



Supporting Environmentally Sound Decisions for Construction and Demolition (C&D) Waste Management

A practical guide to Life Cycle Thinking (LCT) and Life Cycle Assessment (LCA)



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The mission of the JRC-IES is to provide scientific-technical support to the European Union's policies for the protection and sustainable development of the European and global environment.

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Executive Summary

Overview

Large quantities of waste are generated during the construction of developments, and when buildings and structures are decommissioned and demolished at the end of their lives. Improper management of these construction and demolition (C&D) wastes often results in considerable environmental impacts. Using alternative management routes could result in both environmental and cost savings.

The “waste hierarchy”, established in article 4(1) of the Waste Framework Directive (2008/98/EC), sets the legally binding order of management preference: prevention, preparing for re-use, recycling, other recovery, and disposal as the least desirable option.

Generally, applying the waste hierarchy should lead to the waste being dealt with in the most resource-efficient way. However, as supported by Article 4(2) the Waste Framework Directive, Life Cycle Thinking (LCT) can be used to complement the waste hierarchy in order to make sure that the best overall environmental option is identified.

The Life Cycle Thinking (LCT) concept and quantitative tools such as Life Cycle Assessment (LCA) can provide an informed and science-based support to a more environmentally sustainable decision-making in waste management.

Within the concept of LCT, Life Cycle Assessment (LCA) is a structured and internationally standardised method that quantifies all relevant emissions, resources consumed/depleted, and the related environmental and health impacts associated with any goods or services.

About This Guidance Document

This guidance document provides waste policy makers, waste managers, and businesses with the background to Life Cycle Thinking (LCT) and Life Cycle Assessment (LCA) approaches which can be implemented when considering C&D waste management options.

The guidance does not seek to be comprehensive, but outlines the key principles that are useful to understand, and to signpost readers to further sources of information. It will provide you with an overview of what is Life Cycle Thinking, and how to implement this in practice. Implementation can be through tools and criteria that are developed from existing information or through more detailed quantified LCAs. As there are already well-established methods and sources of data to guide you in undertaking a life cycle assessment, this guidance will help you to identify these and to ensure the consistency, credibility and comparability of your results with those of others.

This document is a waste-specific text, building on the more general ISO 14040 series of standards for LCA, the International Reference Life Cycle Data System

(ILCD) Handbook and the JRC guide “Supporting environmentally sound decisions for waste management – A technical guide to Life Cycle Thinking (LCT) and Life Cycle Assessment (LCA) for waste experts and LCA practitioners”.

Key target audience

This guidance document is useful for anyone involved in the management of C&D waste, or involved in making decisions that could affect its generation – policy makers, developers, contractors and site managers alike.

About Life Cycle Thinking (LCT) and Life Cycle Assessment (LCA)

Over their life-time, products (goods and services) contribute to various environmental impacts. Life Cycle Thinking (LCT) is a concept that accounts for the upstream and downstream benefits and trade-offs. LCT seeks to identify environmental improvement opportunities at all stages across its life cycle, from raw material extraction and conversion, through product manufacture, product distribution, use and fate at the end-of-life stage. Its fundamental aim is to provide a structured and comprehensive approach in support of the overall reduction of product impacts and to help optimise benefits.

Life Cycle Assessment (LCA) is a structured and internationally standardised method that transposes Life Cycle Thinking (LCT) principles into a quantitative framework. LCA quantifies all relevant emissions, resources consumed/depleted, and the related environmental and health impacts associated with any goods or services. Therefore, within the concept of LCT, LCA is a vital and powerful tool to effectively and efficiently help make consumption and production globally more sustainable.

When LCT/LCA are applied to waste management services, typically the assessments focus on a comparison of different waste management options, not covering the entire life cycle of the products which have become waste. Therefore, LCT/LCA applied to waste management services can differ from product LCT/LCA, which accounts for the entire life cycle of a product, in which waste management may play only a minor role. However, if one of the evaluated waste management options includes that materials are given back into the life cycle of a product, a product life cycle perspective has to be taken into account also in LCT/LCA for waste management services.

Key issues addressed in this document

The document is set out in sections that cover the following topics:

- Overview of the Life Cycle Thinking (LCT) concept and of the derived quantitative tool Life Cycle Assessment (LCA)
- The common principle of waste management, the “waste hierarchy”
- An overview of C&D wastes: definition, quantities, composition, management methods, environmental issues, etc.
- How to derive straightforward criteria to support environmentally sound management of C&D waste

- How LCA can be used to support the environmentally-sound management of C&D wastes
- How to conduct an LCA in C&D waste management

Remarks

This document focuses on the environmental aspects of waste management services. While economic, social/societal aspects are mentioned, no detailed guidance on how to include them is provided in this document.

The recommendations given in this document are intended to help model a limited set of typical waste management and treatment activities, focussing on those processes, parameters and impacts that typically matter most. However, the LCA/LCT results and conclusions cannot be generalised and it is the responsibility of the expert to judge whether existing studies and information are relevant and can thus be extrapolated to a new situation not covered in this LCA/LCT study.

Links to specific chapters of the International Reference Life Cycle Data System (ILCD) Handbook provided in this guidance refer to the current edition of the ILCD Handbook (Edition 1).

List of abbreviations

C&D	Construction and Demolition
CBA	Cost-Benefit Analysis
ELCD	European Reference Life Cycle Database
ILCD	International Reference Life Cycle Data System
ISO	International Standards Organization
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LCT	Life Cycle Thinking
SLCA	Social Life Cycle Assessment
TS	Thematic Strategies
WFD	Waste Framework Directive

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1 Introduction

Large quantities of waste are generated during the construction of developments, and when buildings and structures are refurbished or decommissioned and demolished at the end of their lives. The management of these construction and demolition (C&D) wastes results in considerable environmental impacts. But using alternative management routes can result in environmental improvements and cost savings.

But how can the management method that offers the most sustainable solution be identified? There is not always a simple answer. For example, improving resource efficiency by recycling might come at the expense of increased emissions from fuel consumed in transportation. Waste wood can either be recycled to recover its material value, or incinerated to recover the energy within. Which management option is preferable?

1.1 How can life cycle thinking help?

Through Life Cycle Thinking (LCT) we can identify opportunities for lowering environmental impacts across all life cycle stages which avoid simply shifting the problem elsewhere ('burden shifting'), which can often happen. Life cycle stages include raw material extraction and processing, manufacturing production, use, marketing distribution and waste management.

Life cycle thinking can therefore help you to identify opportunities and to make decisions that truly deliver an improved environmental performance. Life Cycle Assessment (LCA) applies LCT concepts within a quantitative framework to help further inform the decision making process.

If you aim for a policy outcome or have a business target to meet, taking a life cycle approach with tools like LCA can help you to achieve your desired results. Some example applications for C&D waste management are shown in the box overleaf.

Whatever your goal or motive, there is a common underlying theme: having the right information to hand with which to make an informed decision.

1.2 How can this guidance document help you?

This guidance document provides waste policy makers, waste managers and businesses with the necessary background to implement Life Cycle Thinking (LCT) and Assessment (LCA) when considering C&D waste management options.

This guidance does not seek to be comprehensive. It outlines the key principles that are useful to understand, and signposts readers to further sources of information.

There are already well-established methods and sources of data to guide you in undertaking an LCA. This guide will help you to identify these and to ensure the consistency, credibility and comparability of your results with those of others.

In some cases, such as for use in daily decision making or by small and medium sized enterprises, detailed life cycle assessments may not be practical. Tools and criteria based on detailed assessments can therefore help implement life cycle thinking in such situations. This guidance will help you to evaluate such tools or criteria as well as to develop them.

Example applications of LCA for C&D waste managers

Informing strategies

- to inform design choices in a construction project in help maximise the sustainability of C&D waste management
- to inform site/contract strategy – target setting etc. (e.g. which materials should be prioritised, which processes have the biggest impact and should be targeted)
- to inform a national/regional/local C&D waste policy decision (e.g. on waste prevention or how best to handle a specific waste material)
- to inform a corporate waste strategy for C&D activities

Making specific decisions

- to decide on the best way of managing waste materials arising on site
- to prioritise materials that offer the greatest environmental savings

Demonstrating performance

- to demonstrate that your design/processes/operations will lead to reductions in the environmental impact of C&D waste
- to demonstrate good/best practice in the environmental performance of site activities

Communicating

- to communicate corporate sustainability actions/progress towards defined targets
- to inform reports made to authorities, environmental groups and other partners
- to defend against claims of 'greenwashing'

1.3 Who should read it?

This guidance document is useful for anyone involved in the management of C&D wastes, or involved in making decisions that could affect their generation.

- **Policy makers** – can use life cycle thinking and assessment to support policy directions and choices at the European, national, regional and local level.

- **Businesses, local authorities and government** – can use life cycle thinking and assessment in designing projects, in materials procurement, in setting site waste management targets, and in communicating their environmental performance.
- **Contractors and site managers** – can use life cycle thinking and assessment to demonstrate the environmental performance of management techniques and to identify efficiencies that can also lead to cost savings.

Interventions occur at all stages in the life cycle of development projects, not just on site. Some potential influences and decision points across the life cycle are set out in Table 1.

Table 1: Key considerations during project stages

Development Stage	Considerations	Decision makers and stakeholders
Design	Can influence the type, volume, management and environmental impact of waste later in the life cycle – through lean design, choice of materials etc. Note that the full life cycle of any design choices must be considered so that actions targeted at end-of-life waste management do not lead to increased environmental impacts elsewhere, for example in producing materials or operating buildings.	Architect Procurement managers Product manufacturers
Construction	An important source of waste materials and energy consumption that requires management. Construction activities can affect the amount and type of waste materials and their management (recycling, thermal treatment, disposal, etc.).	Procurement managers Site managers Contractors Waste managers
Use	May sometimes be less important when considering different management options for C&D wastes. However, there are exceptions to this, for example where there are trade-offs between materials use/ recyclability and a building's energy efficiency (e.g. via insulation). Note that the performance and lifespan of materials used are often more important in the life cycle of a building than the management of their end-of-life wastes.	Site managers Procurement managers
Demolition/ end-of-life	An important source of waste materials that requires management. Demolition activities – for example audit and salvage operations – can affect the type (mixed/separated) and management of waste materials.	Site managers Contractors Waste managers

1.4 Remarks

This document focuses on the environmental aspects of waste management services. While economic, social/societal aspects are mentioned, no detailed guidance on how to include them is provided in this document.

The recommendations given in this document are intended to help model a limited set of typical waste management and treatment activities, focussing on those processes, parameters and impacts that typically matter most. However, the LCA/LCT results and conclusions cannot be generalised and it is the responsibility of the expert to judge whether existing studies and information are relevant and can thus be extrapolated to a new situation not covered in this LCA/LCT study.

Although this guidance document provides some key elements on how to approach waste management issues with LCT and LCA, reading this document only is insufficient background to enable a person to conduct an LCA according to the standards and good practices.

1.5 Links to other guidance

This guidance document is to be intended as part of a set of guidelines, all commissioned to the Joint Research Centre (JRC) by the Directorate General (DG) Environment of the European Commission, tailored to the needs of different target audiences and partly focusing on specific waste streams:

- “Supporting Environmentally Sound Decision for Waste Management – A technical guide to Life Cycle Thinking (LCT) and Life Cycle Assessment (LCA) for waste experts and LCA practitioners”.
- “Supporting Environmentally Sound Decision for Bio-Waste Management – A practical guide to Life Cycle Thinking (LCT) and Life Cycle Assessment (LCA)”;
- The present document: “Supporting Environmentally Sound Decision for Construction & Demolition (C&D) Waste Management – A practical guide to Life Cycle Thinking (LCT) and Life Cycle Assessment (LCA)”;

This document focuses on the use of LCT and LCA in the context of C&D waste management. It is not intended to fully reproduce LCA theory, rules and practices which are provided elsewhere. There are a number of key sources of information and data that this document draws on, including the following:

- International Standards Organization standards for LCA (ISO 14040 series)¹. This series of standards sets the methodological framework for undertaking and reporting LCA studies.
- International Reference Life Cycle Data System (ILCD) Handbook². A comprehensive reference manual that interprets the ISO standards for LCA

¹ http://www.iso.org/iso/catalogue_detail.htm?csnumber=37456

² <http://lct.jrc.ec.europa.eu/assessment/assessment/projects>

and provides guidance and rules for consistent and quality-assured life cycle data and studies.

- Society of Environmental Toxicology and Chemistry (SETAC)¹ guide to Life-Cycle Assessment in Building and Construction.

Further information can be found at <http://lct.jrc.ec.europa.eu/>

1.6 Links to EU policy

At a strategic level, and within the broader context of Sustainable Development promoted by the European Commission, Life Cycle Thinking has been fundamental in the development of EU policy. The Thematic Strategies (TS) on the Prevention and Recycling of Waste² and on the Sustainable Use of Natural Resources used in Europe³, for example, have Life Cycle Thinking at their core.

Communication of the EU Thematic Strategy on Resources

“It is necessary to develop means to identify the negative environmental impacts of the use of materials and energy throughout life cycles (often referred to as the cradle to grave approach) and to determine their respective significance. This understanding of global and cumulative impacts along a causal chain is needed in order to target policy measures so that they can be most effective for the environment and more cost-efficient for public authorities and economic operators.”

Other policies that have Life Cycle Thinking at the core of their approach include the EU Integrated Product Policy (IPP)⁴ and the EU Environmental Technology Action Plan (ETAP)⁵. These promote the understanding of environmental impacts across the life cycle of products and encourage innovation and the consideration of these impacts in the design stage.

At the implementation end of the policy scale, Life Cycle Thinking has been instrumental in developing approaches and objectives in the field of product policy. Several such initiatives include the Ecodesign of Energy Using Products (EuP) Directive⁶; Green Public Procurement (GPP)⁷, Ecolabelling⁸; the Eco-Management and Audit System Regulations (EMAS)⁹. These and others have been brought

¹ <http://www.setac.org/>

² <http://ec.europa.eu/environment/waste/strategy.htm>

³ <http://ec.europa.eu/environment/natres/index.htm>

⁴ <http://ec.europa.eu/environment/ipp/>

⁵ <http://ec.europa.eu/environment/etap/>

⁶ http://ec.europa.eu/energy/efficiency/ecodesign/eco_design_en.htm

⁷ http://ec.europa.eu/environment/gpp/index_en.htm

⁸ <http://ec.europa.eu/environment/ecolabel/>

⁹ http://ec.europa.eu/environment/emas/about/summary_en.htm

together and developed in the European Commission's Sustainable Consumption and Production and Sustainable Industry Policy Action Plan (SCP/SIP)¹.

More specifically with regard to waste, the new Waste Framework Directive (WFD) (Directive 2008/98/EC) confirms the waste hierarchy as the legally binding order of priority for waste management (Article 4), but recognises that life cycle thinking is also needed. For example, there is a clear recognition that life cycle thinking can be used to justify departures from the waste hierarchy.

Waste Framework Directive (Directive 2008/98/EC)

"The waste hierarchy shall apply as a priority order in waste prevention and management legislation and policy: When applying the waste hierarchy [...], Member States shall take measures to encourage the options that deliver the best overall environmental outcome. This may require specific waste streams departing from the hierarchy where this is justified by life cycle thinking on the overall impacts of the generation and management of such waste."

The WFD (Article 28) also requires that all Member States ensure that their competent authorities establish one, or more, waste management plans covering their entire geographical territory. These waste management plans should review the current waste management situation (the type, quantity and source of waste generated within the specific country, including information on C&D wastes) and document the measures that will be taken to improve waste management in line with the waste hierarchy. In this respect, article 10 of the WFD stipulates, *"by 2020, the preparing for re-use, recycling and other material recovery....of non-hazardous construction and demolition waste....shall be increased to a minimum of 70 % by weight"*.

¹ http://ec.europa.eu/enterprise/policies/sustainable-business/environment-action-plan/index_en.htm

2 Life Cycle Thinking and Assessment in Brief

The following sections provide an introduction on Life Cycle Thinking (LCT) and Life Cycle Assessment (LCA). A more detailed presentation of the key aspects and methodological procedure related to LCT and LCA is provided in the more general “Supporting Environmentally Sound Decision for Waste Management – A technical guide to Life Cycle Thinking (LCT) and Life Cycle Assessment (LCA) for waste experts and LCA practitioners”.

2.1 Introduction to Life Cycle Thinking (LCT)

Until recently, the focus for environmental improvement actions was on the process, i.e. minimising point sources of pollution, discharges to rivers, emissions from chimneys and so on. In business, this has often meant a strategy of reducing environmental impacts that is confined within the factory gates. These strategies have not considered consequences on upstream supply chains, product use or end-of-life. In Government, actions have focused primarily on the country or region governed, and not considered knock-on impacts or benefits that would occur in other geographies.

In both cases, if there is insufficient attention to the full life cycle (production / supply / use / end-of-life), overall environmental degradation and unwise resource use may result. Additional potential consequences are damaged reputations and impaired financial performance for the parties involved.

Life Cycle Thinking (LCT) is a conceptual approach that seeks to identify improvements and to lower the impacts of goods or services (products) at all stages of associated life cycles, from raw material extraction and conversion, product manufacture, through distribution, use and eventual fate at end-of-life.

The concept of Life Cycle Thinking helps to avoid the situation of resolving one problem while creating another. LCT avoids the so-called “*shifting of burdens*”, e.g., from one stage in the life cycle to another, from one region to another, from one generation to the next or amongst different types of impacts (Figure 1).

This type of approach demands more from the policy developer or environmental manager, in that he needs to look beyond his own practices and knowledge. However, it also offers the possibility of significant advantages from the knowledge gained – for example through identifying process efficiencies or good management practices.

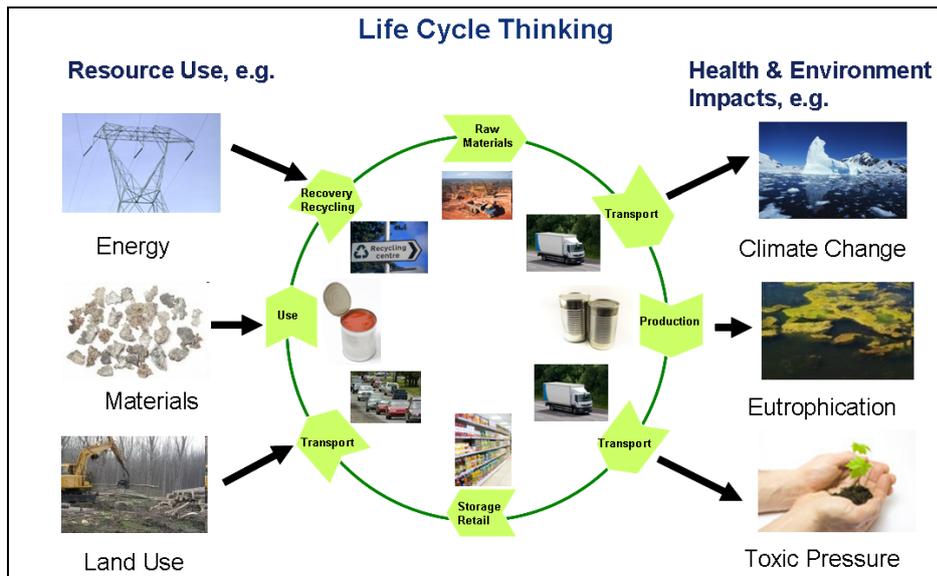


Figure 1: Elements within Life Cycle Thinking

Figure 1 illustrates the correlation between the use of resources, the life-cycle, and the related environmental consequences. This is the most common application up to now. However, the LCT approach can equally be applied to non-environmental aspects (social, practical, economic, etc.), in order to deliver relevant information for a policy in line with sustainable development.

2.2 Life Cycle Assessment (LCA)

Life Cycle Thinking can be quantified in a structured, comprehensive manner through Life Cycle Assessment (LCA). In LCA, one assesses the emissions, resources consumed and pressures on health and the environment that can be attributed to different good(s) or service(s) taking into account their entire life cycle, from “cradle” to “grave”. LCA is an internationally standardised method (ISO 14040 and 14044)¹ that can provide a rigorous approach for improving decision support in environmental management.

Using LCA, we seek to quantify all the physical exchanges with the environment, whether inputs of natural and energy resources or outputs in the form of emissions to air, water and soil. These inputs and outputs are compiled in a balance sheet, or life cycle “inventory” for a given “system”. After the inventory has been completed, the inputs and outputs are translated into indicators associated with different pressures such as resource depletion, climate change, acidification, or toxicity to plants, animals and people.

LCAs express environmental impacts per “impact category” or environmental problem. All emissions contributing to an environmental problem are converted into a common unit (e.g., kg CO₂-equivalent for climate change, or kg SO₂-eq. for acidification) using conversion factors (known as “characterisation factors”; e.g., for

¹ http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_tc_browse.htm?commid=54854

looking at climate change over a 100-year time frame, 1 kg of methane is equivalent to 25 kg CO₂¹).

Figure 2 shows an example of this process – termed “life cycle impact assessment” (LCIA). Using scientifically-derived characterisation factors, the LCIA step calculates the relative importance of each input and output for the different types of environmental problem. Some of these characterisation factors are very reliable and globally harmonised for some impact categories (such as the IPCC factors used for climate change²), but for others (e.g., land use, toxicity) several methods exist and international/European harmonisation is ongoing³.

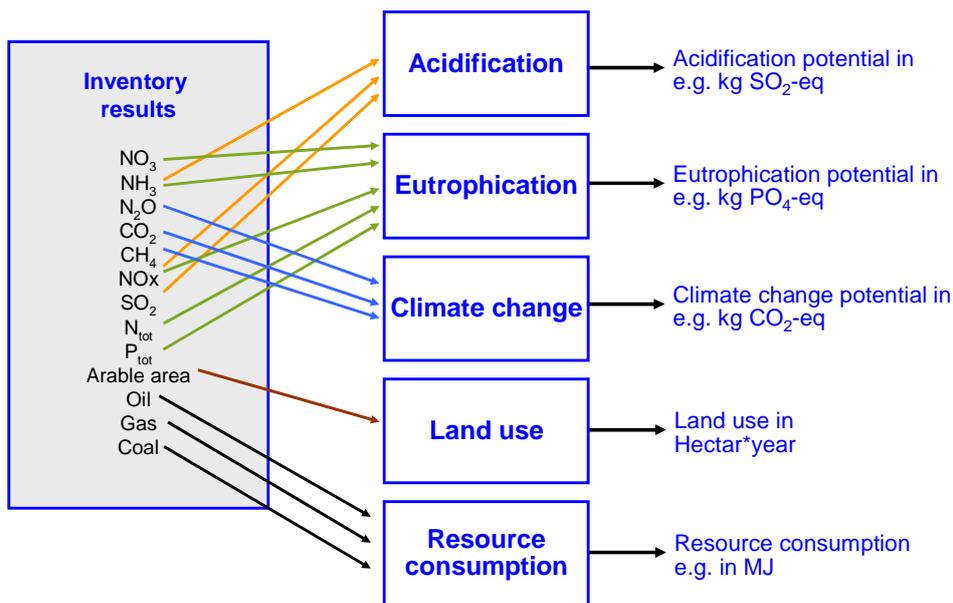


Figure 2: Illustrative example of Life Cycle Impact Assessment – Translating Inputs and Outputs into example Indicators of their Contributions to different Environmental Impacts

The results of an LCA can help businesses and policy-makers understand the benefits and trade-offs they face when making decisions on waste management options. LCA provides quantitative information which puts potential environmental advantages and disadvantages into perspective

When conducting a comprehensive LCA, first of all an independent review panel is chosen. Then, a five-phase procedure is followed:

- 1st phase: Goal definition;
- 2nd phase: Scope definition;
- 3rd phase: Life Cycle Inventory – LCI;
- 4th phase: Life Cycle Impact Assessment – LCIA;

¹ Based on the 4th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC); year 2006

² Intergovernmental Panel on Climate Change (IPCC) 2006, Forth Assessment Report

³ For more information please refer to <http://lct.jrc.ec.europa.eu/>

- 5th phase: Interpretation of results.

These phases often involve iterations (mainly to improve data quality as necessary). Preparation of a draft LCA report follows completion of these five phases. The draft report is then submitted for review to the Review Panel. Preparation of the final LCA report should reflect analyses of reviewer comments and suggested revisions.

The following table (Table 2) provides an overview of the five-phase procedure for conducting LCAs; examples and key elements are provided for each phase. As shown in Table 1, a crucial task in the LCA scope definition is to identify the “**functional unit**”, i.e. the service or function the system being investigated delivers to the user. For example, in municipal waste management the functional unit can be collection and treatment of all household waste in a given region and year. All environmental burdens are then expressed relative to this functional unit. For comparing different waste management options, it is crucial that they provide the same function. Otherwise, a fair comparison between systems is not possible.

LCA is an iterative process. For example, one might need to revise the initial definition of goal and scope based on the findings of the inventory analysis, e.g., refine the system boundary to include a process that was initially disregarded.

Table 2: The five phases of Life Cycle Assessment plus reporting and review

Phase	Key Elements	Description
Goal	Six aspects of the goal definition	Identify the following -: <ul style="list-style-type: none"> • Intended application(s); • Proposed study methods, important assumptions and impact limitations (e.g., Carbon footprint); • Reasons for conducting the study, and the decision context; • Target audience; • Comparisons to be disclosed to the public; • Commissioner of the study and other influential actors.
	Classify the decision context	Identify the decision context: <ul style="list-style-type: none"> • Whether the study is interested in the potential consequences of this decision; • The extent of changes - further differentiates the decision-support cases into those that have only small-scale ramifications versus those that have large scale ramifications.
Scope	Define Function, Functional unit and reference flow	<ul style="list-style-type: none"> • Identify the function of the subject product for both qualitative and quantitative aspects; • Identify the reference unit for measurement and analysis.

	Life Cycle Inventory (LCI) modelling framework	<ul style="list-style-type: none"> Identify the LCI modelling approach according to the decision context.
	System boundary	<ul style="list-style-type: none"> Identify which processes are included and which processes are excluded.
	Preparing the basis for the impact assessment	<ul style="list-style-type: none"> Identify relevant impact categories
	Type, quality and sources of required data	<ul style="list-style-type: none"> Identify whether data quality is sufficient (in terms of data accuracy, precision / uncertainty and completeness of the inventory); Check whether all foreground and background data used in a LCI/LCA study are methodologically consistent.
	Comparisons between systems	<ul style="list-style-type: none"> Identify whether this study includes comparative assertions; Identify if the study includes comparisons and whether additional requirements are needed.
	Identifying critical review needs	<ul style="list-style-type: none"> Identify proper review type according to target audience and final deliverable.
	Planning reporting	<ul style="list-style-type: none"> Identify proper report type according to target audience and final deliverable.
Life Cycle Inventory	Planning data collection	<ul style="list-style-type: none"> Identify foreground and background data; Identify relevant processes; Identify relevant data; Design Data collection format.
	Collecting unit process	<ul style="list-style-type: none"> An actual collection of inventory data is typically only required for the foreground system; Describing what the modelled unit process represents; Collect relevant inputs and outputs of the unit process.
	Life Cycle Data Analysis	<ul style="list-style-type: none"> Select secondary LCI data sets; Filling initial data gaps; Solving multi-functionality of process.
	Calculating LCI result	<ul style="list-style-type: none"> Calculate and aggregate inventory data of a system.
Life Cycle Impact Assessment	Classification	<ul style="list-style-type: none"> Assign LCI results to the selected impact categories.
	Characterization	<ul style="list-style-type: none"> Calculate category indicator results.

	Normalization (optional)	<ul style="list-style-type: none"> • Provide a basis for comparing different types of environmental impact categories (all impacts get the same unit).
	Weighting (Optional)	<ul style="list-style-type: none"> • Assign a weighting factor to each impact category depending on the relative importance.
Interpretation and Quality control	Evaluation	<ul style="list-style-type: none"> • Identify significant issues;
		<ul style="list-style-type: none"> • Perform completeness check;
		<ul style="list-style-type: none"> • Perform sensitivity check;
		<ul style="list-style-type: none"> • Perform consistency check;
		<ul style="list-style-type: none"> • Derive conclusion, limitations and recommendations;
		<ul style="list-style-type: none"> • Check if the LCA results fulfil the goal & scope of study
Reporting		<ul style="list-style-type: none"> • Is the quality sufficient?
Critical Review		<ul style="list-style-type: none"> • Are there potential for improvements?

2.2.1 LCA standards

The International Standards Organization (ISO) aims to assist the standardisation of a wide range of products and activities. The ISO 14000 series addresses environmental issues and includes the 14040 series which relates to Life Cycle Assessment¹.

The 14040 series addresses not only the technical, but also the organisational aspects of LCA, such as stakeholder involvement and independent critical review of studies. Methodological aspects are set out in ISO 14040 and 14044. These specify the general principles and requirements for conducting an LCA.

The standards are supported by Technical Reports that provide guidance on dealing with some of the more difficult methodological issues in LCA.

The European Platform on Life Cycle Assessment (EPLCA) and the International Reference Life Cycle Data System (ILCD)² promote the availability, exchange and use of coherent and quality-assured life cycle data, methods and assessments for reliable and robust decision support. The ILCD consists primarily of the ILCD Handbook³ and the upcoming ILCD Data Network, with the former setting requirements for quality of LCI data and LCAs and the latter providing access to data from a wide range of different data developers and on a global basis.

¹ http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_tc_browse.htm?commid=54854

² <http://lct.jrc.ec.europa.eu/>

³ <http://lct.jrc.ec.europa.eu/assessment/projects>

2.3 LCT and LCA for waste management decision support

European, national and local public authorities and businesses are increasingly encouraged to make use of life cycle thinking and life cycle assessment as support tools for decision making.

LCT/LCA for waste management can be used for a range of applications, from assessing the benefits of avoiding a waste to evaluating different options for management systems. In the context of waste management facilities, an LCA considers the direct impacts of the operations on the environment (e.g. stack emissions from an incinerator). It also quantifies the indirect benefits of recovering materials and energy from the waste (e.g. through combined heat and power and ferrous metal recycling). These impacts and benefits are expressed through indicators for different environmental impact categories – such as climate change, water consumption or toxicity.

When LCT/LCA are applied to waste management services, typically the assessments focus on a comparison of different waste management options, not covering the entire life cycle of the products which have become waste. For example, when evaluating different options for bio-waste management, usually the production stages of the food that has become bio-waste, are not considered.

Therefore, LCT/LCA applied to waste management services can differ from product LCT/LCA, which accounts for the entire life cycle of a product, in which waste management may play only a minor role. However, if one of the evaluated waste management options includes that materials are given back into the life cycle of a product, a product life cycle perspective has to be taken into account also in LCT/LCA for waste management services. For example, when looking at municipal waste management including recycling, the benefits of saving virgin raw materials in the production stages of products have to be taken into account.

2.3.1 The Waste Hierarchy

The waste hierarchy is the legally binding guiding principle behind any waste management decision or system. The waste hierarchy is established in Article 4(1) of the EU Waste Framework Directive (2008/98/EC).

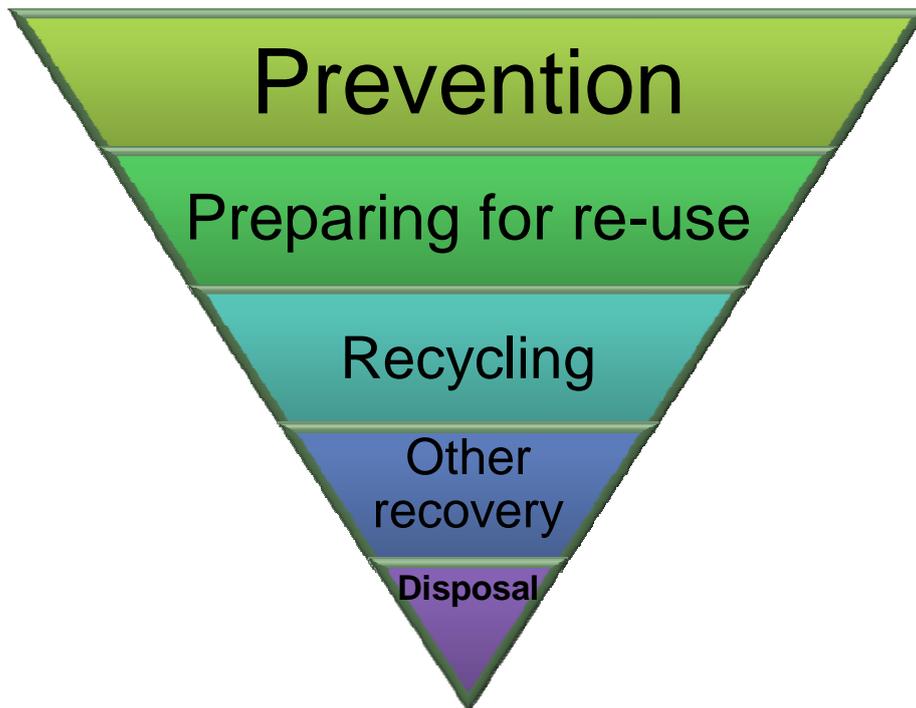


Figure 3: The waste hierarchy, as defined by the Waste Framework Directive (2008/98/EC)

Generally, following this hierarchy should lead to the most resource-efficient and environmentally sound choice for the management of wastes. But this is not always the case. There are exceptions to the rule, and life cycle thinking and life cycle assessment are powerful tools to help identify where the hierarchy does not hold as well as to help compare options at any given level of the hierarchy.

The following sections discuss opportunities for C&D waste management at each stage of the hierarchy and the use of LCA to inform management decisions.

How can LCA support the waste hierarchy?

LCA helps to address questions at all levels of the waste hierarchy, such as:

- Are there instances in which re-using building components could lead to increased environmental impacts?
- Is it always better to recycle waste C&D materials than to dispose of them?

...and LCA also tackles questions on how to reduce environmental impacts:

- What type of gas cleaning is more appropriate for waste incineration plants?
- Should different waste types be collected together or separately?

2.3.2 Waste Prevention

The Waste Framework Directive¹ defines waste prevention as: "*measures taken before a substance, material or product has become waste that reduce:*

- (a) *the quantity of waste, including through the re-use of products or the extension of the life span of products;*
- (b) *the adverse impacts of the generated waste on the environment and human health; or*
- (c) *the content of harmful substances in materials and products".*

Prevention is often the best possible solution for the environment, as resources are not lost and the negative environmental impacts associated with waste management do not occur. Prevention (as defined in the Waste Framework Directive) also refers to measures taken to reduce the adverse impacts of generated waste on the environment and on human health, for example through minimising the content of harmful substances in materials and products.

Opportunities for waste prevention occur across the life cycle of a construction or demolition project, not only at its end-of-life stage. The design stage, for example, offers many opportunities for reducing the environmental impact of both materials and waste, through the choice of materials and 'lean design' techniques.

Waste prevention interventions can therefore range from simple actions on site, such as the introduction of plasterboard carriers to reduce breakage, to early design interventions, for example reducing the quantity of plasterboard needed in the fit-out stage.

- The Waste and Resources Action Programme (WRAP) Design Guide provides many ideas for waste prevention and other good management practices related to construction and demolition activities.
- The Building Research Establishment (BRE) has developed a True Cost of Waste Calculator² which measures the environmental benefit of reducing wastage rates and materials consumption.

Key Life Cycle Concepts

You can use LCA to guide you in making decisions between different waste prevention options and to demonstrate the benefits of waste reduction measures on site, in contract specifications, or in policy choices. LCA is also useful for highlighting where waste prevention measures pose a risk of actually increasing environmental impacts, rather than reducing them. For example, reduced packaging can result in materials or components being damaged more frequently. So, more materials would be needed to complete the final project.

There are some key theoretical concepts to consider when using LCA to assess waste prevention measures. Of particular importance is the choice of '**system boundary**' and what

¹ Directive 2008/98/EC

² <http://www.wastecalculator.co.uk/login.jsp>

to include in the assessment. This is discussed further in the more general “Technical guide to LCT and LCA for waste experts and LCA practitioners”, also developed by the Joint Research Centre (JRC).

2.3.3 Preparing for re-use and re-use

Very simply, re-use means that a product, its components or entire building structures are used again for the same purpose, rather than being dismantled and sent for recycling, recovery or disposal. ‘Preparing for re-use’ means carrying out checking, cleaning or repair operations that enable waste materials to be re-used without any other pre-processing.

Very often, the benefits of re-use are straightforward, as re-use avoids the need for the manufacture of a new product. A simple example is the direct re-use of containers, bricks or other materials on site.

However, re-use can also mean:

- A separate collection and return system is required if the product is not re-used by the same organisation;
- A cleaning or reconditioning stage is needed – for example following salvage of building components before demolition;
- More transport emissions occur – if the re-usable product is heavier or has a larger volume than the disposable one, or if re-conditioning infrastructure is limited and needs to be transported longer distances; and
- Compared to new and more efficient products, higher energy consumption may occur during the use phase, for example for electrical equipment requiring more energy.

Key Life Cycle Concepts

LCA can be used to demonstrate the environmental advantages and disadvantages of different re-use options and initiatives.

Things to consider when using LCA to assess such options include the **lifespan** of a product/material, and its **relative performance in use**. This is discussed further in the more general “Technical guide to LCT and LCA for waste experts and LCA practitioners”, also developed by the Joint Research Centre (JRC).

2.3.4 Recycling

As the original, or ‘primary’, production of materials can require significant amounts of energy and raw materials (its ‘embodied impact’), recycling into ‘secondary’ materials can be environmentally very beneficial. For example, separation of metals from C&D waste and recycling into other metal products has been shown to result in significant

environmental savings. There are also considerable financial benefits, which already drive the recycling of many materials.

Life cycle benefits of recycling metals

In the Waste and Resources Action Programme's (WRAP's) international review of the environmental benefits of recycling (WRAP, 2007)¹, the majority of LCAs examined highlighted that recycling steel can result in greenhouse gas savings of approximately 1.5 tonnes CO₂-equivalents per tonne of material recycled, in comparison with landfilling the same quantity. This figure increases to 10 tonnes CO₂-equivalents where aluminium is recycled.

However, various factors can significantly influence the environmental comparison of recycling and alternative management options (e.g. energy recovery and disposal).

These include:

- The distance to the reprocessing plant and the type of transport used;
- The energy intensity of the recycling process;
- Recycling efficiency (how much product is lost in the process);
- The quality of the secondary products; and
- The product(s) that the recycled material will replace.

Key Life Cycle Concepts

LCA can be used to guide you in making decisions between recycling options and to robustly demonstrate the benefits of actions already taken, or of planned strategies.

Important concepts to keep in mind when assessing the relative impacts and benefits of recycling schemes include '**closed loop**' and '**open loop**' recycling, **recyclability**, **down-cycling** and product '**substitution**'. This is discussed further in the more general "Technical guide to LCT and LCA for waste experts and LCA practitioners", also developed by the Joint Research Centre (JRC).

2.3.5 Energy Recovery

An alternative to recovering the material value from a waste stream (i.e. recycling) is to recover the energy inherent within the waste material(s). This can lead to significant environmental benefits, particularly for materials with a high calorific content. For example, estimates of the savings in greenhouse gas emissions of recovering energy from waste wood range from 0.5 to 3 tonnes CO₂-equivalents per tonne of material incinerated, in comparison with landfilling the same quantity (WRAP, 2007)².

¹ WRAP (2007) International Review of Life Cycle Assessments. WRAP, Banbury, UK.

² WRAP (2007) International Review of Life Cycle Assessments. WRAP, Banbury, UK.

Key Life Cycle Concepts

Various parameters can significantly influence the scale of impacts and benefits associated with energy recovery and affect the environmental comparison between this management route and other levels of the waste hierarchy (e.g. recycling and disposal). For example, the type of waste combusted, its **calorific content**, the **amount of energy** captured and the **type of energy** it replaces. This is discussed further in the more general “Technical guide to LCT and LCA for waste experts and LCA practitioners”, also developed by the Joint Research Centre (JRC).

2.3.6 Disposal

At the bottom of the waste hierarchy there are occasions where disposal of C&D wastes in landfill is unavoidable. There may also be occasions where this presents the best solution environmentally. Consider the case of low grade inert materials. To be recycled as aggregate, they may need to undergo further re-processing and transportation to a distant point of use. The impacts of doing so may be greater than both the ‘avoided burdens’ of producing primary aggregates and disposing of the inert waste material in a landfill. Life Cycle tools such as the WRAP aggregates model can help you to determine whether this is the case.

Key Life Cycle Concepts

There are a number of factors that are important to consider in determining the impacts of landfilling C&D materials, primarily the **composition of the waste** stream. The majority of C&D materials are inert and so they will not degrade in a landfill. Some materials, such as wood, will degrade over time, producing a gas, ‘landfill gas’, which contains methane – a powerful contributor to climate change if it escapes. Harmful elements may also slowly leach out of C&D wastes over time. This is discussed further in the more general “Technical guide to LCT and LCA for waste experts and LCA practitioners”, also developed by the Joint Research Centre (JRC).

2.3.7 Management route comparison

LCA is a useful tool for comparing management routes, identifying the most environmentally preferable solution, and quantifying its benefits.

In making a management route comparison you should be aware of:

- The need to make comparisons on an equal basis (compare like with like); and
- The need to make ‘choices’ where there is no clear preferred option.

Examples of different C&D related LCAs

Application of LCA to demonstrate the benefits of the ‘valorization’ of building demolition materials and products (Sára et al, 2000)¹

The VAMP research project (VAlorization of building demolition Materials and Products, LIFE 98/ENV/IT/33) was set up in order to test an innovative C&D waste system in the district of Modena and Reggio Emilia in Italy.

The partners in the VAMP project realised that a quantitative demonstration of environmental advantages was necessary to support the VAMP system. Therefore, they decided to compare, using an LCA approach, the proposed VAMP system (promoting high levels of recycling, recovery and re-use) with a traditional system, characterised by landfill disposal of mixed demolition waste.

Data from demolition sites, reprocessors and landfill sites were sought in order to use specific information for these operations. To characterise the benefits of ‘avoided’ processes (through recycling, recovery and re-use), data from published studies were sourced, including local environmental studies and international publications. The case study results clearly showed the environmental advantages of the VAMP system. Besides the large amount of solid waste in landfill and extracted natural resources that were avoided, the importance of re-using building components was highlighted. In one case study, for example, a significant amount of energy was saved through the re-use of clay bricks as complete components. It was considered that the application of LCA to other VAMP case studies would help to collect additional data to support the system and to communicate the benefits achieved.

An LCA-based approach to prioritizing methods of preventing waste from residential building construction, re-modelling and demolition in the state of Oregon (DEQ, 2009)²

In Oregon, the residential construction sector is responsible for a significant portion of wastes generated. Waste prevention activities are therefore important. However, it was also recognised that there is a need to ensure that any waste prevention actions that the State Government takes are optimised to achieve maximum benefit across multiple environmental impact categories, and to avoid simply shifting burdens from one type of impact to another.

To meet this need, an LCA was undertaken to identify the residential construction waste prevention practices that provide the greatest overall environmental benefit. Information to support the study was compiled with the help of the Oregon Home Builders Association (OHBA), Earth Advantage Inc. (EAI, the leading building energy certifier in the State), and the Oregon Department of Environmental Quality (DEQ). A wide range of experts on building practices were also consulted. A whole-building LCA framework was established that combines detailed data on building materials and energy use (supplied by OHBA and EAI) with information about residential buildings in Oregon.

More than two dozen possible waste prevention practices were identified, such as the use of salvaged materials and design for ease of disassembly. In a first phase, these practices were evaluated to short-list those practices showing the most promise. The best performing practices were evaluated in a second phase, in which the level of detail was greatly increased and the scope was expanded to consider the practices within the framework of a state-wide residential building stock.

DEFRA scoping study for insulating building panel foam wastes (not yet published)

Feasibility research was recently undertaken by the UK Department for Environment, Food and Rural Affairs (DEFRA) concerning the potential impacts of managing building foam insulating panel wastes. The wastes are known to contain quantities of Ozone-Depleting Substances (ODS) which were

¹ Sára, B., Antonini, E. and Tarantini, M. (2000) *Application of Life Cycle Assessment (LCA) methodology for valorization of building demolition materials and products.*

² DEQ (2009). A Life Cycle Assessment Based Approach to Prioritizing Methods of Preventing Waste from Residential Building Construction, Remodeling, and Demolition in the State of Oregon. Phase 1 Report, Version 1.2

historically used as a blowing agent for the foam in its production. A proportion of the panels have a steel backing which can be removed for recycling. As part of the research, a scoping life cycle study was undertaken, with the aim of comparing the environmental impacts of managing building foam wastes via different waste management routes.

It was established at the outset that the blowing agent remaining in the foam will be extremely potent with respect to global warming potential, dominating other environmental concerns. As such, the study directed its efforts to quantify the effectiveness of different waste management systems to remove and destroy the ODS and reduce GHG emissions. The study did not exclude life stages from the assessment, but used surrogate data for transport and waste management processes, sufficient to provide an indication of the relative impacts associated with each of the options evaluated.

3 Construction & Demolition Wastes: an Overview

This section provides some contextual background regarding C&D waste management in Europe and the quantities and composition of waste materials. It briefly discusses the alternative management options for the different types of wastes and identifies the main environmental and sustainability issues associated with C&D waste generation.

3.1 C&D wastes: definition and EU context

Construction and demolition (C&D) wastes are generated from the construction or deconstruction of buildings and other infrastructures. They are important because they account for around one third of the controlled¹ waste within the European Union.

C&D waste materials typically include soils, concrete, bricks, glass, wood, plasterboard, asbestos, metals and plastics (more detail on this is included in [Section 3.3](#)). Specific material streams that are used for reporting can be found in the EU List of Wastes (2000/532/EC)².

The Waste Framework Directive (WFD) excludes uncontaminated soil and other naturally occurring material excavated in the course of construction activities, when the material is used, and remains, on site. For the purposes of this guidance document, it is assumed that these do not form part of C&D wastes, although the energy consumption linked to excavation, for example, may be useful to consider.

Some caution is always needed when reviewing statistics on C&D waste generation and composition. Different methods and waste definitions are sometimes used in compiling surveys, which makes them incomparable. Here, to provide a general context, we present some high-level statistics on occurrences across Europe and on the composition of the waste stream. However, as waste composition can be an important factor in determining the potential environmental impact of its management (a point explored further in [Section 5.2](#)), it is recommended that local, regional or national estimates are sourced where necessary.

3.2 Quantities generated in the EU

Approximately 3 billion tonnes of waste are generated in EU 27 each year. Of this, around one third (i.e. 1 billion tonnes) comes from construction and demolition activities.

¹ Regulated by governmental institutions or acts

² <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2000:226:0003:0024:EN:PDF>

Figure 4 presents the spread of C&D waste across European countries. Note that waste definitions and reporting (for example the inclusion of excavated soils) may explain some of the differences between countries.

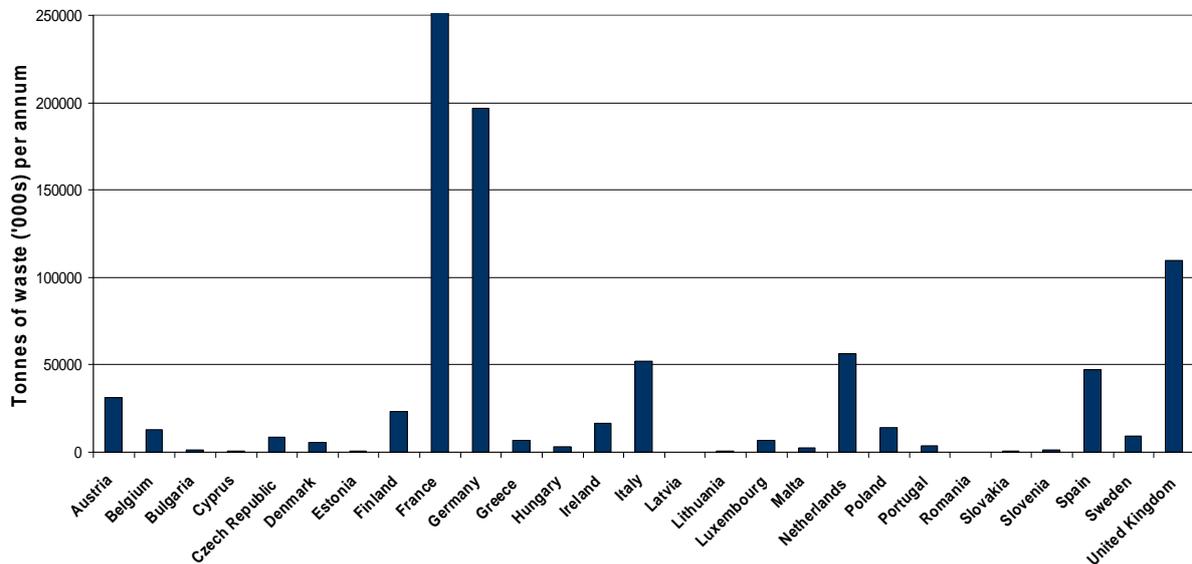


Figure 4: Estimated annual quantity of C&D waste produced in Europe in 2006¹

3.3 C&D waste: composition

C&D wastes typically comprise large quantities of inert mineral materials, with smaller amounts of a range of other components. The following materials are typical:

- concrete;
- bricks, tiles and ceramics;
- wood;
- glass;
- plastic;
- bituminous mixtures and tars;
- metals (ferrous and non-ferrous);
- soils and stones;
- dredging spoils;
- insulation materials (including asbestos);
- gypsum-based materials (including plasterboard);
- chemicals;
- waste electronic and electrical equipment (WEEE);
- packaging materials; and

¹ Eurostat - <http://epp.eurostat.ec.europa.eu>

- hazardous substances.

It is difficult to define a specific composition for C&D wastes (in percentage terms) as it will vary between sites, regions and countries. There are also likely to be considerable differences between the composition of construction wastes and of demolition wastes. Data sources are limited, as detailed surveys and analyses can be costly.

Table 3 and Figure 5 provide examples of C&D waste composition for Scotland and for Wales, respectively. These serve as examples only, and are not representative of the whole of Europe.

Table 3: Estimated composition of C&D waste in Scotland (2004/05)¹

Waste Fraction	Composition (%)
Soil and stones	73%
Bricks, blocks, plaster	0.2%
Other non-combustible materials (concrete, tiles, ceramics, insulation materials)	26%
Wood	0.1%
Other combustible materials (other wood, bituminous material, coal and tarred products)	0.1%
Metals	0.002%
Glass	0.05%
Plastic (dense)	0.01%

Note that hazardous substances may be contained in any number of building components or materials and require special consideration (see [Section 3.4.1](#)). The main hazardous components in C&D waste are:

- asbestos – found in insulation, roofs and tiles and fire-resistant sealing;
- lead based paints – found on roofs, tiles and electrical cables;
- phenols - found in resin-based coatings, adhesives, and other materials;
- polychlorinated biphenyls (PCBs) - found frequently in joint sealing and flame-retardant paints / coats, as well as electrical items; and
- polycyclic aromatic hydrocarbons (PAHs) – frequently found in roofing felt and floorings, amongst other items. Present in a wide array of products.

¹ Scottish Environmental Protection Agency (SEPA), 2005

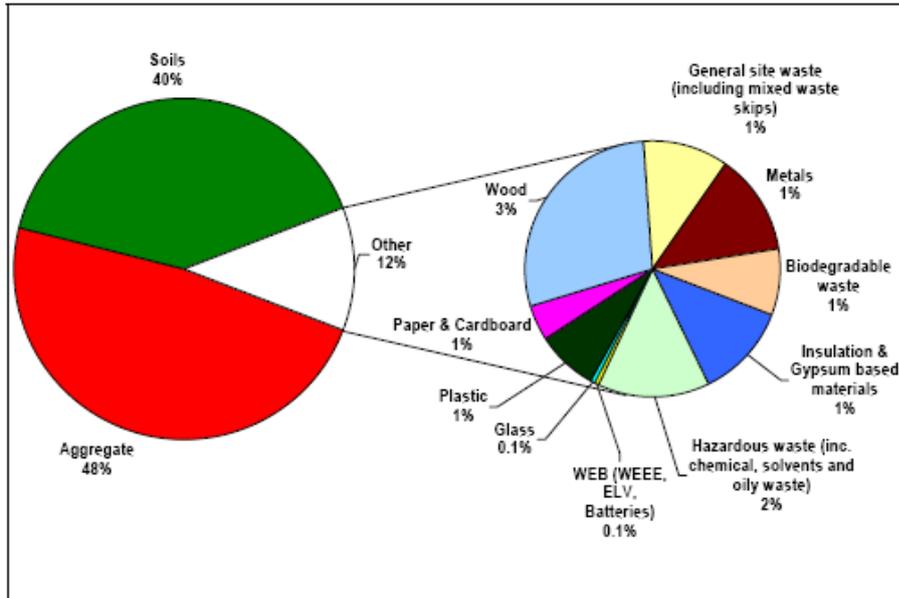


Figure 5: Composition of C&D waste in Wales (2009)¹

3.4 C&D waste: management options

A range of techniques are used in the management of C&D wastes throughout Europe. Some of the materials, such as bricks, are recovered from demolition sites and re-used directly in construction. Other materials can undergo a number of physical and thermal processes, including:

- **Screening** – for the grading of soils and stones for re-use;
- **Crushing** – for processing concrete and rubble for use as sub-base;
- **Shredding** – for processing wood/boards etc;
- **Segregation and recycling** – of waste component materials such as metal, plastic, glass and plasterboard;
- **Incineration** (with or without energy recovery) – of wood, plastics and for the thermal destruction of hazardous components; and
- **Landfill** (inert, non-hazardous, and hazardous) – of various materials, ranging from simple sites for the disposal of inert materials to specific sites specialising in the handling of hazardous materials, such as asbestos and low-level nuclear waste.

¹ Environment Agency for England and Wales (2009)

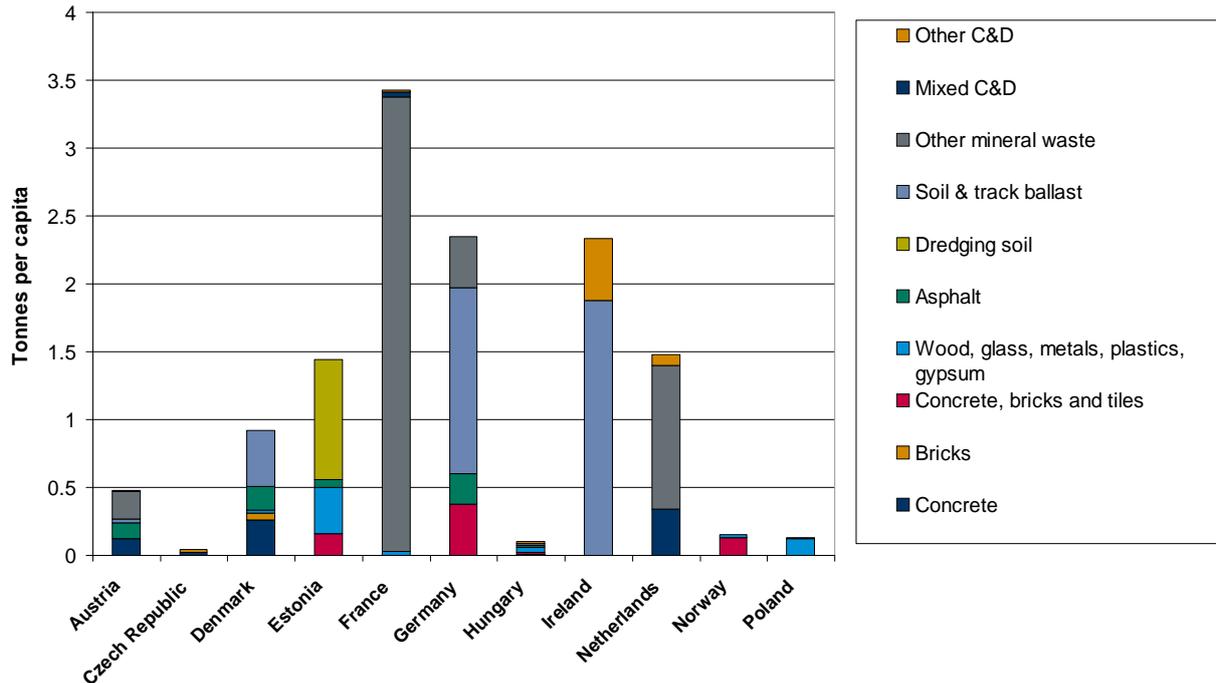


Figure 6: Recycling of specific materials from C&D wastes by selected EU countries (ETC-SCP, 2009)¹

The various forms of recycling and recovery are likely to become increasingly important over time, due to the overarching targets set for this waste stream. Article 10 of the WFD stipulates, “by 2020, the preparing for re-use, recycling and other material recovery....of non-hazardous construction and demolition waste....shall be increased to a minimum of 70 % by weight”. The demolition industry in the UK, for example, already recycles roughly 90% of C&D materials, mainly in order to gain the associated economic benefits.

3.4.1 Hazardous materials and components

The specific properties of waste that render it hazardous are defined in Annex III of the Waste Framework Directive (WFD); a given waste stream is to be considered “hazardous” when it displays one of more of the listed hazardous properties (Article 3). Also, the WFD encourages Member States to collect separately “hazardous compounds from waste streams if necessary to achieve environmentally sound management”.

The management of hazardous components of C&D waste requires special consideration due to their high potential for harm to the environment and human health. Wherever possible they must be minimized through careful selection of materials in the design phase of a project, and the use of non-hazardous substitutes. A number of hazardous substances are either banned in the EU, or their use is restricted. For example:

¹ ETC/SCP (2009) *EU as a Recycling Society Present Recycling Levels of Municipal Waste and Construction & Demolition Waste in the EU*. ETC/SCP working paper 2/2009. April 2009

- asbestos and lead-based paints and PCP preservatives are banned;
- polychlorinated biphenyls (PCBs) have restricted use in a number of countries and the EC has adopted a strategy¹ to limit their release;
- limits are in place with regard to the mercury content of components².

Where hazardous components do occur in the waste stream they should be separately collected to prevent contamination of other materials and maximise their recovery potential (eg for reuse or recycling). There is also a specific legal requirement to do so. The Hazardous Waste Directive 91/689/EEC³ requires that hazardous waste must be recorded and identified and cannot be mixed with other waste (either hazardous or non-hazardous).

Treatment of hazardous waste is costly, as management options are often both limited and specialised. For example:

- PCBs are decontaminated by decolouration or sent for incineration with special fumes treatment;
- PAHs are sent to hazardous landfills, where the leachate may require treatment to avoid contamination. Alternatively, PAHs can be sent for incineration with special fumes treatment;
- phenol contaminated waste, such as wood and insulation panels, is treated by removal of the contaminated surface before being suitable for recycling;
- lead-based paints are sent to lined landfills; and
- selective demolition is a common method of treatment for mercury – eg separation of hazardous lighting components, which can then be sent to specialist recyclers.

3.5 Environment and sustainability issues

The construction industry is one of Europe's largest consumers of natural resources. Yet, currently, large quantities of these materials eventually end up in landfills, without any form of recovery or re-use.

More efficient use of materials both at the beginning and at the end of their life would make a major contribution to reducing the environmental impacts of construction. This benefit would be achieved principally through the reduced depletion of finite natural resources and a reduced dependence on landfill. In addition, efficient use and re-use of materials would also contribute to improving the economic efficiency of the sector and of Europe as a whole.

¹http://europa.eu/legislation_summaries/internal_market/single_market_for_goods/chemical_products/21280_en.htm

² http://www.zeromercury.org/EU_developments/090831%20EEB-letter-MS-RoHS-lamps.pdf

³ http://ec.europa.eu/environment/waste/hazardous_index.htm

The need for the improved use of natural resources in this sector has been recognised at the EU level. This is reflected in the challenging target that has been set to increase the recovery and recycling of C&D wastes across Europe (70% by 2020, as noted earlier).

There are considerable opportunities for improvements in the resource efficiency of C&D waste management. This waste stream contains a high proportion of inert materials that are relatively simple to process and that can be used for various secondary applications rather than being disposed of. Note that one of these potential applications is use as structural material at a landfill site. Some inert material is required in landfills and inert C&D wastes could fulfil this function.

C&D wastes also contain many valuable components with high 'embodied' environmental impacts (in terms of the investment that has gone into producing them). The re-use or recycling of these components can eliminate the need for further investment in primary production. It would be even better if their use were avoided in the first place, and there are many waste prevention techniques available to the construction sector that can help deal with this issue in order to bring significant environmental, and financial, savings.

The EU communication, *A Thematic Strategy on the Prevention and Recycling of Waste*¹ identifies the importance of waste management and introduces life cycle thinking to waste policy.

¹ <http://ec.europa.eu/environment/waste/strategy.htm>

4 Using LCT and LCA to Help Select the Environmentally Preferable Management Option for C&D Waste

This section provides some practical advice on C&D waste management and the most beneficial options for specific types of C&D waste.

- ⇒ An outline to help you decide if an LCA is needed, or if evidence from previous studies can help you decide the best management approach.
- ⇒ Some simple criteria for managing C&D wastes.
- ⇒ Some further details on what to do where these simple criteria do not apply
- ⇒ It will provide you with specific support to assist with C&D waste management decisions and assist you in undertaking an LCA exercise, where needed.

The more general “Supporting Environmentally Sound Decision for Waste Management – A technical guide to Life Cycle Thinking (LCT) and Life Cycle Assessment (LCA) for waste experts and LCA practitioners”, also developed by the Joint research Centre (JRC) provides more detailed guidance on all of these aspects.

4.1 Approaching C&D waste management issues with LCT and LCA

A simplified decision-tree is here provided (Figure 7) to give guidance on how to approach and address waste management issue with LCT and LCA. The next paragraphs expand on how to interpret and use this decision tree. However, for a detailed explanation of the single steps, reference shall be made to the more general guide “*Supporting Environmentally Sound Decision for Waste Management – A technical guide to Life Cycle Thinking (LCT) and Life Cycle Assessment (LCA) for waste experts and LCA practitioners*”.

As the decision-tree shows, the starting point is the recognition of the fact that waste management decisions are to be taken. These should then be formulated in a way that provides a clear description of the alternative waste management options available, especially with focus on their potential environmental consequences.

In order to support environmentally sound decision-making for bio-waste management, the waste hierarchy, i.e. the legally binding priority order established by the Waste Framework Directive, should be considered.

If the waste hierarchy does not help to unambiguously identify the preferable option, it can then be evaluated whether evidence from previous work exist that would be enough to support decision-making.

If this is not the case, straightforward, LCT-based criteria may be derived and used. Straightforward criteria often can be derived from the available experience and knowledge gained from previous successful applications of LCT to comparable waste management contexts. The waste hierarchy can be seen as a first point of reference to derive such straightforward, LCT-based criteria. However, often more specific evaluations are necessary, also to be able to establish the environmental preference amongst specific options belonging to the same level of the waste hierarchy. Developing and using straightforward criteria can thus be seen as a valuable step in between applying the waste hierarchy and conducting a new LCA. Straightforward criteria should be based on scientifically sound methodologies and data that are accepted by relevant stakeholders. These can be for example criteria derived from detailed LCAs based on a consistent framework methodology, like the International Reference Life Cycle Data System (ILCD) Handbook¹ and the ISO 14040 series².

In addition to straightforward criteria, LCT-based software tools for the environmental assessment of waste management systems and strategies may be used. These need to be based on quality-assured data and might take into account straightforward criteria.

LCT-based software tools should allow users to carry out an LCA in a quick and simple manner. If intended for non-LCA experts they must focus on the most relevant technical and management parameters only, not requiring LCA expertise, and helping the user up to results interpretation, identifying its limits. To develop software that provides a useful output and is practical to use, a thorough understanding of the intended user and business requirements is necessary. Depending on the user, the software may be used to quantify environmental impacts across the life cycle of a particular waste stream or an entire integrated waste management system.

The software needs to be designed and developed for a given by-product group or waste, focusing on the key issues or criteria to be considered and building on relevant experience/studies/data sets. Non-specific, simplified tools attempting to cover waste in general will not provide sufficiently robust results and these tools should not be used to support important waste management decisions. The software should also have a user-friendly interface, allowing users to vary default technical and management parameters according to their specific situation.

When straightforward criteria do not apply, then conducting a new LCA may become needed to identify the preferable waste management option. These aspects are presented on the next sub-chapters.

As the decision-tree shows, not only the environmental aspects should be considered to provide comprehensive support to decision making and policy making. The LCA results should, therefore, be complemented with information gained from analyses of the social and economical implications.

¹ <http://lct.jrc.ec.europa.eu/assessment/projects>

² http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_tc_browse.htm?commid=54854

The more general “Supporting Environmentally Sound Decision for Waste Management – A technical guide to Life Cycle Thinking (LCT) and Life Cycle Assessment (LCA) for waste experts and LCA practitioners” provides detailed guidance on all of these aspects.

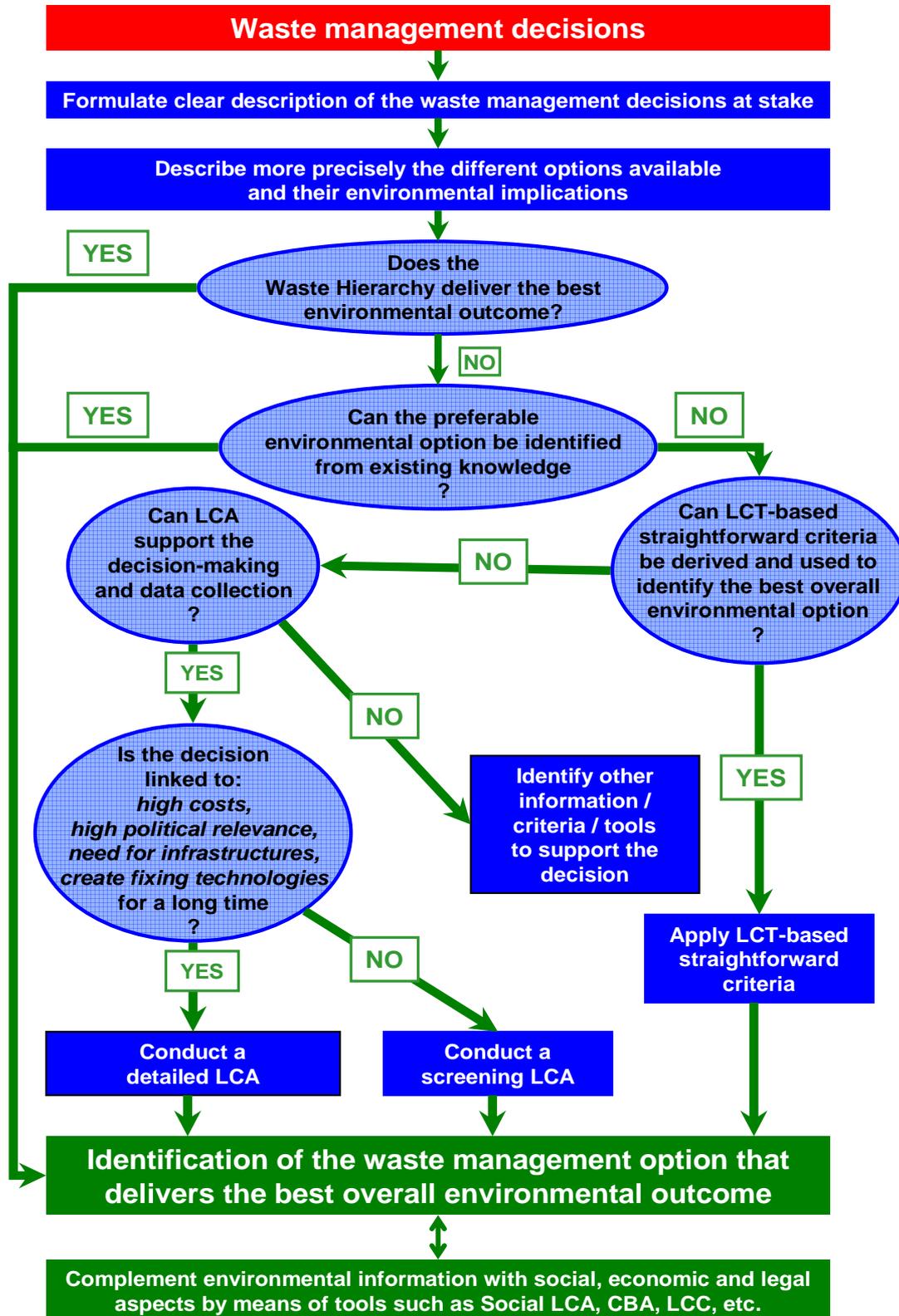


Figure 7: How to approach waste management issues and decision with a LCT-based approach

4.2 Simple life cycle thinking criteria for managing C&D waste materials

This section provides guidance for choosing the typical ‘best environmental options’ for different C&D wastes.

Some simple criteria are outlined, which provide you with a standard by which to inform some of your waste management decisions. These show instances where a particular practice has been demonstrated to be the most environmentally preferable option for a waste material. They are informed by evidence from previous studies, and are based on life cycle thinking principles. You can use them as appropriate to find out what should be done with specific C&D wastes, or to identify the most environmentally beneficial options for the main C&D waste types.

4.2.1 The properties of a mixed C&D waste stream

To be able to treat mixed C&D waste more effectively, firstly it is essential to have an understanding of the properties of the waste stream in question.

- From a **site waste contractor perspective**, visual inspection of the waste stream and other rudimentary waste compositional analysis may be sufficient to provide an indication of the material content of a specific waste stream. Structured sampling techniques may follow, which can help to determine the properties of the ‘typical’ waste stream. These may even consider how the material content may vary in the future. Further analysis may be necessary for some waste streams. For example, if there is a suspicion that the waste stream may possess hazardous properties or have other potentially deleterious impacts, physico-chemical analysis may be necessary.
- **Policy managers** may be reliant on published information concerning the properties of typical C&D waste streams, such as regional estimates for the composition of the waste stream (e.g. those outlined in [Section 3.3](#)). Caution should be exercised when using such data, since these may be either based on statistically robust estimates covering different C&D waste streams and their sources, or on ad-hoc rudimentary sampling/estimates. Obtaining specific information relevant to the local, regional or national area concerned is always recommended.
- **Building designers**, and those responsible for specifying material choices, will have a good insight into the materials contained within a structure and have ultimate control over the future composition of the associated wastes. Consideration should be given to the ease of, and potential for, managing these materials at the end of their lifetime. For example, the inclusion of hazardous components may prevent direct re-use or recycling and recovery opportunities. The WRAP Design Guide provides a good summary of potential interventions and support tools. It is important to remember that the full life cycle of any design choice must be considered, so that actions targeted at

end-of-life waste management do not lead to increased environmental impacts elsewhere, for example in producing materials or operating buildings.

4.2.2 Simple criteria for separated waste materials

With a fuller understanding of the properties of the waste stream, the following criteria provide a guide to help select the best environmental options for typical C&D wastes.

1. Re-using Materials and Components

- Wherever possible, seek opportunities to separate and directly to re-use materials on- or off site. For example, the salvage and re-use of entire components (e.g. fireplaces) and materials such as bricks has been shown to be beneficial in the majority of cases (e.g. Sára *et al*, 2000).
- Where mineral-based products are re-used off site, some attention should be given to the distance that they might be transported. An LCA may be needed to understand the real extent to which transport influences the overall environmental outcome.

2. Materials in the waste stream with high ‘embodied’ impacts

- Where metals (e.g. aluminium, steel, copper) are present in sufficient quantities in a mixed C&D waste stream, separation for recycling is likely to be the best environmental option.
- WRAP’s reviews of LCA studies comparing waste management routes for different materials (WRAP 2007, 2010)¹ support this. The materials are relatively easy to separate (often manually on site, or centrally through physical separation techniques). By separating them, they can be melted down and used in place of primary materials, which are energy-intensive to produce.
- The same principal is applicable to plastics and glass, provided that they are readily separable from the waste stream and are not contaminated.
- Plastics and glass recycling has been shown to be most environmentally beneficial where they are recycled back into their original form, with no loss of quality/performance. Hence, it is important that their final recycling fate is considered.

3. Readily combustible materials derived from biomass

- WRAP (2010) and others (e.g. ERM, 2006)² have indicated that combustion can be a preferred route for wood *if it can be readily separated and energy recovery is maximised* (producing electricity and heat).
- However, depending on the degree of contamination, burning treated wood may only be possible at certain licensed waste facilities.

¹ WRAP (2010) *Environmental Benefits of Recycling – 2010 Update*. WRAP, Banbury, UK

² ERM (2006) *Carbon Balances and Energy Impacts and Benefits of the Management of UK Waste Streams*. Report for Defra, London

- The technologies and facilities available in your region, and potential for their development, also need to be considered (for example their age, the type/ quantity of energy they produce, the use to which this is put and what it replaces).
- Given the importance of these factors, it is recommended that specific attention is paid to determining an appropriate context where wood is an important part of the waste stream.

4. Remaining inert fraction

- It is generally beneficial to recycle mineral materials that contain low levels of contamination.
- Re-use of the aggregate (bricks, etc.) on site is the preferred option wherever possible, since transport impacts are not incurred.
- Off-site crushing, grading and cleaning of aggregate and its subsequent transport and recycling will incur an environmental burden which may need to be considered carefully from a life cycle perspective.
- A recent study investigating the environmental impact of the disposal of construction waste in Catalonia¹ suggested that stone wastes are more suited to recycling when the recycling plant is close to the building site. The re-use of stone as a gravel replacement on building sites is generally the best environmental option for stone waste.
- If it is not possible to reprocess / recycle / re-use the inert fraction locally, other waste disposal options that will minimise transport impacts should be considered for the remaining waste.

The diagram overleaf provides examples of how these straightforward criteria might be applied in practice to a mixed waste stream coming from a construction or demolition site.

¹ <http://ec.europa.eu/environment/integration/research/newsalert/pdf/191na4.pdf>

On a construction site the first step should always be to consider **waste reduction options**. These can range from simple actions on-site, such as the introduction of plasterboard carriers to reduce breakage, to wastage rate reductions and early design interventions. In the UK alone, 13 million tonnes of construction waste are estimated to be unused materials that are over-ordered, or ordered incorrectly (BDG, 2005).

Waste reduction opportunities are not often possible on a demolition site, as the starting point for management is the waste itself.

At either type of site, good **separation of materials** is recommended wherever possible to maximise management options. A series of questions can follow...

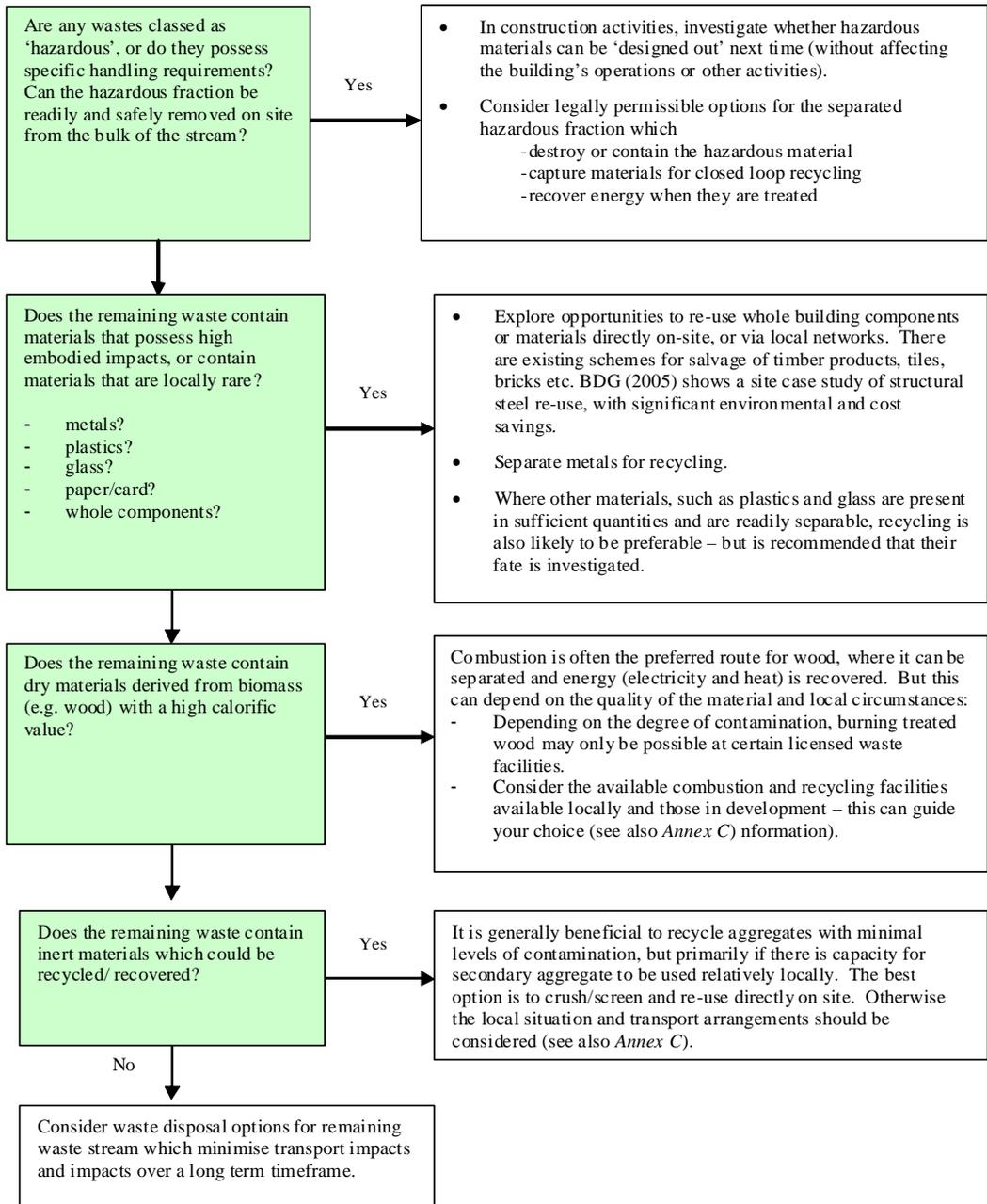


Figure 8: Example of application of straightforward criteria

4.3 What to do when the simple criteria do not apply?

4.3.1 'Trade-offs'

There are several situations for which the straightforward criteria described will not be sufficient to support choices between management options for particular wastes and materials. For example, there may be a 'trade-off', or shift in burden, from one life cycle stage to another or one type of impact to another. This is not always obvious and so care needs to be taken that comparisons are fair and that decisions are made based on robust information.

In these instances, a more detailed approach is required which takes into account your specific local circumstances and the context of the study.

Important examples of such situations for common C&D wastes and management activities are:

- Trade-offs in the impacts of **transporting materials** to recycling centres versus the benefits of recycling them. This is particularly relevant for heavy or bulky inert materials that are used as secondary aggregates;
- Trade-offs between the impacts and benefits of different management options for **waste wood** (to recycle or to recovery energy?); and
- Trade-offs in the quality and fate of recycled materials and the benefits that can be achieved through **different recycling routes**.

A further discussion on each, and some sources of data to support such choices, can be found in [Annex C](#). The examples in [Annex C](#) show where the results of previous life cycle assessments have identified the key aspects which should be considered in specific cases. This is useful, for example, for informing internal decision-making processes and for screening policy options. In more complex or demanding instances, such as when considering mixed wastes arising over large geographical areas or where a public declaration should be made, it is recommended that an LCA is carried out to support the decision-making process. This brings greater robustness, transparency and credibility.

4.3.2 Undertaking an LCA study

If simple rules or existing evidence are not sufficient to provide you with the desired level confidence to reach and justify a decision, it may be necessary to conduct an LCA study.

In the first instance, the ILCD Handbook¹ (ILCD Handbook "General guide – detailed guidance") should be consulted as the main guide for your assessment. It is very detailed and is useful as a reference document. You should use it to provide information on specific methodological aspects, and to ensure that your study is

¹ <http://lct.jrc.ec.europa.eu/assessment/projects>

compliant with its requirements. Only a general ‘snapshot’ of what you need to do is provided here.

From a practical perspective, some initial planning is required, both in terms of setting the scope of what will be assessed and identifying the data required, as well as identifying the other resources that will be needed to complete the assessment such as inventory databases, software, and establishing the necessary contacts to collect data and staff time to complete the work.

The general process for conducting an LCA is always the same, regardless of whether it will assess options for C&D waste management or any other purpose. However, it is important to note that the goal and scope, which is the first phase to be conducted, will nearly always vary. The goal and scope defines the overarching scope for the LCA and acts as a planning document for completing the subsequent steps.

The level of detail and complexity for an LCA is primarily influenced by the type of decision support that is needed, as well as whether any comparisons are to be made and the level of public disclosure. For example, this may range from a small LCA for internal-use, used to support process-improvement decisions by identifying environmental impact ‘hotspots’, to a more complex study which may effect macro-level decision making, such as providing data to support potential national policy options which will be fully disclosed to the public. The scope of the LCA will define the level of resources and decisions needed to carry out the LCA.

Table 4 outlines the broad requirements for different types of LCA studies that might be relevant for assessing C&D wastes.

Table 4: Examples of LCA studies of C&D waste and their different requirements

Type of study	ILCD decision category*	Life cycle stages included/excluded	Data needs	Reporting needs	Review needs
'Confidential study' sent to third parties (e.g. contractor) to advise on the preferred option as evidence to convince them to alter their service	Micro-level decision	Fit-for-purpose	Secondary process data may suffice, but primary data are likely to be needed from the contractor	Detailed project report – of sufficient transparency	Independent critical review necessary
		Single or multiple environmental impacts	Iterations probable in order to produce sufficient accuracy	Sensitivity essential to confirm robustness of findings	
Comparison of impacts of waste management options - report disclosed to the public	Micro-level decision	Fit-for-purpose.	Primary data likely to be sought for systems. Secondary process data unlikely to suffice for all aspects.	Detailed project report – of sufficient transparency	Independent critical review necessary
	or	Single or multiple environmental impacts			
Comparison of options which inform a future policy decision that is disclosed to the public	Meso/macro-level decision support	May be advisable to include all life cycle stages in the study for its completeness	Iterative process and comprehensive sensitivity analysis essential to confirm robustness of preliminary findings	Sensitivity essential to confirm robustness of findings	ISO compliant study advisable
	Meso/macro-level decision support	Fit-for-purpose.	Primary data likely to be sought for systems. Secondary surrogate data likely to have to be used with caution/sensitivity analysis	Detailed project report – sufficient for third party to be capable of replicating work	Independent panel critical review
		May be advisable to include all life cycle stages in the study for its completeness	Best performing and future technology may have to be modelled and consequences of decision/course of action may have to be evaluated	Confidential data to be made available on request	ISO compliant study advisable.
		Likely to require multiple life cycle impacts	Iterative process and sensitivity analysis, criticality and uncertainty analysis likely to be necessary to reach robust conclusions and recommendations.		

* **"Micro-level decision support"**: Life cycle-based decision support on micro-level, i.e. typically for questions related to specific products or processes. "Micro-level decisions" are assumed to have limited and no structural consequences outside the decision-context, e.g. they are assumed not to change available production capacity.

"Meso/macro-level decision support": Life cycle-based decision support at a strategic level (e.g. raw materials strategies, technology scenarios, policy options). "Meso/macro-level decisions" are assumed to have structural consequences outside the decision-context, e.g. they are likely to change available production capacity.

The box below shows some practical aspects that are also useful to consider when conducting an LCA.

Practical tips for carrying out an LCA

Goal and scope:

- ✓ You need clearly to define the goal and scope and to identify any review requirements early on. Any reviewers should ideally be appointed at the start of the LCA.
- ✓ You need to ensure that the unit of comparison used in the study (e.g. total waste from a specific site in one year; or 1 tonne of wood waste) is appropriate and consistent with the aim of the study.

Data collection and validation:

- ✓ Start data collection early - this often takes longer than anticipated.
- ✓ Keep concise and well referenced documentation for all data collected. This will support the review process and provide good transparency for your study.
- ✓ Where possible, focus your data collection on the important aspects which affect the results of the study. For example, those parameters which you know to have significant environmental impacts. Important data may be identified by reviewing other similar LCA studies that have been previously conducted.
- ✓ Use secondary/background datasets that are well documented. This will allow for easier quality assessment and review. Pre-verified data (e.g. via the ILCD Data Network⁴² and ELCD⁴³) are particularly recommended, as this reduces the efforts of verification/review: the data itself will not require any additional review, only that they have been applied correctly and in a suitable context.
- ✓ When collecting data, it is important to check data consistency, such as the use of correct units (e.g. MJ of kWh) and carry out other simple checks such as mass and energy balance checks to ensure all inputs and outputs have been included.

Impact assessment:

- ✓ You need to choose the impact categories that are relevant for the study, for example, where there are potential toxic emissions of leachate from landfill disposal, aquatic ecotoxicity impacts should be assessed.
- ✓ Inventory data should also reflect the impacts being assessed. So when considering toxicity, emissions of toxic substances to land, water and air should be recorded.

Interpretation of results:

- ✓ Before making conclusions and recommendations from the results, it is important to understand the reliability of the data and the assumptions used to generate these results. Checks need to be conducted to reveal significant issues, and check for completeness, sensitivity and consistency should also be conducted.

Reporting:

- ✓ Your records and reporting should follow a clear and concise format to ease communication and review.

⁴² <http://lct.jrc.ec.europa.eu/pdf-directory/ILCD-DN.pdf>

⁴³ <http://lct.jrc.ec.europa.eu/assessment/data>

Annex A: Further sources of information

LCA Standards and Recommendations

- **ISO 14040:2006** Environmental management – Life cycle assessment – Principles and framework
- **ISO 14044:2006** Environmental management – Life cycle assessment – Requirements and guidelines
- **ISO 14063:** Environmental Communication – guidance on general principles, policy, strategy and activities relating to both internal and external environmental communication
- **European Commission, Joint Research Centre – Institute for Environment and Sustainability: International Reference Life Cycle Data System (ILCD) Handbook⁴⁴**; various documents. First edition March 2010. Luxembourg. Publication office of the European Union; 2010.

LCA Resources and Networks

- European Platform on LCA. This website includes links to policy activities and the International LCA Resources Directory: <http://lct.jrc.ec.europa.eu/>. The LCA Resources Directory provides systematic, comprehensive and independently checked information on LCA services, tools, databases, and providers on a global basis.

C&D-specific Resources

The following is intended to be an illustrative, non comprehensive, list of resources that are specifically dealing with construction and demolition waste. No recommendation is made to use them or to prefer them over other resources that already exist or might become available.

- ADEME Eco-guide for the building sector⁴⁵ (FR).
 - http://www.ecoconseil.org/public_files/prodyn_img/e-g-batiment.pdf
- BEES⁴⁶ (US)
 - <http://www.bfrl.nist.gov/oa/software/bees/>
- CEN TC350⁴⁷ on standards for measuring sustainability of construction works

⁴⁴ <http://lct.jrc.ec.europa.eu/assessment/projects#d>

⁴⁵ http://www.ecoconseil.org/public_files/prodyn_img/e-g-batiment.pdf

⁴⁶ <http://www.bfrl.nist.gov/oa/software/bees/>

⁴⁷ <http://www.bsigroup.com/Standards-and-Publications/Committee-Members/Construction-committee-members-area/M350-Standards/?id=158921>

- <http://www.bsigroup.com/Standards-and-Publications/Committee-Members/Construction-committee-members-area/M350-Standards>
- Defra – plasterboard and windows ‘roadmaps’⁴⁸ (UK)
 - <http://www.defra.gov.uk/environment/business/products/roadmaps/index>
- Environment Agency for England and Wales⁴⁹ ‘Carbon Calculator’ for construction activities (UK)
 - <http://www.environment-agency.gov.uk/business/sectors/37543.aspx>
- SETAC. Life-Cycle Assessment in Building and Construction: A State-of-the-Art Report, 2003. Editors: Shpresa Kotaji, Agnes Schuurmans, Suzy Edwards
- WRAP Construction Programme (UK)
 - <http://www.wrap.org.uk/construction/>
 - *Net Waste Tool*
http://www.wrap.org.uk/construction/tools_and_guidance/net_waste_tool/index.html
 - *AggRegain* - carbon dioxide (CO₂) Emissions Estimator Tool.
http://aggregain.wrap.org.uk/sustainability/try_a_sustainability_tool/co2_emissions.html

⁴⁸ <http://www.defra.gov.uk/environment/business/products/roadmaps/index.htm>

⁴⁹ <http://www.environment-agency.gov.uk/business/sectors/37543.aspx>

Annex B: Case Study Example - Undertaking an ISO-compliant LCA of Plasterboard⁵⁰

B1. Defining the study's goal

The WRAP plasterboard LCA: defining the study goal

In January 2007, the Waste and Resources Action Programme (WRAP) commissioned Environmental Resources Management Limited (ERM) to carry out a life cycle assessment of plasterboard.

The goal of the study was to compile a detailed life cycle inventory and to conduct an LCA of the environmental burdens associated with the production, use and disposal of plasterboard in the UK.

The study also sought to establish the potential environmental impact, or benefit, of reducing the conventional gypsum content of plasterboard by increasing the incorporation of post-consumer recycled gypsum from waste plasterboard. This is a very specific aim, and one which influenced the study's design. The reasons for this choice in comparison were as follows.

- Data describing the relative production impacts of primary and synthetic gypsum sources are commercially confidential, and so cannot be reported separately in the study. Instead, an average production mix for the UK was determined in order to derive data describing a 'conventional' gypsum source.
- Conventional sources can be used interchangeably, but there is a limit on the quantity of recycled gypsum that can be incorporated into the product before its use, and functional equivalence, is impaired. Conventional gypsum cannot be replaced entirely.
- The closed-loop recycling of gypsum from waste plasterboard for use in plasterboard manufacture was considered to be the most significant market for post-consumer recycled gypsum in the UK. As such, this end-route for recyclate was selected as the primary focus of the assessment.
- An alternative to using conventional gypsum in plasterboard manufacture is to incorporate increasing quantities of production waste- and post-consumer recycled gypsum. It was assumed that the recycling of production waste is internally optimised, and that the main potential is for the increased utilisation of post-consumer recycled gypsum

The results were intended both to inform decisions on the development of future policy in this area, and to provide a more robust evidence base for WRAP's activities.

In particular, this information was intended for use by WRAP's Plasterboard Programme:

- to inform the basis for its priorities and direction;
- in reporting the performance of the Plasterboard Programme to the UK Government and other stakeholders; and
- when strategically engaging with manufacturers, recycling companies, and other sectors in the supply chain.

⁵⁰ WRAP (2008) *Life Cycle Assessment of Plasterboard*. Technical Report prepared by ERM. WRAP, Banbury, UK.

B2. Setting the study's scope

Scope considerations for the WRAP plasterboard LCA

Taking into account the goal of the study (see earlier box), the following scope choices were made:

- The functional unit of the study was chosen to be one standard sheet of 2,400 mm x 1,200 mm, 12.5 mm thick Type A plasterboard, with a square edge profile. This functional unit was selected following discussions with the GPDA and on the basis that: it is the most common type of plasterboard product on the UK market (in terms of production and sales volume, and for use in general purpose applications); it can be manufactured using conventional, production waste and post-consumer recycled gypsum sources; and it has a standard recipe across the UK market.
- The plasterboard systems assessed in the study were representative of Type A plasterboard (12.5 x 1,200 x 2,400 mm, square edge profile) available on the UK market in 2007.
- To investigate the impacts and benefits of increasing recycled content, the study investigated three plasterboard product systems, differing in proportion of post-consumer recycled gypsum used as raw material: baseline (9.5%); 15%; and 25% (the technological upper limit).
- The study assessed all life cycle stages from raw material production to end-of-life management.
- Specific, or primary, data were considered to be most critical for the following activities: gypsum production from conventional sources; production of facing paper; conversion of raw materials into plasterboard; production waste management; post-consumer waste management (recycling and disposal).
- As the study was to be used externally, it underwent critical review by a panel of external reviewers.

A full outline of the study scope can be found in the LCA report in *Annex X*.

B3. Data collection activities

Data collection activities in the WRAP plasterboard LCA

The WRAP plasterboard LCA study sought to establish the potential environmental impact, or benefit, of reducing the conventional gypsum content of plasterboard, by increasing the incorporation of post-consumer recycled gypsum from waste plasterboard.

Specific, or primary, data were considered most critical for the main materials comprising plasterboard: gypsum from conventional sources; production waste; post-consumer waste recycling, and facing paper. For the production of chemical additives and packaging materials, generic data were used, since their mass flow in relation to the functional unit (one sheet of plasterboard) is limited. Furthermore, these materials were common to the different plasterboard systems (and gypsum sources) under assessment.

Specific data were also required for the conversion of raw materials into plasterboard, plasterboard use and end-of-life management.

In summary, **specific data were researched for:**

- production of conventional and post-consumer recycled gypsum;
- pre-treatment requirements for gypsum from conventional sources, production waste and post-consumer waste recycling;
- production of plasterboard facing paper;

- raw material 'recipe' for the production of 'standard' plasterboard;
- conversion of raw materials into plasterboard;
- distribution/supply systems (transport distances, types of transport, storage requirements);
- construction, refurbishment and demolition operations;
- waste plasterboard collection systems (for both disposal and recycling);
- waste management operations, including recycling, landfill with mixed waste and landfill in high-sulphate mono-cell (process inputs and outputs, transport distances and types of transport); and
- UK electricity mix, i.e. the split between different electricity generation methods such as hydro power, coal power, wind power, etc.

Generic, or secondary, data were used for:

- production of chemical additives;
- production of other raw materials (when generic data are of sufficient quality, or specific data are not available);
- packaging production;
- packaging waste management;
- production of collection containers;
- waste management operations (when specific data are not available);
- electricity generation;
- production of transport fuels; and
- transport emissions.

B4. Characterising closed-loop recycling

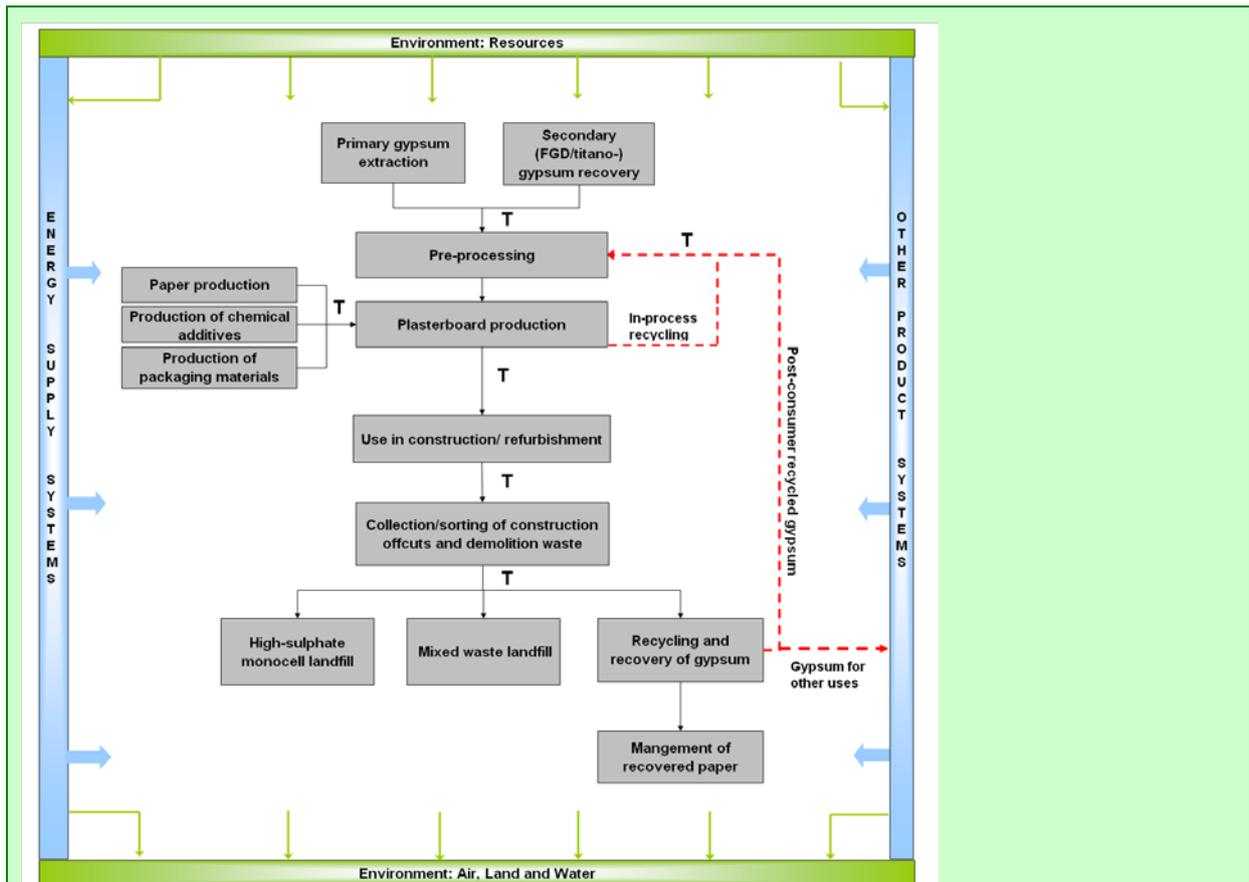
Characterising closed-loop recycling of plasterboard in the UK

The WRAP plasterboard LCA study sought to establish the potential environmental impact, or benefit, of reducing the conventional gypsum content of plasterboard, by increasing the incorporation of post-consumer recycled gypsum from waste plasterboard.

The closed-loop recycling of gypsum from waste plasterboard for use in plasterboard manufacture is currently the most significant market for post-consumer recycled gypsum in the UK. Post-consumer recycled gypsum is used in plasterboard manufacture as an alternative to using 'conventional' gypsum (mined gypsum, secondary gypsum from flue-gas desulphurisation in power plant and titanogypsum from titanium dioxide production).

There is a limit to the quantity of post-consumer and process-waste derived gypsum that can be incorporated into the product before its production, use, and functional equivalence is impaired. To investigate the impacts and benefits of increasing the recycled content, this study investigated three plasterboard product systems, differing in proportion of post-consumer recycled gypsum used as raw material: baseline (9.5%); 15%; and 25% (the upper limit).

The study assessed all life cycle stages from raw material production to end-of-life management. A system diagram is shown in the Figure below.



The results of the assessment showed that there are environmental benefits associated with increasing the recycled gypsum content in Type A plasterboard. However, these benefits are small in comparison with overall system impacts. For example, for the majority of impact categories assessed, there is a less than 10% difference between the current product system and the product with 25% recycled content. Savings were found to be lower for the 'high' transport scenario assessed, which indicates the sensitivity of results to this parameter.

B5. Impact category choices

Impact category choices in the assessment of plasterboard

A wide range of activities are included across the life cycle of plasterboard, and so the study included a range of impact categories. The categories selected for inclusion were those for which there is greater methodological consensus:

- climate change;
- ozone depletion;
- photo-oxidant formation;
- depletion of abiotic resources;
- eutrophication; and
- acidification.

Human, aquatic and terrestrial toxicity impacts were considered, but the limitations associated with these categories were noted.

The release of H₂S gas was of interest for the study – as it is released when high-sulphate wastes are

landfilled alongside organic materials. It was investigated as a separately inventory flow. H₂S contributes to some of the impact categories assessed, but the main impact associated with its release is odour. There are no scientifically sound life cycle impact assessment methods that quantify the odour impacts satisfactorily and so this was not included. Instead, the limitations of its omission were noted.

B6. Sensitivity analysis

Undertaking sensitivity analysis the LCA of plasterboard

Key variables and assumptions that were tested to determine their influence on the results of the WRAP plasterboard study were:

- allocation of burdens to synthetic gypsum production;
- collection containers assumptions;
- collection vehicle assumptions;
- waste transfer and sorting assumptions;
- disposal of plasterboard waste in mixed waste landfill versus monocell landfill;
- the potential influence of changes in future grid electricity mixes;
- assumptions regarding the proportion of plasterboard waste arising from construction versus demolition activities; and
- contamination rates in recovered waste plasterboard.

Conclusions made in the study drew on both the primary results for the systems assessed and the variations resulting from the sensitivity analysis.

B7. Critical review

Critical review procedure for WRAP's plasterboard LCA

In accordance with the ISO standard on LCA, the WRAP plasterboard study was reviewed by a panel of external reviewers. The review panel's report, together with the author's responses, was provided in an Annex to the final report.

The reviewer addressed the following issues.

The goal and scope:

- ensured that the scope of the study was consistent with the goal of the study, and that both were consistent with the ISO standard.

The inventory stage:

- reviewed the inventory for transparency and consistency with the goal and scope and with the ISO standard; and
- checked data validation methods and that the data used were consistent with the system boundaries.

The impact assessment stage:

- reviewed the impact assessment for appropriateness and conformity to the ISO standard.

The interpretation stage:

- reviewed the conclusions of the study for appropriateness and conformity with the goal and scope of the study.

The draft final report:

- reviewed the draft final report for consistency with reporting guidelines in the ISO standard; and
- prepared a review statement including consistency of the study and international standards, scientific and technical validity, transparency and relation between interpretation, limitations and goal.

Annex C: Examples of ‘trade-offs’ for common C&D wastes and management activities

C1. Transport of materials to recycling: the case of inert materials with low ‘embodied’ impact

Waste prevention, re-use and recycling activities are characterised by actions that result in:

1. **Impacts** – energy to separate materials, materials to collect and to store them, fuel to transport them, energy/water to re-process them into secondary materials, management of residues from the process, etc; and
2. **‘Avoided’ impacts** – the environmental impacts of avoided primary material production and the environmental impacts of avoided end-of-life treatment.

Typically in an LCA, both types of impact are accounted for, and a substitution approach is used to estimate the avoided impacts of primary material production. The avoided end-of life treatment is usually considered as an alternative option, or scenario – e.g. comparing a disposal option versus a recycling option.

In some instances, there is a clear benefit to avoiding the impacts of primary production (e.g. for metals, where primary production is energy intensive), regardless of the amount of processing that recycled materials must go through. In other instances, there is clear benefit to be gained from avoiding disposal in landfill sites (e.g. for wood, which degrades to produce greenhouse gases and emissions to watercourses).

Mineral materials that are typically used in construction projects present a different case. They do not require intensive processing in their production, and they do not degrade if disposed to land. The ‘avoided impacts’ of recycling minerals into secondary aggregates are therefore relatively small. It follows that the direct impacts of transporting and processing them become important, and there is a potential trade-off between the impact of processing and the benefits of generating a secondary material.

The most important factor to consider is the distance that recovered material must travel. A second factor is the requirement for washing the aggregate product.

This is clearly demonstrated using an LCA study of aggregates, undertaken for the Waste and Resources Action Programme (WRAP) (2009)⁵¹. The objective of WRAP’s study was to develop a life cycle inventory and LCA model for UK aggregates production, including the extraction and processing of primary and secondary (recycled) products through to the point of their dispatch to customers. A range of aggregate grades were assessed, and specific data were collected from a range of case study sites.

Impact profiles calculated for the different types of aggregate are presented in Table 5 and

Table 6.

Table 5: Primary aggregates system example: impact assessment results per tonne of primary aggregate produced⁵²

	Crushed Rock Aggregate	Land-won Gravel
Impact Category	28 mm, 20 mm, 14 mm, 10 mm	40-20 mm, 20-10 mm, 5-10 mm,
Units		3-5 mm, oversize
Global Warming		
kg CO ₂ eq.	2.4-4.1	0.3-4.0
Eutrophication		
kg PO ₄ eq.	8.24X10 ⁻⁴ -1.31X10 ⁻³	1.8x10 ⁻⁴ -1.2x10 ⁻³
Acidification		
kg SO ₂ eq.	1.39X10 ⁻² -2.38X10 ⁻²	1.4x10 ⁻³ -2.3x10 ⁻²
Photo-oxidant formation		
kg ethylene eq.	8.95X10 ⁻⁴ -1.51X10 ⁻³	1.6x10 ⁻⁴ -1.5x10 ⁻²
Human toxicity		
kg 1,4-DB eq.	0.44-0.63	1.8x10 ⁻¹ -1.1
Freshwater Aquatic Ecotoxicity		
kg 1,4-DB eq.	7.23X10 ⁻³ -1.14X10 ⁻²	1.6x10 ⁻³ -9.2x10 ⁻³
Marine Aquatic Ecotoxicity		
kg 1,4-DB eq.	1.81x10 ³ -3.20x10 ³	24.7-204.7
Terrestrial Ecotoxicity		
kg 1,4-DB eq.	3.3X10 ⁻³ -5.3X10 ⁻³	7.0x10 ⁻⁴ -4.3x10 ⁻³
Ozone layer depletion		
kg R11 eq.	3.2X10 ⁻⁷ -5.8X10 ⁻⁷	2.65x10 ⁻⁹ -6.35x10 ⁻⁷

Table 6: Recycled aggregates system example: impact assessment results per tonne of recycled aggregate produced⁵³

Impact Category	Waste reception	Crushing	Conveying & Magnetic separation	Washing	Secondary Crushing	Material transport & Storage	Total Impact
Global Warming							
Kg CO ₂ eq.		0.2	7.7x10 ⁻³	1.9	0.07	0.2	2.4
Eutrophication		7.2x10 ⁻⁵	1.6x10 ⁻⁶	5.3x10 ⁻⁰⁴	1.4x10 ⁻⁰⁵	9.3x10 ⁻⁰⁵	7.1x10⁻⁰⁴

⁵² WRAP aggregates LCA, shortly to be published

⁵³ WRAP aggregates LCA, shortly to be published

Kg PO ₄ eq.							
Acidification		2.8x10 ⁻⁴	6.2x10 ⁻⁶	10.6x10 ⁻³	5.3x10 ⁻⁵	1.2x10 ⁻³	12.1x10⁻³
Kg SO ₂ eq.							
Photo-oxidant formation		1.7x10 ⁻⁵	4.1x10 ⁻⁷	6.1 x10 ⁻⁴	3.5x10 ⁻⁶	1.7x10 ⁻⁴	8.0x10⁻⁴
Kg ethylene eq.							
Human toxicity		0.09	4.4x10 ⁻⁴	0.14	0.02	22.4x10 ⁻³	0.2
Kg 1,4-DB eq.	1.08x10 ⁻⁰⁵						
Freshwater Aquatic Ecotoxicity		6.2x10 ⁻¹²	4.7x10 ⁻¹⁸	28.6 x10 ⁻⁴	4.0x10 ⁻¹⁷	19.6x10 ⁻⁴	19.6 x10⁻⁴
Kg 1,4-DB eq.							
Marine Aquatic Ecotoxicity		1.8x10 ⁻¹⁰	2.6x10 ⁻¹⁷	93.2	2.2x10 ⁻¹⁶	30.5	30.5
Kg 1,4-DB eq.							
Terrestrial Ecotoxicity		1.0x10 ⁻¹²	4.4x10 ⁻¹⁹	13.7x10 ⁻⁴	3.8x10 ⁻¹⁸	8.6x10 ⁻⁴	8.6x10⁻⁴
Kg 1,4-DB eq.							
Ozone layer depletion kg R11 eq.				2.8x10 ⁻⁷		3.3x10 ⁻⁹	2.8x10⁻⁷

Key points to note:

- ⇒ Impact profiles for primary aggregate and recycled aggregate are very similar.
- ⇒ The assumption used for recycled aggregate is that material is transported a distance of 10km by a 20-tonne truck from the point of generation (e.g. construction or demolition site) to the point of recycling.
- ⇒ If this transport distance is increased to 100km, the impacts of recycling aggregates will increase accordingly. For example, greenhouse gas emissions would increase to 4.3 kg CO₂-eq. per tonne – meaning that the impacts of recycling would be marginally greater than the benefits of avoiding primary production.
- ⇒ Greater distances, smaller truck sizes and sub-optimal vehicle loading rates will make this trade-off even more marked.
- ⇒ Alternatively, if recycled aggregate is sourced locally and primary materials must be transported long distances, the benefits of recycling will increase.
- ⇒ **It is recommended that the local circumstances, available infrastructure and likely transportation patterns are always taken into account where minerals recycling is considered as a management option.**
 - The ELCD transport datasets⁵⁴ are a recommended default for background data to describe transport by road and other modes.
 - These data are flexible - enabling user-defined entry of variables such as distance, load factor, emissions class, etc.

⁵⁴ <http://lca.jrc.ec.europa.eu/lcainfohub/datasetCategories.vm?topCategory=Transport+services>

- Transport distances can be very varied and it is recommended that a best case/worst case/average scenario approach is taken. It is important to consider the local/national circumstances in doing this.
 - The type of vehicle can also be important, and a scenario-based approach or a conservative assumption of a mid-weight lorry and early euro class emissions may also be relevant. Some default types of road transport vehicle used for different C&D waste containers can be found in the WRAP plasterboard LCA study⁵⁵.
- ⇒ The values presented in the tables above can serve as defaults for the impacts of processing in many instances. They are, however, UK-focused, so care should be taken that this does not affect the conclusions of a study. Also note that these are average impact profiles for a given category of aggregate. Within these categories, specific products (e.g. size grades) were found to have impacts of +/- 50%, dependent on the amount of processing it undergoes (e.g. washed/ not washed).

C2. Trade-offs between the impacts and benefits of different management options: the case of energy recovery versus recycling of wood

Due to its inert nature, thermal treatment will *not* generally represent a practicable means of managing C&D waste. However, dry, easily separated materials with a high calorific content – such as wood – are suitable feedstocks for combustion. When these are burnt, they have the effect of acting as a fuel and, where energy is recovered, displace the need to provide energy by other means.

The trade-off in impacts and benefits surrounding different management options for waste wood is a complicated one. Disposal in landfill has been generally found to be the least favourable option (e.g. WRAP, 2010⁵⁶; Jungmeier *et al*, 2001⁵⁷). However, the relative performance of recycling versus energy recovery is dependent on a number of variable factors, and it is not possible to make generalisations. Where this material is important in the waste stream, it is recommended that specific attention is paid to local, regional and national factors.

Results of previous life cycle studies have identified key criteria for choosing between waste management options for wood, and these are set out in Table 7. In particular, where wood is an important material component of the waste stream, it is recommended that these aspects are considered.

⁵⁵ http://www.wrap.org.uk/downloads/Life_Cycle_Assessment_of_Plasterboard.6db39d12.5313.pdf

⁵⁶ WRAP (2010) Environmental Benefits of Recycling – 2010 Update. WRAP, Banbury, UK.

⁵⁷ Jungmeier, G., Merl, A., McDarby, F., Gallis, C., Hohenthal, C., Petersen, A. and Spanos, K. (2001) End of Use and End of Life Aspects in LCA of Wood Products – Selection of Waste Management Options and LCA Intergration.

Table 7: Key criteria influencing the choice of management route for waste wood⁵⁸

Criterion	Key points
Quality of material	<p>Material quality, and the presence of preservatives or coatings, determines the waste management options that are possible for wood. For example, treated utility poles may be used for energy generation in special combustion facilities, but cannot be recycled or combusted in all facilities. Many countries have classification systems for waste wood and different legislations as to the treatment processes required or prohibited.</p> <p>The quality of material input to a combustion process will also affect the resulting air emissions and residues (see later criteria) and so are important to consider. The ILCD recommends that a 'transfer coefficient' approach is used in modelling thermal treatment technologies. In this, the emissions from an energy recovery process, and the residues produced by the process, are responsive to the nature of the waste stream that is treated by the process.</p> <p>The ELCD contains data on incineration that uses a transfer coefficient approach, accessible at http://lca.jrc.ec.europa.eu/lcainfohub/datasetArea.vm</p>
Legislation	All waste streams in LCA should be treated according to current or future legislation. For example, in many European countries there are specific limits on the levels of contamination allowable in wastes that are landfilled or incinerated. In most countries, the maximum emissions allowed for waste treatment technologies are also regulated by law. These could be used as 'worst case' emissions for treated wood products.
Quantity of material	The quantity of material available in the waste stream may also determine possible waste management options. For example, if wood is only a small waste stream in the national context, the range of technologies available to a waste manager may be limited, or it may not be economically feasible to direct policy towards developing appropriate infrastructure.
Infrastructure	The available infrastructure in a local, regional or national context determines factors such as the distances that waste must be transported and, importantly, the technology options that are available to a waste manager (see below).

⁵⁸ Adapted from: Jungmeier, G., Merl, A., McDarby, F., Gallis, C., Hohenthal, C., Petersen, A. and Spanos, K. (2001) End of Use and End of Life Aspects in LCA of Wood Products – Selection of Waste Management Options and LCA Intergration.

Criterion	Key points
State of current/future waste management technologies and their availability	<p>The environmental impacts of managing wood wastes are fundamentally determined by the selected waste treatment option and its technology. In particular for energy recovery options/facilities, key factors are:</p> <ul style="list-style-type: none"> • <i>The amount of energy recovered and 'avoided' impacts.</i> Energy can be recovered as steam and used for electricity production, and/or as hot water and used in district heating. The relative efficiency of a recovery process must be considered, dependent on available, or potential, infrastructure. The 'avoided burdens' of generating energy also need to be identified by considering what the alternative means of energy generation would be. There are different perspectives on how to determine this – either the current mix of national or regional electricity and heat sources, or the energy source if additional capacity were to be developed. The choice depends on the focus of your study. A default approach can be to use the national grid electricity and heat mix. • <i>Type of abatement technology.</i> The type of abatement equipment employed by an energy recovery facility can add to the energy used by the process. These are so called 'parasitic burdens' and hence reduce the overall energy efficiency of the process. The nature of the feedstock will also influence to the type and quantity of chemicals and other materials used to remove pollutants. • <i>Fate of residues.</i> Combustion residues will include relatively benign 'bottom ash' which can be recycled into construction products, and 'air pollution control' (APC) residues, that ultimately contain the contaminants present in the original feedstock. The fate of both residue streams should be considered. This is particularly important where treated wood products, which contain potentially hazardous substances, are combusted. <p>When undertaking a comparative study for waste wood, the specific technology options available and their typical performance must be considered. Consideration should also be given to what the current and future potential is – either for a specific technology or available options.</p>

- ⇒ The COST Action E9 Working Group 3 has produced a working document that gives an overview of general aspects of wood waste management in 10 different European countries, accessible at <http://www1.uni-hamburg.de/cost/e9/free/index.htm>. This provides useful data to help inform a national perspective.
- ⇒ Where a national hierarchy of management options for wood or similar waste exists, this could also be used to inform the appropriate options for a study. For example, the UK Environment Agency has developed a hierarchy of greenhouse gas emissions savings for a range of biomass-to-energy systems.

C3. Trade-offs in the quality and fate of recycled materials: the case of ‘down-cycling’

The technical properties of a material can sometimes be reduced during a separation or recycling process. This ‘down-cycling’ can mean that the secondary (recycled) material cannot directly replace a primary material on a like-for-like basis. More of the secondary material might be needed to perform the same function, or it might be used for a different secondary purpose and replace a different material with different technical properties.

Previous research has shown that, particularly in the case of plastics, glass and wood, the ‘quality’ and ultimate use of the recycled material is an important consideration in selecting the most environmentally preferable option. Consider the case of greenhouse gas emissions savings for plastic and wood, as shown in the table below. Two different recycling routes, product fates and avoided primary production are considered in each case.

Table 8: Greenhouse gas savings for different plastic and wood recycling routes⁵⁹

Material	Maximum savings per kg recycled	Minimum savings per kg recycled	Assumptions
Plastic	1.8 kg CO ₂ eq.	-0.9 kg CO ₂ eq. (i.e. net impact)	<p>Maximum savings - represent the closed-loop recycling of plastics and the avoidance of virgin material production. Account is taken of the energy requirements of pre-treatment (washing, drying, sorting, granulation, etc.) and the production of virgin PET granulate is avoided. There is an assumed 10% loss in production (1kg recovered material offsets 0.9kg virgin material).</p> <p>Minimum savings - represent the recycling of mixed low grade plastics into plastic lumber. Account is taken of the energy requirements of washing, sorting, granulating and thermoforming the recovered plastics into lumber product. The production of air dried, sawn timber is offset on a volumetric basis, as it was considered that such products would be used as, for example, street furniture, and as such would replace wood on a volumetric basis. Savings appear negative as the processing requirements of cleaning and reforming are greater than the avoided burdens of wood production.</p>

⁵⁹Adapted from: ERM (2006) *Carbon Balances and Energy Impacts and Benefits of the Management of UK Waste Streams*. Report for Defra, London. Data to calculate emissions savings were predominantly sourced from the Swiss Ecoinvent database

Material	Maximum savings per kg recycled	Minimum savings per kg recycled	Assumptions
Wood	0.1 kg CO ₂ eq.	-0.001 kg CO ₂ eq. (i.e. net impact)	<p>Maximum savings - represent the recycling of high quality recovered wood into firewood or timber products. Account is taken of the energy requirements of sorting and the production of air dried, sawn timber is avoided. There is an assumed 10% loss in production (1kg recovered material offsets 0.9kg virgin material).</p> <p>Minimum savings - represent the recycling of low quality recovered wood for use in particle board manufacture. It was assumed that waste wood substituted the requirement for wood chips from alternative sources. As a worst case example, by-products from sawmills, with low embodied impacts, are assumed to be substituted. The energy requirements of wood chipping were also taken into account.</p>

The range of potential 'benefits' for recycling these materials vary, and in some cases may not outweigh the impacts associated with processing and transporting them.

- ⇒ **Where there are many possible potential fates for a recycled material** (for example in considering a national policy direction), the range of options should be considered. This can be used, for example, to support a case for promoting materials integrity through re-use and specific, high quality recycling routes. There may also be a need to take a more comprehensive view of the market consequences of generating secondary materials. The ILCD Handbook (General guide – detailed guidance) expands on the different methods that can be taken to do this. It is recommended that this is consulted if a detailed LCA involving waste prevention, re-use and recycling is to be carried out.
- ⇒ **Where it is not possible to influence the fate of a recycled material** (for example, if materials are collected via a centralised system and are not within your scale of influence) it is appropriate to assume that recycled materials replace virgin materials, as this is typically the case for most materials. However, it is useful to be aware of the potential for down-cycling and to test the sensitivity of conclusions to this. Consider the implications of a difference in fate, and what steps can be taken to ensure that the best quality materials can be separated for either direct re-use or high quality recycling.

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Abstract

Large quantities of waste are generated during the construction of developments, and when buildings and structures are decommissioned and demolished at the end of their lives. Improper management of these construction and demolition (C&D) wastes often results in considerable environmental impacts. Using alternative management routes could result in both environmental and cost savings.

This guidance document provides waste policy makers, waste managers, and businesses with the background to Life Cycle Thinking (LCT) and Life Cycle Assessment (LCA) approaches which can be implemented when considering C&D waste management options. The guidance does not seek to be comprehensive, but outlines the key principles that are useful to understand, and to signpost readers to further sources of information.

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