Built environment

9 Built environment

9.1 Key messages

- Key climate risks for the built environment are: damage to infrastructure and buildings due to slow-onset climate change and extreme climate events; and risks to human well-being from climate change impacts on buildings.
- Climate change is associated with risks to the built environment itself as well as to the services that buildings provide to their users and wider society.
- Damage from extreme weather events to the built environment is projected to increase up to 10-fold by the end of the 21st century as a result of the effects of climate change only. The most significant increases are expected for the energy and transport sectors, while the greatest damage in absolute terms is estimated for the industrial sector.
- Investment is needed in climate-proof design for new structures and in retrofitting and reinforcement of existing buildings, without diminishing the cultural or economic values of areas with historical significance or of properties with historical value.
- EU policies increasingly address climate risks to the built environment. Action at Member State level is vital. Policy action at both EU and Member State level is facilitated through, for example, updating construction standards, Eurocodes and European datasets.

9.2 Introduction

The built environment holds a central position in the European socio-economic landscape. It corresponds to everything people live in and around, such as housing, transport infrastructure, services networks and public spaces (EP, 2024). In general, all European cities face at least some vulnerability to climate-related events, increasing temperatures and changes in precipitation patterns, accentuated by climate change, requiring complex and grounded adaptation measures. In this context, EU renovation targets (EC, 2020e) offer a key opportunity to enhance resilience by upgrading the building stock. However, careful planning is essential to avoid unintended consequences or maladaptation.

In this chapter, the built environment has been investigated, from the perspective of buildings and civil engineering works. The former refers to residential (single and multiple residential dwellings) and non-residential (commercial, institutional and public) buildings. The latter includes critical infrastructure (transport, pipelines, communication and electricity lines, energy and industrial infrastructure) and green and blue infrastructure, such as sports grounds, parks, open-air installations and protection areas (such as coastal zone or riverbank defenses, rockfall prevention measures, reforestation or landslide mitigation zones, etc.).

These subsystems are closely related to other sectors and systems. For example, the impact on buildings is connected to water security and marine and coastal ecosystems (see Chapters 4 and 5), especially concerning flood-related damage. Similarly, health facilities' susceptibility to heatwaves and the urban heat island (UHI) effect are of utmost importance, impacting human health (see Chapter 7). Direct damage to critical infrastructure has links to the critical infrastructure sector (see Chapter 15), while transport systems, energy generation plants, industry, and water supply networks have implications for energy and water security (see Chapter 5 and 8). Finally, the built environment, incorporating blue and green infrastructure, is closely tied to biodiversity and marine and coastal ecosystems (see Chapter 3 and4).

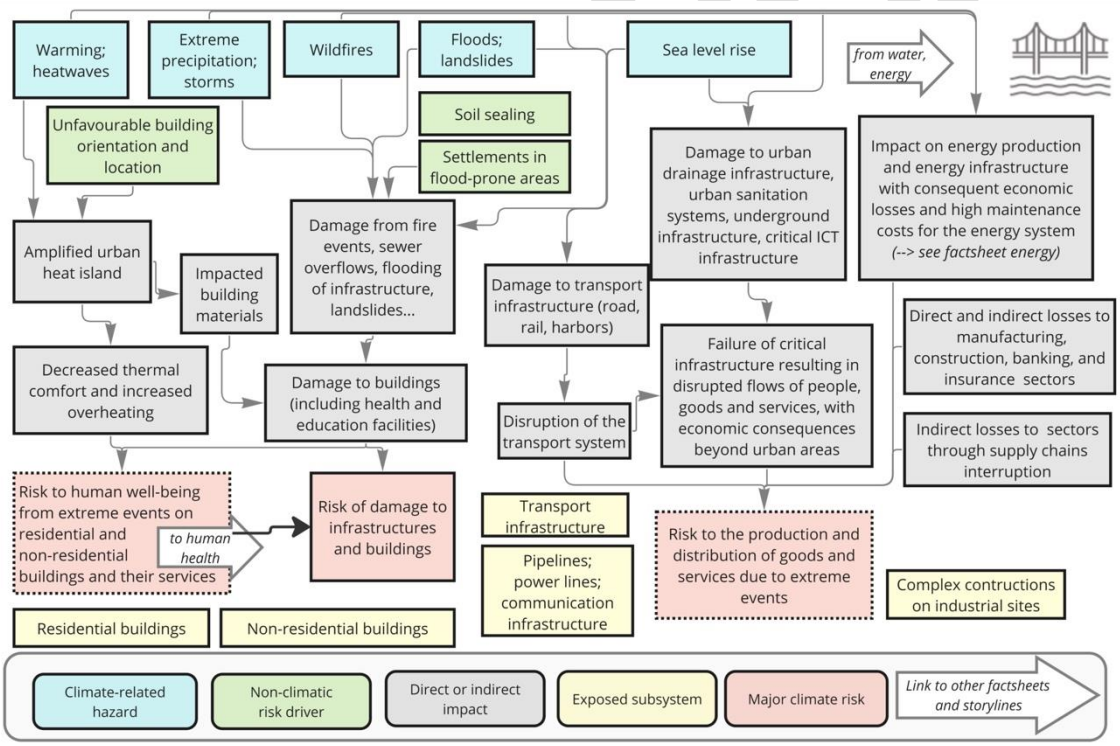
The interconnected nature of the built environment underscores the need for comprehensive risk management, with gaps in understanding of compound climate event dynamics. Indeed,

direct impacts of extreme events on buildings and critical infrastructure, further intensified by climate change, have cascading effects on systems, livelihoods and economies. Rising urbanisation and interactions between severe weather events contribute to compound and cascading risks, impacting the flow of people, goods and services. These risks have economic consequences beyond urban areas and affect overall well-being (Moretti and Loprencipe, 2018; Markolf et al., 2019). Major policies promoting urban resilience, sustainability and climate adaptation highlight the built environment's critical role. Spatial planning not only influences the risk for all infrastructure, but also impacts the distribution of buildings, uses of space, social and economic development, energy matters, positive or negative environments, vegetation and green areas, public spaces, landscape and protected areas, Spatial planning also impacts strategic concepts, zoning plans, or density regulations that affect settlement configuration to better adapt to the hazards posed by climate change.

9.3 Risk drivers and impacts

9.3.1 Impact chain

Figure 9.1 Impact chain for the built environment



Source: ETC-CA, 2024.

9.3.2 Subsystem: residential buildings

What drives the impact

- Residential buildings are vulnerable to chronic and acute climate-related hazards, including extreme temperatures, high humidity, heavy rainfall, strong winds and solid mass impacts (EC DG CLIMA, 2023c).
- Climate change increases the risk of collapse and loss of value due to storms, snow, subsidence, water encroachment, soil degradation and deteriorating indoor climate; these effects are aggravated by more, and more frequent and heavy, torrential rains, hail drops, and unusual snowfalls with much more devastating intensity and effects.

- Buildings experience decreased thermal comfort and increased overheating risks, influenced by factors like solar shading, ventilation, orientation and geographical location (Van Hooff et al., 2014; Dodoo and Gustavsson, 2016; Hamdy et al., 2017; Pérez-Andreu et al., 2018b; Dino and Meral Akgül, 2019). These factors negatively affect the health of occupants via heatstroke, dehydration, aggravation of chronic and respiratory diseases, and even death.
- Vulnerable groups of society often reside in older buildings, social housing, or structures with construction and energy standards that may be inadequate, rendering them more susceptible to the impacts of adverse climate events. Without appropriate retrofit measures, this situation could exacerbate social disparities in the future.
- Rising temperatures and uncontrolled humidity affect structural designs and accelerate corrosion processes in reinforced concrete and steel structures (Athanasopoulou et al., 2020; Bastidas-Arteaga et al., 2022).
- Urban areas, due to building arrangements and characteristics, cause the UHI effect, leading to temperature increases and severe heatwave effects. Heatwaves, in addition to causing large energy losses due to air-condition of buildings and negatively damaging building structures, as indicated previously, cause various health issues, including cramps, heat exhaustion and heatstroke, resulting in increased fatalities and illness rates (Ellena et al., 2020; Ballester et al., 2023c).
- Urban flooding risks are worsened by heavy precipitation, which is expected to become more frequent due to climate change, soil sealing as a result of urban expansion and land use changes, and insufficient or outdated stormwater infrastructure that does not assure proper drainage capacity.
- Coastal areas face flooding and sea level rise, impacting buildings, especially in densely populated subsiding regions (Dodman et al., 2022b).
- Settlement location near steep slopes and adherence to zoning laws significantly influence urban landslide risk (Mateos et al., 2020).

Current situation

- European cities exhibit varying degrees of vulnerability to drought, flooding and heatwaves (Tapia et al., 2017b). Western European cities are more exposed to flooding events, while those in southern Europe are more exposed to droughts. Cities in southern, western Europe and central-eastern Europe face significant exposure to heatwaves, partly due to limited solar shading and air conditioning installations.
- In northern Europe, buildings have been designed for cold winters and without any regard for exceptionally hot summers. Hence, the overheating of residential buildings is a severe issue threathening the health of vulnerable population groups also in northern Europe, even though heatwaves there are, in absolute terms, not as hot as in the warmer areas.
- Existing characteristic values from Eurocodes, a series of European standards for the design of buildings and civil engineering structures, often do not consider the potential effects of climate change (Croce et al., 2018; Rianna et al., 2023). In response to these limitations and the necessity to adapt to climate change, the second generation of Eurocodes (EC, 2023v) is currently under development. This new series aims to enhance the existing suite and broaden its scope. By incorporating new methods, materials, regulatory and market requirements, as well as reinforcing robustness requirements, the updated standards will ensure full compliance with current practices. Additionally,

the second generation of Eurocodes will introduce requirements for the assessment, reuse and retrofitting of existing structures to enhance building resilience, among other features.

- Extreme temperatures lead to issues like shrinking and swelling of clays, jeopardising the stability of houses in peri-urban environments.

Future situation

- Pluvial flooding risk is expected to increase significantly in northern European and some western-central European cities by 2030 (near term) (Komolafe et al., 2018).
- Heat risks will escalate in many cities by the end of the century (long term), especially in southern Europe, leading to a potential decrease of 74% in thermal comfort hours at 3°C of global warming by the end of the century (long term) (Jenkins et al., 2014; Hamdy et al., 2017; Heracleous and Michael, 2018; Dino and Meral Akgül, 2019; Shen et al., 2020).
- Urban landslide risks are expected to increase in regions experiencing higher extreme rainfall, necessitating comprehensive risk mitigation strategies (Gariano and Guzzetti, 2016).
- Heavy hailstorms are becoming more frequent, damaging building appliances and surfaces. The potential impacts of extreme heat, humidity, hail and heavy rain on construction materials, including damage to roofs, facades and insulation materials, and proliferation of mold, bacteria and insects, may become more prevalent in the future.
- Longer and more intense droughts will result in deeper desiccation, extending up to the first 2 metres of the soil surface exposed to evapotranspiration. This will necessitate more extensive and expensive reinforcement measures (Ighil Ameur, 2023).

9.3.3 Subsystem: non-residential buildings

What drives the impact

- Non-residential buildings mainly refer to commercial, institutional and public buildings, with a specific focus on health and education facilities. They are affected by climate-related factors such as heat, flooding, water scarcity, drought and windstorms, both directly and indirectly.
- Climate impacts indirectly affect sectors through supply chains, transport and electricity networks, sometimes more significantly than direct effects (Koks et al., 2019d, 2019b; Knittel et al., 2020).
- Health facilities are particularly vulnerable to increasing climate-related shocks and stresses that could potentially causing significant damage to buildings that house them. This could have a knock-on effect on the provision of health services. Vulnerability depends on factors like building strength, design and the intensity of the event (EEA, 2020f).
- Health and social care facilities often lack air conditioning. Overheating of the buildings during heatwaves is a severe health risk for inpatients/residents (Kollanus et al., 2021) and challenges delivery of healthcare services.
- Overheating in office, industry and public buildings may affect lower learning attainment and worker productivity.
- Climate change poses a significant threat to cultural heritage, protected under the EU Civil Protection Mechanism (EU, 2013b), including tangible and intangible elements. For instance, rising sea levels put building exteriors and indoor collections at risk, leading to

potential income reduction due to the loss of tourism revenue (Phillips, 2015; Fatorić and Seekamp, 2017; Carroll and Aarrevaara, 2018; Sesana et al., 2018).

Current situation

- Health and education facilities are frequently damaged by floods and windstorms, accounting for 44% and 51% of the total Expected Annual Damage (EAD) (EUR 0.6 billion per year) for these sectors in the 2000s (Forzieri et al., 2018b).
- Floods cause the highest direct losses for the manufacturing and utilities sectors (Koks et al., 2019b; Sieg et al., 2019; Mendoza-Tinoco et al., 2020).
- It has been estimated that during, or at the end of, a single work shift in heat stress conditions, 35% of workers experience symptoms of physiological strain and 30% of workers report productivity losses (Flouris et al., 2018).

Future situation

- Structural damage from flooding and windstorms in health and education facilities is expected to increase significantly (Forzieri et al., 2018b), with knock-on effects on the provision of health and education services. These effects may be more significant on these types of buildings compared to others, such as offices or public buildings. Indeed, offices or public buildings may continue to operate, due to the evolution and increased development of teleworking, for example.
- Concerning health and education facilities, EAD related to flooding is projected to be two times higher in the 2080s (long term) (Forzieri et al., 2018b). Moreover, drought-induced subsidence damage could increase substantially, with EAD rising from EUR 10 million per year in the 2000s to EUR 460 million per year in the 2080s (long term) (Forzieri et al., 2018b).
- A warming climate leads to heightened occupational heat stress among workers, reducing their ability to engage in manual labour (Ioannou et al., 2022). This issue is strongest in southern Europe, but other regions may also see a decline in workers' capacity for physically demanding tasks (Kjellstrom et al., 2020).
- Business closures can be influenced by the effects of climate change as well as the local economy. Indeed, default probability for firms in particularly exposed locations might increase by up to four times that of an average firm in all sectors by 2050 (mid-term) (ECB, 2021). Additionally, the shift towards working from home has been favoured and increased post-COVID. This, along with other factors, may lead to a higher number of unused and disused buildings in future, rendering these structures obsolete and with potential for rehabilitation and conversion into other uses.

9.3.4 Subsystem: transport infrastructure

What drives the impact

- Transport infrastructures are vulnerable to various weather-induced hazards, including changing precipitation patterns, temperatures, sea levels, coastal and river floods, droughts, erosion, marine heatwaves and ocean acidity.
- Climate change exacerbates risks, potentially disrupting normal functioning or leading to infrastructure failures during severe weather events.
- Heatwaves cause thermal expansion, buckling of roads and railways, and softening of road asphalt and pavement material.

- Rapidly changing temperatures around the freezing point of roads can lead to the deterioration of both the road surfaces and the main road structure.
- Urban roads and railways are vulnerable to extreme winds, while heavy rainfall impacts underground transport systems. Metro/subway systems face challenges from climate change, including heavy rainfall, storm surges and storms. Precipitation-induced landslides affect transport infrastructures in mountainous regions (Pregnolato et al., 2016).
- Droughts could reduce navigation capacity in rivers, impacting inland waterway transport (Jonkeren et al., 2014; Schweighofer, 2014).
- Airports and harbors, particularly in low-elevation coastal areas, are at risk due to sea level rise. Levee failures can trigger cascading failures in urban transport systems (Zaidi, 2018).
- Wildfire smoke storms and sand dust storms can disrupt airports, causing challenges for air operations and potentially damaging airport infrastructure and materials.

Current situation

- Current damage in the transport sector primarily results from river floods and heatwaves, accounting for approximately 51% and 27% of the total EAD (EUR 800 million per year) in the 2000s (Forzieri et al., 2018b).
- Heatwaves in western, central and northern Europe have led to road melting, railway asset failures and speed restrictions to prevent track buckling, causing significant disruptions in transportation infrastructure (Forzieri et al., 2018b).
- Adaptation measures are essential, integrating climate change considerations into planning and design phases (EEA, 2020a).

Future situation

- Costs associated with weather-induced hazards are projected to increase significantly by the 2080s (long term), potentially reaching over EUR 10 billion, a 20-fold increase from the current level. Heatwaves are expected to be the dominant factor, accounting for 92% of total damage by the 2080s (long term), particularly affecting roads and railways due to rutting and blow-ups (Forzieri et al., 2018b).
- Railways face double or triple the flood risk under different global warming level scenarios, potentially leading to substantial public expenditure increases (Bubeck et al., 2019a).
- Extreme rainfall induced by climate change could significantly increase landslide risks for natural and engineered slopes, disrupting transport infrastructure (Gariano and Guzzetti, 2016; Briggs et al., 2017; Tang et al., 2018; Powrie and Smethurst, 2019; Schlögl and Matulla, 2018; Rianna et al., 2020).
- Soil frost is a relevant phenomenon in cold regions of Europe affecting ecosystems and built infrastructures. For instance, permafrost degradation due to rising temperatures in high-altitude Alpine areas may affect ropeway transport infrastructure (Duvillard et al., 2019).
- Ports, especially in northern and western Europe, are vulnerable to sea level rise, storm surges and changes in wave agitation. Mediterranean ports may face non-operability hours due to wave changes (Christodoulou et al., 2018).
- Droughts are expected to lower water levels in inland waterways, thus hindering their use. For example, the Rhine in Germany has sometimes become more narrow and

shallow in recent years, meaning fewer vessels could pass and resulting in partial loading of vessels to reduce their gauge.

- The frequency of severe windstorms, hailstorms, tropical cyclones, sand and dust storms is expected to rise in various parts of the EU, posing additional challenges to transport infrastructure (EC DG CLIMA, 2023c).
- Wildfire smoke and sand dust storms may disrupt airports, affecting air operations and causing potential damage to infrastructure and buildings (Kwasiborska et al., 2023) .

9.3.5 Subsystem: pipelines, communication and electricity lines

What drives the impact

- Electricity distribution lines and transmission towers are prone to failures during cold spells, heavy snow and rains, and extreme wind speeds (Panteli and Mancarella, 2015; Andrei et al., 2019; Karagiannis et al., 2019a).
- Heat stresses can cause expansion in oil and gas pipes, increasing the risk of rupture. Soil subsidence impacts underground assets, and rising temperatures could reduce the efficiency of steam and gas turbines.
- Disruptions in urban energy distribution, caused by events like flash floods damaging electricity substations, have cascading effects on social infrastructure, urban services and traffic management. Urban areas with high poverty rates are disproportionately affected (Gasbarro et al., 2019; Teotónio et al., 2020b).
- Storms, droughts and heatwaves can induce damage to information and communication technology assets and urban drainage systems, affecting telecomunications and water management (Dale and Frank, 2017).
- Sanitation systems face challenges with low flows during droughts, leading to sedimentation and blocking of sewer infrastructure networks.

Current situation

- Damage to energy distribution (total EAD of EUR 200 million per year in the 2000s) is primarily caused by river floods (33% of the EAD) and windstorms (56% of the EAD) (data elaborated from (Forzieri et al., 2018b).
- Wildfires have a considerable impact on gas pipelines, contributing to 40% of the total EAD (EUR 60 million per year) in the 2000s (data elaborated from (Forzieri et al., 2018b).
- Dry and hot periods in the past two decades have caused significant reductions and interruptions in power supply in European countries like France, Germany and Switzerland. These disruptions are primarily due to water cooling constraints on power plants (Van Vliet et al., 2016c; Abi-Samra, 2017; Vogel et al., 2019a).

Future situation

- The costs associated with weather-induced hazards on electricity lines and gas pipelines due to climate change could increase by approximately 50% and 20%, respectively, by the 2080s (long term). These increased costs are primarily linked to the same hazards as in the current period (Forzieri et al., 2018b).
- Indirect effects on transport and electricity networks (i.e. service disruption and its impact on productivity, job losses, lack of comfort, security issues, etc.) can be as high as, or substantially higher than, direct effects (Koks et al., 2019b, 2019d; Knittel et al., 2020).

- Intense storms can transport various pollutants including dust, trash, pesticides, particulates and oil from impermeable surfaces into nearby waters. This run-off compromises ecological ecosystems and impacts drinking water infrastructure (Delpla et al., 2009; Arnell et al., 2015; Miller and Hutchins, 2017).

9.3.6 Subsystem: energy and industrial infrastructure

What drives the impact

- Fossil fuel, nuclear, and renewable energy production are vulnerable to droughts and heatwaves. Higher temperatures affect cooling system efficiency in power plants due to elevated water/air temperatures.
- Hydroelectric and thermal power plants are impacted by rising water temperatures and cooling water restrictions, leading to reduced energy production. Warmer water conditions can lead to water intake clogging due to excessive biological growth.
- Increasing temperatures affect the efficiency of solar energy technologies. While solar heating efficiency improves, photovoltaic panels become less efficient. Wind-blown sand and dust can further reduce power output, necessitating regular cleaning of solar energy plants. Solar systems are increasingly being integrated into buildings as façade or roof systems, known as building integrated photovoltaics or building integrated solar thermal systems. EU regulations mandate solar installations on new public and commercial buildings by 2026, residential buildings by 2029, non-residential buildings undergoing renovations by 2027, and existing public buildings in a stepwise approach by 2030. This highlights the need to consider the potential impact of climate change on these systems, given their crucial role in buildings (EU solar rooftop strategy, Energy Performance of Buildings Directive and REPowerEU plan).
- Extreme weather events significantly affect the extraction and refining operations of petroleum, oil, coal, gas and biofuels. Proximity to wildlands increases the risk of fires, particularly impacting built environments near these areas (EEA, 2020f).
- Drought and water scarcity directly impact chemical and plastic manufacturing industries in the EU, affecting production processes and resource availability (Gasbarro et al., 2019; Teotónio et al., 2020b).

Current situation

- River floods and storms accounted for approximately 47% and 27% of the total EAD (EUR 1.6 billion per year) in the industry sector in the 2000s. These climate-related events lead to significant economic losses (Forzieri et al., 2018b).
- Drought, floods and heat constituted about 61%, 18% and 17% of the total EAD (EUR 300 million per year) in the energy production sector in the EU during the same period. Droughts and heatwaves impact energy production, particularly affecting cooling systems in power plants (Forzieri et al., 2018b).

Future situation

- In the 2080s (long term), the EU is expected to experience a significant rise in damage to the energy production sector, due to sensitivity to droughts and heatwaves. Drought damage is projected to comprise 67% of all hazard impacts, and heatwave damage to account for 27% in the energy sector (Forzieri et al., 2018b).
- In the industry sector, damage from floods and windstorms is increasing. However, this damage will be surpassed by droughts and heatwaves in the coming decades. Drought-

related damage is projected to increase from EUR 300 million per year in the 2000s to EUR 9.1 billion per year in the 2080s (long term). Heatwave damage is expected to rise from EUR 100 million per year in the 2000s to EUR 5.2 billion per year in the 2080s (long term) (Forzieri et al., 2018b).

- Thunderstorms may disrupt solar photovoltaic plants, leading to halted electricity generation or damage to electrical equipment caused by lightning strikes (Zaini et al., 2016; Ahmad et al., 2021) .
- Climate change-related factors, such as acid rain and carbonation erosion, can accelerate the natural evolution of concrete in aggressive environments. Acid rain and carbonation erosion are both expected to be intensified by increased greenhouse gas emissions (Raposo et al., 2020; Guo et al., 2023; Rodríguez et al., 2023; Sousa et al., 2020).

9.3.7 Subsystem: green and blue infrastructure

This subsystem is closely related to Chapter 3, specifically to the 'Urban ecosystems' subsystem.

What drives the impact

- Green infrastructure ia vulnerable to droughts and extreme temperatures. In addition, it can be affected by water scarcity, extreme wind events, sea level rise, air pollution, fires, invasive species and diseases.
- Drought-induced reductions in soil moisture levels not only stress vegetation health, but also diminish the aesthetic appeal and recreational value of green spaces. Increasing demand for irrigation raises water consumption, potentially sparking conflicts over water resources.

Current situation

- Access to green and blue (water-based) spaces in the EU varies significantly. Northern and western European cities generally have more total green and blue areas compared to southern and eastern European cities (EEA, 2022o).
- On average, green and blue infrastructure make up 42% of the city area in the 38 EEA member countries. However, only 3% of the total city area consists of publicly accessible green spaces (EEA, 2022o).
- The provision of publicly accessible green spaces varies between cities and is often influenced by location and socio-economic status. This indicates disparities in access to natural amenities within urban areas (EEA, 2022o).
- Urban tree cover in these cities averages 30%. Finland and Norway have the highest proportion of tree cover, while Cyprus, Iceland and Malta have the lowest (EEA, 2022o).

Future situation

- Urban trees may face challenges due to increasing temperatures and decreasing water supply, affecting their fitness and potentially enabling more pests, leading to changes in growth trends (Dale and Frank, 2017).
- Increasing green spaces and integrating well-designed green facades and roofs in urban areas can help minimise the heat island effect and enhance environmental benefits (Mihalakakou et al., 2023).
- European beaches may experience reduced amenity due to sea level rise amplifying coastal erosion and inundation risks, particularly in southern Europe. Coastal settlements, especially in regions like Catalonia, Spain, are facing significant

infrastructure damage due to beach erosion and inundation (Toimil et al., 2018; López-Dóriga et al., 2019; Ranasinghe et al., 2021b).

- Acid rain and air pollution pose significant health risks, including eye irritation, respiratory illnesses and skin-related diseases. They also stress ecosystems, damage aquatic environments, lead to soil pollution and harm buildings (Tafazzoli and Sadoughi, 2021).
- Climate change leads to reduced oxygen levels, increased temperatures and water acidity, disrupting water bodies near urban areas, like rivers or lakes.

9.4 Risk assessment and evaluation

9.4.1 Confidence

Risks related to direct impacts on residential and non-residential buildings and critical infrastructure would become severe with high warming, current infrastructure development design and minimal adaptation (high confidence). In some contexts, these risks would become severe even with low warming, current vulnerability and no additional adaptation (medium confidence). Indirect consequences of infrastructure failure on lives, livelihoods and economies also escalate in high warming scenarios with current vulnerability (medium confidence).

Transport and energy infrastructure along coasts and rivers is at risk, even with medium warming (high confidence), with damage leading to potential long-lasting disruption, if there is no additional adaptation (medium confidence).

In disaster situations, infrastructure-related risks can exacerbate capacity issues with emergency response (limited evidence, high agreement). Climate-related impacts on transport and energy infrastructure reach far beyond the direct impacts on physical infrastructure, triggering indirect impacts on health and income (medium confidence). Power outages triggered by heat, flood and drought have substantial health implications, particularly among low-income populations.

9.4.2 Adaptation opportunities, constraints and limits

The main adaptation opportunities identified for the built environment are:

- Many EU policies and strategies (see Section 9.5) address climate risks to, and climate proofing of, infrastructure, and include both short- and long-term risk mitigation.
- Implementing climate-responsive design in buildings and urban settlements involves sustainable spatial planning, strategic densification, walkable neighborhoods, low-mobility transport infrastructure, and the effective use of passive climate strategies, including ventilation, solar irradiation and shading techniques. This should be combined with renewables, energy-efficient measures for net zero energy consumption, biodiversity enhancement, waste reduction, recycling initiatives and community engagement.
- Energy efficiency and smart technologies focus on enhancing building efficiency standards, utilising energy-efficient technologies like lighting and heating, ventilation and air conditioning systems (HVAC), and incorporating smart city technologies such as smart grids, sensors and data analysis.
- The concept of resilient infrastructure includes the development of sustainable drainage systems, flood-resilient buildings, and integrated green spaces to enhance overall climate resilience in urban areas.
- Green roofs, facades and other vegetated spaces act as natural sponges, absorbing rainwater upon contact and allowing it to infiltrate into the ground or evaporate. This natural mechanism serves as flood prevention, while also cooling buildings, promoting biodiversity and enhancing air quality, thereby contributing to citizens' wellbeing .

- Spatial planning is crucial, especially in considering areas at risk due to climate change, which may differ from what is currently outlined in regulations and sectoral plans for improving and relocating areas. Continuously updating data with maps and tools to enable this, as well as considering new construction standards focused on the safety and robustness of buildings, is essential.
- Planning strategies for green and blue infrastructure elements offer potential solutions for adapting to ongoing climate change. However, in certain cases, high temperatures can increase the risk, resulting in difficulties in managing and maintaining these infrastructures. While they offer environmental benefits, they can also lead to increased economic expenditure for maintenance and management, particularly in countries and periods experiencing drought and water scarcity.

The main gaps identified for the built environment are:

- Insufficient understanding of the long-term effectiveness, economic costs and trade-offs of adaptation options.
- Need for more comprehensive studies on urban resilience and ecosystem-based approaches.
- Lack of research on the interactions between climate change, urbanisation and socio-environmental factors.
- Increased collaboration needed for effective and context-specific adaptation strategies.
- Limited studies examining the risks from hailstorms and lightning.

One of the knowledge gaps identified involves the necessity of providing Member States with up-to-date climatic data and with design maps for use in designing new structures and renovating existing ones. Additionally, the development of readily available tools for data post-processing and statistical modelling could assist designers in using continuously updated data for climatic actions. The availability of such data and tools in georeferenced formats, hosted on authoritative platforms, could simplify and expedite the retrieval of reliable characteristic values for climate-responsive design (CDS, 2022; Climate ADAPT, 2022).

There is a need for more comprehensive studies about sectoral risks and cascading risks for vital sectors such as transport. For example, the German research projects KLIWAS (KLIWAS, 2015) and BMDV Network of Experts (BMDV, 2016) deliver detailed knowledge about cascading risks of climate change for transport infrastructure in Germany.

More research is also needed on overheating of residential and non-residential buildings, as well as on the effectiveness of passive and active cooling solutions and UHI reduction solutions in mitigating this overheating. Effective adaptation and mitigation measures for buildings must be resilient against multiple risks and be guided by technical expertise across various climatic zones in Europe (EC DG CLIMA, 2023b, 2023c).

9.4.3 Overall assessment

This section presents the outcomes of the structured risk assessment for the major climate risks identified in this factsheet. This assessment builds on information in this factsheet, and possibly in other chapters of this report. The initial risk assessment was conducted by the authors of this factsheet whereas the final assessment results reported here represent the consensus of the EUCRA risk review panel. Further methodological information is available in Annex 2.

The following major risks assessed in other chapters are also relevant for this factsheet, but they are not presented here to avoid duplication:

- Risk of energy disruption due to damage to energy transportation or storage infrastructure following coastal or inland flooding (Chapter 7).
- Risk of electricity disruption due to the impacts of heat and drought on energy production and peak demand (Chapter 7).

- Risk to the population and built environment from wildfires facilitated by drought and heat (Chapter 11).
- Risk to the population, infrastructure and economic activities from inland flooding (Chapter 12).
- Risk to the population, infrastructure and economic activities from coastal flooding (Chapter 12).
- Widespread disruption of marine transport (Chapter 15).
- Widespread disruption of land-based transport (Chapter 15).

Table 9.1 Risk assessment for the risk of damage to infrastructures and buildings due to slow-onset climate change and extreme climate events

	Current/near term (2021-2040)	**Mid-term (2041-2060)**	**Long term (2081-2100)** • **high warming** • **low warming**
Risk severity	**Substantial** High vulnerability in ageing buildings and infrastructures	**Substantial** Increasing risk if no adaptation is adopted in the design of new structures and retrofitting of existing structures	**Critical** Further increasing risk levels **Substantial** See mid-term
Confidence	**Medium**	**Medium**	**Medium**
Risk ownership	**Co-owned** The EU and Member States share legislative responsibilities with respect to policies relating to spatial planning and infrastructure. Since the EU does not have an explicit competence on spatial planning, zoning and spatial planning policies generally reside at Member State level. However, the EU can exert considerable influence on spatial planning through other sectoral competences (e.g. via the environment, energy and maritime affairs) and different funding instruments (e.g. Cohesion Fund). At the EU level, the main relevant policy frameworks and initiatives include: • Critical Entities Resilience Directive (2022/2557) • Floods Directive (2007/60) • Technical guidance on the climate proofing of infrastructure in the period 2021-2027 (2021/C373/01) • Taxonomy Regulation for Sustainable Activities (2020/852) • European standards: second generation of Eurocodes • Construction Products Regulation (05/2011) • Energy Performance of Buildings Directive (revision provisionally agreed in December 2023) • Renovation wave • Green public procurement At the national level, the main policies of relevance include those relating to: • Spatial planning and infrastructure • Energy • Transportation		
Policy readiness	**Medium** • Many EU policies and strategies address climate risks to, and climate proofing of, infrastructure, and include both short- and long-term risk mitigation. • There are currently no obligatory requirements to incorporate climate scenarios into building plans, and there is a lack of incentives to climate proof the existing building stock. However, the revised Energy Performance of Buildings Directive (foreseen to be adopted in spring 2024) includes provisions on adaptation. • Future climate risks are not sufficiently addressed in the current Eurocodes.		
Policy horizon	**Long term**		
Urgency to act	**More action needed** (assuming a high warming scenario) **Further investigation** (assuming a low warming scenario)		

Source: EEA.

Table 9.2 Risk assessment for the risk to human wellbeing from climate change impacts on residential and non-residential buildings

	Current/near term (2021-2040)	Mid-term (2041-2060)	Long term (2081-2100) • high warming • low warming
Risk severity	**Substantial** The European population is increasingly affected by overheating of buildings during summer heatwaves	**Substantial** Overheating and summer energy poverty will further increase across Europe	**Critical** The built environment is increasingly operated outside its design climate envelope **Substantial** See mid-term
Confidence	**Medium**	**Medium**	**Medium**
Risk ownership	**Co-owned** The EU and Member States share legislative responsibilities with respect to policies relating to spatial planning and infrastructure and to public health. Since the EU does not have an explicit competence on spatial planning, zoning and spatial planning policies generally reside at Member State level. However, the EU can exert considerable influence on spatial planning through other sectoral competences (e.g. via the environment, energy and maritime affairs) and different funding instruments (e.g. Cohesion Fund). At the EU level, the main relevant policy frameworks and initiatives include: • Critical Entities Resilience Directive (2022/2557) • Technical guidance on the climate proofing of infrastructure in the period 2021-2027 (2021/C373/01) • European standards: second generation of Eurocodes • Energy Performance of Buildings Directive (revision provisionally agreed in December 2023) • Renovation wave At the national level, the main policies of relevance include those relating to: • Spatial planning and infrastructure • Public health • Energy		
Policy readiness	**Medium** • Human well-being linked to the built environment (including residential buildings, hospitals and schools) is often not explicitly addressed in EU policies, despite them identifying vulnerable buildings and assets as being subject to climatic risks. • There are currently no obligatory requirements to incorporate climate scenarios into building plans, and there is a lack of incentives to climate proof the existing building stock. However, the revised Energy Performance of Buildings Directive (foreseen to be adopted in spring 2024) includes provisions on adaptation.		
Policy horizon	**Long term**		
Urgency to act	**More action needed** (assuming a high warming scenario) **Further investigation** (assuming a low warming scenario)		

Source: EEA.

9.5 Relevant policies

EU adaptation strategy and nature-based solutions: the EU's adaptation strategy emphasises the importance of enhancing preparedness and resilience in both buildings and infrastructure. It promotes the development of nature-based solutions, such as urban green spaces and green roofs, to combat heat-induced stress and reduce the need for mechanical air conditioning.

EU Taxonomy and sustainability criteria: the EU Taxonomy sets criteria for construction and renovation projects, requiring substantial contributions to climate adaptation in buildings. These criteria aim to ensure the sustainability of economic activities and guide the construction industry towards climate-resilient practices.

Cohesion Policy (2021-2027): the EU's Cohesion Policy addresses climate change adaptation in the built environment sector. Under Policy Objective 2 of the European Regional Development Fund, it promotes climate change adaptation and disaster risk prevention and resilience, emphasising ecosystem-based approaches. Policy Objective 3 focuses on enhancing mobility through developing climate-resilient transport networks.

Trans-European transport corridors (TEN-T): this is the main EU policy defining standards for transport infrastructure and establishing a network of core transport infrastructure corridors in the EU; it is of critical importance for connectivity in Europe and vital transport infrastructure in the EU context. Revisions of the trans-European transport corridors (TEN-T) regulations will put a stronger focus on climate resilience and climate proofing transport infrastructure.

Level(s) framework for sustainable buildings: Level(s) is the European framework for sustainable buildings, enabling designers to assess and report on buildings' sustainability features. It includes indicators related to climate change adaptation, maximising thermal comfort and reducing water consumption to minimise risks related to droughts.

EU Missions and Covenant of Mayors: the EU Missions, particularly the Mission on Adaptation to Climate Change, aim to assist European regions in becoming climate resilient by 2030. The Covenant of Mayors initiative collaborates with cities to achieve the EU's climate targets, focusing on climate change mitigation and adaptation at the local level. These initiatives play a significant role in driving transformative change and sustainable development in European cities.

The InvestEU Fund supports private and public investments in four policy areas of importance for the EU, one of which is sustainable infrastructure (EUR 9.9bn in guarantee). These include transport, energy, nature and other environment, infrastructure and other assets and equipment. The EU adaptation strategy also states that the European Commission (EC) will explore better alternatives to predict climate-induced stress on buildings by introducing climate resilience criteria through green public procurement (GPP) for public buildings. Use of the GPP guidance is voluntary for authorities. Updated guidance is currently under development: it aims to cover health and thermal comfort, extreme weather risks, sustainable drainage and water consumption.

The renovation wave focuses on adaptation measures for existing building stock and aims for the protection and adaptation of buildings to various temperature-, wind-, water- and solid mass-related climate hazards. It also pays attention to vulnerable groups.

Energy Performance of Buildings Directive: the revised version (expected to be formally adopted in spring 2024) includes provisions on adaptation and resilience, including requirements to address resilience in renovation and in new buildings, as well as the option of including information on the adaptive capacity of buildings in the Building Renovation Passports.

The New European Bauhaus (NEB) initiative connects the European Green Deal with living spaces, and promotes projects and practices that are aesthetically beautiful, in harmony with nature and the environment, and inclusive, by encouraging a dialogue between cultures, disciplines, genders and ages. As part of the initiative, it is stressed that reconnecting with nature through the promotion of nature-based solutions in cities can mitigate flood risks and other extreme weather events. The NEB is delivered through identifying synergies among existing funding instruments and policies, as well as through specific and dedicated actions. Projects that advance the NEB objectives are conducted within the NEB Lab, where actions to create enabling conditions for green transitions (including new tools, frameworks and policy recommendations), and to trigger tangible transformation on the ground, are implemented.

The Critical Entities Resilience Directive (2022/2557) adopts a broader scope to identify critical entities which are now understood as those that provide essential services crucial for the wellbeing of EU citizens and functioning of the internal market. Extreme weather events are

identified as physical risks. The critical entities include both the digital infrastructure sector and the transport sector. By January 2026, EU Member States are obliged to formulate strategies to enhance the resilience of critical entities.

The Floods Directive (2007/60/EC) aims to reduce flood impacts on infrastructure, communities and the environment. The directive constitutes an effort to streamline flood risk assessments and management across Member States. It does not specifically address the groups or assets that are most vulnerable to the impacts of floods. However, Member States are obliged to identify areas of potential significant flood risks, assess in detail the flood hazard, prepare flood maps and generate flood risk management plans. As part of this exercise, Member States should identify and map vulnerable assets and people.

The Construction Products Regulation (No 305/2011) (CPR) provides harmonised rules for the marketing of construction products in the EU. An EC evaluation found that the CPR is currently unable to deliver on broader policy priorities, such as the green transition, and hampers the promotion of climate performance-oriented information on construction products. A revision was proposed in 2022, aimed at enhancing the sustainability of construction products and contributing to the objectives of the green transition.

The second generation of Eurocodes will improve standards by promoting harmonisation and ease of use, and requiring assessment and retrofitting of existing structures. Additionally, it will advance pre-normative work on structural elements, strengthening robustness and ensuring infrastructure resilience in the face of climate change impacts.