30 YEARS

European Environment Agency

Addressing the environmental and climate footprint of buildings

EEA Report 09/2024

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Key messages

- More than 30% of the EU's environmental footprint comes from buildings, making it the sector with the highest environmental impact in the bloc.
- Societal trends such as an ageing population, increased affluence and a changing climate are expected to put pressure on the building stock. In addition to a demand for more buildings, especially in cities, there is also a need for different kinds of buildings that contribute to environmental and climate solutions. Thus, building sustainability is of increasing importance in Europe.
- EU Policies target different aspects of buildings such as energy efficiency and climate emissions, construction products and waste management. A unified policy strategy on buildings, covering all life cycle stages and integrating both environmental and climate issues, would help identify synergies and avoid trade-offs.
- Each stage of the building life cycle has a different environmental impact. For example, most natural resources are extracted when producing building construction products and components; most waste is generated when decommissioning buildings. Consequently, sustainability policies need to be nuanced to take these differences into account.
- Renovation and the use of construction products with a low environmental impact should be prioritised in the buildings system of the future. Lower energy consumption and resilience to climate change are vital characteristics of the sector going forward. To support biodiversity, nature-based solutions, green spaces, green roofs and vegetation should also be incorporated into design.
- A sustainable buildings system should create affordable and accessible housing for all. This aim could be supported by participatory approaches to decision-making which foster strong local communities, alongside subsidies for building renovations and upgrades to increase the affordability of sustainable buildings now and in the future.

Executive summary

Buildings are of the highest environmental relevance

Europeans spend around one quarter of their income on housing, mainly on buying or renting residential or commercial spaces and on paying electricity and heating bills. To satisfy this consumption demand, buildings need to be constructed, operated and decommissioned. All of these processes result in pressures on the environment and climate. In fact, more than 30% of the EU's total environmental footprint can be attributed to buildings, making it the sector with the highest environmental impact in the bloc.

Buildings are responsible for 42% of the EU's annual energy consumption, 35% of annual greenhouse gas (GHG) emissions and around one third of all materials consumed annually in the EU. At the same time, buildings represent a EUR 1.7 trillion industry, providing more than 20 million jobs.

An integrated, forward-looking assessment of the EU's building stock may offer options for harnessing the significant potential to mitigate these impacts.

Extensive legislation on buildings exists but a holistic approach is missing

The EU has put in place a robust legislative framework dedicated to buildings alongside an extensive set of legislation linked to them. This includes the newly-revised Energy Performance of Buildings Directive, which seeks to achieve a fully decarbonised building stock by 2050, and the Renovation Wave initiative, which aims to double the annual renovation rate by 2030 to improve the energy efficiency of buildings and reduce energy poverty. Circularity is addressed among other initiatives in the Construction Products regulation. There is also the new, so-called 'EU ETS 2' mechanism, which aims to address GHG emissions from the housing sector by focusing on fuel distributors from 2027 onwards. However, there is no holistic policy approach to buildings to handle them as a unified system across their entire life cycle, and to integrate both environmental and climate issues.

Goal of the report and key definitions

This report undertakes an integrated assessment of the buildings system and proposes a holistic approach to the relevant environmental and climate issues. It explores the future of a sustainable buildings system, key drivers for change and potential responses. The aim is to support policies that promote climate mitigation, preservation and restoration of biodiversity, and a circular economy.

The concept of a buildings system encompasses all elements of and activities related to the production, construction, use, renovation and decommissioning of buildings, as well as their associated socio-economic and environmental impacts. It does not include other construction works and complementary systems not primarily designed to accommodate human activities.

The buildings system is dynamic, influenced by changing conditions like climate, economics and societal shifts. It involves complex interactions with the environment and other socio-economic systems like water and energy systems or waste management.

These interactions result in various environmental issues, including resource depletion, pollution, GHG emissions, waste generation, water scarcity and biodiversity loss.

A 'sustainable buildings system', on the other hand, is one that minimises resource depletion, environmental pollution and ecosystem degradation throughout its life cycle. Such a system should have positive impacts on the climate and natural environment, preserve natural resources and improve quality of life at the same time as being economically and socially responsible. It should contribute to the well-being of people and the biosphere, both now and in the future.

Current state of the buildings system

Understanding the current state of the buildings system in Europe is the first step towards developing principles to ensure that future buildings are sustainable. This involves highlighting hotspots in different life cycle stages, from socio-economic and environmental perspectives, as well as assessing current environmental and climate policies, emerging political trends and various factors (socio-economic, environmental and technological) which influence and drive the sector.

The product stage refers to raw material extraction, their transport and processing into construction products. Mining and quarrying for raw materials needed for construction products can lead to significant environmental impacts like biodiversity loss and land use.

Some of these materials, in particular concrete (75% of which ends up in buildings), are linked to significant GHG emissions due to releases during their production (cement) or the energy required for their processing. It is estimated that 6% of Europe's climate change impacts are due to such emissions embedded in construction products. Overall, 20-35% of the total environmental impacts during a building's life cycle are caused during the product stage.

The construction stage refers to the building assembly and is the most important stage from an economic point of view. Traditional environmental impacts such as climate change are low relative to other buildings' life cycle stages, although the significant land take of buildings (it is estimated that 4.3% of all land in Europe is occupied by artificial areas, much of which are buildings) leads to biodiversity loss.

On the other hand, emerging environmental issues of a mostly local nature are linked to this life cycle stage. Due to their high weight, transport of construction products accounts for around 30% of all urban goods transport, leading to air pollution and traffic congestion. Toxic dust from cement and silica contributes, together with air pollutants generated by heavy machinery, to PM_{10} emissions, which are known carcinogens. Noise within the range of 70 to 120 dB is routinely measured within the vicinity of a construction site.

The use stage of a building refers to its operation and occupancy for residential or commercial purposes. The most significant source of GHG emissions and other air pollutants is the operation of buildings due to energy consumption.

870 million tonnes of CO_2 were emitted in 2020 because of energy consumption, which has stopped decreasing in recent years. However, heating and cooling demand is lower for new buildings. Especially for buildings following advanced performance standards, energy consumption can be so low that emissions embedded in construction products are higher than emissions due to energy consumption. Using a building also requires substantial consumption of water, alongside a wastewater treatment system that requires even more energy and the use of chemicals.

A distinct part of using a building is the renovation stage. Due to the long life spans of buildings, renovations are very likely to happen. Renovation is the only opportunity for large-scale improvements in the environmental performance of existing buildings and is therefore a key policy area in the EU. Deep renovation of buildings is known to offer social, economic and environmental benefits, such as improved indoor air quality. However, such renovation activities lead to increased material consumption, so potential trade-offs should be carefully considered.

The End-of-Life (EOL) stage concerns building decommissioning activities including building demolition, transporting, and managing construction and demolition waste. Demolishing old buildings runs the risk of releasing hazardous substances such as asbestos and PCBs which, when inhaled by humans, can be carcinogenic.

However, the most important environmental impacts at this stage are linked to the management of the great quantities of demolition waste. In 2020, the total amount of construction and demolition waste (excluding soils and dredges) generated in the EU-27 was 333Mt, making it the largest waste stream in the EU by weight. Despite high recycling rates, the current management of such waste leads to downcycling. This misses both resource savings and the GHG emissions reductions that would come from high-quality recycling.

Several trends influencing the future of buildings

While a thorough understanding of the current state of the buildings system helps us conceptualise sustainable building of the future, existing policy and socio-economic trends need to be factored in if we are to devise effective solutions. The current EU policy landscape is scattered with heterogenous buildings-relevant initiatives. Mapping these initiatives helps us identify a set of principles underpinning policy approaches, like the polluter pays principle (PPP) (in the EU Emissions Trading Scheme (ETS)) or the whole-life cycle-thinking principle (in the new Construction Products Regulation).

Current social trends mean there is likely to be an increasing demand for floor space in the EU, with a lot of that extra space required in cities due to continuing urbanisation. More dwellings are also likely to be required due to the ageing population. Projected ongoing economic growth will increase affluence and correspondingly mean there is a need for more or bigger dwellings. In this context and as a result of environmental and climate considerations, buildings increasingly have potential to offer some solutions: they need to be transformed in order to minimise energy use or become vehicles for renewable energy production (e.g. through solar panel installations).

A set of principles for future action

We propose that a set of principles should be developed for future actions for buildings to address identified environmental hotspots and take account of socio-economic and environmental trends. Designing policies around the proposed principles would improve sustainability not only in terms of the environmental performance of buildings, but also in terms of social justice.

The following principles are proposed in this report:

- prioritising renovation of existing buildings to respond to demand for extra floor space and transforming the EU building stock;
- designing circular new buildings to increase resource efficiency and reduce waste;
- prioritising the use of construction products with low environmental impact over their entire life cycle;
- facilitating the green energy transition via buildings, in line with relevant legislation such as the Energy Performance of Buildings Directive;
- in the future, shaping the buildings sector to become resilient to climate change, provide ecosystem services, and contribute to nature and biodiversity regeneration;
- transitioning to a sustainable EU buildings system in a fair and inclusive manner.

1 Introduction

1.1 Goals and definitions

The European Green Deal (EGD) sets forth a vision for a circular, climate-neutral Europe by 2050, with transformative goals for the continent's future economy. It aims to facilitate action against the triple planetary crisis of climate change, biodiversity loss and pollution.

The construction sector, which covers the processes involved in delivering buildings, infrastructure and industrial facilities, is key for the EU economy. At the same time, however, it currently contributes significantly to the triple planetary crisis. Within the sector, buildings — newly constructed and renovated — account for about 78% of the construction market share, with civil engineering works accounting for the remaining 22% (Euroconstruct, 2021). Since buildings are a big part of the problem, they also have the potential to be a big part of the solution. As such, all policy solutions to the triple planetary crisis need to take buildings into account.

This report consolidates the findings of a project under the umbrella of the EEA's European Topic Centre on Circular Economy, looking into the current state of the EU's buildings system. It takes a forward-looking perspective with the aim of defining the sustainable buildings system of the future. This report aims to support future policies to address climate mitigation, biodiversity gain and increased circularity for buildings through an integrated approach to the environmental, social and economic impacts of the European buildings system.

A building is defined as 'a construction work that has the provision of shelter of its occupants or contents as one of its main purposes; usually partially or totally enclosed and designed to stand permanently in one place' (ISO, 2021). Buildings are part of the built environment, together with other civil engineering works (such as roads, bridges and industrial plants) and external works (such as landscaping). From a physical point of view, a 'building' can be defined as a connected collection of interrelated and interdependent parts — building components and products — that interact with the environmental and socio-economic context.

In the scope of this report the buildings system is defined as 'all the elements (environment, people, inputs, processes, infrastructure, institutions etc.) and activities that relate to producing construction products and the construction, use, renovation and decommissioning of buildings alongside the outputs of these activities, including socio-economic and environmental outcomes, throughout the entire buildings' life cycle'. By focusing solely on 'buildings', this definition intentionally excludes other construction works and complementary systems (e.g. energy, water or waste systems); while these are part of the built environment, they are not designed and constructed to accommodate human activities as a primary objective.

The buildings system is dynamic as its functions and performance change over time, in response to changing boundary conditions (e.g. climate, economics, societal changes). It interacts directly and indirectly with the ecosphere and the socio-economic system in multiple and complex ways. These interactions can result in acute and chronic environmental issues such as resource depletion, air pollution, GHG emissions, waste generation, water scarcity or biodiversity loss. As the environmental and energy performance of the buildings system improves and the climate continues to change, there are likely to be shifts in pressure-impact relations within the system due to rebound effects, trade-offs/synergies, lock-in situations or feedback loops.

Box 1.1

Outline of this report

This report:

- assesses the current state of the buildings system in Europe. It investigates the relevance of the current EU building stock from environmental, socio-economic and stakeholder perspectives, and identifies corresponding hotspots at each stage of the building's life cycle;
- explores what a sustainable buildings system may look like in 2050, in the context of broader socio-economic developments and existing EU environmental policy objectives and targets;
- defines a set of responses to enable the EU to arrive at a sustainable buildings system in the future and assesses those responses in terms of advantages and risks, including socio-economic factors and stakeholder considerations.

1.2 Methodology

To achieve its defined goals, this report maps the current interactions of the buildings system with the environment through an integrated environmental and socio-economic assessment based on the Driver-Pressure-State-Impact-Response (DPSIR) framework (Kristensen, 2004). This framework enables an analysis of the complex causal chain within a system, from the forces driving it to its impacts and the responses required.

A modular approach is used to present the relative importance of the different life cycle stages of the buildings system, the environmental as well as the socio-economic impacts per life cycle stage, as well as the role and influence of the respective stakeholders (CEN, 2023).

The assessment in this report focuses on the EU as a whole and analyses data using an integrated overview; it does not differentiate building typologies and climatological zones. While this approach has some limitations because it does not account for site-specific differences, it does allow for impacts to be estimated and hotspots to be identified. The assessment of environmental impacts is based on life cycle assessment (LCA) categories, including climate change, resource consumption, waste generation, toxicity, energy consumption and land use. The socio-economic analysis focuses on inequality, affordability, employment and health-related aspects.

The report follows distinct integrated environmental assessment steps that translate into the structure given below:

- Framing and scoping: Chapter 1 presents the definitions of key concepts and the methodology.
- Assessing the current situation: Chapter 2 presents the current state and relevance of the buildings system in Europe, its relevant stakeholders and impacts in terms of both the environmental and socio-economic dimensions.

- Prospects: Chapter 3 identifies and critically analyses the existing network of environmental policies at EU level to describe the politically desired future for the buildings system. It also takes stock of existing socio-economic and environmental drivers and emerging trends to assess the current outlook for the buildings system.

- Responses: Chapter 4 gives an overview of potential responses to current challenges by identifying six key principles underpinning the sustainable buildings system of the future. These are based on the integrated analysis and assessment of the current buildings system and projected future trends, including socio-economic factors and stakeholder considerations.

The work is based on a literature survey of recently published reports and selected peer-reviewed articles, as well as statistical information from Eurostat. As the study involved a synthesis of the existing literature, rather than the production of primary data, possibilities for comparison and verification of different sources are limited. Key challenges arose due to notable variations in data reported from different sources; in particular, these challenges related to differences in the scope of the data sources (e.g. types of building covered, geography, construction period, global data).

Mapping reliable data in the buildings system is challenging due to the aggregation of data for the entire construction sector and the significant geographical and socio-economic differences across Europe. The analysis identified knowledge gaps in relation to water use in the buildings system, indoor air quality and health impacts, hazardous substances in construction products (including per- and polyfluoroalkyl substances (PFAS)) and their risks for reuse and recycling alongside the impacts of buildings on biodiversity.

2 The buildings system in Europe — current state and impacts

This chapter presents the socio-economic and environmental relevance of the EU's building stock. Additionally, the pressures and drivers of the buildings system are analysed in order to assess specific environmental and climate impacts, including impacts related to stakeholders and the socio-economic context.

2.1 Socio-economic and environmental relevance of the EU's building stock

The construction sector, which covers the processes involved in delivering buildings, infrastructure and industrial facilities (but not their use), is currently responsible for over 35% of the EU's total waste generation, 50% of all raw materials consumed annually and 5-12% of total GHG emissions. At the same time, it also represents a key industrial sector for the EU economy; it has an annual turnover of over EUR 2,201 billion and involves more than 5 million companies (from single-person and family firms to large multinational enterprises) generating jobs for about 24.9 million people (EC, 2023f).

Across the whole sector, buildings — newly constructed and renovated — account for about 78% of construction turnover, with civil engineering works accounting for the remaining 22% (Euroconstruct, 2021). Each year, the EU building industry uses 1.8 billion tonnes of materials (EU parliament, 2023). This equates to roughly a third of all raw materials in the EU (estimated from UEPG statistics (UEPG Aggregates Europe, 2023)([1]). According to Eurostat data, about 330 million tonnes of construction and demolition waste (including infrastructure but excluding soils, track ballast, dredging spoils and asphalt) were generated in the EU-27 in 2020.

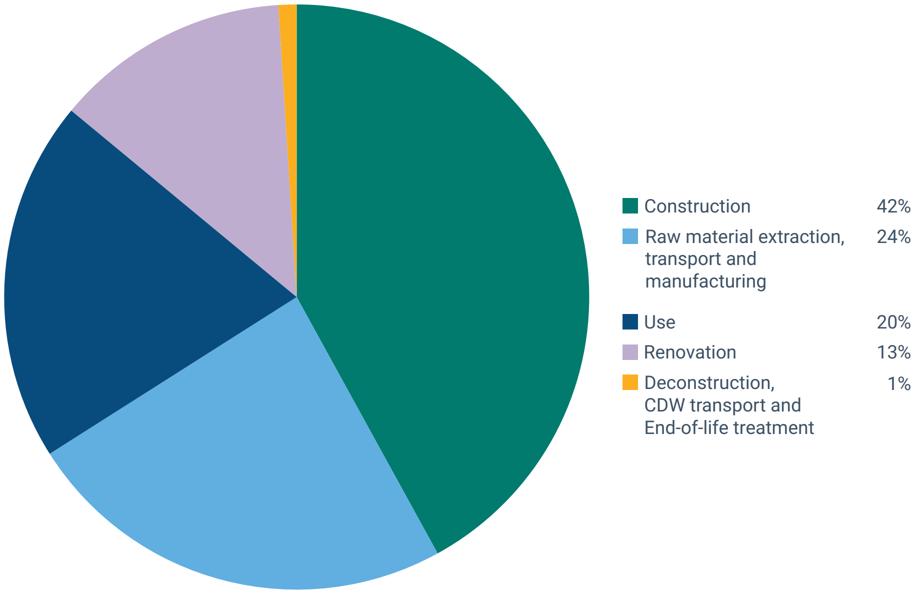
The actual use of buildings is associated with very high energy consumption — around 42% of all energy used in the EU and a share of 35% of the total annual GHG emissions in the region ([2]).

Figure 2.1 describes the relative economic importance of the different life cycle stages of the buildings system (average 2018-2020). Overall, the buildings system represents about 9.4% of the EU-27 gross domestic product (GDP) (2018-2020). The most important elements are the construction stage and the raw material extraction, transport and the manufacturing stage; together these account for two thirds of the total economic value created.

([1]) Half of all raw materials used in the EU (predominantly non-metallic minerals) are used in construction. Furthermore, about 65% of all aggregate (e.g. rock and sand) produced in the EU is used for buildings. Therefore, roughly one third of all raw materials used in the EU is estimated as being used for buildings.

([2]) https://climate-energy.eea.europa.eu/topics/energy-1/energy-and-buildings/data

Figure 2.1 **Relative economic importance of the different life cycle stages of buildings (average 2018-2020)**



Source: ETC CE.

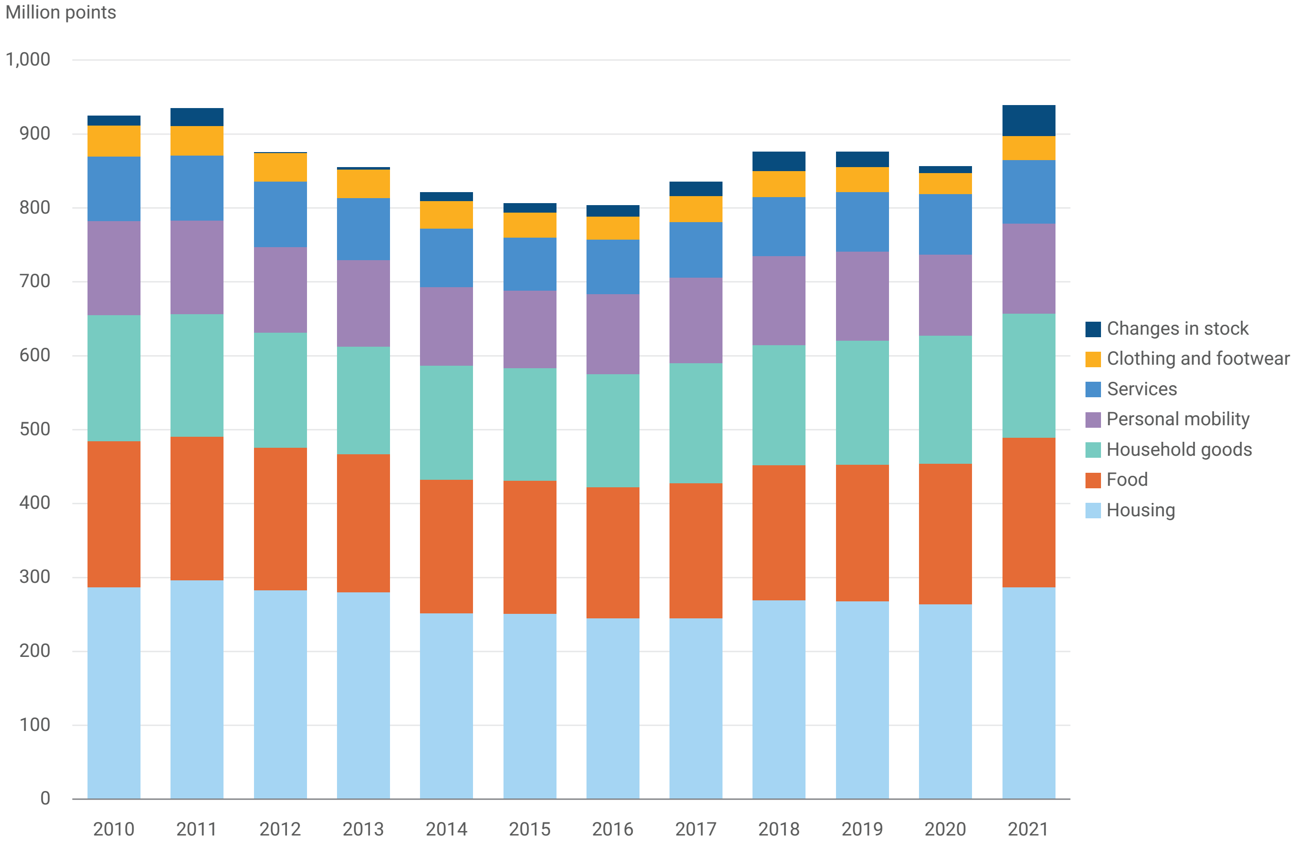
Therefore, the EU buildings system is responsible for a very large share of a wide range of environmental impacts while representing a significant socio-economic pillar of EU society. Consequently, there is great potential for buildings to contribute significantly to addressing environmental issues. It is also reasonable to claim that any solution to climate, energy and resource challenges needs to consider the EU buildings system.

2.2 Impacts of the buildings system

Households in the EU spend around a quarter of their income on housing — mainly on buying dwellings and on heating and electricity. This expenditure means that there is a demand for goods and services; however, their production has environmental and climate impacts for the planet.

The so-called consumption footprint (see Figure 2.2) represents an aggregate sum of the environmental and climate impacts from the consumption of goods and services by EU residents, irrespective of whether they are produced within or outside the EU. Figure 2.2 illustrates the EU's consumption footprint over time, broken down into areas of consumption. One of those areas is housing and the statistics refer, in practice, to money spent on buildings.

Figure 2.2 **The EU consumption footprint, 2010 (in million points), divided into consumption domains)**

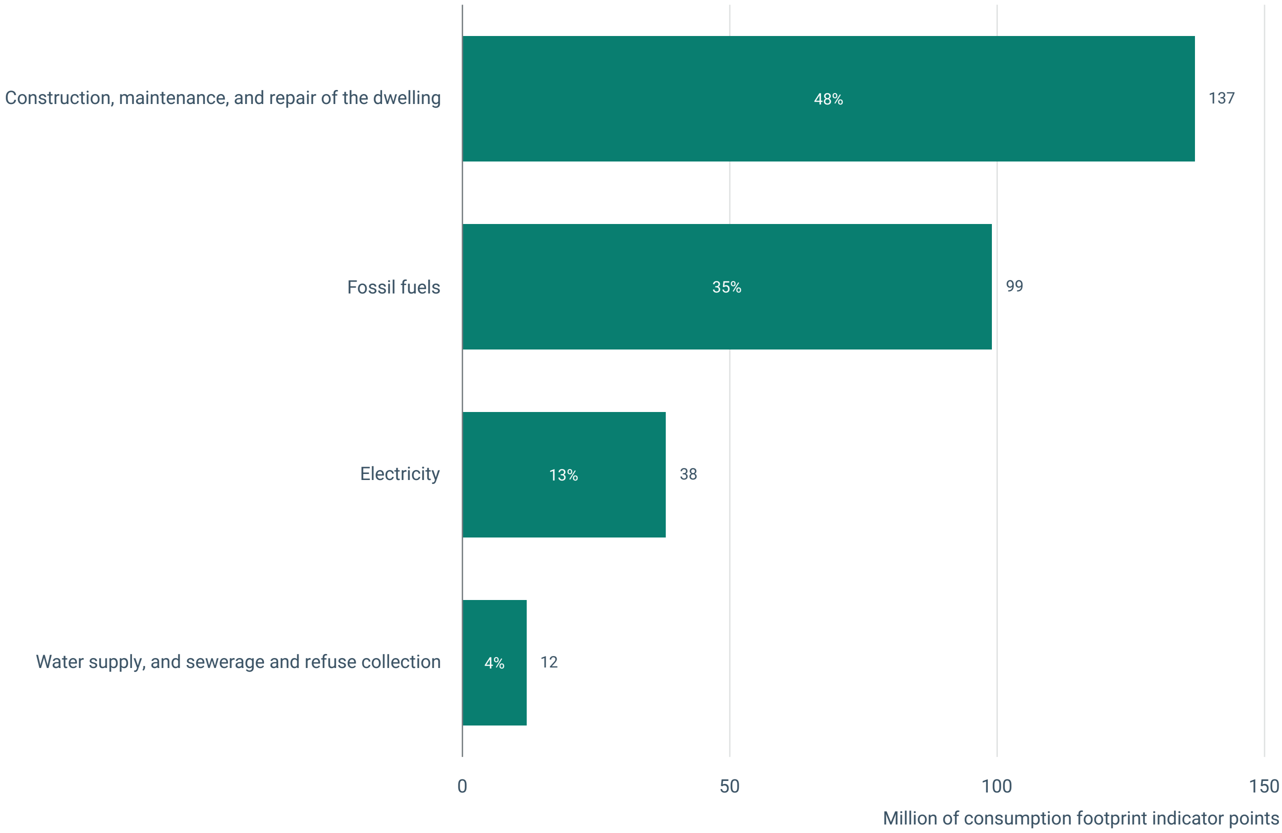


Source: EEA

Overall, 48% of the impact from buildings is related to construction, maintenance and repair, 35% to fossil fuels (from heating), 14% to electricity and the remaining 4% to water supply, sewage and refuse collection (Figure 2.3).

Out of household energy use, in 2021, space heating was responsible for 64% of buildings' total energy consumption, followed by water heating (15%), lighting and electrical appliances (14%), and cooking (6%).

Figure 2.3 **The total consumption impacts of housing according to specific consumption activities**



Source: EEA.

To identify more specific environmental hotspots and critical impacts to develop pathways for intervention, we break down the building life cycle into five distinct stages. Key stakeholders for each life cycle stage are also identified. The life cycle stages are defined below:

1. Product stage, including producing construction products and use of energy systems (supply, transportation and manufacturing of raw materials);

2. Construction process stage, including transportation of all construction products and energy systems to the construction site, and the construction process itself;

3. Building use stage, including operational energy and water use and the use of the building fabric (maintenance, repair, replacement);

4. Renovation(s), including producing additional construction products, heating/cooling and energy systems;

5. EOL stage, including deconstruction or demolition, transportation, recycling suitable materials, reusing construction products, waste treatment and final disposal.

Providing an unambiguous systemic picture of the pressures of the built environment in the EU context is challenging due to limitations in terms of the availability and completeness of data. The analysis presented in this chapter is based on current practice; how these impacts could evolve in the future will be discussed in later chapters.

2.2.1 Product stage

The product stage refers to the extraction of raw materials, their transportation and the manufacturing of construction products. The specific contribution of the product stage to the overall economic value created by a buildings system can vary significantly depending on factors such as the type of building, construction methods, geographical location and market conditions.

In the case of raw materials, for instance, their availability, where they are sourced and their market price influence the overall cost. In times of inflation, the cost of raw materials represents a greater proportion of the overall cost of new constructions and renovations. Estimates suggest that raw materials account for around 20% of the total cost of a project, manufacturing of building components around 25-30% and transportation around 5-10%.

At the same time, the environmental impact of the product stage can vary greatly depending on several factors, including the type of building, construction methods, material choices and energy sources. For instance, in the Belgian context, it has been estimated that around 20-35% of the total environmental impact of the buildings system can be attributed to the product stage (Mouton et al., 2022).

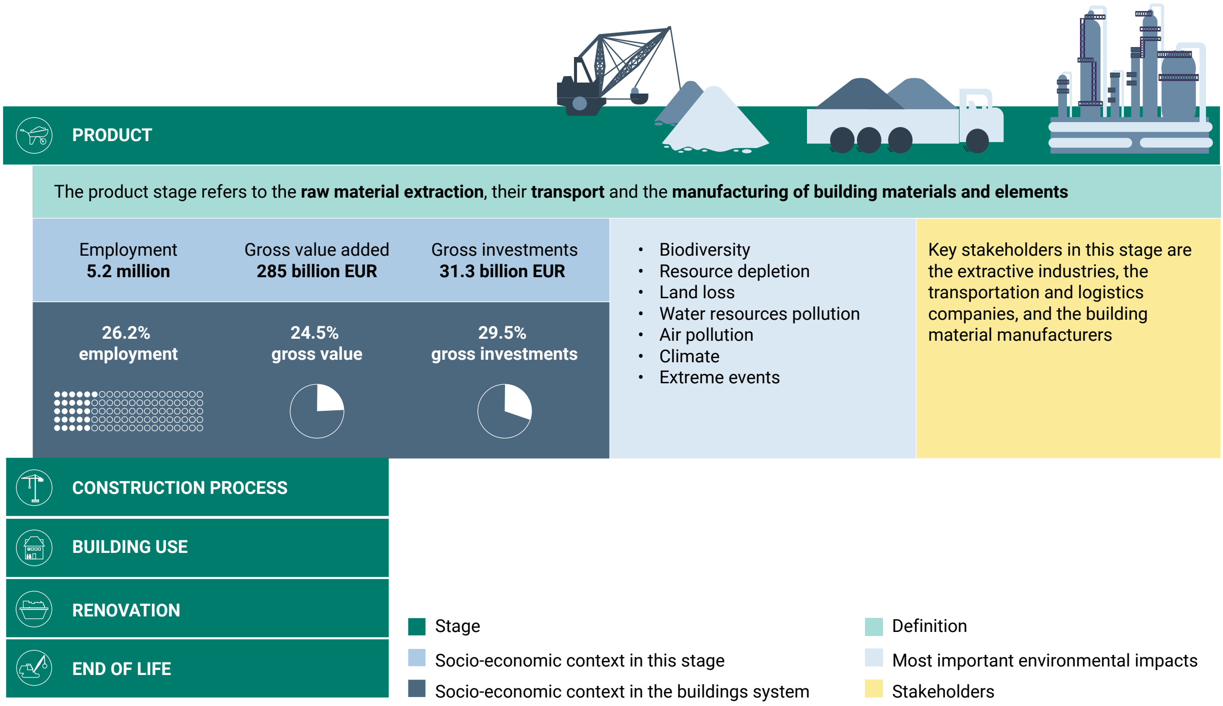
Stakeholders

The product stage includes a variety of industries, some of them fully specialised to serve the buildings system and others which are also relevant for non-construction sectors. Key stakeholders at this stage are the extractive industries, transportation and logistics companies and manufacturers of construction products.

Socio-economic context

From a life cycle perspective, the product stage is the second most important stage in socio-economic terms (Figure 2.4).

Figure 2.4 Socio-economic and environmental relevance of the product life cycle stage of the buildings system



Note: Image © EEA.

Source: Eurostat, 2022b.

Environmental impacts

There is a lack of widespread secondary raw material value chains. As such, the main environmental hotspot within the buildings value chain is related to the extraction of resources. Mines and quarries have a direct impact on local ecosystems, as they influence local fauna and flora. They also require the removal of vegetation, topsoil and subsoil to reach the aggregate underneath and can have an impact on surface water quality and the water balance in general. Resource extraction causes environmental impacts in the following areas (GreenFacts, 2023; JRC, 2021; SITRA, 2022):

- Biodiversity: there are impacts on flora and fauna, destruction of habitats and risks for groundwater.
- Land loss: there are impacts on land use, inland and coastal erosion, and soil degradation.
- Pollution of water resources: there are impacts on water balance and water quality, for instance through the transport and disposal of tailings.
- Air pollution and climate impacts: this is due to the use of heavy machinery with high energy consumption (e.g. excavation and crushing processes), with significant CO_2 emissions associated with extraction and transport.
- Extreme events: extraction causes higher geological vulnerability to extreme events, for instance due to the collapse of tailings ponds.

When we look at the consumption of materials within the buildings sector relative to overall consumption in Europe, we see that buildings use 70% of bricks consumed per year, 70% of clay, 75% of concrete and 65% of aggregate materials.

Embodied energy is a calculation of all the energy used to produce the construction products that go into making a building. It includes the energy used in the mining, manufacturing and transportation of the construction products. Embodied energy can vary for the same construction product due to differences in the efficiency of a particular process, sources of energy used, where and how the construction products are transported, and where and how the construction products are produced.

Because most of the embodied energy of construction products is due to the manufacturing process, improvements in energy efficiency within the manufacturing industries can make a significant contribution to lowering their embodied energy. However, any comparison of embodied energy for different construction products needs to be limited to construction works with the same function and performance.

Buildings typically use a large number of materials with relatively low embodied energy (e.g. bricks and concrete) and a smaller amount of materials with high embodied energy (e.g. aluminium and steel). Just the production of all the EU's construction products results in 250 million tonnes of CO_2 emissions annually or 6% of the total European climate change impacts (annual CO_2 equivalent emissions related to production of construction products total 250 million tonnes and emissions across the EU overall total about 4,065 million tonnes) (EU Parliament, 2023; 2018).

Additionally, the production of the energy technologies used in buildings (e.g. for heating) can have a significant environmental impact depending on the energy source they use (e.g. fossil fuels) or produce (e.g. solar panels) and the construction products required to build them.

Main insights

- The product stage accounts for around 20-35% of the total environmental impact of the buildings system, i.e. a comprehensive assessment of all the effects that a building has on its surrounding environment throughout its entire life cycle (Mouton et al., 2022). It can also be estimated that the product stage makes up on average about 6% of the EU's entire climate change impacts.

- Roughly one third of the total material consumption in the EU is due to construction materials in buildings. The production of cement and concrete dominate in terms of the environmental impacts of the product stage, with nearly all CO_{2e} emissions from concrete production (95%) resulting from the production of cement clinker, the main binder component in concrete.

- Steel is the second largest material group used; about half of it is made from virgin materials. Despite its high recyclability, in Europe, the key issue in steel production is related to energy consumption during processing.

- The increased demand for construction products for insulation, to improve the energy efficiency of buildings, results in an associated increase in production impacts. Although the net benefit from improved energy efficiency is very large from a life cycle perspective, improvements in the production of construction products for insulation should not be neglected.

2.2.2 Construction stage

The construction life cycle stage is currently one of the most relevant from an economic perspective, although it is not directly responsible for the most significant environmental impacts compared to the other life cycle stages of the buildings system.

Stakeholders

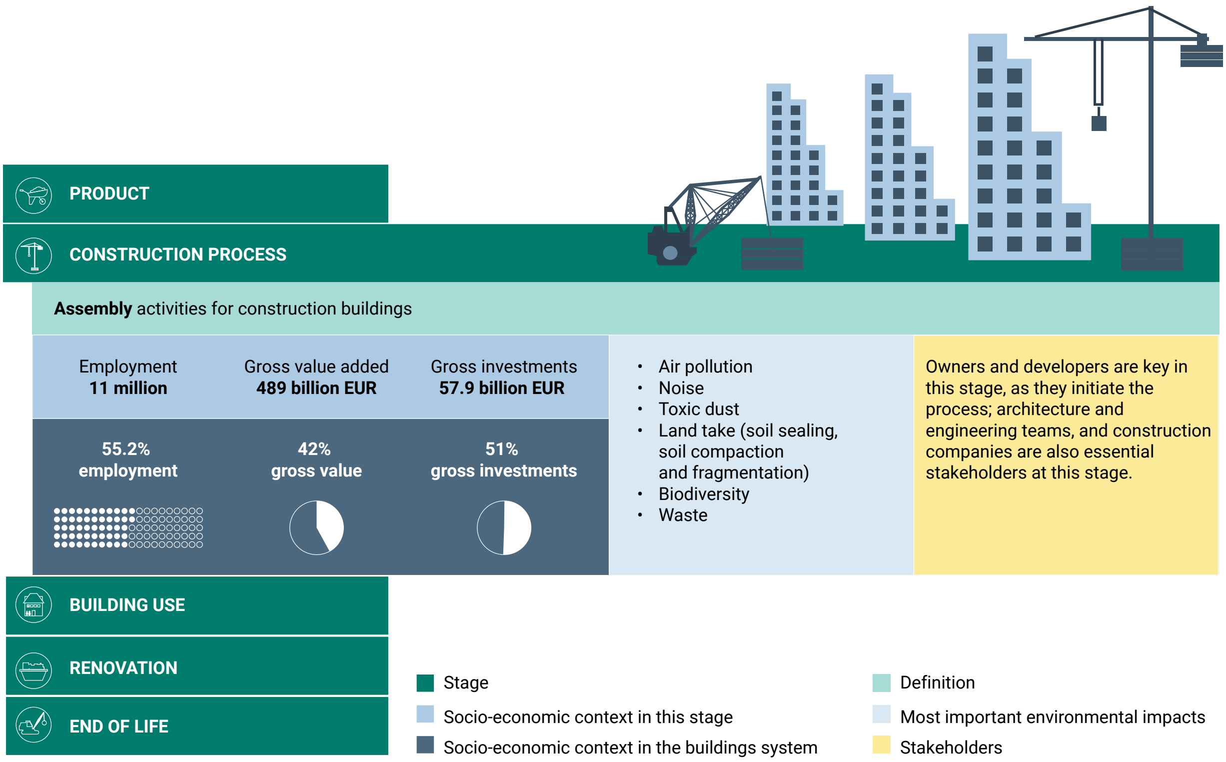
Owners and developers are key stakeholders at this stage of the life cycle, as they initiate the process. Building design has a significant impact on their environmental performance; thus, architects and engineering teams play a crucial role in critical choices around preferred construction products. Construction companies are also significant. Moreover, local governments influence the process by issuing and enforcing laws, regulations, urban codes and construction standards. Municipalities also play a role in issuing construction permits and ultimately certificates of habitability.

Socio-economic context

The construction life cycle stage is the most relevant from a socio-economic perspective (Figure 2.5). However, it is important to note that it is not easy to quantify the relative importance of the 'construction' and 'renovation' stages separately, as the same companies may be involved in both activities (see Annex 1).

For those sub-sectors for which it is not possible to distinguish between construction and renovation, we use information from the European Construction Industry Federation (FIEC, 2023) on the relative importance of value added arising from renovation over total value added of building construction and renovation.

Figure 2.5 **Socio-economic and environmental relevance of the construction life cycle stage of the buildings system**



Note: Image © EEA.

Source: Eurostat, 2022b.

Environmental impacts

Construction transport is almost entirely road bound — one of the least sustainable modes of transport with very high externalities. The environmental impact of **transportation** of construction products to the **construction site** is estimated to account for at least 30% of urban goods transport (Guerlain et al., 2019).

In addition to energy consumption, emissions and costs, other transport externalities might have direct (e.g. pollution, noise, congestion) or indirect (e.g. loss of ecosystems, health impacts, reduced quality of life) impacts (Chatziioannou et al., 2020). Another indirect impact is traffic congestion in urban areas due to construction activities. In this case, interruptions to vehicle flows result in higher emissions and pollution.

Building construction processes can be responsible for the release of toxic dust from cement, concrete, silica or hardwood, which are classified as PM_{10} and recognised as having carcinogenic properties (WorldGBC, 2020). Many tasks on a construction site, such as cutting paving blocks, dry sweeping site areas and cutting roof tiles, produce high levels of dust.

Very heavy machinery and related vehicles on site, which have diesel-based engines, are also responsible for releasing various types of atmospheric pollutants like PM_{10}, together with gases like carbon oxides (carbon monoxide and carbon dioxide), nitrogen oxides, sulphur and other hydrocarbons.

Furthermore, certain types of construction equipment, including air compressors and vehicles, typically generate noise within the range of 70 to 120 decibels within the vicinity of a construction site (Kaur & Arora, 2012).

Construction projects have high energy requirements. In particular, excavators, haul trucks, concrete mixers and construction cranes require plenty of power to operate and, if not well-maintained, can also waste significant amounts of fuel. A significant proportion of energy utilised on construction sites is associated with the mechanical plant used for transportation, levelling, earthworks, lifting, compacting and mixing. The major sources of energy used in construction production processes on site include diesel, electricity, petrol and gas (Talukhaba et al., 2013). Adopting plant machinery operated by electricity has been found to offer a significant reduction in the environmental impact of construction. However, whether this is an option depends very much on the national electricity mix present in any country.

At construction sites, large amounts of naturally-occurring materials (a mix of soil, mineral masses such as decomposed bedrock, clay, silt, sand, gravel, stones and topsoil) need to be managed because of excavation activities prior to construction.

Buildings influence land use mainly due to the land they occupy during their entire service life. In Europe, 4.3% of the total surface is covered by artificial areas (EEA, 2019). These include built-up areas but also transport networks and associated areas. Housing, services and recreation account for 80% of the surface covered by artificial areas.

Population growth and income have been reported to drive land take for urbanisation, yet the demand for urbanised land in Europe is growing faster than the population and even grows where there is no additional population. The total surface area of cities in the EU has increased by 78% since the mid-1950s, whereas the population has grown by only 33% (EEA, 2019). The occupation of land for building purposes leads to environmental impacts (Häkkinen et al., 2013) listed below:

- Soil sealing occurs when agricultural or other non-developed land is built upon. It normally includes the removal of top soil layers and leads to the loss of important soil functions, such as food production or water storage (EEA, 2010). When vegetated soils are replaced with impermeable surfaces, the result is an increase in surface runoff (with higher risks of flooding), infiltration reduction and natural storage bypass.

- Soil compaction is caused by high construction loads. Compaction reduces soil porosity, increases bulk density and reduces the soil's absorptive capacity. Soil sealing and compaction influence the soil's function in terms of environmental interactions (storage, filtering and transformation) and therefore also have a large influence on changes in the quality and amount of groundwater (Häkkinen et al., 2013).

- Fragmentation, caused by built-up areas, leads to the isolation of inhabitants and disruption of ecological corridors, which negatively affect habitats. Ecosystems become more vulnerable to the effects of other external pressures such as drainage, eutrophication and acidification. Overall, 30% of Europe's surface area is moderately highly or very highly fragmented.

As hotspots for land-use change due to urban expansion and urban sprawl, these issues represent a main driver of biodiversity loss. Biodiversity in the EU continues to decline and deteriorate due to land use changes, overexploitation, pollution, invasive alien species and climate change.

Environmental impacts during the construction stage are also caused by generated waste which has to be managed. One source (Material Economics, 2019) states that some 15% of products are wasted in construction. According to another source (JRC, 2022), on average 5% of all products that are used for construction end up as waste on construction sites in the EU-27. Furthermore, Norwegian statistics on construction and demolition waste generated from 2009 to 2021 (SSB, 2022) indicate that between 24% and 28% of construction and demolition waste was generated in the construction phase. The waste (excluding asphalt waste) consisted mainly of wood waste, bricks and concrete ,and other heavy building materials and mixed waste.

Main insights

- The construction life cycle stage is the most relevant from a socio-economic perspective.

- Transport of construction products and building components has significant impacts. Low transport efficiency leads to unnecessarily high levels of emissions, noise and vibrations from construction transport.

- Environmental impacts of construction processes include waste, noise, air pollution, water pollution, climate change, land use and hazardous emissions.

- During the construction phase, over 10% of construction products used are wasted.

- Land use management in the construction stage is important to avoid continued loss of biodiversity.

2.2.3 Building use stage

The use stage represents the consumption phase of a building and includes operational energy use such as space heating, domestic hot water production, lighting and appliances, cooling and ventilation. The use stage is characterised by high energy consumption for heating/cooling and electricity along with environmental impacts associated with energy production. Data show that expenses for heating are the most significant in terms of total consumption expenditure across the EU.

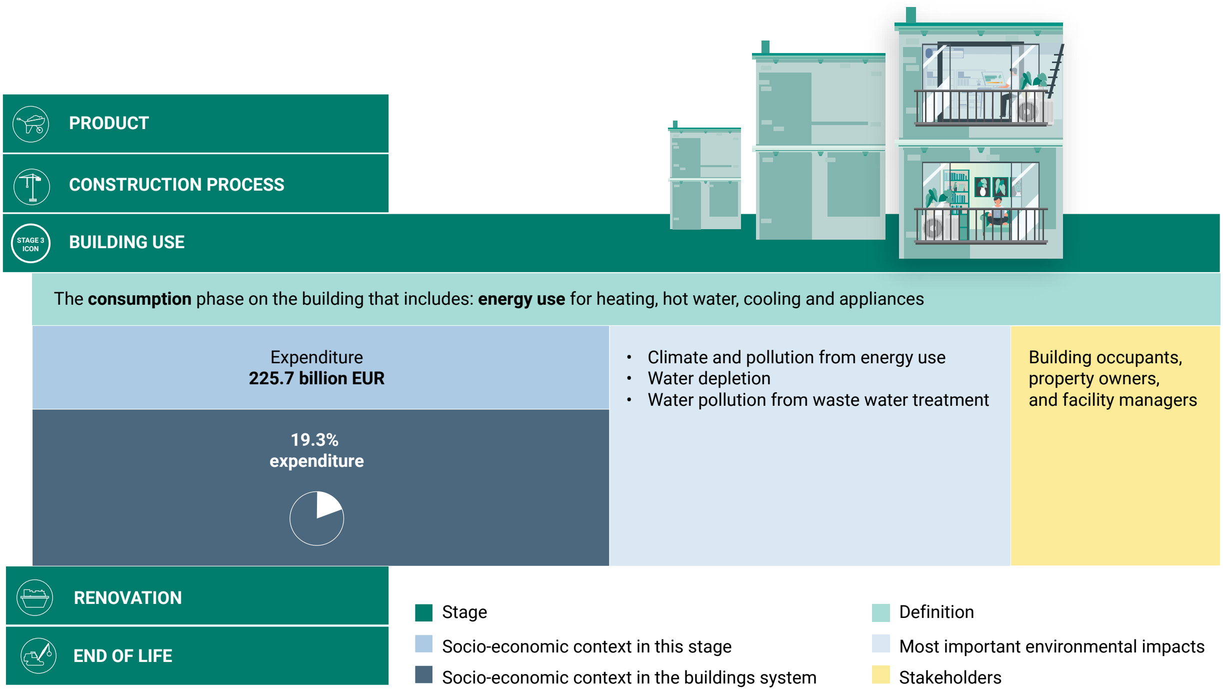
Stakeholders

Building occupants, property owners and facility managers are the key stakeholders at this stage.

Socio-economic context

The building use life cycle stage is the 'consumption phase' of the whole system. This makes it hard to compare the economic value of this life cycle stage with other stages as different metrics are needed. The economic value of both residential and non-residential buildings for users and owners is already accounted for in the other stages. Indeed, there is no simple way to quantify the value of buildings at this stage, unlike for the construction phase when additional building stock is added and this is reflected in the market value of the new building for its owners.

Figure 2.6 Socio-economic and environmental relevance of the use life cycle stage of the buildings system (³)



Note: Image © EEA.

Source: Eurostat, 2022b.

(³) The expenditure here refers to the energy needed to operate buildings. Only residential buildings were considered since, for non-residential buildings, it is not possible to disentangle the amount of energy used for the operation of the building from that used for 'production'.

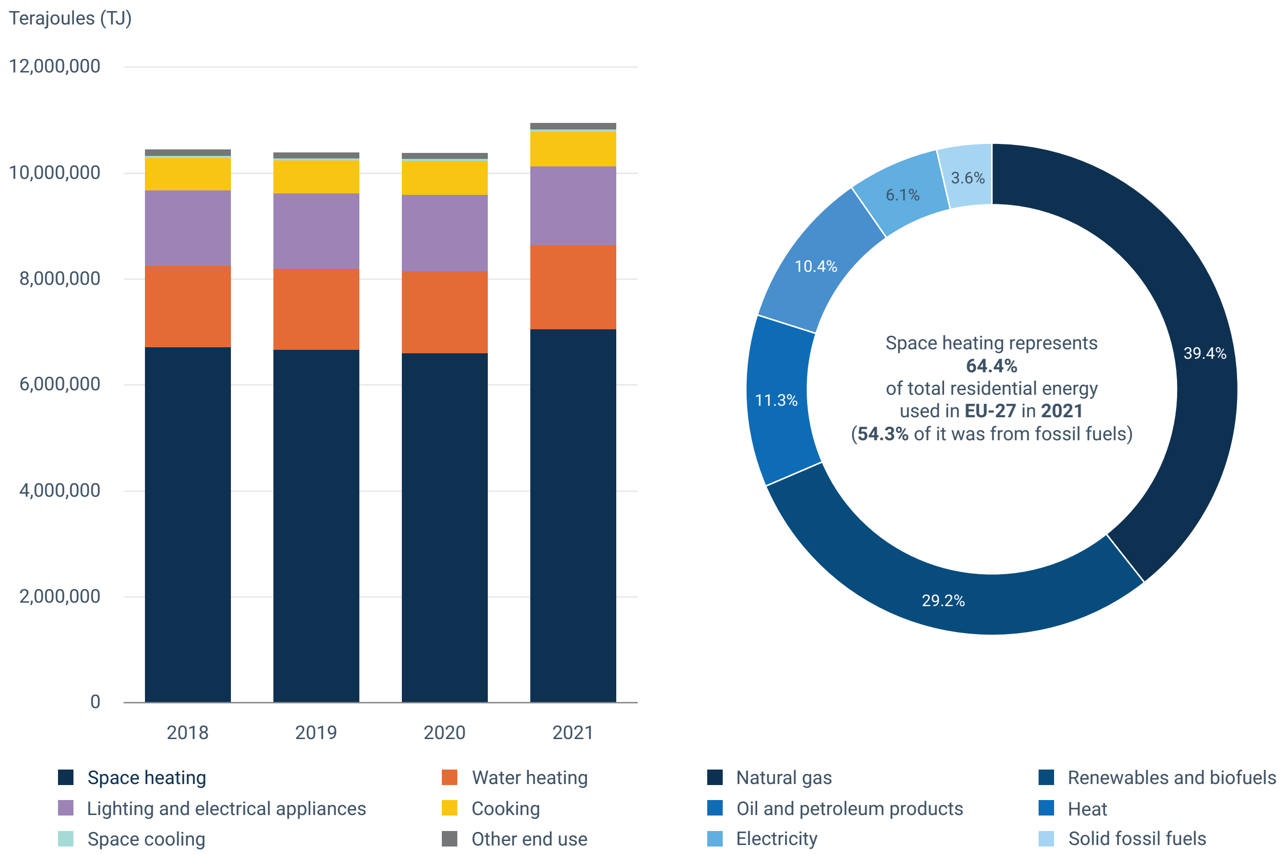
Environmental impacts

Pressures and impacts from energy demand during the use phase

The energy use of buildings is the greatest source of GHG emissions and pollution in a building's life cycle. In 2020, these GHG emissions totalled around 870 million tonnes of CO_2e in the EU (EEA, 2023d).

The total energy consumption in the EU is around 10 million terajoules (TJ) but there are large disparities between countries, even after adjustment for climatic conditions. While no significant changes have been observed in recent years (Figure 2.7), prior to that, data from the European Commission (EC) (2022c) show that between 2000 and 2019, a downward trend was observed for space heating. This downward trend came about as a result of a long-term active energy policy, energy renovations and more efficient space heating equipment becoming available. Additionally, the demand for heating or cooling energy is lower for new than existing buildings.

Figure 2.7 Residential energy demand by use



Source: EC, 2022c.

A recent study (Röck et al., 2020)one must go beyond operational energy consumption and related GHG emissions of buildings and address their full life cycle. This study investigates the global trends of GHG emissions arising across the life cycle of buildings by systematically compiling and analysing more than 650 life cycle assessment (LCA, looking at 238 LCA building cases, analyses the contribution of both the embodied and operational impacts of building life cycles in different regions of the world. The results indicate that in new buildings, built according to new standards for energy performance, the share of embedded impacts over impacts across the building's entire life cycle increases. Additionally, in buildings following advanced standards, such as nearly zero energy buildings (NZEBs) or passive buildings, the embedded impacts may be even higher than the use stage impacts. This balance is further discussed in Sections 4.3 and 4.4 of this report, which focus on the material (embodied) impacts and energy impacts of buildings.

Further impacts on the environment from the use stage relate to pollutants. Energy consumption in the residential, commercial and institutional sectors has been reported as the main source of several air pollutants (e.g. particulate matter, carbon monoxide and black carbon). For example, regarding particulate matter, energy use in buildings was responsible for 44% and 58% of PM_{10} and $PM_{2.5}$ emissions, respectively (EEA, 2022e).

Pressures and impacts from water demand during the use phase

Water used in the operational phase of buildings refers to the total water used by residents, both inside and outside the building, over the total period the building is in use.

Most of the water used in residential buildings is for personal washing (35%), toilet flushing (25%), washing clothes (14%), dish washing (8%), drinking and cooking (5%), room cleaning, garden irrigation and car washing (5%), and other uses (8%). The typical amount of water used for these activities depends on several factors such as culture, income, number and age of residents, quality of appliances, weather conditions and building type (Mannan and Al-Ghamdi, 2020).

Wastewater treatment processes typically require a lot of energy and the use of various chemicals. Hence, energy use typically causes the highest environmental impact of all aspects of water use. Additionally, metals from sludge can contribute significantly to human toxicity and aquatic ecotoxicity (Suh and Rousseaux, 2002).

Only a limited amount of information has been published to date on water consumption as it relates to buildings. A recent German study on environmental impacts in residential and non-residential buildings looked at building life cycle stages from raw material extraction to the use phase; it reports that the highest water consumption occurred during the use phase is followed closely by the initial phase when construction products are being produced (Ramseier and Frischknecht, 2020).

Pressure and impacts from the emission of hazardous substances from the surface of buildings

Construction products (e.g. flooring, paints, insulation products, glues) may emit chemical pollutants such as volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs). This affects the indoor air quality in buildings and poses a risk to the health and well-being of building occupants (Halios et al., 2022; Pelletier et al., 2018).

The leaching of hazardous substances from building surfaces during the use phase may pollute soils near the building and runoff water from the building. In particular, biocides leaching from façade coatings (e.g. plaster, mortar, paint) and herbicides leaching from roof membranes treated against root penetration contribute significantly to urban water pollution (Kiefer et al., 2024; Schoknecht et al., 2021; Vega-Garcia et al., 2022; Wicke et al., 2022).

Main insights

- The main environmental impacts while a building is in use are due to energy consumption for heating/cooling and electricity use, which results in GHG emissions and other air pollutants.
- Currently, air emissions generated during the use phase of buildings have a significant environmental impact in the EU building sector.
- Other environmental impacts from building use are also relevant, including water depletion due to water use and pollution from wastewater treatment.

2.2.4 Renovation stage

In this report, renovation indicates extensive changes to a building (e.g. renovating the façade while improving the insulation of all the windows and the roof and changing the heating system, as opposed to installing new kitchen countertops). Renovation, in terms of life cycle stages, is an integral part of the use stage of a building.

In terms of environmental impacts, renovation is a key vehicle for changing the way buildings interact with the environment and other, environmentally-significant systems such as the energy system. Due to the fact that buildings can be used for a long period of time, renovation may happen more than once for the same building and may have limited or far-reaching consequences in terms of the building's environmental performance. Renovation is the only way to improve the performance of existing EU building stock without engaging in extensive demolition and new construction. As such, it is a key policy area in the EU.

Renovation strategies to reduce energy use and carbon emissions while a building is in use may also have positive socio-economic effects. Some of these effects can include higher levels of user comfort, health improvements, the provision of local jobs during renovation works and economic development.

Stakeholders

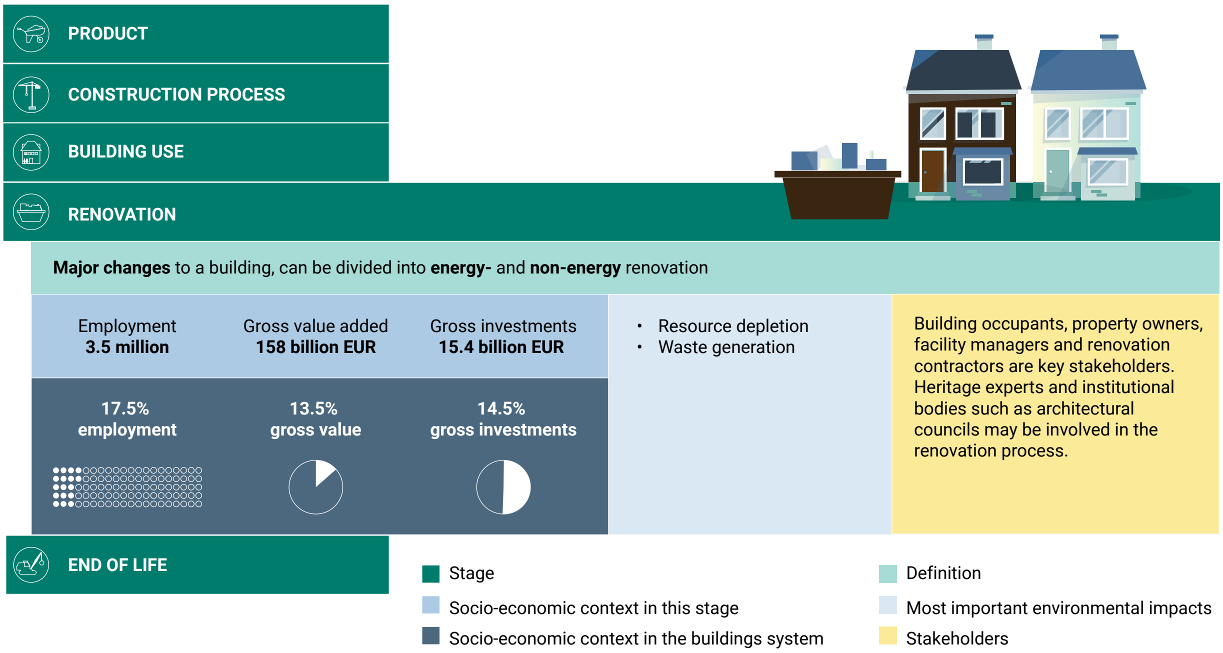
Key stakeholders in the renovation stage include building occupants, property owners, facility managers, local governments and city planners as well as renovation contractors. The key stakeholders involved at this stage are very similar to those for the construction stage. Depending on the context and the building to be renovated, heritage experts and institutional bodies such as architectural councils may also be involved in the renovation process in the identification and preservation of cultural values.

Socio-economic context

The economic contexts for the renovation life cycle stage and the construction life cycle stage often overlap, as the same companies can be involved in both activities ([4]).

([4]) The relative economic figures for the renovation and construction stages are described in Section 2.2.2.

Figure 2.8 Socio-economic and environmental relevance of the renovation life cycle stage of the buildings system



Note: Image © EEA.

Source: Eurostat, 2022b.

Though relatively small in economic terms, the renovation life cycle stage grew in the decade 2011-2020 and is set to play an increasing role in the EU economy in the future. The economic relevance of renovation is expected to grow much faster in the medium term due to subsidies for 'energy' renovation introduced by many EU governments in post-COVID recovery packages as well as an expected increase in the demand for 'energy' renovation as a result of EU climate and energy targets. Due to its substantial overlap with the construction life cycle, in terms of relevant sectors, a shift in economic value from construction to renovation is expected in the EU in the coming decades.

Despite an increase in investments in the EU on renovation to improve building energy efficiency between 2015 and 2022 (up to EUR 198 billion), there exists a large investment deficit (69%) with respect to the level required to achieve the EU 2030 climate targets. It is estimated that opportunities for renovation investment in the EU-27 will total EUR 243 billion per year until 2050 (BPIE, 2020).

However, there are several socio-economic barriers to achieving a significant acceleration in renovation efforts towards a decarbonised building stock by 2050. The limitations can be financial but also related to inconvenience and effort level for homeowners (EEA, 2024). The magnitude of the financial challenges relating to energy renovations becomes evident when considering the costs involved: payback times can often extend to several decades — commonly falling within the range of 30 to 50 years (EC, 2020c). At the same time, levels of residential ownership vary considerably across the EU; they stand at just over 50% in Germany to nearly 100% in Romania, with an EU average of around 70% (EC, 2020c). This diversity in ownership levels poses challenges when it comes to realising economies of scale in building renovation.

Building renovation offers several social, economic and environmental benefits. Deep renovations of residential buildings lead to healthier environments for building owners, occupants and society while delivering high energy savings and lower bills. For every EUR 1 million invested an average of 18 local, long-term jobs are created in the EU, offering a significant boost to the economy (Renovate Europe, 2020). Energy-efficient renovations of office buildings have been shown to enhance productivity by approximately 12%; this productivity boost equates to a potential economic benefit of about EUR 500 billion annually (Renovate Europe, 2020).

Less air pollution and a better indoor climate can lead to fewer respiratory diseases and hospitalisations, improved worker productivity and improved performance in schools. A study has shown that the aggregation of direct and indirect benefits from energy renovation leads to an annual benefit to society of EUR 104-175 billion, considering EUR 52 lower n average energy bills and a reduced outlay of subsidies from energy production. Health benefits from an improved indoor climate alone can account for savings of up to EUR 42-88 billion per year (Copenhagen Economics, 2012).

These benefits require significant investment, though. The poorest parts of the population are expected to benefit most from renovation-related improvements but in the absence of well-designed policies, significant trade-offs could be triggered because those who would benefit most cannot afford to pay the costs for renovation. This is a general issue that should not be disregarded (see Section 3.2.1 and Chapter 4 in this report).

Environmental impacts

Energy renovation in the EU building stock is a crucial component of efforts to reduce CO_2 emissions and energy consumption. Effective energy renovation is the most important approach in terms of substantially decreasing both direct and indirect emissions within the building sector while also cutting down energy expenses for households, businesses and administrations.

Renovation includes thoroughly insulating building envelopes (including walls, roofs, floors, windows and doors) and enhancing heating and ventilation systems. However, the prevalence of a large volume of less ambitious or shallow retrofits can inadvertently result in suboptimal lock-in situations; this can slow down progress towards decarbonisation objectives and have negative environmental and economic consequences in the long term. The following are examples of potential negative consequences:

- Ineffective window solutions: poor choices in window renovations, such as opting for single-pane glass instead of energy-efficient double or triple-glazed windows, can lead to heat loss, increased energy use and higher emissions.

- Lack of smart building technologies: failing to incorporate smart technologies for energy management and control can result in inefficient energy use, missed savings and higher emissions.

Optimal renovation scenarios involve improvements in a combination of different areas (e.g. insulation, windows, heating/cooling system, materials). Additionally, choices must be feasible for the given context and adapted for the building in question. The right choices also support the generation of co-benefits (e.g. in terms of the health and comfort of occupants) and take into account multi-cycle effects, anticipating future maintenance and renovation needs. This kind of forethought contributes to increased circularity in the buildings system.

These kinds of renovation actions increase material needs especially for insulation products, followed by ceramics, wood and concrete. Non-energy waste is typically in the form of ceramics from replacements of construction products in bathrooms and kitchens. Energy-related renovation includes the installation of insulation products, replacement of windows, replacement or installation of heat/electricity distribution systems and heat/electricity generation systems. In general, more materials (mainly glass and some insulation) are added to the stock during energy renovation.

Particular attention must be paid to renovation scenarios (e.g. functional, structural, energy-efficient, aesthetic or complete overhaul renovations) to avoid negative environmental impacts over a building's life cycle. This is due to the fact that increased insulation in energy renovations can increase the carbon footprint of insulation products (Goldstein et al., 2013). Bio-based insulation products are expected to have a lower carbon footprint than mineral-based ones, but they may have higher impacts in areas like land and water use, highlighting the importance of holistic, whole life cycle approaches to the buildings system (Horup et al., 2022).

The levels of renovation waste are generally relatively difficult to quantify due to diverse retrofitting options as well as different levels of renovation. Big variations are reported in the literature in attempts to assess the share of waste generated by renovation in relation to total construction and demolition waste (Sáez, 2018). Furthermore, the share of renovation waste is typically not reported in statistics or the literature. Often, amounts of renovation waste (as well as amounts of construction waste) are simply included in the figures for demolition waste.

Data from Norwegian statistics on construction and demolition waste generated during the period 2009-2021 (SSB, 2022) indicate that on average 33% (with variations from 26-40%) of construction and demolition waste is generated in the renovation phase. This waste consists mainly of bricks, concrete and other heavy construction products and, to some extent, wood waste and mixed waste.

Main insights

- Renovation is essential to improve the existing EU building stock in terms of economic, environmental and social sustainability.

- Energy renovation of the EU building stock is a driver for reducing future EU CO_2 emissions and energy consumption. However, if poor decisions are made, there is a risk that lock-in situations will arise.

- The main obstacles to energy improvement in buildings are high investment costs, lack of information on energy-efficient solutions at all levels as well as a perceived or real lack of specific available solutions.

2.2.5 EOL stage

The EOL stage relates to activities to decommission buildings including building demolition and the transportation and management of construction and demolition waste (CDW). It also encompasses reuse and recycling as means to avoid the use of virgin materials and associated CO_2.

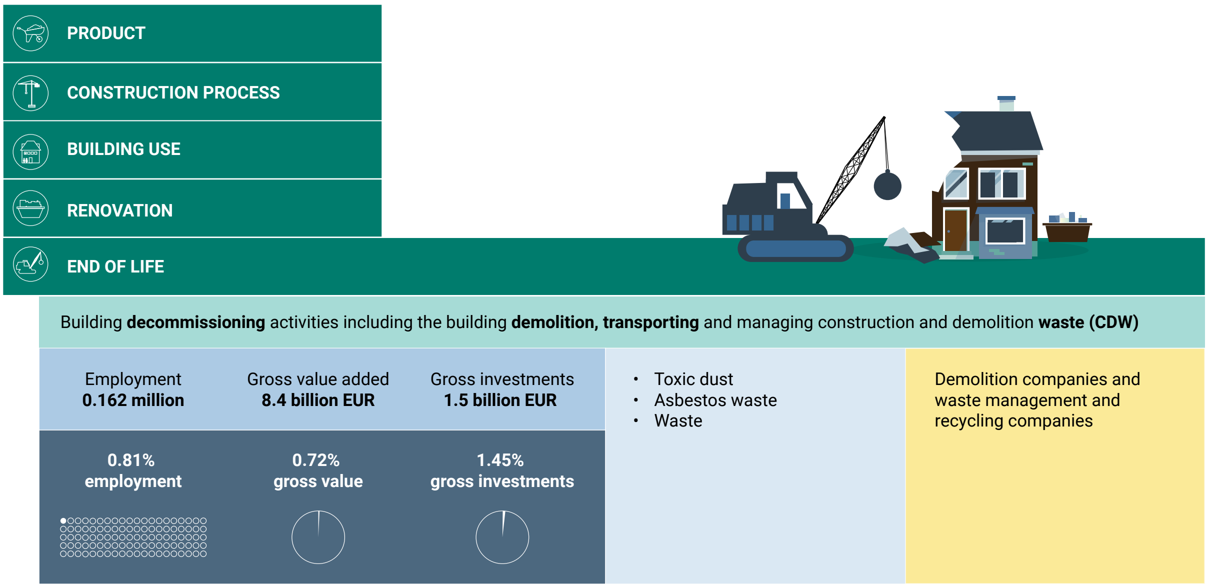
Stakeholders

In the EOL stage, new stakeholders come into play; namely, demolition companies, and waste management and recycling companies.

Socio-economic context

The EOL life cycle stage, involving deconstruction, CDW transport and waste treatment, is the final stage of a building's life. This stage currently represents a very small share of the total economic value of the buildings system.

Figure 2.9 Socio-economic and environmental relevance of the EOL life cycle stage of the buildings system



- Stage
- Socio-economic context in this stage
- Socio-economic context in the buildings system
- Definition
- Most important environmental impacts
- Stakeholders

Note: Image © EEA.

Source: Eurostat, 2022b.

Environmental impacts

The most important environmental consideration linked with building demolition is the generation of CDW. In 2020, the total amount of CDW (excluding soils and dredges) generated in the EU-27 was 333million tonnes ([5]), making it the largest waste stream in the EU by weight, if the generation of extractive waste is discounted. This total includes all the waste produced as a result of the construction and demolition of buildings and infrastructure, as well as road planning and maintenance.

Based on figures for waste from building activities during 2009-2021 in Norway (excluding asphalt waste), an average of 26% of CDW originates from construction activity; an average of 33% is generated by renovation projects and an average of 41% is caused by demolition (SSB, 2022).

A recent study used material flow analysis to estimate outflows from renovation and demolition in the EU based on data for the composition of building stock in different EU regions. It took into account building types, the ages of buildings in representative Member States, and renovation and demolition rates (JRC, 2022).

([5]) Data retrieved 3 July 2023.

The material with the highest percentage of outflow is concrete, ranging between around 38% in Northern Europe and 61% in Western Europe. In Northern Europe, the fraction of outflow from concrete is relatively low, while the wood (circa 5%) and brick (circa 15%) fractions are significantly higher than in other regions. The steel fractions are roughly equal between the regions (ranging from circa 4% to circa 6%), while the percentage of plastic outflow is highest in Southern Europe (2.3%) ([6]).

The demolition of buildings involves dismantling or destroying structures using various methods such as excavators, drills or explosives, which can significantly affect the composition and quality of CDW. In the past, buildings were not designed for deconstruction and re-use of their building elements or products. Consequently, building demolition, like building construction, can be responsible for the release of toxic dust, such as silica or hardwood, which have carcinogenic properties (Roadmap on Carcinogens, 2020).

People who work at construction sites every day are therefore at higher risk of health problems like coughing, wheezing and shortness of breath, including aggravation of asthma, heart and respiratory complications, strokes and various cancers including lung cancer (Dar et al., 2022). Asbestos and polychlorinated biphenyls (PCBs) are of particular concern on renovation and demolition sites. Dust from materials like asbestos and silica can be hazardous because of its physical characteristics or it can contain toxic chemicals like PCBs which are inhaled.

In terms of energy use, even when the operation of large equipment used in demolition consumes a significant amount of energy, typically with fuel oil as the energy source, the total energy need at demolition stage is relatively small (e.g. compared to the energy needed during the life cycle of a building). In a case study in Türkiye, it was shown to be only around 0.1% (Bozdağ and Seçer, 2007; Coelho and De Brito, 2012). Compared to other stages in the value chain, GHG emissions related to the demolition process are also insignificant in the EU (GABC et al., 2019; Staniaszek et al., 2021).

Reuse and recycling of demolition waste leads to savings in virgin materials and reduces the need for landfilling. However, a lot more material is consumed in the construction of new buildings than the demolition waste generated. This means that demolition waste can only substitute virgin materials to a limited extent even where rates for reuse of construction products or recycling rates for materials are high.

Recycling metal scrap not only has economic value but also significantly reduces GHG emissions and pollution, with electric arc furnaces in steel recycling emitting only 25% of the CO_2 produced in traditional steel production. Similarly, the use of aluminium scrap saves about 95% of the energy required for primary production.

LCA calculations (JRC 2022) also indicate that high-quality recycling of concrete (here defined as the recovery of cement to be used for new concrete along with gravel and fines) can lead to significant CO_2 savings. In contrast, low-quality recycling (e.g. for use as aggregate in concrete and road construction) results in only small net CO_2 savings, if any. The savings are small because the extraction of recycled aggregate from concrete waste requires additional processing and machinery. Additionally, GHG emissions are caused by long transport distances currently involved in recycling heavy materials like those in CDW.

When mineral CDW are recycled in roads, or backfilled or disposed of in landfills, there can be negative impacts for soil and ground and surface water due to the release of salts and metals. The impacts are highly dependent on the quality of the waste and the actual site conditions.

([6]) In this context it should also be noted that the modelled outflows differ for many countries from the Eurostat waste data, even if taking into account that this data also include waste from the construction phase. One reason for this discrepancy relates to how and what data are reported to Eurostat.

Incineration of CDW in waste-to-energy plants may lead to air emissions. For instance, in the case of polyvinyl chloride (PVC) waste, often found in tubes, flooring and windows, mechanical recycling may not be feasible (due to legacy substances or impurities). However, the incineration of large quantities of PVC at once can lead to emissions of hydrogen chloride (HCl) and dioxins, posing environmental risks (Fråne et al., 2019).

The economics of recycling solutions are the overriding consideration in their uptake. The market acceptance of products made using waste as an input material will only be assured when production costs are lower than for virgin materials. Furthermore, the transport distances for recyclables may be critical for the economic viability of recycling (usually maximum 35km, after that it becomes too expensive) (EC, 2016). This is especially the case for high-volume waste, such as concrete aggregates or mineral wool, in Member States in which raw materials are readily available near the end user.

Main insights

- The most important environmental consideration linked to building demolition is the generation of CDW, which reached 333million tonnes in the EU in 2020.

- A truly circular construction life cycle requires as many EOL products as possible to be reused and recovered materials to be directed from downcycling to high-quality recycling. Despite high recycling rates for inert mineral waste, most CDW is downcycled, meaning that the main benefit currently is in lowering natural resource use.

- Even if all materials at EOL stage could be recovered for reuse or recycling (which is not the case due to technical reasons), there would not be sufficient recovered materials to cover more than a fraction of the demand for construction products.

- Although the GHG emissions from the EOL stage are insignificant, there is substantial mitigation potential from recycling demolition waste (mainly metals) since they emit only a small fraction of the GHGs released in the production of their virgin alternatives.

The EOL stage also has implications for other systems outside the scope of the buildings system:

- The creation of dust, vibrations, noise and GHG emissions during the demolition process can have significant environmental impacts, affecting air quality and biodiversity around the demolition site.

- Traffic related to transporting generated CDW causes noises and air emissions in the proximity of the demolition site, especially in urban environments.

2.3 Synthesis of the mapping of the current state and impacts of the buildings system

Table 2.1 presents a comprehensive snapshot of the current state of the buildings system across Europe, focusing on the various life cycle stages. This table serves as a valuable resource for understanding the key actors, essential socio-economic factors and critical environmental impacts. Mapping these elements through different life cycle stages informs a holistic perspective on the outlook for a sustainable buildings system and the actions required to get there.

Table 2.1 Summary of the state of the current buildings system in Europe

Life cycle stage	Key actors	Key socio-economic factors	Key environmental impacts
Product stage	Extractive industries, transportation and logistics companies, and construction products manufacturers.	Accounts for 24% of the total economic value created.	• Accounts for 15-35% of total environmental impact of the buildings system. • Contributes about 6% of the total European climate change impacts. • Dominated by bricks, cement and concrete production. • High energy consumption in steel production. • Increased demand for insulation products.
Construction process stage	Owners and developers. Architecture and engineering teams, and construction companies.	Accounts for 42% of the total economic value created.	• Low transport efficiency leading to emissions, noise and reduced productivity. • Waste, noise, air and water pollution, climate change, land use, hazardous emissions. • Approximately 15% of construction products wasted during construction. • Land use management required to maintain biodiversity.
Use stage	Building occupants, property owners and facility managers.	Accounts for 20% of the total economic value created.	• Energy consumption for heating and cooling. • Impact of floor area growth on embodied impacts.
Renovation stage	Building occupants, property owners and facility managers.	Accounts for 13% of the total economic value created.	• Generally, the best solution for sustainability. • Energy renovation impacts on EU CO_2 emissions and energy consumption. • High investment costs and lack of information and qualifications.
End-of-Life stage	Demolition companies and waste management and recycling companies.	Accounts for only 1% of the total economic value created.	• High recycling rates for inert mineral waste. • Need to increase reuse and high-quality recycling. • Challenges related to waste sorting and waste quality.

In the points below, the key socio-economic and environmental factors in the current buildings system in the EU are outlined, based on an integration of the analysis conducted in this chapter:

- Most jobs and more than half of the value in the buildings system are created in the construction stage.

- The product stage uses the most materials like cement, concrete and steel; about one third of all raw materials consumed in the EU is used for building construction and renovation. Significant GHG emissions are associated with the production of these materials, as 5-12% of annual EU emissions are attributed to producing construction products and building construction.

- Buildings systems have a limited impact on biodiversity loss. What links there are between buildings and biodiversity are related to the construction stage in terms of the use of timber in construction and the occupation of land by buildings (around 4.3% of the surface area of the EU).

- Incredible amounts of energy are currently used in heating/cooling and providing electricity to EU buildings at their use stage. Energy production still has significant climate change impacts in the EU.

- Renovation is currently a key focus in the EU buildings system. This is due to the ageing building stock and renovation's potential to significantly improve buildings' environmental performance by reducing CO_2 emissions and energy consumption.

- Adopting circular economy principles in building renovation can reduce the use of virgin materials in existing buildings and minimise emissions embedded in building materials.

- Construction and demolition waste is the largest waste stream in the EU, excluding extractive waste, and most of it originates from the EOL stage of buildings.

3 The future of buildings in Europe

Chapter 3 identifies and critically analyses the existing network of environmental policies at EU level to describe the politically-desired future for the buildings system. It also takes stock of existing socio-economic and environmental drivers, and emerging trends, to assess the current outlook for the buildings system.

Initially, the report outlines some of the key current policies that directly or indirectly impact developments in the EU building sector. The chapter then goes on to consider the development horizon, with a focus on observable policy/political trends that give an indication and have the potential to influence the sustainable buildings' trajectory. Similarly, the report outlines additional influencing trends in the social, economic, environmental as well as technological domains.

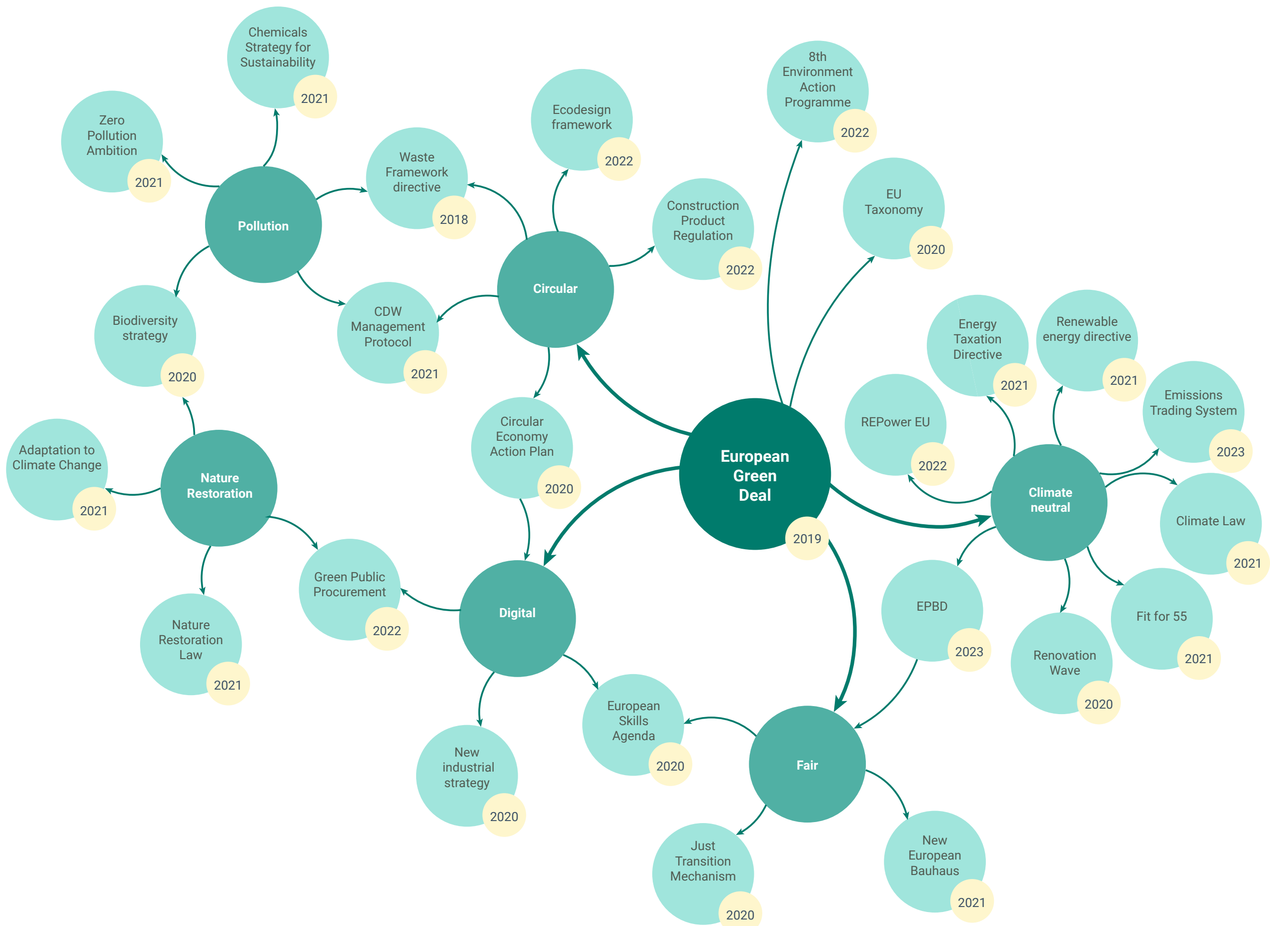
Based on the evidence from Chapter 2 (i.e. hotspots in the building sector), current policies and forward-looking trends, the report then presents a visualisation of a potential sustainable buildings system for 2050. It is important to emphasise that this visualisation describes a set of desired characteristics for the buildings system of the future, in line with the EU's vision of living well within planetary boundaries by 2050.

3.1 Main principles underpinning EU buildings-related policies

This section critically analyses the existing network of environmental legislation at EU level to identify key principles and ambitions for the buildings system up to 2050. Several topics emerge from these policies, namely energy and climate-neutrality (e.g. Fit for 55, the Energy Taxation Directive, Energy Performance in Buildings Directive (EPBD), Energy Efficiency Directive and the Renewable Energy Directive), circularity (e.g. Circular economy action plan (CEAP), Ecodesign for Sustainable Products Regulation, Construction Products Regulation (CPR)), digitalisation (e.g. new industrial strategy and CEAP), nature regeneration (e.g. EU biodiversity strategy) and a socially just transition (e.g. New European Bauhaus (NEB), Just Transition Mechanism). These ambitions are represented in Figure 3.1.

While some topics are specifically targeted by certain policies and regulations, such as energy, others are transversally integrated across policies, such as digitalisation and the socially just transition. Overall, however, there is currently no comprehensive policy initiative targeting buildings as a system and addressing all the relevant environmental issues together at EU level; policy in this area is mostly thematic at the moment.

Figure 3.1 **EU policies of particular relevance to the buildings system and the key ambitions of the EGD**



Note: Dates refer to the latest amendments or recast proposals.

Source: Adapted with persmission from ETC CE.

The 2030 Agenda for Sustainable Development (with the 17 Sustainable Development Goals — SDGs at its core), the Paris Agreement and the United Nations Framework Convention on Climate Change (UNFCCC) are fostering increasing levels of ambition worldwide. In the EU these high ambitions are set out in the European Green Deal (EGD) (EC, 2019). This action plan includes a comprehensive set of policy initiatives launched by the EC in December 2019, addressing several domains, towards a fair and prosperous society that tackles climate- and environment-related challenges. It aims to achieve net-zero GHG emissions by 2050, increase the share of renewable energy, improve energy efficiency, promote sustainable mobility, protect biodiversity and reduce pollution, while ensuring a just and inclusive transition for citizens and regions.

The EGD involves a package of measures and policies for different sectors. Additionally, roadmaps for implementation are outlined in greater detail in key documents such as the New EU industrial strategy (EC, 2020d), the circular economy action plan (EC, 2020a) and the Renovation Wave strategy (EC, 2020b). The Renovation Wave is a key strategy for implementing the major changes needed in the building sector, as currently renovation rates are too low to achieve the EU's climate neutrality ambitions (BPIE, 2022).

Figure 3.2 Current rates for building renovations and the levels required to meet EU climate targets

Annual renovation rate	Annual deep renovation rate	Annual investment (vol.)	Annual investment (share)
Current: 1% (EU level, small national variation)	Current: 0.2% (EU level, small national variation)	Current EUR 58 billion spent on medium and deep renovation	Current: EUR 127 billion with 66.3% light renovation, 28.3% medium, 5% deep
Needed for 2030 targets: double the current rate to 2% (renovation wave)	Needed for 2030 targets: 3% overall (BPIE estimate)	Needed for 2050 target: EUR 243 billion need annually to align building stock with climate neutrality	Needed for 2030 target: 70% of renovations to be deep*

Note: *, The European Commission does not have a set target for deep renovation

Source: BPIE, 2022.

The Eighth Environment Action Programme (8th EAP) is the EU's current legally-agreed common agenda for environmental policy and anchors the EU's commitment to environmental and climate action until 2030; it is guided by a long-term vision to 2050 of wellbeing for all, while living within planetary boundaries. The 8th EAP builds on the EGD. It has six priority objectives related to climate neutrality, climate adaptation, circular economy, zero pollution, protecting and restoring biodiversity, and reducing environmental and climate pressures related to production and consumption. In addition, the programme sets out enabling and monitoring frameworks to measure progress towards the required systemic change.

Key principles are outlined below. These principles are derived from the entire complex legislative framework around buildings but are not necessarily connected unilaterally to one piece of legislation. They reflect the guiding principles for the EU's strategic orientation around the buildings system.

'Polluter pays' principle

The Fit for 55 communication (EC, 2021a) outlines a plan to achieve the EU's 2030 climate target and reduce GHG emissions by at least 55% in comparison to 1990 levels. It is formally implemented in the European Climate Law (European Union, 2021). Besides setting binding emission reduction targets, the Climate Law also strengthens the PPP through a revision of the EU Emissions Trading System (ETS) (European Parliament and Council, 2024a). The so called 'EU ETS 2' will cover emissions from the housing sector, where fuel distributors will be regulated entities. This ETS, covering fuel combustion in buildings, road transport and additional sectors, is expected to benefit sectors which are currently not subject to the existing EU ETS through cost-effective emission abatement. It will start operating in 2027 (EC, 2022a). In spite of the potential benefits, the implementation process for this system offers a clear example of trade-offs (including impacts on vulnerable households, covered in other parts of this report) which need to be properly addressed. The Social Climate Fund (SCF) included in the Fit for 55 is intended to protect citizens against trade-offs resulting from the ETS for buildings.

'Energy efficiency first' principle

Across policies there is an emphasis on the 'energy efficiency first' principle. The Climate Law sets binding targets for the gradual reduction of GHG emissions, highlighting the role of heating and cooling in buildings to achieve climate neutrality. The Renovation Wave (EC, 2020b) aims to double the annual renovation rate by 2030 to improve the energy efficiency of buildings and reduce energy poverty. To trigger the renovation of existing buildings on a large scale, the revised Energy Performance of Buildings Directive (European Parliament and Council, 2024b) introduces mandatory minimum energy performance standards (MEPS); this will gradually phase-out the worst-performing buildings, and is linked to financial solutions for lower-income households.

A proposal for the amendment of the Renewable Energy Directive (EC, 2021d) sets out a roadmap for decarbonising heating and cooling and including Renewable Energy Sources (RES) in buildings. In 2022, in the context of the Ukrainian-Russian War, REPower EU (EC, 2022a) aims to reduce the region's dependence on energy imports by increasing RES (from the 32% in the Renewable Energy Directive to up to 45% by 2030) and transitioning to a more decentralised energy system with local communities playing an active role.

'Whole life cycle thinking' principle

There is a clear tendency towards the inclusion of embedded GHG and whole life cycle carbon in EU policies. The Fit for 55 plan (EC, 2021a) identifies the construction sector as a significant emitter of GHG, both in terms of energy use and material production. At the same time, the Renovation Wave (EC, 2020b) stresses the importance of integrating circularity and life cycle environmental impacts in renovation activities. The new EPBD (European Parliament and Council, 2024b) will introduce the legal requirement to calculate and declare the life cycle environmental impacts of buildings.

The CEAP (EC, 2020a) promotes sustainable product design to reduce environmental impacts and enhance long-lasting products. The goal is to double the rates for circular material use in the coming decade and ensure that resource consumption remains within planetary boundaries. The Ecodesign for Sustainable Products Regulation (ESPR) framework (EC, 2023g) mandates the assessment and declaration of life cycle impacts. This requirement will also be integrated in the revised Construction Products Regulation (EC, 2022c), which will require digital product passports and environmental product declarations.

The Waste Framework Directive defines the concept of end-of-waste, establishing how it can be identified. In the buildings system these identification criteria need to take into account the fact that the zero pollution ambition and the chemicals strategy for sustainability may influence whether historical construction products are recyclable and ensure that any new construction products placed on the market do not contain hazardous substances that may make them hard to recycle (e.g. PFAS).

'Fit for the ambitions of today and the realities of tomorrow' principle

Digitalisation is a key element in European policies. It is integral to the objectives of the proposal for a revised CPR through Digital Product Passports (EC, 2022c) and the EPBD (European Parliament and Council, 2024b), which promotes digital building logbooks and centralised access to data, including energy performance certificates and renovation roadmaps. In the Renovation Wave (EC, 2020b), smart technologies like digital twins and smart meters optimise building performance, safety and productivity.

These initiatives align with the new industrial strategy's vision for a Europe ready for ecological and digital transitions (EC, 2020d). Addressing the challenges of climate change is an economic opportunity to develop new technologies and new business models for long-term competitiveness. As part of this transition, existing jobs will need to be transformed (EC, 2020b). For example, the European Skills Agenda for sustainable competitiveness, social fairness and resilience (EC, 2020c) expresses the need for investment in upskilling in the areas of energy and resource efficiency, decentralised renewable energy solutions, digitalisation and the renovation of existing buildings.

Principle of 'avoiding significant harm'

The EU Taxonomy Regulation (European Parliament and Council, 2020) sets out a common definition for financial and non-financial players operating in the European Union to assess the extent to which their activities can be considered environmentally sustainable. A crucial aspect of this taxonomy is the 'Do No Significant Harm' (DNSH) principle, which mandates that investments aimed at improving one environmental dimension should not negatively impact other dimensions. This principle, initially established within the EU Taxonomy for sustainable finance, has been extended and introduced in various other EU initiatives and regulations. Criteria related to climate change mitigation and adaptation (e.g. renewable energy, energy efficiency, clean mobility, for instance) have applied from 1 January 2022. Meanwhile, criteria related to the following areas came into force in 2023:

- transition to a circular economy (e.g. facilitating the repurposing and deconstruction of buildings or reducing the use of construction products);
- pollution prevention and control (e.g. minimising the impact on human health and adequate removal of hazardous waste);
- protection of water (e.g. management and efficiency);
- restoration of biodiversity (e.g. land management and remediation of contaminated sites).

'Giving more to the planet than taking' principle

Biodiversity restoration is one of the aspects highlighted both in the green public procurement strategy (Donatello et al., 2022; EC, 2008) and the EU Taxonomy Regulation (European Parliament and Council, 2020). The EU's biodiversity strategy (EC, 2020c) and the *EU Bioeconomy Strategy Progress Report* (DG Research and Innovation (EC), 2022) stress that buildings and urbanisation can endanger biodiversity; this can lead to displacement and extinction of species, air and water pollution, and harm to wildlife. A key principle expressed is to give back to nature more than taking away, an idea also included in the CEAP (EC, 2020a). While the current buildings system can cause harm it may also offer potential solutions for resilience, mitigation of adverse impacts and biodiversity regeneration.

The strategy on adaptation to climate change (EC, 2021b) focuses on climate resilience. It envisions a society fully adapted to the unavoidable impacts of climate change and highlights the importance of integrating climate resilience in the criteria for green public procurement strategy for buildings (Donatello et al., 2022; EC, 2008), the EPBD (European Parliament and Council, 2024b) and the CPR (EC, 2022c).

'Leaving no one behind' principle

The concept of a just transition is at the forefront of EU policy, as outlined in the CEAP (EC, 2020a) and the European Climate Law (European Union, 2021). These policies emphasise the importance of leaving no one behind and promoting a socially balanced and fair transition towards a low-carbon economy. This is linked to the 'beautiful, sustainable, together' principle, introduced in the NEB initiative (EC, 2021c). This aims to bring a cultural and creative dimension to the EGD by promoting lifestyle changes (EC, 2019), with community involvement, multi-disciplinarity and co-design as key priorities.

The EPBD (European Parliament and Council, 2024b) recommends integrating socially inclusive and participatory design in renovation processes and supporting vulnerable households through financial incentives, including rent-cap measures. The Just Transition Mechanism was created to leverage private and public resources to provide access to re-skilling programmes, energy-efficient housing and financial support to the regions, industries and workers that will face the greatest challenges. Additionally, the Fit for 55 package introduced the SCF that will be in force for the period 2026-2032 (EC, 2021a).

'Decoupling growth' ambition

European environmental policies aim to create a green, circular, digital, climate-neutral and just Europe but often fall short of fully addressing various environmental concerns. While some policies like Fit for 55 and the Climate Law focus on decoupling economic growth from GHG emissions, others such as the CEAP and ESPR emphasise decoupling growth from resource consumption and waste generation (Hickel, 2019). This fragmented approach reveals differing priorities and a lack of integration in addressing all environmental pressures.

Climate change is a major focus due to the Paris Agreement targets, with circularity seen as crucial for economic growth. However, there is a lack of clear, enforceable targets for biodiversity and nature regeneration in relation to the building sector. Some policies point towards a 'sufficiency' approach that is not explicitly stated (e.g. reducing the consumption footprint, prioritising building renovation over new construction, reducing net land take) and may conflict with the goal of economic growth.

Coordination challenges and minimising trade-offs

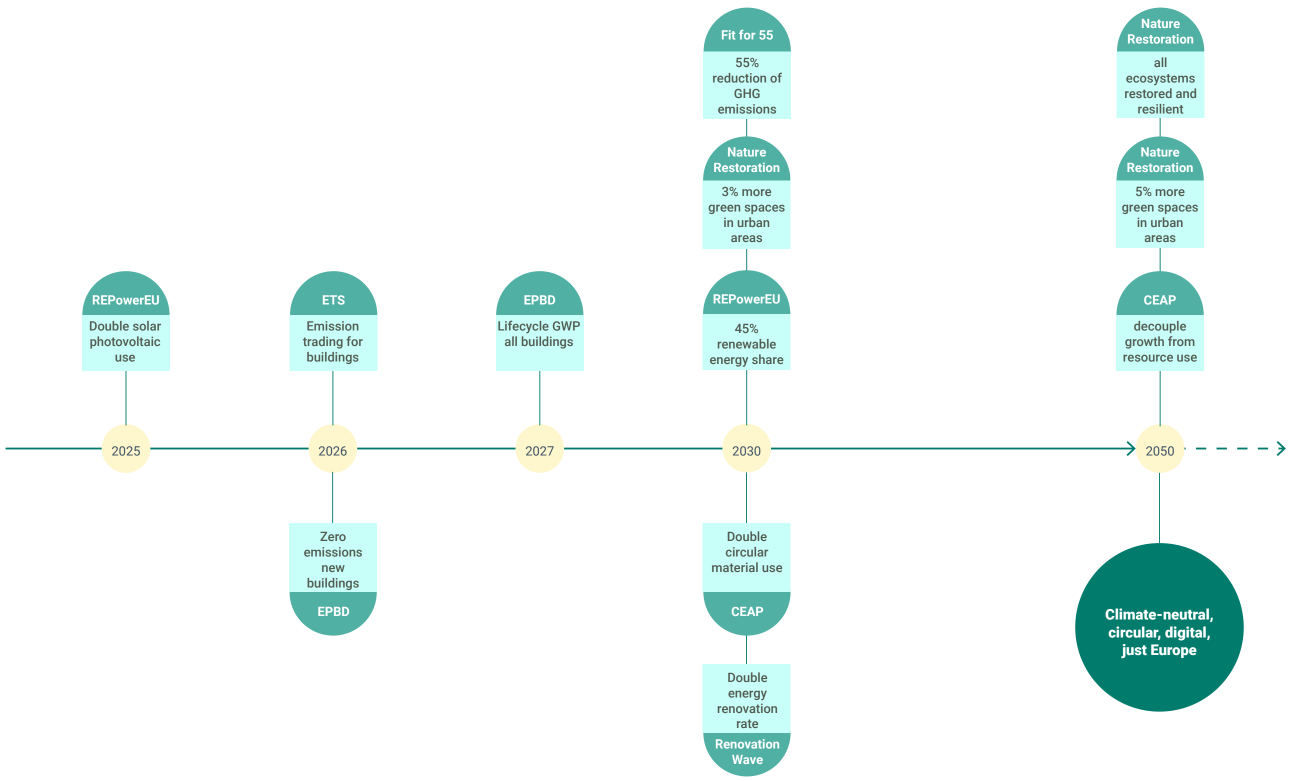
Some trade-offs need to be considered, for instance in the relationship between energy efficiency and resource efficiency measures. Key milestones for 2030 include doubling circular material use (EC, 2020a) while doubling annual energy renovation rates (EC, 2020b). While the former calls for a more frugal use of natural resources, energy renovation might require a significant increase in material consumption. These goals must be integrated and tools like life cycle assessment must be used if this balance is to be achieved.

Clear targets can take years to define in the context of the CPR, but there may not be sufficient time for this process given the urgent need for sustainable construction practices. Additionally, there are significant challenges relating to coordination, particularly in aligning different policies for better coherence and synchronising their implementation. However, with better coordination, the inconveniences of sustainable practices should be minimised and there should be an acceleration towards achieving the objectives.

Digitalisation brings many benefits, but it also leads to increased administrative burdens, requires additional resources and expertise, and involves risks around data privacy and cybersecurity.

The higher standards for energy performance in buildings are likely to contribute to increases in property values and could result in green gentrification that accentuates socio-economic disparities. Affordability, accessibility, fairness and inclusivity are keywords emerging in EU strategic policies. Clear pathways are needed to protect such aims alongside environmental goals.

Figure 3.3 Timeline of the key milestones towards a climate-neutral, circular, digital and just Europe by 2050



Source: Adapted with persmision from ETC CE.

3.2 Key trends and drivers of change influencing the EU buildings system

Policy is one of the most important drivers of change in terms of directing the future development of the EU buildings system. However, broader socio-economic, environmental and technological trends that permeate EU societies also affect the way we construct, renovate, use and decommission our buildings. Table 3.1 offers a comprehensive overview of the broad trends and drivers, categorising them into three main dimensions: socio-economic, environmental and technological. The trends and supporting evidence listed under each dimension provide a holistic perspective on how the buildings system is evolving.

The socio-economic drivers encompass factors such as changing demographics, urbanisation and economic growth, all of which impact housing preferences and the demand for sustainable living spaces. The environmental drivers include climate change mitigation and adaptation, resource scarcity and regulations driving the need for energy-efficient and environmentally-friendly buildings. On the technological front, innovations in construction products, building automation and smart technologies are key trends that are revolutionising how buildings are designed, constructed and operated.

Table 3.1 Key trends and drivers of change influencing the EU buildings system

Theme: Socio-economic	
Trends	**Supporting evidence**
Continuing increases in urban growth	• The number of people in high density cities was 1.5 billion in 1975 and 3.5. billion in 2014; it is expected to grow to up to 5 billion by 2050. • In 2021, the urbanisation rate in the EU was at 75% and is expected to grow to up to 80% by 2050. • People are concentrated in cities with under 1 million inhabitants, followed by those of 1-5 million — meaning that there is an increase in small and medium-sized cities. This is a global trend.
Europe's ageing population	• The European population is forecast to decrease from 749 million in 2020 to 630 million in 2100. A decrease of 7 million is expected between 2020 and 2050, from 448 to 441 million. • Europeans are living longer; 25.5% of the population will be over 65 by 2030 compared to 19% in 2017. In 2050, half a million people will be over 100 in the EU, with continued growth of the 65-85 and above age group.
The convergence between single-person households and co-housing schemes	• The number of households in the EU has increased by 9.5% (2009-2021), with a 27% increase in single-adult households with children and a 28% increase in those without. • Between 2025 and 2030, 30% of households in Organization for Economic Cooperation and Development (OECD) countries will be one-person households, two-person households without children and/or single-parent households. • It is expected that by 2025, 46 million people will be living alone in OECD countries. • There is an observable increase in communal living and/or co-housing schemes. For example, 8% of Danish households follow a co-housing model.
People are moving	• Globally, the number of people living in a country other than that of their birth increased from 153 million in 1990 to 281 million in 2020. • 2-3 million non-EU citizens have received residence permits or have registered as asylum seekers since 2010. • 1 million EU citizens emigrate to non-EU countries per year and 1.4 million have moved from one EU Member State to another.
The continuing inequality gap	• Income inequality is increasing with a growing gap between the wealthy and the rest of society. This can lead to inequalities in terms of e.g. life expectancy, healthy living years, access to education, labour markets, health services, distribution of income and exposure to the adverse effects of climate change. • Inflation shocks add to this. In 2022, the inflation rate for the bottom 10% was 3% higher (i.e. 10.9%) than that for the richest 10%. • 8.3% of EU citizens spend approximately 40% of their disposable income on housing.
Bottom-up and local initiatives on the increase	• The number of bottom-up initiatives is increasing, with the majority focusing on making public spaces sustainable and regenerative. • Local governments are increasing their efforts to meet sustainability targets, often exceeding national level actions. This is being complemented by increased cooperation between cities to boost sustainability efforts.
Economic growth will continue	• The global economy is expected to grow 3% annually in the coming years, with a growth rate of 3.6% in developing countries. • The economic growth of the EU is forecast to be 1.7% for 2024 and an average of 1.4% annually up to 2030. • Globally, there are currently 3.2 billion people who are classified as middle class; this number is expected to grow to 5.3 billion. • On a global level, the goal to reduce the rate of extreme poverty to 3% by 2030 is likely to be met.

Table 3.1 Key trends and drivers of change influencing the EU buildings system (cont.)

Theme: Socio-economic	
Trends	**Supporting evidence**
Digitalisation and the disruptive effect of COVID-19	• The share of people working from home has increased from 5.5% in 2019 to 12.3% in 2020 and 13.5% in 2021. • Automation and technological advancements are giving rise to more flexible employment models across sectors. • There is an increasing demand for safer and healthier workplace spaces. • E-commerce has also been growing; the figure for people buying online jumped from 55% in 2012 to 75% in 2022 across different product categories.
Theme: Environmental	
Trends	**Supporting evidence**
Buildings are adapting to climate change	• It is anticipated that the expected annual damages (EAD) from floods will increase substantially in the next century both in the optimistic and pessimistic scenarios. • The trend in cooling degree days is expected to have a substantially increasing trajectory up to 2100 (almost 700 cooling degree days in all EU macro-regions) even in an optimistic (2° Celsius increase in average global temperatures) scenario, especially so in the Mediterranean region. • There was a 212% increase in energy used for cooling between 2010 and 2019.
Buildings do not contribute enough to climate mitigation targets	• It is projected that there will be a 9% reduction in CO_2 from fossil fuels used in buildings by 2030 compared to 2015 levels, due in part to existing policies and measures. Additional policies and measures are expected to lead to a further 9% reduction, resulting in an overall reduction of only 18%. To achieve carbon neutrality for the building stock, the energy renovation rate must dramatically increase (EEA, 2024).
High exposure to air pollution	• Currently over 90% of the urban population is exposed to pollution levels above the standards set by the World Health Organization for most of the specified pollutants.
Buildings as local air polluters	• Fossil fuel combustion as an energy source for heating buildings (residential, commercial and institutional) represents one of the largest sources of local air pollutants.
Construction material scarcity	• The different life cycle stages of the buildings system require substantial amounts of materials and resources. While some of these materials are readily available and abundant, others are scarce (e.g. rare earths required for photovoltaic panels). • Supplies of these materials will be at risk in the coming decade due to growing global demand, limited availability of resources and geopolitical tensions leading to the disruption of specific value chains. • The shortage of critical materials could make the transition to the buildings system of the future slower and more expensive than expected ex ante.
Theme: Technological	
Trends	**Supporting evidence**
Digitalisation of the buildings system	• Digitalisation of the construction sector value chain will continue to expand over time. • Digitalisation is highly significant in relation building use and the environmental performances of buildings, given the relevance of energy efficiency and renewable energy improvements in the decarbonisation process. • There is heterogeneity across EU Member States in terms of the degree to which different digitalisation technologies are being implemented in the building sector.
Technological innovation is slowing down	• While innovation in environmental technologies and the subset of climate mitigation technologies reached its peak in 2012 and then remained constant, technologies specifically related to buildings experienced a substantial slowdown: they represented 1.63% (1.51%) of European (world) patents in 2011 and just 1.24% (0.93%) of European (world) patents in 2020.

Source: Own elaboration.

3.2.1 Socio-economic drivers

At a global level, the growing rate of urbanisation and its impact have been monitored and recorded for many years now. There has been a steady increase in urban growth and this trajectory is expected to continue (EC, 2023a; The World Bank, 2023).

The number of people living in high-density cities has grown from 1.5 billion in 1975 to 3.5 billion in 2014 and is expected to grow to up to 5 billion by 2050 (EC, 2023a). This equates to almost half of the global population living in cities, though variations are observable in different regions. Most of the upcoming movement to urban centres is expected to happen in the developing world in years to come (EC, 2023a).

A similar urbanisation trajectory can be observed in the EU as well. In 2021, 75% of EU citizens were living in urban areas and this figure is expected to rise to 80% by 2050 (EEA, 2022d).

It is important to note that while megacities are growing, a large share of the population will continue to live in cities with under 1 million inhabitants, followed by those with 1 to 5 million, globally — giving rise to the urban expansion of small and medium-sized cities (Gaub, 2019). This is certainly true for Europe; most of the European population lives in cities with between 100,000 and 1 million inhabitants and only 7% in cities with more than 5 million inhabitants (Gaub, 2019).

The expansion of built-up areas is another indication of the growing urbanisation megatrend. For example, built-up areas in the EU are expected to cover 7% of the bloc's territory by 2030, with a growth rate of 3% between 2015 and 2030 (EC, 2023a).

Such ongoing growth in urbanisation holds great potential for economic growth and social development. The productivity of a city has been shown to improve as the number of citizens increases due to advantages from labour pooling, access to education and more dynamic innovation patterns (Bertaud, 2015; EC, 2023a). Similarly, measures for sustainability, energy consumption and emissions tend to improve the denser a city is (ESPAS, 2019; Zhao & Zhang, 2018). However, this is only the case where there is adequate infrastructure and operating systems. If we narrow the lens, for the buildings sector, this urban growth is expected to double the number of buildings by 2060 (EC, 2023a) ([7]).

In Europe, the population is expected to decrease from 749 million in 2020 to 630 million by 2100 (EC, 2022e). Honing in on a shorter timeframe between 2020 and 2050, the population is expected to decrease from 448 to 441 million, though this figure could also be influenced by migration flows to the EU (EC, 2022e).

Simultaneously, improved living conditions mean that globally and in Europe people are living longer, especially in high- and medium-income countries (Zhang et al., 2023). In Europe, 25.5% of the population will be over 65 by 2030 compared to 19% in 2017(ESPAS, 2019). By 2050, it is expected that almost half a million people will be over 100 years old in the EU, while the numbers of people aged 65-85 and above will continue to grow too (EC, 2022a).

For the buildings sector, population projections point to an increasing number of people who will be living alone and/or with a second person in large dwellings (Eurostat, 2023b). In this scenario, plenty of buildings, especially houses, will not be fully utilised, with implications for the sustainability of the buildings' ecosystem as a whole. However, this could give rise to other opportunities, such as the potential

([7]) It should be noted that decisions about land use changes might have important implications for local government budgets. For example, taxes on building licences accounted for around 2.1% of tax revenues for municipal governments in Italy in 2023.

for elderly people to live with younger people and thus utilise all the available spaces efficiently.

Over the years, the number of households in the EU has increased, for example by 9.5% between 2009 and 2021, with a 27% increase in single-adult households with children and a 28% increase in those without children (Eurostat, 2023b). Looking to the future, it has been projected that 30% of the households in OECD countries will be either one-person households two-person households without children and/or single-parent households by between 2025 and 2030.

In other words, it is expected that by 2025, 46 million people will be living alone (OECD, 2011). Such a trend would imply an increased demand for housing and thus higher property prices (Tyvimaa and Kamruzzaman, 2019) as well as increases in the overall resource consumption per capita (Buildings and Cities, 2021).

At the same time, there is an observable increase in communal living and/or co-housing schemes, with multiple houses and/or flats brought together around shared facilities such as gardens and offices. In certain cases, this kind of housing has been built around old factories, hospitals and other buildings that allow for such a composition (coming close or in line with the trend for repurposing buildings). For example, 8% of Danish households now follow a co-housing model (Norwood, 2013; Hagbert et al., 2020; Larsen, 2019). Besides the positive effects in terms of social cohesion and well-being (Carrere et al., 2020) this trend allows for more efficient use of buildings and resource consumption, and also avoids the need for new buildings (ESPON, 2020).

Globalisation, the desire for a better life and/or displacement because of shocks such as wars or extreme natural events have led to an increased movement of people from their country of birth to another place. Globally the number of people living in a country other than that of their birth increased from 153 million in 1990 to 281 million in 2020 (IOM, 2022). This situation calls on the EU to realise the potential for innovation offered by repurposing buildings as well as co-housing schemes.

Globally, including in Europe, there has been progress in elevating (extreme) poverty as well as improving overall social welfare (Christensen, 2023). Nonetheless, at the same time, the gap between the wealthy and the rest of society is continuing to grow (EC, 2023c)). The increasing wealth gap influences the number of buildings and also property prices. There is a sharp increase in the latter, especially in large EU cities such as Berlin, Paris and Amsterdam, among others. Currently, about 8.3% of EU citizens spend approximately 40% of their disposable income on housing (Eurostat, 2023c).

The high proportion of disposable income spent on housing contributes to social inequalities since the people who are most affected by it are the medium- to low-income social groups. The high cost of housing can lead those groups to move towards deprived neighbourhoods with poorer housing conditions.

That can have an impact on health (both physical and mental) since deprived neighbourhoods may be closer to industrial zones and/or roads with high traffic volume and may be badly built and have inadequate heating, among other problems. Ultimately, this can affect life expectancy and healthy living years (EC, 2023a). For example, it has been estimated that the life expectancy of residents in London, Turin, Barcelona and Helsinki depends on the residential area, with a higher risk of death among those in poorer neighbourhoods.

Other types of inequality persist as well. These include unequal access to education, the labour market, health services, uneven distribution of health outcomes, income and exposure to the adverse effects of climate change. While such inequalities are not directly linked to housing, the disadvantages arising from such inequality can impact people's finances, access to information, networks and general social cohesion, which can then impact where they can live (good housing/neighbourhood accessibility and affordability) (EC, 2023e).

Inflation shocks only exacerbate inequality and the financial pressure experienced by medium- and low-income groups. For example, in 2022, the inflation rate for the bottom 10% was 3% higher (i.e. 10.9%) than that for the richest 10% (EC, 2023e). In sum, lower income households living in buildings with low energy efficiency in a context of increasing energy prices have experienced a worsening situation in terms of energy poverty and, consequently, inequalities.

Sustainability is gaining traction among citizens, with 93% saying that climate change is the problem of our generation and similarly 93% indicating that they have taken at least one action against climate change (EU, 2023). In this context, it has been observed that the rate of bottom-up initiatives is increasing, with many of them focusing on making public spaces more sustainable as well as regenerative. This also includes redesigning and/or repurposing buildings that are not being fully utilised. Regarding residents as active co-creators and shapers of the sustainability agenda helps increase the transparency, validity and feasibility of proposed solutions. It also improves their effectiveness (EC, 2023a).

The trend is also being complemented and supported by increased local government efforts to meet sustainability targets, including attempts to get ahead of the game and avoid waiting for actions on a more national level.

For example, there is a sharp increase in the number of cities (i.e. approximately 30 across the EU) that are looking at developing their sustainability agendas and engaging to achieve more sustainable patterns. These efforts are also being complemented by increased cooperation between cities and/or networks of cities across borders in order to drive joint initiatives and solutions and share best practices (EC, 2023a). For the building sector, this could result in a greater focus on the sustainability performance of buildings and more initiatives which seek to improve sustainability.

Over the years, national economies around the world have improved, resulting in higher welfare for citizens. Prospects for ongoing economic improvement remain good with projections of 3% annual growth in the global economy. A large share of this growth is likely to be concentrated in developing economies with a projected 3.6% growth rate; developed economies look set to grow too, but at a slower rate (ESPAS, 2019).

The forecasts project 1.7% economic growth in the EU for 2024 and an average of rate of 1.4% growth per year up to 2030 (ESPAS, 2019).

In spite of these positive projections, inflation does impacts EU consumers and their purchasing ability; it is projected to rise to 1.8% in 2024 (EC, 2023d). Overall, however, such economic growth is expected to have a positive impact on many people's socio-economic circumstances, lifting a majority of them (approximately 5.3 billion up from 3.2 billion now) into the middle-income class group, globally. In addition, it also means that the goal of bringing the extreme poverty rate down to 3% by 2030 most likely will be met. In the context of the building sector, this means that more people will be able to spend and/or invest in better housing conditions (ESPAS, 2019).

The COVID-19 pandemic has changed a lot of aspects of the world as we know it. However, the biggest change is in the way we work. Digitalisation of the workplace has accelerated and remote working among knowledge workers has been normalised

(EC, 2022a). For example, in 2019 only 5.5% of employed people (20-64 years) were working from home; in 2020 this number went up to 12.3% and 13.5% in 2021 (Eurostat, 2022a)a large proportion of employed people was faced with changing patterns of work – including working from home. In 2019, approximately 1 in 20 (5.5%. One of the potential downsides of this may be increased inequality within and across societies, mainly because not everyone is able to work remotely.

In addition to the accelerated digitalisation of the workplace due to COVID-19, automation and technological advancements are also contributing to changes in the ways we work, making it possible for more flexible employment models to be adopted across different sectors, even for frontline workers. This has a number of benefits; there is a reduced environmental impact from work due to a reduced need to travel, and lower operating costs for companies (i.e. shrinking offices).

In this context, the impact of teleworking on the building sector is most apparent in the reduced need for buildings for corporate purposes (either new builds or use of existing spaces). This offers an opportunity for them to be used for other purposes (EC, 2022b).

Besides changing the way we work, the COVID-19 pandemic has also increased the demand for safer and healthier spaces (e.g. improved air quality in the buildings where we live and work, giving rise to a demand for more efficient air ventilation and filtration systems). Businesses and building owners have listened and have taken action to renovate existing buildings to improve comfort and safety (EC, 2023a).

In addition, e-commerce has been growing across many sectors, partly propelled by COVID-19. People now make a substantial share of their purchases online and this could affect the need for physical shops going forward. For example, in 2012 only 55% of people between the ages of 16 and 74 had relied on e-commerce; by 2022 this figure had jumped to 75%. In 2022, the majority of online purchases were wearable with 42% of users, followed by food deliveries with 19% and beauty or wellness products 17% (Eurostat, 2023a). The implication for the building sector is that there may be more empty spaces available going forward and thought needs to go into how such spaces should be used (EC, 2023a). This calls for specific public policies (e.g. related to urban planning principles and procedures).

Overall, the socio-economic trends we anticipate are:

- strong demand for more buildings due to the ageing population and more one-person households, especially in cities;
- a focus on the environmental aspects of buildings and affordability issues;
- opportunities for repurposing buildings due to social innovation.

3.2.2 Environmental drivers

In a recent report (EEA, 2020a) the EEA identified a set of six thematic clusters to classify the most relevant global drivers of change that impact the environment and sustainability. Two of them relate to the environment: i) climate change and environmental degradation worldwide and ii) increasing scarcity of and global competition for resources. Both are strongly connected with the buildings system and represent relevant drivers of change in the sector.

The buildings system should be considered a crucial component of policies for adaptation to climate change. The EEA report on climate risk assessment indicates that Europe is the fastest-warming continent in the world. Extreme heat, once relatively rare, is becoming more frequent while precipitation patterns are changing. Downpours and other precipitation extremes are increasing in severity and there have been catastrophic floods in various regions in recent years. At the same time, southern Europe can expect considerable decreases in overall rainfall and more severe droughts.

These rising temperatures and extreme weather events call for deep changes in the buildings system to make the built environment less vulnerable to climate-related impacts (EC, 2023b).

Urban planning and zoning laws are increasingly taking into account projected trends in various natural hazards (Sharifi, 2021), with the aim of preventing the construction of new buildings in high-risk areas and also supporting settlements in the most vulnerable areas to move over time.

Additionally, both the design of new buildings and the deep renovation of existing buildings are now incorporating building-specific adaptation measures (e.g. strategies to cope with extremely high temperatures and raising the ground-floor level to reduce damage from floods (see Attems et al. (2020) for an overview on floods)). Indeed, according to Steinhausen et al. (2022) the EAD from floods are expected to increase substantially in the next century both in the optimistic (RCP 4.5) and pessimistic (RCP 8.5) scenarios. Similarly, there has been an increase in the demand for adaptation measures in buildings to reduce the negative consequences of exposure to extreme temperatures (EEA, 2020b). The trend in cooling degree days ([8]) is expected to have a significantly increasing trajectory up to 2100 (almost 700 cooling degree days in all the EU macro-regions even in an optimistic (2° Celsius increase in average global temperatures) scenario (IPCC, 2023), especially in the Mediterranean region (Eurostat, 2020).

Some of the solutions to this (e.g. cooling systems), however, lead to growing demand for energy inputs. In the context of a 212% increase in energy used for cooling between 2010 and 2019, this is problematic (EEA, 2022a). The energy requirements directly undermine targets for energy use and bring seasonal challenges by increasing peak electricity demand. Other solutions are emerging, such as nature-based solutions in buildings and passive-cooling techniques (EEA, 2022a).

All of the possible responses to changing climatic conditions will generate private benefits for users of both residential and non-residential buildings. However, there are barriers to fully deploying these optimal adaptation responses and upscaling the solutions due to financial constraints, asymmetric incentives for tenants and landlords, and supply-side constraints (e.g. in relation to materials).

Significant additional emission reductions in the buildings system are necessary to comply with 2030 climate targets. According to the EEA (2022b), existing policies and measures alone will contribute to a reduction of 32% by 2030 compared to 2005 levels. Additional policies and measures are expected to lead to an additional 7% reduction. The planned reduction in emissions in the buildings system is set to 60% so together, these measures look likely to contribute less than half the required reduction. To reduce the gap, additional policies are likely to be introduced to further accelerate the transformation of the buildings system, thus contributing to accelerating the transition.

([8]) The cooling degree days index is defined as the sum of the temperature gap between the predicted average daily temperature and 21°C (provided the temperature is >24°C).

While trends in air pollutant emissions (e.g. PM_{10}, nitrogen oxides (NO_x), sulphur oxides (SO_x)) are declining in the EU, 90% of the urban population is currently exposed to pollution levels above the standards set by the World Health Organization (EEA, 2024).

People's growing awareness about the damage caused by air pollution (EEA, 2023c) will mean that house prices, for example, are increasingly affected and there will be more pressure to develop solutions so that buildings can contribute to dissipating or capturing air pollution (e.g. by means of nature-based solutions, see Anderson and Gough (2020)).

According to the EEA (2023c), one of the largest sources of local air pollution is heating buildings (residential, commercial and institutional) using energy sources based on fossil fuel combustion. The role of buildings as generators of local air pollution via fossil-based energy use reinforces the pressure to increase the number of nearly zero-emissions buildings.

As highlighted in Chapter 2 of this report, the different life cycle stages of the buildings system require substantial amounts of materials and resources. While some of these materials are readily available and abundant, some others are scarce.

For example, photovoltaic panels, which are crucial for the deployment of nearly-zero emissions buildings, require rare earths and other critical raw materials. The supply of these materials will be at risk in the coming decade due to a combination of growing global demand, limited availability of resources and geopolitical tensions leading to the disruption of specific value chains (EC, 2020e).

Another example is bio-based resources (e.g. timber) used for construction. Demand for timber for construction in Europe (IMARC group, 2023) is expected to increase 11.15% per year from 2023-2028. It would be very hard for the timber sector in Europe (and abroad) to keep pace with that kind of increased demand, given the high competition for the use of biomass from different stakeholders (EEA, 2023).

While policies, market dynamics and individual preferences all push for smart and efficient buildings, the evolution of the buildings system in the future must take into account the possible constraints to undertaking new building projects and deep renovations due to the scarcity of certain crucial material inputs, which could limit the potential for upgrades. The shortage of critical inputs could make the transition to the buildings system of the future slower and more expensive than expected *ex ante.*

The global decrease in biodiversity is a pressing environmental concern, with habitat destruction, climate change and pollution contributing to a decline in many species. In response to this crisis, the construction and maintenance of sustainable buildings have become vital in safeguarding local ecosystems. Sustainable buildings prioritise the use of eco-friendly and toxic-free products, energy-efficient design and responsible landscaping practices. In doing so, they help minimise negative impacts on biodiversity by reducing habitat fragmentation and protecting native species.

Features like green roofs also play a pivotal role, providing urban habitats for various plants and animals, thereby contributing to net-positive actions on existing structures. By integrating such practices, sustainable buildings can become a cornerstone for the preservation of biodiversity, forging a harmonious coexistence between human development and the natural world. In addition, sufficiency principles can play a crucial role in reducing biodiversity loss related to buildings by encouraging a re-evaluation of how we use and design buildings and built areas.

In regions susceptible to water scarcity and droughts, careful management of water resources is imperative. Given our heightened awareness of this, there is now a greater demand for the buildings system to integrate water-saving innovations, including rainwater harvesting and wastewater recycling systems. By harnessing rainwater and recycling wastewater, buildings can significantly alleviate the strain on conventional water sources, promoting sustainability and resilience in the face of drought challenges.

In this evolving landscape, efficiently utilising water resources emerges as a vital component of responsible urban and architectural planning.

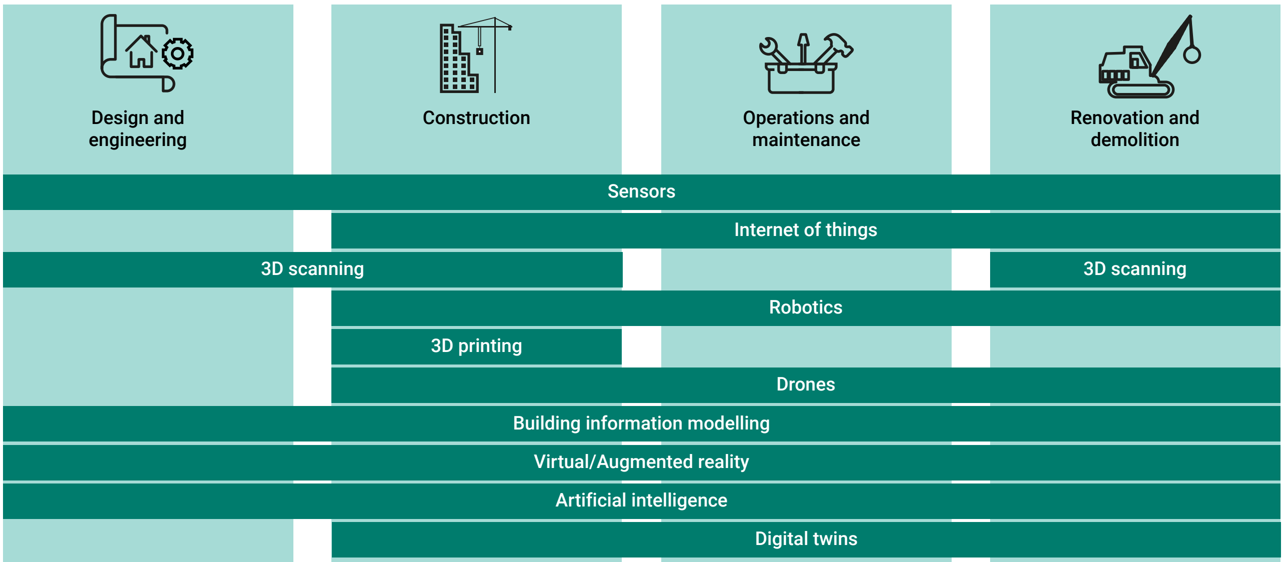
These considerations mean that existing and new buildings need to be retrofitted or designed differently in the future to adapt to and contribute to mitigating environmental challenges.

3.2.3 Technology drivers

The buildings system will strongly rely on new technologies for its future development due to the highly ambitious objectives set at a European level. EU policies are encouraging digitalisation in the construction sector (ESCO, 2022). The targets set in the Renovation Wave (which double the renovation rates across the EU in the next ten years), in the Directive on the Energy Performance of Buildings and, more generally, in the EGD (in terms of circularity of the construction sector) appear to go in this direction, as earlier identified in Section 3.1.

Digital technologies can be applied not only in the construction stage, but also in all other stages of a building's life cycle (see Figure 3.4). Energy efficiency measures are facilitated by the use of digital technologies and real-time information such as sensors, actuators, meters and energy management systems, which must be connected through communication networks (Konhäuser, 2021). The Digitalisation Working Group of the Energy Efficiency Hub (Otte et al., 2022) suggests that widespread digitalisation will contribute to very substantial reductions in energy use up to 2040 (about 10PWh in the EU) (Otte et al., 2022).

Figure 3.4 Digital technologies and the buildings sector



Source: Adapted with permission from European Cyber Security Organisation (ECSO), 2021, Figure 6, p. 28.

ESCO (2022) also highlights that the relevance of digitalisation and related policies for existing stakeholders is quite heterogeneous across the different value chain stages. So, for example, its application in 'upstream' phases (planning, design, construction, operation and maintenance) appears to be more important than in 'downstream' phases (renovation, demolition and recycling).

There are several other technological drivers and trends which might be relevant for a sustainable buildings system. Lower costs for technology, higher availability and higher applicability in the context of the buildings system can all represent technological drivers. Some examples include:

- Solar panels: the cost of solar panels has been steadily decreasing, making them more affordable for both residential and commercial buildings. As solar technology advances and economies of scale are realised, its use is likely to increase.

- Energy-efficient windows: improvements in window technology, such as double glazing and low-emission coatings, have made energy-efficient windows more accessible.

- Smart thermostats: these are becoming more affordable and accessible. They offer precise control over heating and cooling systems, leading to energy savings and increased comfort.

- Energy storage: the cost of energy storage systems will begin to decrease, making it more feasible to store excess energy from renewable energy for use during peak times.

- Heat pumps: these are becoming more cost-effective, offering efficient heating and cooling systems by replacing traditional heating systems.

- Green and living roofs: there is an increase in the number of companies offering green roof solutions, with vegetation and living roofs that can improve insulation, reduce urban heat islands and enhance air quality. Advances in green roof technology and increased demand are making these roofs more accessible.

- Sustainable products: there is increased research and development (R&D) into the use of recycled, low-impact and sustainable construction products that can reduce a building's environmental footprint.

- Water efficiency technologies: there are advances in innovative water-saving technologies like greywater recycling that can reduce water consumption.

Buildings will therefore be a prime sector for technological innovation in the future.

3.3 Exploration of the sustainable buildings system in 2050

The analysis of current trends and drivers of change indicates that climate change is one of the most important priorities we face, with rising temperatures and extreme weather events such as heatwaves, heavy rainfall, wind and flooding becoming more frequent and severe. Despite the pressing concerns and complex landscape of European policies, it is apparent that reductions in GHG emissions from the buildings sector are not currently in line with the EU's climate ambitions. The rate of building renovations achieving the desirable level of improvement in terms of energy performance, defined as deep renovation, is only 0.2% in contrast with the necessary 3% yearly (BPIE, 2021).

Simultaneously, the population living in urban areas continues to increase and is challenged by escalating housing prices. At the same time, the ageing population and a rising number of people living alone are both factors which are expected to lead to an increase in the average housing space per person. As the rich-poor gap widens, housing affordability becomes a critical issue for a growing proportion of the population.

A large number of the buildings existing today will still exist in 2050. However, there is also a great need for new residential buildings due to housing shortages in many European cities. Continuous growth in the buildings system is not in line with current renovation ambitions as it puts enormous pressure on resources and exacerbates the issue of embedded carbon emissions.

The EU policy landscape emphasises digitalisation, smartness and automation as key tools for achieving sustainability, harnessing the potential of new technologies to enable environmental objectives to be monitored and controlled. But overall policies point towards a decoupling vision; this puts the onus of change on innovative companies as central actors to achieve technological breakthroughs that will enable GDP growth to be decoupled from adverse impacts. However, there remains a concern that these technological responses may not arrive fast enough to address urgent environmental challenges. The changes needed primarily relate to energy and operational carbon, with frequent mention of circularity and resource efficiency, too. However, there is currently still a need to define specific and enforceable targets related to nature-based solutions, constraining new construction and ensuring circular supply chains.

There are six key principles for a sustainable buildings system to be achieved by 2050. These address the critical hotspots identified in Chapter 2 and the adaptations needed to respond to the trends identified in the previous sections of this chapter.

- Prioritising building renovation to minimise carbon material and energy consumption, waste generation and land take. This is a central strategy for achieving decarbonisation goals and addressing the hotspots in the buildings system, promoting resource-efficient practices, limiting demolition and new construction, and encouraging high levels of reuse.

- Constructing long-lasting, adaptable buildings designed for disassembly. These should maximise the reuse of construction products and new products with recycled content and minimise waste generation, raw material consumption and hazardous substances. Recycling and reusing construction products and components is a central strategy in achieving the desired future for the buildings system, promoting circular supply chains to reclaim and source reused construction products as far as possible, and minimising energy-intensive recycling for materials such as steel and concrete.

    - Constructing and renovating buildings using low-carbon construction products which minimise embodied impacts across the whole life cycle. The use of materials such as wood, fibres, clay and other bio-based and vernacular materials, which are locally-sourced, is expected to increase as environmentally-friendly alternatives to conventional construction products.

    - Ensuring that buildings enable users to consume less energy, thereby minimising GHG emissions in the use stage. For residential buildings the priority for renovation is energy efficiency, with an emphasis on well-insulated walls and roofs, high-performance windows, smart systems for automation, monitoring and management, and reducing consumption and carbon emissions. This priority requires decentralised energy systems which allow buildings to generate and distribute energy locally; it also ensures that heating and cooling technologies are carbon-free, and district heating systems can efficiently provide temperature control to multiple buildings. In the desirable future, building occupants need to be more energy-conscious and adopt practices to reduce their energy consumption and be flexible about energy use in coordination with the electricity grid.

- Promoting the role of buildings in contributing to fair and inclusive communities that work for everyone. Community engagement with participatory decision-making, intergenerational living and a sharing economy should all promote diversity, inclusivity and shared responsibility. In the sustainable buildings system of the future, spaces must be more accessible, flexible and multi-functional, fostering a sense of community and inclusivity. Decentralised energy systems will allow localised energy generation and distribution, while shared district heating will efficiently allow the temperature in multiple buildings to be controlled, increasing resilience and reducing transmission losses.

- Ensuring that buildings are resilient to climate change, provide ecosystem services and help regenerate nature and biodiversity. The sustainable buildings system of 2050 will provide various ecosystem services and actively contribute to net-positive effects on communities and the environment. Nature-based solutions will promote biodiversity in urban environments, reduce pollution and urban heat islands, and enhance the mental health and quality of life of inhabitants.

Digitalisation, new approaches to design and the transition of the workforce are all essential to achieving the six principles identified.

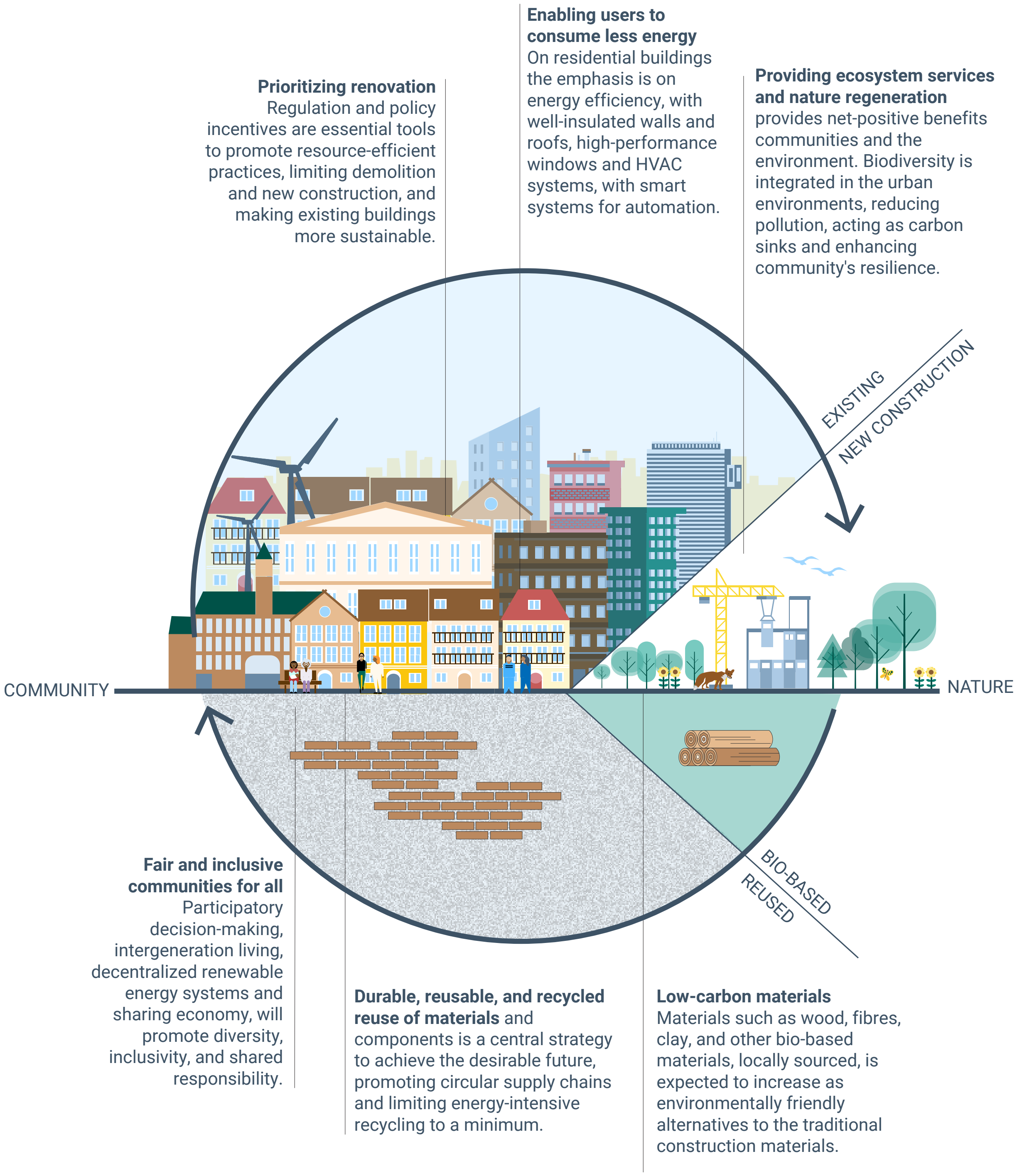
Box 3.1

A scenario for 2050

The date is 18 September 2050. Sarah wakes up in her carbon-neutral apartment building; it has been renovated with the latest low-carbon construction products and bio-based products by a local company, which was only a start-up not so long ago. Through the high-performance windows in her bedroom, she sees the sun rise over the buildings covered in greenery and the garden rooftops in the heart of the city. Despite the chilly weather, which is a bit unseasonal for September, the apartment is comfortably warm mainly because of its enhanced insulation and the complementary heating and cooling technologies which have smartly memorised Sarah's preferred temperature and are regulating the apartment accordingly. The newest technological advancements have removed the need for Sarah to take care of temperature regulation, leading to more efficient energy consumption; this also saves Sarah quite a lot of money — energy, time and financial efficiency all in one.

Sarah heads to the communal kitchen, where she prepares breakfast alongside her neighbours with locally-sourced ingredients from their rooftop garden. As Sarah strolls through the city to go to work she admires the diverse architectural styles. Buildings incorporate green façades, local vernacular materials, and reused elements and components. She greets her friend Tom when she passes his building; he is now deconstructing, 'mining' the urban environment for parts to be reused elsewhere. The streets are buzzing with people walking and biking, the air is clean and she can hear the birds singing. Sarah joins her colleagues in a bright, collaborative workspace filled with natural light and greenery. The building operates on renewable energy generated from integrated solar panels and wind turbines and excess energy is fed back into the neighbourhood grid. In this transformed world, the buildings of 2050 are not just structures; they are living ecosystems that contribute positively to the environment and the well-being of a vibrant community.

Figure 3.5 **The sustainable buildings system of 2050: a circular, regenerative ecosystem**



Source: Adapted with permission from ETC CE.

4 The responses needed to achieve a sustainable buildings system by 2050

The last chapter defined the vision for the sustainable buildings system of 2050. This chapter presents an array of responses (i.e. actions) required now and in the coming years by different stakeholders, to turn the vision for a sustainable buildings system in 2050 into a reality.

The necessary responses are outlined according to the six key principles identified in the previous chapter. They bring together a combination of top-down and bottom-up approaches as well as suggestions for hard and soft actions. The responses address and incentivise the engagement of different actors operating within the buildings system and other linked systems, signposting the pathway towards a systemic sustainable buildings transition. Design, new technologies and the transition of the workforce have a cross-cutting relevance for all the principles, from building renovation to nature regeneration. Consequently, they are addressed in each of the following sections.

To achieve the sustainable buildings system of 2050, all six key buildings system principles identified in this report need to be integrated.

In order to allow for synergistic solutions that extend beyond the design of individual buildings, we need to take a whole life cycle approach which factors in energy efficiency and generation, demand flexibility, circularity and resource efficiency, community inclusivity and fairness, climate resilience and nature regeneration. It must involve the design of products, buildings, policies and incentives which keep the whole buildings system in mind, including energy production and consumption, water management, transportation and food production.

Integrated solutions that promote resource efficiency, reduce emissions, and foster resilient and self-sustaining urban ecosystems can be developed by considering these interconnections. This will allow us to go beyond a merely sustainable future towards a future in which we have created positive change.

It is thus necessary to encourage collaboration among architects, industry and business, houseowners and users, policymakers, communities and other stakeholders beyond the construction sector (e.g. the agro sector for the growth of bio-based construction materials; and electricity producers and distributors). This would enable us to realise the full potential of the sustainable buildings system of the future, and avoid fragmented solutions that risk missing synergies between the different policy areas and inducing trade-offs.

4.1 Making building renovation a priority

Principle 1: Prioritising building renovation to minimise material and energy consumption, waste generation and land take.

Relevant drivers: The benefits of renovation are cross-cutting across life cycle stages. Since renovation extends the lifespan of the existing building stock it can lead to a reduction in the long-term demand for new construction, lowering demand for land, raw materials and energy, and reducing waste. By improving energy efficiency, renovation also contributes to reducing the operational impacts of buildings.

However, energy renovation can also involve the need for new construction products and could lead to a shift in the environmental burden of a building across its life cycle. It is thus essential to design renovation programmes for circularity and according to a whole life cycle perspective.

Figure 4.1 illustrates the significant potential for climate mitigation from building renovations in the EU-27 from 2020-2050, assuming that circularity principles are applied (Metabolic, 2022). Renovation actions can be supported by making demolition less attractive. This could be achieved by introducing a demolition permit and drawing up strict rules for these permits, underscoring the importance of promoting renovation while also considering the likely trade-offs, as discussed in the following sections (4.2-4.6).

Short description: Renovation implies the enhancement of an existing building. Achieving a decarbonised building stock by 2050 is an ambitious goal which demands a significant acceleration in renovation efforts and financial investments. Insulating and ventilating buildings efficiently saves on the energy required for heating and cooling (and decreases related emissions). It is a key step in the renovation process (EEA, 2024). Besides improving the energy efficiency of buildings, renovation also contributes to the improved health and comfort of inhabitants and, at a large scale, to preserving the cultural heritage of Europe with benefits for social cohesion, identity and well-being.

From an economic perspective, deep energy renovation can provide a competitive edge in the rental market, creating attractive high-quality environments for living and working while creating long-term jobs and boosting the economy. However, the upfront investment is high and there is a risk of green gentrification and segregation along the lines of energy efficiency/inefficiency, where renovation benefits are not distributed fairly. Energy renovation approaches and policies need to consider splitting the incentives between owners and tenants and integrating societal objectives to ensure a just transition.

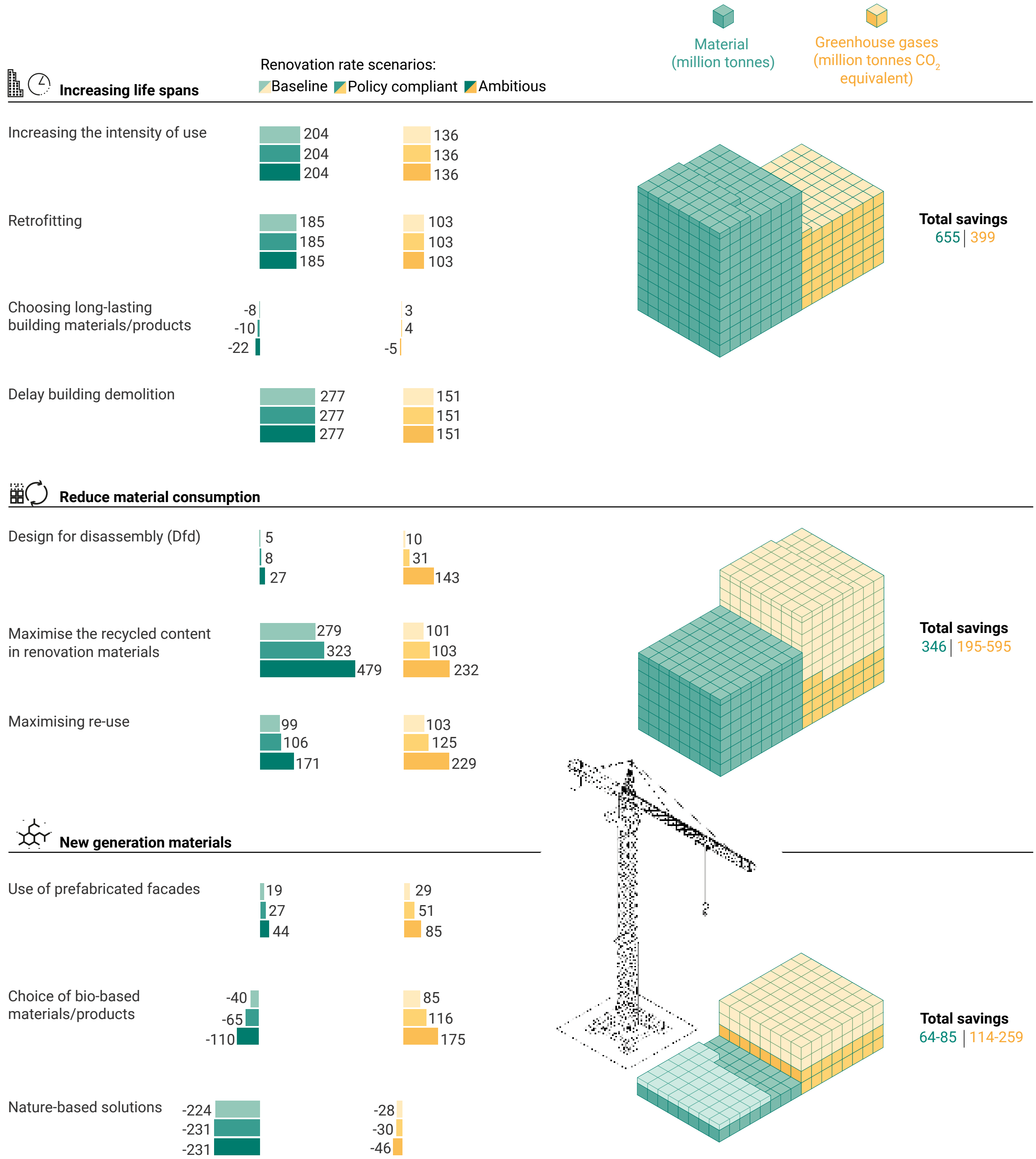
Technological innovation: While specific technologies are relatively 'mature', their actual implementation in the field remains a crucial point of intervention for achieving a more substantial impact. Digital technologies have a transformative potential for the building renovation industry. They have the capacity to maximise factory-prepared and semi-automated output while improving data quality and sharing, efficiency and sustainability. Quality standardised metrics, pre-defined renovation approaches and enhanced participation among all stakeholders are critical to the effective use of such technologies.

Examples of promising technological advances in the construction sector are digital building logbooks, prefabrication and robotics. They will contribute to faster and more cost-effective renovation processes while improving safety, particularly in terms of handling hazardous materials, and allowing renovation processes to be scaled up.

Prefabricated building skins offer an innovative solution for improving energy efficiency. These can be added to existing houses, moving them closer to a Net Zero Energy standard.

Innovations relating to digitalisation in the renovation sector, and their role in overcoming many challenges, are discussed widely in successful research projects (e.g. BIMSPEED, BIM4EEB) and several commercial solutions are being adopted on a broader scale.

Figure 4.1 **Cumulative material and GHG emissions savings which could be achieved by implementing circular renovation actions within the EU building stock from 2020 to 2050**



The range represents results according to each scenario modelled: lower limit for baseline, upper limit for ambitious.

Source: EEA, 2022.

Design approach: Good renovation practices begin with a clear understanding of the current context and future scenarios. Place-based design considers local conditions, current and future climate patterns, cultural heritage and social dynamics, optimising resource use and responding to the specific needs of the community.

Building renovation should prioritise passive design principles, such as proper insulation, energy-efficient windows and efficient heating, ventilation and air conditioning (HVAC) systems; incorporate sustainable construction products and reduce waste during renovation; use universal design principles to make spaces welcoming for all, regardless of ability; maintain the heritage character of buildings during renovation; prioritise natural light, ventilation and green spaces to enhance occupants' well-being; design spaces that foster community engagement, social interaction and cultural enrichment; use flood-resistant products, strengthen foundations and adapt buildings to climate change.

Actions:

- The actions of the EU Renovation Wave must be implemented; this would include enforcing strict energy efficiency standards and codes, with incentives for exceeding them.

- It is essential to raise awareness within society about the co-benefits of renovation to make more convincing arguments in favour of it, which go beyond discussion of the high up-front investments.

- Targeted non-regressive incentives and financing schemes like tax credits or low-interest loans should be offered for preservation and renovation projects that stimulate the local economy and preserve historic buildings.

- Behavioural insight and non-monetary obstacles (e.g. hassle factor, uncertainty and perceived financial risks) must be considered when designing policies. Local one-stop shops can help break down barriers by providing unbiased advice and simplifying the decision-making process.

Actors:

- The public sector has a key role to play as it oversees relevant decision-making processes (e.g. related at various levels to the design and implementation of policies, as well as to permissions and monitoring phases).

- The skills and expertise of installers and builders are crucial in determining the technical solutions that should be implemented. Their technical and practical knowledge is essential for carrying out renovations, building trust with property owners and increasing the renovation rate.

- Architects and designers have responsibility for providing advice and aligning the needs of building owners and users with building codes and regulations, while designing solutions that make the most of existing buildings and optimise space and resource use.

- Institutional owners, like housing corporations, can drive progress in building renovation, motivated by the potential for increased rental revenues. However, there's a need to consider the risk of green gentrification. Community-led co-housing initiatives with social objectives would benefit from the economies of scale offered by increased renovation while also offering a model that ensures affordability of housing.

- Buildings owners and occupants can demonstrate their willingness to contribute to environmental improvements by adopting 'anticipating' behaviour, although public policies should also unlock renovation subsidies.

Transition of the workforce: As discussed in Section 3.3, the rate of renovation must accelerate in the EU to remain on track with targets for reducing emissions. This implies a substantial increase in the demand for labour for renovation activities. While increased labour demand generates work opportunities, these will only materialise if prospective workers have the relevant skills.

The type of renovation described in Figure 3.6 points to the need for specific knowledge in the following fields: renovation design, selecting construction products, combining technologies and installing equipment in very heterogeneous contexts.

A skills shortage could seriously constrain the capacity to fully realise the potential of renovation. It is already the case that construction is an industrial ecosystem with one of the highest shares of professionals requiring green skills (EC, 2024).

4.2 Making buildings circular

Principle 2: Constructing long-lasting, adaptable buildings designed for disassembly, which maximise the reuse of construction products and new products with recycled content and minimise waste generation, raw material consumption and hazardous substances.

Relevant drivers: The buildings system contributes significantly to waste generation and raw material consumption. At the same time, carbon embodied in the production of materials contributes significantly to the overall GHG emissions of buildings. Circular strategies can tackle these challenges while also reducing dependency on the primary supply and the risk of shortages in critical raw materials. This principle is closely related to Principle 1 as renovation extends a building's lifespan, with associated benefits. Circular strategies need to be incorporated into the construction of new buildings but also renovation processes in order to achieve the best possible outcomes.

Short description: Circular material use entails the selection of construction products based on their durability, renewability, non-toxicity, biodegradability, reusability and recyclability. Circular design delivers products and components that are long-lasting, easy to disassemble and can be reused, refurbished or recycled in closed-loop systems with the maximum possible value retention.

To minimise waste generation and ensure resource efficiency, some inertia must be integrated within the system in terms of how building elements are dealt with (e.g. do not repair what is not broken, do not remanufacture something that can be repaired and do not recycle a product that can be remanufactured). This idea is explored in the 9R framework that establishes a hierarchy of strategies from Reuse to Energy Recovery.

There are key challenges to increasing this approach in the future, however. They relate to identifying and removing hazardous materials in existing buildings, uncertainty around the quantity and quality of secondary materials that can be harvested and reused, and facilitating the reverse logistics infrastructure.

Technological innovation: It still takes three to eight times longer to disassemble an existing building than to demolish it mechanically. Developing new technologies that facilitate the creation of comprehensive inventories for building materials, assessing their quality, are key for the future of the buildings system.

Remote sensing, robotics and artificial intelligence technologies can all facilitate scanning and data acquisition. They can also reduce the time taken to disassemble a building and improve the safety of those processes.

Data on materials and products need to be stored, transferred and managed across their whole life cycle. Digital building logbooks and material passports will support the systematic collection, organisation and updating of information on the installed construction elements, components and products, their lifespan and whether they can be dismantled, reused and recycled.

These tools will improve overall transparency, trust and traceability in the system, ultimately preserving the value of the products for longer.

There is also room for innovation in terms of developing technologies to remove hazardous substances from construction products and components so more of them can be reused and recycled.

Design approach: Several design approaches can contribute to this principle. Adaptive reuse of existing buildings (in the context of building renovation) focuses on the reuse of existing buildings in their existing locations. This kind of renovation helps preserve heritage values and communities' sense of place. It also reduces the demand for new buildings and thus the demand for construction products and the need for complex deconstruction processes.

Construction products and components that can be reused elsewhere in renovation or construction can be harvested from urban mining of buildings that are vacant and due to be demolished.

In deep renovations and the construction of new buildings, design for disassembly and design for adaptability play an important role. The first focuses on ensuring that building elements can be taken apart and reused with minimum effort, thereby minimising waste. The second focuses on creating flexible spaces that can accommodate changing needs and users, reducing the need for structural transformations and ensuring the longevity of buildings.

At the product level, circular design must ensure that waste and energy consumption are minimised during production. It must also factor in durability, ease of disassembly and the potential for reuse or recycling at the end-of-use stage.

Actions:

- Pre-demolition audits: these must be undertaken to allow resources, which already exist in the built environment, to be mapped, thereby maximising value retention.

- Quality standards: protocols need to be in place to evaluate toxicity and estimate building performance and the potential for reuse of materials.

- Circular business models: these must be promoted, including take-back services, leasing and products as a service that can encourage and ease the processes for reusing building products.

- Recycling and reuse programmes: manufacturers should be incentivised to implement recycling programmes to recover and repurpose their products at the end of their useful life. Options for take-back programmes should also be explored, where used materials or products are returned to the manufacturer for refurbishment or recycling (new circular business models).

- Certification: manufacturers can be transparent about the environmental and circularity performance of their products. This would include providing information on the construction products used, their environmental impact and recycling options. Manufacturers can seek certification for their products (e.g. environmental product declarations (EPDs) at product level or LEVEL(s) at the building level) which assess and promote the sustainability and circularity of construction products.

- Extended Producer Responsibility (EPR): manufacturers should be incentivised to support EPR programmes, which require them to take responsibility for the proper disposal and recycling of EOL products. This would encourage the design of products with recycling and reusability in mind.

Actors:

- Policymakers should incentivise the transition to a sustainable buildings system by adjusting the regulations around material use and circular design. Additionally, they should ensure that the standards are harmonised at the European level.

- Consumers should also be involved. This could be achieved by changing the relative incentives towards a more circular approach, namely by adopting policies that increase the circularity of construction products (such as explicit tax credits). A similar firm-side approach could also be implemented, with policies aimed at reducing waste and increasing reuse (through incentives to promote the use of specific materials or to remove undesirable ones).

In the context of the proposal for digital building logbooks, several key actors have a crucial role to play in ensuring the efficient and sustainable management of building information. These actors are described below:

- Building owners and operators are responsible for maintaining and updating the digital logbooks with relevant data and information.

- Facility managers and maintenance teams also play a significant role in logging real-time maintenance records and ensuring a building operates optimally.

- Software developers and technology providers are instrumental in developing and maintaining the digital platforms that store the logbooks.

- Regulatory bodies and industry associations are instrumental in establishing standards and guidelines for the implementation of logbooks.

Collaboration among these key actors is essential for the successful implementation and utilisation of Digital Building Logbooks in the construction and facility management industry.

Transition of the workforce: To operate in line with the principles for the sustainable buildings system in 2050, there is a critical need to increase skills and awareness amongst workers, material and product developers, auditors and renovation architects/consultants.

These professionals must be well-equipped to embrace sustainable practices and keep up to date on evolving standards. Standardisation will also play a crucial role in ensuring consistency and efficiency in sustainability efforts, reducing ambiguity and promoting widespread adherence to sustainability guidelines. However, at the same time, plans to increase the expected lifetime of newly-constructed buildings will contribute to a gradual slowdown in the demand for workers employed in new construction projects. Job losses are also anticipated throughout the traditional construction value chain (e.g. in the cement sector).

4.3 Constructing buildings using products which have a low environmental impact over their entire life cycle

Principle 3: Constructing and renovating buildings using low-carbon construction products which minimise embodied impacts across the whole life cycle.

Relevant drivers: The production of raw materials for new buildings and for deep energy renovations is responsible for increasingly significant embedded impacts when the whole life cycle of a product is considered. Criteria and guidelines in the EU Taxonomy can be used to assess the sustainability of buildings, including their total life cycle impacts. The connection between the EU Taxonomy Regulation and the EPBD recast (including requirements on the embodied carbon of buildings) can indirectly influence the consideration of embedded impacts in building practices.

Short description: The use of bio-based materials, such as wood, straw, hemp, flax and vernacular materials (locally-sourced and traditional materials that are used in construction based on regional availability, indigenous knowledge and cultural practices) can reduce the environmental impact of building elements and contribute to CO_2 storage and capture.

Environmental concerns, sustainability goals and a desire to reduce the environmental footprint of the construction industry all drive the use of bio-based construction products. This principle is linked to Principle 2 as harvesting, reusing products and recycling materials can all contribute to buildings with a low environmental impact across their life cycle.

Life cycle assessment tools and whole life cycle accounting allow the impact of a building element or entire building over its complete life cycle to be assessed. They shift the focus from energy considerations during the operational 'use phase' towards energy use and environmental concerns across the entire life cycle of the building.

This kind of assessment is further supported by EPDs, which are descriptive summaries of construction products, published by manufacturers to provide an overview of the environmental properties of their products in a transparent, uniform and reproducible way. The benefits of using EPDs are felt throughout the entire value chain. For building element manufacturers, they have made it possible to benchmark environmental scores for products and differentiate themselves from the competition.

Technological innovation: Building certification and sustainability performance assessment tools such as LEVEL(s) support building owners and architects to make educated choices between products and consider whole life cycle approaches. LEVEL(s) offers a common language on the sustainability and circularity of buildings in the EU, from conception right through their entire life cycle. Moreover, this kind of transparent accounting across the entire life cycle of a building allows individual EU countries to make it mandatory to disclose whole life cycle impacts.

Advancements in software technology allow architects and engineers to test building designs iteratively, optimising their performance before construction begins. Building Information Modelling (BIM) allows data to be captured and sustainability performance to be visualised and simulated during the early design stages.

Design approach: When following this principle, material efficiency, waste reduction and ease of disassembly are all considered during the design process. Furthermore, the design process should question the need to use a material at all, considering alternative strategies for achieving the same function, such as increasing the use of existing assets through renovation. During design, construction products are selected and factors affecting the environmental impacts of different products should be considered in any decision-making process.

The overall embedded impacts of products can be reduced if future-use scenarios are planned for and potential EOL disassembly is considered. This leads to a balancing act between durability and adaptability. If a construction product is durable but is likely to go out of fashion or become obsolete quickly, it is possible that it will be discarded long before the end of its useful life. By minimising the maintenance or replacement of a product, environmental impacts over its life cycle can be reduced. This results in an efficient use of resources and helps to divert construction products from landfill.

Finally, simplicity minimises the number of elements, components or materials that need to be used for any intended function. This leads to a reduction in the likelihood of failure or breakdown and also facilitates repair. Design options include limiting the use of decorative details, thus minimising the quantity and diversity of materials used, while working within a client's aesthetic parameters (e.g. using a standard and limited colour palette). One of the aims of simplicity is to remove barriers to disassembly.

Actions:

- Incentivising the selection of construction products with low environmental impacts over their entire life cycle: manufacturers should be incentivised to prioritise the use of sustainable and responsibly-sourced raw materials. This may involve using recycled or upcycled materials, promoting sustainable forestry practices, reducing the environmental impact of material extraction and choosing locally sourced materials where possible.

- Efficient manufacturing: encouraging manufacturers to adopt energy-efficient processes and technologies can help reduce emissions during the production of construction products. Site work can be reduced by using prefabricated building elements; this would also allow greater control over the quality and conformity of components, leading to reduced material consumption and lower embodied impacts.

- Optimising transport: transport distances should be minimised where possible and adequate transport methods should be chosen.

- Product innovation: manufacturers should invest in R&D to create new construction products that are more sustainable, efficient, circular and resilient. This can include the development of products made from recycled content, advanced composites and products that are made with fewer resources.

This set of actions may be achieved by improving existing regulations. It could also be supported by changing the incentives for manufacturers and/or for energy providers by, for example, extending the EU ETS 2 to the building sector. This system is expected to reduce the climate-related impacts of energy use and contribute to objectives to mitigate climate change.

Actors: with these actions in mind, it is essential that the following actors collaborate and coordinate to advance the use of bio-based products in the construction sector.

- Researchers and scientists are involved in studying and developing new bio-based products, exploring their properties and testing their suitability for construction applications. They also need to carry out additional research.
- Manufacturers are responsible for producing bio-based construction products.
- Policymakers play a crucial role in setting standards, regulations and incentives for the use of bio-based products for buildings.
- Architects and designers can specify and incorporate bio-based products into building designs, taking into account aesthetics and structural considerations.
- Users and owners can choose to use bio-based products in buildings, often driven by environmental concerns or regulatory requirements.

The same set of actors is expected to play a crucial role in the more general transition of the buildings system. As demonstrated by the EU ETS 'extension' to the building sector (among other policies), policymakers can adjust economic incentives (by changing the relative price of less vs. more desirable sources of energy) while also enhancing our understanding of measures that are coherent with climate change mitigation (as testified by the so-called EU Taxonomy). This kind of work is expected to complement and enhance the attitude of architects, designers and manufacturers, as well as final consumers.

Transition of the workforce: the increased use of construction products with a low environmental impact will contribute to the creation of new work opportunities in novel and existing sectors. These opportunities could partly, fully or more than compensate for job losses in the 'traditional construction and renovation' value chain. It should not be taken for granted, however, that workers displaced in the 'traditional' value chain can be directly employed in the sectors producing construction products with a low environmental impact, since several barriers exist:

- place-based barriers, as new job opportunities could arise in regions or countries that are different from where workers are displaced;
- skill mismatch, as the sets of skills possessed by displaced workers might not be appropriate for the new sectors;
- job market frictions, making it difficult to match demand and supply easily.

4.4 Reducing energy consumption in the use stage

Principle 4: Ensuring that buildings enable users to consume less energy, thereby minimising GHG emissions in the use stage.

Relevant drivers: Buildings have the potential to contribute in a systemic way to achieving ambitious climate and energy goals, set by European policies; this potential relates to consumption, production, storage, and supply of energy and services.

By reducing demand for energy and CO_2 emissions, buildings can be a major driver in changing the energy mix as well as increasing flexibility around demand to help balance the electricity grid. Energy efficiency improvements and decarbonised heating/cooling can be linked to building renovation as discussed in Section 4.1 under Principle 1. Alongside demand-side management strategies for energy (including energy efficient appliances and behavioural changes) there is great potential to address the hotspot identified in the use stage.

Short description: When analysing the interactions between the buildings system and energy systems, it is important to consider the desired overall energy system transition in the EU from a centralised, fossil fuel-based model centred around national interests towards a more decentralised, renewables-based system with more variable renewable electricity generation at its core.

The energy system must adapt at scale to ensure that there is adequate resource flexibility (from both the demand and supply side) to adjust to fluctuating renewable electricity supply (EEA & ACER, 2023).

Buildings are expected to play an increasingly active role in both energy generation and in responding actively to demand. Integrated energy solution approaches address both individual building measures (e.g. building envelope retrofit solutions, renewable generation and HVAC solutions), district energy systems (e.g. energy cooperatives, district batteries), urban functionalities (e.g. shared electric vehicle (EV) charging facilities) and their mutual interactions (EEA, 2022b).

Smart control is also needed to manage fluctuations in demand and generation profiles and to assess potential capacity issues in the thermal or electrical network.

Energy efficiency measures are not sufficient to achieve the decarbonisation and energy goals; additional actions which reduce demand are also required. These are linked to behavioural change among users, for example by reducing the temperature a building is heated to, switching to low energy consumption appliances and adapting their consumption habits when needed.

Technological innovation: Efforts to switch from fossil fuels to renewable energy for heating and cooling have been slow and have focused primarily on biomass. Since 2005, an acceleration in the development of options like heat pumps has provided more opportunities to reduce carbon emissions in buildings and industry (EEA, 2023a). District heating and cooling systems can now integrate various emission-neutral energy sources. This is particularly effective in urban areas where neighbourhood solutions are feasible.

Another important innovation is the Smart Readiness Indicator (SRI) that allows the smart readiness of buildings to be rated (i.e. the capability of buildings or building units to adapt their operation to the needs of the occupant while also optimising energy efficiency and overall performance, and to adapt their operation in reaction to signals from the grid (energy flexibility)). The indicator aims to raise awareness amongst building owners and occupants of the value of building automation and electronic monitoring of the technical side of the buildings system.

One of the key functionalities of the SRI is the readiness to adapt in response to the capacity of the energy grid. This technology is highly significant for all policy initiatives which aim for further decarbonisation and decreased dependency on fossil fuels.

Design approach: The distance between buildings is an important design parameter that affects the capacity to make use of solar energy and wind power, based on the speed and direction of wind within the artificial environment. In the design process, buildings should be placed and considered within their wider environment. The distance between buildings has a significant effect on energy performance in a building's use phase.

Whether or not a building is shaded by other buildings also influences its capacity to make use of solar power. If these factors are not taken into consideration in the design phase then the building is likely to consume are larger amount of energy once built. Moreover, there is a direct relationship between the geometrical shape and energy performance of buildings.

Actions:

- Energy efficiency: implementing energy-efficient measures such as insulation, efficient HVAC systems and light-emitting diode (LED) lighting can significantly reduce energy consumption and operational emissions.

- Renewable energy integration: incorporating renewable energy sources, such as solar panels or wind turbines and heating and cooling systems based on renewable energy sources (e.g. heat pumps), can offset the consumption of fossil fuel-based electricity and reduce operational emissions.

- Smart building technologies: utilising smart technologies, such as automated energy management systems and occupancy sensors, can optimise energy use and minimise operational emissions.

- Revising building standards: building regulations and standards should be constantly revised to incorporate and codify the most up-to-date practices relating to energy efficiency measures and targets.

- Behaviour change: promoting energy-conscious behaviour among occupants through awareness campaigns and education can lead to reduced energy consumption and operational emissions through, for example, reductions in the demand for floor space. Behavioural change can be driven by incentive-based policies (e.g. differentiated taxation) or by reviews of urban planning and building regulations (ESABCC, 2024).

The measures described above that may trigger both environmental and economic benefits are also likely to be relevant for issues related to equity and income distribution. This is an aspect that needs to be taken into account in policy design.

Actors: A transformational change is ongoing and characterised by a move towards a new value chain constellation where construction and energy actors collaborate closely together or even merge:

- Policymakers are central to the constellation since the EU is a key player, setting ambitious climate targets and regulations to drive decarbonisation efforts. These include the EPBD and the Renovation Wave strategy. Each EU Member State is responsible for implementing EU directives and developing national policies and incentives to promote buildings which are energy-efficient and low-carbon across their whole life. Local authorities, including cities and municipalities, have a significant role in enforcing building codes and zoning regulations, and promoting sustainable construction and renovation projects. Policymakers can also collaborate with industry associations, technology providers and research institutions to integrate, update and improve the SRI framework continuously, ensuring it remains relevant and aligned with the latest sustainable building practices.

- Construction industry actors such as builders, architects and developers are essential actors in adopting energy efficiency measures, implementing renewable energy technologies and reducing carbon emissions in construction and renovation processes.

- Owners and users of buildings are critical in implementing energy-efficient measures, such as insulation and efficient heating systems and in integrating renewable energy. In particular, building owners can voluntarily assess their buildings using the SRI to understand their current smart readiness and identify areas for improvement.

- Energy providers and grid managers contribute by supplying renewable energy sources, promoting energy-efficient technologies and services, ensuring that local electricity producers are connected to the grid and providing information to users to support flexible demand.

- Technology providers which develop and supply innovative technologies for energy-efficient HVAC systems, insulation and renewable energy solutions play a key role in the transition.

- Financial institutions such as banks, investment funds and financial bodies also play a crucial role in providing financing options and incentives for energy-efficient building projects.

Transition of the workforce: As for the other principles discussed above, the adoption of new technologies and business models to reduce energy use in buildings generates both new job opportunities and job losses. Opportunities exist when new technologies and business models are being adopted (e.g. energy communities) and in the operation, management and maintenance of these solutions. At the same time, reduced consumption of non-renewable energy reduces the number of jobs in the traditional fossil-based power-generation sector.

4.5 Fostering fairness and inclusion

Principle 5: Promoting the role of buildings in contributing to fair and inclusive communities that work for everyone.

Relevant drivers: In many EU countries and regions, increasing urban property prices, speculation, housing market deregulation and persistent urbanisation make housing unaffordable for lower-income groups.

At the same time energy poverty, defined as the lack of access to essential energy services, is a growing concern extending beyond low-income households; this is because the rise in energy prices has left even middle-income households struggling to afford their basic energy needs. The links between poverty and inequality on the one hand and environmental quality on the other work in both ways: poorer households live in more polluted environments (due to 'green' gentrification) and at the same time, their ability to improve the energy efficiency of their homes is limited by affordability issues and financial barriers.

The importance of a socially just transition has been identified across EU policies, from the European Climate Law to the NEB initiative.

Community initiatives have an untapped potential to accelerate decarbonisation, in particular by addressing climate hotspots in the use stage of buildings.

Short description: The buildings system is complex and depends on multiple actors including architects, urban planners, local communities, clients and policymakers. It can contribute to fair and inclusive communities by integrating participatory approaches to decision-making, supporting community initiatives for energy and housing, and ensuring affordability for all. Participatory approaches foster inclusive decisions that consider diverse perspectives and empower communities.

Energy communities address renewable energy production and supply but can also go beyond this to enable collective renovation strategies and coordinate district heating and cooling.

Co-housing models offer a collective solution, where communities control the financing, development and maintenance of housing. This fosters stable, non-speculative and affordable housing.

Participatory strategies have the potential to enhance people's sense of ownership and social cohesion while supporting economies of scale and optimised logistics, leading to lower costs and improved quality.

Community approaches can represent an active part of the solution to complex problems with consumption, production, storing and the supply of energy and services in a larger ecosystem, within the buildings system. Promoting social dialogue and inclusive decision-making is key to developing mutually beneficial solutions and ensuring that costs and benefits are fairly distributed (EEA, 2021).

Technological innovation: Energy communities allow the transformation from a top-down centralised system to a low-carbon, smart and combined centralised-decentralised system. They provide flexibility to local grid operators through demand-response services, enabling increased renewable energy penetration without extensive infrastructure investment.

Collective self-consumption is a central concept in energy communities; it involves the instantaneous or near-instantaneous matching of production and consumption within a local area. This kind of responsiveness is supported by various technologies such as smart meters, micro-controllers, batteries, EVs and online trading platforms to efficiently match consumption and production at the community level. This increases energy security and, in certain contexts, helps reduce energy costs.

Digitalisation also has the potential to foster social engagement through online platforms, social media and apps that can support community-led initiatives along with the sharing of resources and services. These can also help people engage in decision-making.

Design approach: Design choices are significant in determining the affordability of housing. Co-design, including collective decision-making and involving end-users in an iterative design process, is one approach which allows preferences and values to be incorporated into building design. It also allows for trade-offs such as improved space-efficiency, prioritisation of common areas and choices around overall building quality over the whole life cycle.

Digital technologies such as virtual reality and digital twins can make the design process more accessible and transparent. Additionally, passive design strategies offer cost-effective solutions to energy efficiency issues at affordable prices.

Actions:

- Encouraging policies: policymaking should identify suitable areas for community projects, revise energy market regulations and provide technical assistance for citizen-led initiatives. This would allow initiatives to be scaled up and costs to be reduced and would level the playing field with adjusted market regulations. Multilevel and multistakeholder involvement alongside active integration of social considerations in policy design can further support an inclusive and fair transition.

- New business models: these can attract and encourage residents to invest in and benefit from sustainable energy production. Peer-to-peer trading can help reduce energy poverty and lower electricity prices by matching local production and demand. It can also strengthen social cohesion and pro-environmental behaviours.

- Technical support: this should be offered to cooperatives by property investors and professionals. It would involve sharing expertise and assistance with monitoring projects to make sure that proposed solutions are viable for the future of the buildings system.

- Alignment with EU Agenda: clear legal definitions and guidelines should be offered which formalise the links between the buildings system and ambitions for a socially just transition. Community initiatives should have access to EU financial instruments and anti-speculative mechanisms should be put in place alongside measures to support inclusivity and affordability.

- Citizen participation: increased citizen participation should be encouraged at all stages of policy-making and design within the buildings system. This would empower multi-level governance and promote transparency.

Actors: An affordable buildings system involves various actors. Some of the most important ones are listed below:

- Policymakers can implement and enforce regulations and policies that promote affordable and inclusive housing. This might include financial incentives such as feed-in tariffs offering fixed payments for excess electricity generated by small-scale renewable energy systems, zoning changes to allow for mixed-income neighbourhoods or incentives for developers to build affordable housing. They can provide financial incentives, subsidies and grants to developers or individuals to help them build or purchase affordable housing. Local policymakers can introduce zoning regulations that allow for community solar or wind projects and reduce barriers relating to permissions. They can invest in and support local renewable energy projects, serving as a model for other communities and actively involving citizens in energy planning and decision-making processes (EEA, 2023b).

- Architects and designers can design buildings to meet functional and aesthetic requirements while also optimising cost-efficiency.

- Builders and contractors can specialise in affordable housing projects and work closely with policymakers to secure funding and resources for such projects. They can invest in innovative construction methods, such as modular or sustainable building practices.

- Communities can engage with local government and developers to voice their housing needs and preferences, ensuring that the housing stock meets the demands of the population. They can establish community land trusts to ensure that land remains affordable and accessible for future generations. They can also encourage community members to participate in energy cooperatives, organise community energy projects and advocate for local renewable energy solutions. A further action could be to support crowdfunding campaigns for community energy projects, enabling residents to invest collectively in renewable energy infrastructure.

- Energy service providers can develop community solar programmes that enable residents to invest in shared solar arrays and receive credits on their energy bills. They could cooperate with local residents around demand flexibility and offer green energy tariffs that allow customers to opt for renewable energy sources, even if they can't install their own systems. Additionally, they could offer energy efficiency programmes and incentives to help customers reduce their energy consumption, thereby promoting active energy citizenship. They could raise awareness about energy conservation, renewable energy options and the benefits of community energy projects.

- Financial institutions can offer affordable loans and financing options for both developers and potential homeowners. This would make it easier for people to purchase homes and for developers to undertake affordable housing projects. They can provide low-interest loans and financial support for community energy projects. They could also attract investors interested in socially responsible investments and renewable energy projects by creating opportunities for them to support community initiatives.

- Technology providers and designers can develop cost-effective and sustainable building technologies and design solutions that lower construction costs and improve energy efficiency. Innovation may help reduce the cost of generating renewable energy and also increase its feasibility. It may also support the storage and distribution of energy, to make it easier for communities and individuals to engage.

Transition of the workforce: Fairer and more inclusive communities allow for better access for all to education, training and dynamic labour markets. Thicker labour markets, characterised by more jobs, increase the opportunities for access to shared working spaces and more efficient commuting.

4.6 Climate-resilient and nature-positive buildings

Principle 6: Ensuring that buildings are resilient to climate change, provide ecosystem services and help regenerate nature and biodiversity.

Relevant drivers: Climate change poses significant challenges for the buildings system, as rising temperatures can affect the integrity of buildings and the comfort of users. Land take, soil sealing and loss of biodiversity limit ecosystem functions essential for ensuring resilience to climate change and extreme weather events. Loss of biodiversity associated with the buildings system is mainly related to the product stage (land use associated with extraction of resources, especially timber) and to a lesser extent, the construction stage (through urbanisation) and the EOL stage (through waste production and landfill).

Short description: Increasing resilience in the buildings system requires systemic approaches that go beyond the boundaries of the buildings system itself and address the complexity of its interrelationships with the surrounding environment. Land recycling, for instance, refers to the redevelopment of land previously developed for economic purposes, upgrading ecological land for soft use and the re-naturalisation of land. It is a crucial step in achieving the goal for there to be no net land take by 2050 and for all EU soil ecosystems to be in a healthy condition, as expressed in the soil strategy for 2030 with monitoring targets set out in the 8th EAP.

Additionally, adopting a circular economy for the built environment can significantly reduce the demand for virgin building materials by ensuring that assets and construction products remain in use. This has the effect of limiting negative impacts on biodiversity while also supporting the regenerative production of bio-based materials — a measure that is necessary to ensure well-managed forests which minimise habitat disturbance, to reduce erosion and enhance soil health.

At the building scale, incorporating nature-based solutions in the built environment like green spaces, green roofs and vegetation can further support biodiversity, regulate the local climate, and mitigate urban heat islands and the effects of air pollution.

Technological innovation: In indoor environments, advanced sensors and smart ventilation systems linked to occupant feedback systems are important to ensure real-time monitoring and optimisation of indoor air quality. Rainwater harvesting and management, which promote sustainable water practices, rely on filtration, recirculation and quality monitoring technologies. Modular solutions facilitate the integration of biodiversity into existing structures. Additionally technology will be essential for sustaining optimal ecological conditions to maintain green walls and roofs. This will enable urban farming solutions with automated climate control and irrigation systems.

Design approach: Climate-resilient building design includes simple solutions like shading windows, insulation and ventilation to address certain climate-related issues.

Regenerative architecture goes beyond energy efficiency and circularity measures to include strategies such as renewable energy generation, water management, nature-based and locally sourced materials, the promotion of human health as well as fostering and restoring the connection to nature. Regenerative design approaches can contribute to waste reduction, and reduce CO_2 emissions and the overall ecological footprint of the buildings system.

At the urban scale, regenerative design includes interconnected blue-green networks and planning for '15-minute' cities with human-scale spaces, mindful of the proximity and diversity of amenities (Khavarian-Garmsir et al., 2023).

Actions:

- Compact urban planning: this involves the promotion of compact and efficient urban planning to reduce urban sprawl. It encourages renovation and mixed-use developments that combine residential, commercial and recreational spaces, reducing the need for extensive land use and limiting new construction.

- Green infrastructure: this involves the integration of green spaces, parks and green roofs within urban areas to provide habitats for wildlife and enhance biodiversity in cities.

- Brownfield redevelopment: rehabilitating and repurposing brownfield sites minimises the need for development on new land.

- Land set-asides: designating protected areas where human activities are limited can allow natural ecosystems to thrive.

- Urban forests: planting and maintaining urban forests is important for providing habitats for birds and other wildlife while also offering various benefits to cities, such as improved air quality and temperature regulation.

- Permeable pavements: along with surfaces that allow rainwater to infiltrate, these reduce the need for extensive stormwater infrastructure and help maintain natural hydrological cycles. This kind of system can also involve capturing water which runs directly off roofs in rainwater troughs instead of in the sewerage system.

- Policy targets: targets need to be set and integrated into urban planning at the Member State level to limit land take and soil sealing and encourage the circular use of land. Policy must also embed biodiversity in the recovery programmes of national governments and international financial institutions.

Actors: Although several actors can be identified as relevant to this principle, there are two crucial groups when it comes to promoting climate resilience and adaptation as well as the preservation of biodiversity.

- Local policymakers play a highly significant role. A combination of EU, national and local policymakers are likely to prove crucial in changing the way planning decisions around land use are designed and implemented.

- Designers and architects responsible for the design of buildings (especially in the case of new ones) may be a central driver for climate and ecological resilience, both in terms of anticipating future trends and reacting to policies and demand-side changes (e.g. due to increasing awareness among 'consumers').

Transition of the workforce: The construction of new buildings, the renovation of existing ones to make them more resilient to climate change, as well as nature-based solutions for buildings all generate important opportunities for new jobs. However, as already discussed in a number of the earlier sections in this chapter, these new jobs can require specific and relatively scarce skills. Skills shortages may represent a serious barrier to the full realisation of solutions discussed in this section. This points to the need for well-designed and accessible training programmes to boost the supply of relevant skills at the local level.

References

Anderson, V. & Gough, W. A., 2020, Evaluating the potential of nature-based solutions to reduce ozone, nitrogen dioxide, and carbon dioxide through a multi-type green infrastructure study in Ontario, Canada. *City and Environment Interactions, 6, 100043.*

Attems, M., Thaler, T., Genovese, E., & Fuchs, S., 2020, Implementation of property-level flood risk adaptation (PLFRA) measures: Choices and decisions, *WIREs Water*, 7(1), e1404 (https://doi.org/10.1002/wat2.1404)

Bertaud, A., 2015, *Cities as Labour Markets* (https://www.itf-oecd.org/sites/default/files/docs/bertaud.pdf)

Bio Intelligence Service, 2012, *Water Performance of Buildings — Final Report,* European Commission (DG ENV).

BOZDAĞ, Ö., & Seçer, M., 2007, *Energy consumption of RC buildings during their life cycle* (https://avesis.deu.edu.tr/yayin/917054cc-3607-4d66-83da-7434211b5f89/energy-consumption-of-rc-buildings-during-their-life-cycle)

BPIE, 2020, *Covid-19 recovery: investment opportunities in deep renovation in Europe,* BPIE (https://www.bpie.eu/publication/covid-19-recovery-investment-opportunities-in-deep-renovation-in-europe)

BPIE, 2021, *Deep Renovation: Shifting from exception to standard practice in EU Policy,* BPIE (https://www.bpie.eu/publication/deep-renovation-shifting-from-exception-to-standard-practice-in-eu-policy)

BPIE, 2022, *Report on the evolution of the European regulatory framework for buildings efficiency,* BPIE (https://www.bpie.eu/wp-content/uploads/2022/02/rev6_SPIPA_EU.pdf)

Buildings and Cities, 2021, *The Sustainability Implications of Single Occupancy Households,* Buildings and Cities (https://www.buildingsandcities.org/insights/commentaries/sustainability-single-households.html)

Carrere, J., Reyes, A., Oliveras, L., Fernández, A., Peralta, A., Novoa, A. M., Pérez, K., & Borrell, C., 2020, The effects of cohousing model on people's health and wellbeing: A scoping review, *Public Health Reviews,* 41(1), 22 (https://doi.org/10.1186/s40985-020-00138-1)

CEN, 2023, Technical Bodies — CEN/TC 350, (https://standards.cencenelec.eu/dyn/www/f?p=205:7:0::::FSP_ORG_ID:481830&cs=1F34565A9E5B582575682802C33AE3275)

Chatziioannou, I., Alvarez-Icaza, L., Bakogiannis, E., Kyriakidis, C., & Chias-Becerril, L., 2020, A Structural Analysis for the Categorization of the Negative Externalities of Transport and the Hierarchical Organization of Sustainable Mobility's Strategies. *Sustainability,* 12(15), Article 15 (https://doi.org/10.3390/su12156011)

Christensen, 2023, *Economic poverty trends: Global, regional and national,* Development Initiatives, (https://devinit.org/resources/poverty-trends-global-regional-and-national)

Coelho, A., & De Brito, J., 2012, Influence of construction and demolition waste management on the environmental impact of buildings, *Waste Management,* 32(3), 532-541.

Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions, The European Green Deal, European Commission, COM(2019) 640 final (2019) (https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1576150542719&uri=COM%3A2019%3A640%3AFIN)

Copenhagen Economics, 2012, *Multiple benefits of investing in energy efficient renovation of buildings,* Renovate Europe, (https://copenhageneconomics.com/publication/multiple-benefits-of-investing-in-energy-efficient-renovation-of-buildings)

Damgaard, A., Lodato, C., Butera, S., Fruergaard, A. T., Kamps, M., Corbin, L., Tonini, D., & Astrup, T. F., 2022, *Background data collection and life cycle assessment for construction and demolition waste (CDW) management* (https://doi.org/10.2760/772724)

Dar, I. Y., Rouf, Z., Javaid, M., & Dar, M. Y., 2022, Atmospheric Emissions from Construction Sector in J. A. Malik & S. Marathe (eds.), *Ecological and Health Effects of Building Materials (pp. 13-31) Springer International Publishing* (https://doi.org/10.1007/978-3-030-76073-1_2)

DG Research and Innovation (EC), 2022, *European bioeconomy policy: Stocktaking and future developments*, Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Publications Office of the European Union. https://data.europa.eu/doi/10.2777/997651

DG Research and Innovation (EC), 2023, *ERA industrial technology roadmap for circular technologies and business models in the textile, construction and energy-intensive industries,* Publications Office of the European Union, (https://data.europa.eu/doi/10.2777/188014)

Donatello, S., Arcipowska, A., Perez, Z., & Ranea, A., 2022, *EU Green Public Procurement (GPP) criteria for the design, construction, renovation, demolition and management of buildings.*

EC, 2008, GPP Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions Public procurement for a better environment (SEC(2008) 2124) (SEC(2008) 2125) (SEC(2008) 2126) (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52008DC0400)

EC, 2016, *EU construction and demolition waste management protocol*, European Commision (https://single-market-economy.ec.europa.eu/news/eu-construction-and-demolition-waste-protocol-2018-09-18_en)

EC, 2020a, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, A new Circular Economy Action Plan For a cleaner and more competitive Europe, (https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN)

EC, 2020b, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, A Renovation Wave for Europe — Greening our buildings, creating jobs, improving lives (https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1603122220757&uri=CELEX:52020DC0662)

EC, 2020c, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, EU Biodiversity Strategy for 2030 Bringing nature back into our lives (https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1590574123338&uri=CELEX%3A52020DC0380)

EC, 2020d, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, A New Industrial Strategy for Europe (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0102)

EC, 2020e, *Critical Raw Materials for Strategic Technologies and Sectors in the EU*, (https://rmis.jrc.ec.europa.eu/uploads/CRMs_for_Strategic_Technologies_and_Sectors_in_the_EU_2020.pdf)

EC, 2021a, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, 'Fit for 55': Delivering the EU's 2030 Climate Target on the way to climate neutrality (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0550)

EC, 2021b, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Forging a climate-resilient Europe — The new EU Strategy on Adaptation to Climate Change (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2021:82:FIN)

EC, 2021c, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, New European Bauhaus Beautiful, Sustainable, Together (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2021%3A573%3AFIN)

EC, 2021d, Proposal for a Directive of the European Parliament andof the Council amending Directive (EU) 2018/2001 of the European Parliament and of the Council, Regulation (EU) 2018/1999 of the European Parliament and of the Council and Directive 98/70/EC of the European Parliament and of the Council as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652 (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021PC0557)

EC, 2022a, *Changing nature of work,* Knowledge for Policy, (https://knowledge4policy.ec.europa.eu/foresight/changing-nature-work_en)

EC, 2022b, *EU Emissions Trading System (EU ETS)*, European Commission (https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets_en)

EC, 2022c, *EU Reference Scenario 2020* (https://energy.ec.europa.eu/data-and-analysis/energy-modelling/eu-reference-scenario-2020_en)

EC, 2023a, *Continuing urbanisation,* Knowledge for Policy (https://knowledge4policy.ec.europa.eu/continuing-urbanisation_en)

EC, 2023b, *EU technical guidance for adapting buildings to climate change,* BUILD UP, (https://build-up.ec.europa.eu/en/resources-and-tools/publications/eu-technical-guidance-adapting-buildings-climate-change)

EC, 2023c, *Widening inequalities,* Knowledge for Policy (https://knowledge4policy.ec.europa.eu/diversifying-inequalities_en)

EC, 2024, COMMISSION STAFF WORKING DOCUMENT First annual report on key findings from the European Monitor of Industrial Ecosystems (EMI) Accompanying the document Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, 'The 2024 Annual Single Market and Competitiveness Report', European Commission (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52024SC0077)

EEA, 2010, Soil. in *The European environment — State and outlook 2010,* European Environment Agency.

EEA, 2020a, *Drivers of change of relevance for Europe's environment and sustainability,* EEA Report 25/2019, European Environment Agency, (https://www.eea.europa.eu/publications/drivers-of-change)

EEA, 2020b, *Urban adaptation in Europe: How cities and towns respond to climate change,* EEA Report 12/2020, European Environment Agency, (https://www.eea.europa.eu/publications/urban-adaptation-in-europe)

EEA, 2021, *Exploring the social challenges of low-carbon energy policies in Europe,* European Environment Agency. (https://www.eea.europa.eu/publications/exploring-the-social-challenges-of)

EEA, 2022a, *Cooling buildings sustainably in Europe: Exploring the links between climate change mitigation and adaptation, and their social impacts,* European Environment Agency (https://www.eea.europa.eu/publications/cooling-buildings-sustainably-in-europe/cooling-buildings-sustainably-in-europe)

EEA, 2022b, *Energy prosumers in Europe: Citizen participation in the energy transition,* EEA Report No 01/2022, Publications Office of the European Union.

EEA, 2022c, *Trends and projections in Europe 2022, EEA Report 10/2022,* European Environment Agency (https://www.eea.europa.eu/publications/trends-and-projections-in-europe-2022)

EEA, 2022d, *Urban sustainability in Europe — Post-pandemic drivers of environmental transitions,* European Environment Agency (https://www.eea.europa.eu/publications/urban-sustainability-drivers-of-environmental)

EEA, 2022e, *Sources and emissions of air pollutants in Europe,* European Environment Agency (https://www.eea.europa.eu/publications/air-quality-in-europe-2022/sources-and-emissions-of-air)

EEA, 2023a, *Decarbonising heating and cooling — A climate imperative* , European Environment Agency, (https://www.eea.europa.eu/publications/decarbonisation-heating-and-cooling/decarbonising-heating-and-cooling)

EEA, 2023b, *Energy prosumers and cities,* European Environment Agency (https://www.eea.europa.eu/publications/energy-prosumers-and-cities/energy-prosumers-and-cities)

EEA, 2023c, *Europe's air quality status 2023,* European Environment Agency (https://www.eea.europa.eu/publications/europes-air-quality-status-2023)

EEA, 2023d, *Greenhouse gas emissions from energy use in buildings in Europe,* European Environment Agency (https://www.eea.europa.eu/ims/greenhouse-gas-emissions-from-energy)

EEA, 2023e, *Exceedance of air quality standards in Europe,* European Environment Agency (https://www.eea.europa.eu/en/analysis/indicators/exceedance-of-air-quality-standards)

EEA, 2024, *Accelerating the energy efficiency renovation of residential buildings — A behavioural approach,* European Environment Agency (https://www.eea.europa.eu/publications/accelerating-the-energy-efficiency/accelerating-the-energy-efficiency-renovation)

EEA/ACER, 2023, *Flexibility solutions to support a decarbonised and secure EU electricity system,* EEA/ACER Report 09/2023, Publications Office of the European Union.

ESABCC, 2024, *Towards EU climate neutrality Progress, policy gaps and opportunities* (Assessment report), European Scientific Advisory Board on Climate Change.

ESCO, 2022, *European Skills, Competences and Occupations classification Annual Report 2021,* European Commission (https://esco.ec.europa.eu/en/about-esco/publications/publication/annual-reports)

ESPAS, 2019, *Global Trends to 2030: Challenges and choices for Europe,* European Strategy and Policy Analysis System (https://ec.europa.eu/assets/epsc/pages/espas/ESPAS_Report2019.pdf)

ESPON, 2020, *Reuse of spaces and buildings,* Policy Brief, ESPON (https://archive.espon.eu/reuse-spaces-and-buildings)

EU Parliament, 2018, Greenhouse gas emissions by country and sector (infographic) *(*https://www.europarl.europa.eu/news/en/headlines/society/20180301STO98928/greenhouse-gas-emissions-by-country-and-sector-infographic)

EU Parliament, 2023, *Revision of the Construction Products Regulation, (*https://www.europarl.europa.eu/RegData/etudes/BRIE/2022/739243/EPRS_BRI(2022)739243_EN.pdf)

EU Smart Cities Information System, 2020, *Upscaling urban residential retrofit for the EU's low carbon future: Challenges and opportunities | Smart Cities Marketplace,* European Commision, (https://smart-cities-marketplace.ec.europa.eu/insights/publications/upscaling-urban-residential-retrofit-eus-low-carbon-future-challenges-and)

Euroconstruct, 2021, *95th Euroconstruct Conference: European Construction Market Outlook until 2025 – Risks and uncertainties impeding the growth of the European construction market, Summary Report (Summary Report 91st),* WIFO Studies.

European Parliament and Council, 2020, Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088 (Text with EEA relevance) (https://eur-lex.europa.eu/eli/reg/2020/852/oj/eng)

European Parliament and Council, 2024a, Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a system for greenhouse gas emission allowance trading within the Union and amending Council Directive 96/61/EC (Text with EEA relevance)http://data.europa.eu/eli/dir/2003/87/2024-03-01/eng

European Parliament and Council. (2024b, April 24). Directive (EU) 2024/1275 of the European Parliament and of the Council of 24 April 2024 on the energy performance of buildings (recast) (Text with EEA relevance) (http://data.europa.eu/eli/dir/2024/1275/oj/eng)

European Union, 2021, Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law') (https://eur-lex.europa.eu/eli/reg/2021/1119/oj/eng)

European Union, 2023, *Special Eurobarometer 538: Climate Change,* European Union, (https://climate.ec.europa.eu/system/files/2023-07/citizen_support_report_2023_en.pdf)

Eurostat, 2020, Energy statistics — Cooling and heating degree days, (https://ec.europa.eu/eurostat/cache/metadata/en/nrg_chdd_esms.htm)

Eurostat, 2022a, Rise in EU population working from home, Eurostat (https://ec.europa.eu/eurostat/web/products-eurostat-news/-/ddn-20221108-1)

Eurostat, 2022b, (https://ec.europa.eu/eurostat/databrowser/view/SBS_NA_CON_R2/default/table?lang=en)

Eurostat, 2023a, E-commerce continues to grow in the EU — Products Eurostat News — Eurostat (https://ec.europa.eu/eurostat/web/products-eurostat-news/w/ddn-20230228-2)

Eurostat, 2023b, Household composition statistics (https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Household_composition_statistics)

Eurostat, 2023c, Living conditions in Europe — Housing (https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Living_conditions_in_Europe_-_housing)

Factsheet on Greening Freight, 2021, European Commission (https://ec.europa.eu/commission/presscorner/detail/en/fs_23_3771)

FIEC, 2023, *Overall construction activity,* European Construction Industry Federation, (https://fiec-statistical-report.eu/european-union)

Fråne, A., Miliute-Plepiene, J., Almasi, A. M., & Westöö, A.-K., 2019, *PVC waste treatment in the Nordic countries (2018:501),* Nordic Council of Ministers, (https://doi.org/10.6027/TN2019-501)

GABC, IEA, & UNEP, 2019, 2019 *global status report for buildings and construction: Towards a zero-emission, efficient and resilient buildings and construction sector,* Global Alliance for Buildings and Construction; International Energy Agency; United Nations Environment Programme.

Goldstein, B. P., Herbøl, M., & Figueroa, M. J., 2013, Gaps in tools assessing the energy implications of renovation versus rebuilding decisions, *Current Opinion in Environmental Sustainability, 5(2), 244-250* (https://doi.org/10.1016/j.cosust.2013.03.005)

GreenFacts, 2023, *The mining of sand, a non-renewable resource,* GreenFacts: Facts on Health and the Environment (https://www.greenfacts.org/en/sand-extraction/index.htm)

Guerlain, C., Renault, S., & Ferrero, F., 2019, Understanding Construction Logistics in Urban Areas and Lowering Its Environmental Impact: A Focus on Construction Consolidation Centres. *Sustainability, 11(21), Article 21* (https://doi.org/10.3390/su11216118)

Hagbert, P., Larsen, H. G., Thörn, H., & Wasshede, C., 2020, *Contemporary co-housing in Europe: Towards sustainable cities?* Taylor & Francis (https://library.oapen.org/handle/20.500.12657/76001)

Häkkinen, T., Helin, T., Antuña, C., Supper, S., Schiopu, N., & Nibel, S., 2013, Land Use as an Aspect of Sustainable Building. *International Journal of Sustainable Land Use and Urban Planning,* 1, 21-41 (https://doi.org/10.24102/ijslup.v1i1.202)

Halios, C. H., Landeg-Cox, C., Lowther, S. D., Middleton, A., Marczylo, T., & Dimitroulopoulou, S., 2022, Chemicals in European residences – Part I: A review of emissions, concentrations and health effects of volatile organic compounds (VOCs), *Science of The Total Environment,* 839(156201) (https://doi.org/10.1016/j.scitotenv.2022.156201)

Hickel, J., 2019, Is it possible to achieve a good life for all within planetary boundaries? *Third World Quarterly,* 40(1), pp. 18-35. https://doi.org/10.1080/01436597.2018.1535895

Horup, L. H., Birgisdottir, H., & Ryberg, M. W., 2022, *Defining Dynamic Science-Based Climate Change Targets for Countries and Absolute Sustainable Building Design,* (SSRN Scholarly Paper 4243132) (https://doi.org/10.2139/ssrn.4243132)

IMARC group, 2023, European Cross-Laminated Timber Market Report by Application (Residential, Educational Institutes, Government/Public Buildings, Commercial Spaces), Product Type (Custom CLT, Blank CLT), Element Type (Wall Panels, Flooring Panels, Roofing Slabs, and Others), Raw Material Type (Spruce, Pine, Fir, and Others), Bonding Method (Adhesive Bonded, Mechanically Fastened), Panel Layer (3-Ply, 5-Ply, 7-Ply, and Others), Adhesive Type (PUR (Polyurethane), PRF (Phenol Resorcinol Formaldehyde), MUF (Melamine-Urea-Formaldehyde), and Others), Press Type (Hydraulic Press, Vacuum Press, Pneumatic Press, and Others), Storey Class (Low-Rise Buildings (1-4 Storeys), Mid-Rise Buildings (5-10 Storeys), High-Rise Buildings (More Than 10 Storeys)), Application Type (Structural Applications, Non-Structural Applications), and Country 2024-2032, IMARC group (https://www.imarcgroup.com/european-cross-laminated-timber-market)

Increasing demographic imbalances | Knowledge for policy, 2022, (https://knowledge4policy.ec.europa.eu/increasing-demographic-imbalances_en)

IOM, 2022, *World Migration Report 2022, (*https://publications.iom.int/books/world-migration-report-2022)

IPCC, 2023, *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Intergovernmental Panel On Climate Change (IPCC).

ISO 15392:2019, 2021, ISO. (https://www.iso.org/standard/69947.html)

Joint Research Centre (European Commission), Hamor, T., Vidal-Legaz, B., Zampori, L., Eynard, U., & Pennington, D., 2021, A review of European Union legal provisions on the environmental impact assessment of non-energy minerals extraction projects. Publications Office of the European Union, (https://data.europa.eu/doi/10.2760/705726)

Kaur & Arora, 2012, Environment Impact Assessment and Environment Management Studies for an Upcoming Multiplex—A Case Study, *Journal of Mechanical and Civil Engineering*, 1(4), 22-30.

Khavarian-Garmsir, A. R., Sharifi, A., & Sadeghi, A., 2023, The 15-minute city: Urban planning and design efforts toward creating sustainable neighborhoods, *Cities*, 132, 104101 (https://doi.org/10.1016/j.cities.2022.104101)

Kiefer, N., Nichterlein, M., Reiß, F., Runge, M., Biermann, U., Wieland, T., Noll, M., & Kalkhof, S., 2024, Eluates from façades at the beginning of their service time affect aquatic and sediment organisms, *Science of The Total Environment*, 906, 167531 (https://doi.org/10.1016/j.scitotenv.2023.167531)

Konhäuser, W., 2021, Digitalization in Buildings and Smart Cities on the Way to 6G, *Wireless Personal Communications*, 121(2), 1289-1302 (https://doi.org/10.1007/s11277-021-09069-9)

Kristensen, P., 2004, The DPSIR Framework, Workshop on a comprehensive/detailed assessment of the vulnerability of water resources to environmental change in Africa using river basin approach, UNEP Headquarters, Nairobi, Kenya. (https://www.studocu.com/latam/document/universidad-autonoma-de-occidente/medio-ambiente-y-desarrollo/kristensen-2004-the-dpsir-framework-overview/15944910)

Larsen, H. G., 2019, Three phases of Danish cohousing: Tenure and the development of an alternative housing form, *Housing Studies*, 34(8), 1349-1371 (https://doi.org/10.1080/02673037.2019.1569599)

Mannan, M., & Al-Ghamdi, S. G, 2020, Environmental impact of water-use in buildings: Latest developments from a life-cycle assessment perspective, *Journal of Environmental Management*, 261(110198) (https://doi.org/10.1016/j.jenvman.2020.110198)

Material Economics, 2019, *Industrial Transformation 2050: Pathways to Net-Zero Emissions from EU Heavy Industry,* University of Cambridge — Institute for Sustainability Leadership.

Mouton, L., Trigaux, D., Allacker, K., & Crawford, R. H., 2022, Development of environmental benchmarks for the Belgian residential building stock, *IOP Conference Series: Earth and Environmental Science*, 1078(1), 012077 (https://doi.org/10.1088/1755-1315/1078/1/012077)

Norwood, G., 2013, Co-housing: A lifestyle with community spirit built into the foundations, The Observer (https://www.theguardian.com/money/2013/feb/24/co-housing-lifestyle-community)

OECD, 2011, *The Future of Families to 2030*, OECD (https://doi.org/10.1787/9789264168367-en)

Otte, K., Stelmach, T., Chandan, V., & Delgado, A., 2022, Digitalisation for the Energy Efficiency of Buildings Operations: Lessons Learned from the EE Hub Digitalisation Working Group, *Energy efficiency hub* (https://energyefficiencyhub.org/wp-content/uploads/2022/09/DWGReport.pdf)

Pelletier, M., Glorennec, P., Mandin, C., Le Bot, B., Ramalho, O., Mercier, F., & Bonvallot, N., 2018, Chemical-by-chemical and cumulative risk assessment of residential indoor exposure to semivolatile organic compounds in France, *Environment International*, 117, 22-32 (https://doi.org/10.1016/j.envint.2018.04.024)

Ramseier, L., & Frischknecht, R., 2020, Umweltfußabdruck von Gebäuden in Deutschland (https://www.bbsr.bund.de/BBSR/DE/veroeffentlichungen/bbsr-online/2020/bbsr-online-17-2020-dl.pdf?__blob=publicationFile&v=3)

Renovate Europe, 2020, Building Renovation: A kick-starter for the EU economy, (https://www.renovate-europe.eu/2020/06/10/building-renovation-a-kick-starter-for-the-eu-economy)

Roadmap on Carcinogens, 2020, The Facts on Hardwood dust, Roadmap on Carcinogens, (https://roadmaponcarcinogens.eu/hardwooddust)

Röck, M., Saade, M. R. M., Balouktsi, M., Rasmussen, F. N., Birgisdottir, H., Frischknecht, R., Habert, G., Lützkendorf, T., & Passer, A., 2020, Embodied GHG emissions of buildings – The hidden challenge for effective climate change mitigation, *Applied Energy*, 258, 114107, (https://doi.org/10.1016/j.apenergy.2019.114107)

Sáez, P. V., 2018, Estimation of construction and demolition waste in building energy efficiency retrofitting works of the vertical envelope, *Journal of Cleaner Production*, 172, 2978-2985 (https://doi.org/10.1016/j.jclepro.2017.11.113)

Schoknecht, U., Mathies, H., & Lisec, J., 2021, Leaching and Transformation of Film Preservatives in Paints Induced by Combined Exposure to Ultraviolet Radiation and Water Contact under Controlled Laboratory Conditions, *Water,* 13(17), Article 17 (https://doi.org/10.3390/w13172390)

Sezer, A. A., & Fredriksson, A., 2021, Environmental impact of construction transport and the effects of building certification schemes, *Resources, Conservation and Recycling*, 172, 105688.

Sharifi, A., 2021, Co-benefits and synergies between urban climate change mitigation and adaptation measures: A literature review, *Science of the Total Environment*, 750, 141642.

SITRA, 2022, Tackling root causes: Halting biodiversity loss through the circular economy (https://www.sitra.fi/en/publications/tackling-root-causes)

Squicciarini, M. & Asikainen, A., 2011, A value chain statistical definition of construction and the performance of the sector, *Construction Management and Economics*, 29. 671-693

SSB, 2022, Waste from building and construction, Statistics Norway, (https://www.ssb.no/en/natur-og-miljo/avfall/statistikk/avfall-fra-byggeaktivitet)

Staniaszek, D., Rapf, Oliver, Gruner, Andreas, Agyemang-Bonsu, William, & Pillay, Marlan., 2021, Compendium on greenhouse gas baselines and monitoring building and construction sector, UNFCCC (https://unfccc.int/sites/default/files/resource/UNFCCC%20Compendium%20GhG%20Building%20Sector.pdf)

Steinhausen, M., Paprotny, D., Dottori, F., Sairam, N., Mentaschi, L., Alfieri, L., Lüdtke, S., Kreibich, H., & Schröter, K., 2022, Drivers of future fluvial flood risk change for residential buildings in Europe, *Global Environmental Change*, 76, 102559. (https://doi.org/10.1016/j.gloenvcha.2022.102559)

Suh, Y.-J., & Rousseaux, P., 2002, An LCA of alternative wastewater sludge treatment scenarios, *Resources, Conservation and Recycling*, 35(3), 191-200 (https://doi.org/10.1016/S0921-3449(01)00120-3)

Talukhaba, A., Phungula, B., & Manchidi, M., 2013, Managing the efficient use of energy on construction sites and cost reduction, Creating a Resilient and Regenerative Built Environment, 9.

The World Bank, 2023, Urban Development, The World Bank (https://www.worldbank.org/en/topic/urbandevelopment/overview)

Tyvimaa, T., & Kamruzzaman, Md., 2019, The effect of young, single person households on apartment prices: An instrument variable approach, *Journal of Housing and the Built Environment*, 34(1), 91-109 (https://doi.org/10.1007/s10901-018-9618-1)

UEPG, 2023, Interesting facts over the aggregates sector, *Aggregates Europe* (https://www.aggregates-europe.eu/facts-figures/facts)

Vega-Garcia, P., Lok, C. S. C., Marhoon, A., Schwerd, R., Johann, S., & Helmreich, B., 2022, Modelling the environmental fate and behavior of biocides used in façades covered with mortars and plasters and their transformation products, *Building and Environment*, 216, 108991 (https://doi.org/10.1016/j.buildenv.2022.108991)

Wahlström, Teittinen, Kaartinen, & van Cauwenberghe, 2019, Hazardous substances in construction products and materials (PARADE Best Practices for Pre-Demolition Audits Ensuring High Quality RAw Materials), EIT RawMaterials (https://cris.vtt.fi/ws/portalfiles/portal/27439115/EIT_RM_PARADE_Hazardous_substances_in_construction_Final_2019.pdf)

Wicke, D., Tatis-Muvdi, R., Rouault, P., Zerball-van Baar, P., Dünnbier, U., Rohr, M., & Burkhardt, M., 2022, Emissions from Building Materials — A Threat to the Environment? *Water*, 14(3), Article 3 (https://doi.org/10.3390/w14030303)

WorldGBC, 2020, *Air Quality in the Built Environment,* World Green Building Council (https://worldgbc.org/better-places-for-people/air-quality-in-the-built-environment)

Zhang, Z., Zhao, M., Zhang, Y., & Feng, Y., 2023, How does urbanization affect public health? New evidence from 175 countries worldwide, *Frontiers in Public Health*, 10, 1096964.

Zhao, P., & Zhang, M., 2018, The impact of urbanisation on energy consumption: A 30-year review in China, *Urban Climate*, 24, 940-953.

In mapping different resources related to specific life cycle stages, limited information about the use of water in the buildings system in Europe was noted. There is a paucity of data concerning, for example, both quantities of water used and the type of water used in buildings in Europe. In the use phase of buildings, water use is also connected to energy consumption for functions such as water purification, heating, pumping and finally wastewater treatment (EC, 2012). The characteristics of water use are highly country-specific across Europe due to geographical differences (water abundance in northern Europe in contrast to low water availability in southern Europe due to low rainfall and tourism). Furthermore, water is also used in producing construction products (e.g. in extracting minerals), but no data were found relating to this. The use of water puts pressure on water bodies, especially in water-scarce areas.

As people in Europe spend significant amounts of time indoors (e.g. in their homes or workplaces (with seasonal and geographical differences)), there are risks involved in exposure to poor indoor air quality. Indoor air quality can be negatively affected by harmful substances (e.g. volatile organic compounds, carcinogens) emitted from construction products, furniture, textiles, cleaning agents and poor ventilation in airtight buildings. Furthermore, low temperatures and humidity in buildings due to leaking roofs, damp walls, floors or foundations, in combination with insufficient ventilation, cause mould problems. These exposures are associated with a range of health impacts (e.g. asthma, cardiovascular disease) and reduce the well-being of building occupants. There are currently no data at the European level on indoor air quality. Emissions data are currently scattered (e.g. unclear quality); they are not easy to get hold of publicly and consequently do not allow for exposure assessment for the European context (Halios et al., 2022).

PFAS and fire-retardants are added to different construction products to improve their performance. For example, PFAS are applied to coated rain gutters and concrete roofing tiles to repel dirt and resist staining and mildew. PFAS are also used to resist weathering and prolong a roof's useful life. They are applied to reflect solar radiation and keep building interiors cool. There is a lack of information on PFAS discharge into the environment from coatings on construction products (Fernández et al., 2021; Janousek et al., 2019; Heisterkamp et al., 2019).

Especially during the construction phase, construction products and materials are transported to the building site. Reliable European information on CO_2 emissions related to the transport of construction products and materials is not currently available. Based on single data, it can be estimated that transport accounts for about 5% of the CO_2 emissions for the whole construction process, but this figure could be an underestimate (Guerlain et al., 2019; Sezer and Fredriksson, 2021; EC, 2021).

Chemicals are used as ingredients or additives in manufacturing construction products and/or used in agents (e.g. glues, paints) needed for the installation of construction products in buildings. However, there is a lack of information on the actual use of hazardous substances (e.g. PCBs, PFAS, brominated flame retardants), especially for historical construction products, though some are currently classified as persistent organic pollutants which may be a source of risk if products containing them are reused or recycled (Wahlström et al., 2019).

Impacts from crosslinking between different goals (e.g. energy or material efficiency and circularity) and measures/actions are only assessed to a limited extent (so called burden-shifting in energy solutions). Furthermore, there are limited data published on the impact of the buildings system on biodiversity. The use of bio-based construction products (e.g. timber) was the only area for which the impact on biodiversity was found in the literature (SITRA, 2022). It is probable that the impacts of buildings on biodiversity are generally limited in the built environment (e.g. they mainly involve local impacts in certain areas, e.g. in mining). The impacts of infrastructure more generally on biodiversity are likely to be much more significant. However, this statement needs to be verified and potential critical scenarios identified.

Mapping of reliable information on streams from statistics and the literature was often challenging. A big drawback is that Eurostat data are often presented in an aggregated form (e.g. socio-economic data, production data, waste data); additionally, some of the data available relate to construction generally and not specifically to buildings. In the literature, the data presented were either very case-specific or linked to specific scenario conditions.

Annex 2 Definition of sectors

Table A2.1 Four-digit NACE industries by life cycle stage

Code	NACE sector	Life cycle stage
41.10	Development of building projects	2. Construction
41.20	Construction of residential and non-residential buildings	2. Construction
43.11	Demolition	5. Deconstruction
43.12	Site preparation	2. Construction
43.13	Test drilling and boring	2. Construction
43.21	Electrical installation	2. Construction + 4. Renovation
43.22	Plumbing, heating and air-conditioning installation	2. Construction + 4. Renovation
43.29	Other construction installation	2. Construction + 4. Renovation
43.31	Plastering	2. Construction + 4. Renovation
43.32	Joinery installation	2. Construction + 4. Renovation
43.33	Floor and wall covering	2. Construction + 4. Renovation
43.34	Painting and glazing	2. Construction + 4. Renovation
43.39	Other building completion and finishing	2. Construction + 4. Renovation
43.91	Roofing activities	2. Construction + 4. Renovation
43.99	Other specialised construction activities n.e.c.	2. Construction + 4. Renovation
08.11	Quarrying of ornamental and building stone, limestone, gypsum, chalk and slate	1. Raw material
09.90	Supporting activities for other mining and quarrying	1. Raw material
13.96	Manufacture of other technical and industrial textiles	1. Raw material
16.21	Manufacture of veneer sheets and wood-based panels	1. Raw material
16.22	Manufacture of assembled parquet floor	1. Raw material
16.23	Manufacture of other builders' carpentry and joinery	1. Raw material
20.30	Manufacture of paints, varnishes and similar coatings, printing ink and mastics	1. Raw material
22.23	Manufacture of builders' plastic	1. Raw material
23.14	Manufacture of glass fibres	1. Raw material
23.20	Manufacture of refractory products	1. Raw material
23.31	Manufacture of ceramic tiles and flags	1. Raw material
23.32	Manufacture of bricks, tiles and construction products, in baked clay	1. Raw material
23.51	Manufacture of cement	1. Raw material
23.52	Manufacture of lime and plaster	1. Raw material
23.6	Manufacture of articles of concrete, cement and plaster	1. Raw material
23.7	Cutting, shaping and finishing of stone	1. Raw material
25.11	Manufacture of metal structures and parts of structures	1. Raw material
25.12	Manufacture of doors and windows of metal	1. Raw material
25.21	Manufacture of central heating radiators and boilers	1. Raw material

Table A2.1 Four-digit NACE industries by life cycle stage (cont.)

28.92	Manufacture of machinery for mining, quarrying and construction	1. Raw material
28.99	Manufacture of other special-purpose machinery n.e.c.	1. Raw material
27.52	Manufacture of non-electric domestic appliances	1. Raw material
28.21	Manufacture of ovens, furnaces and furnace burners	1. Raw material
38.21	Treatment and disposal of non-hazardous waste	5. Deconstruction (proportional to CWD flows share of total)
38.22	Treatment and disposal of hazardous waste	5. Deconstruction (proportional to CWD flows share of total)
38.32	Recovery of sorted materials	5. Deconstruction (proportional to CWD flows share of total)
46.73	Wholesale of wood, construction materials and sanitary	1. Raw material
46.74	Wholesale of hardware, plumbing and heating equipment and supplies	1. Raw material
47.52	Retail sale of hardware, paints and glass in specialised	1. Raw material
77.32	Renting and leasing of construction and civil engineering machinery and equipment	2. Construction + 4. Renovation
77.39	Renting and leasing of other machinery, equipment and tangible goods n.e.c.	2. Construction + 4. Renovation
71	Architectural and engineering activities; technical testing and analysis	2. Construction + 4. Renovation

Source: Based on Squicciarini and Asikainen, 2011.

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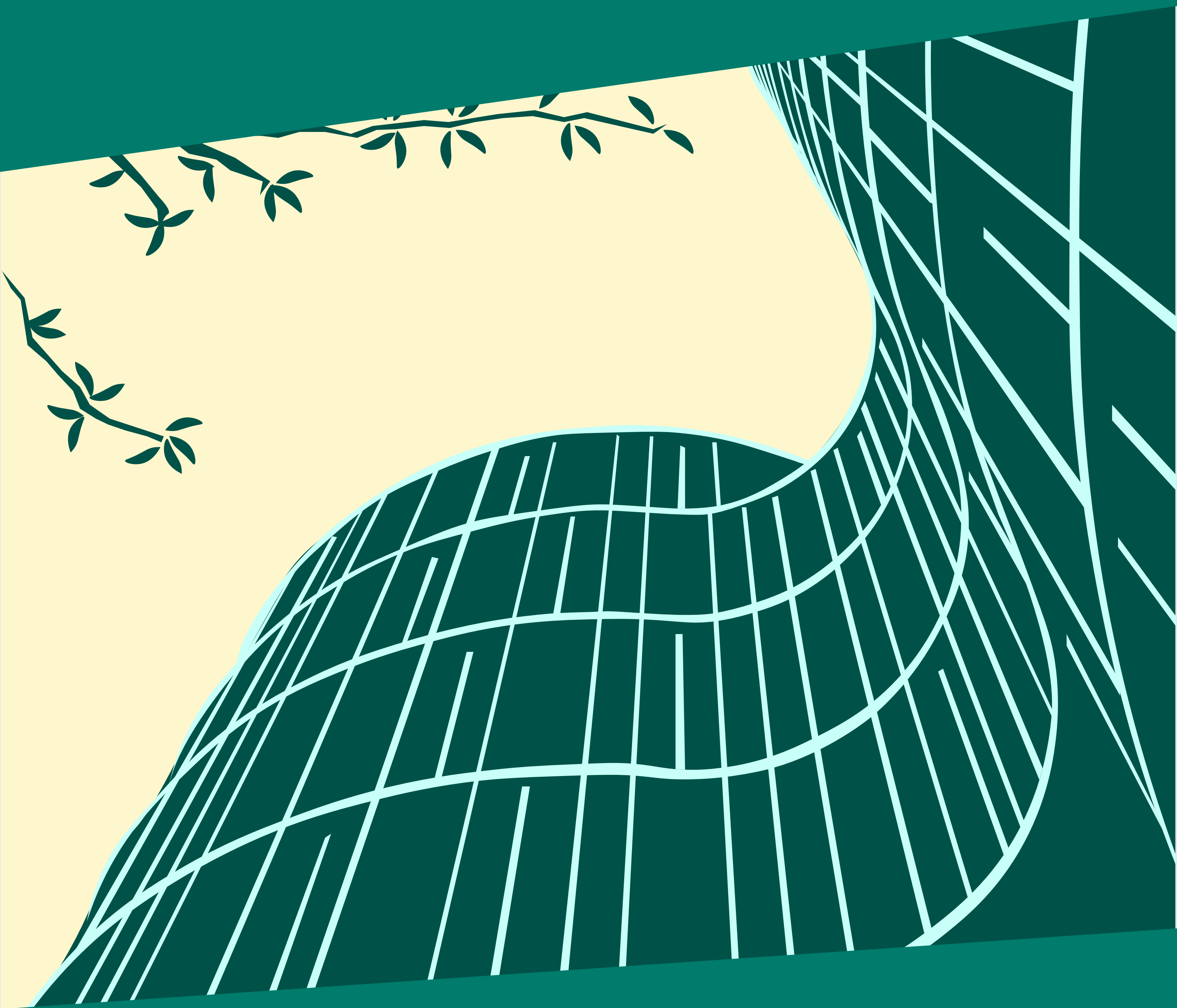

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