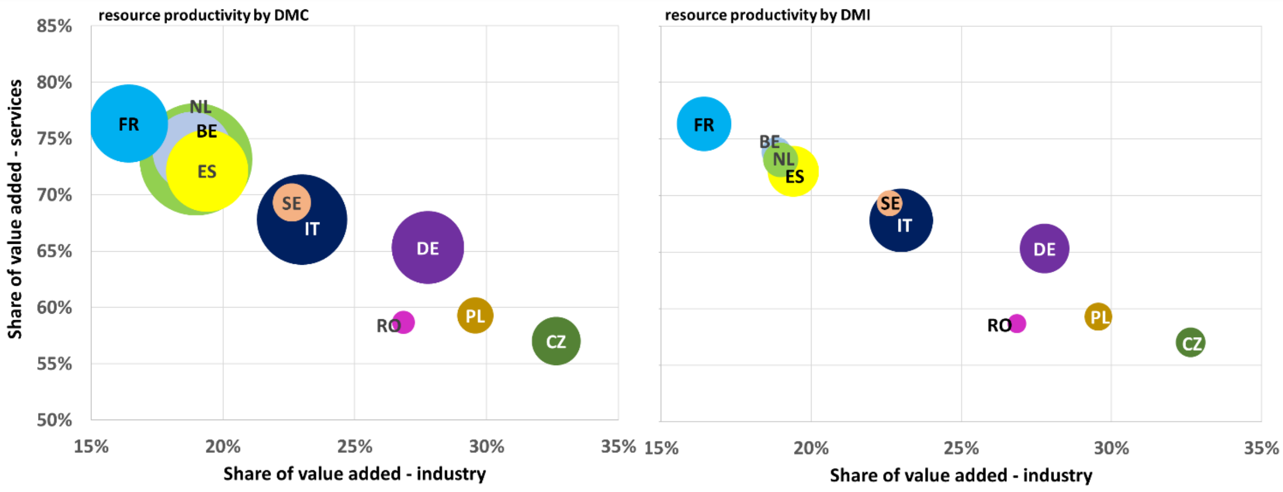
Although productivity provides information on the economic efficiency of the whole system, it is nevertheless necessary to consider that efficiency depends not only on maximizing the performance of the material used but also on the country's economy structure which plays a decisive role as concerns the material consumption. A service-based economy will have lower material consumption than an economy based more on manufacturing industry. Industrial activities are more energy intensive than service activities. This is true to a greater extent for the material consumption which is the subject of extraction and transformation of industrial activities.

The resource productivity depends jointly both on the efficiency of resource use in each sector and on sector's share for each State. Material consumption at sectoral level is not available but it is possible to assess the role of each sector using *proxy* variables to unbundle material consumptions at the sector level. To assess the impact of economic sectors on the productivity index, final energy consumption was used as a proxy to disaggregate the material consumption among sectors. Even though there is not a perfect correspondence between energy consumption and material flow, such approach provides insight on the different order of magnitude of resource productivity by sector. The material consumption, like energy consumption, also takes place in sectors that do not have a corresponding value added, such as the households and transport sectors. In addition, transport is a cross-cutting sector which contributes to the value added of the productive sectors. No breakdown of transport energy consumption in the economic sectors was made for the following elaboration. The purpose of the breakdown is to assess the productivity range of the following economic sectors: industry (including construction), services and agriculture.

Domestic material consumption of each country has been broken down into sectors (including households and transport) according to their share of final energy consumption. The value added for industry and construction, services and agriculture has been divided by their estimated material consumption. Sectoral productivity highlights the contribution of each sector to total productivity. The following graph makes it clear that a predominantly service-based economy has a higher resource productivity than an industry-based economy regardless of the efficiency of individual sectors. The median sector productivity in 2022 is 1 €/kg in the industry and construction, 0.9 €/kg in agriculture, and 7.1 €/kg in services. The sectoral productivities in the countries examined range from 0.3 €/kg (Romania) to 2.6 €/kg (Italy) for industry and construction, 2.5 €/kg (Romania) to 24 €/kg (the Netherlands) for services and 0.3 €/kg (Poland) to 2.1 €/kg (Italy) for agriculture.

The following graph summarize the resource productivity for each country, considering the relative positioning of the countries' economy in the industry/service space. The left side graph shows that Italy, despite having a higher share of industrial value added than France and Spain, has higher productivity (DMC); a clear result of greater efficiency in the use of resources, mainly in the industrial sector. This result is in line with what was previously seen for energy intensity indicators. Considering the DMI the right-side graph shows that the productivity is significantly lower than for DMC. DMI productivity in the Netherlands falls by 65.7% compared to DMC productivity. For the other countries the gap ranges from 7.8% for Romania to 57.9% for Belgium, while Italy's DMI productivity is 22.1% lower than DMC productivity.

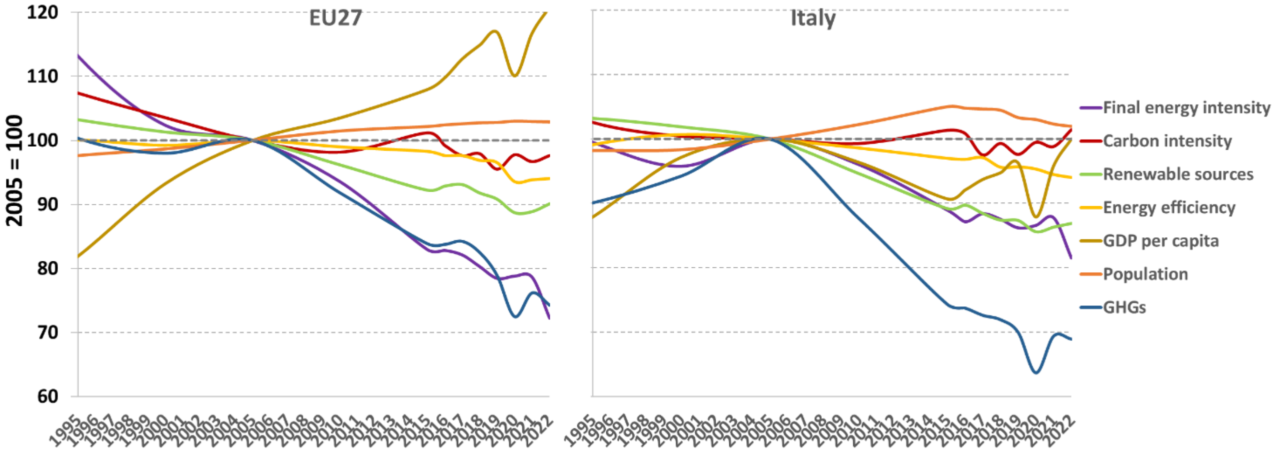
Figure 2.53 – Examined countries arranged in the space defined by the percentage of added value of industry (abscissa) and services (ordinate). For each country the circle size is proportional to the resource productivity for the domestic material consumption (left) and direct material inputs (right).



2.1.4 Kaya Identity and decomposition analysis

The same factors considered to carry out the analysis on Italian data are considered for the European data. The trend of *kaya identity* parameters for EU27 and Italy in the period 1995-2022 shows a quite different pattern for the driving factors in GHGs reduction. Whereas in EU27 the most powerful factor is the final energy intensity, in Italy both renewable sources and final energy intensity (final energy consumed per GDP) are the driving factors. Moreover, in EU27 population and GDP increased, while in Italy such factors have a downward trend. The GHGs change is the integrated result of the driving factors change. So, in EU27 is evident an absolute decoupling between economy and GHGs, while in Italy only a relative decoupling is recorded.

Figure 2.54 – Trend of Kaya identity parameters normalized to 2005 in EU27 and Italy.



Decomposition analysis for the EU biggest countries and Italy, carried out according *Logarithmic mean Divisia index* (Ang, 2005), allows to quantify the role of each factor to reduce the GHGs. The outcome of the analysis in Italy has been shown in paragraph 1.2.2. The outcomes of decomposition analysis show that in Italy the improvement of final energy efficiency played a less important role than in other countries because of the better performance of the indicator in Italy already in 2005. Moreover, unlike Italy, all countries recorded the sensible increase of GDP per capita since 2005.

Figure 2.55 – Decomposition analysis in the period 2005-2022 in the biggest countries.

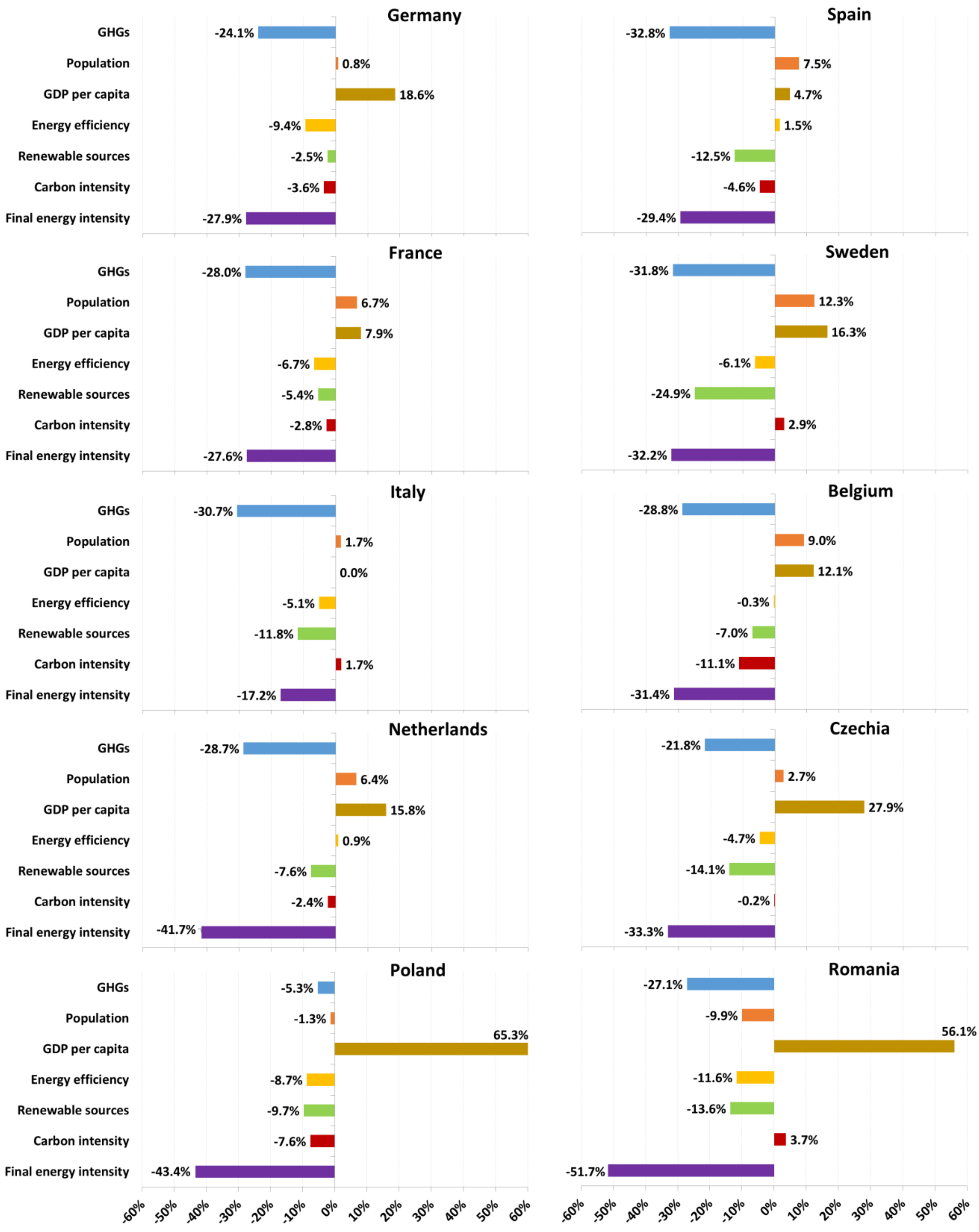
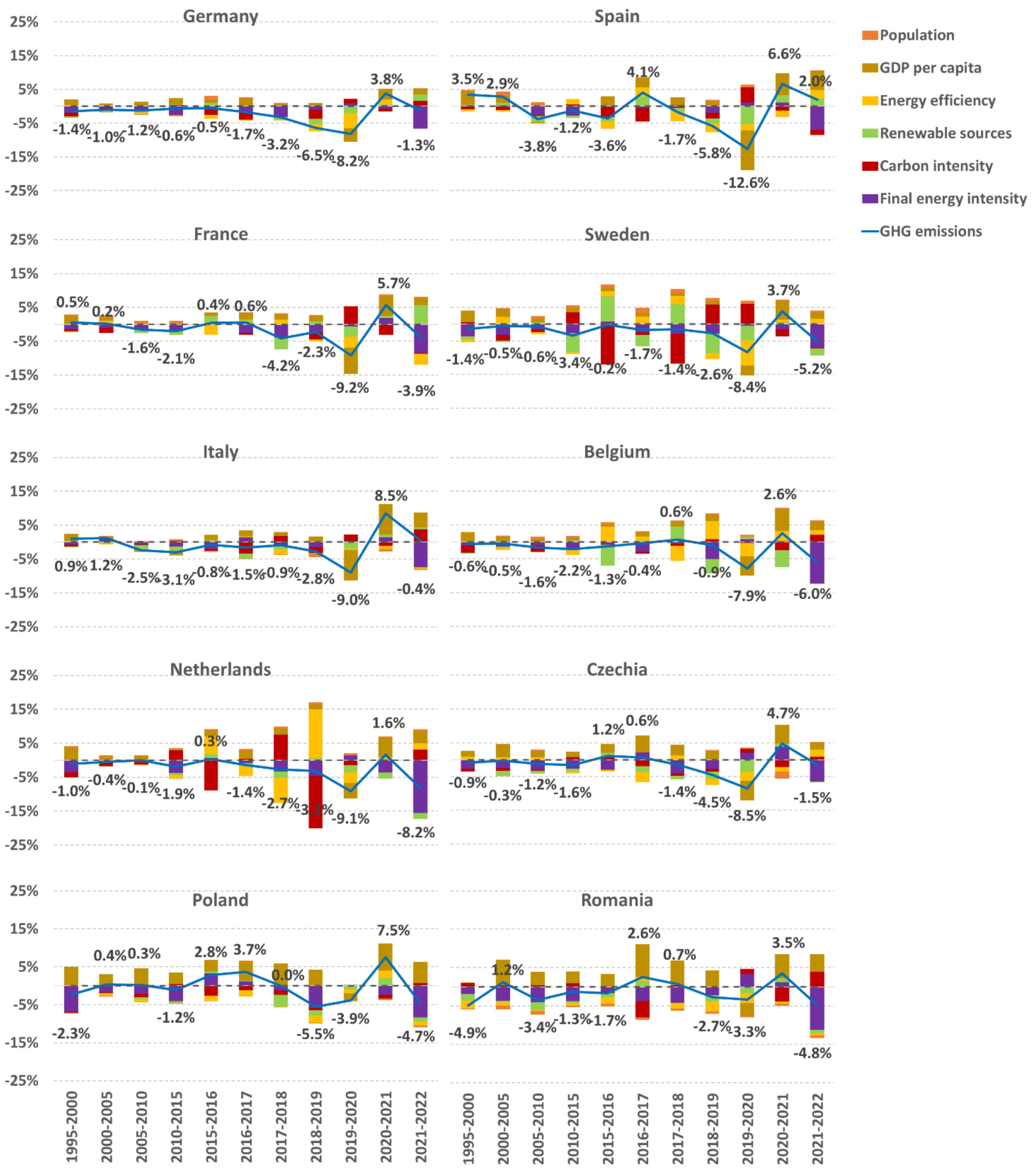


Figure 2.56 provides the detail of decomposition analysis since 1995 to 2022. The analysis up to 2015 has been carried out on five years basis, while after 2015 a year-by-year GHGs change has been decomposed in the driving factors. The examined countries show different patterns and different GHGs trend, but it is possible to find a quite common pattern at European level as the relevant acceleration of GHGs reduction since 2017. The further decrease in 2020 was mainly due to the sharp contraction of economy because of

the effect of the measures adopted to contrast the pandemic. The economy rebound in 2021 determined the GHGs increase in all countries, although with different rates. GHGs in 2022 show a new downward trend compared to 2021, except for Spain.

Figure 2.56 – Decomposition analysis in the biggest countries since 1995 for the shown time frame. The average annual rate of GHG emissions is reported.



In summary, higher decoupling between economy factor and GHGs has been observed in any countries than that recorded in Italy. The analysis year-by-year shows that since 2008 the economy played a more relevant role to decrease GHGs in Italy than in other countries.

The decoupling does not necessarily correspond to GHGs reductions in line with the targets. Decomposition analysis focuses on the relative change of the parameters, without assigning any weight to the starting points. The absolute values of parameters and relative trends in the biggest European countries have been investigated in the previous paragraphs. As already mentioned, the economic and energy efficiency of the Italian system is among the highest in Europe. The last edition of the *International Energy Efficiency Scorecard*, issued by ACEEE in 2022, reported for Italy the drop of four ranks since the previous edition in 2018, mainly due to buildings section, but Italy managed to rank within the top five, after France, UK, Germany, and the Netherlands. The ACEEE International Energy Efficiency Scorecard evaluates the efficiency policies and performance of 25 of the most energy-consuming countries globally. ACEEE used 36 metrics, both policy and performance-oriented metrics, to score each country's efforts to save energy and reduce greenhouse gas emissions across four categories: buildings, industry, transportation, and overall national energy efficiency progress. "*Policy metrics highlight best practices in government actions and can be either qualitative or quantitative. Examples include national targets for energy efficiency, building and appliance labelling, and fuel economy standards for vehicles. The performance-oriented metrics are quantitative and measure energy use per unit of activity or service extracted. Examples include the efficiency of thermal power plants, energy intensities of buildings and industry, and average on-road vehicle fuel economy.*" (Subramanian *et al*., 2022).

The efficiency improvement cannot be separated from the assessment of the potentials and cost effectiveness of the energy system change. Moreover, a mindful assessment of the countries' economy structure must be considered, especially concerning the role of services and industry which have very different energy intensities and carbon footprints.

2.2 Power sector

Data of power sector are from Eurostat database. Fuels are considered according to Eurostat nomenclature. Default emission factors for CO_2, CH_4, and N_2O (IPCC, 2006, 2019; Table 2.1) and GWP from AR5 (IPCC, 2013) have been applied to esteem GHGs. Data up to 2022 are final data. Preliminary data of electricity production in 2023 have been issued by Eurostat on 27 June 2024. On such data heat production and GHGs have been estimated according to the ratio of heat/electricity by thermal plants and the transformation efficiency recorded in 2022.

Table 2.1 – List of fuels used in the thermoelectric sector according to the Eurostat classification and default emission factors of CO_2, CH_4, and N_2O for stationary sources in the energy industries (IPCC, 2006, 2019).

Type	Fuels	Emission factors		
		CO_2 t/TJ	CH_4 kg/TJ	N_2O kg/TJ
Solid fuels	Patent fuels	97.5	1.0	1.5
	Anthracite	98.3	1.0	1.5
	Coking coal	94.6	1.0	1.5
	Other bituminous coal	94.6	1.0	1.5
	Sub bituminous coal	96.1	1.0	1.5
	Coke oven coke	107.0	1.0	1.5
	Gas coke	107.0	1.0	0.1
	Coal tar	80.7	1.0	1.5
	Lignite	101.0	1.0	1.5
	Brown coal briquettes	97.5	1.0	1.5
	Peat and peat products	106.0	1.0	1.5
	Oil shale and oil sands	107.0	1.0	1.5
Oil and oil products	Crude oil	73.3	3.0	0.6
	Natural gas liquid	64.2	3.0	0.6
	Refinery gas/Refinery feedstocks	57.6	1.0	0.1
	Liquefied petroleum gas	63.1	1.0	0.1
	Other kerosene	71.9	3.0	0.6
	Kerosene-type jet fuel (excluding biofuel portion)	71.5	3.0	0.6
	Naphtha	73.3	3.0	0.6
	Gas oil and diesel oil (excluding biofuel portion)	74.1	3.0	0.6
	Fuel oil	77.4	3.0	0.6
	Bitumen	80.7	3.0	0.6
	Petroleum coke	97.7	3.0	0.6
	Other oil products n.e.c.	73.3	3.0	0.6
Natural gas	Natural gas	56.1	1.0	0.1
Derived gases	Coke oven gas	44.4	1.0	0.1
	Blast furnace gas	260.0	1.0	0.1
	Gas works gas	44.4	1.0	0.1
	Other recovered gases	50.3	1.0	0.1
Other non-renewable	Industrial waste (non-renewable)	143.0	30.0	4.0
	Non-renewable municipal waste	91.7	30.0	4.0
Other renewables	Renewable municipal waste	-	30.0	4.0
	Primary solid biofuels	-	30.0	100.0
	Biogases	-	1.0	0.1
	Pure biodiesel	-	3.0	0.6
	Other liquid biofuels	-	3.0	0.6

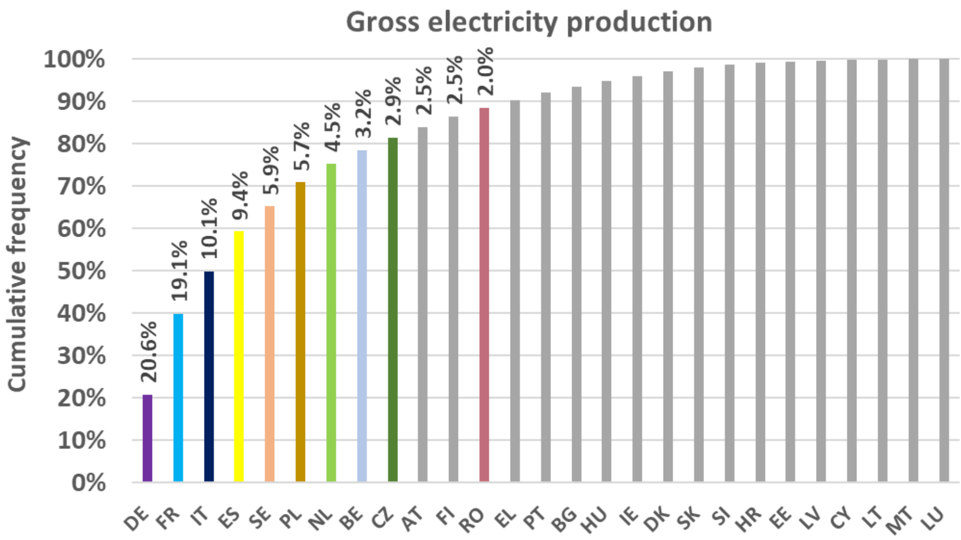
The power sector is one of the largest GHGs sources in Europe. Sector 1.A.1.a, according to the classification adopted by the Common Reporting Formats submitted to UNFCCC, represents emissions from "Public electricity and heat production", i.e. thermoelectric plants that supply electricity to the grid. The sector's GHGs in 2005 in EU27 were 33.6% of the energy emissions and 26.3% of total emissions, both shares sharply decreasing to 28.3% and 21.9% in 2022, respectively. However, it should be noted that sector 1.A.1.a does not represent the whole electricity system, since emissions from auto producers shall be allocated in the specific categories and subcategories (refineries, other energy industries, iron and steel plants and other manufacturing industries) of the Energy sector. In 2005, auto produced electricity from thermal energy in EU27 accounted for 12.3% with an increasing share (18.9% in 2022). GHGs due to electricity generation are therefore higher than the figures reported in sector 1.A.1.a of CRF.

The sector is therefore one of the main targets for measures aimed to decarbonize the economy, both for the amount of emissions and for the renewable energy potential. The countries examined for comparison with Italy accounted for 83.1% of EU27 gross electricity production in 2022.

The power sector is characterized by a relatively small number of large point sources, unlike other sectors, such as transport, which even more relevant in emissive terms and characterized by millions of small and mobile sources with greater inertia as far as the deployment of renewable energies are concerned. Therefore, the electrification of final consumption is a key strategy to achieve the decarbonization.

The analysis of the main parameters of the power sector will concern the selected European countries, as illustrated in the previous chapter, and at aggregate level the group of other countries and EU27.

Figure 2.57 – Cumulative frequencies for gross electricity production in the EU27 Countries in 2022. The labels of country frequencies higher than 2% are reported.



The amounts of energy allocated to the production of electricity and heat in cogeneration plants have been calculated according to the methodology proposed by Eurostat (2016) for the compilation of national questionnaires by Member States.

The following equation defines the total efficiency (ε):

$$\varepsilon = (H + E) / F \qquad (1)$$

where H is the heat produced, E is the electricity produced and F is the fuel energy.

The fuel used for electricity production, F*e*, and that used for heat production, F*h*, are given by the equations:

$$Fe = F - (H / \varepsilon = F \times [E / (E + H)] \qquad (2)$$

$$Fh = F – (E / ε = F x [H/ (E + H)] \quad (3)$$

In this way it is possible to allocate the fuel energy used in cogeneration plants to produce electricity and heat to calculate the emission factor for electricity production.

The total efficiency (ε_t) and the electrical efficiency (ε_{el}) are calculated with the equations:

$$\varepsilon_t = (H + E) / F \quad (4)$$

$$\varepsilon_{el} = E / F \quad (5)$$

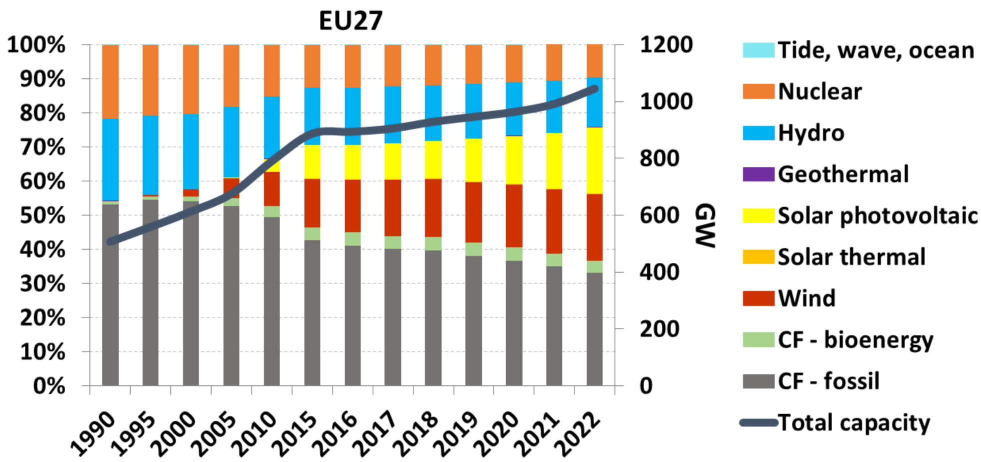
Another way for comparing the electrical efficiency of different countries considers only the share of fuel allocated to electricity generation after having parted the share of fuel for heat generation (according to equations 2 and 3). The electrical efficiency thus defined (equivalent electrical efficiency), ε'_{el}, will be given by the equation:

$$\varepsilon'_{el} = E / Fe \quad (6)$$

2.2.1 Power capacity and electricity production

The installed capacity in 1990 consisted mainly of thermoelectric plants (54% in EU27), nuclear (21.8%) and hydroelectric (24%). Wind and photovoltaic sources had marginal shares. In 2022 the thermoelectric capacity was 36.7%, 9.6% nuclear, 14.4% hydroelectric, 19.5% wind, and 19.4% photovoltaic. The total capacity has increased by 54.8% in 2022 compared to 2005, from 676 GW to 1,046 GW. The nuclear capacity is the only one with a notable reduction, from 123 GW to 100 GW (-14.6%). It is also noteworthy the increase of bioenergy net capacity from 15.8 GW in 2005 to 36.9 GW in 2022, representing 9.6% of total thermoelectric capacity. All countries experienced considerable decreasing share of the thermoelectric capacity since 1990, as well as for nuclear capacity (except Czechia and Romania).

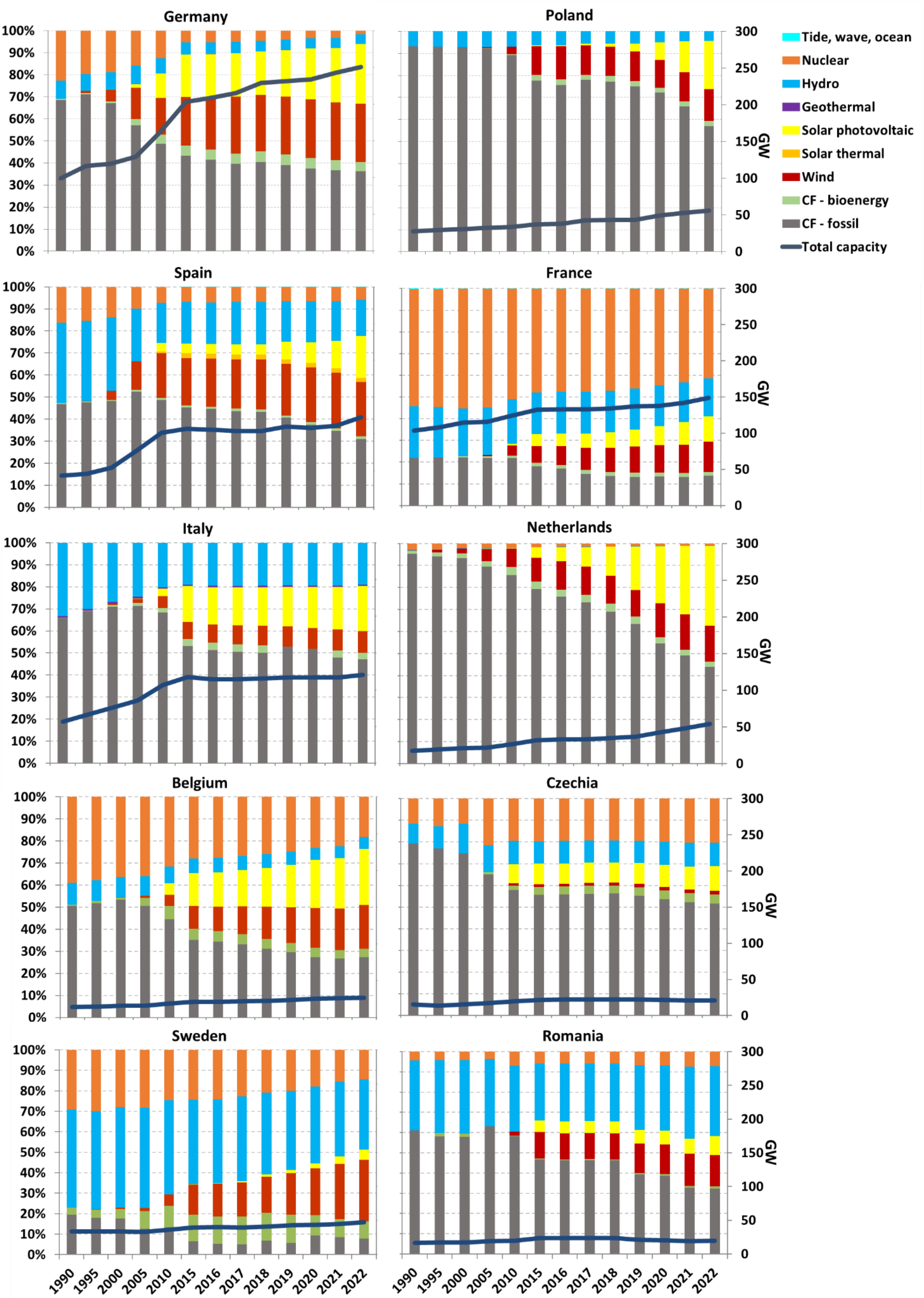
Figure 2.58 – Power capacity trend (blue line – right axis) and share by source in EU27 (bars – left axis). CF=Combustible fuels.



The power capacity among countries is very heterogeneous. In Poland, there is a clear prevalence of thermoelectric plants with a minor role for bioenergy. The nuclear plants, which are not present in Italy and Poland among the considered countries, make up significant share of the capacity in France (41.3% in 2022), Sweden (14.4%), Belgium (18.2%), and Czechia (20.3%), although the shares of other countries are not negligible (from 0.9% in the Netherlands to 7.3% in Romania). Germany, Sweden, and Belgium recorded a downward trend of nuclear power capacity in the long run.

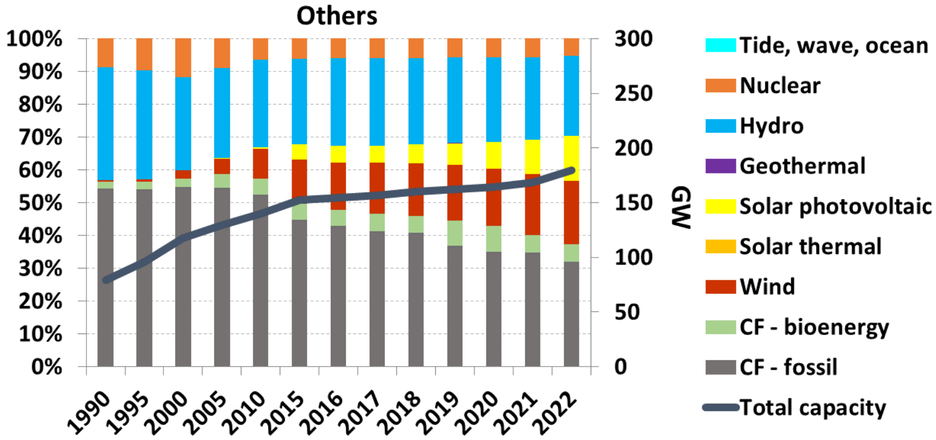
Since 1990, hydroelectric capacity has accounted for a considerable share of traditional renewable sources in Romania, Spain, France, Italy and Sweden. Wind power has increased in all countries since 2005. Photovoltaic plants begun to have significant shares only after 2010.

Figure 2.59 – Power capacity trend (blue line – right axis) and share by source in the biggest European countries (bars – left axis). CF=Combustible fuels.



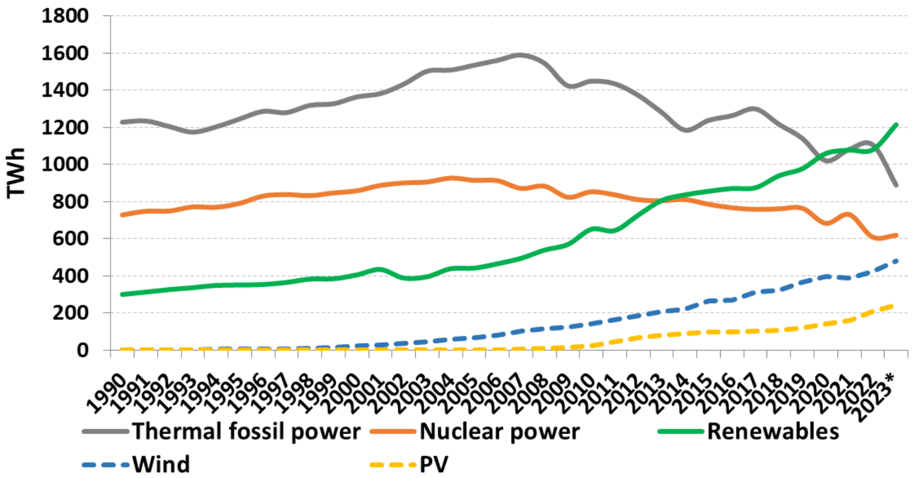
The group of smallest countries has a relevant average share of hydro capacity, 24.3% in 2022, while the combustible fuels plants are 37.2% and nuclear plants are 5.3%.

Figure 2.60 – Power capacity trend (blue line – right axis) and share by source in the others European countries (bars – left axis). CF=Combustible fuels.



Gross electricity production without pumping in EU27 increased from 1990 to 2015 with an average rate of 1% per year, in the following years up to 2019 wide oscillation was recorded with 2019 level approximately the same of 2015. In 2020 the electricity fell, due to measures adopted to contain SARS-CoV-2 pandemic. In 2021 there was a recovery (+4.6% compared to 2020), followed by a new slowdown in 2022 (-3.3% compared to 2021). From 2015 to 2022 the annual average rate has been -0.4%. Preliminary data on gross electricity production by source show that at European level the electricity in 2023 decreased by 2.6% compared to the previous year. The production by fossil power decreased by almost 20% (solid fuels -28.8%; liquid fuels -19.7%; natural gas -13.5%; manufacturing gases -6.1%), like electricity by bioenergy (-9.5%), while all other sources increased: from 1.7% of nuclear to 18.9% of photovoltaic. All renewables increased by 12.5% overcoming the fossil production. Electricity from renewables sources outweighed electricity from nuclear plants since 2013.

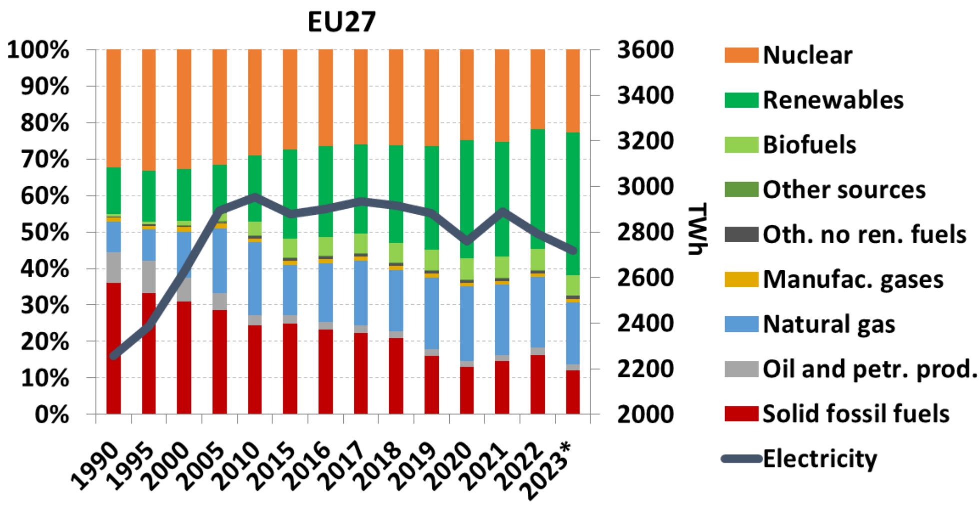
Figure 2.61 – Gross electricity production without pumping in EU27. Wind and PV are included in the green line of renewables.



* Preliminary data.

The share of EU27 electricity production by fuels without pumping in 2022 is 16.3% from solid fuels and 19.4% from natural gas. Oil and petroleum products account for 2%. Nuclear source accounts for 21.8%, while renewable energy (renewables and biofuels) is 38.7%. All considered countries increased the electricity production since 1990, from 4.9% in Germany to 90.4% in Spain, except Romania whose electricity production decreased by 13.5%. Preliminary data for 2023 show the further shrinking of fossil share, particularly evident for solid fuels (from 16.3% in 2022 to 11.9% in 2023. The share for natural gas decreases to 17.2%, while electricity by nuclear power and renewables reaches 22.8% and 44.6%, respectively.

Figure 2.62 – Gross electricity production without pumping (blue line – right axis) and share by source in EU27 (bars – left axis).



* Preliminary data.

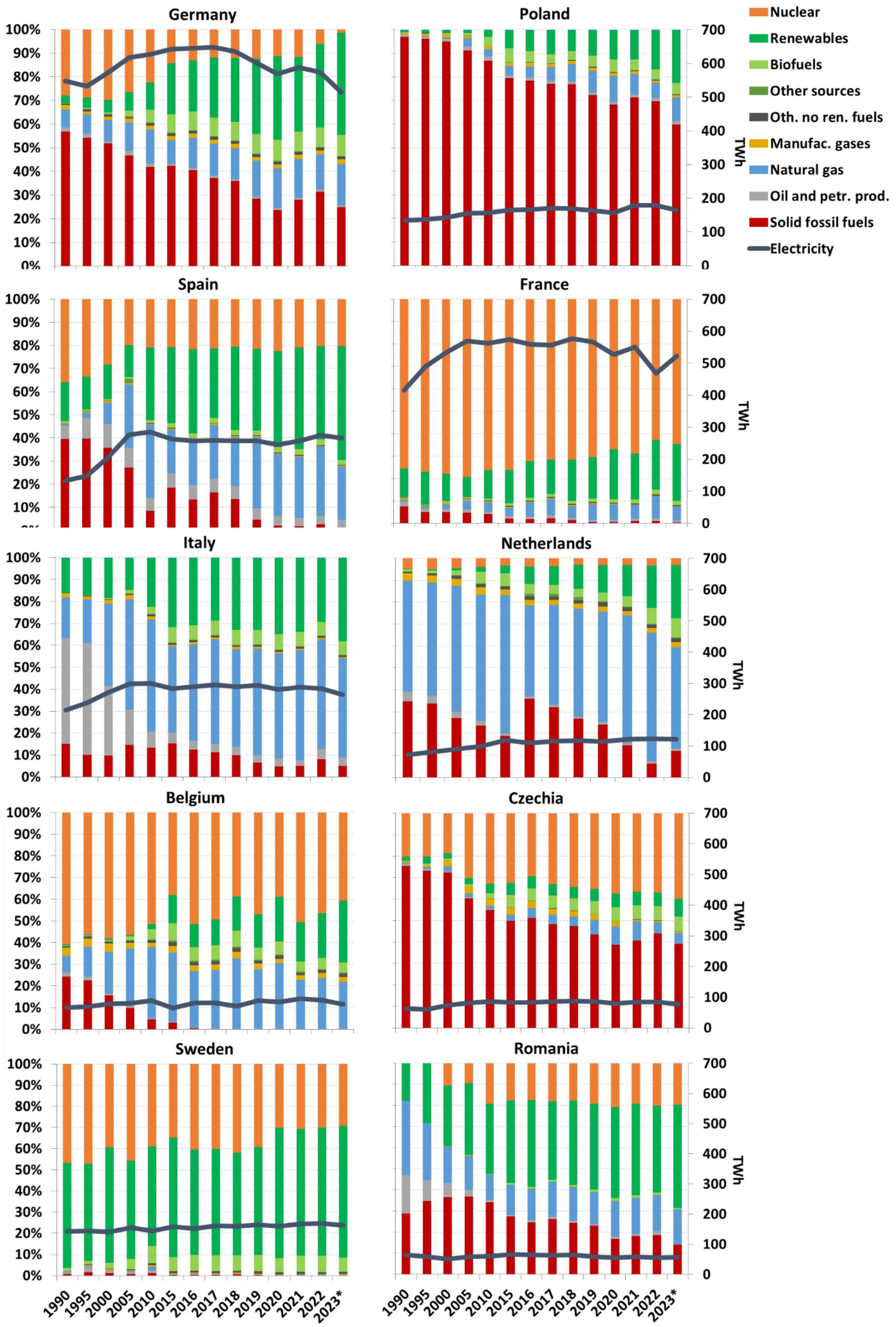
The energy mix in the examined countries is quite heterogeneous, mainly as far as fossil fuels are concerned. In 2022, solid fuels make up 69.8% of electricity production in Poland, 44% in Czechia, and 31.3% in Germany. Even more interestingly, 53.7% of EU27 electricity production from solid fuels originates from lignite, with higher carbon content than coal. Germany, Poland, Czechia, and Romania are the main users of such fuel for electricity production and account collectively for 86.2% of the EU27's electricity production by lignite (47.8% Germany, 19.8% Poland, 14.3% Czechia, and 4.3% Romania). The remaining 13.8% is used by the group of smallest countries (mainly Bulgaria, Greece, and Slovenia). The electricity produced from lignite in Germany, Poland, Czechia, and Romania is 64.1%, 38.3%, 93.4%, and 99.3% of electricity from solid fuels respectively. Data of 2023 shows very sharp contraction of solid fuels in Poland (59.8%), Czechia (39.3%), and Germany (24.8%).

France has the highest share of electricity production from nuclear plants in Europe (62.8% in 2022), followed by Belgium (46.4%), Czechia (37%) and Sweden (30%). In the other biggest countries, the nuclear electricity ranges from 3.4% in the Netherlands to 19.9% in Romania. Poland and Italy do not have nuclear plants. At EU27 level, the nuclear source provides 21.8% of electricity with a clear downward trend since 1990, when it was 32.3%. The absolute production of electricity by this source increased quite constantly from 1990 to 2004, then a downward trend has been recorded with wide oscillation in the last years. In this regard, the most emblematic case, as stated by TERNA 2023b, is the French nuclear power: in 2022, the availability rate of the nuclear fleet in this country was 54% compared to the average of 73% from 2015 to 2019. Notably, during autumn 2022, only 25 GW of the total 63 GW of the nuclear fleet remained in service. This caused generation from nuclear power in 2022 to plummet by 30% compared to the average of the previous 20 years. Anyway, the preliminary data show that the French nuclear production in 2023 rebounds by 14.7% compared to 2022. Among the biggest countries the only one, beyond France, with increasing nuclear production is Romania (+0.9% wrt to 2022), all other biggest countries decreased the production from -2.9% in Spain to -79.2% in Germany. Belgium and Sweden reductions were 25% and 7% respectively. The group of the other minor countries increased the nuclear production by 14.2%.

Italy and the Netherlands have the highest share of electricity by natural gas in 2022, 50.1% and 39.2% respectively. Italy experienced a massive transition of its thermal power plants since 1990 with a sharp shrink of oil and petroleum products and the corresponding expansion of natural gas. Solid fuels show significant contractions in all countries although some countries as Germany, Poland, and Czechia still have relevant shares of such fuels.

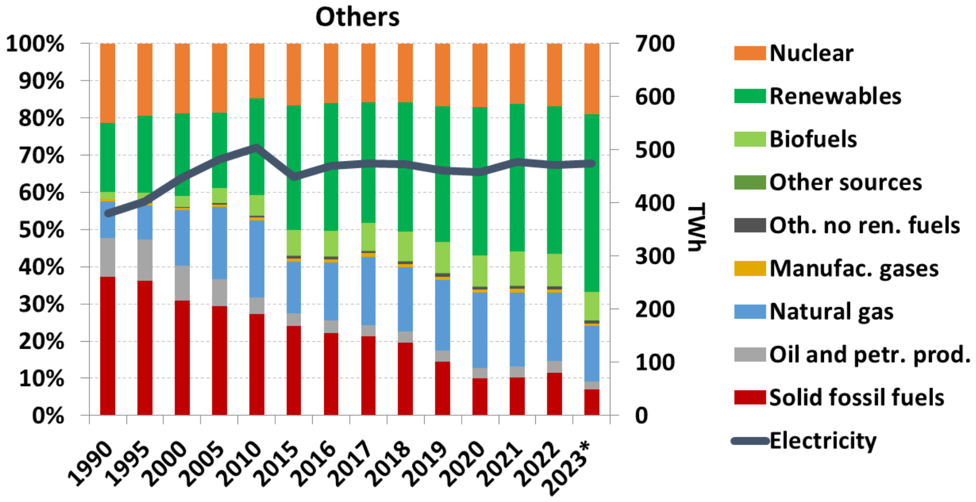
The renewable electricity share in EU27 has increased from 13.4% to 38.7% since 1990 to 2022. In 2023 there is a further robust increase reaching 44.6%. Since 2005 the renewable share has shown a quite steady increasing trend. All countries recorded a notable increase of renewable electricity production with a strong acceleration since 2005. After 2015 the growth slowed down and has resumed in recent years, although with different rates among the States. Sweden has one of the highest renewable shares in Europe. In 2023 the increases of Spain and Germany are particularly steep reaching 51.3% and 52% respectively. Italy’s share increased from 35.6% in 2022 to 44.2% in 2023.

Figure 2.63 – Gross electricity production (blue line – right axis) and share by source in EU27 (bars – left axis).



* Preliminary data.

Figure 2.64 – Gross electricity production (blue line – right axis) and share by source in the others European countries (bars – left axis).

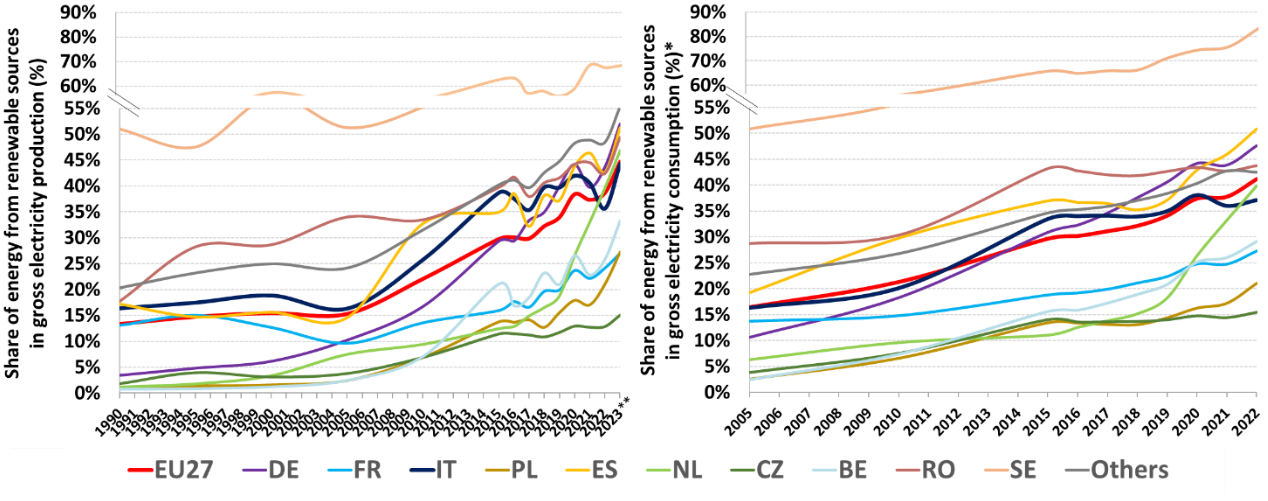


* Preliminary data.

Figure 2.65 shows the trend of renewable share in gross electricity production without pumping and gross electricity consumption as required by European targets. Sweden has one of the highest shares in Europe. At European level the share has been growing rapidly since 2005. The Italian figures, as for electricity production, are higher than the EU27 average up to 2021. In 2022 Italy's renewable share is below the EU27 average (35.6% *vs* 38.7%) because of the serious lack of hydroelectricity (see paragraph 1.3.1). Preliminary data for 2023 show that Italy returns close to the European average. The Netherlands recorded an astonishing surge of renewable share in the last few years.

The renewable share for the achievement of the European targets in accordance with the Directive 2009/28/EC (up to 2020) and Directive (EU) 2018/2001 (up to 2030), refers to gross inland consumption of electricity, i.e., electricity production without electricity from pumping plus the net import of electricity. No provisional data are available for 2023. The available data show that Italy' share is below the European average and share of countries as Germany and Spain. For net importing countries, as Italy, the share of renewable electricity consumption is lower than the share of renewable electricity production.

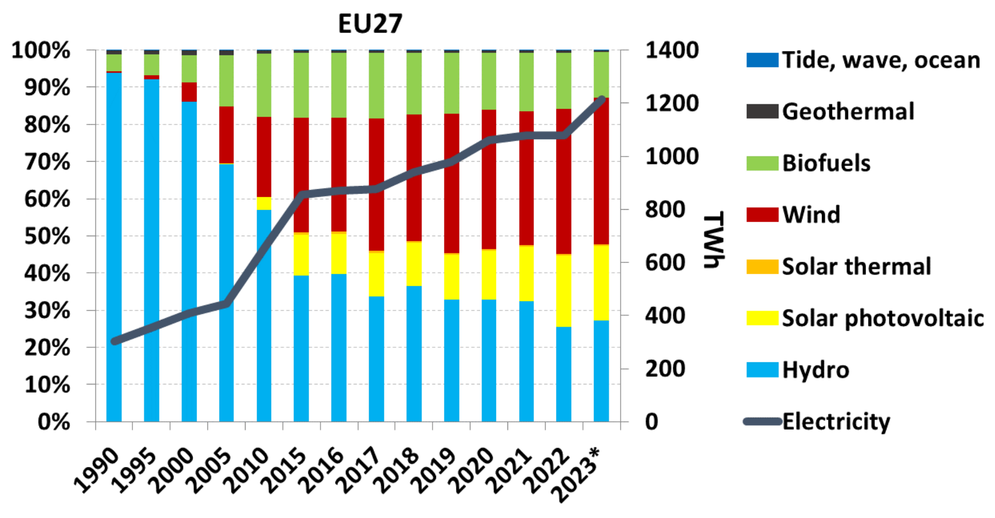
Figure 2.65 – Renewable share in gross electricity production (left side) and gross electricity consumption since 2005 (right side).



* Data until 2020 are based on Directive 2009/28/EC, while data from 2021 onwards follow Directive (EU) 2018/2001. ** Preliminary data.

Figure 2.66 shows in more details the renewable electricity production without pumping and the shares of sources. All the countries examined show marked increase of renewable electricity production with a strong acceleration since 2005, with an average rate of 5.4% per year. Preliminary data for 2023 recorded the highest annual increase with 12.5% compared to 2022.

Figure 2.66 – Renewable share in gross electricity production by source (left side), and total renewable gross electricity production in EU27 (right side).



* Preliminary data.

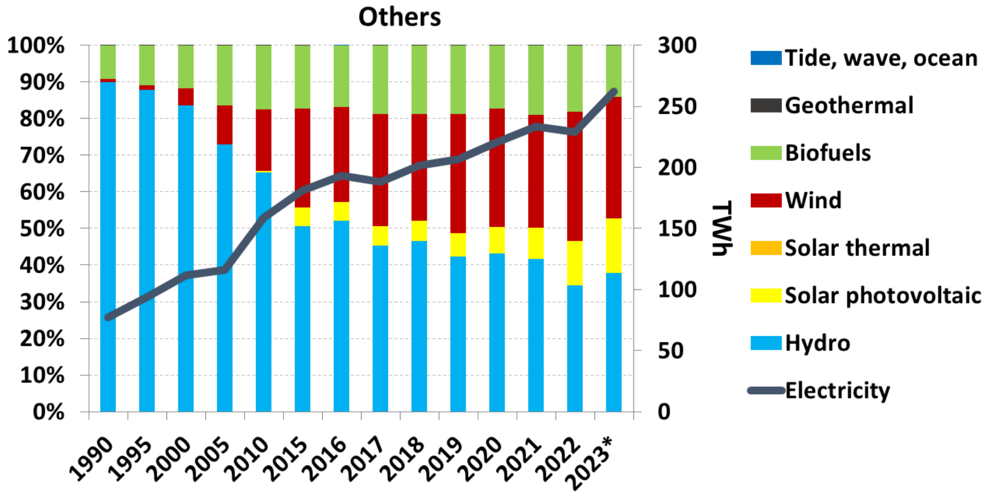
In 1990, almost all renewable electricity was from hydroelectric (94% in EU27). Countries show different development trends for the renewable sources related to the peculiarities of their power systems and national circumstances. Hydropower continues to cover more than a quarter of Europe's renewable production in 2022 with a share of 25.6% in 2022, much lower than 32.3% recorded in 2021. In 2022 the hydropower has been hit by the serious drought which mainly affected the Mediterranean countries, as Italy, France, and Spain. Such countries recovered only partially their hydro production in 2023 remaining much below their tops.

Among the examined countries, hydroelectric power supplies in 2023 about 58% of renewable production in Sweden and 64.1% in Romania, but the shares recorded in France, Italy, and Spain are not less relevant (respectively 39.8%, 34.8%, and 17.4%). Such figures and the severe fall of electricity recorded in 2022 witness the relevance of a source which is volatile and sensitive to drought. The wind source shows considerable development in Germany (52.5% of renewable electricity in 2023), Spain (44.8%), Poland (51.6%), the Netherlands (51.3%), and Belgium (57.9%). Photovoltaic electricity production plays a significant role in Germany (23%), Italy (26.4%), Belgium (27%), the Netherlands (35.2%), Poland (25.2%), and Czechia (28%). Bioenergy covers 45.3% of renewable production in Czechia, followed by Poland with 17.8% and Germany with 17%. Italy, Belgium, and the Netherlands are below 14%. The shares of bioenergy for the other countries range between 1.2% in Romania and 9.5% in Sweden. The electricity production from biofuels decreased steeply in all countries except in Poland. Among the countries under examination, the geothermal source is present significantly only in Italy (5.8% in 2022 and 4.9% in 2023).

Figure 2.67 – Renewable share in gross electricity production by source (left side), and total renewable gross electricity production in the selected countries (right side).

* Preliminary data.

Figure 2.68 – Renewable share in gross electricity production by source (left side), and total renewable gross electricity production in the other countries (right side).



* Preliminary data.

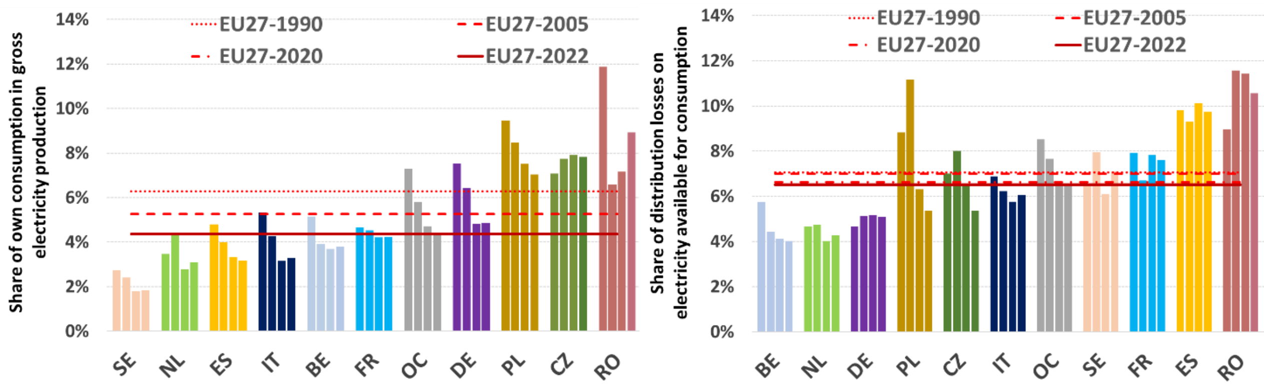
2.2.2 Efficiency of thermal power plants

The performance of the countries' power sectors will be compared through parameters such as the share of own consumption, the distribution losses and above all the transformation efficiency of the fuel energy to produce electricity and heat. In the case of cogeneration plants, it should be considered that not all the electricity and heat produced in such plants can be regarded to as cogeneration production. However, it is reasonable to compare the overall efficiency of the thermoelectric plants in different countries in terms of the transformation of the fuel energy into the final products regardless of the way in which the plants were used. In this respect, the distinction between cogeneration and non-cogeneration plants was made considering the activities classified by Eurostat: "combined heat and power" and "electricity only".

Own consumption is the consumption of electricity utilities functional to the electricity production and is an indicator of the energy required by the electricity generation system. The share of own consumption in Italy has always been below the EU27 average (3.3% vs 4.4% in 2022). In general terms, thermoelectric, geothermal and nuclear generation are the sources with the greatest demand of energy, while renewable sources, such as hydroelectric, wind and photovoltaic, have very low own consumption. The greatest own consumption in thermoelectric plants is related to plants powered by solid fuels and bioenergy, less energy is required by plants fuelled by oil and petroleum products and even less own consumption is required by plants fuelled by natural gas. Therefore, in addition to the efficiency, a decisive parameter is represented by the fuel mix used by each country.

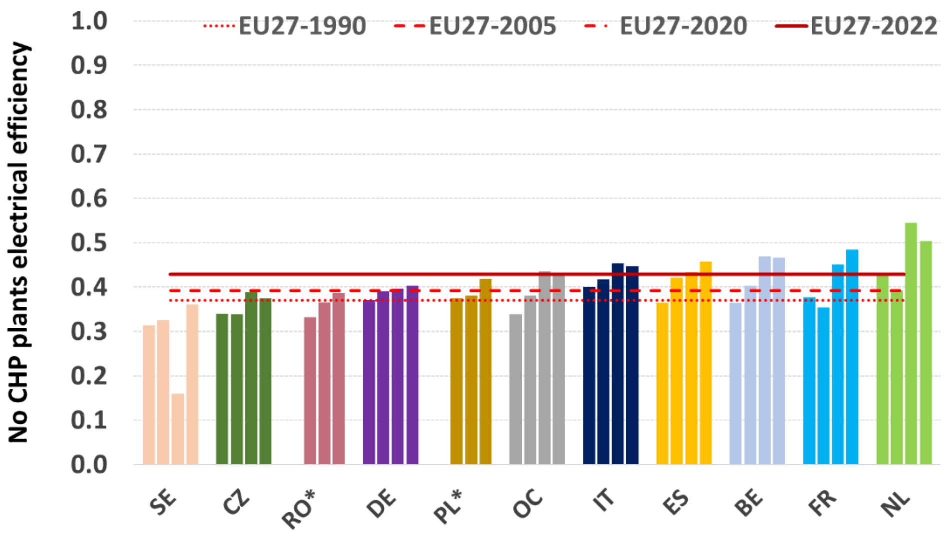
On the other hands, distribution losses give insight on the network performance, higher losses determine higher electricity production to supply the electricity demand. In 2022 the distribution losses compared to the electricity available for final consumption in Italy are lower than the EU27 average (6.1% *vs* 6.5%).

Figure 2.69 – Own consumption compared to gross electricity production (left side) and distribution losses on electricity available for final consumption (right side). For each country the three bars refer to 1990, 2005, 2020, and 2022. Data in ascending order of 2022 value. OC – Other countries.



The most important parameter to assess the efficiency of power systems is the transformation efficiency of fuels into electricity and heat. The electrical efficiency of Italian non-cogeneration plants is just over the EU27 average (0.447 *vs* 0.429).

Figure 2.70 – Electrical efficiency of no CHP plants. For each country the three bars refer to 1990, 2005, 2020, and 2022. Data in ascending order of 2022 value. OC – Other countries.

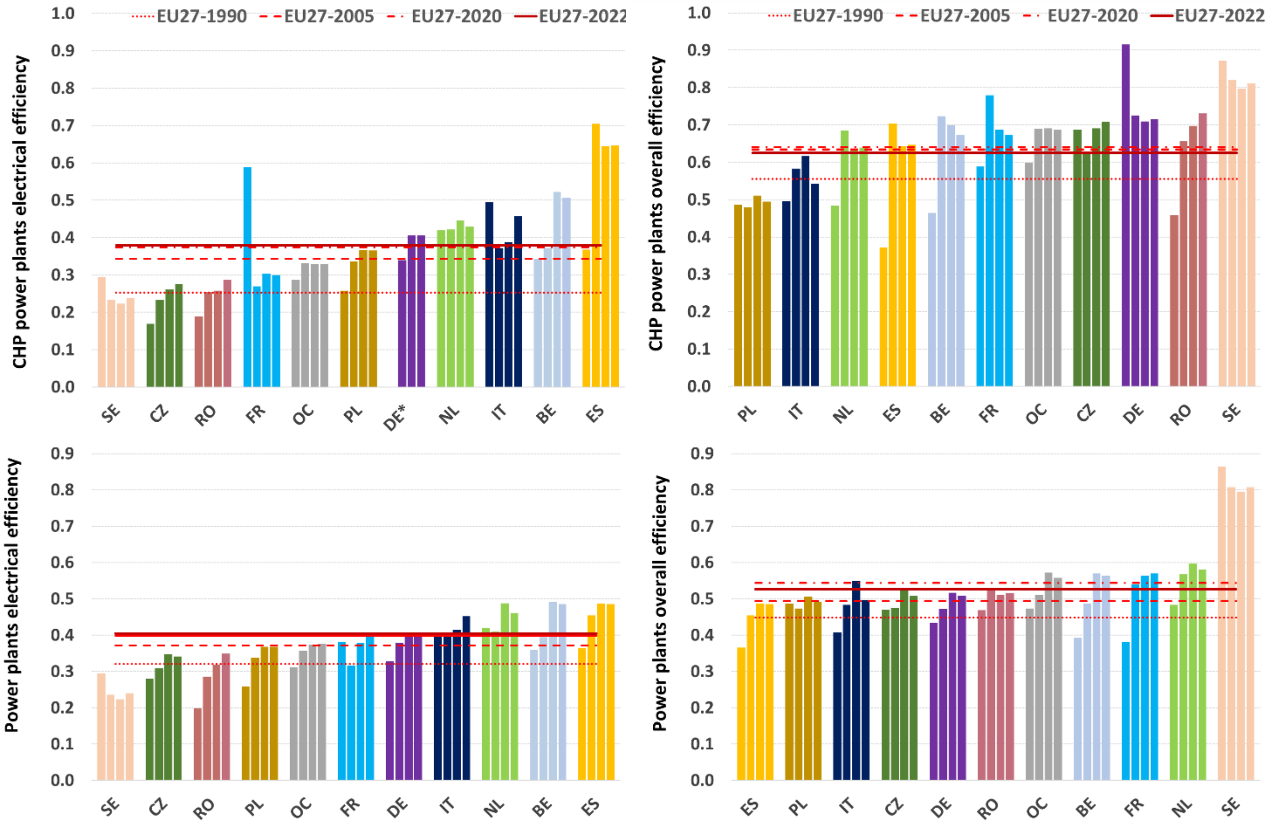


* 1990 not available.

As for CHP plants, the electrical efficiency in Spain shows the highest value among the main European countries (0.646), far higher than the EU27 average (0.38). Italy's electrical efficiency is 0.457. The total efficiency, for electricity and heat production, of the Italian cogeneration plants (0.542) is below the EU27 average (0.625).

The Italian electrical efficiency for all power plants (CHP and electricity only) in 2022 is 0.452, exceeded by Spain, Belgium, and the Netherlands, from 0.461 to 0.486. Sweden has the lowest electrical efficiency among the examined countries (0.24), well below the EU27 average (0.404). The overall efficiency of Italian plants, for electricity and heat production, is 0.497, below the EU27 average (0.527). Sweden shows the highest value (0.808) due to the highest ratio between heat and electricity recorded in this country in CHP plants (about 2.4), followed by Czechia (1.56). Italy is at the lowest end together with 0.19, while Spain does not report heat production so there is no difference between electrical efficiency and overall efficiency for such country.

Figure 2.71 – Electrical and overall efficiency of CHP plants (up) and all power plants (down). For each country the three bars refer to 1990, 2005, 2020 and 2022. Data in ascending order of 2022 value. OC – Other countries.

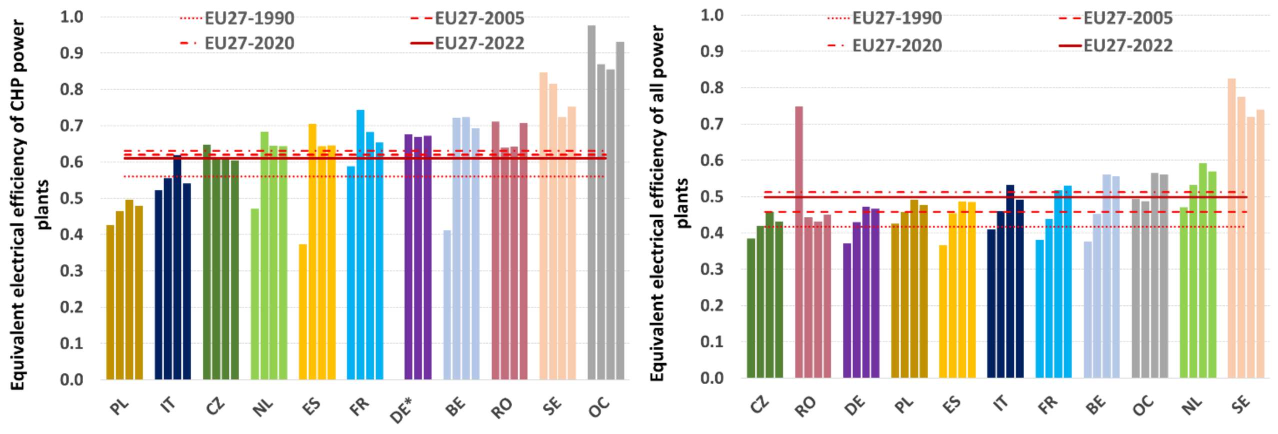


* 1990 not available.

The equivalent electrical efficiency of CHP plants, calculated after unbundling the share of fuels for heat production, is 0.597 for Italy, below the EU27 average (0.622), with a growing trend (+7.4% since 2005). The equivalent electrical efficiency ranges from 0.483 in Poland to 0.749 in Sweden. The average for group of smallest countries is 0.856.

As for the equivalent electrical efficiency for all power plants in 2021, Italy (0.522) is exceeded Belgium (0.568), the Netherlands (0.578) and Sweden (0.741), among the biggest countries. The EU27 average is 0.507 and the average for group of smallest countries is 0.563.

Figure 2.72 – Electrical and overall equivalent electrical efficiency for CHP plants (left) and all power plants (right). For each country the three bars refer to 1990, 2005, 2020, and 2022. Data in ascending order of 2022 value. OC – Other countries.



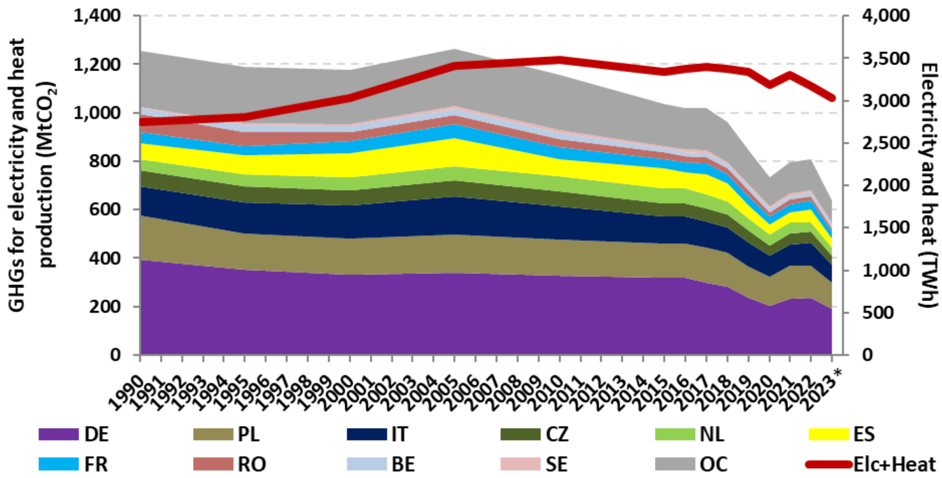
* 1990 not available.

2.2.3 GHGs from the power sector

The Tier 1 approach has been adopted to estimate the GHGs from the power sector of countries. Tier 1 methodology with default emission factors for the fuels consumed is adopted only to carry out international comparison. Such purpose requires a common methodology for the States. Moreover, the energy balance here adopted follows Eurostat allocation methodology concerning the self-production of heat. As already mentioned, such methodology requires that only the energy to produce the heat transferred to third parties is accounted in transformation, while the energy for heat self-production is accounted in industry. Italy complied such criteria since the current submission for years 2021 and 2022. A country specific approach, with national emission factors, is available for Italy (see paragraph 1.3).

Since 1990 there has been a decoupling between electricity production and GHGs by power sector in almost all European countries, although emissions show a significant decrease only after 2005, with an increasing decoupling mainly due to the growing share of renewables. The following graph shows the cumulated contribution of each country to the EU27 GHGs by power plants and the trend of gross electricity and heat production.

Figure 2.73 – Contribute of EU27 countries to GHGs and gross electricity and heat production from thermal power plants.



* Preliminary data.

Preliminary data show that in 2023 the GHGs by power sector recorded a sharp reduction compared to the previous year (-21%; Table 2.2). GHGs for electricity and heat production, are 637.7 Mt CO_2eq in 2023, 49.3% lower than 1990 level and 49.6% lower than 2005 level. Since 2005 a significant reduction of GHGs begun to take place. Overall, in 2023 the GHGs from power sector in the selected countries (545 Mt CO_2eq) account for 85.4% of EU27 sector's emissions and Italy's share is 11.6%.

Table 2.2 – GHGs estimated (Mt CO_2eq) for electricity and heat production in thermal power plants. Countries in descending order of 2023 value.

Source	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023*
EU27	**1256.6**	**1187.7**	**1177.5**	**1264.2**	**1157.1**	**1037.4**	**733.6**	**795.4**	**807.6**	**637.7**
Germany	393.3	350.5	333.1	341.5	327.5	318.3	201.5	230.1	234.3	190.5
Poland	181.4	150.2	146.7	154.5	149.4	142.9	119.8	138.9	132.7	109.0
Italy	123.3	130.4	137.0	160.1	137.0	110.6	88.8	87.1	95.2	73.7
Spain	66.4	77.5	98.1	117.7	71.4	84.3	42.3	42.7	50.9	37.9
Czechia	63.8	64.1	64.0	64.5	63.0	53.8	42.3	45.2	46.0	37.4
Netherlands	45.0	52.5	53.6	57.7	61.0	61.9	43.3	44.0	40.5	32.9
France	46.4	38.4	48.7	59.1	49.9	37.3	32.2	34.1	36.8	27.5
Romania	73.2	56.8	37.5	36.2	31.2	27.5	18.1	19.1	18.0	14.4
Belgium	26.2	28.3	26.0	25.9	23.8	18.0	16.4	15.3	15.6	12.6
Sweden	5.3	9.0	8.3	10.7	13.1	9.1	9.1	10.2	9.6	9.1
Other countries	232.1	230.0	224.5	236.4	229.9	173.7	119.7	128.6	127.9	92.7

* Preliminary data.

GHGs emissions factor for electricity and heat production due to fuel combustion in thermal power plants reduced since 1990. In 2023 the emissions factor in Italy, 413.8 g CO_2eq/kWh, is lower than EU27 average, 474.3 g CO_2eq/kWh. The average reduction since 2005 (-21%) ranges from -8.3% in Romania to -29% in Spain. Italy reduced the emissions factor by -21%.

Table 2.3 – GHGs emission factors for electricity and heat production by thermal power plants (g CO_2eq/kWh). Countries in descending order of 2023 value.

Source	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023*
EU27	**726.9**	**706.8**	**655.6**	**600.8**	**557.5**	**565.4**	**457.1**	**478.0**	**490.2**	**474.3**
Czechia	785.8	785.7	740.6	766.8	748.7	696.1	618.1	620.1	653.0	638.6
Poland	723.4	760.6	749.4	723.5	713.3	704.0	633.8	659.1	667.5	636.5
Romania	587.9	548.3	562.3	589.0	615.0	595.5	561.5	551.4	562.8	540.4
Germany	784.9	779.8	745.4	681.2	638.3	635.8	515.5	537.1	553.9	531.6
Spain	928.8	893.6	780.2	628.6	501.6	653.8	451.1	447.1	450.9	446.3
Belgium	877.6	818.6	649.0	583.5	455.4	446.4	400.8	420.1	437.1	444.4
Italy	691.7	666.3	623.8	523.9	477.8	441.1	370.0	414.1	436.2	413.8
Netherlands	572.6	505.8	448.8	445.6	411.4	495.5	373.5	400.7	409.4	386.2
France	951.5	855.7	547.0	519.2	576.7	507.7	379.7	393.2	369.8	372.0
Sweden	340.3	276.1	267.4	254.5	212.5	179.5	188.5	181.3	178.6	193.5
Other countries	666.2	656.9	598.2	560.9	522.1	512.7	398.7	399.6	420.6	399.4

* Preliminary data.

GHGs for electricity production have been estimated after unbundling the fuel energy consumption for heat production in CHP plants according to the methodology proposed by Eurostat (2016). EU27 GHGs in 2023 are 540.1 Mt CO_2eq and the countries examined account for 85.6%.

Table 2.4 –GHGs estimated (Mt CO_2eq) for electricity in thermal power plants. Countries in descending order of 2023 value.

Source	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023*
EU27	**991.2**	**989.1**	**1018.8**	**1070.5**	**966.2**	**879.7**	**598.1**	**664.7**	**687.5**	**540.1**
Germany	350.5	322.8	306.4	308.1	293.4	288.1	176.8	202.7	209.2	168.5
Poland	110.5	108.0	109.9	115.2	112.3	109.2	90.0	106.7	103.2	83.8
Italy	122.7	129.8	134.4	141.7	116.7	91.2	70.0	79.6	88.2	67.8
Spain	66.4	77.5	98.1	117.7	71.4	84.3	42.3	42.7	50.9	37.9
Czechia	46.2	43.3	49.8	48.4	46.5	41.5	31.8	34.3	36.3	29.5
Netherlands	40.9	42.1	42.0	45.6	48.2	53.3	36.9	37.7	34.7	27.7
France	46.4	37.0	40.9	45.6	43.1	31.7	25.6	27.6	29.8	21.7
Romania	16.9	25.5	20.6	24.8	23.0	21.1	14.2	15.4	14.6	11.6
Belgium	25.2	27.3	24.9	23.5	21.3	15.9	14.7	13.5	14.1	11.3
Sweden	1.7	3.4	3.3	3.6	4.8	2.7	2.7	3.2	3.2	2.7
Other countries	163.7	172.4	188.5	196.3	185.5	140.7	93.3	101.3	103.3	77.5

* Preliminary data.

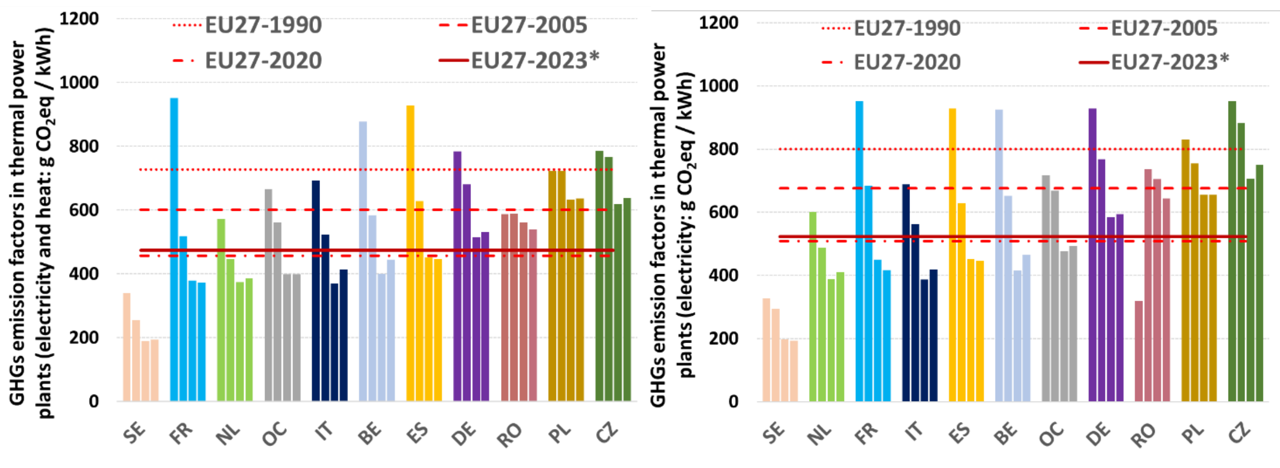
Italian emissions factor for thermal plants in 2023 (418.6 g CO_2eq/kWh) is well below the EU27 average of 523.5 g CO_2eq/kWh. Czechia, Poland, Romania, and Germany have the top four emission factors, from 749.8 g CO_2eq/kWh to 593.4 g CO_2eq/kWh, much higher than the European average.

Table 2.5 – GHGs emission factors for electricity production by thermal power plants (g CO_2eq/kWh). Countries in descending order of 2023 value.

Source	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023*
EU27	**799.4**	**783.5**	**732.3**	**675.7**	**621.5**	**637.7**	**508.8**	**533.4**	**543.8**	**523.5**
Czechia	952.3	934.0	865.4	882.8	868.7	812.2	707.0	719.1	767.2	749.8
Poland	830.8	799.0	779.3	754.5	736.9	721.0	655.6	682.9	694.7	654.4
Romania	319.4	601.7	657.1	736.3	797.4	739.2	705.7	695.1	675.6	642.8
Germany	928.1	906.0	824.6	767.1	710.7	702.1	584.7	610.2	624.0	593.4
Belgium	924.8	858.9	730.4	652.4	497.2	479.3	415.4	440.4	458.0	463.9
Spain	928.9	893.5	780.0	628.6	501.6	653.8	451.1	447.1	450.9	446.3
Italy	688.3	663.0	611.6	562.4	506.4	476.6	387.3	421.0	444.2	418.6
France	951.5	917.0	770.4	683.4	693.8	618.6	449.3	474.2	425.3	417.3
Netherlands	600.4	550.6	497.5	487.9	434.7	555.3	389.0	427.2	442.3	409.7
Sweden	327.3	339.6	368.0	294.7	232.8	191.1	198.3	198.0	196.9	193.8
Other countries	716.3	715.1	714.7	668.2	623.2	629.7	476.4	482.5	504.6	492.8

* Preliminary data.

Figure 2.74 – GHGs emission factors in thermal power plants (g CO_2eq/kWh). For each country the bars refer to 1990, 2005, 2020, and 2022. Data in ascending order of the 2023 value. OC – Other countries.



* Preliminary data.

The emission factors for total electricity and heat production by the whole power sector, including all renewables and nuclear power production, in Italy are higher than the European average (264.2 *vs* 210.3 g CO_2eq/kWh). All countries with lower emission factors than Italy have relevant amount of electricity by nuclear plants and/or higher renewable share. The average EU27 emissions factor shows a reduction of 43.2%, compared to the 2005 level. Italy reduced the emissions factor by 42.2%. Spain recorded the highest reduction rate since 2005, -66.7%, on the other side Poland and Sweden have the lowest ones, -26.8% and -19.2% respectively, but Sweden has the lowest emissions factor. The emissions factor in Germany, which has the highest share of European GHGs by power sector, decreased by -32.2% since 2005.

Table 2.6 – GHGs emission factors for total electricity and heat production (g CO_2eq/kWh). Countries in descending order of 2023 value.

Source	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023*
EU27	**457.3**	**423.1**	**388.0**	**370.3**	**333.0**	**311.1**	**229.9**	**240.5**	**254.3**	**210.3**
Poland	719.2	753.4	741.4	714.6	697.7	662.1	573.3	595.3	579.7	523.3
Czechia	672.1	669.0	628.9	579.8	543.2	494.3	407.9	414.8	430.1	392.4
Germany	585.1	559.6	514.4	476.9	450.5	434.4	306.5	336.6	353.9	323.4
Italy	578.6	549.5	507.6	456.8	385.9	324.5	262.9	282.7	315.4	264.2
Netherlands	546.1	483.9	430.2	424.4	389.7	444.9	299.8	306.4	284.7	237.0
Romania	538.6	472.1	431.4	415.1	377.8	329.5	267.2	266.5	272.4	219.2
Belgium	359.9	370.7	293.4	279.2	231.8	237.5	174.2	145.2	156.9	147.8
Spain	439.0	468.2	444.0	406.8	239.5	303.6	162.8	157.4	176.9	135.6
France	111.5	77.7	85.5	95.7	84.9	62.5	57.9	58.9	73.9	50.5
Sweden	33.8	52.6	49.5	56.9	69.1	45.7	46.0	48.2	45.7	45.9
Other countries	460.6	445.6	398.3	384.6	352.0	303.4	210.2	215.4	220.4	168.9

* Preliminary data.

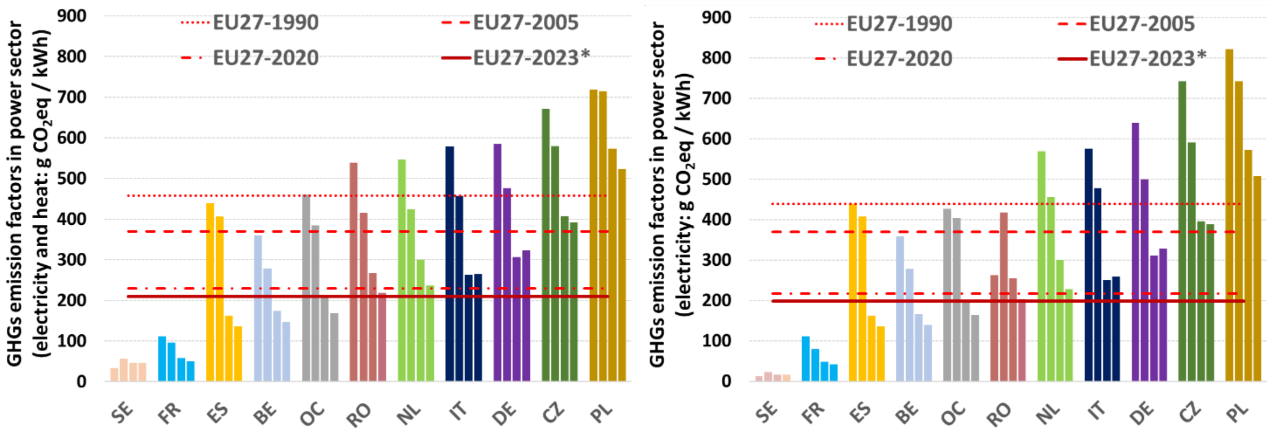
Also considering only the total electricity generation the average EU27 emissions factors have always been below the Italian ones, thanks also to the contribution of nuclear power in the European countries. Italy reduced the emissions factor by 45.9% since 2005, in line with the EU27 rate, while the reduction rates for the other two top emitters, Germany and Poland, are -34.5% and -31.6%.

Table 2.7 – GHGs emission factors for total electricity production (g CO_2eq/kWh). Countries in descending order of 2023 value.

Source	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023*
EU27	**439.1**	**414.2**	**387.4**	**370.0**	**327.0**	**305.5**	**216.6**	**230.1**	**246.2**	**198.6**
Poland	822.0	788.0	767.8	741.7	715.0	664.6	572.3	596.7	577.6	507.5
Czechia	742.1	714.5	683.2	590.5	544.7	502.0	395.9	409.1	433.1	387.7
Germany	640.0	605.8	535.4	499.9	468.1	448.4	310.7	345.0	364.3	327.5
Italy	575.8	546.8	497.7	477.4	390.6	324.1	251.4	277.4	312.6	258.0
Netherlands	568.5	518.7	468.9	456.4	404.5	483.8	299.1	309.0	285.1	228.4
Romania	262.7	431.7	399.2	417.1	378.9	320.7	254.9	260.5	262.0	202.8
Belgium	359.1	371.7	301.2	278.2	228.5	231.2	165.8	135.7	149.0	139.3
Spain	438.9	468.2	443.9	406.8	239.5	303.6	162.8	157.4	176.9	135.6
France	111.5	75.6	76.7	80.0	76.5	55.1	48.4	50.1	63.6	41.6
Sweden	11.9	23.3	22.5	22.8	32.5	16.4	16.5	18.6	18.2	16.4
Other countries	427.1	424.2	417.7	403.6	363.5	307.9	200.7	208.8	214.7	163.6

* Preliminary data.

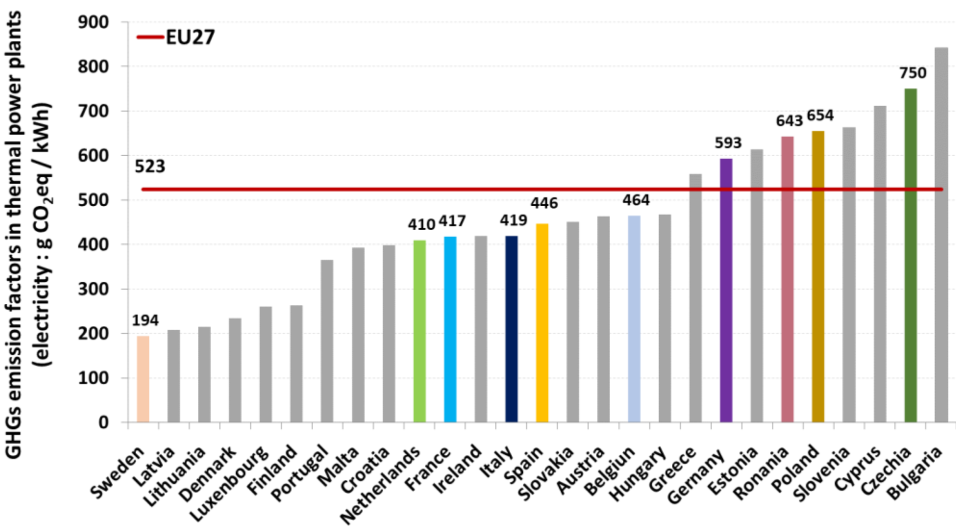
Figure 2.75 – GHGs emission factors in power sector (g CO_2eq/kWh). For each country the bars refer to 1990, 2005, 2020, and 2022. Data in ascending order of the 2023 value. OC – Other countries.



* Preliminary data.

As concerns electricity production the outcomes allow to conclude that, among the biggest European countries, Italy's thermal power plants are in the lowest end of the GHGs emissions factor's range, apart France, the Netherlands, and Sweden which have cumulative share of solid and oil fuels much lower than Italy. Italian emissions factor has the median position among all the European countries, well below the EU27 average. The Italian fuels mix, with greater share of natural gas than many other countries and the contribution of bioenergy, is a driving factor for the emission factor.

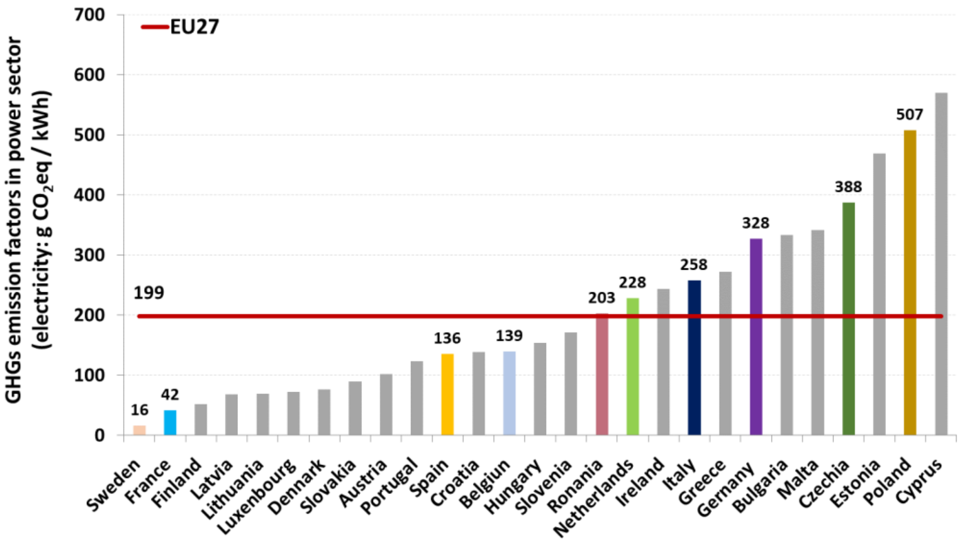
Figure 2.76 – GHGs emission factors in thermal power plants for electricity production (g CO_2eq/kWh) in 2023 (preliminary data). States in ascending order.



On the other side, as for the whole power sector, therefore also considering the no thermal renewables and nuclear power plants, the Italian emissions factor loses positions compared to other countries. France, Belgium, and Spain have relevant amount of electricity from nuclear power plants, which determine the lower emissions factor. Overall, nuclear electricity share in EU27 was 22.8% in 2023, a relevant share although with a steady downward trend since 2005 (-2.2% per year). In 2023, 85.4% of EU27 nuclear electricity comes from the countries examined, with France accounting for 54.6% of European value. The nuclear electricity plays a key role for the correct interpretation of the emission factors in the countries with higher share of nuclear energy. Remind that the difference between the emission factors in Figure

2.76 and Figure 2.77 for each country is due to the contribution of nuclear and other renewables than bioenergy.

Figure 2.77 – GHGs emission factors in power sector for total electricity production (g CO_2eq / kWh) in 2023 (preliminary data). States in ascending order.

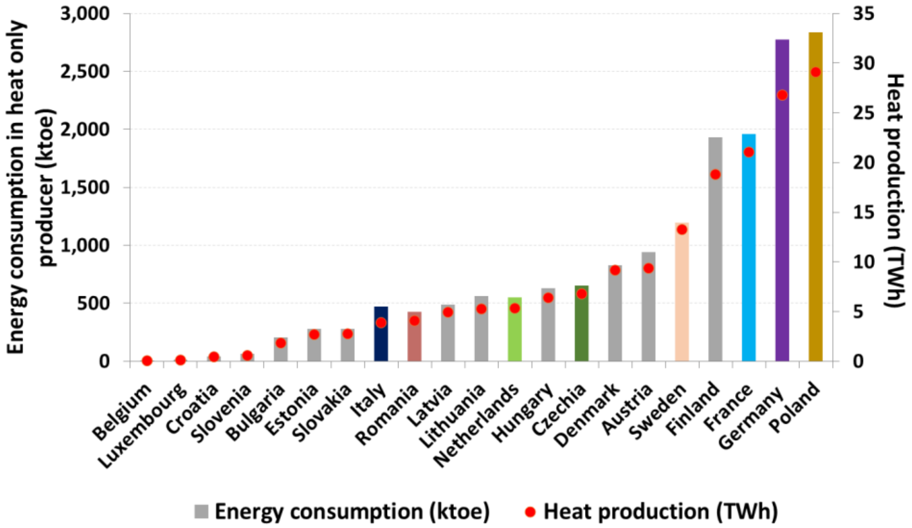


To sum up: as concerns the power sector, Germany, Poland, and Italy are the three biggest emitters in Europe. Because of many factors (fuel mix shift, efficiency, share of renewables) Italy reduced the emissions factor for electricity production by -55.2% from 1990 to 2023 and by -45.9% since 2005. The reduction in Germany was -48.8% since 1990 and -34.5% since 2005, while the figures in Poland was -38.3% since 1990 and -31.6% since 2005. The three countries account for almost 60% of EU27 GHGs from power sector.

2.2.4 Heat-only producers

Heat production accounts for a significant share of energy transformation processes. Plants dedicated to heat production for district heating and other uses (mainly for industry) consume an important share of the energy in the European balance. In 2022 the energy consumption of such plants in EU27 was 17.1 Mtoe of which 0.71 Mtoe from geothermal and solar thermal, and 0.27 Mtoe from heat pumps. The energy consumption of fuels was 16.2 Mtoe, of which 5.8 Mtoe from bioenergy. The consumption of bioenergy in 2022 is more than double the 2005 level and about 8 times the consumption in 1990.

Figure 2.78 – Energy consumption and heat produced by heat-only producers in European countries (2022). Data in ascending order for energy consumption.



Total energy consumption in 2022 is about 33% lower than that recorded in 1990, and a marked fuel shift occurred, with sensible decrease of solid and liquid fuels being replaced by natural gas and bioenergy. The contribution of other renewable sources (more than 90% from geothermal energy and the rest from solar thermal) and heat pumps recorded an increasing trend and in 2022 represented 5.7% of total consumption.

As a result of fuel shift and decreasing energy consumed (-33.4% in 2022 compared to 1990) and heat production (-24%), GHGs registered a sharp decrease by 56.2% since 1990. GHGs emissions factor decreased by 42.3%. At EU27 level the GHGs from these plants were 38.1 Mt CO_2eq in 2022. Since 2005 the emissions factor decreased by 21.1% in EU27 (from 279.7 to 220.7 g CO_2eq/kWh).

Figure 2.79 – Energy consumption (left side), GHGs, and average GHGs emissions factor (right side) by source in heat only producer in EU27.

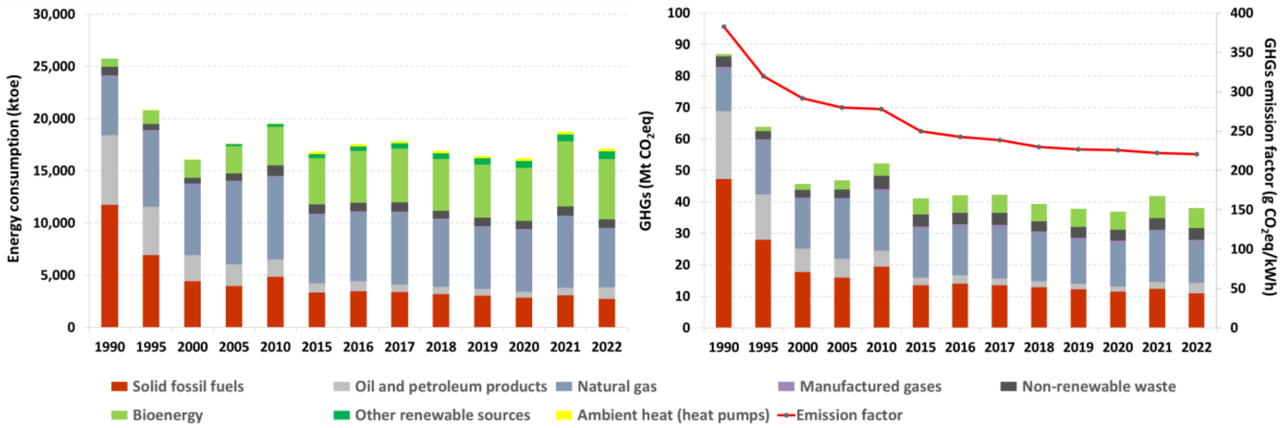
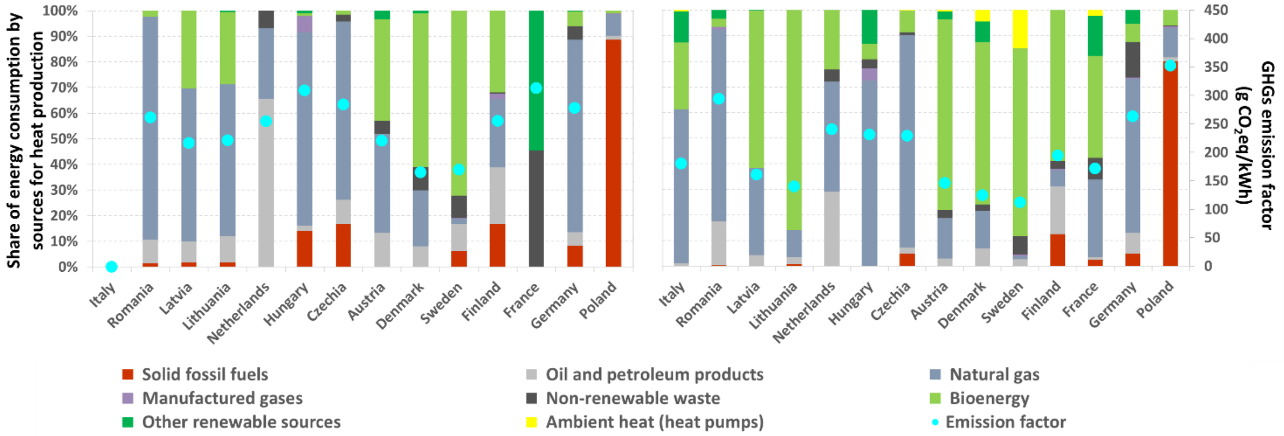


Figure 2.80 shows the share of energy sources and GHGs emissions factor for countries with heat production higher than 3 TWh, accounting for 95% of European heat production by heat-only producers. Italy's emissions factor in 2022 is 18.2% lower than the EU27 average. The relevant solid fuels or non-renewable waste consumption in Poland and Germany results in higher emission factors, respectively 95% and 45.7% higher than the Italian one.

Figure 2.80 – Share of energy sources for heat only producer plants and GHGs emission factor in the greatest heat producers in 2005 (left) and 2022 (right). Countries in ascending order of heat produced in 2022.



CONCLUSIONS

National data

The main outcomes of this report can be summarized as follows:

- Gross inland energy consumption increased from 1990 until 2005 when it peaked at 189.4 Mtoe, then there was a reduction accelerated by the economic crisis with the minimum value of 149.8 Mtoe reached in 2014. In 2020 there was a further contraction of energy consumption due to measures aimed to contain SARS-CoV-2 pandemic (-8.9% lower than 2019 level and -4.4% lower than 1990 level). In 2021 it was recorded a rebound of consumption (+8.8% higher than 2020), with 154 ktoe, followed by further setback in 2022 (-3.9% lower than 2021). The renewable share in gross inland consumption grew from 4.4% to 19% from 1990 to 2022.
- GHGs increased since 1990 until 2005, the following decrease was accelerated by the economic crisis. In 2020 emissions, as energy consumption, was heavily affected by lockdown measures. In 2021 and 2022 the GHGs rebounded, although to level below the 2019 level. The GHGs in 2022 fell by 20.9% compared to 1990 and by 30.7% compared to 2005.
- The emissions from plants subject to EU ETS represent 33% of total GHGs, emissions and from sectors considered in ESR are 66.4% of total GHGs. The latter compartment is involved in the national targets of emissions reduction, while the former is subject to market and to emissions cap set at European level. The ETS emissions decreased by 44.5% from 2005 to 2022, while the ESR emissions decreased only by 20.1%, to be compared with the national target of -43.7% to achieve in 2030.
- National methane emissions, without the contribution of natural sources, represent on average 10.6%$\pm$0.8% of CO_2eq emissions from 1990 to 2022. Methane emissions without LULUCF decreased from 55 to 45.7 Mt CO_2eq, -16.8%. The reduction of methane emissions is lower than the reduction of total GHGs (-20.9%). Agriculture contributes with 45.6% of methane emissions, while the waste sector accounts for 40.3%. Fugitive emissions make up 7.1%, and unburned methane in the energy sector accounts for 7%.
- The trends of gross inland energy consumption (GIC), gross domestic product and GHGs show an increasingly decoupling. Such decoupling is mainly due to fuel shift towards lower carbon content fuels, such as natural gas, and, most of all, to the increasing share of renewable energy.
- The energy and carbon intensities by GDP decreased since 1995. The gross inland energy consumption per GDP decreased from 107.5 toe/M€ in 1995 to 83.5 toe/M€ in 2022 (-22.3%). Over the same period, GHGs per GDP fell by 34.9%, from 357.8 t CO_2eq / M€ to 233 t CO_{2eq}/M€, while energy emissions per primary energy goes from 2.81 t CO_2eq/toe to 2.34 t CO_2eq/toe, with a reduction of 16.8%. The average carbon intensities by sector shows notable differences between sectors depending upon the different deployment of renewable sources and electrification of final energy consumption. Among the sectors transport recorded the highest carbon intensity in the last years with the lowest change since 1990.
- The decreasing energy intensity per value added at national level is partly due to increased efficiency in industry and the declining share of value added of this sector compared to services, which have significantly lower energy intensity.
- The analysis of decomposition shows that the reduction of GHGs since 2005 is mainly driven by increasing renewable share and decreasing energy intensity by economy.
- The renewable sources in the power sector had a significant boost since 2007 following the adoption of policies to reduce GHGs and to achieve the renewable target in final consumption. The increase in renewable energy has been achieved through many measures, such as subsidies and priority dispatching renewable electricity. In 2022 the renewable share in electricity production is 35.6%, mainly due to the drastic fall of electricity from hydropower. Preliminary data for 2023 show a relevant rebound of the renewable electricity share up to 44%, likely to be overcome in 2024 with about 50%.

- CO_2 emissions factor in power sector decreased since 1990 with a strong decoupling between electricity generation and emissions because of the increasing share of renewable electricity, fuel shift toward low carbon fuels as natural gas, and increasing efficiency of power plants fuelled with natural gas.
- The analysis of the decomposition shows that historically the increase in technological efficiency in the thermoelectric sector and the related increasing share of natural gas have played a dominant role to reduce CO_2 emissions, while since 2007 the significant increasing share of renewable electricity assumed the main role compared to the other factors considered.
- The electric carrier in final consumption shows a faster increase in gross domestic energy consumption, indicating an increasing electrification of final consumption destined to further growth to pursue the carbon neutrality. Therefore, power sector's emission factors are useful to plan and monitor initiatives aimed at reducing GHGs. In practical terms, the emission factors allow to calculate the avoided emissions by replacing fossil sources with renewable sources on the production side or saving electricity on the consumption side.

Italy and the biggest European countries

The main outcomes can be summarized as follows:

- Italy's ratio between final and primary energy consumption has been historically higher among the biggest European countries, showing high energy transformation efficiency. Italy is one of the largest European countries with the lowest gross inland energy consumption per GDP.
- The renewable energy per gross inland consumption in Italy is greater than the EU27 average since 2005. The Italian renewable share accelerated sharply since 2007, with an increase in the distance between the Italian and European average up to 2020 when the Italian share decreased approaching the European average. In 2022 Italy is, among the countries considered, second only to Sweden. However, the European target in 2030 of renewable share concerns the gross final consumption and Italy's overall share is well below the European average in 2022 (19.1% vs 23%) and behind countries as France, Germany, and Spain.
- Italian GHGs per capita increased until 2004, unlike other European countries, which have seen decreasing emissions per capita since 1990. Italian emissions per capita were always below the EU27 average and in 2022 are higher to those recorded in Spain, France, Romania, and Sweden where the nuclear energy represents a not negligible share of inland consumption.
- The energy intensity per GDP also considering the energy consumption by international bunkers confirms that among the largest countries, Italy and Germany have the lowest values.
- At sectoral level, the final energy and carbon intensities per value-added show that Italian industry, as well as agriculture, has one of the lowest values among the 27 European States with the highest levels of electrification of final consumption among the biggest countries. On the other hand, the electrification of households in Italy is much below the EU27 average (18.5% *vs* 25.1% in 2022) showing a potential to reduce the sector's carbon footprint. Even the transport sector in Italy has wide room for reducing emissions, mainly in the segment of cars. Italian emissions per capita and per GDP for such segment are over the European average and one of the highest among the biggest countries.
- Italy's resource productivity per direct material inputs is the highest among the biggest countries, despite the relevant share of energy intensive industrial activities.
- The results of decomposition analysis on GHGs change since 2005 show that, among the driving factors, the decreasing final energy intensity and the increasing renewable energy have played a key role to reduce European emissions. The outcomes of decomposition analysis show that in Italy the improvement of final energy efficiency played a less important role than in other countries because of the better performance of the indicator in Italy since 2005.

- The comparison of the largest countries of the European Union shows greater decoupling between GDP and GHGs in other countries than the one observed in Italy, although indicators as energy efficiency, energy consumption per GDP, and GHGs per GDP performed better in Italy than European average since ’90s and many countries with much higher values approached Italian values.
- The Italian GHGs emissions factor in thermal power plants for electricity and heat production is well below the European average. The emissions factor calculated also considering all other sources (nuclear and renewable energy) shows that the Italian value is higher than the EU27 average because of the zero emissions benefit of nuclear plants in many European countries.

To sum up: the results show that Italy has one of the more efficient economies among the biggest countries in Europe. The figures show that energy intensity per GDP as well as resource productivity are among the lowest in Europe despite a relevant role of industry in the Italian economy. Low energy intensity often corresponds to more service-based economies with a minor role of industrial activities. EU27's carbon intensity per energy consumed is on average lower than Italian one, since in several countries is present a not negligible share of nuclear energy.

GHGs trends depend on many factors. The emission reductions in European countries are mainly due to the decreasing energy intensity and increasing renewable energy consumption. In 2020 the measures adopted to contain the diffusion of SARS-CoV-2 pandemic heavily affected the European economy and GHGs emissions. Independently from contingencies there is a clear decoupling between GDP and GHGs in the European countries, often higher than in Italy, although decoupling does not necessarily correspond to the emission reductions in line with the targets. The potential for reducing emissions must be assessed also considering the starting points of the driving factors and the costs to change the energy system, as well as the economy structure, especially concerning the services and industry assets.

Sectoral decarbonization indicators in Italy show sectors such as industry and agriculture with energy and carbon intensities by GDP among the lowest in Europe and sectors such as households and transport with wide room of improvement. The Italian electrification level in households is well below the European average. Italian GHGs per capita for cars are over the European average: one of the highest values among the biggest countries. Such outcomes are consistent with the worrying distance of Italian GHGs projections from the target to be achieved in 2030 (ISPRA, 2024b; MASE, 2024). The emission targets are focused on the partition between biggest energy and manufacturing industries (subject to emissions trading system, ETS) and other sectors (ruled by Effort Sharing Regulation, ESR). The country’s emission targets are set only for sectors not subject to the ETS, i.e. transport, services, households, agriculture, waste and small industry, while emissions from large plants as thermal power plants, refineries, cement plants, steel plants, etc. are in the European cap and trade system of emissions trading.

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