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EXECUTIVE SUMMARY & CONCLUSIONS

This work sets out to provide a foundational understanding of embodied carbon in the EU, encompassing both the technical and the policy sides.

It is clear that embodied carbon represents an important share of buildings’ emissions, and that to fully decarbonise the sector, it needs to be tackled. The largest share of embodied emissions come from the manufacturing of construction products, whose decarbonisation necessitates significant efforts.

Said efforts must be grounded in a common understanding of embodied carbon across all stakeholders, in particular of what the characteristics of a low-carbon material are. Evidently, this is not a straightforward question, but rather one that requires research, reflection, and dialogue among stakeholders.

To answer these questions, this report proposes a 3-criteria approach to qualitatively assess the decarbonisation potential of a proposed pathway to achieve emissions reduction:

- positive climate impact
- no harmful trade-offs, and
- reasonable timeframe.

Taking the standard production process of cement and steel as a starting point (as they represent the largest share of emissions from construction materials), a review of the potential decarbonisation pathways for each sector is done, looking at:

**For cement:**
- Fuel substitution.
- Clinker-to-cement ratio reductions using SCMs.
- Adoption of lower-carbon cement chemistries.
- Implementation of CCS technologies.
- Exploration of CCU methods.
- (Re)carbonation of concrete.
- Material efficiency strategies.
- And recycling and end-of-life options.

**For steel:**
- Improvement of energy efficiency in conventional processes (BF–BOF) through iron content maximisation and fuel injection.
Utilisation of coke oven gas and increase the use of direct reduced iron (DRI) combined with electric arc furnaces (EAF) for lower emissions.

Use of biomass instead of coke, when and where appropriate.

Adoption of hydrogen-based DRI and EAF processes.

Increasing the share of scrap-based EAFs.

Implementation of CCS when and where appropriate.

Promotion of steel recycling.

The mentioned pathways are then assessed against the 3-criteria approach. The conclusions from the assessment are the following:

**Defining low-carbon**

The report moves on to identify what the general understanding of “low-carbon cement” and “low-carbon steel” is, in references to emission reductions, from both an industry and an academia perspective. It finds that there is a lack of a common understanding when it comes to a common definition, and it analyses the different uses of the term in both industry and academia. While some of the uses are aligned with the respective industry’s decarbonisation goals, others misuse the wording, which could result in misinformation, greenwashing and potentially interfere with decarbonisation actions. A universal understanding of “low-carbon” materials in line with the decarbonisation needs would provide important levers, especially if the definition was supplemented with progressively tightened embodied carbon thresholds for both the cement and concrete industry and the steel industry.

**For cement:**

The assessment of decarbonisation pathways for cement production highlights the need for a combination of strategies and technologies to address shortcomings and achieve emission reduction goals. There is no single solution that offers the lowest climate impact, minimal trade-offs, and immediate availability. However, many of these strategies are complementary and should be implemented together to reduce emissions as soon as possible while addressing potential trade-offs. Material efficiency strategies, along with policies and designs that promote reduced material use, are essential. Additionally, clinker-to-cement ratio reductions should be pursued to decrease emissions at the source, while capturing and permanently storing remaining emissions underground.

**For steel:**

The decarbonisation of the iron and steel industry requires a combination of solutions. Transitioning from fossil fuels in the BF/BOF route to DRI and EAF production will significantly reduce greenhouse gas emissions. However, this shift necessitates investments in new production facilities and a rapid expansion of renewable electricity capacities for the widespread production of green hydrogen. To achieve emission reductions, it is advisable to combine hydrogen with other solutions such as reducing steel use, increasing recycling, and employing CCS when and where appropriate. The specific mix of DRI, EAF, CCS, and potentially new breakthrough technologies will depend on available resources and timing.

**Regulation**

A second part of the report focuses on the embodied carbon-related policy at EU level. It provides a detailed overview of what the key objectives of each file are and how they relate to embodied carbon, highlighting the most relevant: EPBD, CPR and ESPR. Since some of these policy files are undergoing a legislative revision process, the information is subject to change.

The importance of well-functioning standards is also highlighted, as they play a crucial role in the regulation and market placement of construction products. Standards are key for the uptake of low-carbon materials.
In addition to standards, reporting and certifications are powerful tools for promoting sustainability and driving positive change, by providing valuable information on product environmental impacts, enabling informed decisions, and driving sustainable choices. However, addressing the weaknesses in current systems, such as enhancing standardisation, improving enforcement, and ensuring accessibility, is crucial to maximise their effectiveness.

This report provides an overview of the most common certification schemes and assessment tools and methodologies with regards to embodied carbon in the building sector. A short explanation of LCA methodology, WLCA, PEF and EPDs, the Level(s) framework and a comparison of the most common certification mechanisms such as LEED and BREEAM is then offered, with the intention of showcasing the various approaches while highlighting the advantages and limitations from them. No matter the approach, the need for data collection and harmonisation becomes evident to be able to realise WLC savings.

Lastly, the report delves into the question of lead markets, and the importance of developing them for low-carbon materials. It concludes that creating green lead markets is essential for promoting more sustainable and lower-carbon products and technologies. By leveraging measures like green public procurement, financial support, and regulations, lead markets drive innovation, make sustainable options more accessible, and stimulate the adoption of environmentally friendly solutions.

"Tackling embodied carbon, in particular the emissions associated with the manufacturing of construction materials, is vital for a complete decarbonisation of the building sector."
DEFINITIONS & ABBREVIATIONS

EMBODIED CARBON
emissions are associated with energy consumption (embodied energy) and chemical processes during the extraction, manufacture, transportation, assembly, replacement and deconstruction and end-of-life treatment.

END-OF-LIFE CARBON
emissions are associated with deconstruction/demolition, transport from site, waste processing and disposal of a building or infrastructure.

LIFE CYCLE ASSESSMENT
is a methodology for emission analysis that can be done with various scopes (cradle to gate, gate to grave, etc). It is worth noting that, generally, LCAs serve to measure a wide array of environmental impacts. However, in the context of this study, we refer to the part of the analysis that looks at greenhouse gases (GHG) emitted during a building’s lifecycle and their global warming potential, and therefore their contribution to climate change.

LOW-CARBON BUILDING
is one that optimises the use of resources both to build it and to use it over its lifetime by reducing both operational and embodied emissions, in particular those related to the manufacturing of the construction materials.

OPERATIONAL
emissions are associated with energy consumption (operational energy) while the building is occupied, e.g. heating, cooling, lighting and appliances.

UPFRONT CARBON
emissions associated to the materials production and construction phases, before the building is operational.

WHOLE-LIFE CARBON (WLC)
Embodied Carbon + Operational Carbon. The carbon emissions resulting from the materials, construction and use of a building over its entire life, including its demolition and disposal. Other terms used are lifecycle carbon or cradle-to-grave carbon.

WLC ASSESSMENT (WLCA)
is a study that uses LCA methodology to analyse the whole-life carbon of a building.
1. INTRODUCING EMBODIED CARBON: THE SILENT CLIMATE GIANT

This report takes a wide look at the current state of embodied carbon at EU level. Its overall aim is to provide a foundational terms of reference on where we find ourselves, in order to make it clearer where we need to go from here.

Accounting for and setting limit values for embodied carbon is a critical part of the EU’s ongoing efforts to reduce the Union’s carbon footprint and achieve climate goals. Buildings account for approximately 40% of energy consumption and 36% of CO₂ emissions in the EU. Of these emissions, embodied carbon is estimated to make up 10-25% of the total carbon footprint of buildings. This proportion is higher in new buildings and generally increases as energy efficiency reduces the proportion of operational emissions.

In order to achieve a building sector with net zero emissions by 2050, which is necessary to meet the EU’s climate goals, all new buildings and renovation projects must take embodied carbon into account. Two-thirds (65%) of Europe’s building stock was built before 1980 and approximately 97% of the EU’s buildings need to be upgraded to reach the 2050 target. A huge renovation wave is before us.

In this first chapter we take a closer look at what embodied carbon is and why it matters that we tackle it.

1.1. Embodied carbon 101

1.1.1. What is embodied carbon?

Embodied carbon is an emission category that includes the CO₂ footprint of the ingredients and processes included in manufacturing a product (so-called upfront carbon), as well as the emissions resulting from such a product’s end-of-life treatment or disposal process (so called end-of-life carbon).

Embodied carbon differs from operational carbon or operational emissions, which is the carbon emitted when a product or building is used, for example from heating, cooling, or lighting in a building. In other words, embodied carbon are all the emissions that are linked to or that are “included in” a
specific good, minus operational carbon. Together, embodied carbon and operational carbon make up the entire climate footprint or life-cycle emissions of, for example, a building (see Figure 1). This is also known as ‘Whole-Life Carbon’ (WLC).

1.1.2. Why do we distinguish between embodied and operational carbon?

The advantage of distinguishing between embodied and operational carbon is that we can focus on the emissions from production and disposal of materials. This often includes so-called ‘harder-to-abate’ emissions, or process emissions, which can result from unavoidable chemical processes, and which thus cannot be reduced or eliminated by switching to renewable energy. This applies, for example, in the production of cement, where CCS is needed (together with other decarbonisation solutions) to reduce otherwise unavoidable process-related CO₂ emissions.

Another advantage of distinguishing between embodied and operational carbon is that it helps us better understand the climate footprint of, for example, a building. When it comes to climate measures in the buildings and construction industry, the focus until now has often been on operational emissions, through energy savings and energy efficiency measures. Here, the EU’s energy efficiency directive has proven successful in bringing down operational emissions. But energy efficiency is only one part of a building’s climate footprint, and as energy efficiency improves, the proportion of the climate footprint that is made up of embodied carbon increases.

1.1.3. Why does embodied carbon matter?

A focus on embodied carbon helps us to see and understand what other measures we need to implement beyond energy efficiency. And these are often measures that need to be taken long before a building is even constructed or completed, for example in the choice of materials.

Embodied carbon can make up to 50% of the total emissions of greenhouse gases from a new building, although this can vary depending on the type of building. A warehouse for example, will generally have lower operational emissions than for instance an office building, and therefore a higher proportion of its whole-life carbon footprint will be from embodied carbon.

Being able to compare the emissions of various components of a building beyond the operational emissions is fundamental to achieving climate neutrality. By including embodied carbon in the total footprint of any material and product, we raise awareness of the entire carbon footprint of a building. This in turn can help us drive climate neutral production of materials along the entire value chain.
1.1.4 What are the main materials concerned?

Material production globally amounted to 12.7 Gt CO₂ in 2020, including the energy used to produce them. This is a quarter (25%) of total 2020 emissions. The main materials produced were iron & steel (7% of global emissions), cement & concrete (6%), plastics (4%) and aluminium (2%), with other various materials making up the other 6%\(^\text{iii}\). In the case of the construction industry, materials widely use also include glass and timber. Construction chemicals also play a role.

![Greenhouse gas (GHG) emissions from material production globally in 2020. Source: Eunomia, 2022.](image)

**Plastics and construction chemicals**

In Europe, 10 million tonnes of plastics each year (20% of total plastics consumption) is attributed to the construction sector. Plastic applications in buildings include insulation, piping and window frames\(^\text{iii}\). The emissions of plastics vary depending on the product. For example, plastic production accounts for approximately 1.6-1.95 tonnes of CO₂ per tonne of polypropylene\(^1\), a type of plastic commonly used in piping\(^4,5\).

Aside from plastics, there are other chemicals that are used in construction, such as concrete admixtures, glues, coatings, lacquers... among others\(^6\). Of course, due to the characteristics of the application of these materials, they are used in smaller amounts than the other materials presented.

**Aluminium**

After steel, aluminium is the most common metal used for construction purposes, being extensively employed in various sectors ranging from commercial buildings to residential homes. The construction industry in the UK utilises 40% of the annual production of aluminium. It is used in windows, roofing, cladding, curtain walling and structural glazing, prefabricated buildings, piping, shop fitting and partitions. Aluminium is also used extensively in ladders and scaffolding during the construction phase\(^7\). However, aluminium is also a carbon-intensive product, with primary aluminium emitting on average 16.5 tonnes of CO₂ per tonne of metal\(^8\).

**Glass**

Glass has been conventionally employed as window panes in the construction industry. However, over the past 25 years, there has been a growing trend of using glass as a primary building material. The embodied carbon of glass is mostly associated with the high temperatures needed to produce it. To contextualise it, the value (in MJ/kg) is higher than the embodied carbon of reinforced concrete, and less than the embodied carbon of steel\(^9\). The emissions of glass production amount to 0.46 tonnes of CO₂ per tonne of glass produced\(^4\).

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1. This value does not include end-of-life emissions.
Timber

Wood has been used as a construction material for centuries, and engineered timber has gained traction as a building material in the past years. When sourced and harvested responsibly, observing sustainable forest managing strategies, it can be a renewable material

Insulation

With the increase of energy efficiency measures for buildings, consumption of insulation materials is bound to increase as well. The most common types of materials used for insulation include cellulose, fiberglass, mineral wool (from rock or slag), polyurethane foams and polystyrene.

Raw material use is predicted to double by 2060, which means that decarbonisation of already widely used, and carbon-intensive materials needs to happen as soon as possible. In Chapter 3 we will take a closer look at the two most impactful construction materials, cement and steel.

The World Commission on Environment and Development’s 1987 Brundtland report ‘Our Common Future’ defined sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” But putting this into concrete action, for example certifying something as ‘low-carbon’, ‘green’ or ‘sustainable’ can be challenging due to several reasons.

Upfront carbon represents the largest share of embodied carbon, particularly the product stage. Decarbonisation of the manufacturing processes of construction materials is key to avoid locking in emissions.
2. DEFINING ‘LOW-CARBON’

Environmental issues are multifaceted and interconnected. Factors such as energy efficiency, resource conservation, waste management, biodiversity preservation, and social equity all play a role in sustainability. Attempting to capture all these dimensions in a single definition can be challenging.

Our understanding of environmental impact and sustainable practices is constantly evolving. As scientific research progresses and new technologies emerge, our understanding of what is considered “green” or “low-carbon” evolves as well. This means that definitions must be flexible to adapt to new information and advancements.

In many cases, there are trade-offs between different environmental, social, and economic goals. For example, a product may be environmentally friendly but not socially equitable, or it may be sustainable in one context but not in another. Defining what is “green” or “sustainable” requires considering these trade-offs and contextual factors, which adds complexity to the definition.

Finally, terms like “green”, “low-carbon” and “sustainable” have become highly marketable, leading to the risk of greenwashing: when companies or organisations make false or unsubstantiated claims to be environmentally friendly, climate neural or the like. This further complicates any definition as it requires distinguishing genuine sustainability efforts from mere marketing tactics.

Nonetheless, it is possible to draw some protective lines or “guard-rails” around these terms, that can help us to progress the conversation and not lose sight of the path toward a carbon negative, restorative and just world. To do so, a 3 criteria-method is used in this report, which is described in the following section.

2.1. Climate technology assessment criteria

This report looks at three criteria to assess climate technologies or solutions:

Climate impact: What are the greenhouse gas reductions?
Trade-offs: What is the use intensity of the resource and the effect on decarbonisation pathways?
Timing: What is the deployment potential at scale in the near-, mid-, and long-term?

At the core of this method is system thinking, recognising that each component is only part of a greater whole where they all impact on each other and where it is vital to understand these interactions.

With this in mind, we conclude that the following requirements must be in place for something to be classified as low-carbon, a low-carbon base metric of sorts. To be able to declare that something is low-carbon, it should be aligned with these principles:
CLIMATE IMPACT

In the absence of science-based thresholds in line with the Paris Agreement, whole-life emissions from a particular product or process need to be reduced to the minimum. When it is a product integrating several intermediate products (e.g. a building made up of different materials) it can only be called low-carbon when all its components and the processes related to the final product during its whole lifecycle are also low-carbon. If only part of the final product is made up of low-carbon products or processes, then it should be indicated which parts. Emissions should be accounted for properly, following a robust methodology that includes all relevant emissions, both direct and indirect, caused by a product including its production, use and disposal.

TRADE OFFS

There should not be trade-offs in terms of emissions (no switching of emissions to another value chain: no carbon leakage), and the decisions for using low-carbon products should always be justified in terms of emitting less at a system level. When there is an impact, it needs to be taken into account. For example, when building a structure, if a low-carbon material is chosen, it is necessary to make sure that the overall quantity of material going into the building is going to emit less overall than the alternative. If a material has less embodied carbon per mass unit, but more material is needed to achieve the required structural properties and this results in more CO₂ emissions overall, efforts to decarbonise could be futile. Lower emissions should also not be traded for a shorter lifespan of the building, and a ‘minimum waste first’ strategy should be in place when using byproducts from other industries (like SCMs or blast-furnace slags).

TIMEFRAME

When strategic decisions need to be taken regarding the timing of the reduction, ‘the sooner, the better’ principle shall apply. In particular in the case of buildings, where the biggest share of embodied carbon is emitted before the building is put to use (upfront carbon), there is a risk of “locking in” emissions for the lifespan of the building. Once it is constructed, there is limited potential for reductions of embodied carbon. Therefore, measures that aim to tackle upfront carbon should be prioritised and incentivised with proper financing and regulation. However, this principle should enable the minimising of emissions from a holistic perspective, over the whole lifespan of the building, also considering the potential variations of operational carbon emissions (for example: waiting longer to install a heat pump than instantly setting up a hydrogen-ready gas boiler).

An important embodied carbon measuring unit to consider is kg CO₂ emitted/kg/m², which also accounts for the amount of material that goes into the space.
In this chapter we will take a closer look at some of the most commonly used and most carbon-intensive construction materials. We break down their composition and standard manufacturing process, in order to illustrate where and how we best can reduce their carbon footprint.

3.1 Cement and concrete
Cement is a key component of concrete, which is the final construction product. However, even though cement only makes up a relatively small part of concrete, it is responsible for most of its emissions. The production of cement emits 0.9 tonne of CO₂ per tonne of cement produced\textsuperscript{xvi}.

Concrete
Concrete is a composite material made of aggregates bound together with a binding material, most commonly cement mixed with water. The share of each component is a range; for example, for cast-in-place concrete, aggregates can represent from 60 to 75\% of concrete, cement from 7\% to 15\%, from 14 to 21\% of water, and up until 8\% of air\textsuperscript{xvii}.

Figure 3: Usual composition of concrete.

Even though OPC only makes up 11\% of concrete, 90\% of concrete emissions are directly linked to the production of clinker, the main ingredient in cement\textsuperscript{xviii}.

Nowadays, cement is commonly combined with one or more supplementary cementitious materials (SCMs), such as fly ash, silica fume, blast furnace slag, or limestone powder\textsuperscript{xix}. 
Cement

Cement is the binder in concrete, which makes it an integral component in the construction industry. However, as mentioned before, most emissions also happen during its production. Emissions in cement come from two main sources: process emissions and fuel combustion emissions. Process emissions are those related to the calcination of limestone (which decomposes into lime and CO₂) and are indeed unavoidable emissions in clinker production. Fuel combustion emissions are those related to the chemical reactions that happen when fuel is burned to heat up the kiln.

3.1.1. Overview of standard production process

The most commonly used type of cement is Portland cement (abbreviated OPC). Portland cement gets its name from the Isle of Portland in Dorset, England, where it was first developed and produced. Its widespread adoption is due to its strength, versatility, and ability to endure different environmental conditions.

Production process of Portland cement (OPC)

The main raw materials are:

- **Limestone:** CaCO₃
- **Clay:** SiO₂, Al₂O₃, Fe₂O₃
- **Gypsum:** CaSO₄ × 2 H₂O

The mixing procedure can be done in two main methods (dry and wet). There can be slight variations (semi-dry and semi-wet).
Even though the processes seem the same at a first glance, with the exception of added water in the first process, the characteristics are somewhat different, and they are collected in Table 1 below.
Table 1: Comparison of dry and wet processes - Source: The Constructor (2021)\textsuperscript{xxi}.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Dry process</th>
<th>Wet process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness of raw material</td>
<td>Quite hard</td>
<td>Any type of raw material</td>
</tr>
<tr>
<td>Fuel consumption</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Time of process</td>
<td>Lesser</td>
<td>Higher</td>
</tr>
<tr>
<td>Quality</td>
<td>Inferior quality</td>
<td>Superior quality</td>
</tr>
<tr>
<td>Cost of production</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Overall cost</td>
<td>Costly</td>
<td>Cheaper</td>
</tr>
<tr>
<td>Physical state</td>
<td>Raw mix (solid)</td>
<td>Slurry (liquid)</td>
</tr>
</tbody>
</table>

**Manufacturing of cement, step by step**

These are the main chemical and physical processes that take place.

**Calcination of limestone into lime (stage where most of the emissions happen):**

\[
\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2
\]

- Calcination of mixture of limestone (\(\text{CaCO}_3\)) and clay (\(\text{SiO}_2, \text{Al}_2\text{O}_3, \text{Fe}_2\text{O}_3\)).
  - Takes place between 900 and 1200 °C. At this stage, fuel combustion emissions happen, since high temperatures are needed for the calcination process to occur. Fuel combustion related-emissions amount to around 35% of total emissions produced during this process\textsuperscript{xxi}.
    - Fuel to heat the kiln:
      - Powdered coal
      - Oil
      - Hot gases
      - Derived fuel (high calorific municipal solid waste, mostly plastics and tyres)
  - Limestone decomposes into lime and \(\text{CO}_2\) due to the high temperatures. This is where process emissions happen, which amounts to around 65% of total produced emissions in the clinker manufacturing process.

**Reaction of the mixture of lime and clay:**

\[
\begin{align*}
2 \text{CaO} + \text{SiO}_2 & \rightarrow \text{Ca}_2\text{SiO}_4 \\
3 \text{CaO} + \text{SiO}_2 & \rightarrow \text{Ca}_3\text{SiO}_5 \\
3 \text{CaO} + \text{Al}_2\text{O}_3 & \rightarrow \text{Ca}_3\text{Al}_2\text{O}_6 \\
4 \text{CaO} + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3 & \rightarrow \text{Ca}_4\text{Al}_2\text{Fe}_2\text{O}_{13}
\end{align*}
\]

- Lime reacts with the silicates and aluminates to form aluminates and silicates of calcium.
- Aluminates and silicates of calcium fuse together, creating clinkers.

**Powered clinker and gypsum are mixed to form cement:**

- Clinker is cooled and grinded and gypsum is added.
- Cement is stored.
3.1.2. Decarbonisation pathways for the cement industry

In this section, we will run through the main decarbonisation pathways identified in the concrete and cement industry. A brief description of each will be provided, and a final analysis of the technologies will be carried out, according to the three Bellona criteria for climate solutions (climate impact, trade-offs, and timeframe).

Examples of decarbonisation pathways for the concrete and cement industry

Table 2: Examples of decarbonisation levers for the cement industry. Source: Climateworks (2021)

<table>
<thead>
<tr>
<th>Decarbonisation lever</th>
<th>Technology maturity</th>
<th>Stakeholder involvement</th>
<th>Current status</th>
<th>Key barriers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement plant technology options</td>
<td>Conventional</td>
<td>Production-side</td>
<td>Commercial-scale</td>
<td>High investment</td>
</tr>
<tr>
<td>Clinker-to-cement ratio reductions</td>
<td>Conventional</td>
<td>Production-side</td>
<td>Commercial-scale</td>
<td>Low-reactivity, Resource scarcity</td>
</tr>
<tr>
<td>Lower-carbon cement chemistries</td>
<td>Emerging</td>
<td>Production-side</td>
<td>Pilot-scale</td>
<td>Low market penetration</td>
</tr>
<tr>
<td>At-plant carbon capture and sequestration</td>
<td>Emerging</td>
<td>Production-side</td>
<td>Pilot-scale</td>
<td>Very-high investment</td>
</tr>
<tr>
<td>Carbon utilisation</td>
<td>Emerging</td>
<td>Production-side</td>
<td>Commercial-scale</td>
<td>Low market penetration</td>
</tr>
<tr>
<td>Material efficiency strategies</td>
<td>Conventional/Emerging</td>
<td>Demand-side</td>
<td>Commercial-scale</td>
<td>Risk concern, Lack of awareness, Higher price</td>
</tr>
<tr>
<td>End-of-life options</td>
<td>Emerging</td>
<td>Demand-side</td>
<td>Pilot-scale</td>
<td>Regulatory framework, Higher price</td>
</tr>
</tbody>
</table>

The CO₂ mitigation potential of these conventional at-plant CO₂ mitigation measures (cement plant technology options and clinker-to-cement ratio reductions) is subject to theoretical limits, availability of input materials, and cement producers' willingness to replace their assets. Therefore, cement and concrete producers will need to consider additional disruptive and innovative measures for delivering CO₂ emission reductions in line with the 1.5 °C target of the Paris Agreement (focus on lower-carbon cement chemistries & at-plant carbon capture and sequestration).

Cement plant technology options

Dry-process kilns with a pre-calciner, a multi-stage cyclone pre-heater, and multi-channel burners are regarded as the state-of-the-art technology for clinker production.

One important aspect affecting the outlook for plant energy efficiency improvements is that cement kilns are long-lived capital assets with a typical lifetime of 30-50 years, limiting the pace at which they can be replaced with new ones in a cost-effective manner, which is unlikely without mechanisms like public support.

It is also important to note that the average reported electrical efficiency of the global 10% best in class is 85 kWh/t cement. The predominant fuels used in cement kilns have historically been coal and natural gas due to their widespread availability, high heating values, and generally low costs. It is considered a hard-to-electrify process due to the high temperatures needed.
Cement kilns' fuels:
- Coal
- Natural gas
- Oil
- Waste fuels (shredded tires, waste oils, plastics, textiles, paper residues...)
- Biogenic fuels

Waste-based fuels can be less CO₂-intensive than coal. However, in terms of accounting for its emissions, it is important to treat them as Municipal Solid Waste (MSW) is treated in waste incinerators: the fossil part of the waste must be accounted for.

In theory, cement kilns can utilise up to 100% of alternative low-carbon fuels, albeit subject to kiln heating value requirements, local availability, and contamination of these fuels. Therefore, switching to less carbon-intensive fuels is a viable option, so long as these are sustainably sourced and available. Moving forward, there is ample room for incorporating such fuels into cement kilns, considering the abovementioned characteristics.

**Clinker-to-cement ratio reductions**

The clinker content of standardised cements in the EU can range from 5% to 95% in theory. The clinker content traditionally determines the range of applications suitable for the cement. Ordinary Portland cement can include as much as 95% clinker, with the remaining 5% typically consisting of gypsum. The current clinker-to-cement ratio in the EU is an average of 73.7%.

Clinker can be substituted by various supplementary cementitious materials (SCMs), including:
- limestone,
- fly ash
- ground granulated blast furnace slag (GGBFS)
- natural pozzolana,
- calcined clay

It is worth mentioning that some of these SCMs, such as fly ash and GGBFS, come from very carbon-intensive sources, so an adequate carbon accounting is especially relevant in such substitutions. The lifecycle emissions of GGBFS-substituted cement is 22-40% lower greenhouse gases (GHGs) and with fly ash 15-46% lower GHGs compared to conventional cement.

From a technical point of view, the clinker-to-cement ratio can be reduced up to around 60% without sacrificing key cement or concrete properties. In practice, however, the implementation of clinker-to-cement ratio reductions relies on local material availability and regional standards that regulate the proportions of SCMs.
Table 3: Characteristics of commonly used SCMs for cement.

<table>
<thead>
<tr>
<th>SCMs</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limestone</td>
<td>Widely available, as it is the main ingredient in cement.</td>
</tr>
<tr>
<td>Fly ash</td>
<td>Availability of fly ash is subject to the local capacities of coal-based thermal power plants, and the share of coal-based power capacity is expected to decrease moving forward.</td>
</tr>
<tr>
<td>Ground granulated-blast furnace slag (GGBFS)</td>
<td>Availability hinges on the locations and output of crude iron production. Recent climate change scenarios project that the iron and steel industry may shift from crude iron to secondary steel in a low-carbon future, thereby reducing global available quantities of GGBFS.</td>
</tr>
<tr>
<td>Natural pozzolans</td>
<td>Natural pozzolans have advantages on top of emission reduction by substituting clinker. However, the use of natural pozzolans may have certain drawbacks, including reduced workability, increased water and superplasticizer demands.</td>
</tr>
<tr>
<td>Calcined clay</td>
<td>While calcined clay is not limited by feedstock supply, its activation requires calcination, but leads to no process CO₂ emissions from carbonate decomposition and consumes 45% less energy compared to OPC clinker.</td>
</tr>
</tbody>
</table>

Lower-carbon cement chemistries

There are two main types:
- Lime-silica-alumina cements.
- Alkali-activated cement.

These lower-carbon cement chemistries depend on varying raw materials and/or combinations of raw materials that effectively decrease process CO₂ emissions (and occasionally reduces thermal energy needs too) when compared with OPC clinkers.

The table below presents six lower-carbon cement chemistries (lime-silica-alumina cements) that are either commercially available or have been piloted or demonstrated on small production scales. They have been found to have reasonable commercial market potential within the next decade.

Table 4: Process CO₂ and energy savings of lower-carbon cement clinker compared to OPC clinker. Source: ClimateWorks (2021).

<table>
<thead>
<tr>
<th>Cement type</th>
<th>Process CO₂ savings</th>
<th>Energy savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactive belite cement</td>
<td>3.1%</td>
<td>8.2%</td>
</tr>
<tr>
<td>Belite-ye’elimite-ferrite cement (BYF)</td>
<td>29.1%</td>
<td>34.9%</td>
</tr>
<tr>
<td>Carbonatable calcium silicate cement (CCSC)</td>
<td>24.8%</td>
<td>38.9%</td>
</tr>
<tr>
<td>Calcium sulfoaluminate cement (CSAB)</td>
<td>42.8%</td>
<td>46.9%</td>
</tr>
<tr>
<td>Celitement</td>
<td>33.2%</td>
<td>50.6%</td>
</tr>
<tr>
<td>Magnesium oxides derived from magnesium silicates (MOMS)</td>
<td>100%</td>
<td>46.5%</td>
</tr>
</tbody>
</table>

Alkali-activated binders serve as an alternative to OPC clinkers, yet they depend on the same raw materials employed in blended cement. However, the utilisation of fly ash, GGBFS, natural pozzolana, and calcined clay in alkali-activated binders offers fewer environmental advantages than blended cement.
In short, Portland cement is not the only existing binder for concrete. Today, there are cements with a different composition with lower embodied carbon and comparable structural properties, whose uptake could have environmental benefits or, at least, produce less CO₂ than OPC.

**Carbon Capture and Storage (CCS)**

Due to the intrinsic nature of emissions in the manufacture of conventional cement, process emissions (which amount to 60–65% of total emissions in a standard production process) are inevitable. In addition, the high temperatures needed in the kiln make it very challenging to electrify. Therefore, the deployment of carbon capture and storage (CCS) technologies is necessary to abate emissions from the cement industry, more so than in other industrial sectors. This is especially true in the long-term (2050) as the CCS ladder developed by E3G and Bellona shows in the figure below:

![2050 CCS ladder (for Europe)](image)

Figure 7: Carbon Capture and Storage 2050 Ladder. Source: E3G, Bellona (2023)

When it comes to cement production, there are two possible capture technologies. Due to the amount of process emissions in conventional cement production, post-combustion capture is preferred, being able to capture both combustion- and process-based emissions. Oxyfuel combustion is generally considered the better option for cement given that flue gas contains higher concentration of CO₂ and reduced pollutants. It reduces the energy requirements of the CO₂ capture process and thus cost of capture due to higher partial pressure of CO₂.

**Other pathways**

The pathways presented here have a less straight-forward implementation or have less obvious benefits than those presented above.

**Carbon Capture and Utilisation (CCU)**

Carbon capture and Utilisation (CCU) means capturing the CO₂ generated from the production process of cement, and instead of releasing it into the atmosphere, utilising it in different processes or products.

While CCU shares common attributes with CCS, particularly in terms of capture and CO₂ transport infrastructure, unlike CCS, CCU has a business case stemming from the sale of CO₂ as a product. Meanwhile, stored CO₂ via CCS does not provide an economic value per se, rather a climate one (which is then valorised via the ETS in the EU). CCS represents a proven emission reduction technology,
with the primary objective of permanently sequestering CO₂ away from the atmosphere. On the other hand, CCU operates within the CO₂ market, aiming to supply CO₂ to entities seeking it for their products and services, irrespective of its permanence in their end applications. Consequently, these two technologies offer distinct levels of contribution to climate change mitigation.

Since CO₂ emissions are not permanently stored underground and isolated from the atmosphere, it is relevant to know what happens to the CO₂ during and after its utilisation, as there’s a possibility that it is emitted further contributing towards climate change. In fact, one of the main challenges is the risk of shifting emissions from one industry to another, which can lead to the initially captured emissions finding their way back to the atmosphere. This brings into question the effectiveness of emission reduction measures of CCU because emissions are merely displaced in the system, instead of being reduced.

**Recarbonation**

Cement recarbonation is the phenomenon where a portion of the carbon dioxide released during cement production is absorbed again by concrete through a process known as carbonation. Carbonation is a gradual chemical reaction that takes place within concrete, where the lime (calcium hydroxide) present in the cement reacts with carbon dioxide present in the surrounding air, resulting in the formation of calcium carbonate. Therefore, for this process to occur, concrete needs to be in contact with air. If at the end of their service life, a structure is demolished and the concrete crushed, the surface area in contact with air will increase. However, CO₂ absorption in significant quantities is not a given, as it depends on the end-of-life conditions.

**Material efficiency strategies**

Material efficiency strategies build on the fact that the lower the consumption of cement and concrete, the fewer emissions are produced in the first place. They can be implemented all throughout a building’s lifetime, from design to end-of-life.

Some of these strategies are:

- **Material-efficient design**: such as including performance-based concrete design, promoting the utilisation of precast concrete elements, post-tensioning techniques, and avoiding excessive design of concrete structures. It also involves incorporating recycling and waste materials in concrete production.

- **Material substitution**: this can be about using alternative supplementary cementitious materials (SCM) with lower embodied carbon content than cement, and about using other low-carbon construction products instead of concrete.

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*Process CO₂ (which amount to 60–65% of total cement emissions) is inevitable, but emissions to the atmosphere can be reduced or eliminated via the decarbonisation pathways explored.*
**Intensive use:** this refers to implementation of policy that reduces the need for building space, and a more efficient use of existing infrastructure.

**Lifetime extension:** this is about reducing premature demolition, promoting more adaptable and durable designs, and implementing policies that allows to repurpose buildings instead of demolishing them when they no longer serve their original purpose, but they are still functional and safe from a structural integrity point of view.

### 3.1.3. Recyclability, end-of-life options, other considerations

When concrete structures reach the end of their lifespan, the structure can be demolished, and the concrete can be crushed into recycled concrete aggregate (RCA). RCA can be used as a substitute for virgin aggregates in new concrete, reducing the need for natural resource extraction\(^{xxx}\). Additionally, corrugated steel bars can be separated from reinforced concrete and recycled. Concrete downcycling helps conserve resources, reduces waste, and lowers the environmental impact of the construction industry.

The concrete recycling rates in Europe vary among countries. The average downcycling rate for construction and demolition waste, which includes concrete, in Europe is around 50%\(^{xxx}\). However, specific downcycling rates for concrete differ based on local practices and regulations, ranging from less than 10% to over 90% across the EU\(^{xxx}\).

Other considerations when it comes to the end-of-life of an infrastructure, is component reuse. This means reusing modular components for new construction projects, which has a higher potential savings than recycling as it heavily reduces the need of cement production for new products.

End-of-life measures face the challenge of accountability of emissions, as it is often unclear who bears the responsibility or the benefit of having reduced emissions\(^{xxx},^{xxx}\).

### 3.1.4. Conclusions

This section entails an analysis of the decarbonisation pathways presented, in particular of how they stand against the Bellona method. That is, how they perform in terms of climate impact, the trade-offs that need to be made for the solution to be feasible, and what is the timeframe for this solution to become a reality.

This analysis is made for each of these technologies as a standalone solution, as opposed to standardly used OPC and usual concrete compositions.

"Establishing on a solid definition of 'low-carbon' construction products is crucial to promote their uptake and prevent greenwashing."
# Table 5: Assessment of decarbonisation pathways of the cement and concrete industry against the 3 criteria.

<table>
<thead>
<tr>
<th>Decarbonisation pathway</th>
<th>The Bellona criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Climate impact</td>
</tr>
<tr>
<td><strong>Plant technology options</strong></td>
<td>Plant technology options have a positive, though fairly limited, effect on emissions reductions.</td>
</tr>
<tr>
<td><strong>Clinker-to-cement ratio reductions</strong></td>
<td>Depending on what the reduction is, the impact on climate would change (though reductions generally would have a positive climate impact, as long as clinker content is not replaced with a more carbon-intensive product).</td>
</tr>
<tr>
<td><strong>Lower-carbon cement chemistries</strong></td>
<td>As seen in Table 3, some of the different chemistries have potential for significant emission reductions, both at process and thermal emissions.</td>
</tr>
<tr>
<td><strong>Carbon capture and storage (CCS)</strong></td>
<td>CCS has a positive and large impact on emissions reduction, as emissions are captured and stored permanently in geological storage sites.</td>
</tr>
<tr>
<td><strong>Carbon capture and usage (CCU)</strong></td>
<td>The emission reduction potential of CCU depends on overall energy requirements, the source of CO₂ and finally, whether the used CO₂ is emitted during the use and disposal of the product. If emissions end up in permanent storage afterwards, emission reduction potential would be comparable to CCS.</td>
</tr>
<tr>
<td><strong>Material efficiency strategies</strong></td>
<td>They may have varying emission reduction potential, depending on the strategy.</td>
</tr>
</tbody>
</table>
The combinations of some of these pathways could solve some of their shortcomings, when technologies are complementary. Solutions available in the short term could also be undertaken to reduce emissions as soon as possible, while ensuring that it is not to the detriment of the latter implementation of more effective technologies.

Based on this analysis, it is evident that when it comes to cement and concrete decarbonisation, there is no silver bullet: no solution alone has the lowest climate impact, the least concerning trade-offs, and is available in the shortest time. However, most of these strategies are complementary, and they should be implemented in a way that reduces emissions as soon as possible, while addressing the potential trade-offs.

Material efficiency strategies need to be implemented across the entire value chain, from material-efficient design to effective policy instruments. At the same time material use goes down, low-carbon materials need to become readily available. Clinker-to-cement reductions must be undertaken to reduce emissions at the source, while the remaining emissions are captured and permanently stored underground.

### 3.2. Steel

Steel is an alloy of iron (Fe) and carbon (C), with a carbon content ranging up to 2%. Steel can also contain different amounts of other elements, depending on the properties needed for a particular use.

Steel is an integral part of buildings and infrastructure due to its mechanical properties. Its production globally accounts for 7% of annual greenhouse gas emissions. Steel is a crucial material in our society, as it makes up infrastructure such as buildings. However, massive steel production poses a problem, since it is a very carbon-intensive industry, meaning that its production traditionally releases a lot of CO₂ to the atmosphere (between 1.4 and 2.3 tonnes of CO₂ per ton of steel, depending on the production route).

In the IEA Net Zero Scenario, steel production emissions need to decrease to 1 ton of CO₂ per ton of steel by 2030, to be able to reach net-zero in 2050. To achieve that, we need to understand how steel is produced currently and the different decarbonisation pathways that exist.

#### 3.2.1. Overview of standard production process

**Raw materials**

To produce steel, you need two main elements: iron (Fe) and carbon (C).

Iron can be obtained from iron ore. The ore contains iron in an oxide form, meaning that to be able to use iron, the first thing needed is to remove the oxygen (via a chemical reaction called reduction).

<table>
<thead>
<tr>
<th>Iron oxide: Fe₃O₂</th>
</tr>
</thead>
</table>

Reduction of iron ore into iron

\[
\text{Fe}_3\text{O}_3 + 3 \text{CO} \rightarrow 2 \text{Fe} + 3 \text{CO}_2
\]

Steel production

\[
\text{Fe} + \text{C} \rightarrow \text{FeC}
\]

**How to produce steel**

There are two main processes to produce steel: using an integrated blast furnace (BF)/basic oxygen furnace (BOF) or an electric arc furnace (EAF).

To produce steel, you need to obtain iron first. That is why traditionally, the process to produce steel is divided in two: iron making and steel making.
Iron making

This reaction to obtain iron requires very high temperatures (~1500 °C), it includes a reduction of iron ore with various potential feedstocks and it can be done by different processes. The most relevant are:

◆ **Blast furnace**

The blast furnace burns coke (from coal) to be able to achieve the high temperatures required to produce iron. The reactions that take place in the furnace also result in some impurities:

\[
\text{Fe}_3\text{O}_4 + \text{CO} + \text{CaO} + \text{impurities} \rightarrow \text{Fe} + \text{CO}_2 + \text{slag}
\]

“Impurities” means other elements such as phosphorus, silicon, manganese, etc. Slag is a by-product, mostly calcium compounds, which can be used as a binder in concrete.

◆ **Direct-reduced iron (DRI)**

Direct reduction refers to solid-state processes which reduce iron oxides to metallic iron at temperatures below the melting point of iron. The reducing agents are carbon monoxide (CO) and hydrogen (H2).

Traditionally, the sources of reducing agents have been natural gas, syngas or coal. One of the most promising decarbonisation pathways for steel production is considered to be the use of 100% green hydrogen instead of natural gas. This process is called Hydrogen-Based Direct Reduction (H-DR).

In the short term, the economic feasibility of H-DR is heavily dependent on the low-cost green hydrogen or high carbon emissions. In the long term, 80–90% of carbon emissions can be avoided on application of H-DR in the steel industry; therefore, the widespread application of H-DR technology is expected to be a milestone in the transition of the steel industry to cleaner production.

It is important to keep in mind that green hydrogen is a renewable electricity-intensive process, and both renewable electricity and hydrogen are also needed for several other industries and processes to decarbonise.

Steel making

There are two main routes for steel production. The main difference between the routes is the raw material they use.

Currently, 70% of steel is produced via the blast furnace-basic oxygen furnace (BF-BOF) route, while a 30% is produced via the EAF route (in the EU, the share increases to 40%).

◆ **Basic oxygen furnace (BF-BOF)**

The basic oxygen furnace (BOF) process utilises the pig iron obtained from the blast furnace. In the basic oxygen furnace, oxygen is blown through molten pig iron that is heated to approximately 1,600 °C to convert it into steel.

◆ **Electric arc furnace (EAF)**

Electric arc furnaces are a type of furnace that heats materials through the creation of an electric arc. The typical capacity of an EAF is about 15 million tonnes per year.

The molten metal in an industrial furnace can reach temperatures of 1800 °C, and the arc, 3,500 °C. Normally, the EAF route is fed with steel scrap and electricity. Other potential sources of metallic iron would be:

◆ Direct-reduced iron (DRI)
◆ Hot metal

Therefore, there are 3 main steel production routes:

◆ Coal-based BF-BOF (primary iron and steel production).
◆ (Natural gas or hydrogen-based) DRI with EAF (primary iron and steel production).
Scrap-based EAF (secondary steel production).

As in any other steel making process, high temperatures are needed. This energy comes from the creation of an electric arc, that arises when the graphite electrodes (powered with electricity) make contact with the metal scrap. The outputs are molten steel and slag.

### 3.2.2. Decarbonisation pathways for the steel industry

The different production routes have different climate impact. The production via the BF-BOF route emits between 1.8 to 2.3 tonnes of CO₂ per tonne of crude steel cast, whereas the production via the natural gas DRI-EAF route produces 1.65 tonnes of CO₂ per tonne of crude steel cast. In the case of scrap-based EAF, the emissions are 0.67 tonnes of CO₂ per tonne of crude steel cast, lower as it does not produce virgin steel\[xlii\].

There are several decarbonisation pathways for steel production, some of them being complementary. Below is a general representation of potential decarbonisation pathways (from boosting efficiency, switching fuels, to preventing or capturing emissions)\[xliii\].

#### Optimisation pathways

These pathways decrease emissions compared to conventional iron and steelmaking processes, but do not eliminate them.

**BF/BOF efficiency**

1. Reducing the use of coal by maximising the iron content in raw materials (i.e., sourcing high quality iron ore).
2. Increasing the use of fuel injection through, for example, Pulverised Coal Injection (PCI), natural gas, biomass, or hydrogen (as an additional reagent on top).
3. Using coke oven gas in the BF as an energy source.

**DRI and EAF optimisation**

Boosting usage of DRI in combination with EAF, because:

- DRI-based reduction emits less CO₂
- than the integrated BF-BOF production method. However, most DRI processes today use unabated fossil gas and hence emit a significant amount of greenhouse gases to the atmosphere.
- DRI-based reduction enables the production of high-quality steel products when highest quality of steel scrap is unavailable or insufficient to use in an EAF-only route.

#### Fuel-switching pathways

These pathways have the potential to eliminate emissions, but it is not a given - the emissions related to the production of the fuel (as in the case of hydrogen) have to be considered.

**Biomass**

Use of biomass as a source of carbon for reduction, instead of coke. Its potential depends heavily on local availability, which is why in Europe it will not likely be enough to reduce emissions at scale. Biomass implementation for steel depends on local availability and competing uses. In addition,
biomass must be sustainably sourced to contribute to decarbonisation.

**DRI and EAF using hydrogen**

Hydrogen direct reduction (H-DR) is considered the most promising technology for steel decarbonisation, when the hydrogen used is “green”, i.e. produced with renewable energy. A less impactful option in terms of emission reductions, but still better than unabated fossil fuels, is to use “blue” hydrogen, which is the name given to hydrogen produced with natural gas and CCS.

Pre & post-process emission pathways

Increase share of scrap-based EAFs

It requires:

- Future supply of renewable electricity to be commercially available.
- Sufficient supply of high-quality steel scrap.

**Carbon capture and storage (CCS)**

The benefits of CCS for steel production are not the same as for cement. As seen in Figure 8 (CCS ladder for 2030), the case for CCS in steel is more compelling for 2030, with its relevance as a decarbonisation pathway diminishing in 2050 in favour of other technologies (in Europe). This is due to the fact that, in the short term, there are less alternatives available for decarbonisation of steel production.

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Figure 8: Carbon Capture and Storage 2030 Ladder. Source: E3G, Bellona (2023).

Nonetheless, CCS can play a role in steel decarbonisation in several ways. Firstly, by capturing emissions from conventional blast furnaces. The chief challenge in this option is the multiple streams of flue gas. The blast furnace itself contributes to 60-70% of emissions in conventional steel making. Top gas recycling, which cycles the CO and H2 from the output of the blast furnace back into it, increases the overall efficiency of the combustion process and produces a purer stream of CO₂, which

---

3 The climate impact of the biomass used must be assessed on a case-by-case basis to ensure that factors such as land-use change are taken into account.
can then be captured\textsuperscript{d}. Given its limited emissions reductions, CCS on conventional blast furnaces may only play a limited role; for relatively new plants that have decades left in their lifespan. CCS could still play a role in DRI as natural gas DRI would still have emissions (~8-28% less than BF-BOF\textsuperscript{4}). For H2-DRI, required demand for hydrogen in the near to mid-term will not be met by green hydrogen due to the large amounts of renewables required. To produce 10 Mt of green hydrogen it would require approximately 500 TWh of renewable electricity, or approximately the total electricity consumption of France in a year\textsuperscript{xli}. Blue hydrogen, which requires CCS, could fill demand in the interim in the event that there is not enough green hydrogen and steel is being produced with fossil gas\textsuperscript{4}.

Carbon capture and use (CCU) was explained in the previous section, and it was compared against the three criteria. The emission reduction potential of CCU depends on energy requirements, CO₂ source, and whether CO₂ is emitted during product use. CCU requires significant investments and partnerships, with only a few projects effectively reducing emissions by utilising carbon without subsequent CO₂ release.

Converting CO₂ into a usable product generally requires a lot of energy (e.g., in the case of chemicals and fuels). In most projects today, the CO₂ is used in products which end up emitting CO₂ during their use or disposal. In those cases, CCU products would, unless they store the CO₂ permanently, incur large energy costs and result in minimal emission reductions.

### 3.2.3. Scraps, recyclability, other considerations

Steel is a highly recyclable material, with over 90% of the end-of-life stainless steel being recycled in 2015 in the EU. Recycling steel uses 72% less of the energy needed for primary production. In addition, it does not require the same amount of raw materials (14 tonnes of iron ore, 0.8 tonnes of coal, 0.3 tonnes of limestone are ‘saved’ per tonne of steel recycled). It also emits much less greenhouse gases compared to the conventional steelmaking process (approximately 1.67 tonnes of CO₂ less per tonne of recycled steel\textsuperscript{li}).

Steel recycling, also known as secondary steel making, amounts to 50% of total EU steel production. Over time, this share can be increased; however, there is a limitation (varying across different models) to how much scrap steel will be available. In addition, for high-quality demanding applications, impurities in scrap steel must often be diluted with new primary steel\textsuperscript{lii}. Decarbonisation efforts in steel cannot rely on recycling alone.

The recycling of steel faces challenges due to incomplete separation, complex product design, and inadequate recycling technologies\textsuperscript{lii,liii}. Steel is often combined with other metals and materials, resulting in the accumulation of impurities like copper and tin during each recycling cycle. Overcoming these challenges requires improved sorting of metal waste and innovative purification methods to remove contaminants and enhance the quality of recycled steel. These efforts are essential for advancing steel recycling and achieving higher levels of purity in the recycled steel output\textsuperscript{lii}.

On another note, an additional potential decarbonisation pathway which is currently being researched is Molten Oxide Electrolysis (MOE) applied in steel production. This electrometallurgical production method enables the direct production of liquid metal from its oxide, and it’s considered a promising route for CO₂ emissions mitigation\textsuperscript{lv}. It hasn’t been assessed in this report due to the need to find non-consumable anode materials that sustain oxygen evolution. While research on this field make progress by the day, it is still in too early a development stage for it to be analysed using the 3-criteria approach in this report.

### 3.2.4. Conclusions

The pathway chosen to decarbonise steel production will depend on a few key factors, including the existing technologies of the plant and local resource availability.

While there are of course several considerations when it comes to upgrading or replacing a plant technology, and there is not a “one-size-fits-all” solution, several of the mentioned pathways have a big potential to reduce emissions. The table below analyses these solutions against the three criteria, and aims to find the best-case scenario for steel decarbonisation.

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4 These figures have been calculated with the referenced numbers above as input.
Table 6: Assessment of decarbonisation pathways of the steel industry against the 3 criteria.

<table>
<thead>
<tr>
<th>Decarbonisation pathway</th>
<th>The Bellona criteria</th>
<th>Timeframe</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BF/BOF efficiency</strong></td>
<td>This pathway has a positive, though fairly limited, effect on emissions reductions. Putting the focus on improving BF/BOF systems reduces the incentive to switch to more efficient technologies and maintains dependence on fossil fuels.</td>
<td>Ready for implementation in the short term.</td>
</tr>
<tr>
<td><strong>DRI and EAF optimisation (using natural gas)</strong></td>
<td>This pathway has a positive, though fairly limited, effect on emissions reductions, as it still uses fossil gas. The dependence on natural gas within the EU reduces the industry's resilience and autonomy.</td>
<td>Ready for implementation in the short term.</td>
</tr>
<tr>
<td><strong>Fuel-switching to biomass</strong></td>
<td>This pathway has the potential to eliminate emissions, as long as biomass is sustainably sourced. Competing uses, local availability, high storage capacity needed due to low energy-density.</td>
<td>Ready for implementation in the medium term, when the necessary infrastructure adaptation projects (e.g., facilities to store and treat biomass) have been completed.</td>
</tr>
<tr>
<td><strong>DRI and EAF using hydrogen</strong></td>
<td>This pathway has the potential to eliminate emissions, when using green hydrogen, and heavily reduce them, when using blue hydrogen. The renewable energy needed to produce green hydrogen is not additional to the renewable electricity deployed to decarbonise the electricity grid. Deployment of blue hydrogen has similar trade-offs as CCS as a steel decarbonisation technology.</td>
<td>While the technology for hydrogen production exists, hydrogen with a low climate impact is not available at scale yet.</td>
</tr>
<tr>
<td><strong>Increase share of scrap-based EAFs</strong></td>
<td>This pathway has a positive, though limited, effect on emissions reductions. Availability of high-quality scraps is decreasing, so virgin steel would need to be part of the mix to produce quality products, which decreases the effectiveness of the method. Important to note where the electricity comes from. Use of renewable electricity is preferred, especially if additional sources are deployed. If not additional, there is a risk that renewable resources to decarbonise the grid are not available.</td>
<td>This solution is feasible in the short-medium term and will play an important role in the transformation of the sector. However, constraints might include the availability of renewable electricity and in the long-term, the limited availability of quality scrap.</td>
</tr>
<tr>
<td><strong>Carbon capture and storage (CCS)</strong></td>
<td>CCS has a positive and large impact on emissions reduction, as emissions are captured and stored permanently in geological storage sites. However, its climate benefit depend on which production technology it is applied. It can be done on natural gas-based DRI, with limited potential for reducing emissions in BF-BOF. It is not applicable in scrap-based EAF or green hydrogen-based DRI-EAF. CCS requires very high investments and international collaboration. Final product costs are bound to increase. Storage capacity will be shared with other industries.</td>
<td>While the technology exists and projects are being developed, the magnitude and international characteristics of CCS make implementation complex. Current EU policy aims to accelerate CCS deployment. Some CCS projects are expected to be running by 2026; however, global implementation is still far from a reality. Lead market development is needed for at-scale deployment.</td>
</tr>
</tbody>
</table>
This analysis shows that several solutions will play a role in decarbonising iron and steel making and that the starting point of the steel production plant determines which pathways could be taken, and when. Ideally, the BF/BOF route will be entirely rid of fossil fuels while still functioning, looking to transition to DRI and EAF.

The transition to a cleaner industry involves more than just changing the fuel source; it necessitates investments in completely new production facilities. Shifting to Direct Reduced Iron (DRI) production and utilising renewable hydrogen as a reducing agent in primary steel manufacturing can result in a substantial reduction of greenhouse gas emissions –potentially up to 95% compared to the traditional blast furnace route emitting around 1.85 tonnes CO₂ per tonne of steel. The potential of hydrogen to decarbonise the European steel industry is significant, but it requires a rapid expansion of renewable electricity capacities to enable the widespread production of green hydrogen. Therefore, being conscious of the challenges associated to hydrogen production, to achieve emission reductions, it is advisable to combine hydrogen with other solutions, like reducing steel use as much as possible in favour of less carbon-intensive alternatives, increasing steel recycling, and carbon capture and storage where appropriate.

After a detailed analysis, it becomes clear that the solution will be a mix of DRI, EAF, CCS – and potentially molten oxide electrolysis, depending on what resources are available, and when.

Steel emissions can be completely eliminated by switching to electrified processes. However, the high amount of clean electricity needed to truly decarbonise makes imperative to consider a mix of alternatives.

More information on this topic can be found here: Bellona’s article on hydrogen’s role in steel.
4. CURRENT USES OF THE TERM ‘LOW-CARBON’

4.1. What others define as low-carbon

As addressed, subjectivity is rife when it comes to these definitions, with them differing across stakeholders. Here, this study therefore looks at some other stakeholders’ and evaluates these vis-a-vis the 3 criteria used to analyse the technologies.

4.1.1. Cement and concrete

Cement industry

The cement industry is composed of numerous players of all sizes, from multinational companies to Small and Medium Enterprises (SMEs). For this study, we have selected the two largest cement companies in Europe by market cap as of December 2022, Holcim LTD and Heidelberg Materials (formerly Heidelberg Cement) and the European Cement Association, CEMBUREAU, which is the representative organisation of the cement industry in Europe. Academia’s perspective is also included. The objective is to have an overview of how “low-carbon cement” is understood by major market players, and identify gaps in understanding that need to be remedied to drive effective decarbonisation forward. Definitions of “low-carbon concrete” are also presented (though not assessed later in detail).

- **Holcim**

Low-carbon concrete product, called ECOPact, produces 30% less emissions than standard concrete, while maintaining the same level of performance. If regulation allows, it may also include recycled construction and demolition waste. It is made from a mix of supplementary cementitious materials (SCMs) and admixture technology.

Low-carbon cement product range, called ECOPlanet, also achieves 30% less CO₂ emissions compared to ordinary Portland cement (OPC). It includes 20% of recycled construction and demolition materials.

Their Portland Limestone Cement that they produce in the US, which could offer up to 10% less CO₂ emissions, is also referred to as low-carbon.

They also claim to have a carbon-neutral concrete, called ECOPact Zero, which includes clinker-reduced cements and optimised mix design based on binder content. Process related emissions are not captured and stored geologically but rely on offsetting schemes.

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**Disclaimer:** the information presented from the selected stakeholders is publicly available online, in their respective websites.

**Claiming climate neutrality when there is offsetting of emissions is strongly discouraged. “The trading of reductions via offsetting may result in a responsibility being fulfilled on paper, but does not change the fact that carbon is still being emitted to the atmosphere”** (Source: The Carbon Credits Conundrum, Bellona).
As of February 2023, as part of the ECOPlanet portfolio, they have a new product of calcined clay cement that achieves 50% lower CO₂ footprint when compared to OPC. Operations are powered by 100% biomass-based alternative fuels and waste heat recovery systems.

- **Heidelberg**

While Heidelberg has invested in decarbonisation pathways, the projects have not produced any low-carbon products yet. The investment made until this point is on two different pathways: calcined clay cement, and CCS. They are also putting a focus on CCU.

They have a “criteria for sustainable products” where low-carbon cement and concrete is that that achieves 30% less CO₂ (vs. CEM I in 2020) in the case of cement, and 30% less CO₂ (vs. CEM-I-based concrete in 2020) in the case of concrete.

On their portfolio, they have 4 low-carbon products:

- EcoPlus (60% CO₂ reduction, with the use of slag, GGBS)
- Ecocrete (70% CO₂ reduction, with the use of up to 100% recycled aggregate)
- Nor Lavkarbon (20% CO₂ reduction, with the use of fly-ash)
- Green Concrete (45% CO₂ reduction, with the use of reduced, specified cement percentage substituted with residuals and by-products like slag).

- **CEMBUREAU**

CEMBUREAU, as an association and not a manufacturer, instead of defining low-carbon products, provides a list of low-carbon technologies. These technologies are:

- carbon capture, utilisation and storage (CCUS),
- circular use of waste,
- 3D printing,
- recarbonation.

**Academia**

Low-carbon cement are cited commonly when the composition is different: it is either a product with lower clinker-to-cement ratios or with a different (lower carbon) chemistry, usually blended cements consisting of calcined clays, with some references to sulfoaluminate cements and cement with CCS technologies.

As an example, one of the mentioned research papers refers to the general standards set by the World Business Council for Sustainable Development (WBCSD) and the International Energy Agency (IEA) for the decarbonisation of the cement industry. On that basis, it applies four principles to assess CO₂ reductions in cement-based composites, and refers to low-carbon cement as one that performs well on these four aspects:

- Use of low-heat firing in order to mitigate power consumption during production.
- Use of low-carbonate minerals as raw materials to avoid CO₂ emissions directly (e.g. by the addition of SCM's).
- Application of low-calcium clinkers.
- Enhancement of the life cycle of cement composites, including performance enhancement and durability.

It is worth noting that this list only includes pathways that are available now, and that in the future it could be expanded to include cement produced with CCS technology.

Low-carbon concrete is generally referred to when it includes recycled materials, waste from other industries (GGBFS, fly-ash), and/or high volume of SCMs. It is important to note that waste products from other industries are not generally considered carbon neutral (e.g., GGBFS has a carbon intensity of 83 kg CO₂ per tonne of material).
4.1.2. Steel

Steel industry

For steel, even though there seems to be more of a general consensus among industry players about the decarbonisation pathway to follow (a transition towards hydrogen-based DRI and EAF), currently there are not many available products labelled or referred to as low-carbon other than recycled steel (which still needs to account for the energy-related emissions associated with transport and the energy used in the EAF process). Some of the definitions used by biggest steel manufacturers are outlined, together with the European Steel Association and a sample of peer-reviewed research papers.  

◆ Tata Steel

Tata Steel plans to transition into producing “green steel”, mainly by eventually switching to H2-based DR. In the meantime, they offer a range of “green steel solutions”, such as Zeremis® Carbon Lite, which is a “certificate-based, low carbon emission steel solution offering the potential for up to 90% reduction in CO₂e intensity”.

◆ ArcelorMittal

ArcelorMittal claims to have several projects that contribute to “CO₂ savings” in steel, which would enable them to sell “green steel credits” for their flat steel products made from iron ore in a blast furnace. These CO₂ savings come from steel produced using one or several technologies: mostly involving green hydrogen for both blast furnaces and DRI-EAF, but also CCU and biomass.

◆ Thyssenkrupp

Thyssenkrupp also uses the term of green steel to refer to steel produced with green hydrogen. While not directly using the term “low-carbon”, the company does present a CCU project that recycles emissions, and a steel product called bluemint® that is less carbon-intensive due to alternative iron carriers in the blast furnace that reduce the amount of coal needed.

◆ EUROFER

EUROFER, the European steel association, presents a map of “low-carbon emissions projects”. Projects that include circular economy considerations, H2 or electricity-based metallurgy, carbon usage or CCS are all listed, but there is no standard when it comes to the definition of low-carbon steel, or the emission reductions necessary to qualify as such.

Academia

In academia particularly, the term “low-carbon steel” could lead to misunderstandings. Throughout this work, the term “low-carbon” is used to signal a production process with significant CO₂ emission reductions when compared to the standard production method. However, when it comes to steel chemistry, since steel is an alloy of iron and carbon, the term low-carbon could be used to refer to a steel type with actual low contents of the element carbon (C), known as ferrite steel.

Papers researching steel with less carbon-intensive production processes generally use the term “green steel”. Some of them used it to only mean steel produced with green hydrogen, while others use the term “low-carbon steel” in the sense of emission reductions and include blue steel (with CCS) and brown steel (with biomass). It is worth noting that the latter study does not refer to European industry but global, with a focus on developing countries.

One especially interesting piece of research interviewed “key industry stakeholders” asking them what they understood of the term “green steel”. According to the study, “participants had a converging, yet imprecise, overall concept of what ‘green’ means for steel as a product. All interviewees considered the carbon footprint, or the ‘embodied carbon content’, as a primary – and at times sole – factor for how green (or non-green) a steel product is. However, some interviewees argued that ‘greenness’ implies more than just lower GHG emissions, with the term ideally encompassing other aspects such as material use efficiency, water...”.

Disclaimer: the information presented from the selected stakeholders is publicly available online, in their respective websites or the cited publications.
The same study defines green steel as that “produced by less GHG-intensive production processes”, including carbon capture, utilisation, and storage (CCUS), hydrogen or biomass as reducing agents, and electrolysis (MOE).

4.2. Assessing the definitions
There is a clear lack of general agreement when it comes to defining low-carbon materials.

4.2.1. Cement
For the cement industry, low-carbon cement is generally understood as one that produces less CO₂ emissions than conventional cement (OPC), by undertaking any (or several) of the decarbonisation pathways explored in section 3.1.2. Decarbonisation pathways for the cement industry and analysed in section 3.1.4. Conclusions. There is no set floor of reductions, though the lowest reduction observed for a so-called “low-carbon cement” is 10% less emissions than OPC. “Low-carbon concrete” would be one that uses low-carbon cement, and/or includes recycled materials as aggregates.

While the production of less carbon intensive cements is good news, ambitions on emission reductions should be high in order to achieve the sector’s decarbonisation needs. In order to drive progress within the industry, a certain threshold of reductions should be achieved. While it is not the aim of this work to provide a quantitative answer to the question of what the threshold should be, it does aim to provide a common ground of understanding as to what considerations should be taken in order to establish it.

The definition of low-carbon cement and concrete should not be a “static” one, but one that evolves as the industry progresses. One interesting methodology, similar to what Building Transparency showcases via the use of its Embodied Carbon in Construction Calculator (EC3) tool\textsuperscript{xci}, is to promote the 20% best-in-class (in terms of embodied carbon of the product). That way, there would be an incentive for the industry to keep evolving. Nevertheless, this approach fails to consider what are the emission reductions that the industry needs to achieve climate neutrality for 2050. Another way of approaching it would be to set thresholds based on the sectors’ “carbon budget” to be compatible with the Paris Agreement, and therefore limit global warming to 15 degrees. This carbon budget should be set at every level: from clinker production to cement, from concrete to building.

An evolving definition for both cement and concrete would promote the uptake of some of the decarbonisation pathways: lower clinker-to-cement ratios, use of lower-carbon chemistries, and the development of CCS for the cement industry.

In any case, an evolving definition should also include quantitative thresholds of embodied carbon content, that would be decreasing as decarbonisation in the industry progresses. Having a quantitative unit would enable policymakers to set limits on embodied carbon in buildings (either by setting a max; CO₂ value per square metre, max; CO₂ content per unit of a product/material, or a combination of the two thresholds), and include criteria that drives down emissions in public procurement processes, enabling the creation of lead markets for low-carbon products. Measures to improve data collection processes on embodied carbon, which encounters several challenges in the EU, must be undertaken\textsuperscript{xci}.

4.2.2. Steel
For the steel industry, there seems to be even less consensus on a definition, and more confusion around the terms “low-carbon steel” and “green steel”.

Therefore, it is extremely important for all stakeholders involved that whenever the term “low-carbon steel” is used, it is clarified whether it refers to a steel product with a low content of the element carbon, or to a steel product with a low embodied carbon content in the context of emission reductions.

Similarly, when the term “green steel” is used, it must be clarified whether this term implies the use of any (or several) of the decarbonisation pathways presented in section 3.2.2. Decarbonisation pathways for the steel industry, and which one(s); or in turn it is used to mean that the product was produced using green hydrogen in the DRI-EAF production process. The denomination of “green” applied to the hydrogen produced with renewable energy may lead to confusion when the term “green steel” is used, especially when the use of green H2-based DRI systems is more widespread.
At the same time, the term “sustainable steel” is generally used in a broader sense than just emission reductions, including energy and resource efficiency, circularity and reduction of other pollutants.

In any case, when stakeholders refer to less carbon-intensive products, whatever the term used to define it, they do not generally mean the same, as seen in the definitions above. They include H2-based DRI, carbon credits certificates, use of biomass, CCS, and CCU.

In the same way as the cement and concrete industry, a low-carbon definition for steel must be an evolving one. The definition should cover steel made with less carbon-intensive production methods that effectively drive down emissions, such as clean hydrogen-based processes, scrap-based processes, and carbon capture and storage where and when appropriate. Biomass and CCU projects should be analysed in a case-by-case basis, and appropriate carbon accounting must be carried out to ensure that it actually serves a decarbonisation purpose, and is not merely a tool for delaying emissions. And even though carbon credits certificates have their role to play, a low-carbon steel claim must not be based in offsetting mechanisms. A mass balance approach with free allocation of credits with the purpose of making claims should be avoided, as this does not reflect the embodied carbon of the product and therefore may lead to misinformation and greenwashing, and even become detrimental to decarbonisation efforts in the industry.

4.2.3. Remarks

A low-carbon material definition must be based on embodied carbon considerations. For both the cement and concrete industry and the steel industry, determining progressively tightened embodied carbon thresholds would enable swifter progress in the decarbonisation of these industries.

While defining low-carbon materials correctly is an important step that would enable important decarbonisation mechanisms (such as lead markets for low-carbon products), it is not enough to drive full decarbonisation of the building sector: material efficiency strategies are also needed, in particular at a building level. As presented in section 2.1 Climate technology assessment criteria, it is also important to keep the end goal in sight: the overall decrease of emissions at a system-level. The total climate impact of the building sector must be decreased, not only of its building blocks.
5. EU Policy on Embodied Carbon

5.1. EU policy context

Embodied carbon has been moved up the EU’s agenda through the European Green Deal. This initiative from the European Commission describes the actions needed to achieve a climate transformation of European society and the economy toward 2030 and climate neutrality by 2050. The building and construction sector is here designated as one of seven priority areas, on the basis of its large climate footprint and thus associated potential for emission reductions.

One of the measures within Europe’s Green Deal is the Renovation Wave (‘A Renovation Wave for Europe’). This is not a legislative proposal, but it sets out seven main principles for which the EU must work in relation to the building stock: energy efficiency, affordability, decarbonisation and the inclusion of renewable energy, life cycle thinking and circularity, high health and environmental standards, green and digital transformation, and architecture with natural building materials (“Bauhaus”).

Another measure within Europe’s Green Deal is Fit for 55. This package consists of a set of interrelated legislative proposals, all of which aim to ensure a fair, competitive and green transition by 2030 and beyond. Where possible, the level of ambition of existing legislation is strengthened, such as the emission trading system (ETS), the renewable energy directive (RED) and Energy Efficiency Directive (EED). And where there is a need for new legislation, such proposals are put on the table, such as the Carbon Border Adjustment Mechanism (CBAM). Overall, the Fit for 55 package strengthens eight existing pieces of legislation and presents five new initiatives, across a range of policy areas and economic sectors covering climate, energy and fuels, transport, buildings, land use and forestry.

Last, but not least, we will highlight the EU’s Circular Economy Action Plan. Here, the European Commission has presented a number of initiatives, with an ever-expanding scope. Originally the focus was on resource extraction and waste, but the topic now also covers hazardous substances, resource efficiency and an action plan for the goals in the above-mentioned Green Deal.

Within the circular economy action plan we find, among other things, the Sustainable Products Initiative (SPI), which is intended to establish sustainability principles to regulate, among other things, durability, reusability, repairability, hazardous chemicals, energy and resource efficiency, carbon and environmental footprints, digitisation of product information, including digital product passports. Both the Ecodesign for Sustainable Products Regulation (ESPR) and the Construction Products Regulation (CPR) are relevant here. The following section dives deeper on these two files and the role they play in reducing emissions from the building sector.

Green public procurement is also an important element of creating demand for low-carbon products. Here, the EU’s Public Procurement Directive is the core of the regulations, but in the ongoing revision processes (for example the CPR) there are proposals to include specific requirements for green procurement in several sector-specific regulations.
5.2. Most relevant EU policy files

With this as a backdrop, the EU has initiated a revision of a number of pieces of legislation that deal with buildings and building materials, with the aim of updating these in accordance with the climate targets and these designated focus areas. One such aspect involves reducing the footprint of building materials by strengthening the legislation around embodied carbon. Measures with such relevance can be found in the following ongoing initiatives:

Revision of the Energy Building Directive (EPBD) – ongoing
Revision of the Construction Products Regulation (CPR) - ongoing
Revision of the Ecodesign Directive (turning into a Regulation) (ESPR) - ongoing
Update of the taxonomy’s requirements regarding buildings and property - ongoing


The EPBD is the cornerstone of European legislation aimed at transforming the construction sector. The EPBD was first adopted in 2002 and has been through two revisions, in 2010 and 2018, before the current ongoing revision. The aim of this EPBD revision has been to accelerate the decarbonisation of buildings by setting higher energy performance standards, promoting the use of low-carbon building materials, and adding the right to renovations that reduce both operational and embodied carbon.

5.2.2. Construction Products Regulation (CPR)

The Construction Products Regulation (CPR) is a European Union (EU) legislation that establishes harmonised rules for the marketing of construction products within the EU. It aims to ensure the reliability of information about the performance of construction products and their conformity with essential characteristics, allowing for fair competition and the free movement. The CPR also introduces the CE marking system, which is affixed to construction products that meet the CPR requirements. The CE marking signifies that the product can be legally placed on the EU market. The CPR is undergoing a revision which aims to improve the regulation’s general functioning as well as the environmental provisions.
5.2.3. Ecodesign for Sustainable Products Regulation (ESPR)

The Ecodesign Directive, which is now undergoing a revision that will also change the directive to a regulation, is an umbrella law that aims to cover all products that are not covered by a sector-specific piece of legislation (such as the Construction Products Regulation for construction products). The ESPR aims to promote the circular economy and reduce the environmental impact of products.

5.3. Other EU policy files of relevance

Embodied carbon-relevant policies are also found in a number of other EU legislation. Here we summarise a few of them and how they could impact embodied carbon.

5.3.1. Public Procurement Directive

In the EU today, Green Public Procurement (GPP) is mostly voluntary, with the exception of a few sector-specific mandatory requirements. It is the EU directive on public procurement (Directive 2014/24/EU) that sets out procurement rules and guidelines, with the overall aim to promote fair competition and transparency across the Union. The procurement directive's voluntary approach to GPP is complemented by some voluntary guidance criteria for sectors that are deemed of particular importance to GPP, such as construction and transport.

The procurement directive has been periodically updated (last time in 2014) to reflect changes in technology, market conditions, and policy objectives. And in 2020 the New Circular Economy Action Plan stated that the Commission is to propose minimum mandatory GPP criteria, though it falls short of saying how and when this will be done.

5.3.2. Taxonomy

The EU Taxonomy sets requirements for environmentally sustainable buildings, including energy efficiency, emissions, resource use, and climate adaptation. Criteria cover aspects like building performance, energy consumption, renewable energy, water, and waste management. Lifecycle assessment evaluates overall environmental impact, considering embodied carbon, operational energy use, and material recycling. Primarily targeting investors and asset managers, the EU Taxonomy supports sustainable investments, promotes green building practices, and reduces the construction sector’s environmental impact, driving investment towards sustainability.

5.3.3. Net-Zero Industry Act

The ongoing negotiations of the Net-Zero Industry Act (NZIA) aim to facilitate the deployment of climate-related technologies in order to achieve net-zero emissions in the EU by 2050. The act seeks to expedite the permitting process for net-zero technologies to align with climate timelines. Additionally, the proposed regulation supports the European Just Transition agenda by emphasising the development of skills and the creation of sustainable jobs for a net-zero future.

The European Commission’s proposal includes strengthening green public procurement (GPP) to establish leading markets for net-zero technologies. However, there are three key areas of improvement that negotiators can focus on, particularly in relation to embodied carbon. Firstly, the proposal lacks a definition of “environmental sustainability” and fails to mention “emission reduction” as a criterion in public tenders. Secondly, the weighting of sustainability and resilience criteria in public tenders should be increased, with a suggested minimum of 25% rather than the proposed 15% by the Commission. Lastly, as the NZIA is highly relevant to materials with significant carbon footprints like steel and cement, the procurement of lower-carbon alternatives for these materials should be explicitly addressed in the text.

5.3.4. ETS for buildings

The EU Emission Trading Scheme (ETS) is a cornerstone of the European Union’s policy to combat climate change and reduce greenhouse gas emissions. It is the largest “cap and trade” emissions trading system in the world and covers various sectors, including power generation and manufacturing.

Under the ETS, a cap is set on the total amount of greenhouse gases that can be emitted by installations (such as power plants and factories) covered by the scheme. This cap decreases over time, ensuring a gradual reduction in emissions. Each installation receives emission allowances, which represent the right to emit a specific amount of greenhouse gases. These allowances can be bought, sold, or traded among participants.

The relevance of the EU ETS for buildings directly, primarily lies in operational emissions as
the scheme covers the power generation sector: Buildings are major consumers of electricity, and the emissions resulting from electricity generation and use (operational carbon) contribute to the overall carbon footprint associated with buildings. In late 2022 the EU agreed a new “ETS II” where, among other things, a separate ETS for road transport and buildings was established, covering car users and households by regulating the fuel distributors.xcv.

This latest update to the ETS also entailed changes. Emissions in the ETS sectors must now be cut by 62% by 2030 and free allowances to industries are to be phased out from 2026 and fully phased out entirely by 2034. This will naturally impact manufacturers of construction products such as cement, steel and aluminium, who will need to take enhanced measures to cut emissions.

However, with the phase-out of free allowances there would be increased concerns for EU industry competitiveness, and for the risk of carbon leakage. This is mostly addressed by the Carbon Border Adjustment Mechanism (CBAM), which is explained in the following section.

5.3.5. Carbon Border Adjustment Mechanism (CBAM)

The CBAM is a tool which aims to address potential carbon leakage by equalising the carbon price of carbon-intensive imported goods, to the ones produced in the EU. Under the CBAM, EU importers of goods at high risk of carbon leakage will need to buy a carbon certificate corresponding to the same amount of money that a local producer would pay under the European Trading System (ETS). By doing so, this instrument not only tries to favour low-carbon production in the EU, but it also tries to increase climate ambition worldwide, in light of carbon leakage risks.

The new CBAM regulation can affect embodied carbon as it covers sectors such as cement, iron and steel, and aluminium, which are crucial for the building and construction sectors. As it aims to incentivise the use of lower-carbon alternatives in construction or manufacturing processes, the CBAM will have an influence in the choice of materials and their carbon alternatives.

5.3.6. Green Claims Directive

The Green Claims Directive is a legislative proposal by the European Commission that aims to promote transparency of environmental claims to prevent greenwashing. It includes establishing explicit criteria for companies to substantiate their environmental claims and labels, mandating that these claims and labels undergo verification by an independent and accredited verifier, and implementing enhanced governance rules for environmental labelling schemes to ensure their integrity, transparency, and reliability.xcv.

While it does not tackle embodied carbon directly, it could still be a tool against greenwashing in construction products, ensuring that low-carbon claims are substantiated by data on lifecycle emissions. It aims to tackle “barriers to boosting the potential of green markets in the EU through consumer empowerment”, so it could be a tool to promote the development of lead markets for low-carbon construction products.

5.4. Potential outcomes of EU policy revisions

In this section, we’ll first consider potential outcomes of the aforementioned ongoing EU policy revisions, before also considering how these revisions could impact key stakeholders. These stakeholders include investors, building owners and developers; architects and designers; product and material manufacturers; contractors; and politicians and decision-makers.

It is impossible to predict with accuracy what consequences these ongoing initiatives will have, partly because it remains to be seen how they will be implemented in the member states and how the various initiatives will affect and interact with each other. Not to mention, the legislative processes themselves will have to be concluded before we know exactly what we have to decide on. However, we can already draw some general and likely conclusions about possible effects:

The renovation rate will increase. As the requirements become stricter, for example building owners will have to refurbish and achieve certain certification requirements in order to be allowed to continue, for example, to continue renting. The current annual renovation rate in the EU is 0.2%, but if the EU’s climate goals are to be reached, this must be up to 3% annually by 2030 and maintained at this level until 2050.xcv Another likely consequence is that we will see less new construction in favour of more renovation.

Costs will go up. Building owners will have to build and renovate according to stricter documentation requirements as well as, for example, reinforced product requirements, for example in relation to climate footprints. For material producers, one will have to invest in decarbonisation of the production line, for example by switching to input factors with a lower climate footprint or, where this is not possible, use carbon capture and storage (CCS) to overcome process emissions. This could increase the costs of the product.
itself, but for an entire project it will only increase the costs marginally (e.g. the construction of a concrete bridge using CCS only increases the total cost by 1%, while cutting CO₂ emissions by 5%⁶⁸vii).

New and increased support schemes for renovations and climate measures. Renovation financing has received increased interest from the EU and the European financial institutions (e.g. the EIB), as appropriate financing flows and well-tailored financing mechanisms are essential to speed up large-scale renovations, thereby helping to achieve the 2030 and 2050 targets. The European Commission has launched a number of financing initiatives such as Smart Finance for Smart Buildings (SFSB) as well as requirements that financial support be linked to documented energy savings (EPBD)⁶⁸viii.

We build less, smaller and for increased sharing. There is often some focus on larger buildings, but 75% of the floor area in Europe is private homes⁶⁹viii. Within the remaining 25%, there is great variation, with approximately half being commercial buildings and the rest including everything from public office buildings and health institutions to industrial facilities and warehouse buildings. Public buildings make up a relatively small proportion of the building stock.

New business opportunities and revenue streams. New business opportunities may arise for wholesalers and contractors in circular construction through, for example, “smart demolition”, where entire building parts can be retrieved from a demolition site by dismantling the building in a way that allows these parts to be reused. As we know from the waste hierarchy, a wooden frame will have greater value than the wood it is made from and should therefore be preserved as much as possible. Increased reuse will result in lower sales of new building materials, which reduces the amount of embedded carbon.

New business models. Business models within the construction industry will have to be further developed to adapt to more sustainable operations. This will affect all actors throughout the value chain. For example, increased data availability represents another new opportunity, as more and more data is collected and made available. The EU’s Building Stock Observatory (BSO) collects data on all building typologies across the EU; while national databases on energy performance certificates (EPCs) will provide up-to-date information on the performance of buildings that are sold, rented or that have undergone major renovations. Data can, for example, be used to assess the achievement of goals, compare different countries, regions and building types, and monitor the effectiveness of policies and financial instruments⁶⁹viii. It could also potentially be used to spur on new value-chain models.

**These changes will affect a number of stakeholders:**

For investors, building owners and developers: There will be an increased focus on embedded carbon in construction and renovation projects, which will give an increased understanding of the climate footprint of their buildings and opportunities to reduce this. This may result in increased costs in relation to planning and procurement of materials, but in the long-term, drive forward markets and increase the availability of building materials with a lower carbon footprint. It can also ensure that tenants want to rent the building.

For architects and designers: it is currently architects and designers who are leading the way in efforts to reduce the carbon content of building materials, by seizing the opportunity to design with innovative materials, facilitate increased reuse and rethink both design and construction processes. Architects and designers will have to make choices about new construction vs renovation, design buildings that can change the type of use more easily, ensure that building parts can be dismantled and reassembled, plan for more sustainable construction methods and the use of more sustainable materials, as well as design aesthetically valuable buildings that we want to provide a long life.

For product and material manufacturers: In particular, the Construction Products Regulation (CPR) and the Ecodesign Regulation (ESPR) may set requirements to improve the climate footprint of materials, such as cement and steel and products such as windows. Requirements to reduce the content of embedded carbon can lead to changes in production processes. For example, CCS will be necessary to manage process emissions from cement production, in addition to new mixing materials for concrete. The competitiveness of innovative manufacturers with low-carbon solutions will increase. This places higher demands on product and material manufacturers to adopt new methods and materials with a lower climate footprint, as well as more reused and recycled materials. There will also be increased documentation requirements, for example in the form of product passports. Both manufacturers and contractors may have to deal with new players in the value chain, for example those who specialise in trade in reused building materials or in “smart demolition/disposal”.

For contractors: Contractors will have increased tasks in ensuring that construction projects meet sustainability requirements. They will also have
to work proactively with suppliers to ensure that
tenders meet higher sustainability requirements.
This places higher demands on knowing and
adopting more sustainable production methods
and materials. They will also have to adapt
production to increased use of recycled and
reused materials, for example types of concrete
that need different curing conditions, which
could affect the entire construction process.

For politicians and decision-makers: The
revisions increase the pressure on the Norwegian
authorities to prioritise embedded carbon
emissions in building regulations and provide
increased support for sustainable building
practices. In addition to this, it also increases
the pressure to keep up with EU legislation. For
example, Norway has not yet introduced the
previous (third) revision of the EPBD, which came
in 2018, and thus puts Norwegian companies in
a situation where the second version of the EPBD
may be applicable when European competitors
relate to the (upcoming) fourth version. This
could have adverse consequences for Norwegian
competitiveness, especially for innovative SMEs.

5.5. Standards and the
standardisation process

The standardisation process involves the
development and establishment of technical
standards that ensure products, services, and
processes meet certain requirements for safety,
compatibility, and quality. The process for making
European standards involves the collaboration
of various stakeholders, including industry
representatives, consumer organisations,
national standardisation bodies, and other
relevant parties, such as civil society (represented
by ECOS). The European standardisation
system is primarily coordinated by the European
Committee for Standardisation (CEN) and
the European Committee for Electrotechnical
Standardisation (CENELEC).

5.5.1. The standard-making process
in short

A European standardisation process usually
looks something like this:

1. Identification of the need: The process starts
with identifying the need for a new European
standard. This can be initiated by industry
associations, national standardisation bodies,
or other interested parties. They submit a
proposal outlining the scope and purpose of
the standard.

2. Preparatory work: Once the need for a
standard is identified, a Technical Committee
(TC) or a Working Group (WG) is established
within CEN or CENELEC to handle the
standardisation process. The TC/WG
consists of relevant experts from member
countries who are interested in contributing
to the development of the standard.

3. Drafting the standard: The TC/WG members
collaborate to develop the draft standard.
They review existing national standards,
international standards, and other relevant
documents to ensure consistency and avoid
duplication. The drafting process involves
discussions, consultations, and consensus-
building among the members.

4. Public Enquiry: Once the draft standard
is ready, it is published for public enquiry.
This allows interested parties, including
organisations and individuals, to provide
comments, suggestions, and feedback on
the proposed standard. The public enquiry
period typically lasts for a specified period
(e.g., several months).

5. Consensus and approval: The comments
received during the public enquiry are
carefully considered by the TC/WG members.
They may revise the draft standard based
on the feedback received. The goal is to
achieve consensus among the stakeholders.
Once consensus is reached, the final draft is
submitted for formal approval.

6. Formal Approval: The final draft standard is
submitted to CEN or CENELEC for formal
approval. The standard undergoes a final
review process to ensure compliance with
the organisation’s requirements. If approved,
the standard is published and made available
to the public.

7. Implementation and adoption: After
publication, the European standard can be
implemented voluntarily by organisations,
or it may be referenced in legislation to
become mandatory in specific areas. The
member countries of CEN and CENELEC are
encouraged to adopt the European standards
as national standards, thus promoting
harmonisation across Europe.

As can be gathered by this step-by-step, there
are two major weaknesses with this process: First,
that it is time-consuming, often taking 3-5 years,
and secondly, that the stakeholders involved are
limited. The time it takes to make a new standard
can have detrimental effects on innovation,
which can negatively impact the development
and market-entry of lower-carbon products. By
the time a standard is done, available technology
may have already moved far beyond it. The fact
that the stakeholders who are involved in the
standard-making process is limited means that
large, incumbent industry representatives can
have an undue say over what the outcomes are, again to the detriment of smaller, newer and potentially more innovative and climate-friendly solutions.

5.5.2. Harmonised vs non-harmonised standards

There are two main types of standards in Europe: harmonised and non-harmonised standards. In short, harmonised standards are directly linked to EU legislation and provide a means for demonstrating compliance with EU requirements, while non-harmonised standards are voluntary and serve as industry-specific guidelines or best practices but do not have a direct legal relationship with EU law.

Harmonised Standards: Harmonised standards are developed under the European Standardisation System and are linked to European Union (EU) legislation. They are designed to support the implementation of EU Directives and Regulations that aim to harmonise technical requirements across member states. Harmonised standards provide a presumption of conformity with the relevant legislation when followed. Manufacturers can use harmonised standards to demonstrate that their products or services meet the essential requirements set out in EU law. Harmonised standards facilitate the free movement of goods and services within the EU’s single market by ensuring a common baseline of technical requirements.

Non-Harmonised Standards: Non-harmonised standards, also known as voluntary or national standards, are developed by standardisation bodies at the national or international level, such as national standards organisations or international standards development organisations like ISO (International Organisation for Standardisation). These standards are not linked to specific EU legislation and do not provide a presumption of conformity with EU law. Non-harmonised standards are generally voluntary and serve as reference documents for best practices, technical specifications, and guidelines in various industries. While non-harmonised standards are not mandatory for compliance with EU law, they can still be used to demonstrate compliance with industry-specific requirements or customer expectations.

5.6. Reporting and certification

Reporting and certifications, such as Environmental Product Declarations (EPDs), play a crucial role in our collective efforts to combat climate change. Such reporting tools and certifications provide valuable information about the environmental impact of products, helping consumers and businesses make informed decisions and drive more sustainable choices. They can offer insights into a product’s lifecycle, including its carbon footprint, energy consumption, and resource depletion.

Standardised metrics and transparent data enable us, the consumers, to compare products, identify more sustainable alternatives, and prioritise environmentally friendly options. Moreover, they can encourage manufacturers to optimise their production processes and make greener choices, as they strive to obtain and maintain certifications – which can be increasingly important for market access. This creates a positive ripple effect throughout the supply chain, fostering innovation, reducing emissions, and minimising waste. By leveraging certifications that are based in reporting frameworks, we can also empower policy makers to strengthen and target climate mitigation efforts, for a more sustainable and resilient future.

There are, however, also some important weaknesses in such systems.

They can have limited or inconsistent scope, meaning that essential elements may be included or excluded depending on the certification in concern or how it is applied, and that it becomes difficult to compare them. This also means that they rarely give a complete understanding of a product’s overall performance, perhaps leaving out essential elements like certain scope emissions or water usage.

These challenges are exacerbated by a general lack of standardisation, for instance in the way that certifications are verified or the ways that
self-reporting is done. This can lead to further difficulties in comparison and confuse both consumers and businesses. It can also increase the risk that companies might manipulate or selectively disclose data to present a more favourable environmental profile for their products.

Lack of enforcement and oversight might also make it easier to make misleading or unsubstantiated claims, undermining the credibility and effectiveness of certifications. And finally, the certifications can be complex and highly technical. While this is not a challenge in itself – rather, it is a given if we want robust datasets – the translation of this data into effective information can be challenging and pose risks that their accessibility is limited, particularly for small businesses or consumers who lack the resources or expertise to access and comprehend them.

Taking the mentioned points into account, this report now presents some of the most important embodied carbon-related reporting and certification methods in the building sector.

5.6.1. Life Cycle Assessments in the building sector

Life Cycle Assessment (LCA) is a systematic methodology used to evaluate the environmental impacts of a product, material, or system throughout its entire life cycle, from raw material extraction to end-of-life disposal. It considers all stages, including manufacturing, transportation, use, and sometimes even potential recycling or reuse. LCA takes into account various environmental indicators, such as greenhouse gas emissions, energy consumption, water use, and resource depletion, to provide a holistic understanding of a product's sustainability performance.

LCA methodology is regulated by the standard ISO 14040, and the EU has developed other codes of practice to support it, such as the Environmental Footprint methods\cite{ISO14040}. In the context of embodied carbon reporting, WLCA stands for “Whole Life Carbon Assessment”. WLCA is an assessment methodology used to evaluate the total carbon emissions associated with a building or construction project over its entire life cycle, including both the operational and embodied carbon, also known as whole life carbon (WLC).

By considering both operational and embodied carbon, decision-makers can make more informed choices about design, materials, and construction methods to reduce the building's overall carbon impact. WLCA is especially valuable in sustainable construction practices as it ensures that efforts to mitigate carbon emissions go beyond just energy-efficient operation and extend to the full life cycle of the building, taking into account its embodied environmental impact as well.

However, there is still a lack of general understanding of WLCA within the industry, worsened by the lack of regulation and enforcement of WLCAs, which in turn does not solve the data challenge (the lack of widely available and accurate data that enables benchmarking)\cite{ISO14040}.

5.6.2. Product Environmental Footprint (PEF) & Environmental Product Declarations (EPDs)

There are several tools to assess and communicate the environmental impact of products. For the building sector, two of the most relevant are the Product Environmental Footprint (PEF)\cite{EPF} and the Environmental Product Declarations (EPDs)\cite{EPDs}. Nonetheless, there are some differences among them.

Firstly, on the scope and focus. An EPD is a standardised and verified document that provides transparent and comparable information about the environmental performance of a product. It typically focuses on a specific product, material, or system and provides data related to its life cycle, including raw material extraction, manufacturing, use, and disposal. The PEF methodology is a comprehensive and harmonised approach developed by the European Commission. It goes beyond individual products and aims to evaluate the environmental impact of products within a specific product group or category. The PEF covers a broader scope, including multiple products with similar functionalities.

Secondly, on the methodology used: EPDs are based on Life Cycle Assessment (LCA) methodologies, which evaluate the environmental impacts of a product throughout its life cycle. LCAs consider various aspects, such as resource consumption, greenhouse gas emissions, water use, and other environmental indicators. PEF also utilises LCA methodology, but it has a more standardised and harmonised approach to assess environmental impacts, making it easier to compare products within the same category.

Thirdly, on the geographical scope. EPDs can be developed following regional or international standards, and their scope can vary depending on the region and market for which they are intended. The PEF methodology was primarily developed by the European Commission and
is commonly used within the European Union. However, its principles and guidelines may influence other regions’ efforts to standardise environmental assessments.

Lastly, on the purpose, EPDs are often used for marketing and sustainability communication purposes. They allow companies to communicate the environmental performance of their products to consumers, architects, and other stakeholders. PEF is more commonly used for policy development and regulatory purposes. It aims to provide a standardised method for assessing and comparing environmental footprints within a product category to support sustainable procurement and policy-making decisions.

In summary, EPDs focus on individual products, offering specific environmental information based on LCA methodologies. On the other hand, PEF takes a broader perspective, aiming to harmonise environmental assessments within product groups for policy and regulatory purposes, primarily within the European context.

While both methodologies offer valuable insights into the environmental impact of products, they do have some weaknesses and limitations:

**Limitations of EPDs:**

1. **Data availability and accuracy:** Developing an EPD requires access to comprehensive and accurate data from various stages of a product’s life cycle. Sometimes, this data may not be readily available or difficult to obtain, leading to potential data gaps or reliance on estimates, and therefore potentially incomplete LCAs.

2. **Limited scope:** EPDs focus on individual products, and as a result, they might not capture the broader impacts of product systems or multi-component building assemblies. This can lead to a fragmented view of a building’s overall environmental performance.

3. **Lack of comparability:** EPDs may have different methodologies and boundaries, leading to challenges when comparing products from different sources. Variability in data collection methods or regional considerations can affect the comparability of EPDs.

4. **Subjectivity in LCA interpretation:** While LCA methodologies are scientific, there can be some degree of subjectivity in interpreting the results and setting the system boundaries, leading to potential bias or misinterpretation.

**Limitations of PEF:**

1. **Complexity and resource intensiveness:** PEF is a comprehensive methodology that covers multiple environmental impact categories and requires extensive data collection, making it resource-intensive and time-consuming to implement.

2. **Limited applicability:** PEF was primarily developed within the European context, and its applicability might be challenging in regions with different industrial structures, product standards, and regulatory frameworks.

3. **Difficulty in handling product diversity:** Within a product category, there can be a wide variety of products with diverse characteristics. Creating a single representative assessment for such diverse products can be challenging and may not accurately capture the entire category’s environmental performance.

4. **Focus on average performance:** PEF aims to find the average environmental performance of a product category, which might not provide enough information to identify best-in-class or worst-in-class products.

5. **Insufficient industry adoption:** PEF is a relatively new and evolving methodology, and not all industries or sectors may have embraced it fully. Limited adoption could hinder the availability and comparability of PEF data across different product categories.

Stakeholders should be aware of the limitations. Both methodologies can be complementary in the assessment and communication of environmental impacts for building materials. While they have distinct purposes and scopes, they can work together to provide a comprehensive understanding of a product’s environmental performance. They can complement each other in the following ways:

1. **Detailed LCA data from EPDs:** EPDs provide detailed life cycle assessment (LCA) data for individual products, materials, or systems. This data includes information on raw material extraction, manufacturing, transportation, use, and end-of-life phases.

2. **Standardisation and comparability from PEF:** PEF methodology provides a harmonised approach to assess and compare the environmental impacts of products within a specific product category. By standardising the assessment process, PEF allows for better comparisons between similar products and helps identify the most environmentally friendly options within a group, something which EPDs alone cannot do.
3. **Supporting Green Procurement:** PEF's comprehensive approach helps government agencies and private organisations in their procurement decisions by considering the environmental impacts of products. EPDs can provide the detailed data needed to evaluate the environmental performance of individual products, supporting the broader PEF approach.

4. **Addressing different stakeholder needs:**

   EPDs are valuable for architects, engineers, and construction professionals who want detailed information about specific products they use in their projects. PEF, on the other hand, is useful for policymakers, regulators, and sustainability experts seeking standardised environmental information at the product category level.

5. A summary table is presented below:

   **Table 7: Summary between the differences and similarities of EPDs and PEF.**

<table>
<thead>
<tr>
<th>Aspect</th>
<th>EPDs</th>
<th>PEF</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Focus</strong></td>
<td>Individual products, materials, or systems</td>
<td>Product groups or categories</td>
</tr>
<tr>
<td><strong>Scope</strong></td>
<td>Specific product's life cycle</td>
<td>Multiple products with similar functionalities</td>
</tr>
<tr>
<td><strong>Methodology</strong></td>
<td>Life Cycle Assessment (LCA)</td>
<td>LCA with standardised and harmonised approach</td>
</tr>
<tr>
<td><strong>Geographical Scope</strong></td>
<td>Can follow regional or international standards</td>
<td>Primarily developed by the European Commission</td>
</tr>
<tr>
<td><strong>Purpose</strong></td>
<td>Marketing and sustainability communication</td>
<td>Policy development and regulatory purposes</td>
</tr>
</tbody>
</table>
   | **Limitations** | 1. Requires comprehensive and accurate data throughout the product's life cycle.  
                        | 2. Focused on individual products, potentially missing broader impacts of product systems or multi-component building assemblies.  
                        | 3. Lack of comparability.  
                        | 4. Subjectivity in LCA interpretation  
                        | 5. Relatively new and evolving methodology, adoption may vary across industries, hindering data availability and comparability. | 1. Complex and resource-intensive.  
                        | 2. It may not be fully suitable for regions with different industrial structures and standards to the EU.  
                        | 3. Struggles to provide a single representative assessment for diverse products in a category; though it allows standardisation within product groups, facilitating comparisons.  
                        | 4. Aims to find average environmental performance, not identifying best-in-class or worst-in-class products. |
   | **Complementarity** | Detailed LCA data from EPDs provides insights into specific product's environmental impact across the life cycle.  
                        | PEF complements EPDs in providing a harmonised approach to assess and compare environmental footprints within product groups or categories; | |

Combining the strengths of EPDs and PEF can create a more holistic understanding of the environmental impact of products. By using EPDs to delve into the specifics of individual products and PEF to compare performance within broader product categories, stakeholders can make more informed decisions to promote sustainability and reduce the environmental footprint of the built environment. However, given the advantages of comparing among different products within the same category and the more comprehensive approach, PEF should be the preferred option.
5.6.3. Level(s)

Level(s) is a framework designed for professionals in the built-environment sector within Europe, providing guidance for assessing and monitoring the sustainability performance of buildings. Level(s) is not a certification scheme, but its straightforward framework enables different schemes to communicate effectively. It establishes clear sustainability priorities for schemes to adopt, enhancing consistency in the certification market. The common language of Level(s) facilitates consistent assessment methods, reporting, and data comparison across projects and countries. By aligning with this framework, schemes can actively contribute to its implementation throughout Europe, supporting the EU’s sustainability goals and keeping pace with market leaders already embracing Level(s).

The European Commission has developed several resources to enable the successful use of this framework, which is open source and freely available.

5.6.4. Certification schemes

LEED (Leadership in Energy and Environmental Design) and BREEAM (Building Research Establishment Environmental Assessment Method) are two of the most widely recognised and utilised sustainability assessment methods for buildings.

LEED

LEED is a green building rating system developed by the U.S. Green Building Council (USGBC). It aims to encourage sustainable building practices and design, promoting environmental responsibility, energy efficiency, and occupant health. LEED offers a comprehensive set of guidelines and criteria for new construction, existing buildings, and various building types.

LEED and Embodied Carbon: LEED addresses embodied carbon through the Low Carbon Design and Construction (LCDC) credit. This credit focuses on reducing the environmental impacts associated with the construction and materials used in a building. To earn the LCDC credit, projects need to demonstrate a commitment to reducing embodied carbon emissions and using low-carbon materials in their construction process.

The LCDC credit encourages the following strategies:

1. Material reuse and recycling: Encourage the use of salvaged, reclaimed, or recycled materials to reduce the demand for new resource extraction.
2. Low-carbon materials: Give preference to materials with low embodied carbon, promoting the use of products with lower carbon footprints.
3. Life Cycle Assessment (LCA): Conduct an LCA to assess the environmental impacts of different material choices, including embodied carbon.
4. Carbon offset: Offset a portion of the project’s embodied carbon emissions through carbon credits or other verified offset mechanisms.
5. Limitations of LEED.
6. Focus on energy efficiency: While LEED covers a range of sustainability aspects, it places significant emphasis on energy efficiency and resource conservation. Some critics argue that it might not adequately address other critical environmental and social issues.
7. Global adaptability: LEED was developed primarily for the United States, and while it has been adapted for other countries, some aspects may not be entirely applicable or relevant to certain regions or building types.
8. Cost and complexity: Pursuing LEED certification can be costly and time-consuming, particularly for smaller projects or organisations with limited resources. The complexity of the rating system may also deter some projects from seeking certification.
9. Focus on new construction: LEED has historically been more oriented toward new construction projects, although there are efforts to incorporate existing buildings and retrofit projects.

BREEAM

BREEAM is another widely used sustainability assessment method, developed by the Building Research Establishment (BRE) in the United Kingdom. It evaluates the environmental performance of buildings, communities, and infrastructure projects.

BREEAM and Embodied Carbon: BREEAM addresses embodied carbon within its “Embodied Carbon in Construction” category. This category evaluates the environmental impacts associated with the materials used in the construction process, including greenhouse gas emissions, resource depletion, and other ecological factors. To earn points in this category, BREEAM encourages projects to implement the following strategies:

1. Sustainable material selection: Use materials...
with lower embodied carbon emissions and environmental impacts.

2. Life Cycle Assessment (LCA): Conduct a life cycle assessment to quantify and assess the environmental impacts of construction materials.

3. Circular economy principles: Promote material reuse, recycling, and upcycling to reduce the consumption of virgin resources.


5. Limitations of BREEAM:

6. Global adaptability: BREEAM originated in the United Kingdom and was initially designed with a European focus. Although it has been adapted for international use, some aspects may be more relevant and effective in European contexts.

7. Complexity and scoring system: BREEAM’s scoring system and the complexity of its assessment can make it challenging for some users to fully understand and navigate. This complexity might deter certain building owners or developers from pursuing certification.

8. Continuous improvement: While BREEAM has been regularly updated and improved over time, some critics argue that the process could be more responsive to rapidly evolving sustainability challenges and innovations.

9. Limited focus on local context: BREEAM’s assessment criteria may not fully address region-specific sustainability issues or cultural considerations, potentially leading to less effective sustainability outcomes in some locations.

As the field of sustainability evolves, these certifications should continually update their criteria to address emerging environmental challenges, including those related to embodied carbon. To ease the comparison between the two certifications, the results are presented in Table 7 below.

Table 8: Summary of the similarities and differences between the LEED and BREEAM certifications.

<table>
<thead>
<tr>
<th>Aspect</th>
<th>LEED</th>
<th>BREEAM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Origin</strong></td>
<td>Developed by the U.S. Green Building Council (USGBC)</td>
<td>Developed by the Building Research Establishment (BRE) in the UK</td>
</tr>
<tr>
<td><strong>Focus</strong></td>
<td>Promotes sustainable building practices and design, emphasising environmental responsibility, energy efficiency, and occupant health</td>
<td>Evaluates the environmental performance of buildings, communities, and infrastructure projects</td>
</tr>
<tr>
<td><strong>Applicability</strong></td>
<td>Originated in the US, widely recognised and used globally</td>
<td>Originated in the UK, adapted for international use with a European focus</td>
</tr>
<tr>
<td><strong>Embodied Carbon Focus</strong></td>
<td>Addressed through the Low Carbon Design and Construction (LCDC) credit</td>
<td>Covered within the “Embodied Carbon in Construction” category</td>
</tr>
<tr>
<td><strong>Limitations</strong></td>
<td>1. Emphasises energy efficiency, possibly at the expense of other environmental and social issues. 2. Developed primarily for the US, adaptation may not fully suit all regions. 3. Costly and complex certification process. 4. Historical focus on new construction.</td>
<td>1. Some aspects may be more relevant in European contexts. 2. Complex scoring system may be challenging to navigate. 3. Continuous improvement process could be more responsive. 4. May not fully address region-specific sustainability issues.</td>
</tr>
</tbody>
</table>
There are several tools that can contribute to embodied carbon accounting.

**Embodied Carbon in Construction Calculator (EC3)**

One of the most relevant is the Embodied Carbon in Construction Calculator (EC3)\textsuperscript{cxi}. This is Building Transparency’s online tool, developed by C Change Labs, that allows users to assess and compare the embodied carbon emissions of construction materials. EC3 provides a comprehensive database of building materials and their associated carbon emissions, helping designers and builders make informed decisions to reduce the carbon footprint of their projects.

EC3 stands out from other Life Cycle Assessment (LCA) tools by incorporating a unique feature - the display of uncertainty bounds and integrating it directly into the comparison tools. Due to the possibility of uncertainty in certain methodologies, Building Transparency defined a set of uncertainty categories that can be quantitatively assessed, and that enable to be at least 80% confident that the actual emissions (not the reported ones) are still below a reasonable limit. The chosen value corresponds to the 80th percentile, which serves as a sensible and conservative estimate, encouraging better EPD data quality and specificity compared to simply relying on the reported average value in the EPD\textsuperscript{cxv}.

**The Carbon Leadership Forum (CLF)**

The Carbon Leadership Forum is an organisation at the University of Washington dedicated to “accelerating the transformation of the building sector to radically reduce the embodied carbon in building materials and construction through collective action”\textsuperscript{cix}. They have developed tools and resources to help designers and builders assess and mitigate embodied carbon in their projects.

**One Click LCA**

One Click LCA is an LCA software tool that helps building professionals (architects, green building consultants, civil engineers, eco-designers, manufacturers, CSR consultants, and builders) assess the life cycle environmental impacts of their projects, including embodied carbon. They offer free upskilling training on LCA to building professionals, focusing on construction LCAs and EPDs\textsuperscript{cx}.

**ECO Platform EPD**

The ECO Platform is a network of European Environmental Product Declaration (EPD) program operators. EPDs issued by ECO Platform members are recognised across Europe and can contribute to various building certifications\textsuperscript{cvi}.

**Science Based Targets Initiative (SBTi)**

The Science Based Targets Initiative (SBTi) is a collaborative effort that aims to assist companies in setting ambitious greenhouse gas emission reduction targets aligned with the Paris Agreement’s goal to limit global warming to well below 2 degrees Celsius above pre-industrial levels. It encourages companies to address embodied carbon in materials such as cement and steel used in their products and projects. By advocating for lower-carbon alternatives, promoting material efficiency, and considering life cycle assessments, SBTi seeks to drive significant reductions in the carbon footprint of these key construction materials, contributing to the construction industry’s efforts to mitigate its impact on climate change\textsuperscript{cxvi}.

As part of its sectorial guidance, SBTi also sets targets for the cement and the steel industry.

For cement, it offers comprehensive guidance tailored to the cement and concrete sector, covering target-setting and process management, specific greenhouse gas accounting criteria, and practical examples illustrating how diverse companies can utilise the tools and recommendations to submit their targets for validation. It provides in-depth insights into establishing targets and addressing industry-specific challenges, facilitating companies in aligning their efforts with sustainability objectives\textsuperscript{cxvii}.

For steel, the process has not yet finished. Between November 2022, and January 2023, the SBTi conducted a two-month public consultation for the Steel Science Based Target Setting Guidance and Tool. The aim was to gather feedback and ensure that the criteria and guidance provided to support steel companies in their decarbonisation endeavours were strong, transparent, and feasible. Considering the received comments, the SBTi proceeded with the revision of the guidance and tool, which was subsequently published in Q3 2023, with the official launch and socialization of the developed resources expected in September 2023\textsuperscript{cxiv}.
Lead markets, also known as early adopter markets, refer to specific geographic regions or industries where innovative products, services, or technologies are first introduced and gain meaningful traction. These markets often serve as indicators or predictors of future trends and developments in a particular field. Green lead markets pioneer products that are more sustainable and lower-carbon.

### 6.1. What are lead markets?

Lead markets are characterised by the presence of “lead users” or early adopters who have a strong need for and/or high prioritisation of innovative solutions. With this comes a certain willingness to take risks involved with being first or early movers, including potential “green premiums”. A green premium refers to the additional cost or price-premium associated with more environmentally friendly or sustainable products, technologies, or services compared to their conventional counterparts. It represents the difference in price between a sustainable option and a less sustainable alternative, arising from the fact that more sustainable products can involve higher production costs, research and development investments, and costs associated with adherence to stricter standards.

The opposite of a green premium is a ‘brown penalty’. This can occur, for example, when a functioning carbon price has internalised the environmental cost of products, making more climatically and environmentally harmful production processes and their outputs more expensive.

Lead markets are key in driving down the green premium, as they contribute to technological advancements being brought to market, economies of scale, and increased consumer demand, which in turn helps make sustainable options more accessible and cost-competitive.

A useful example of what lead markets can be is to think of Silicon Valley as a lead market for tech innovation, certain German regions as lead markets for the automotive industries or Denmark as a lead market for wind power technology development. Certain countries, regions or even cities can establish themselves as lead markets based on a concentration – existing or strategically developed, as elaborated upon below – of expertise, resources and infrastructure.

### 6.2. How can lead markets help realise lower-carbon buildings?

A fundamental first step of creating green lead markets is to identify what is ‘green’ and which products should be pulled to the market (see chapter 3). Once this has been done, there are a number of measures that can be taken, ranging from the municipal, regional or national level. These can include:

1. Green public procurement (GPP) requirements. Public buyers can leverage their purchasing power to drive demand for innovative products and technologies. By prioritising the procurement of sustainable or cutting-edge solutions, public buyers can create a market pull for these products, stimulating their development and adoption.
2. Green purchasing agreements between public and private entities. As with to GPP, there are several large private buyers, who often collaborate with public authorities, that can leverage their purchasing power in a similar way. They can send clear signals to the market through statements of demand or green purchasing agreements.

3. Financial support. Governments can provide financial support to R&D and to scale-up existing solutions. This can be done through grants, subsidies, or tax incentives to encourage desired activities in targeted industries. Or low-interest loans, grants or venture capital funds to incentive startups. This reduces financial barriers to develop and scale up new solutions, helps stimulate innovation and enables companies to bring new products or technologies to the market.

4. Standards and regulations. The establishment of standards and regulations that promote sustainability or encourage innovation can shape the market environment and drive the development of lead markets. These standards can provide a level playing field and create incentives for companies to invest in research and development to meet the requirements.

5. Education and skill development. Investments in education, training, and skill development programs for big buyers (public and private) can cultivate a highly skilled tendering workforce that is up-to-date on emerging industries and capable of demanding innovation. Industry themselves also have a responsibility to facilitate collaboration and knowledge-sharing. Innovation clusters, incubators and technology parks represent valuable hubs for the exchange of ideas, resources, expertise that can spur on lead markets. Other exchanges could take the shape of regular “pitching sessions” where industries are invited by big buyers to share their innovations, or that industry hosts regular “tours” and site visits.
In this report, we have taken a bird’s eye view on the state of embodied carbon in the EU. We have strived to present a robust foundation upon which further work can be done. We have done this by looking at both the political context as well as the on-the-ground situation of some of the main industries concerned.

This work will continue and be expanded upon. For now, we present the following recommendations for next steps, divided in two tracks focussing on the political and technical. Each of these steps (what they involve and what needs to happen for them to be taken) are covered in more detail throughout this report.

**Track 1: Technical solutions**

The first step to reducing embodied carbon is to avoid emitting unnecessary carbon through improved product design. This involves a reduction in new extraction of raw materials (for example mining) as well as increased reuse of existing materials. Reducing the addition of new raw materials and increasing the use of recycled or repurposed materials, reduces the overall upfront carbon footprint associated with the material’s production and, in turn, the embodied carbon content. Nonetheless, it is worth noting that this decrease happens only when there is an absolute reduction on material production. Therefore, we need to reduce the absolute amount of materials used, decreasing the demand. For example, buildings and infrastructure are often over-dimensioned to be on the ‘safe side’. Health and safety must of course come first, but it is a fact that this is often done even when we know it is not necessary. Architects and designers, as well as project commissioners play a central role in this first step. This also includes designing products not only to reduce material use, but also to include plans for improved disassembly and recyclability or reuse at the end of life.

The second step to reducing embodied carbon is about choosing renovation over new construction, as well as smaller buildings over larger ones. For example, apartments or terraced houses will have a reduced whole-life carbon footprint than a detached house. And smaller, lighter cars will use less material, crucially steel, than larger, over-dimensional cars. Saving on materials makes both ecological and economic sense.

The third step is to reduce emissions across the necessary production processes, such as replacing high-carbon cement with low-carbon alternatives, including through the use of CCS and through more climate-friendly types of cement and concrete with other constituents. This can also be about electrifying construction machinery and improving logistics around the transport of materials and other resources to and from the construction site.
Track 2: Political solutions

The first step is to improve awareness of the amount of embodied carbon by increasing the use of transparent, verifiable and comparable calculation methods and certifications. This is both about improving consumer power through access to information, but also about improving the opportunities for innovative manufacturers to develop and verify their credible low-carbon alternatives, avoiding greenwashing and ensuring better market access for future-oriented products.

Second, policy makers must empower producers to reduce the climate footprint of building materials by setting limit values for the amount of embodied carbon they can contain. Here we can start where there is the most to be gained: cement, steel and other widely used building materials that have a significant carbon footprint. This step is also about facilitating the roll-out of technological solutions that enable the production of lower-carbon materials.

Third, we must demand greener public procurement for building materials with a lower embodied carbon content. Public purchasing power is huge and harbours great untapped potential to drive new markets for greener solutions, empowering the private sector to follow suit. We have already seen examples of this power being successfully deployed with municipalities setting criteria for emission-free construction sites. Let’s recreate the success with low carbon materials.
BIBLIOGRAPHY


Bellona Europa is an international, independent and non-profit organisation that meets environmental and climate challenges head on. We are solutions-oriented and have a comprehensive and cross-sectoral approach to assess the economics, climate impacts and technical feasibility of necessary climate actions. To do this, we work with civil society, academia, governments, institutions, and industries.