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Urban adaptation in Europe: how cities and towns respond to climate change

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Key messages

- In the changing climate, the most pronounced impacts in European cities are likely to be caused by extreme weather events, such as heatwaves, heavy precipitation, flooding and droughts, but other risks including wildfires and vector-borne diseases are also on the rise.
- Adapting European cities and towns to inevitable climate change is crucial for the overall resilience of European society because of the population concentration — including vulnerable groups — assets and economic activities in urban areas.
- The number of cities and towns committed to acting on adaptation to climate change has grown substantially in Europe, supported by the emphasis on urban adaptation in national adaptation strategies, EU policy and key international frameworks. However, the implementation of adaptation actions is still in its infancy, lagging particularly far behind in smaller cities and towns.
- Early warnings, awareness raising and nature-based solutions emerge as effective and cost-efficient adaptation actions. However, the success of adaptation measures is highly context-dependent and the limited amount of knowledge on the successfulness of various adaptation measures calls for improved monitoring and evaluation of the solutions implemented.
- There is an urgent need to change the way we plan and construct our cities in the changing climate, because unsustainable urban development — built-up floodplains, progressive surface sealing, small amounts of green space or urban sprawl encroaching on wildfire- and landslide-prone areas — magnifies the impacts of climate-related hazards.
- Concerted action at all governance levels — from EU through national to local — is needed to support urban adaptation through improved access to knowledge and funding; political commitment and community engagement; and mainstreaming adaptation into all policy areas.
- The absence of a single, comprehensive overview of adaptation planning and action at the local government level in Europe precludes a detailed assessment of the level of preparedness for climate change in Europe. Streamlined monitoring and reporting of local adaptation plans and actions is needed if EU and national governments are to effectively support local adaptation.

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Executive summary

In 2020, the urgent need to improve the resilience of European society and economy to shocks of unprecedented scale became obvious in the light of the coronavirus disease 2019 (COVID-19) pandemic. The public health crisis showed that — despite plenty of early warnings — Europe is unprepared and extremely vulnerable to events of such magnitude. Under the projected trajectory of climate change, threats of a comparable degree to COVID-19 cannot be ruled out.

While climate change is a global phenomenon and its mitigation through reduced greenhouse gas emissions requires a global effort, the impacts of the changing climate are more localised and must be tackled in their given contexts. In a highly urbanised continent such as Europe, cities and towns play a crucial role in responding to climate change. This is not only because of the concentration of population and economic assets in urban areas, but also because local authorities perform key functions that are central to climate adaptation, such as land use regulation or emergency planning. This report investigates to what extent cities and towns across Europe are prepared for the increasing risks posed by climate change, focusing on extreme weather events.

Through the actions of the 2013 EU adaptation strategy and resources committed under the multiannual financial framework 2014-2020, EU support for urban adaptation has greatly advanced local climate change adaptation in Europe in recent years. As of April 2020, over 2 600 local authorities across the EEA's 38 member and collaborating countries, covering nearly 123 million people, are signatories to the Covenant of Mayors for Climate and Energy on adaptation. Several hundred cities benefited from funding for research, implementation and knowledge exchange via the Horizon 2020, LIFE and Interreg programmes.

Most national adaptation strategies in Europe identify subnational governments as key implementing actors of adaptation, with local-level adaptation planning or climate change risk assessments mandatory in some countries. However, national-level support for local adaptation — in terms of regulation, knowledge and funding — varies among EU Member States.

Therefore, while many local authorities have realised the importance of adaptation and have started acting, progress in adaptation planning is still slow and the implementation and monitoring of actions even more so. This is largely caused by the insufficient human and financial resources available for local-level adaptation, especially in smaller cities and towns. Further engagement of the private sector, citizens and civil society can support local authorities in adaptation planning and implementation.

In addition, the adaptation actions currently planned and put into action in Europe at the local level are mostly aimed at developing knowledge, awareness or policy, with fewer material measures being implemented. This reflects the overall early stages of adaptation in Europe, as well as the generally lower costs of the institutional and social actions in comparison with physical measures. Thus, there is an urgent need for developing and putting in place tangible adaptation measures.

Heatwaves, heavy precipitation, flooding and droughts will remain the most pronounced climate change impacts facing European cities, but other risks such as wildfires and vector-borne diseases are on the rise. Climate risks are highly context-dependent, as they depend on the hazards occurring in a given location as well as on the characteristics of the local area. Thus, local climate risk and vulnerability assessments, supported with high-quality data, are key to understanding the current and projected threats. Accessible, robust knowledge on climate change, exposure and vulnerability of local areas is key to support adaptation planning, calling for closer collaboration between cities and the research community, as well as other information holders such as the insurance industry.

Surprisingly little concrete knowledge is available about the successfulness of measures that can be used to address climate risks. The existing evidence suggests that awareness raising and early warnings are highly cost-efficient and effective in reducing climate impacts. Nature-based solutions also emerge as feasible measures, especially considering their multiple benefits for the environment and society. However, the effectiveness and cost-efficiency of most of the adaptation options require more research. Monitoring and evaluation of the actions already in place is necessary to understand what works well and which options are a sound investment of public funds.

Crucially, climate-adapted land use planning and urban design can substantially reduce the scale of future damage under the changing climate. The model of urban development involving construction in floodplains, progressive surface sealing, small amounts of green space or urban sprawl encroaching on wildfire- or landslide-prone areas magnifies the current and projected impacts from the changing climate. Planning and land use regulations that account for climate change must be put in place in all countries to ensure that European cities are safe, liveable and thriving in the future.

Yet urban adaptation to climate change is not just about changing the physical shape of our cities. The COVID-19 pandemic has served as a reminder of the risks faced by the most vulnerable groups in our society: the elderly, those in poor health or people in difficult economic situations. This calls for reflection on the justice perspective of the climate risks and adaptation actions, exploring how they affect different groups in our society. As Europe continues to battle the public health crisis, we also need to think about how we can prepare our health and social care systems, where and how we live, work and attend education for an uncertain future. Thus, making our cities more resilient to climate change requires mainstreaming adaptation into all policy areas and making it an essential part of sustainable development.

The implementation of urban adaptation should be supported by concerted action at all levels of governance. Urban- and local-level adaptation is firmly anchored in national adaptation strategies, key international frameworks and EU policy, but adaptation generally lags behind climate mitigation with regard to binding EU legislation. The current developments in EU policy under the European Green Deal — including the proposed European climate law, the new EU adaptation strategy and others — offer the opportunity to further emphasise the importance of adaptation as a key policy area that ensures the liveability and prosperity of European cities, towns and settlements. Importantly, streamlined monitoring and reporting of local adaptation plans and actions are vital for measuring the progress of local adaptation across Europe, identifying gaps and effective targeting of EU and national support.

1 Introduction

1.1 Rationale and aim

Climate change is upon us. With global temperature records being broken year after year and increasingly dire prospects for the magnitude of future climate change and its effects, in the 2020s the world and Europe have entered a new era. Unprecedented extreme weather and climate events — deadly heatwaves, devastating droughts, sudden floods sweeping through city streets — are no longer tales from distant lands or far futures but a reality in the European context. In November 2019, the European Parliament declared a global 'climate and environmental emergency' as it urged all EU Member States to commit to net zero greenhouse gas emissions by 2050 (EP, 2019). At the local level, the climate emergency was recognised by the mayors of 94 major global cities in September 2019 (C40 Cities, 2020b). A number of smaller towns in Europe within the Climate Alliance network also signed the climate emergency declarations (Climate Alliance, 2020). Despite the increasing awareness, the United Nations Environment Programme (UNEP) *Emissions gap report 2019* finds that, even if all countries' unconditional nationally determined contributions (NDCs) under the Paris Agreement are implemented, we are still on course for a 3.2 °C global temperature rise (UNEP, 2019). Therefore, as recognised by the proposed European climate law, which aims for climate neutrality by 2050 and enhanced climate resilience, climate change is already creating and will continue to create significant stress in Europe, despite mitigation efforts. Thus, increasing efforts to enhance adaptive capacity, strengthen resilience and reduce vulnerability are crucial (EC, 2020h). The vulnerability of our society and the urgent need to increase its resilience to shocks have been brought home in 2020 by the coronavirus disease 2019 (COVID-19) crisis.

The sense of urgency in addressing climate change is felt by European citizens, too: 2019 will be remembered as the first year when school children initiated climate strikes out of concern for their future. The number of Europeans who consider climate change to be a very serious problem — currently 8 out of 10 — has grown over the past few years, and over two thirds of Europeans believe that adapting to the adverse impacts of climate change can have positive outcomes for EU citizens (EC, 2019a).

Cities, towns and other human settlements are particularly important locations for urgent implementation of adaptive measures. Nearly 75 % of Europeans live in urban areas and this percentage is expected to grow to just over 80 % by 2050 (Eurostat, 2016b). Adaptation of cities is also necessary from an economic perspective. Urban areas host industry and services and are focal points of economic activity, generally characterised by high values of gross domestic product (GDP) per capita (Lavalle et al., 2017). Failure of climate change mitigation and adaptation was in 2019 seen as the number one risk to the economy in terms of its impact, and the second biggest risk in terms of likelihood of occurrence within the next 10 years, according to the World Economic Forum (WEF) multistakeholder survey. Since 2017, extreme weather has been assessed in the *Global risks report* as having the highest likelihood among the threats to the economy (WEF, 2020).

Despite global mitigation efforts, climate change is a reality requiring urgent action

As the risk of spread of infectious diseases was seen in 2019 as less probable and having less economic impact than climate change (WEF, 2020), the anticipated crippling effects of the COVID-19 crisis on the global economy should not distract policymakers' attention from the need to address climate change. In fact, lessons for increasing resilience to climate change can be learned. The crisis induced by COVID-19 has many characteristics to be expected of climate change impacts on society: the pandemic arose rapidly, was foreseen in general but not precisely, is a global phenomenon with substantial economic impact and has a disproportionate impact on vulnerable groups (Group of Chief Scientific Advisors, 2020). It has changed how cities function, and will probably have a lasting impact on how people work, spend their free time and use public spaces.

The importance of urban resilience to climate change is emphasised in the key international and European agreements, frameworks and policies, including the Paris Agreement (UNFCCC, 2015) and the United Nations (UN) 2030 Agenda for Sustainable Development (UN, 2015). The EU adaptation strategy (EC, 2013a), the outcomes of its evaluation (EC, 2018b) and the blueprint of the new EU adaptation strategy (EC, 2020c) all draw attention to building the resilience of cities to climate change. The European Green Deal emphasises that under the new EU adaptation strategy cities (among other stakeholders) should be able to access data and to develop instruments to integrate climate change into their risk management practices (EC, 2019c). The means of implementation of national adaptation strategies and plans in Europe operate largely on subnational (regional and local) administrative levels. In particular, local authorities play a key role in public functions that are central to adaptation, including land use regulation and planning, development and maintenance of infrastructure, as well as (with various powers in different European countries) emergency planning, public health and social care (Aguiar et al., 2018).

Adaptation in the European context, especially at the local level and in urban settings, is progressing. From a few pioneer cities a decade ago, the number of local authorities committed to adaptation and the number of those planning and implementing adaptation measures has grown rapidly. Nonetheless, the evaluation of the EU adaptation strategy (EC, 2018b) suggests that, while almost all Member States now have a national adaptation strategy in place, progress in adaptive actions at the local level varies among countries and has been slower than originally envisaged in 2013. However, there is no comprehensive overview of urban and local governments' adaptation efforts across Europe. Also, globally, the systematic data on local-level adaptation measures are lacking, which impedes the monitoring and evaluation of a growing body of national-level adaptation policies and legislation (UNEP, 2018a).

The aim of this report is to present the status quo of adaptation to climate change at the local level in Europe and to suggest further steps for various stakeholders to expedite action. This is done by addressing the following objectives:

- presenting the scale of current and projected future impacts of climate- and weather-related hazards on European cities and towns (Chapter 2);
- showing the effectiveness and cost-efficiency of various adaptation measures (Chapter 3);
- discussing the evolving roles of international, EU, national and subnational governance in progressing adaptation in the urban context (Chapter 4);
- taking stock of adaptation planning at the local level (Chapter 5) and providing examples of how cities and towns are addressing climate- and weather-related hazards;
- identifying barriers to adaptation and highlighting opportunities for policy and action that cities and towns, regional and national governments, the EU and other bodies could take to progress adaptation (Chapter 6).

1.2 Scope

1.2.1 Thematic scope

The report aims to provide a solid, up to date evidence base on adaptation planning and actions in the local and urban context. It follows previous EEA reports on urban adaptation. The first report (EEA, 2012) introduced the subject of adaptation at the local level and focused on the risks to cities; steps and success factors linked to planning urban adaptation; and the role of multi-level governance in supporting urban adaptation. The 2016 report concentrated on the five driving factors of transformative adaptation: governance, knowledge, planning, economics, and monitoring and evaluation (EEA, 2016). A specific report on financing urban adaptation to climate change has also been published (EEA, 2017c). This report builds on these three previous publications and attempts to summarise the scientific evidence on climate- and weather-related hazards facing European cities and their impacts, which has grown substantially since 2012.

While the 2016 report provided a brief overview of the urban adaptation activities carried out at that time, this report looks in more detail at the adaptation actions planned and implemented, stakeholders involved and financial resources of local authorities. The database of submissions of the signatories to the Covenant of Mayors for Climate and Energy (extract dated 19 June 2019) is used as a key source of information about the current state of adaptation planning and action at the local level across Europe. It is complemented with information on the climate- and weather-related hazards faced by European cities, actions planned, stakeholders engaged and barriers to adaptation available from CDP (1) (Box 1.1). In addition, the research carried out in recent years — largely under the EU Research and Innovation Horizon 2020 programme — has generated knowledge regarding adaptation planning at the local level and the effectiveness and cost-efficiency of various adaptation measures.

Finally, the report provides an updated picture of the multi-level governance of urban adaptation, particularly focusing on the role of the national level. This is based on the adaptation preparedness scoreboard (EC, 2018a), used by the European

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(1) Formerly the Carbon Disclosure Project, CDP is a not-for-profit charity that runs the global disclosure system for investors, companies, cities, states and regions to measure and manage their environmental impacts on, and the risks and opportunities of climate change for water security and deforestation (https://www.cdp.net/en).

Commission to collect information from the EU-28 Member States primarily for the evaluation of the EU adaptation strategy in 2018. The individual country fiches, i.e. descriptive documents structured around 11 indicators of progress in adaptation policy making, provide information about the support offered by the national level to local adaptation planning, and about the involvement of local authorities in the development of national adaptation strategies and plans. This information is supplemented by the Member States' 2019 round of reporting under Article 15 (Adaptation) of the Monitoring Mechanism Regulation (MMR) (EU, 2013).

This report complements and draws conclusions from other important information and guidance sources focused on urban adaptation. To mention the key ones, as of June 2020 the Climate-ADAPT portal includes 50 in-depth urban adaptation case studies (2), many of which are referenced in this report, and describes in detail 59 adaptation options (3). Climate-ADAPT also hosts the Urban Adaptation Map Viewer (4), which provides interactive maps giving an overview of the current and future climate hazards facing European cities, the vulnerability of the cities to these hazards and their adaptive capacity. Those interactive maps offer more detail than the illustrations

Box 1.1 Investigating the databases of local adaptation planning in Europe

To investigate the status of local adaptation planning across Europe, two databases were analysed. The database of signatories to the Covenant of Mayors on Climate and Energy contains signatories' reports on their risk and vulnerability assessments and adaptation plans. The database version as of 19 June 2019 was obtained from the Joint Research Centre (JRC), which is responsible for the maintenance of the database. It had 2 021 adaptation signatories in 34 (a) EEA member and collaborating countries. However, only 226 signatories carried out self-assessments of their progress. Even fewer signatories reported on adaptation actions planned and implemented, stakeholder involvement or their adaptation budgets. This is likely to be related to them having recently joined the initiative and not having yet performed the reporting required after 2 and 4 years since joining (see also Box 4.4). In addition, signatories have a minimal requirement to report three actions on adaptation, while their detailed action plans developed usually contain a much wider array of identified actions. Thus, the Covenant database presents selected actions, which are either completed or at an advanced stage of implementation but does not provide a comprehensive overview of all actions planned or implemented.

The database is a rich source of information; however, it cannot be seen as a representative sample of the local authorities engaged in adaptation planning across Europe, given its uneven regional distribution: over three quarters of the signatories are from southern Europe, fewer than 2 % (32 local authorities) are from the north, 16 % are from the west and 7 % are from central and eastern Europe. Thus, the conclusions drawn should be treated with caution.

The signatories are mainly small: 54 % have under 10 000 inhabitants, and a further 30 % between 10 000 and 50 000 inhabitants. Only 81 cities, or 4.5 % of the sample, have over 250 000 inhabitants. Thus, the database provides a useful insight into adaptation activities of small municipalities.

The CDP database on adaptation in cities (https://data.cdp.net) contains reporting from 163 cities in 26 EEA member and collaborating countries and the United Kingdom on the experienced and expected impacts of climate change, adaptation planning and implementation of actions. These data were collected in partnership by CDP and ICLEI — Local Governments for Sustainability. The cities reporting to CDP are predominantly large and located in southern or northern Europe (65 and 52 cities, respectively), with fewer cities from western Europe (32) and the lowest number from central and eastern Europe. Therefore, these two databases provide complementary information but not a complete overview of local-level adaptation activities in Europe. Many additional local authorities not captured by those databases also act on adaptation, for example owing to the requirements of national legislation (see Section 4.4.1), through participation in other initiatives or networks (see Section 4.3), or on their own initiative. Therefore, the investigation into those two databases is complemented by compiling results from relevant research as well as illustrative case studies.

Notes: (a) With the exception of Kosovo (under UN Security Council Resolution 1244/99), Liechtenstein, Luxembourg, Montenegro and Malta. The databases of the Covenant of Mayors for Climate and Energy and CDP were obtained before the United Kingdom left the EU, and therefore include UK local authorities in their scope.

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(2) https://climate-adapt.eea.europa.eu/knowledge/tools/case-studies-climate-adapt

(3) https://climate-adapt.eea.europa.eu/knowledge/adaptation-information/adaptation-measures

(4) https://climate-adapt.eea.europa.eu/knowledge/tools/urban-adaptation

included in this report allow. Moreover, within Climate-ADAPT, the Urban Adaptation Support Tool (5), managed jointly by the Covenant of Mayors for Climate and Energy — Europe Office and the EEA, provides guidance on adaptation planning and implementation. The Covenant of Mayors for Climate and Energy website includes resources such as guidance on funding available for climate action in cities (6), materials from webinars on local adaptation and others.

1.2.2 Geographical scope

The report predominantly focuses on cities, usually defined as densely populated areas, exceeding 50 000 inhabitants, with a link to a political level (Dijkstra and Poelman, 2012). However, it also looks more broadly at adaptation in the context of a local government. Europe is generally characterised by a large number of relatively small cities and towns (Eurostat, 2016b); only 39.3 % of the EU-27 plus United Kingdom population lives in cities with at least 50 000 inhabitants, 31.6 % lives in towns and suburbs, and 29.1 % lives in rural areas (Eurostat, 2020). This split is reflected in the sizes of the signatories to the EU Covenant of Mayors for Climate and Energy initiative (see Box 1.1). Importantly, from the policy perspective, national adaptation strategies and plans in Europe tend not to distinguish between urban and non-urban local authorities.

The report, whenever possible, aims to provide information for 38 (7) EEA member and collaborating countries. However, the geographical scope of the studies cited, maps or charts differs depending on the data source used, and is specified. The United Kingdom is included in many of the statistics reported, as most of the evidence was collected in 2019, before the United Kingdom formally ceased to be a member of the EU. In many instances the report refers to Urban Audit cities (8), as the main set of cities for which data are collected across Europe.

The report categorises EEA member and collaborating countries (and the United Kingdom) into regions following the EuroVoc classification (9), as follows:

- central and eastern Europe: Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Czechia, Hungary, North Macedonia, Poland, Romania, Serbia, Slovakia, Slovenia;
- northern Europe: Denmark, Estonia, Finland, Iceland, Latvia, Lithuania, Norway, Sweden;
- southern Europe: Cyprus, Greece, Italy, Malta, Portugal, Spain, Turkey;
- western Europe: Austria, Belgium, France, Germany, Ireland, Liechtenstein, Luxembourg, Netherlands, Switzerland, United Kingdom.

1.2.3 Target audience

The report contains information for experts and policymakers concerned with adaptation at the local, regional, national and European levels.

Local decision-makers can find details about the multiple impacts of climate change on cities, with comparisons between different parts of Europe (in Chapter 2), which gives them an up-to-date overview and leads to further information sources. They will also find information about the effectiveness and cost-efficiency of different adaptation measures (in Chapter 3), which can provide first pointers to which measures to choose in specific situations and which criteria to consider. Local decision-makers can also find out about the various networks, initiatives and support available from higher governance levels (Chapter 4) and draw inspiration from the examples provided throughout the report (see Annex 1).

National-level policymakers on adaptation can see how other countries support local-level adaptation in Chapter 4, and find inspiring case studies throughout the report. Areas for action are summarised in the concluding section of each chapter.

European policymakers can benefit from the assessment of multi-level governance of adaptation in Europe (in Chapter 4). The European overview of local-level adaptation (in Chapter 5) can be a useful baseline for further policy developments under the European Green Deal, in particular the implementation of the new EU adaptation strategy and the proposed European climate law, with opportunities for action highlighted in Chapter 6.

Researchers can find in the report knowledge gaps and emerging opportunities for research.

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(5) https://climate-adapt.eea.europa.eu/knowledge/tools/urban-ast/step-0-0

(6) https://www.covenantofmayors.eu/support/funding.html

(7) The European Environment Agency member countries are the EU-27, Iceland, Norway, Liechtenstein, Switzerland and Turkey. The EEA cooperating countries are Albania, Bosnia and Herzegovina, North Macedonia, Montenegro, Serbia and Kosovo (under UN Security Council Resolution this designation is without prejudice to positions on status, and is in line with UNSCR 1244/99 and the ICJ Opinion on the Kosovo Declaration of Independence).

(8) See glossary (Annex 2) for the explanation of Urban Audit cities.

(9) https://op.europa.eu/en/web/eu-vocabularies/th-dataset/-/resource/dataset/eurovoc

2 Climate-related impacts on European cities and towns

Key messages

- All of Europe's cities are at risk from climate change, but the current and projected impacts vary depending on the hazards in the given location, combined with the city's exposure and vulnerability. Most impacts on European cities are likely to be connected to changes in climate extremes.
- European city representatives, consistently with scientific knowledge, identify heatwaves, heavy precipitation, flooding and droughts as the most severe current climate- and weather-related hazards, and expect the frequency and magnitude of these hazards to increase, affecting most areas of their activity — mainly the natural environment, water management, buildings and transport.
- Some cities across Europe share characteristics in terms of the risks they face and their vulnerabilities. These similarities can help to facilitate the exchange of adaptation knowledge and experience.
- While temperatures are projected to rise across Europe, cities in south-eastern Europe face the highest projected increase in the frequency of heatwaves combined with the lowest provision of green space and the most pronounced urban heat island (UHI) effect.
- Heatwaves claim more human lives than any other weather-related disasters, and UHI exacerbates the risks to vulnerable populations. Urgent actions are needed to adapt housing and social infrastructure such as hospitals and schools, which tend to be disproportionately located within UHI extent, to high temperatures.
- Heavy precipitation events are projected to increase in frequency in the most of Europe. Their impacts are exacerbated by increasing surface sealing in cities and sewerage infrastructure that is often not fit for purpose.
- Large proportions of residential, commercial and other valuable types of land in European cities may be at risk of flooding due to their location in river or coastal floodplains. Around 10 % of the European urban population lives in potential river floodplains.
- The continuing development of urban floodplains combined with increasing river flows in most of Europe in the future is likely to magnify the already substantial impacts.
- The projected sea level rise is expected to raise the level of damage associated with coastal flooding and coastal erosion.
- By the end of this century, cities in southern Europe may experience droughts up to 14 times more intense than the worst episodes between 1951 and 2000, but water scarcity in cities in other European regions is also becoming a reality as a result of overexploitation of water resources and increasing frequency and magnitude of droughts.
- Urban sprawl and rural land abandonment exacerbate the risk of wildfires in hot and dry conditions — predominantly, but not exclusively, in southern Europe. Nearly 70 000 urban residents live in areas that were directly affected by forest fires between 2000 and 2018, mainly in southern Europe.
- Windstorms are one of the most destructive natural hazards affecting the EU. The change in the frequency of windstorm events is uncertain as the climate changes, and urban areas remain vulnerable to impacts associated with damage to infrastructure and property.
- Climate change is conducive to the incidence of vector-borne diseases in Europe, in particular in the south. Higher urban temperatures improve the climatic suitability for vectors such as the tiger mosquito, contributing to the risk of disease spread.

2.1 Introduction

The aim of this chapter is to summarise existing knowledge of the climate- and weather-related hazards facing European cities, and the current and projected climate-related impacts on them, considered in terms of money, fatalities, productivity loss and other aspects. While the EEA reports on the economic losses and fatalities associated with extreme weather and climate events (EEA, 2019b) and has provided a broad assessment and indicators of impacts on ecosystems, the economy and human health (EEA, 2017b), the information specific to cities is less readily available and has been obtained through an extensive literature search.

Impacts of climate- and weather-related extremes are driven by the magnitude of climate hazards in combination with the vulnerability and exposure of a given location (Box 2.1). Cities in Europe are exposed to various climate- and weather-related hazards, depending on their location and topography, while their physical and socio-economic characteristics influence their vulnerability. Most impacts on European society are likely to be connected to changes in climate extremes, because their projected rise is disproportionate to the corresponding change in the climatological variables (IPCC, 2013; Ciscar et al., 2018). Therefore, the focus of this report is on extreme weather events. This chapter provides an overview of the climate risks to European cities, focusing on high temperatures, river and pluvial flooding, coastal flooding and coastal erosion associated with sea level rise, windstorms, droughts, wildfires, and water- and vector-borne diseases.

Box 2.1 Investigating the databases of local adaptation planning in Europe

Climate risk is defined as resulting from the interaction of climate-related hazards (including hazardous events and trends) with the vulnerability and exposure of human and natural systems.

Hazard is the potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources. In this report, the term 'hazard' usually refers to climate-related physical events or trends or their physical impacts.

Exposure is the presence of people, livelihoods, species or ecosystems, environmental functions, services, resources, infrastructure, or economic, social or cultural assets in places and settings that could be adversely affected.

Vulnerability is the propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

Source: IPCC (2014a).

2.2 Overview of climate-related risks to European cities

2.2.1 Climatic hazards and impacts at a glance

The key climate change hazards and impacts, both present and projected, vary among European regions (EEA, 2017b; Map 2.1). In the boreal region, projections suggest a larger than average temperature increase, in particular in winter, an increase in annual precipitation and river flows, less snow and greater damage from winter storms. Climate change in this region could offer some opportunities such as lower energy consumption for heating and possibly more summer tourism. However, more frequent and intense extreme weather events are projected to have an adverse impact on the region; for example, heavy precipitation events are projected to increase, leading to increased urban floods and associated impacts.

Extreme weather events pose high threats to urban areas in Europe

The low-lying coastal areas in the Atlantic region have been affected by coastal flooding in the past and these risks are expected to increase as a result of sea level rise and potentially stronger storm surges, with North Sea countries being particularly exposed. Stronger extreme precipitation events, in particular in winter, are projected to increase the frequency and intensity of winter and spring river flooding, urban floods and associated impacts. The risk of severe winter storms, and possibly of severe autumn storms, is projected to increase.

The Mediterranean region is facing decreasing precipitation and increasing temperatures, in particular in summer. The competition between different water users over decreasing water resources is expected to increase. Forest fires and adverse impacts of heat on human health and well-being are expected to increase, alongside propensity for vector-borne diseases.

Map 2.1 **Key observed and projected climate change and impacts for the main biogeographical regions in Europe**

⬜ **Arctic region**
Temperature rise much larger than global average
Decrease in Arctic sea ice coverage
Decrease in Greenland ice sheet
Decrease in permafrost areas
Increasing risk of biodiversity loss
Some new opportunities for the exploitation of natural resources and for sea transportation
Risks to the livelihoods of indigenous peoples

⬜ **Coastal zones and regional seas**
Sea level rise
Increase in sea surface temperatures
Increase in ocean acidity
Northward migration of marine species
Risks and some opportunities for fisheries
Changes in phytoplankton communities
Increasing number of marine dead zones
Increasing risk of water-borne diseases

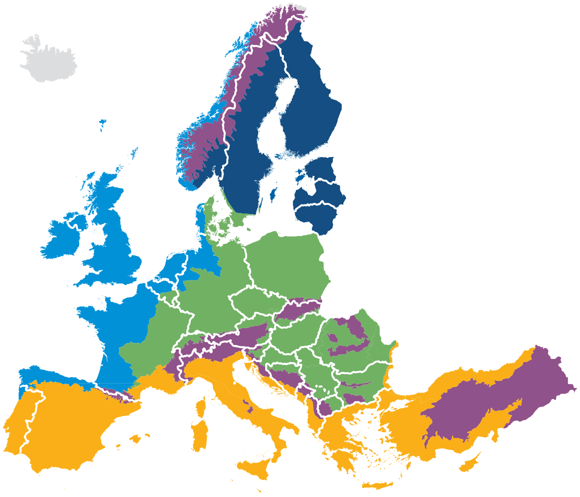
🟧 **Mediterranean region**
Large increase in heat extremes
Decrease in precipitation and river flow
Increasing risk of droughts
Increasing risk of biodiversity loss
Increasing risk of forest fires
Increased competition between different water users
Increasing water demand for agriculture
Decrease in crop yields
Increasing risks for livestock production
Increase in mortality from heat waves
Expansion of habitats for southern disease vectors
Decreasing potential for energy production
Increase in energy demand for cooling
Decrease in summer tourism and potential increase in other seasons
Increase in multiple climatic hazards
Most economic sectors negatively affected
High vulnerability to spillover effects of climate change from outside Europe

🟦 **Atlantic region**
Increase in heavy precipitation events
Increase in river flow
Increasing risk of river and coastal flooding
Increasing damage risk from winter storms
Decrease in energy demand for heating
Increase in multiple climatic hazards

🟦 **Boreal region**
Increase in heavy precipitation events
Decrease in snow, lake and river ice cover
Increase in precipitation and river flows
Increasing potential for forest growth and increasing risk of forest pests
Increasing damage risk from winter storms
Increase in crop yields
Decrease in energy demand for heating
Increase in hydropower potential
Increase in summer tourism

🟪 **Mountain regions**
Temperature rise larger than European average
Decrease in glacier extent and volume
Upward shift of plant and animal species
High risk of species extinctions
Increasing risk of forest pests
Increasing risk from rock falls and landslides
Changes in hydropower potential
Decrease in ski tourism

🟩 **Continental region**
Increase in heat extremes
Decrease in summer precipitation
Increasing risk of river floods
Increasing risk of forest fires
Decrease in economic value of forests
Increase in energy demand for cooling



Note: The inclusion of specific climatic changes and impacts reflects a qualitative assessment of their relative importance for most of a given region. However, there is considerable variation within each region, and impacts mentioned for a specific region can also occur in other regions where they are not mentioned.

Source: Reproduced from EEA (2017b).

In the continental region, increasing heat extremes are a key hazard. Together with reduced summer precipitation, they can increase drought risk, health risks and energy demand in summer. The intensity and frequency of river floods in winter and spring is projected to increase in various regions as a result of increases in winter precipitation. Climate change is also projected to lead to an increased risk of river floods and an increased occurrence of forest fires. Specific threats occur in coastal zones (sea level rise and a possible increase in storm surges) and in mountain regions (increase in temperatures, decreased snow cover, increased risk to settlements from floods due to topography, landslides and rock falls). For more detailed information on climatic hazards and impacts across Europe see EEA (2017b).

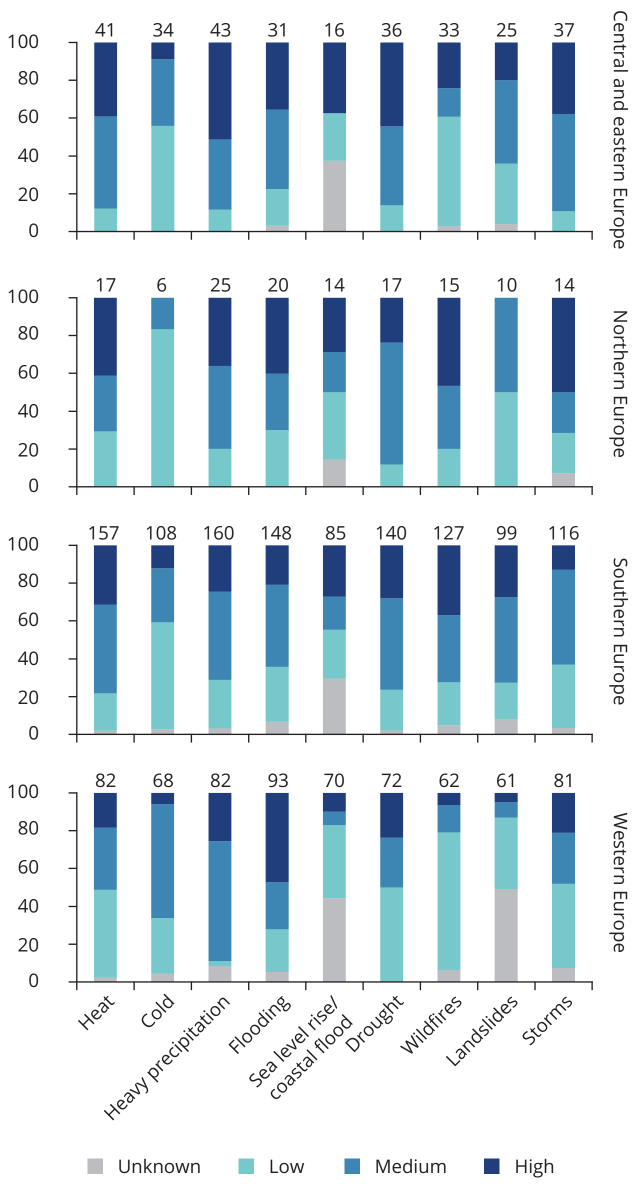
2.2.2 *Local assessments of climate- and weather-related hazards*

Local decision-makers' awareness and perception of the climate- and weather-related hazards are an important factor for the planning and implementation of adaptation actions (Ford and King, 2015). Heatwaves, heavy precipitation, pluvial and river flooding, and droughts are recognised as the most severe current hazards by the European cities reporting to CDP and the Covenant of Mayors, based on the local climate change risk assessments (Figure 2.1; see also Bertoldi et al., 2020). In western Europe, flooding is the hazard most frequently indicated as having high severity; storms are seen as having high severity in northern Europe, heavy precipitation in central and eastern Europe and wildfires in the south. Interestingly, heat and wildfires are seen as more severe risks in northern Europe, and cold in southern Europe, than in other regions.

The regional differences in the assessments of which climate- and weather-related hazards are currently causing the most severe consequences for cities, and how the intensity of these hazards is expected to change (Figure 2.2), tend to reflect the current and projected climate hazards in the biogeographical regions (Map 2.1). Therefore, there seems to be a good recognition of the hazards faced by cities currently and in the future, providing a solid basis for adaptation planning. However, while the quality and relevance of the climate risk assessment are clearly important, it is the interpretation and the application during the decision-making process that determine if and what action is taken (McDermott and Surminski, 2018). Chapter 5 explores in more detail the steps from recognition of a problem to acting on them in European cities.

In addition to the hazards facing the cities, it is also important to recognise the varying vulnerability of different locations and how the combination of vulnerability with hazards may translate into impacts. This is covered in the remainder of Section 2.2.

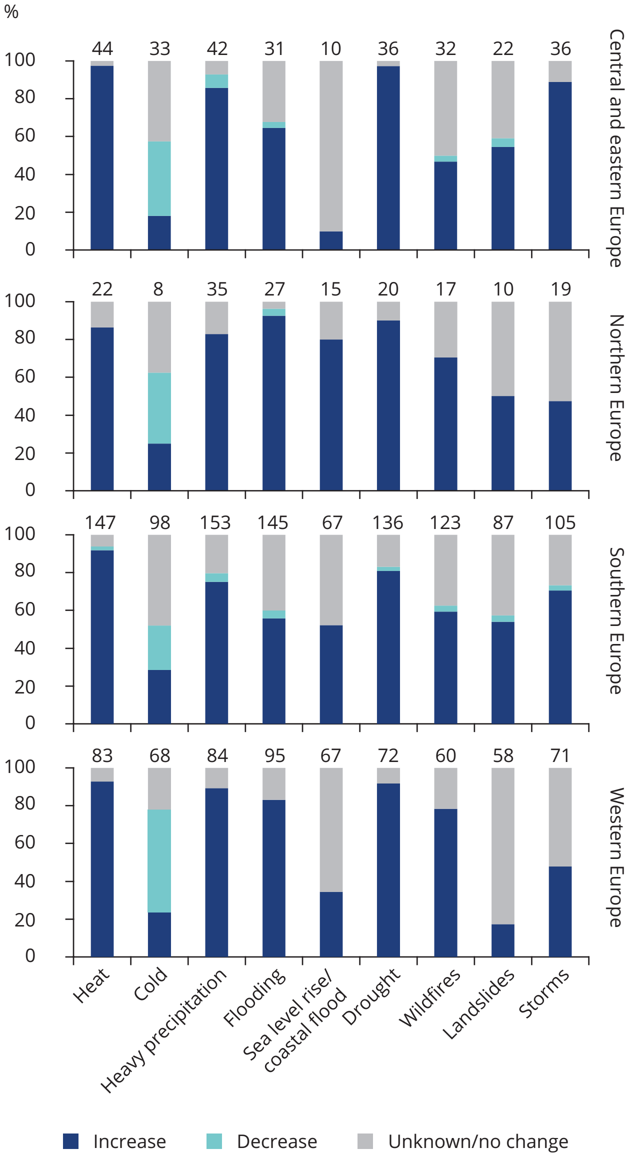
Figure 2.1 **Current severity of climate- and weather-related hazards according to representatives of European cities, by region**



Note: As reported to CDP by 99 cities from 23 EEA member and collaborating countries and the United Kingdom, and to the Covenant of Mayors by 242 local authorities from 21 EEA member and collaborating countries and the United Kingdom. The number above the bar relates to the total number of cities in a European region that responded to the question about a given hazard. For 'current hazard risk level', the Covenant of Mayors signatories could select the options of 'low', 'medium', 'high' and 'unknown'. For 'current probability of hazard', the cities reporting to CDP could choose from the following options: 'no impact', 'low', 'medium low', 'medium', 'medium high' and 'high'. To align the CDP data set with the Covenant of Mayors data set, the 'no impact' and 'low' options were treated as low, 'medium low' and 'medium' as medium, and 'medium high' and 'high' as high.

Sources: Authors' compilation based on the analysis of the CDP (2019) database and information extracted from the Covenant of Mayors for Climate and Energy database on 19 June 2019.

Figure 2.2 **Future changes in intensity of climate- and weather-related hazards expected by European cities' representatives, by region**



Note: As reported to the Covenant of Mayors by 235 local authorities from 22 EEA member and collaborating countries and the United Kingdom, and to CDP by 95 cities from 24 EEA member and collaborating countries and the United Kingdom. The number above the bar relates to the total number of cities in a European region that responded to the question about a given hazard. If the same city was reporting to CDP and to the Covenant of Mayors, only the response to the Covenant of Mayors was considered. In response to the question 'expected change in intensity', the Covenant of Mayors signatories could select between the options of 'increase', 'decrease', 'no change' and 'unknown'. The cities reporting to CDP could only select 'increase', 'decrease' or 'unknown' for 'future change in intensity of hazard'. Therefore, the 'unknown' and 'no change' categories have been merged to enable the presentation data from these two data sets combined.

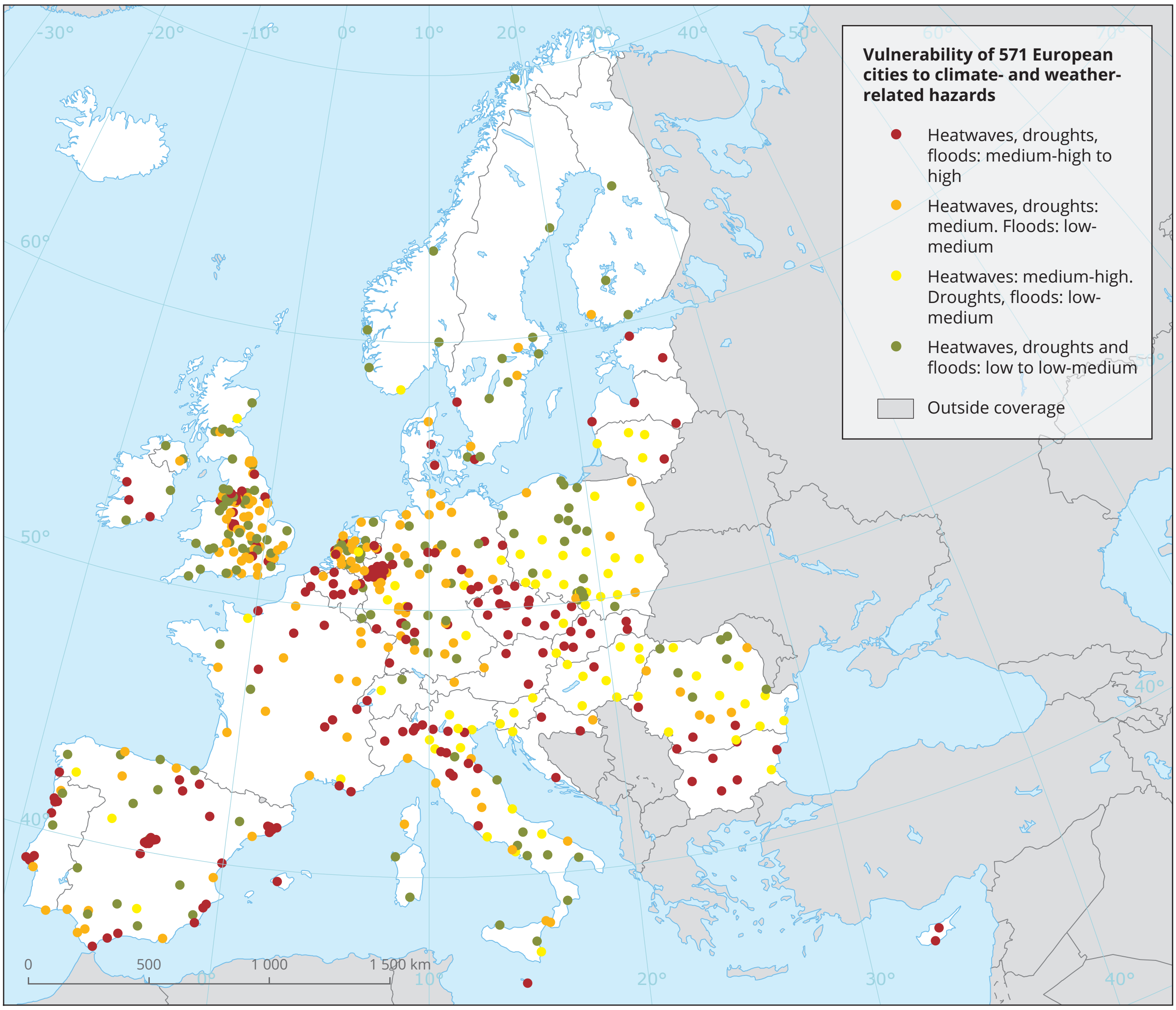
Sources: Authors' compilation based on the analysis of the CDP (2019) database and information extracted from the Covenant of Mayors for Climate and Energy database on 19 June 2019.

2.2.3 Vulnerability of cities to climate risks

European cities vary not only in their exposure to climate- and weather-related hazards but also in their vulnerability, i.e. the intrinsic characteristics shaping how they may be affected by hazards (see Box 2.1). The vulnerability of cities is a combination of their economy, socio-demographic characteristics of their population, state of infrastructure, governance and other aspects.

Within the framework of the Horizon 2020 research project Reconciling adaptation, mitigation and sustainable development for cities (Ramses), Tapia et al. (2017) assessed the vulnerability of 571 European cities using a range of indicators from thematic domains including human capital, governance and institutions, socio-economic conditions, built environment and natural capital. The cities were clustered according to their vulnerability to heatwaves, flooding and droughts. According to this analysis, it is difficult to identify clear spatial patterns of vulnerability among European cities. The cities with high levels of vulnerability to all hazards are more numerous in central Europe, Estonia, parts of Germany, Latvia and Romania but also scattered throughout Europe. The presence of cities more vulnerable to heatwaves mainly in the southern and central EU and the Baltic republics is linked to a combination of elderly populations, high air pollution levels and small average dwelling sizes. Vulnerability to flooding — a function of socio-economic conditions (e.g. population income levels and employment rates), extent of soil sealing, awareness of citizens and the cities' commitment to adaptation — was found across Europe. Cities more vulnerable to droughts owing to less diversified economies, growing populations or less efficient water management systems did not show a clear spatial distribution pattern (Map 2.2).

Map 2.2 **Vulnerability of 571 European cities to climate- and weather-related hazards**



Reference data: ©ESRI

Note: Based on investigation into 571 European cities included in the Geographic Information System of the Commission Urban Audit 2004 Database. The information on individual cities included in this analysis, following the original classification into seven clusters, is available through the Urban Adaptation Map Viewer (factsheets).

Source: Adapted from Tapia et al. (2017).

2.2.4 Climate risks to European cities and regions

The risk typology of NUTS 3 ([10]) regions, accounting for regions' exposure, vulnerability and hazards faced (Carter et al., 2018) emphasises that all of Europe's cities and NUTS 3 regions are at risk from climate change, albeit for different reasons.

Similar patterns of exposure and vulnerability can be present in cities or regions that are not located in the same part of Europe (Map 2.3).

([10]) NUTS (French Nomenclature des unités territoriales statistiques) is a hierarchical system for dividing up the economic territory of the EU for the purpose of collecting, developing and harmonising European statistics, socio-economic analyses of the regions and framing EU policies. NUTS 3 are areas of 150 000-800 000 inhabitants (Eurostat, 2015)

Map 2.3 Climate risk typology of NUTS 3 regions in Europe

🟪 **North west coasts**

C: coastal
KH: coastal flooding
E: high (high exposure of population and infrastructure to coastal hazards)
S: average
AC: average

⬜ **Lowlands and estuaries**

C: coastal
KH: coastal and river flooding, heavy precipitation
E: very high exposure of population and infrastructure to coastal hazards and river flooding
S: average (relatively low proportion of population at risk of poverty)
AC: relatively high (relatively high GDP, good infrastructure provision, higher than average innovation levels)

🟦 **North west urban**

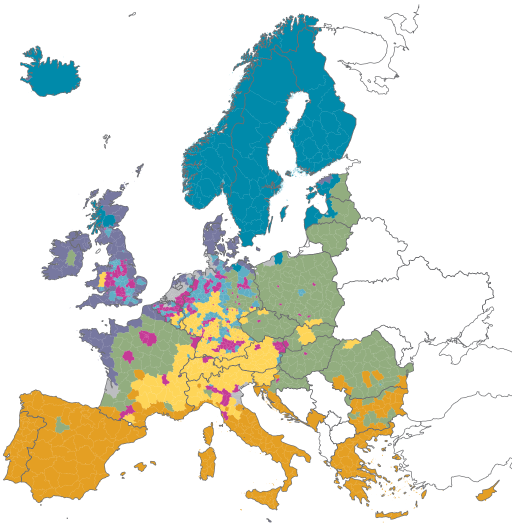
C: mainly inland cities
KH: heavy precipitation
E: lower than average exposure of population and infrastructure to fluvial flooding and landslides
S: average
AC: relatively high (high transport infrastructure density, higher than average GDP, relatively high innovation levels)

🟪 **Inland and urbanised**

C: inland, large cities, including capital cities
KH: river flooding, heavy precipitation
E: relatively high exposure of population and transport infrastructure to river flooding
S: low (projected increase of young people)
AC: high (affluent cities, high provision of critical infrastructure, high innovation levels)

🟦 **Northern lands**

C: low density, green cities and small rural settlements
KH: coastal hazards; heavy precipitation; low and high temperatures
E: higher than average exposure of population and infrastructure to coastal flooding
S: low (projected increase of young people and immigrants)
AC: high (high provision of critical infrastructure, high innovation levels)



🟩 **Inland hinterlands**

C: peri-urban and rural settings, relatively low population densities
KH: multiple climate hazards
E: relatively high exposure of population and transport infrastructure to river flooding
S: average (projected decrease in young people)
AC: lower than average (lower than average GDP and employment opportunities; high priority allocation funding; low innovation levels)

🟨 **Landlocked and elevated**

C: mountainous and upland areas, relatively low population densities
KH: landslides, river flooding, heavy precipitation
E: high exposure of population and infrastructure to landslides
S: lower than average (lower than average proportion of people at risk of poverty)
AC: higher than average (relatively affluent areas, dense road infrastructure; relatively high innovation levels)

🟧 **Southern lands**

C: Mediterranean, high density
KH: high temperatures, droughts, wildfires, landslides, coastal hazards
E: higher than average exposure of transport infrastructure and population to landslides
S: relatively high (higher than average population at risk of poverty)
AC: relatively low (lower than average GDP, relatively low critical infrastructure provision, lower than average innovation levels)

Notes: For full description of groups in the risk typology, see http://european-crt.org/map.html. The Urban Adaptation Map Viewer provides information about Urban Audit cities in the respective groups.

C, city type; **KH**, key hazard; **E**, exposure; **S**, sensitivity; **AC**, adaptive capacity.

GDP, gross domestic product.

Source: Adapted from Climate resilient cities and infrastructures (RESIN) climate risk typology, http://european-crt.org/map.html.

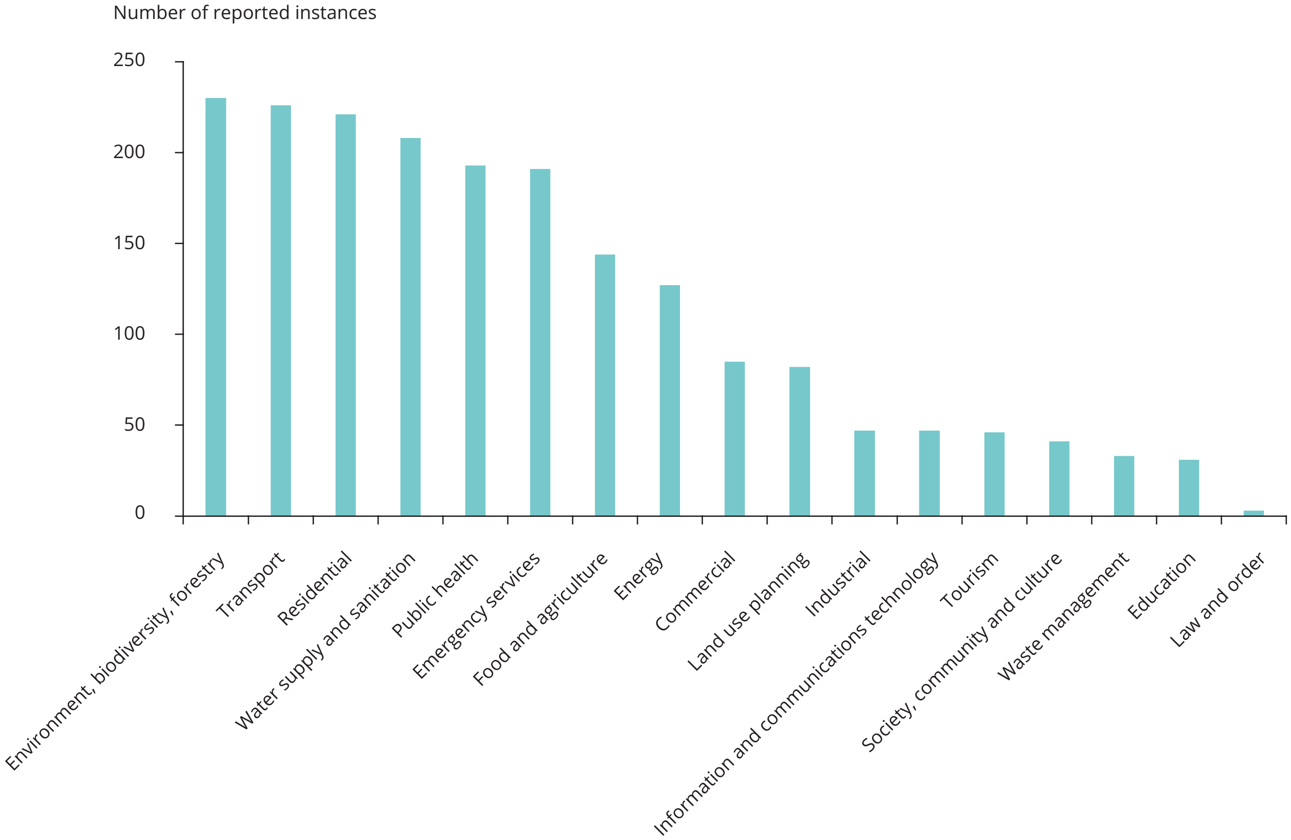
Such assessments carried at the European scale obviously cannot capture the complexity of the local conditions, which require more detailed climate change risk and vulnerability assessments. Nonetheless, they emphasise the complex nature of climate risks, which are not just a simple function of the magnitude of climate- and weather-related hazards in a given location but rather emerge from the interactions between aspects of hazards, sensitivity, exposure and adaptive capacity. The clustering exercises also indicate that the climate risks may be similar among various cities in Europe, emphasising the importance of exchange of experiences and learning from each other regarding how these risks are most effectively and efficiently addressed.

2.2.5 *Expected climate change impacts on cities*

The assets and services already affected by climate- and weather-related hazards are mainly identified as environment, transport, built environment and water management, followed by public health and emergency services by the city representatives reporting to CDP (Figure 2.3). Similarly, those Covenant of Mayors signatories who have carried out the climate risk and vulnerability assessments expect the highest impacts in the areas of water management, agriculture and forestry, health, and environment and biodiversity. Tourism and waste management are the least frequently reported sectors in terms of expected impacts (Bertoldi et al., 2020). The cities reporting to CDP see societal impacts from climate- and weather-related hazards mainly in increased demand for public services (200 counts), increased risk to already vulnerable populations (168 counts), increased demand for healthcare services (161 counts) and general increased resource demand (122 counts) ([11]) (CDP, 2019).

The next sections explore the nine types of climatic hazards in detail. Each section presents briefly the climatic hazard in relation to cities, including climate projections (see Box 2.2), followed by a discussion of how the urban characteristics exacerbate or mitigate the risks and the exploration of impacts experienced in or projected for urban areas.

Figure 2.3 **Assets and services expected to be most affected by climate- and weather-related hazards in European cities**



Note: As reported by 163 cities from 26 EEA member and collaborating countries and the United Kingdom. Assets and services could be selected multiple times for various climate hazards.

Source: Author's compilation based on analysis of the CDP (2019) database.

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[11] The city respondents could select societal impacts multiple times in relation to various climate hazards.

Box 2.2 Understanding climate change scenarios

The Intergovernmental Panel on Climate Change (IPCC) in its fifth assessment report (IPCC, 2013) based climate projections on four representative concentration pathways (RCPs). These climate scenarios describe four different 21st-century pathways of greenhouse gas (GHG) emissions and atmospheric concentrations, air pollutant emissions and land use, which are related to population size, economic activity, lifestyles, energy use, land use patterns, technology and climate policy. The RCP scenarios superseded the Special Report on Emissions Scenarios projections published in 2000 and were based on similar socio-economic models.

The RCP scenarios are named after the 21st-century peak of radiative forcing, also called stabilisation value, expressed in watts per square meter of surface (W/m^2). The RCPs include a stringent mitigation scenario (RCP 2.6), two intermediate scenarios (RCP 4.5 and RCP 6.0) and one scenario with very high GHG emissions (RCP 8.5).

- **RCP 2.6** is a stringent pathway, which would require that carbon dioxide (CO_2) emissions start declining by 2020 and go to zero by 2100. RCP 2.6 is likely to keep global temperature rise below 2 °C by 2100. In this pathway, the radiative forcing level reaches 3.1 W/m^2 by mid-century but returns to 2.6 W/m^2 by 2100.

- **RCP 4.5** and **RCP 6.0** are intermediate scenario pathways with a stabilised radiative forcing at approximately 4.5 W/m^2 and 6.0 W/m^2 before 2100. The reduced concentrations are achieved by employment of a range of technologies and strategies for reducing GHG emissions. RCP 4.5 is more likely than not to result in a global temperature rise of between 2 and 3 °C by 2100.

- In the **RCP 8.5** pathway, GHG emissions continue to rise throughout the 21st century. The radiative forcing exceeds 8.5 W/m^2 by 2100 and continues to rise thereafter (the corresponding extended concentration pathways assume constant emissions after 2100 and constant concentrations after 2250). This scenario delivers a global temperature increase of about 4.3 °C by 2100.

The probability of the RCP 8.5 scenario is debated by scientists, as its development was based on an overestimation of projected coal burning (see, for example, Hausfather and Peters, 2020). Nonetheless, many scientific studies cited in this report are based on the RCP 8.5 pathway. As it refers to a not improbable worst-case scenario, projections based on RCP 8.5 are useful for raising awareness of potential risks of low-likelihood, high-impact events. The results of scientific studies based on the RCP 4.5 scenario — a probable scenario if mitigation measures already taken are continued and the scheduled ones are implemented — are also included in this report. For a short-term perspective (e.g. until 2035) differences in global mean temperature expected under different RCPs will be minor, whereas from 2050 onwards substantial differences will become evident.

Sources: IPCC (2013, 2014b, 2014d).

2.3 High temperatures

2.3.1 Climatic hazard

Climate projections for Europe show a temperature increase across the continent, the strongest seasonal warming occurring during summer in southern Europe and during winter in northern Europe (IPCC, 2014c). In particular, the projections show a marked increase in temperature extremes, leading to an increase in the number, frequency, and intensity of heatwaves. Under a high-emissions scenario, by the end of the century 90 % of the summers in southern, central and north-western Europe will be warmer than any summer from 1920 to 2014, with the most severe health risks for southern Europe and the Mediterranean coasts, where many densely populated urban centres are located (Lehner et al., 2016). In the second half of the 21st century, under the RCP 8.5 scenario, very extreme heatwaves are projected to occur as often as every 2 years (Russo et al., 2014); however, these will remain rare under more moderate climate change scenarios.

For some cities, the projected temperature increases are much higher than the computed global averages. Under the RCP 8.5 scenario, by the end of the century, many cities (e.g. Bucharest, Madrid and Zagreb) are likely to experience average temperatures of up to 7 °C in the hottest months compared with current conditions (Milner et al., 2017); for some cities, the number of heatwave days is expected to increase by a factor of 10 (Lauwaet et al., 2015; Wouters et al., 2017).

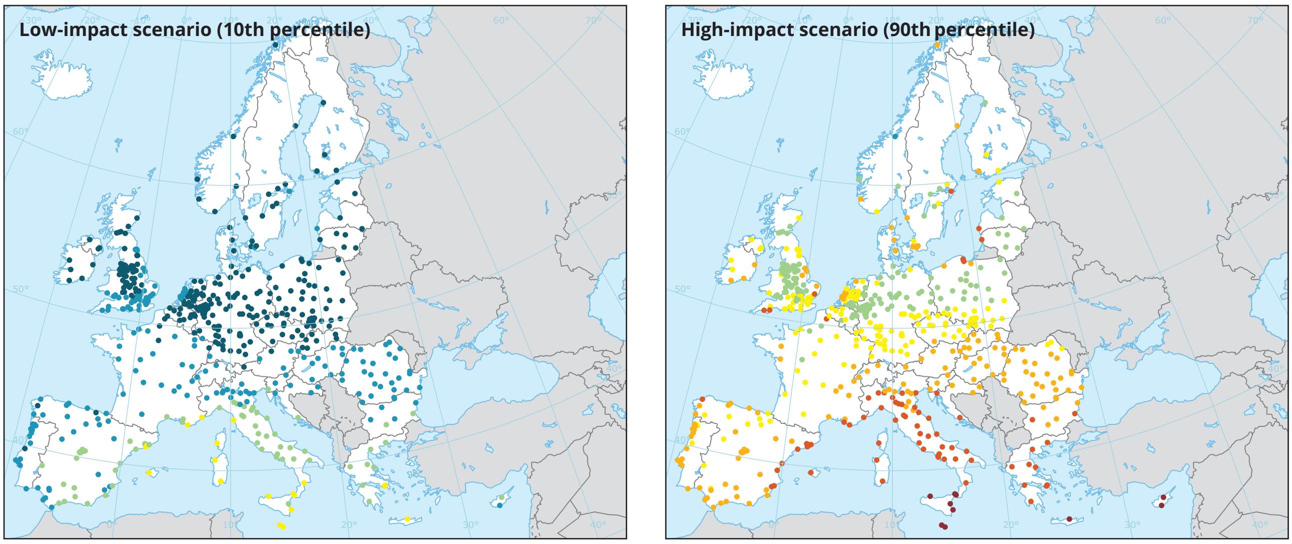
According to Guerreiro et al. (2018), cities in southern Europe will see a larger increase in the number of heatwave days (Map 2.4). The projected increase in the number of heatwave days ranges from 4 % in Trondheim (Norway) for the low-impact (10th percentile ([12])) scenario to 69 % in Lefkosia (Cyprus) for the high-impact (90th percentile) scenario. However, increases in maximum temperature during heatwaves are expected to be larger in cities located in central Europe (Guerreiro et al., 2018).

While the discussion on future higher temperatures most often revolves around the impacts of heatwaves, higher temperatures also result in warmer mean winter temperatures and fewer extreme cold events. Between 1950 and 2018, days and nights with extremely cold temperatures decreased by a factor of two to three across Europe, and during this time minimum temperatures have risen by more than 3 °C (Lorenz et al., 2019). In northern and central Europe, the winter mean warming is thereby 2.5 times larger than the global average temperature warming of 0.2 °C per decade (Lorenz et al., 2019). This has implications for cold-related mortality (see Section 2.3.3) as well as for snow cover (see Section 2.4.1).

2.3.2 Factors exacerbating or reducing heat risk in cities

Cities experience air temperatures higher than rural areas because of the urban heat island (UHI) effect, which quantifies the air temperature difference between urban areas and their rural surroundings. The UHI is caused by the increased heat capacity of cities, anthropogenic heat sources and the imperviousness of urban surfaces, which inhibit evaporative cooling (Lauwaet et al., 2016). Differences from average urban area temperature in European cities caused by UHIs vary widely, reaching as much as 9 °C (for nighttime temperatures in central Paris under heatwave conditions) (Tzavali et al., 2015). The UHI effect's intensity increases during hot periods (e.g. Li and Bou-Zeid, 2013; De Ridder et al., 2016). Cities across Europe may already experience twice as many heatwave days ([13]) as their rural surroundings (Hooyberghs et al., 2017; Wouters et al., 2017).

Map 2.4 Change in the percentage of summer (May-September) days classified as heatwave days between the historical period (1951-2000) and the future period (2051-2100) in 571 European cities



Reference data: ©ESRI

Change in the percentage of summer (May-September) days classified as heatwave days between the historical period (1951-2000) and the future period (2051-2100) in 571 European cities

Change percentage (%)

● < 10 ● 10-20 ● 20-30 ● 30-40 ● 40-50 ● 50-60 ● > 60

0 500 1 000 1 500 km

▨ Outside coverage

Notes: Heatwaves were defined as three consecutive days when both the maximum and the minimum temperature exceed their respective 95th percentiles from the historical period. Based on 50 climate model projections from the Coupled Model Intercomparison Project Phase 5 (CMIP5) (Taylor et al., 2012), under the RCP 8.5 climate scenario. The 50th percentile (median) scenario is available in the Urban Adaptation Map Viewer; see also Guerreiro et al. (2018).

Source: Adapted from Guerreiro et al. (2018).

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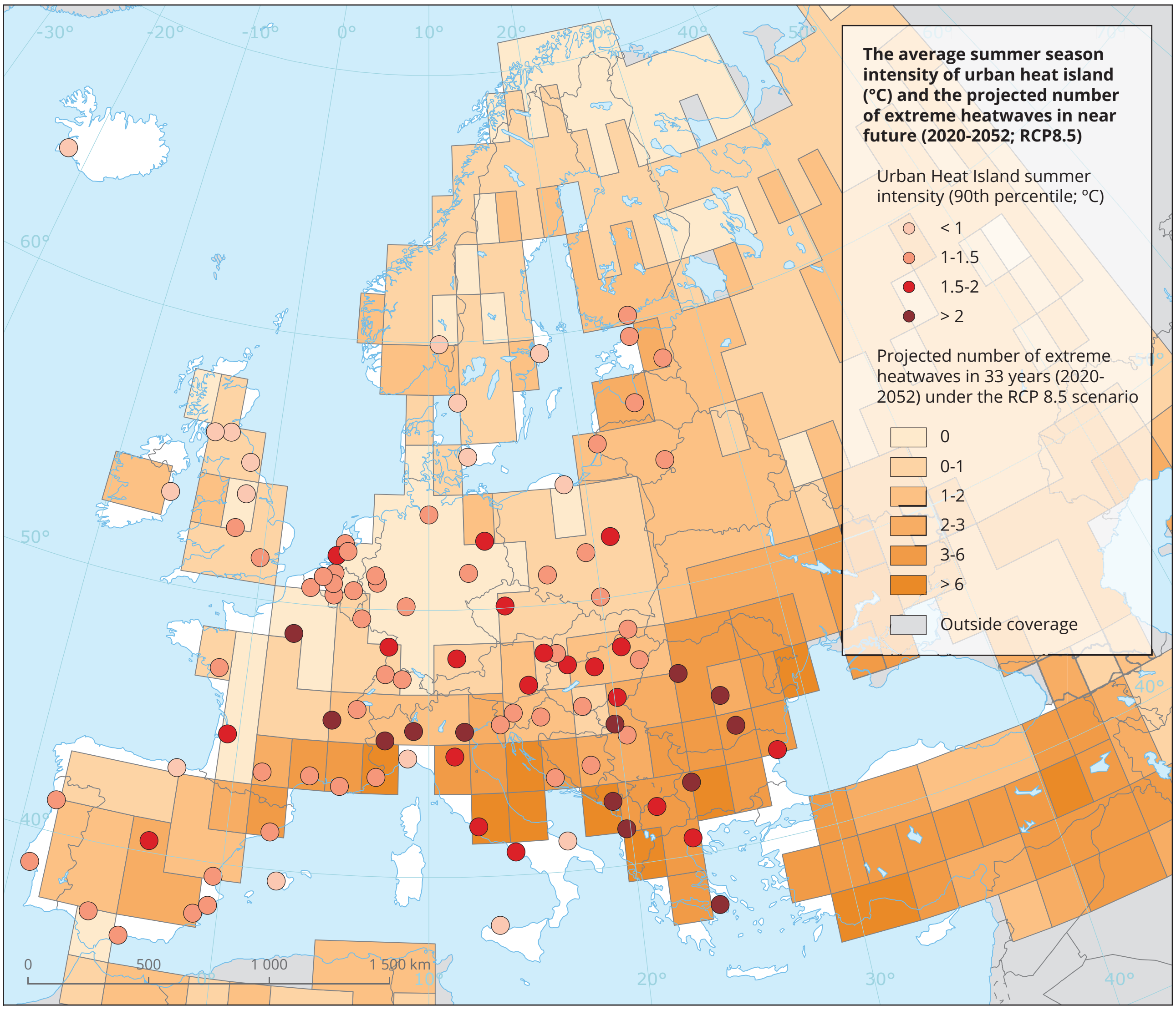
[12] In this context, the 10th percentile scenario relates to the low end of the projections, while the 90th percentile refers to the high end of projections. See glossary (Annex 2).

[13] Days during which the maximum air temperature is above a local temperature threshold.

The UHI effect is strongly linked to climate conditions (the average wind speed and the number of sunny days), so a strong north-south gradient is present among the European cities. The UHI effect is particularly strong in some of the locations that are projected to experience a dramatic increase in the number of extreme heatwaves (14) (Map 2.5). These include cities in south-eastern Europe, such as Tirana (Albania), Sofia (Bulgaria) or Podgorica (Montenegro). For example, in Podgorica heatwaves occurred nine times in the period 2003-2014 (GIZ, 2015).

Map 2.5 **The summer season intensity of urban heat islands (UHIs) (°C) and the projected number of extreme heatwaves in the near future (2020-2052; RCP 8.5)**



Reference data: ©ESRI

Notes: The intensity of UHI was estimated for 100 European cities in the framework of the Copernicus European Health contract for the Copernicus Climate Change Service (C3S). High-resolution (100 m) hourly temperature (2008-2017) was simulated with the urban climate model UrbClim (De Ridder et al., 2015). Summer season is June, July and August. The intensity of UHI is represented by spatial 90th percentile UHI intensity of a given city. This indicator is calculated by subtracting the rural (non-water) spatial 10th percentile temperature value from the average, height-corrected (to exclude terrain effects), air temperature map. For information on individual cities and detailed modelling of the UHIs for the 100 European cities see the Urban Adaptation Map Viewer.

Sources: EEA (2019e); VITO (2019a).

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(14) An extreme heatwave is defined by the Heat Wave Magnitude Index of Russo et al. (2014), where a heatwave is a period of ≥ 3 consecutive days with maximum temperature above the daily threshold for the reference period 1981-2010. The threshold is defined as the 90th percentile of local daily maxima, centred on a 31-day window. Under strong heatwave conditions, southern European cities seem to develop weaker UHIs (based on the surface temperatures) than northern cities (Ward et al., 2016). This is because soil in southern Europe tends to dry out strongly during these types of events, making the countryside warmer, and hence the surface UHI effect is less pronounced or even negative.

Therefore, reducing the urban temperatures is particularly important in Southern Europe. However, also in more temperate locations, increased exposure of inhabitants to high temperatures is projected through the combination of changing climate and urban development (Lauwaet et al., 2018; Box 2.3).

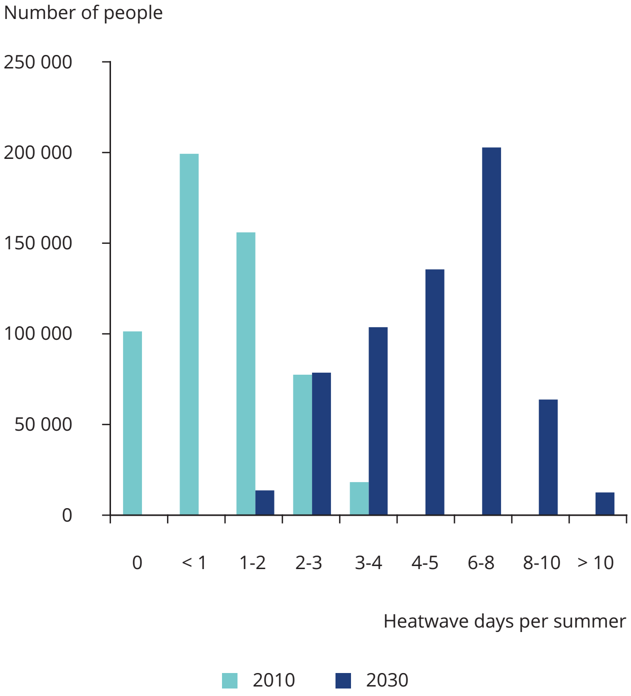
Vegetation reduces the UHI effect. At present, around 40 % of the surface area of European cities consists of green space, with an average of 18.2 m^2 of publicly accessible green space per inhabitant. Only 44 % of Europe's urban population currently lives within a walkable distance (300 m) of a public park (Maes et al., 2019).

In addition, the presence and accessibility of green areas (both public and private) varies greatly between countries and between individual cities. According to the 2016 European Quality of Life Survey, the highest numbers of people with difficult access to recreational or green areas were in Albania, Turkey, Romania, and the lowest numbers were in Denmark, Sweden and Finland (Eurofound, 2016). The access to publicly available green space shows a North-South disparity in Europe (Map 2.6). Therefore, in some of the cities where the highest increase in frequency of heatwaves is projected (Map 2.5), poor access to green space may deprive the urban population of an effective cooling mechanism.

Box 2.3 Estimating near-future heat stress based on climate and land use scenarios in Liège, Belgium

Analysis of 1996-2015 summer air temperatures across Liège shows that the city centre is, on average, about 4 °C warmer than the coolest surrounding areas because of the urban heat island effect. Given the projected climate and population changes, this suggests that a substantial part of Liège's population is likely to experience high temperatures in future, with potentially detrimental effects on public health.

Figure 2.4 Population exposure to heatwave days in the region of Liège for current (2010) and future (2030) conditions, given the RCP 8.5 climate scenario and 'business as usual' urban development, and accounting for projected population change



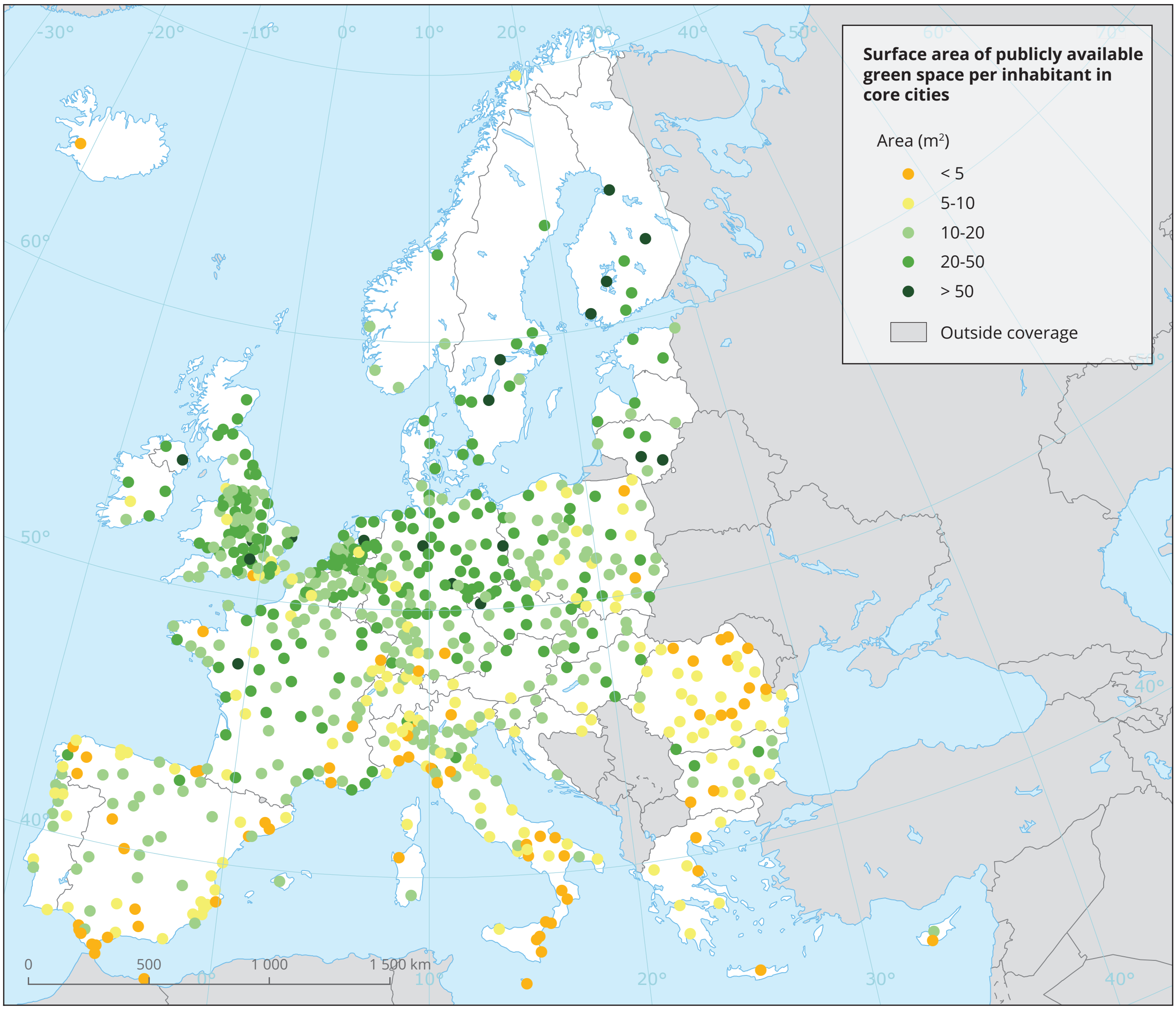
To estimate the number of people that may be affected at present and in future by heat, an annual number of heatwave days (defined by the Belgian Federal Public Service for Health as a period for which the 3-day mean maximum temperature is above 30 °C and the 3-day mean minimum temperature is above 18 °C) was calculated within the SmartPop (Spatial planning for the growth of the Walloon population) project by the research organisation VITO (the Flemish Institute for Technological Research). The heatwave days projections were based on the representative concentration pathway (RCP) 8.5 climate scenario and modelling of population density and land use. Using the UrbClim model, high-resolution (100 m) urban climate simulations were produced based on 11 climate models from the Coupled Model Intercomparison Project Phase 5 archive of the IPCC, and the present-day and future (to 2050) land use maps of the SmartPop model.

This study resulted in a prediction of UHI spatial distribution and intensity, in turn affecting the frequency of future heatwave days. The number of heatwave days for Liège is likely to increase markedly over time (see Figure 2.4). Currently, Liège's city centre inhabitants experience up to 5 heatwave days per year, compared with 1-2 days for those in rural areas. Under the RCP 8.5 scenario and given 'business as usual' urban development in Liège, the number of heatwave days doubles before mid-century and will increase fivefold by the end of the century.

Sources: http://www.smartpop.be and personal communication from Dirk Lauwaet, VITO (2019).

Section 3.2 discusses the effectiveness of various green infrastructure ([15]) options in addressing high temperatures in cities. Boxes 3.3, 3.4 and 3.8 present examples of the European cities' actions to increase the presence of green space in the city — from building-level interventions to city-wide masterplans.

Map 2.6 **Surface area of publicly available green space per inhabitant in core cities**



Reference data: ©ESRI

Source: Adapted from Maes et al. (2019).

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(15) Green infrastructure is defined as a 'strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services' (EC, 2013b). In the context of this report, the term is used interchangeably with 'nature-based solutions' or 'ecosystem-based adaptation'. They share a common focus on biodiversity and ecosystem services and aim to address societal challenges, recognising the fundamental role that ecosystems play in supporting human safety and well-being.

2.3.3 Impacts of high temperatures

Impacts on human health and well-being

High temperatures and heatwaves have to date claimed more victims in Europe than any other weather-related disasters (EEA, 2019e). Events such as the heatwave of 2003, which led to 70 000 reported heat-related deaths across Europe (Robine et al., 2008), and 100 000 estimated lost life-years in France alone (Keller, 2015), are expected to become more frequent, especially in southern Europe (Forzieri et al., 2017). Assuming present vulnerability of people and no additional adaptation measures, annual fatalities from extreme heat could rise from 2 700 deaths/year now to approximately 30 000 or 50 000 by 2050, with 1.5 °C or 2 °C global warming, respectively. With the global temperature higher by 3 °C in 2100, each year 90 000 Europeans could die from extreme heat. These projections do not account for increasing urbanisation in Europe and the ageing population. The number of people aged more than 65 years in the EU and the United Kingdom will grow from 100 million now to 150 million by 2050, which could further negatively affect human mortality from temperature extremes (Feyen et al., 2020).

In cities, additional health risks are posed by the UHI effect causing increased ambient temperatures and reduced nighttime cooling. A mean estimate of 2 % of deaths across 15 European cities in the 1990s were attributable to heat (Baccini et al., 2011). Deaths due to heat extremes have already substantially increased in cities as a result of the changing climate; the risk of heat-related mortality in 2003 compared with pre-industrial climate conditions increased by 70 % in Paris, and 20 % in London (Mitchell et al., 2018). In present-day London, only 10 % of summers result in zero heat-related deaths and, with the 1.5 °C and 2 °C global average temperature increases, this percentage drops to ~4 % and ~2 %, respectively. In Paris, fewer than 1 in 100 summers result in no heat-related deaths (Mitchell et al., 2018).

The impact of heat on mortality varies among European cities. In general, cities in northern Europe have lower temperature thresholds from which heat-related mortality begins to increase; cities with higher average temperatures have higher thresholds (Baccini et al., 2011; Gosling et al., 2007). The percentage of deaths attributable to maximum apparent temperature exposure above the threshold tends to be greater in the cooler European cities and smaller in the warmer cities (Leone et al., 2013). Acclimatisation of the population to heatwaves may play a role in reducing the mortality rates in cities with frequently occurring extreme temperatures (Gosling et al., 2007). Reduced vulnerability of the population to heat stress (through acclimatisation and adaptation measures) has been observed over the past few decades in Finland and the United Kingdom (Ruuhela et al., 2017; Arbuthnott et al., 2016), which may be relevant for estimating mortality in future climatic conditions.

Heat-related mortality differs also within urban areas (López-Bueno et al., 2019; Savić et al., 2018). In Novi Sad, Serbia, citywide measurements of nighttime air temperatures during two heatwaves reveal higher rates of mortality in the most densely built-up areas (Savić et al., 2018). Thus, understanding the within-city differences in temperatures and thermal comfort can be crucial for planning effective adaptation, as was the case in Antwerp (Box 2.4).

Understanding the vulnerability of the urban population is key to address heat-related mortality in cities. There is unambiguous evidence of higher heat-related mortality among the elderly, those suffering from cardiovascular, respiratory or renal diseases and those with mental health issues (see EEA, 2020c, for more details). Women emerge as more vulnerable than men, because of their higher numbers in the older age groups, frequently living alone and reduced sweating capacity, which affects the ability to respond to heat stress (D'Ippoliti et al., 2010; Marí-Dell'Olmo et al., 2018).

People, especially the vulnerable groups, tend to spend most of their time in buildings, so indoor temperatures are a crucial factor influencing their exposure to heat. Many victims of the 2003 heatwave in France lived in top-floor studio apartments where the temperatures reached 40 °C (Poumadère et al., 2005). Houses inhabited by lower-income groups may be especially subject to overheating due to poorer insulation or building standards, as was found in Nuremberg (Germany), for example (Seebaß, 2017). In Athens, during three extended heatwaves in 2007, temperatures recorded in 50 low-income dwellings had a maximum of 40 °C and an average minimum above 28 °C (Sakka et al., 2012). Similarly, temperatures exceeding 28 °C were recorded in social housing in Spain, with residents present in their dwellings for most of the hot period (Escandón et al., 2019).

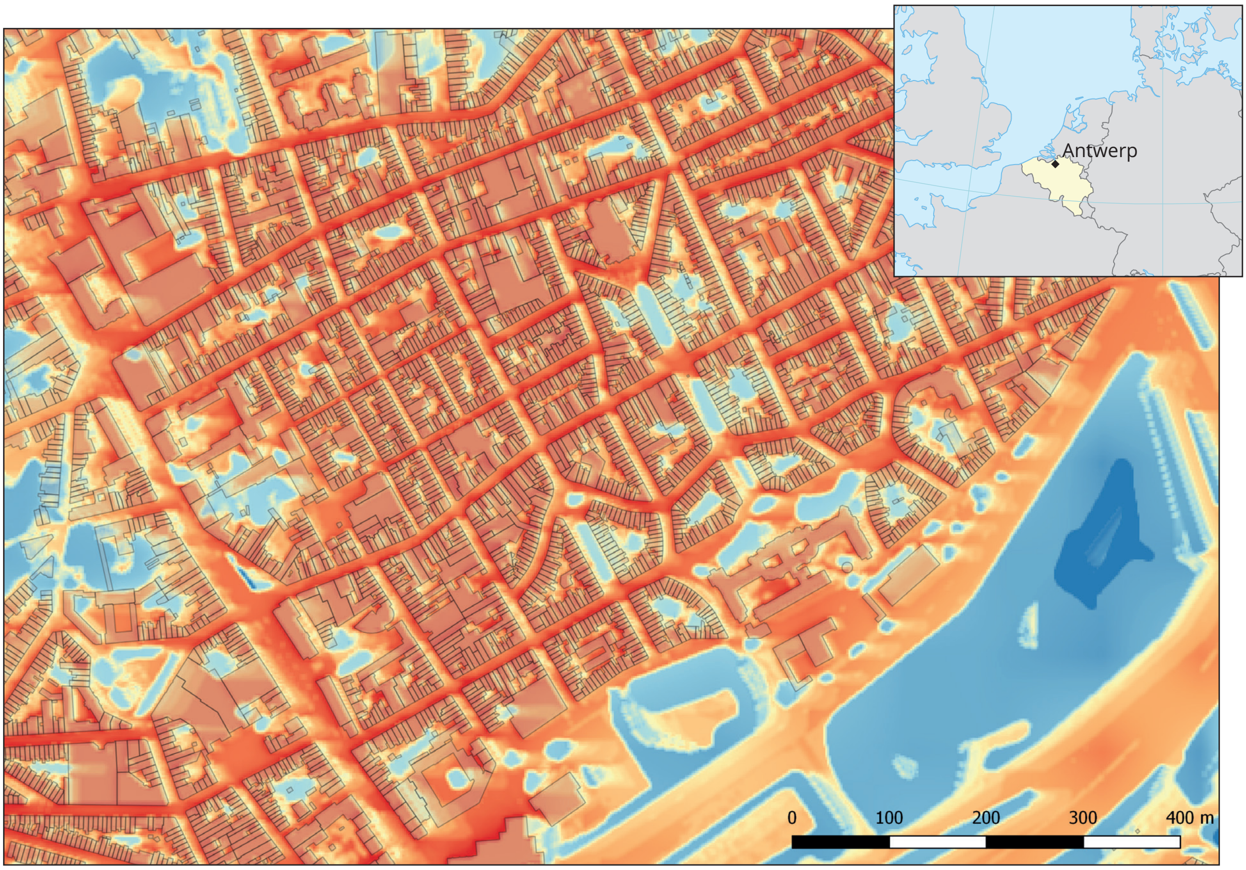
Building design is a key factor influencing indoor temperatures. In a temperate climate, the differences in indoor temperatures between buildings in a single neighbourhood may be twice as large as those recorded for outside air temperatures, owing to differences in architecture and shading options (Liu et al., 2017). Counterintuitively, newer buildings, characterised by higher thermal insulation standards against cold (including passive houses) may be at risk of summer overheating if no adequate measures for shading or cooling are included (Pathan et al., 2017). This emphasises the importance of building-level adaptation measures reducing indoor temperatures (see Figure 3.1), and specifically the inclusion of adaptation to high temperatures in building standards alongside thermal insulation addressing the cold. In addition, ensuring that facilities catering for vulnerable groups (such as schools or hospitals, which tend to be located within the intense UHI;

Box 2.4 Responding to heat stress in Antwerp based on detailed thermal mapping

To better understand the problem of heat stress, the city of Antwerp commissioned the research organisation VITO (the Flemish Institute for Technological Research) to map thermal comfort in the city. The results indicate that UHI in Antwerp exacerbates the impact of climate change on the urban population, as the number of heatwave days in the city rises twice as fast as in the rural surroundings. Within the city, detailed mapping was done by modelling hourly 2 m wet-bulb globe temperature (WBGT) values for a specific warm summer day (24 July 2012). The model outputs were validated through a citizen science campaign in the framework of the Horizon 2020 Ground truth 2.0 project (https://gt20.eu). Map 2.7 shows the maximum WBGT values; those exceeding 25 °C indicate heat stress. Locations with trees and/or water surfaces are the coolest, whereas the highest heat stress values are found over paved squares and streets where there is no shade.

To tackle heat stress in the city, adaptation measures are proposed at three different scales. At the citywide scale, new regulations require installation of green roofs on new or renovated buildings with a suitable roof; permeable and green parking lots; and increased albedo of public buildings. Locally, thermal comfort is planned to be improved by installing fountains, ponds, trees and parks in renovated public spaces. Finally, a heat forecast and warning system has been established to minimise health impacts on individual citizens (https://hitteverklikker.antwerpen.be).

Map 2.7 The maximum WBGT (°C) during a hot summer day in the Antwerp city centre



Reference data: ©ESRI

The maximum WBGT [°C] during a hot summer day in the Antwerp city centre

Maximum wet-bulb globe temperature (WBGT)

🟦 22.0 🟦 23.5 🟨 25.0 🟧 26.5 🟥 28.0

Source: Climate-ADAPT (2020a).

see Box 2.5) are well adapted to high temperatures is crucial for maintaining thermal comfort for their users and continuity of service. Furthermore, working in an overheated building may reduce productivity. In a typical south-facing office building in Antwerp, around 4 % of working hours are currently lost to heat during the summer period annually, and the number of hours lost may quadruple by 2100 (Hooyberghs et al., 2017).

The combination of heat stress and air pollution is particularly damaging to human health (EEA, 2020b); for example, air pollution and heat exposure have been linked to low birth weight (Dadvand et al., 2014). In nine European cities, the increase in mortality rate from natural causes on hot days was 1.8 % per 1°C temperature increase; however, it rose to 2.2 % on days with high levels of ground-level ozone. For 1° C of temperature increase, mortality rates due to cardiovascular causes were found to increase for all age groups by 2.2 % on days with low particulate matter (PM_{10}) concentrations and 2.6 % on high PM_{10} days (Analitis et al., 2018). A research study in 15 European cities observed combined impacts from nitrogen dioxide (NO_2) concentrations and high temperatures on mortality (Baccini et al., 2011).

The 2020 coronavirus disease 2019 (COVID-19) pandemic may amplify the health effects of high temperatures in cities. Many vulnerable groups are susceptible to both COVID-19 and heat stress (the elderly, those with pre-existing conditions, or those living in crowded or poor-quality housing). Self-isolation increases heat-related illness and mortality risk at home — particularly of older people, individuals with disabilities, people with mental health issues and those in residential care facilities. Emerging evidence shows that the communities that are the most exposed to hot temperatures in dense cities also have some of the worst COVID-19 outcomes, due to their pre-existing exposures to air pollution and high rates of non-communicable diseases. Hot weather conditions may complicate COVID-19 responses by increasing patient loads and creating occupational health risks for health workers and responders working in protective personal equipment (GHHIN, 2020).

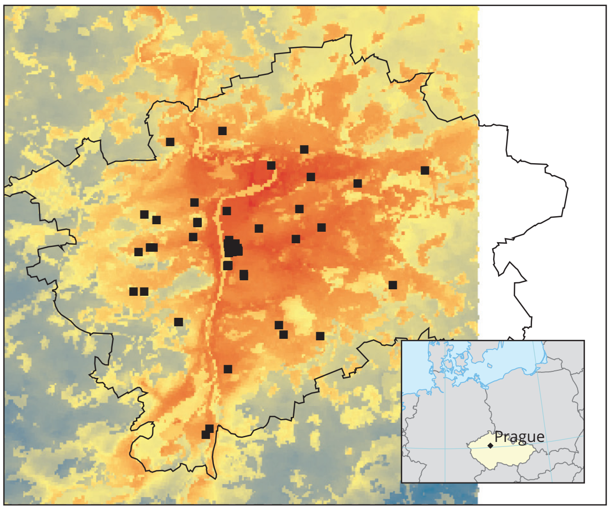
The rise in heat-related deaths is counteracted by a reduction in cold-related mortality (Ballester et al., 2011). However, a study on 200 regions in Europe found a seasonal change in mortality from winter to summer and that increases in heat-related

Box 2.5 Location of hospitals and schools in relation to urban heat islands

Location of facilities catering for vulnerable groups, such as schools and hospitals, may affect the exposure of their users to heat stress. Out of 1 304 hospitals identified in the Open Street Map (OSM) located within the extent of the UHIs modelled for 100 cities across Europe, nearly half (625 hospitals) are located in areas where the average UHI effect exceeded 2 °C, while 91 hospitals were located in areas where UHI effect is higher than 4° C. When all healthcare facilities are considered, nearly 40 % of them are in UHIs > 2 °C (see Map 2.8 for an example), and 5 % of them are located in UHIs > 4 °C. The mean temperature differential for hospital locations was 2.1 °C (for all healthcare facilities 1.96 °C), while the mean differential for all areas in the UHI maps was 0.96 °C. This overrepresentation of hospitals and other healthcare facilities in the warmer city centres, linked to their central location, which is crucial for their accessibility, requires urgent adaptive actions to protect the health and well-being of both the vulnerable groups and those caring for them.

Similarly, the average UHI intensity for school locations was 1.8 °C. Around 3 % of the assessed schools were located in UHIs > 4 °C, and over 30 % in UHIs > 2 °C. On average, the highest UHI intensities for school locations were found in Bosnia and Herzegovina, followed by Greece, Croatia and Bulgaria. The lowest were in Sweden, Denmark and Finland. See Section 6.5.4 for an example of adaptive actions to heat in schools.

Map 2.8 **Location of hospitals in relation to urban heat island intensity in Prague, Czechia**



Reference data: ©ESRI

Location of hospitals in relation to urban heat island intensity in Prague, Czechia

Difference in temperature in relation to city average (°C)
-0.9 … 3.1

■ Hospitals

☐ City boundary

Source: Authors' analysis based on Open Street Map (2019) and UHI modelling (VITO, 2019a).

mortality will outweigh decreases in cold-related mortality by mid-century, resulting in an average lifespan shorter by up to 3 or 4 months by the end of the 21st century (Ballester et al., 2011). The estimated net effects on temperature-related mortality are likely to vary regionally, with a small negative net change in temperature-related deaths (-0.6 %) in northern Europe and a more substantial increase in central and southern Europe (3.5 % and 6.4 %, respectively) projected under the RCP 8.5 scenario for the end of the century compared to the 2010-2019 decade (Gasparrini et al., 2017).

Impacts on energy demand

High indoor temperatures can translate into increased energy demand. Peak electricity demand for cooling, which is almost exclusively electric, will increase throughout Europe, with the largest increases projected for Italy, Spain and France (EEA, 2019a). Modelling of energy demand for a recently built, typical western European, multi-storey office building in Antwerp points towards a 25 % increase in energy demand for ventilation and cooling during summer by the end of the 21st century under the RCP 8.5 scenario. For a similar building in Bilbao, Spain, the future cooling demand could be 1.6 times as high as for current climate conditions (Hooyberghs et al., 2017). However, in certain contexts the increased demand for cooling may be offset by reduced demand for heating in winter, as modelling of future change in building-related energy demand in Madrid suggests (San José et al., 2016).

Impacts on transport

Heat-related impacts on infrastructure are not expected to be as large as the impacts of flooding and other precipitation-related climate change (Christodoulou and Demirel, 2017; see also Section 2.4), but rising temperatures and extreme heat can negatively affect transport systems and other major infrastructure. Evidence for the impact of heat on transport at the local level is lacking, but research suggests that, without appropriate adaptation measures, most critical transport infrastructure in European cities will be at risk towards the end of the century (Forzieri et al., 2018). A 2-day heatwave in the United Kingdom in 2015 necessitated the use of speed restrictions on railway services because of rail buckling, causing more than twice the daily average delay-minutes, with an economic cost of GBP 16 million (EUR 17.7 million) (Ferranti et al., 2018). In July 2015, a 6-day heatwave in Flanders, Belgium, caused damage to 129 sections of regional roads, causing repair costs of almost EUR 600 000 (HLN News, 2015). Koetse and Rietfeld (2009) cite records for climate impacts on the Dutch railway system, where weather appears to cause approximately 10 % of all rail infrastructure failures, most of these due to high temperatures (followed by ice, storms and lightning). At airports and seaports, the main consequences of higher temperatures and extreme heat are the faster degradation of materials, such as asphalt and concrete, and the impact this has on speed of transportation and delays to services. Extreme heat also raises costs, and water and energy requirements, for cooling, for example in stations, transport vessels and cargo containers or holds (Christodoulou and Demirel, 2017).

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2.4 Pluvial and river flooding

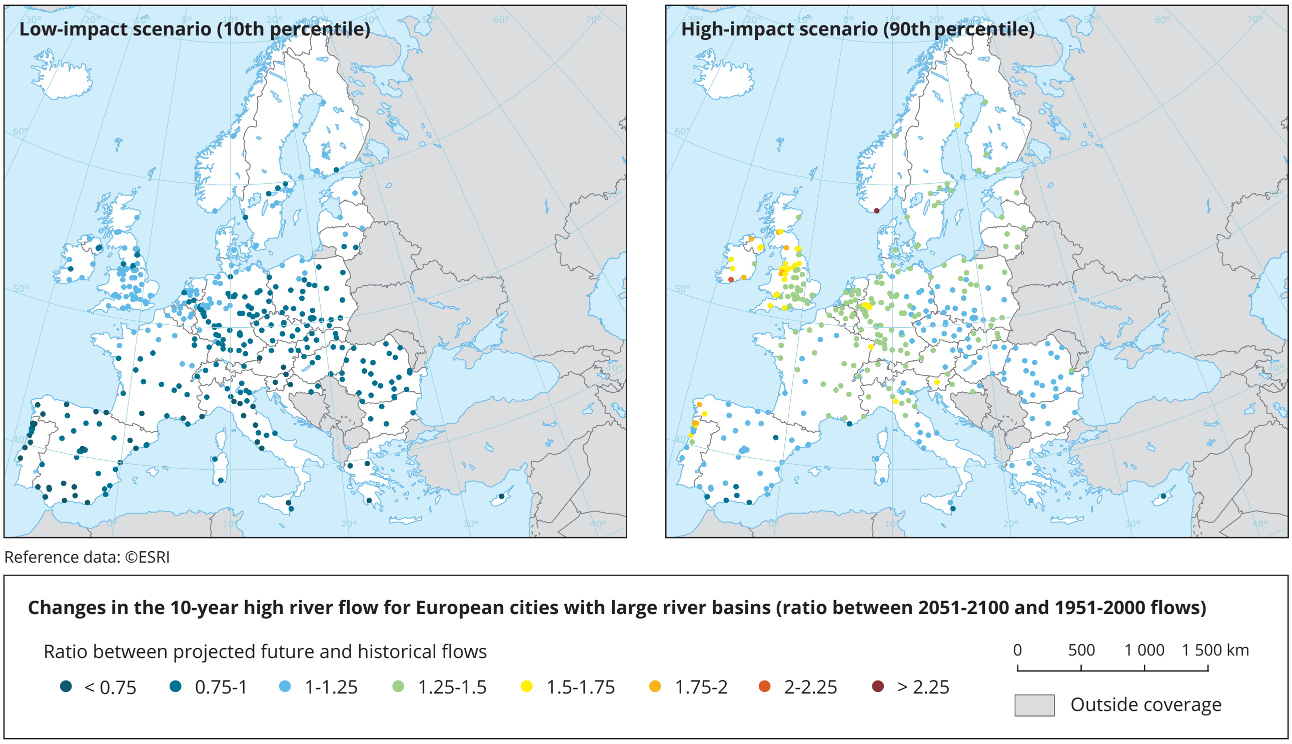
2.4.1 Climate hazard

Annual average precipitation is projected to increase in northern Europe and to decrease in southern Europe, with seasonal differences: most of Europe is already experiencing reduced precipitation in the summer and increased precipitation in the winter. Heavy precipitation events are projected to increase over most of the continent, leading to increased incidence of pluvial and fluvial flooding. For instance, in Flanders (Belgium), heavy precipitation intensity might increase by 50 % in winter and 100 % in summer by the late 21st century (Tabari et al., 2015).

Regarding the risk of flooding under the changing climate, Guerreiro et al. (2018) found a strong north-south divide in projected changes in 10-year high river flow (Q10), with the British Isles seeing the worst projections. While for the low-impact (10th percentile) scenario over two thirds of European cities on a river show either no change or a reduction in Q10, many cities in Belgium, the Netherlands, the United Kingdom and Scandinavian countries still experience an increase (Map 2.9). For the high-impact scenario (90th percentile), half of the United Kingdom's cities see increases above 50 % and several European cities see increases above 80 % (Santiago de Compostela in Spain, Cork and Waterford in Ireland, Kristiansand in Norway, Braga and Barcelos in Portugal, and Derry/Londonderry in the United Kingdom) (Guerreiro et al., 2018).

Cryosphere changes such as loss of snow cover and snow mass also affect flooding patterns. Between 1967 and 2015, snow cover extent in Europe was reduced by 13 % in the spring and by 76 % in June (EEA, 2017b). Reduced snow accumulation may decrease the risk of early spring flooding and, according to projections, north-eastern Europe will see a decrease in large floods associated with snow melts (EEA, 2017a, 2017b). For instance, snowmelt is likely to be reduced in the northern parts of Sweden (Sjökvist, et al., 2015).

Map 2.9 **Changes in the 10-year high river flow for European cities with large river basins (ratio between 2051-2100 and 1951-2000 flows)**



Reference data: ©ESRI

Notes: The 10-year high flow (Q10) corresponds with the one in 10-year return periods of annual maximum daily discharge. The changes are calculated as the projected 2051-2100 Q10 divided by the 1951-2000 Q10. They are shown for low-impact (10th percentile) and high-impact (90th percentile) scenarios. Based on 50 climate model projections from the CMIP5 (Taylor et al., 2012), for the RCP 8.5 emissions scenario. The digital elevation model Hydro1K was used to delineate river basins for each city. Q10 was estimated using a regression model based on gauge discharge data from the Global Runoff Data Centre (GRDC), and the European daily gridded data set, E-OBS (Haylock et al., 2008). The cities included in the analysis (365) are those that have an upstream river basin larger than 500 km^2. The 50th percentile (median) scenario is available in the Urban Adaptation Map Viewer; see also Guerreiro et al. (2018).

Source: Adapted from Guerreiro et al. (2018).

The rising intensity and frequency of severe rainfall events will also lead to an increased frequency of landslide events in Europe through the 21st century, in particular in highland areas (Schlögl and Matulla, 2018). Of 3 846 landslides in Europe that affected urban areas and road and rail infrastructure between 2015 and 2017, 69 % were triggered by intense or prolonged rainfall events (Mateos et al., 2020). Jaedicke et al. (2014) estimated that between 1.3 and 1.6 million Europeans and between 8 000 and 20 000 km of road and rail infrastructure are highly exposed to landslides, which are mainly caused by extreme precipitation.

2.4.2 Factors exacerbating or mitigating flooding risk in cities

Surface sealing in cities

Urban areas tend to exacerbate the intensity of flooding from heavy precipitation events owing to development on floodplains, channel straightening and the large share of impermeable surfaces in cities that convert incoming precipitation into runoff (overland flow) (Gharbia et al., 2016). Although artificial surfaces (such as concrete or asphalt) cover less than 5 % of the total area of EEA member and collaborating countries (both urban and rural), 16 600 km^2 became sealed between 2000 and 2018. The rate of increase in artificial surface areas seems to be slowing down, from 1 086 km^2 per year between 2000 and 2006 to 711 km^2 per year between 2012 and 2018 (EEA, 2019f).

According to the unpublished EEA analysis of the Copernicus Imperviousness High Resolution Layer (16), the average proportion of surface sealing in the administrative areas of the Urban Audit cities in 2015 was around 19.5 % (up from 19.1 % in 2006), and in the urban morphological zone (UMZ, see glossary in Annex 2) it was 35.6 % (up from 34.9 % in 2006). The combination of high soil sealing and increased precipitation may increase the risk of pluvial flooding in some cities, especially in north western Europe (see the Urban Adaptation Map Viewer).

The majority of European cities are becoming more built up and denser, but at differing pace. Several cities in the Netherlands, Poland, Portugal and Spain experienced considerable increases in surface sealing in the core city area between 2006 and 2015; in some Polish, Portuguese, Romanian and Spanish cities also densification of the already heavily urbanised areas has occurred (see Urban Adaptation Map Viewer). This is consistent with the urban sprawl observed in the period 1975-2010, especially in less developed (as of 1975) regions and countries, which were gradually catching up with the more advanced regions and countries in the EU (Lavalle et al., 2017).

Research for individual cities explores how surface sealing translates into increased risk of flooding. For example, in Odense, Denmark, an urban land cover change analysis based on remote sensing estimates shows an overall increase in absolute imperviousness from 32 % in 1984 to 51 % in 2014. This change in the land cover has increased the overall extent of flooding during heavy precipitation (100-year rainfall) by between 6 % and 26 % under current climatic conditions. Corresponding estimates for the increase in extent of flooding under the RCP 4.5 and RCP 8.5 climate change scenarios (2071-2100) are in the order of 40 % and 100 %, respectively (Skougaard Kaspersen et al., 2015). Therefore, land cover changes within cities can play a central role in the cities' exposure to flooding and in their adaptation to a changed climate.

Status of urban drainage systems

Risk of pluvial flooding is also influenced by the capacity and state of the stormwater drainage systems in cities. The average age of the sewers for 36 cities included in the Urban water atlas for Europe (Gawlik et al., 2017) is 40 years, varying from 10 in Reykjavik to 90 in London (Figure 2.5) (17). This raises the question of whether the relatively old sewer network infrastructure in European cities is capable of dealing with higher volumes of rainwater during periods of intense precipitation. Based on a study of the cities of Nice, Odense, Strasbourg and Vienna, it seems necessary to increase the urban drainage systems' capacity to cope with additional surface runoff under the changing climate and with the increasing surface sealing in cities (Skougaard Kaspersen et al., 2017).

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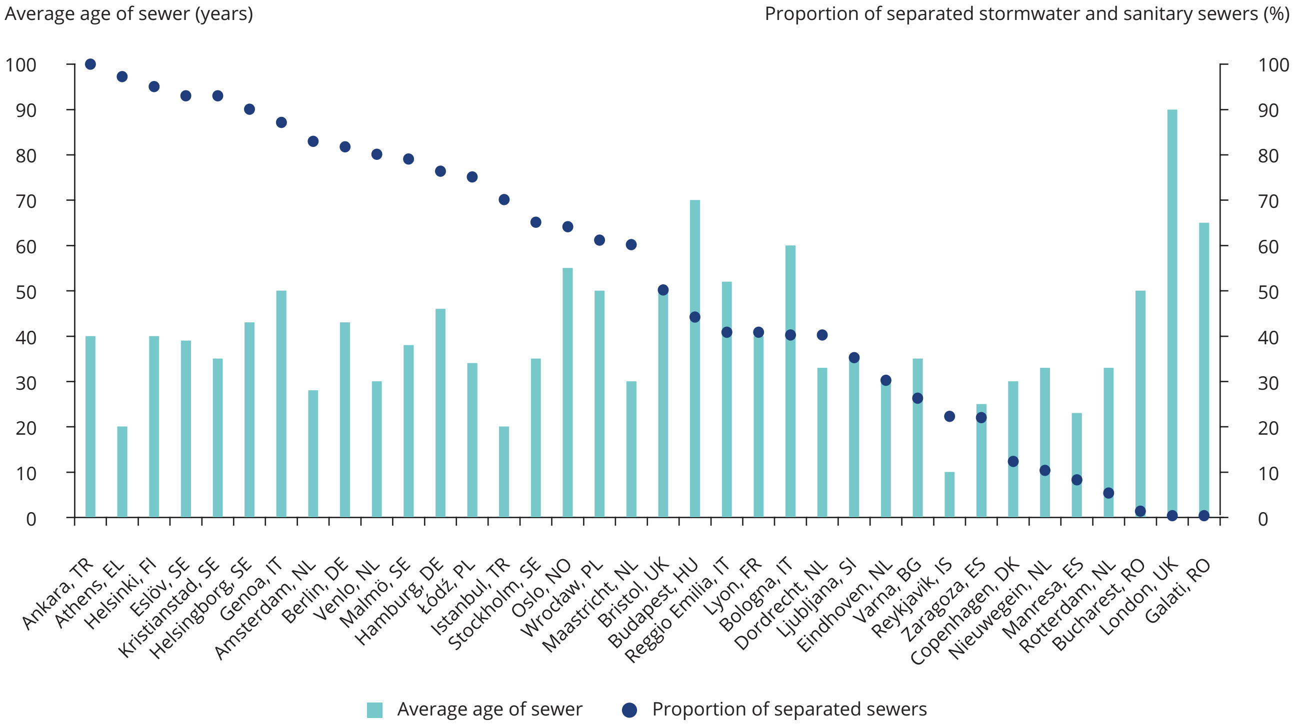
(16) https://land.copernicus.eu/pan-european/high-resolution-layers/imperviousness

(17) This dataset should not be treated as representative of Europe. Information about the age of the sewer systems in European cities is not collected systematically.

Figure 2.5 **Average age of sewer (years) and percentage of sewers with separated stormwater and sanitary water in 36 European cities**



Note: The selection of cities comes from the source of data and is not meant as representative of Europe. Limited information exists on the percentages of combined versus separate sewers in Europe (Eureau, 2017). Milieu Ltd (2016) provides an overview of the proportion of combined and separate sewers in EU Member States (data not specific to cities).

Source: Author's compilation based on data from Gawlik et al. (2017).

The separation between stormwater and wastewater networks is needed to better manage fluctuating volumes of water and to avoid health risks associated with flooding events (see also Section 2.7). Nonetheless, the separation should come with downstream treatment using wetlands, ponds, filtration or other suitable systems (in particular to control substances washed from pavements by rainwater). Accordingly, Germany and the Netherlands promote separation programmes only where suitable treatment for rainwater is provided (OECD, 2020). An alternative approach is to prevent stormwater from entering the sewer network by using green infrastructure to intercept water (see also Section 3.3).

Land use and population in urban floodplains

Historically, cities have often developed near major rivers (Beckers et al., 2013). Consequently, a substantial proportion of cities in Europe is located within potential floodplains (see Annex 2 Glossary) associated with rivers. According to an unpublished EEA analysis, around 11.6 % of the total Urban Audit core cities' area lies within potential floodplains and, in the case of Dutch cities such as Zoetermeer or Spijkenisse, potential floodplains cover as much as 95 % of the city (see Urban Adaptation Map Viewer for details).

Urban floodplains contain land with various uses, which may incur substantial losses when flooded. EEA analysis estimates that, overall, 8.5 % of the land use in urban potential floodplains is classified as urban fabric and nearly 12 % is industrial or commercial land (18). Social infrastructure such as schools or hospitals can also be located in floodplains (Box 2.6). Potential floodplains in Urban Audit cities contain 3 513 km^2 of industrial/commercial land and 2 751 km^2 of dense urban fabric. If land with these uses is flooded, there may be considerable losses. According to the EEA analysis of floodplains and Copernicus Urban Atlas 2012 data, cities with the highest areas of land classified as 'urban fabric' and 'industrial, commercial, public, military, private and transport units' located in the potential floodplains include Berlin, Bremen, Hamburg, Rotterdam and Wrocław (see Urban Adaptation Map Viewer).

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(18) Urban fabric land use/land cover class (1.1) in the Copernicus Urban Atlas contains areas of continuous and discontinuous urban fabric of various densities. Class 1.2 (industrial, commercial, public, military, private and transport units) is referred to in this report as 'industrial or commercial'. See EC (2016a) for more information on land use/land cover classes in the Urban Atlas.

Box 2.6 Location of hospitals and schools in relation to potential floodplains

Around 7.8 % of hospitals identified in the Open Street Map (OSM) within the Urban Audit core cities are located in potential floodplains. Just over 6 % of all healthcare facilities identified in the OSM are located in floodplains. According to the OSM, out of nearly 141 000 schools located in Urban Audit core cities, nearly 12 000 (8.3 %) are within potential floodplains. The highest proportions of urban schools located in floodplains are in the Netherlands, Austria and Belgium. The assessment does not account for the presence of flood defences, specific local terrain variability or facility level adaptation to flood risk.

Source: EEA analysis based on Open Street Map (2019) and potential floodplains (EEA, 2019c).

EEA floodplain statistics (EEA, 2019c) show that, across the EU-27 Member States plus the United Kingdom, between 2012 and 2018 urban sprawl occurred on 35 km^2 of floodplains; 99 km^2 of floodplains were subject to urban development, infilling or recycling of urban land, and 290 km^2 were subject to sprawl of economic sites and infrastructure. The ongoing construction activities in floodplains show that short-term interests and perceived societal benefits (increased housing availability, jobs in industrial areas) outweigh the longer term flood risk management interest and potential increases in damages or other costs (Kreibich et al., 2015). For example, the vulnerability of the Po Valley in Italy has increased substantially since the 1950s owing to the expansion of industrial activities into the floodplain (Domeneghetti et al., 2015).

At the same time, urban floodplains can provide an important water storage function, as, according to the unpublished EEA analysis, over half of their area is permeable, vegetated land. Agricultural land accounts for over a third of the land use in urban floodplains, and natural areas constitute nearly 12 %. Artificial vegetated spaces, such as urban green spaces or sport areas, make up nearly 5 %. Wetlands cover 1.3 %.

When the land use in potential river floodplains within cities is explored by country (Figure 2.6), Luxembourg emerges as having the highest proportion of urban fabric in floodplains. The highest proportion of industrial/commercial land is in Belgian cities (35.6 %), followed closely by Luxembourg and Switzerland. Switzerland, Lithuania and Estonia have the highest proportions of artificial non-agricultural vegetation in urban floodplains (all over 13 %). In Denmark over 71 % of the floodplains within urban areas is committed to agriculture, followed by southern countries (where rivers are crucial for irrigation): Cyprus, Greece and Italy. The highest percentages of natural areas in urban floodplains are in northern countries: Iceland, Norway and Finland.

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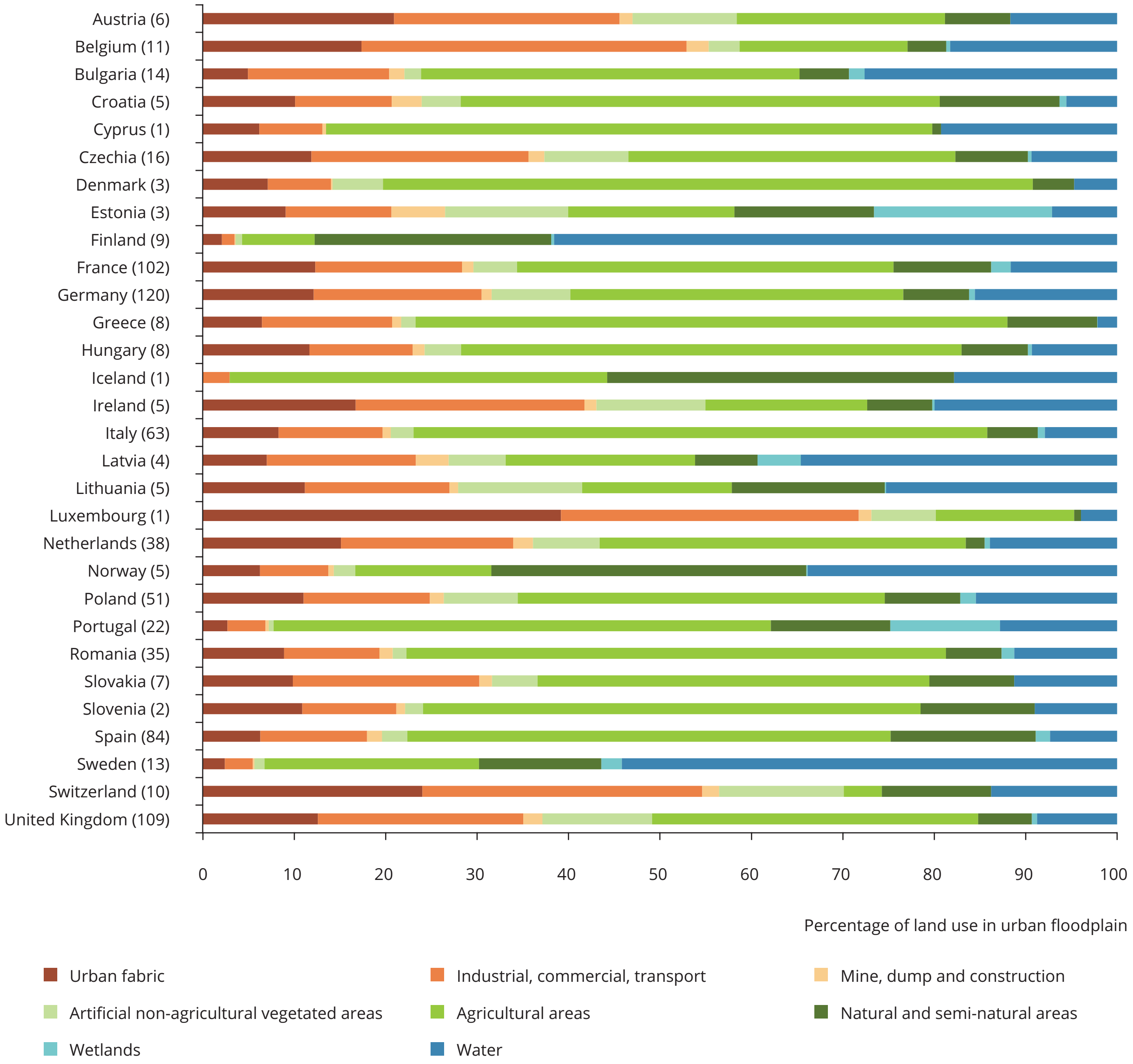
Figure 2.6 **Land use classes in urban floodplains per country, 2012**

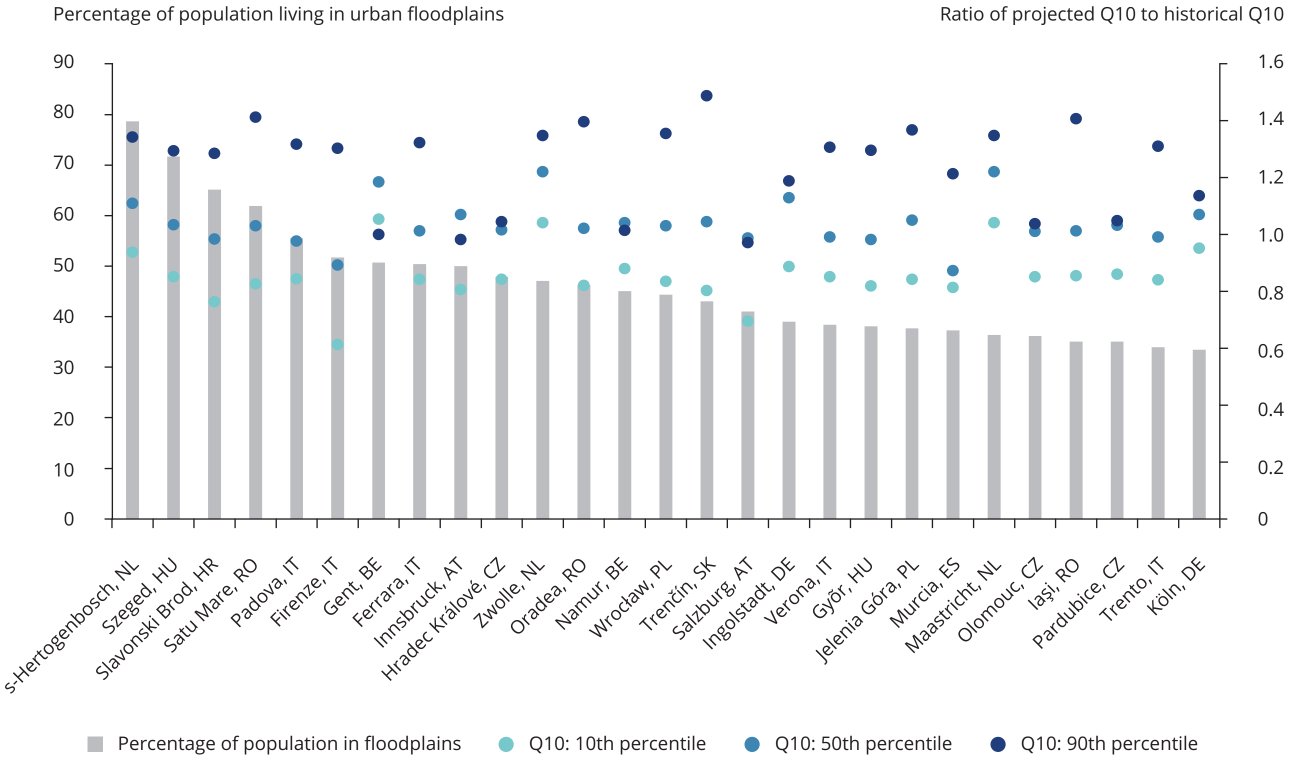


Note: The number of Urban Audit cities in each country covered by the analysis appears in brackets. Cities with no floodplains were excluded from the calculations.

Source: Authors' own compilation based on the analysis of Copernicus Urban Atlas 2012 and EEA potential floodplains by European Topic Centre on Urban, Land and Soil Systems (ETC/ULS).

Nearly 10 % of the combined population of Urban Audit cities lives in potential floodplains and in nearly 13 % of the cities over a quarter of the city population lives within a floodplain. The cities where a considerable proportion of population living in potential floodplains coincides with a high projected increase in Q10 (Figure 2.7) require the most urgent adaptive actions. For details on individual cities, see the Urban Adaptation Map Viewer.

Figure 2.7 **Cities with the highest percentages of population (> 33 %) living in potential floodplains and the projected (2051-2100) increase in 10-year high river flow**



Note: The projected change in the 10-year high river flow (Q10) is the ratio of the projected one in 10-year return period of annual maximum discharge to the one in 10-year annual maximum discharge in the historical period (1951-2000). Q10 is presented for three possible futures: 10th, 50th and 90th percentiles.

Source: Authors' own compilation based on Guerreiro et al. (2018) and analysis of population in urban floodplains by the European Topic Centre on Urban, Land and Soil Systems (ETC/ULS).

2.4.3 Impacts of flooding

Direct costs of pluvial flooding

Urban flooding, following intense short-term precipitation, when the volume of rainwater exceeds the capacity of urban sewerage systems, may lead to substantial damage in urban areas. Examples of such events include Münster, Germany, where in 2014 pluvial flooding resulting from 290 mm of rain in 7 hours caused insured damage of EUR 72 million (GDV, 2015), and in Copenhagen in 2011, where 135 mm of rain fell over 2 hours, causing losses of more than DKK 6 billion (EUR 800 million; City of Copenhagen, 2014).

The frequency of heavy rainfall events is expected to increase further, with a corresponding rise in damage if no adaptive actions are taken. For instance, in Norway, rainfall intensity for durations of a few hours under the RCP 8.5 scenario may increase by more than 30 % by the end of the century (Hanssen-Bauer et al., 2017). Accordingly, the number of flood events is expected to increase by between 10 % and 100 % by 2100 (Scheel and Hinnerichsen, 2012). In Dresden, a 1-hour event with approximately 50 mm of precipitation, resulting in losses of approximately EUR 49 million, might have a 2 % probability of occurring in any one year by the end of the century (Golz et al., 2016). For Copenhagen, under the RCP 8.5 scenario, by the end of the century annual losses from precipitation events similar to that in 2011 could increase by 3.7 times. However, the full implementation of the Cloudburst management plan in Copenhagen (see Box 3.8) would reduce the current damage by 90 %, while the expected additional damage for 2100 would be 60-100 % of the present damage (Arnbjerg-Nielsen et al., 2015).

Direct costs of flooding from rivers

Hydrological events, predominantly river flooding, are responsible for 28 % of insured losses caused by natural hazards in Europe (EEA, 2019b). Some of the costliest natural disasters in Europe have been floods; for example, a river flood in Bilbao, Spain, in 1983 caused material damage costing EUR 1.2 billion and 37 fatalities (Abadie et al., 2017).

Damage to buildings and infrastructure dominates the losses, indicating high vulnerability of cities where those concentrate. Flooding on the Danube and Elbe rivers in Germany in 2013 caused direct losses of between EUR 1.5 billion and EUR 2.1 billion due to damage to buildings (Sieg et al., 2019). In January 2018, flooding of the rivers Seine and Marne in France, which affected the Paris metropolitan area, caused between EUR 190 million and EUR 350 million of damage overall, despite flood risk protection measures in place (CCR, 2018).

Future damage will vary between countries and regions, depending on the climate change scenario, urbanisation patterns and adaptive actions taken. For example, modelling results for the River Meuse in the Walloon Region (Belgium) show that, between 2009 and 2100, flood damage could multiply between 1.01 (a scenario with decreasing precipitation, in which only urbanisation acts as a factor increasing the risk) and 6.3 times. Under wetter scenarios, the effect of climate change is 3-8 times more influential than the effect of urbanisation (Beckers et al., 2013).

Indirect costs of flooding

Indirect costs of floods, such as lost business activities, are also considerable. In 2013, flooding of the Danube and Elbe rivers in Germany caused between EUR 1.1 billion and EUR 1.6 billion of indirect losses, with manufacturing, transport, storage, and wholesale and retail sales having suffered most (Sieg et al., 2019). Small and medium-sized enterprises may be severely affected by flooding, especially if their activities are interrupted for periods longer than several days (see also Box 5.3).

Interruption of various urban services, particularly transport, generates indirect losses. For the city of Newcastle (UK), Pregnolato et al. (2017) calculated the costs of road traffic disruptions caused by a single pluvial flooding event in terms of time lost as approximately GBP 93 000 for a high-probability event (one in 10 years) and GBP 130 000 for a low probability event (one in 50 years). By 2080, these costs could rise to GBP 130 000 and GBP 220 000, respectively. If adaptation measures had been taken, these costs could have been reduced by 50 % for present conditions, and taking such measures now could result in the same reduction for future conditions (Pregnolato et al., 2017).

Access to services can be limited even if relatively small areas are affected by flooding, if they correspond with key points of infrastructure networks, as identified for York, United Kingdom (Coles et al., 2017). This is particularly dangerous if inaccessibility of transport networks excludes some areas from being reached by emergency services (Arrighi et al., 2019).

Health impacts of flooding

In the European context, deaths associated with flooding are relatively low in number compared with, for example, deaths associated with heatwaves. Although no data specifically for European cities exist, in the EEA-32 countries plus the United Kingdom just over 4 600 fatalities were associated with hydrological events (floods and mass movements) between 1980 and 2017 (EEA, 2019b). The annual number of fatal landslides in Europe linked to extreme weather events or earthquakes increased in the period 1995-2014. Among the areas with the highest numbers of landslide deaths were southern Italy and Portugal, where landslides mostly occurred in densely populated areas (Haque et al., 2016).

Sewage overflow caused by flooding increases the risk of infectious diseases; this risk is higher in cities with high proportions of combined stormwater and sanitary sewerage systems. In 36 European cities, the average percentage of separated sewers varies from 0 (in Galati, Romania, and London, United Kingdom) to 100 % (Ankara, Turkey) (Figure 2.5). In the Netherlands, according to a quantitative analysis of exposure data, contact with flood water contaminated by sewage from combined sewers carries a risk of infection of 33 % for children and 4 % for adults; water from separated rainwater drainage systems has a lower risk of infection (23 % for children and 0.58 % for adults) (de Man et al., 2014). In relation to river flooding, sporadic cases of symptomatic leptospirosis (19) have been reported in Italy (Vitale et al., 2018); see EEA (2020c) for an overview of water-borne diseases that may be exacerbated by flooding. Floods may also mobilise chemicals such as mercury from landfills, soil or silt, resulting in increased exposure of people (EEA, 2020c).

People affected by flooding can also suffer mental health problems both immediately and long after a flood event. Up to 75 % of people affected by flooding have suffered impacts on their mental health (EEA, 2020c). Problems can range from trauma and mental distress in the short term to post-traumatic stress disorder (PTSD), anxiety, insomnia, psychosis, depression and even suicide (Zhong et al., 2018). Victims of flooding may have significantly higher rates of depression and PTSD even 3 years after the flood event (Mulchandani et al., 2020). Secondary stressors, such as disruption to public services including health and education, as well as impact on relationships, loss of personal items of sentimental value, and difficulties faced in accessing compensation and making repairs, can play a significant role in affecting long-term mental health (Tempest et al., 2017; Mulchandani et al., 2019). Social groups with high levels of dependency on others or low levels of resources, such as the elderly, children and those living in low-income households, are more vulnerable to mental health problems after a flooding event (EEA, 2020c).

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(19) Leptospirosis is a bacterial disease that affects humans and animals. It is caused by bacteria of the genus *Leptospira*. In humans, it can cause a wide range of symptoms, some of which may be mistaken for other diseases. Some infected persons, however, may have no symptoms at all. Without treatment, leptospirosis can lead to kidney damage, meningitis (inflammation of the membrane around the brain and spinal cord), liver failure, respiratory distress, and even death.

2.5 Coastal flooding and coastal erosion

2.5.1 *Climatic hazard*

All coastal regions in Europe have already experienced an increase in absolute sea level, but with some regional variation. Most coastal regions have also experienced an increase in sea level relative to land. During the 21st century, the rate of global mean sea level rise will very likely be higher than during the period 1971-2015. Process-based models considered in the *IPCC special report on the ocean and cryosphere in a changing climate* project a rise in sea level during the 21st century in the range of 0.29-0.59 m for a low-emissions scenario and 0.61-1.10 m for a high-emissions scenario. However, substantially higher values cannot be ruled out (IPCC, 2019). Several recent assessments have suggested an upper bound for the 21st-century global mean sea level rise in the range of 1.5-2.5 m (EEA, 2019d). The projected scale of sea level rise for selected European cities is presented in Figure 2.8).

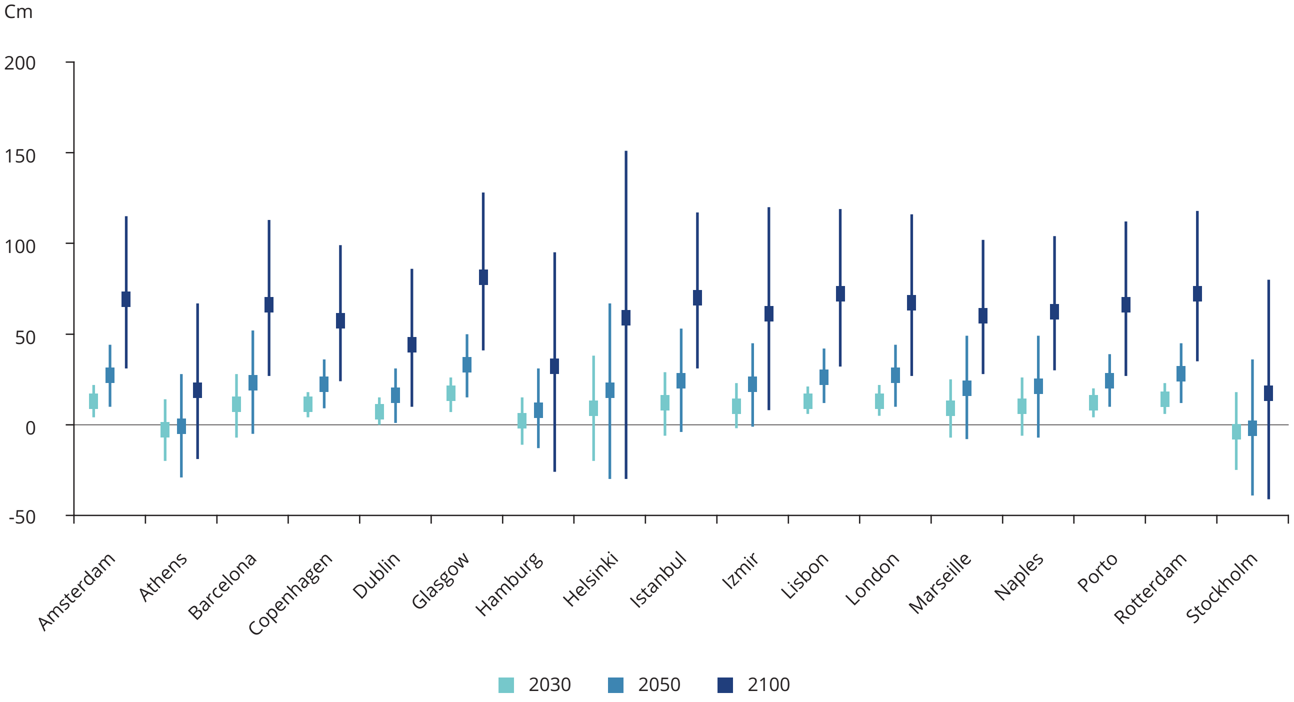
The projected sea level rise will increase the number of coastal floods very substantially, unless adequate adaptation measures are taken. All available studies project that the economic damage from coastal flooding in Europe would increase manifold in the absence of adaptation (EEA, 2020a).

Around one-fifth of Europe's coastline is prone to coastal erosion (Eurosion, 2004), with the Mediterranean and North Sea coastlines under particular threat (Deduce Consortium, 2007). Around 42 % of Italy's low coastline is eroding despite coastal protection mechanisms (Pranzini, 2018). Eroding cliffs and vulnerable low-lying shores constitute 25 % of the Portuguese coastline, particularly in the Algarve region (Andrade et al., 2002). Coastal erosion is likely to increase as a result of climate change, largely due to rising sea levels and the increase in storminess and wave height. Although there is a consensus on this trend, forecasting coastal erosion in the context of a changing climate is challenging and contested (Orombelli and Pranzini, 2020).

2.5.2 *Factors exacerbating or reducing risks in cities*

European coastal zones are densely inhabited, and they host economic assets and activities that are pivotal for Europe's economy (Vousdoukas et al., 2018). In 2013, approximately 42 % of the total population of the 26 European coastal countries lived in coastal regions (Iglesias-Campos et al., 2015). However, estimating the current and projected exposure to coastal flooding is difficult because the coastal flooding exposure maps available for Europe do not include local flood defences

Figure 2.8 **Future sea level rise projections for 17 coastal cities in Europe under RCP 8.5 (cm)**



Note: The selection of cities comes from the source and is not representative of Europe. The top of the whisker corresponds with the 95th percentile and the bottom with the 5th percentile of the modelled values. The marker in the middle reflects the median value (50th percentile).

Source: Authors' compilation based on data from Kopp et al. (2014) in Abadie et al. (2016).

(Vousdoukas et al., 2020). Forzieri et al. (2017) estimate that, by the year 2050, the number of people residing in coastal flood zones in the EU-27 and the United Kingdom (not considering the protection measures) will increase by 24 % compared with current values, although there is a large degree of variability between countries. When the existing coastal protection is not accounted for, in the worst-case scenario the population exposed will increase, for example, from under 5 million to 8.8 million in the Netherlands, from 3.2 million to 5.4 million in the United Kingdom, and from 1.5 million to 2 million in Germany (Kulp and Strauss, 2019).

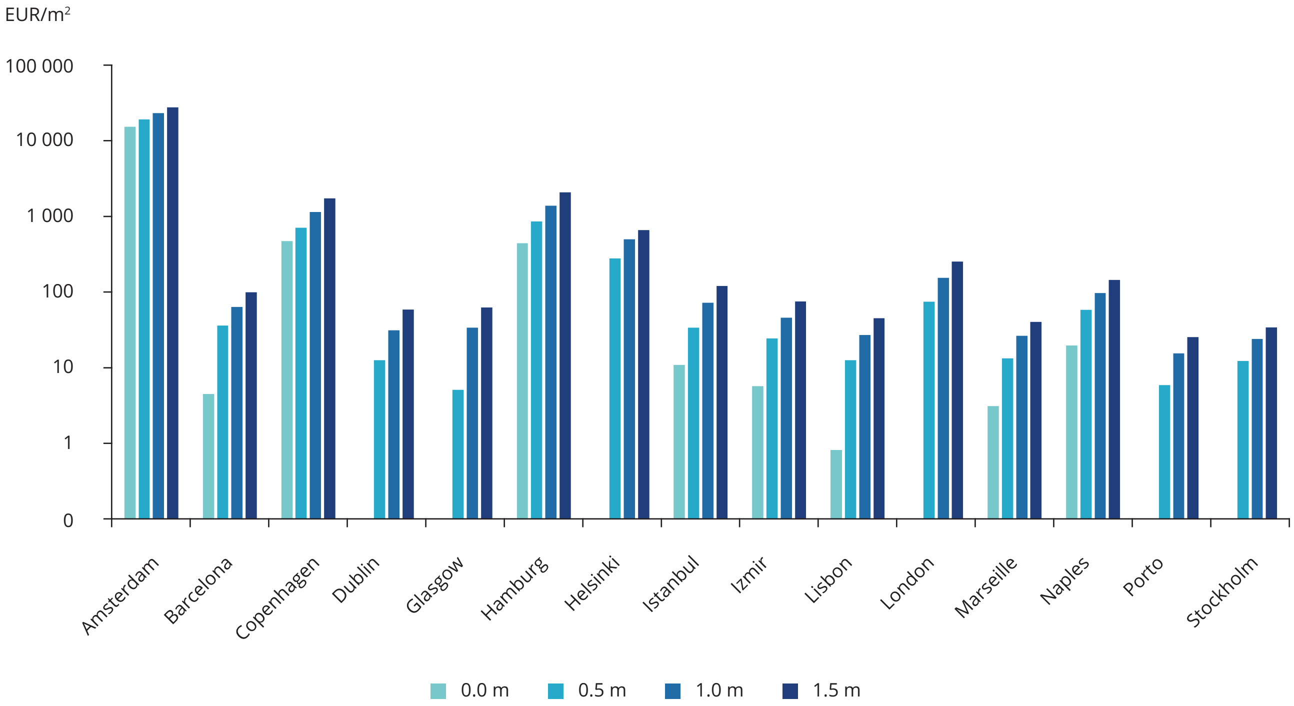
According to an unpublished EEA analysis ([20]), if existing flood protection measures are not considered, Dutch cities top the list in terms of the possible inundation extent. British cities such as Kingston-upon-Hull, Great Yarmouth and Thanet are also among those with most of their area potentially under water given a 1 m increase in sea level rise (see Urban Adaptation Map Viewer for detailed maps).

In the case of coastal erosion, it can be difficult to separate the effect of climatic factors, such as sea level rise, from the effect of human activity, including degradation of natural protection structures, construction of coastal defence structures and riverbed quarrying (Nicholls and Cazenave, 2010; Pranzini et al., 2015). Pereira and Coelho (2013) forecast developments on the 35 km of coastline between the settlements of Aveiro and Mira (Portugal) and suggest that human activity is likely to be a stronger determinant of coastline evolution than sea level rise or wave height. However, of 31 European case studies of coastal erosion covered in five EU-funded research projects, around 70 % indicated that severe and extreme storms were the strongest determining factor in erosion processes (EEA, 2017b).

2.5.3 Impacts of coastal flooding and coastal erosion

The losses from sea flooding in European coastal cities are likely to increase in the future if no further adaptive actions are taken. Assuming no protection measures are in place, the losses modelled for 17 cities in the EEA member countries would increase from about EUR 1 billion in 2030 to EUR 31 billion in 2100 under the RCP 8.5 scenario (Abadie et al., 2019). Figure 2.9 presents the modelled annual damage costs associated with coastal inundation for 15 European cities.

Figure 2.9 Damage costs associated with coastal inundation of various depth in selected European cities, assuming no adaptation measures



Note: The selection of cities is illustrative and not representative of Europe. The damage costs (EUR/m^2 calculated for 2016 prices) are presented on a logarithmic scale and pertain to modelling for the present. Potential damage costs for other European cities, depending on the projected inundation depth, are available on the Urban Adaptation Map Viewer.

Source: Authors' compilation based on data from Prahl et al. (2018).

([20]) Based on inundation data from CReSIS (Centre for Remote Sensing of Ice Sheets) 2018, Lawrence, Kansas, USA.

Coastal zones are an important element of Europe's cultural history, with many historical sites situated on the coasts. In an analysis of the exposure of World Heritage Sites in the Mediterranean, 37 of the 49 cultural heritage sites located in low-lying areas along the Mediterranean coasts are currently at risk of being flooded by a one in 100-year flood, and 42 sites are at risk from coastal erosion (Reimann et al., 2018). In Venice, in November 2019, a storm surge of 187 cm (the second highest in history), caused by a combination of high tide, heavy rain and wind, resulted in the flooding of more than 85 % of the city. While the costs are still being estimated at the time of writing, damage to St Mark's cathedral alone has been estimated to be more than EUR 4 million (Lorenzini, 2020). Venice may be at risk of losing its World Heritage status without adequate flood protection (Scholz-Carlson, 2019).

Coastal erosion can cause significant economic losses for coastal settlements (EEA, 2017b). For example, the coastal town of Sant'Alessio Siculo (Italy) was estimated to have lost EUR 114 million, caused by a total loss of 95 000 m^2 of beach from 1967 to 1997 (Foti et al., 2020).

Rising sea levels can contribute to saltwater intrusion into coastal aquifers affecting the supply of fresh water for cities. For example, in the region of Gdańsk (Poland), the combined effects of land subsidence (0.1-0.2 mm/year) and sea level rise threaten intrusion of saltwater into the aquifers crucial for public water supply (Staudt and Kordalski, 2005).

2.6 Droughts and water scarcity

2.6.1 Climatic hazard

In general, water scarcity is currently more frequently experienced in southern Europe, where more than half of the population lives with constant water scarcity. This is particularly so during summer, resulting from higher levels of abstraction for agriculture, public water supply and tourism. Because of very intensive irrigation, the middle Apennines and the Po basin (Italy), and the basins of Rivers Guadiana (Portugal and Spain) and Segura (Spain), experience severe water stress almost all year long (EEA, 2020e). Nevertheless, water scarcity is not limited to southern Europe, and is driven in other regions by significant urbanisation, combined with high levels of abstraction for cooling purposes by the energy and industrial sectors (Behrens et al., 2017). Higher pressures than the regional average can be observed in, for example, the greater Copenhagen, London and Stockholm areas (EEA, 2020e).

Because of reduced precipitation and enhanced evapotranspiration, southern and central Europe show a trend towards an increase in the duration and intensity of drought in the future. The number of Europeans living in areas that are considered to be water scarce for at least 1 month every year could rise from 52 million now to 65 million in a 3 °C warming scenario, which is equivalent to 15 % of the current EU and United Kingdom population (Feyen et al., 2020).

Map 2.10 shows that, under the high-impact scenario, drought conditions increase in most European cities in the second half of the 21st century, and cities in southern Europe may experience droughts up to 14 times more intense than the worst drought in the historical period (1951-2000). Even in the low-impact scenario, cities such as Almeria and Malaga may experience droughts more than twice as intense as in the historical period (Guerreiro et al., 2018).

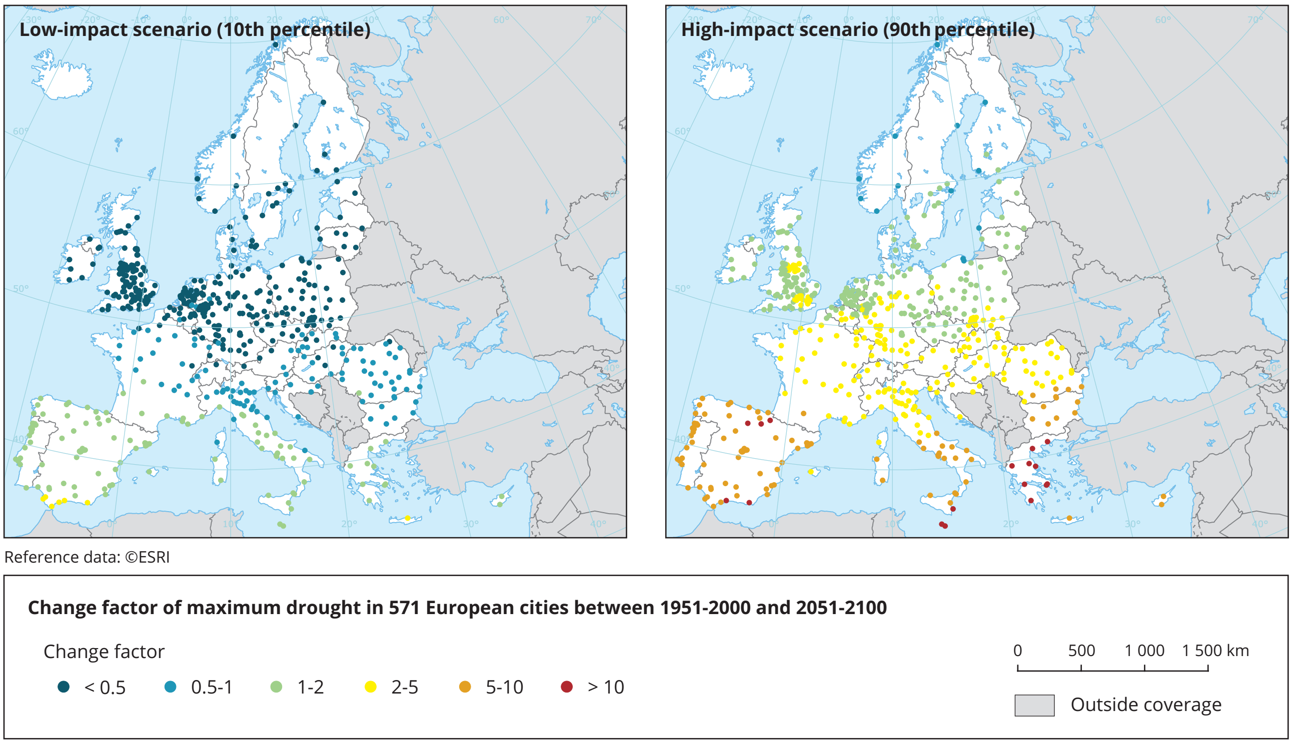
Moreover, the shrinking of the cryosphere, with loss of ice sheets and glaciers and reductions in snow cover, is expected to further contribute to water scarcity (IPCC, 2019), particularly affecting cities immediately north and south of the Alps. Glaciers in the Alps have lost about half of their volume since 1900, and losses have accelerated since the 1980s. Glaciers in central Europe (the Alps and the Pyrenees) are projected to lose as much as 83 % of their volume (± 10 %) under the RCP 4.5 scenario or 95 % (± 4 %) under the RCP 8.5 scenario by 2100 compared with the current situation (EEA, 2017b). Shrinking glaciers typically result in increases in annual runoff until it peaks and starts to decline. There is evidence that summer runoff in the European Alps, which have mostly smaller glaciers, has already decreased and most glaciers have passed their runoff peak (IPCC, 2019). Snow mass in the Alps is also significantly reduced. This can also have a dramatic impact on downstream river flows, as snow melts contribute up to 60 % or even 70 % of annual river flows (EEA, 2017b).

2.6.2 Factors exacerbating or mitigating risks in cities

Water demand across Europe has steadily increased over the past 50 years. One reason is population growth, which has contributed to an overall decrease in renewable water resources per capita by 24 % across Europe. This decrease is particularly evident in southern Europe (EEA, 2018b).

Cities may experience water scarcity, especially where high demand for water is combined with overexploitation of the existing water resource, exacerbated during periods of dry weather. For instance, in the summer of 2015, renewable freshwater resources (such as groundwater, lakes, rivers or reservoirs) were 20 % lower than in the same period in 2014 because of a 10 % net drop in precipitation. Water stress (occurring when he total water use exceeds 40 % of the renewable freshwater resources for a given territory and time scale) in some regions such as the Iberian Peninsula, Italy, and Benelux countries is compounded by high water consumption in cities (Map 2.11).

Map 2.10 **Change factor of maximum drought in 571 European cities between 1951-2000 and 2051-2100**


Low-impact scenario (10th percentile)

High-impact scenario (90th percentile)

Reference data: ©ESRI

Change factor of maximum drought in 571 European cities between 1951-2000 and 2051-2100

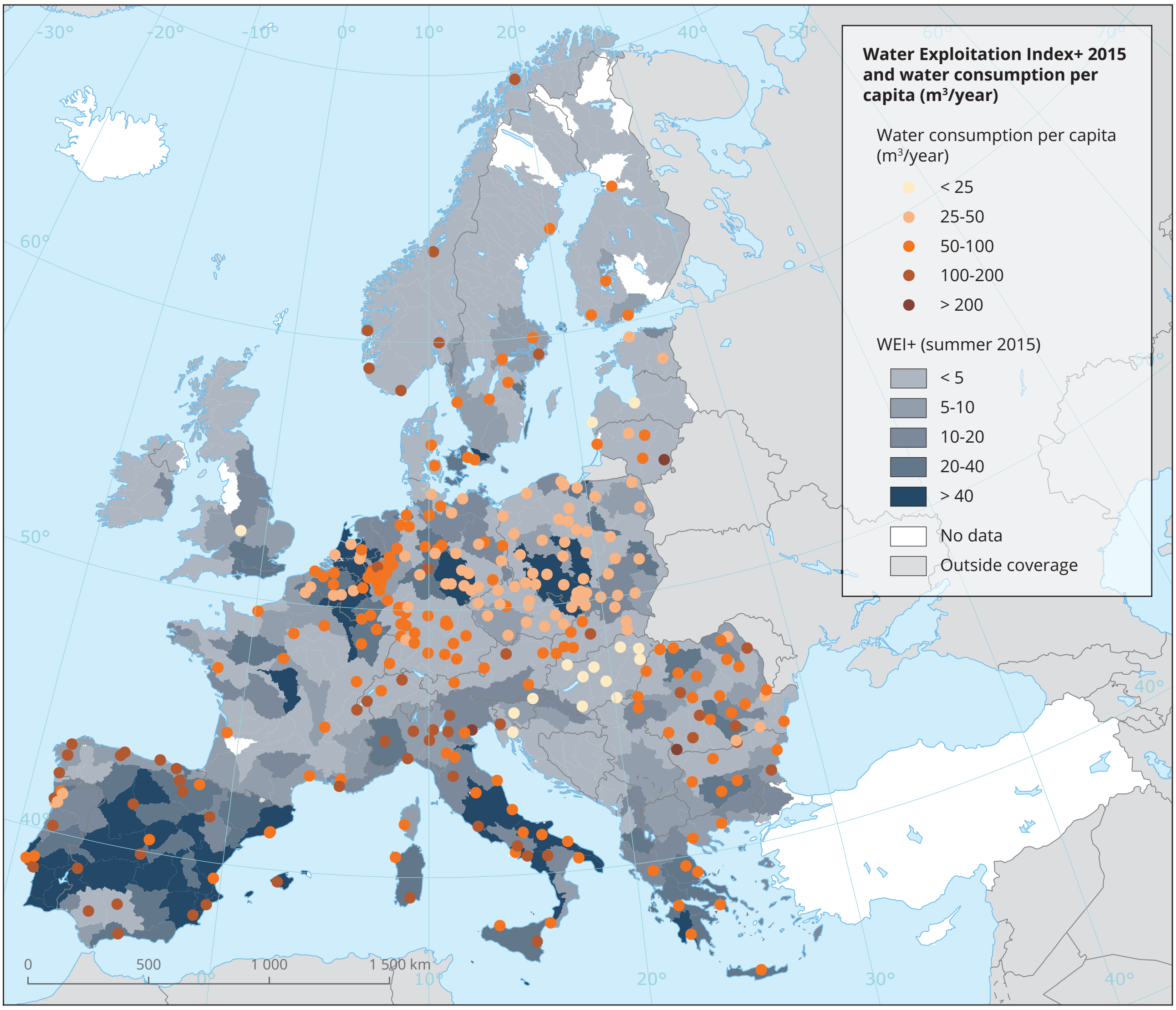
Note: The 12-month scale Drought Severity Index (DSI-12) was used. It is based on cumulative monthly precipitation anomalies, whereby the absolute deficit (in mm) is divided by the mean annual rainfall and multiplied by 100. DSI-12 is a rainfall index and therefore does not account for an increase in drought due to increasing temperatures (and consequently potential evaporation). The map shows the ratio of the maximum DSI-12 in the future to the maximum DSI-12 in the historical period. Based on 50 climate model projections from the CMIP5 (Taylor et al., 2012), in the RCP 8.5 climate scenario. The low-impact scenario (left) refers to the 10th percentile and the high-impact scenario (right) refers to the 90th percentile of projections. Median (50th percentile) scenario can be found in the Urban Adaptation Map Viewer.

Source: Adapted from Guerreiro et al. (2018).

The impacts of soil sealing on groundwater recharge are uncertain. Frequently, in urban areas less water infiltrates the soil to replenish groundwater supplies. For example, in Leipzig, the urban development over the 20th century reduced groundwater recharge by 4 % (Haase and Nuissl, 2010). However, a study in Dübendorf, Switzerland, found that expansion of urban area was associated with higher rates of recharging of groundwater due to the reduction in evapotranspiration, which more than compensates for the increase in runoff, and water main leakages (Minnig et al., 2018).

The water supply type can affect the impacts of water scarcity on people. For example, in Sweden, about 15 % of the population permanently rely on their own wells for drinking water. In the spring and summer of 2018, precipitation in Southern Sweden was extremely low, causing water shortages for those citizens, forcing them to cut down water consumption and sometimes rely on the municipality to provide additional water supply (Sjökvist et al., 2019).

Map 2.11 **Pressure on water resources in Europe**



Reference data: ©ESRI

Note: WEI+ is the total use of water as a percentage of renewable freshwater resources. Water consumption for 335 Urban Audit cities (total annual use of water in m^3 per capita) is provided for various years (2004-2012), depending on data availability for a given city. See the Urban Adaptation Map Viewer for details. Source: Author's compilation based on EEA (2020e) and Eurostat water consumption statistics.

Source: Author's compilation based on EEA (2020e) and Eurostat water consumption statistics.

2.6.3 Impacts of drought and water scarcity

Water scarcity in urban areas affects human well-being through reduced public water supply, as well as the economic activities and infrastructures that depend on water use, for example cooling of power plants, inland navigation and functioning of urban ecosystems. For example, in Sweden, recent warm winters and low levels of spring and summer precipitation have led to prolonged low groundwater levels and consequent shortages in drinking water. Several municipalities have restricted the use of drinking water, including Enköping near Stockholm, and Visby on the island of Gotland, which was also forced to issue a watering ban in early 2020. As these cities grow, new infrastructure is needed to secure a safe supply of drinking water. In 2019, the largest water desalinisation plant in northern Europe opened in southern Gotland, providing drinking water to the southern areas of Visby using water from the Baltic Sea. The regional government on Gotland plans to build an even larger desalinisation plant on the island. Enköping municipality has turned to neighbouring areas for help with the water shortages; in late 2019, a plan was devised to construct a pipeline between Enköping and Västerås municipality. Skierniewice, Poland, also had insufficient water supply in 2019 (Box 2.7).

Box 2.7 Drought impacts in Skierniewice, Poland

Annual precipitation in Central Poland is very low (around 400 mm per year) and parts are at risk of desertification. The increasing risk of droughts associated with the changing climate is emphasised in the *Project of environmental policy 2030* (Ministerstwo Środowiska, 2019). The sustainable management of water resources has become one of Poland's key environmental concerns.

In June 2019, central Poland was affected by a heatwave and drought. Owing to high water use and insufficient renewal of supplies, little or no tap water was available to the residents of the city of Skierniewice (48 000 inhabitants) for several days. In particular, people living on upper floors had problems with water shortages due to low pressure in the supply networks. Water was brought to Skierniewice's residents in cistern tanks and containers.

In order to avoid water shortages in future, the city of Skierniewice has focused on improving water supply to the city. The audit of the existing groundwater supply infrastructure has indicated that its effectiveness could be substantially increased through renovation and reconstruction, which have been actioned. In addition, the city has constructed a high-efficiency well to supplement its current water supply, and three further wells will be developed soon. Finally, the city is planning an extensive assessment of the water supply in the long term, including additional actions that need to be undertaken to avoid water shortages in future.

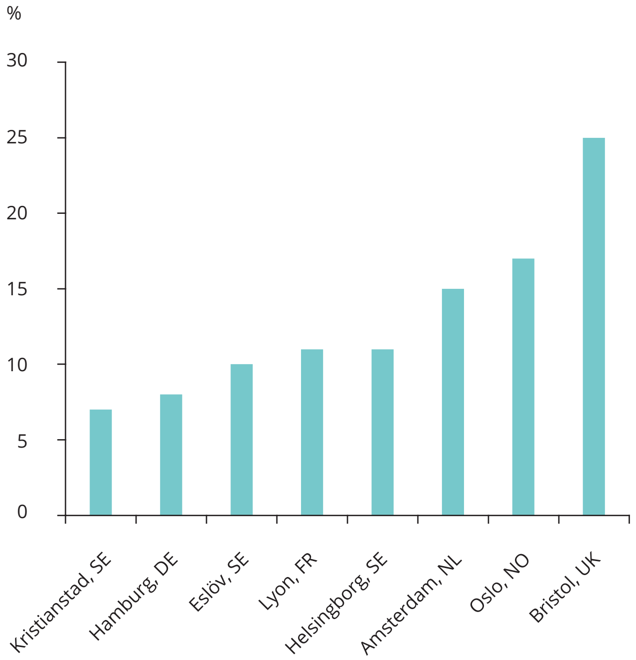
Sources: Personal communication from Marek Rdest, Skierniewice City Council, 2019; Ministerstwo Środowiska (2019); Rutkiewicz (2019).

Prolonged periods of water scarcity can be costly to cities. The drought in Barcelona in 2007-2008 gave rise to total costs of EUR 1.6 billion, representing nearly 0.5 % of the Catalonia region's GDP. These costs included losses from the interruption of industrial production in various sectors (EUR 540 million) and indirect costs to the regional economy due to reduced productivity in other economic sectors (EUR 360 million). The direct costs of emergency measures implemented during the period reached nearly EUR 82 million, and welfare losses due to restrictions of outdoor water uses amounted to over EUR 691 million (Martin-Ortega et al., 2012).

Urban ecosystems, especially trees, are affected by droughts. In world regions prone to droughts, such as Australia, some species of deciduous trees may need to be replaced by more drought-resistant species (Nitschke et al., 2017). Similar issues are also being recognised in European cities. According to the Urban water atlas for Europe, in 8 out of 40 investigated cities, some of the urban vegetation did not recover completely after the meteorological conditions went back to normal following a drought episode between 2012 and 2015 (Gawlik et al., 2017; and Figure 2.10). Water scarcity may affect ecosystem services provided by green infrastructure, for example shading and cooling through evapotranspiration (see Section 3.2).

In addition, reduced water consumption during drought events can potentially lead to lower water flows in sewerage networks, causing intensified odour and corrosiveness (Sofoulis, 2015) as well as higher concentrations of pollutants in waste water discharges from urban areas (Novický et al., 2009)

Figure 2.10 Proportion of vegetated area that did not recover when meteorological conditions returned to normal (2012-2015), selected European cities



Note: The selection of cities comes from the source of data and is not representative of Europe.

Source: Authors' compilation based on data from Gawlik et al. (2017).

2.7 Wildfires

2.7.1 *Climatic hazard*

Wildfires occur as natural processes mainly in the Mediterranean area and in the boreal forests of north-eastern Europe (Gomez-Armisén and Ubeda, 2015; Pereira et al., 2015; Xanthopoulos, 2015). However, the predominant cause of European wildfires is human activity (San-Miguel-Ayanz et al., 2019). Around 48 % of all wildfires recorded in the European Forest Fire Information System (EFFIS) were caused by human activity, and almost 29 % of all fires were started deliberately. Although there is a high level of uncertainty — the causes of around half of all fires were unknown — it is estimated that more than 80 %, and probably more than 90 %, of fires in Europe are caused by humans (de Rigo et al., 2017). The data also suggest that around 60 % of the human-caused fires in Europe are deliberate. In Croatia, Italy, Poland and Spain, where wildfires are a particular problem and data uncertainty is low (causes are known for more than 70 % of fires), human activity accounts for more than 90 % of fires (de Rigo et al., 2017).

However, while fire ignition may originate in human activity, the establishment and spread of a fire are determined by climate and weather as well as fuel load and connectivity. Climatic drivers of fires, such as hot and dry conditions, and high wind speed, can change the fire regime and characteristics, leading to expansive and enduring wildfires (Hernandez et al., 2015). Climatic factors can also directly affect the condition, composition and structure of vegetation, leaving landscapes more vulnerable to fire risk (Costa et al., 2020).

Fire danger (21) will increase in the future owing to increased incidence of droughts and reduced soil moisture, in particular in the Mediterranean area. The three countries with the highest current and projected danger are Spain, Portugal and Turkey. Greece, parts of central and southern Italy, Mediterranean France and the coastal region of the Balkans also show increasing danger both in relative and absolute terms. Areas at moderate danger from forest fires are being pushed north by climate change, up to central Europe. In northern Europe, there is relatively little change in projected fire danger directly driven by weather due to climate change (de Rigo et al., 2017). Nonetheless, more European countries suffered from large forest fires in 2018 than ever before, and Sweden experienced the worst fire season in reporting history (EEA, 2020b). The forest fire season in Sweden is likely to be extended by 50 days in the south and 10-30 days in the north of the country. The frequency of high-risk periods is also expected to increase in the Baltic coastal area (MSB, 2013; SMHI, 2020).

2.7.2 *Factors exacerbating or mitigating risk in cities*

The increase in the number and intensity of wildfires observed in the Mediterranean since the 1970s is mainly attributed to socio-economic transformations, urbanisation and urban sprawl alongside the changing climate (Bento Gonçalves and Vieira, 2015; EEA, 2017b). The depopulation of rural areas and the expansion of cities and towns has led to the creation of interfaces between the built environment and forests or other vegetation types with accumulated biomass (wildland-urban interface, WUI) (Cardoso Castro Rego et al., 2018). The number of Europeans living near wildland and exposed to at least 10 days of high-to-extreme fire danger per year is projected to increase from 63 million at present to 78 million with 3 °C global warming; in the 1.5 °C scenario, 68 million people would be exposed (Feyen et al., 2020).

Most fires start close to WUIs; in Portugal, 85 % of all forest fires start within 500 m of a WUI (Catry, 2007). Large areas also tend to be burned more frequently in proximity (up to 5 km) to WUI areas in Albania, Bulgaria, Cyprus, France, Italy and Spain. The probability of large areas being burned increases as the distance from WUIs diminishes in tourist regions such as Sardinia and Provence-Alpes-Côte d'Azur, or in regions with a strong peri-urban component, such as Catalonia, Madrid or Valencia (Modugno et al., 2016). The combination of high fuel load and close proximity of the built environment contributes to intense wildfires that are able to devastate large geographical areas, causing significant loss of human life and property, and making firefighting and other civil protection operations difficult to coordinate (Cardoso Castro Rego et al., 2018).

At the landscape level, vegetation characteristics, such as species composition, functional diversity, age and stand structure, also affect fire risk, as they determine fuel load and continuity (Bajocco and Ricotta, 2008; Fernandes, 2009; de Rigo et al., 2017). The interaction of different types of land use or land cover in the WUI produces different levels of fire risk; ignition risk is higher for forestry plantations in the WUI than for native forests and agriculture (Calviño-Cancela et al., 2016). For example, in Portugal, mature deciduous forests are less prone to fires than pine forests and eucalyptus plantations (Moreira et al., 2009).

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(21) Based on the Canadian Fire Weather Index (FWI), which provides a uniform numerical rating of the relative fire potential by dynamically combining the information from local temperature, wind speed, relative humidity, and precipitation values (de Rigo et al., 2017).

2.7.3 Impacts of wildfires

According to an unpublished EEA analysis ([22]), out of the 918 Urban Audit cities, 95 were directly affected by forest fires recorded in the EFFIS database between 2000 and 2018, and most of them were in Spain (30), Italy (21), Portugal (18) and France (15). However, in recent years cities in Latvia, Sweden and the United Kingdom (Greater Manchester area) have also been affected by wildfires. In total, over 26 000 km^2 of the administrative areas of those 95 cities was burned over the course of 19 years, affecting nearly 68 000 people in total ([23]). The cities with the highest population numbers affected by wildfires are located mainly in Portugal (e.g. Gondomar, Coimbra, Paredes, Viana do Castelo, Funchal), Spain (e.g. Vigo, Santiago de Compostela), Italy (e.g. Palermo, Messina, Reggio Calabria), France (e.g. Aix-en-Provence, Marseille) and Croatia (Split).

The fatalities caused by wildfires are linked to lack of landscape management in WUIs, urban sprawl, development of second homes in wildland areas and low levels of fire risk awareness (San-Miguel-Ayanz et al., 2013; Lafortezza et al., 2015; Xanthopoulos, 2015). Between 1945 and 2016, 865 people in four Mediterranean regions (Greece, Portugal, Spain and the Italian island of Sardinia) lost their lives because of wildfires. Most fatalities were civilians, with 366 people killed, followed by firefighters (266) and aircraft crew (96). Over a third of deaths with a known location happened in WUIs (Molina-Terrén et al., 2019). In 2017 alone, 112 lives were lost in Portugal during two major fire incidents (Independent Technical Commission, 2017, 2018). In July 2018, 100 people died in a fire in Mati, a coastal village on the outskirts of Athens, Greece (BBC News, 2018b).

Wildfires affect health, as smoke from wildfires increases air pollution. Kollanus et al. (2017) estimated that, in 2005 over 1 400 premature deaths could be attributed to $PM_{2.5}$ air pollution caused by vegetation fires across Europe; in 2008, over 1 000 premature deaths occurred for that reason. Following a series of wildfires in 2002 near Vilnius, Lithuania, the concentration of NO_2 in the city was twice as high as the permitted level, and cases of respiratory diseases increased 20-fold (Pereira et al., 2015). Strong positive correlations between wildfire occurrence and the number of pneumonia cases were found in some municipalities in Portugal (Santos et al., 2015).

2.8 Windstorms

2.8.1 Climatic hazard

The spatial pattern of windstorms, as well as their frequency and intensity, was highly variable throughout the 20th century (EEA, 2017a). The number of extreme wind events reported in Europe significantly increased during the period 1981-2016 (Spinoni et al., 2020). Wind damage models show that coastal regions are particularly affected by windstorms (Koks and Haer, 2020). Given the concentration of urban environments in coastal areas (see Section 2.5), this generally increases the exposure of European cities to wind hazards.

There is still significant uncertainty around the estimation of risk from extreme winds. The uncertainty largely stems from a lack of high-resolution wind data that capture local extremes, as well as poor representation of wind within current climate models (Feyen et al., 2020). According to recent studies, in the 3 ˚C global warming scenario, no significant change in windstorm frequency and intensity is projected for three quarters of Europe's land area by 2100, with a mix of increased and decreased wind speeds across the remaining area. Southern Europe is the only region where a trend of increasing windstorm intensity is projected for a larger area than decreasing intensity (17 % versus 12 %, respectively). Changes in wind extremes will be even less pronounced across Europe with 1.5 ˚C and 2 ˚C warming (Spinoni et al., 2020). However, earlier studies indicated that the risk of severe windstorms in winter and autumn will increase for the North Atlantic and for northern, north-western and central Europe, and that severe storms in the Mediterranean will become less frequent but more intense (EEA, 2017b).

2.8.2 Factors exacerbating or reducing wind damage in cities

Reported wind events have increased in the past 30 years, but the lack of a trend in extreme winds in this period indicates that the small increase in reported damage during this period resulted mainly from the rising value of assets and the increasing population that are exposed to windstorms (Spinoni et al., 2020). With urbanisation and rising economic growth, Europe's valuable assets and people are increasingly concentrated in its cities, increasing the impacts of wind on the economy and on human health in urban areas.

The built physical structures in cities, such as tall buildings, alter how the wind flows through the city and sometimes create wind tunnels with high wind speeds. As cities become denser with more tall buildings, average wind pressure decreases

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([22]) Based on overlay of EFFIS burnt areas with administrative boundaries of cities and with GEOSTAT 2011 population data, see Urban Adaptation Map Viewer for more details and information for individual cities. ([23]) According to unpublished EEA analysis based on overlaying EFFIS burned areas with 2011 population data.

but fluctuations increase, which leaves building elements, such as cladding, more vulnerable to wind damage (Elshaer et al., 2017). Low-rise industrial buildings made with metal cladding roofs can be significantly damaged by windstorms (Stewart et al., 2016). The combination of wind pressure and precipitation can reduce the durability of facades through water penetration. Pérez-Bella et al. (2013) modelled the exposure of the built environment to this combined hazard across 80 sites in Spain, finding that the Canary Islands, the Gulf of Cadiz and the Strait of Gibraltar are particularly exposed because of strong Atlantic winds, while eastern Spain also showed high exposure, probably due to the frequency of short, high-intensity rainfall.

Green infrastructure in urban settings is more vulnerable to strong winds than rural vegetation, as trees and plants in cities are exposed to existing stressors, such as air pollution and soil compaction (Lopes et al., 2009).

2.8.3 Impacts of windstorms

Windstorms are one of the most destructive natural hazards affecting the EU and United Kingdom, and caused annual losses of EUR 5 billion in 2015 (Feyen et al., 2020). Extreme wind affects cities through damage to transport and energy infrastructure, vegetation, private property and human health. By 2050, annual losses due to windstorms in the EU and United Kingdom are projected to be around EUR 7 billion, rising to EUR 11 billion by 2100. However, since wind hazards are not projected to change significantly as a result of global warming, these increases will not be caused by climate change; instead, economic growth, increased asset value and exposure, and rising construction costs will lead to greater economic damage (Spinoni et al., 2020).

Currently, around 16 million EU citizens are exposed to 30-year intensity windstorm events each year, which lead to nearly 80 fatalities annually (Spinoni et al., 2020). Estimated average annual economic losses from windstorms have been highest in Germany (EUR 850 million), France (EUR 680 million), Italy (EUR 540 million) and the United Kingdom (EUR 530 million), but several eastern European countries, such as Bulgaria and Estonia, have also been badly affected relative to the size of their economies, losing up to 0.08 % of GDP (Spinoni et al., 2020). Storm Gudrun damaged 30 000 km of power lines in Sweden in January 2005, leading to prolonged power outages for 730 000 homes and losses of EUR 250 million for the Swedish network operators, and an overall cost of EUR 3 billion (Gündüz et al., 2017). In January 2018, gusts of up to 140 km per hour from storm Friederike caused major disruption and damage to transport infrastructure in Germany and the Netherlands; hundreds of flights were suspended and departure halls closed at Schiphol Airport in Amsterdam (Netherlands) because of windy conditions and roof damage and, nearby, police closed Almere city centre to protect its inhabitants (BBC News, 2018a).

Urban trees can damage infrastructure and property as well as harming human health. In 2014, storm Ela uprooted more than 20 000 trees in the city of Düsseldorf (Germany), and storm Xavier damaged thousands of trees across cities in northern Germany in 2017 (Gross, 2018). Trees falling as a result of natural hazards injure or kill five or six people per year in the United Kingdom alone (Referowska-Chodak, 2019). Damage to urban green infrastructure also has indirect health impacts because of the loss of the benefits provided by trees in terms of shading, mitigation of the Urban Heat Island effect and improvement of air quality (Lopes et al., 2009; Referowska-Chodak, 2019).

2.9 Water- and vector-borne diseases

2.9.1 Climatic hazard

The incidence of water-borne diseases is expected to alter with climate change — directly by slow-onset changes (EEA, 2017b), or indirectly by cascading risks from extreme weather events (Semenza, 2020).

The number of vibriosis infections, which can be life-threatening, has increased substantially in Baltic Sea states since 1980. This increase has been linked to observed increases in sea surface temperature, which has improved environmental conditions for *Vibrio* species blooms in marine waters (EEA, 2017e). In addition, the increased flood incidence is likely to enhance exposure to water-borne pathogens (de Man et al., 2014). For example, links have been found between heavy precipitation and increased numbers of hepatitis A cases (Gullón et al., 2017). Cases of infection with leptospirosis have also been linked to climate-related factors, such as mild and wet climate conditions and street flooding, in combination with other risk factors, such as garbage accumulation (Vitale et al., 2018). On the other hand, persistent decreases in summer precipitation can lead to a higher incidence of viral infections due to increased viral concentrations in river water and seawater during warmer months (Rusiñol et al., 2015).

Climate change has already had an impact on the transmission of a wide range of vector-borne diseases in Europe, and it will continue to do so in the coming decades (Semenza and Suk, 2018). Climate change has been implicated in the observed shift of ticks to higher altitudes and latitudes, notably including the species *Ixodes ricinus*, which is a vector for Lyme borreliosis and tick-borne encephalitis. Climate change is also linked to the expansion of other important disease vectors in Europe: *Aedes albopictus* (the Asian tiger mosquito), which transmits diseases such as Zika, dengue and chikungunya and has become a common occurrence in southern Europe; the *Culex pipiens* mosquito, which transmits the West Nile virus; and *Phlebotomus* sandfly species, which transmit diseases including leishmaniosis (Tjaden et al., 2017; Rocklöv et al., 2019). In addition, high temperatures in the summer of 2010 were associated with an epidemic of West Nile fever in south-east Europe, and subsequent outbreaks have been linked to summer temperature anomalies (Paz et al., 2013). Semenza and Suk (2018) warn about future increases in climate-sensitive health impacts, in part due to the intricate interplay between non-climatic and climatic drivers, weather-sensitive pathogens and climate change adaptation of pathogens.

2.9.2 *Factors exacerbating or mitigating risks in cities*

Urban environments, through the UHI effect and physical conditions, can increase their populations' exposure to vector-borne diseases that are associated with the increasing presence of exotic species migrating north due to climate change. For example, *Aedes albopictus* can be common in the peri-domestic environment, particularly in urban areas with abundant vegetation (ECDC, 2020a).

As part of the Copernicus Climate Change Service, the European Health Sectoral Information System has produced climate suitability maps for *Aedes albopictus* (ECDC, 2009; VITO, 2019b). Of all regions of Europe, the climate of the north-east is the least suitable for the tiger mosquito. The most suitable areas are in cities near the Adriatic coast (see Map 2.12 for Ljubljana, Slovenia) and in France and Italy, but also some Belgian and Dutch cities (Map 2.13).

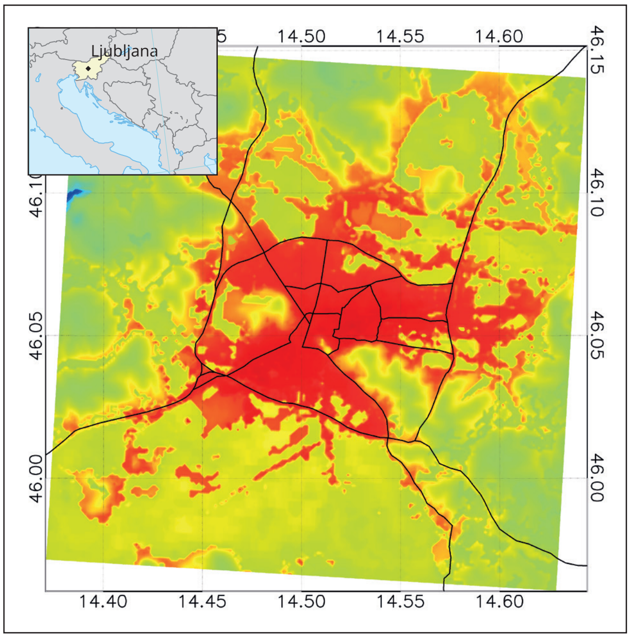
Moreover, cities that are international travel and trade hubs may contribute to pathogen and vector dispersion through travellers and goods.

2.9.3 *Impacts of water- and vector-borne diseases*

The European Centre for Disease Prevention and Control Surveillance Atlas of Infectious Diseases (²⁴) provides numbers of cases of vector-borne diseases in European countries, indicating that, to date, most cases of dengue, chikungunya and other diseases are travel-related. However, in 2007, an outbreak of chikungunya fever in the Emilia-Romagna region of Italy caused by a local population of *Aedes albopictus* mosquitoes marked a turning point in Europe. Since then, several locally acquired cases of dengue and chikungunya fevers have been detected in France, and dengue fever in Croatia (ECDC, 2017).

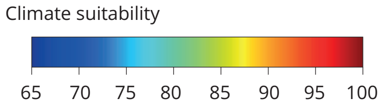
Poor vector management has the potential to create a negative economic impact, in terms of direct and indirect medical costs associated with an outbreak, but also by loss of tourism income if there is a perceived risk of disease in the region or if vectors reach nuisance levels that may put off tourists. However, measuring the economic impact of mosquitoes is very challenging (ECDC, 2017).

Map 2.12 **Average climatic suitability for the tiger mosquito in the city of Ljubljana based on climate data for 2008-2009**



Reference data: ©ESRI

Average climate suitability map for the tiger mosquito for the city of Ljubljana based on climate data for 2008-2009

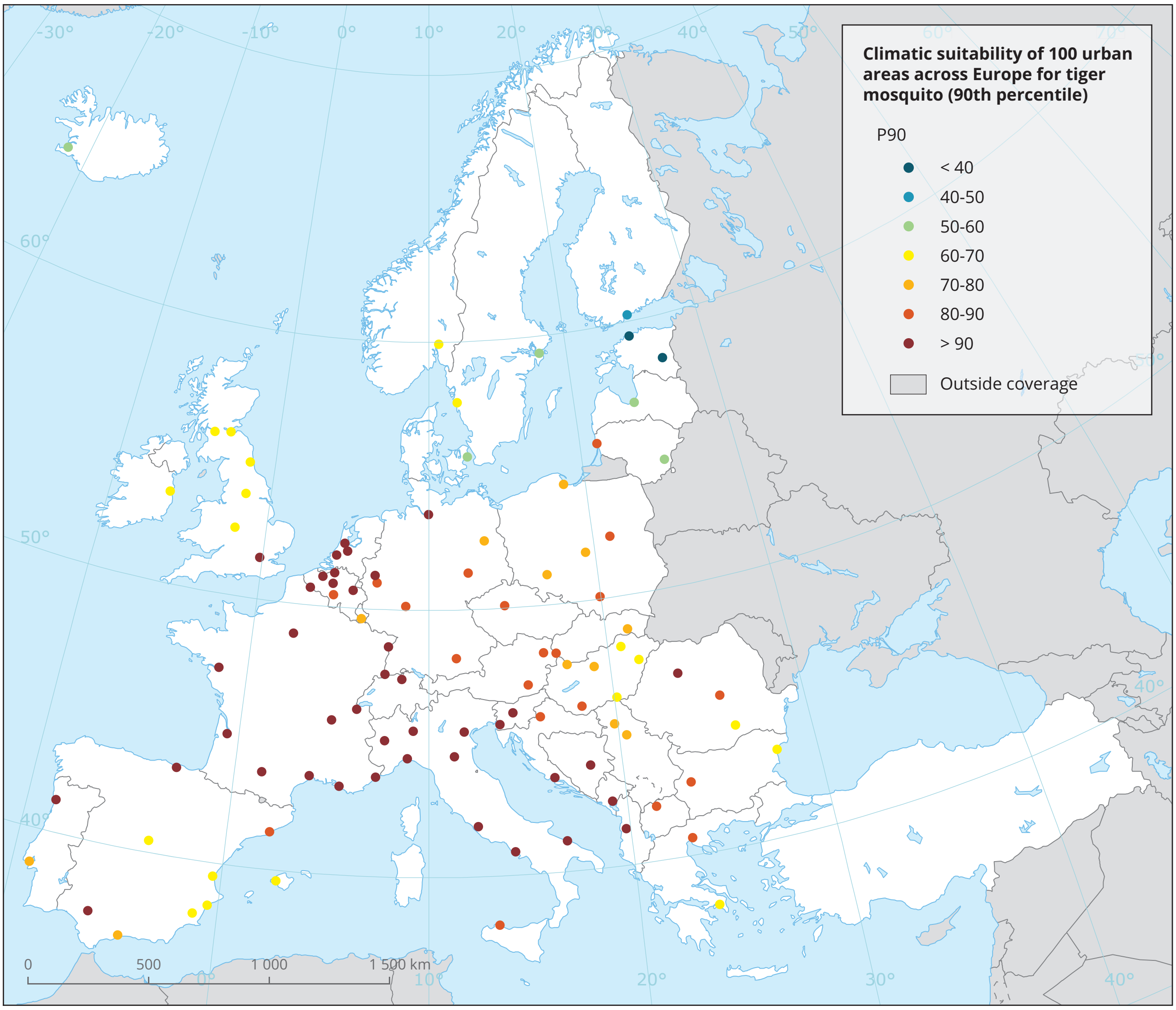


Notes: The climatic suitability map for the tiger mosquito has a scale from 0 to 100 and is calculated based on annual rainfall amounts, and winter and summer average air temperatures. The climatic suitability for the tiger mosquito is 0 when the annual rainfall is lower than 450 mm, and maximum when the annual rainfall exceeds 800 mm. For summer temperatures, the suitability is 0 when average temperatures are below 15 °C and above 30 °C, and maximum between 20 °C and 25 °C. In winter, the suitability is 0 when average temperatures are below –1°C, and maximum when temperatures are above 3°C. The resulting suitability functions are entered into a weighted linear combination approach and the results are rescaled to a range between 0 and 100 (VITO, 2019b). For detailed maps of the cities included in the project, see the Urban Adaptation Map Viewer.

Sources: Reproduced from VITO (2019b); based on data from the Copernicus European Health contract for the Copernicus Climate Change Service (C3S).

(²⁴) http://atlas.ecdc.europa.eu/public/index.aspx

Map 2.13 Climatic suitability of 100 urban areas across Europe for the tiger mosquito (90th percentile)



Reference data: ©ESRI

Note: The selection of cities comes from the source data. The P90 (90th percentile) indicator of the climatic suitability of the urban area for the tiger mosquito represents the specific exposure of single cities and is independent of the model domain or size of the city. Since it is the 90th percentile, there are grid cells (areas) in a city with an even higher suitability value, so it can be considered a rather conservative value. For specific values for individual cities, see the Urban Adaptation Map Viewer.

Sources: Adapted from Vito (2019b); based on data from the Copernicus European Health contract for the Copernicus Climate Change Service (C3S).

2.10 Climate-related impacts on European cities and towns: conclusions

Climate- and weather-related hazards affect all human settlements in Europe, albeit in different ways and to different extents, depending on the city's exposure and vulnerability to hazards. The differences in the impacts already experienced and in those projected emphasise the need for local climate risk and vulnerability assessments, based on high-quality data. Such assessments are essential to guide the development of adaptation strategy and selection of relevant measures The Urban Adaptation Support Tool (25) offers guidance on preparation of the climate risk and vulnerability assessments, in line with the Covenant of Mayors for Climate Energy reporting guidelines (26). The Urban Adaptation Map Viewer (27), previous EEA publications (EEA, 2017b) and Copernicus Climate Data Store (28) are useful sources of climatic data and information. Section 6.2 of this report describes some opportunities for improving access to knowledge through collaboration with different actors.

At the same time, the similarities in the hazards faced and in the underlying vulnerabilities of cities suggest that much knowledge can be gained from exchange of experiences between cities that share some characteristics. Section 4.3 provides information about the city networks focused on adaptation that can help to facilitate the exchange of experiences, and about various other initiatives.

Many of the challenges associated with the changing climate are not new (e.g. flooding or heatwaves) but their intensity and frequency will change in the future, requiring different approaches to risk management, from urban planning and design accounting for the changing magnitude of extreme weather events, to collaboration among those concerned with different policy areas (see Section 6.5).

Risk management needs to be informed by sound science. The modelling of future climate changes is characterised by a probabilistic character and uncertainty. The wide range of possible futures requires careful communication between scientists and non-experts, including policymakers and the general public, in order to avoid scaremongering but convey the sense of urgency. See Section 5.1.4 for some examples of effective stakeholder engagement.

The exact impacts of climate change vary between cities, but similarities in hazards and vulnerabilities offer opportunities for knowledge exchange

In Chapter 2, the hazards and their impacts have been discussed one by one, whereas in reality multiple hazards often occur in the same location — often within a short timespan. This may cause cumulative or cascading impacts. The assessment of the risks caused by multiple hazards should ideally be included in the climate risk and vulnerability assessments.

A key conclusion emerging from the overview of impacts from various climate- and weather-related hazards in Chapter 2 is that unsustainable urban development — construction in floodplains, progressive surface sealing, small amounts of green space or urban sprawl into wildfire-prone areas — magnifies the projected impacts of the changing climate. Effective land use planning and urban design, accounting for climate impacts, are crucial to reduce the scale of future damages (see Section 6.5.1). Chapter 3 provides an overview of knowledge of the effectiveness and cost-efficiency of various adaptation measures that can be deployed, and Section 6.5.1 presents some opportunities for mainstreaming adaptation into urban planning.

Finally, cities do not exist in a vacuum but are situated in a wider regional context, and many climate hazards cross city boundaries; for example, cities may compete with surrounding farming areas for scarce water resources, or flooding of cities may be caused by the management of a river basin upstream. This requires multi-level governance of climate change adaptation, covered in Chapter 4.

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(25) https://climate-adapt.eea.europa.eu/knowledge/tools/urban-ast/step-2-0
(26) https://www.eumayors.eu/index.php?option=com_attachments&task=download&id=843
(27) https://climate-adapt.eea.europa.eu/knowledge/tools/urban-adaptation
(28) https://cds.climate.copernicus.eu

3 Effectiveness and cost-efficiency of adaptation measures

Key messages

- The assessment of the effectiveness and cost-efficiency of various adaptation measures is in its infancy and requires further development to support decisions about the choice of adaptation measures to implement. The most extensive scientific evidence exists for effectiveness of measures against heat, heavy precipitation and flooding.
- The effectiveness of adaptation measures and their cost-efficiency are highly dependent on the location and context of the intervention, as well as the timescale and the inclusion of ancillary benefits in the assessment. Therefore, the suitability and impacts of individual solutions need to be assessed on a case-by-case basis.
- According to the existing evidence, awareness raising and early warning systems are highly effective and cost-efficient in relation to most climatic hazards.
- Green infrastructure measures emerge as effective in addressing high temperatures and flooding in cities. Nature-based solutions may simultaneously address multiple hazards and provide co-benefits to the environment and society. Thus, their use in adaptation could be further encouraged.
- Grey infrastructure (structural) measures, while in many cases highly effective, may not offer sufficient protection from the magnitude of future climate hazards. They should be complemented by green infrastructure and soft adaptation measures for optimal effectiveness and cost-efficiency.
- Adaptation-oriented urban planning could reduce damage from almost all climate change impacts, by discouraging development in risk-prone areas and promoting resilient land use and management.
- Consideration of climate change impacts is needed in designing urban infrastructure (e.g. sewerage systems) and built environment (homes and workspaces) to ensure their functionality in the future.
- It is necessary to avoid maladaptation by discouraging in the long term measures that have detrimental effects on other aspects of the environment, such as air conditioning or desalination, and those that cause displacement of risks.

3.1 Introduction

While the costs of adaptation measures are immediate, the benefits may be less apparent or may only transpire in the future. In the face of more immediate priorities, as well as a lack of public demand, decision-makers tend to focus on the most pressing agenda items and invest in proposals that will generate short-term returns (Vogel and Henstra, 2015). The knowledge of effectiveness of adaptation options can provide arguments for investment in them and support the choice of the measures to implement.

This chapter aims to summarise the existing knowledge on the effectiveness and cost-efficiency of adaptation measures, based on empirical evidence from implemented solutions and modelling studies. This is done drawing on the information collected in the 'Adaptation options library' within the Horizon 2020 Climate resilient cities and infrastructures (RESIN) project (Mendizabal and Zorita, 2018; Box 3.1). The greatest amount of evidence on effectiveness and cost-efficiency is available for measures addressing high temperatures, heavy precipitation and flooding. This reflects the assessment of significance of current and future importance of various climate-related hazards by cities (see Figures 2.1 and 2.2).

Box 3.1 Effectiveness and cost-efficiency of adaptation options in the adaptation options library compiled by the Horizon 2020 RESIN project

The RESIN project (Climate resilient cities and infrastructures; 2015-2018) was an interdisciplinary, practice-based research project financed by the Horizon 2020 programme. In collaboration with practitioners from the cities of Bilbao, Bratislava, Manchester and Paris, researchers from 14 institutions created tools to support the development and implementation of urban adaptation strategies.

One of these tools is the **library of adaptation options**: a searchable database of information on the cost-efficiency and **effectiveness** of various adaptation measures (structural, social and institutional), based on a review of scientific studies published up to 2017 (Table 3.1).

Based on scientific evidence extracted from research papers, each measure was assessed on its effectiveness, i.e. its capacity to reduce the impacts of a given climate hazard (out of the four categories listed in the table), and on its **cost-efficiency**, i.e. benefit-to-cost ratio (BCR). An adaptation measure could be assessed on different metrics of effectiveness and may therefore appear with multiple, often different, performance scores.

Table 3.1 Contents of the RESIN adaptation options library, European evidence (global case numbers are in brackets)

Hazards	Adaptation measures	Effectiveness cases	Benefit-cost cases	Scientific papers
High temperatures	26 (44)	1 131 (1 570)	18 (18)	157 (243)
Flooding	43 (60)	211 (327)	129 (281)	48 (74)
Sea level rise	10 (19)	6 (9)	43 (171)	23 (52)
Water scarcity	7 (13)	11 (41)	10 (21)	9 (30)

Note: Cases relate to the number of locations/instances assessed in scientific studies.

The metrics to assess effectiveness and cost-efficiency were harmonised to allow the comparison and ranking of various measures, as scientific studies differ in the climate scenarios assumed, assumptions about adaptation, categories of costs and benefits, and impacts.

For effectiveness, the harmonisation was carried out as follows. The metrics used for each adaptation option (e.g. air temperature reduction in the case of heat, or peak flow reduction in the case of pluvial flooding) were identified. The values of effectiveness were harmonised for each adaptation option by defining ranges for different scales of events. Percentile values were used to classify effectiveness into 'low' (below the 33rd percentile), 'medium' (33rd–66th percentile) and 'high' (above 66th percentile). In order to enable comparability, linear regression analyses for each adaptation option were conducted on its effectiveness and cost-efficiency in order to detect the variables that have the most influence on effectiveness and on cost-efficiency, respectively.

For cost-efficiency, metrics used in studies were identified, including the economic indicators net present value, net benefit, cost-effectiveness ratio, BCR and payback period; the range of discount rates and time horizons applied for the different adaptation options; the spatial and temporal units (relevant to e.g. currency conversion using purchasing power parity); and the physical units. Next, values of effectiveness were harmonised for each adaptation option by calculating the ranges of values. The RESIN adaptation options library uses BCR as the harmonised indicator of cost-efficiency, where possible. BCR summarises the overall value for money of an adaptation option: BCR above 1 indicates that the option is economically beneficial; BCR below 1 suggests that the option is costly.

Sources: RESIN (2018); Mendizabal et al. (2017).

3.2 High temperatures

High temperatures affect various aspects of cities (human health, built environment, energy use, etc.). Therefore, the effectiveness of adaptation measures addressing heat is measured with a variety of indicators, including those related to human comfort, outdoor and indoor temperatures or energy saving (Figure 3.1).

Green infrastructure measures dominate the list of adaptation options assessed on their effectiveness for addressing high temperatures in the RESIN library of adaptation options (RESIN, 2018; see Box 3.1). The presence of vegetation can reduce the heat storage capacity of urban surfaces and reduce air temperature, through increased evapotranspiration and shading. Green infrastructure can also provide other benefits, such as reduction of flood risk (see Section 3.3) and a variety of socio-economic and well-being benefits (EEA, 2020c). However, its maintenance is associated with water use, which may be a problem in water-scarce conditions, so its application to manage heat requires careful consideration of benefits and trade-offs (see Section 3.9). In addition, in many locations, plants need to be resilient to extreme heat and cold to ensure the viability of the solution implemented (see Box 6.3).

Other options for the reduction of temperatures include the use of cool materials (materials with high solar reflectance and infrared emittance) on facades, roofs and pavements; water-based solutions such as outdoor water spraying (with the caveat about sufficient water availability; see Section 3.9); and urban configuration changes (e.g. reduced building density, increased building height and optimised street orientations) (Figure 3.1).

Green infrastructure reduces impacts of high temperatures in cities and offers multiple benefits

3.2.1 Reducing the urban heat island effect

The urban heat island (UHI) effect is reduced when the surface and near-surface air temperatures in the city are lowered. The adaptation measures that are most effective in reducing surface temperatures, as backed up by a considerable body of evidence, are various elements of green (and blue, i.e. water bodies) infrastructure (RESIN, 2018). Their deployment combined with use of reflective materials can lead to substantial decreases in urban temperatures. For example, in a modelling study simulating a future heatwave event for the city of Porto, doubling urban green areas from 5 % to 10 % of the urban surface was found to decrease near-surface maximum temperatures in built-up areas close to green areas by 1 °C during daytime and by 0.3-0.5 °C at night. Application of green or white roofs across 75 % of the built-up area of the city produced less pronounced, yet more widespread temperature reductions. The combined application of green areas and widespread white roofs produced larger reductions of nighttime temperatures (Carvalho et al., 2017). Similarly, the ADAPT-UHI (29) project modelling various scenarios addressing UHI in three Austrian cities suggests that doubling the reflectivity of sealed surfaces (roofs, walls and pavements), combined with reducing sealed surfaces by 30 %, greening 50 % of roof surfaces, increasing the number of trees by 50 % and replacing bare soil with grass would keep the number of hot days in Salzburg at the same level as in 1981-2010 until 2050, with a chance that the denser urban areas of the city could be even cooler than in the historical period (under the RCP 4.5 scenario).

Photovoltaic panels (which provide shading for rooftops), increased building heights and outdoor water spraying were also assessed as effective ways of reducing surface temperatures, but the evidence base was less extensive (RESIN, 2018). While RESIN (2018) found cool pavements to be ineffective at reducing surface temperatures, a recent study modelling the impacts of cool road surfaces and reflective roofs in Geneva, Switzerland, showed a reduction of the annual mean surface temperature by 2.5 °C, with up to 5 °C reductions in July (Coccolo et al., 2018). In areas with many sunshine hours, cool roofs have more potential for mitigating the UHI effect through increased albedo (the decrease in average ambient temperatures is about 0.3 °C per 0.1 rise in albedo (30)), whereas in moderate and cold climates the contribution of green roofs is more important for cooling during the night (Santamouris, 2014).

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(29) ADAPT-UHI is part of a wider programme addressing UHI effect in Central Europe: 'Development and application of mitigation and, adaptation strategies and measures for counteracting, the global Urban Heat Islands phenomenon', led by the International Institute of Applied Systems Analysis to simulate the effects of different adaptation scenarios on UHI in small to medium-sized cities in Austria.

(30) Albedo is measured on a scale from 0 (a black body that absorbs all incident radiation) to 1 (a body that reflects all incident radiation).

Figure 3.1 Overview of effectiveness of adaptation measures: high temperatures

Notes: Based on scientific evidence from both within and outside Europe. For description of the individual measures see RESIN (2018). The colours reflect different types of indicators associated with heat; see above.

Source: ETC/CCA analysis based on RESIN (2018).

3.2.2 Improving outdoor thermal comfort

A lot of research focuses on indicators that quantify human thermal comfort, which is influenced by humidity alongside temperature. Some green infrastructure measures, such as trees, parks or grass, tend to have medium to high effectiveness in improving outdoor thermal comfort, as extensive evidence shows (RESIN, 2018; Figure 3.1). Increasing building height (or appropriate street orientation) can increase shade and create wind channels, improving thermal comfort (Mendizabal et al., 2017). Urban configuration (affecting solar radiation and ventilation) and activities (e.g. traffic flows) also influence thermal comfort. For example, pedestrianising a street with high traffic volume is more effective than reducing the traffic intensity (Mendizabal et al., 2017). There is a mixed picture with regard to measures such as cool facades, combining grass and trees, and street configuration optimisation; their effectiveness in improving outdoor thermal comfort ranges from low to high (RESIN, 2018).

3.2.3 Improving indoor thermal comfort

The most effective measures for improving indoor thermal comfort include cool roofs, and combinations of green and white roofs, alongside passive cooling and exterior shading devices. In various modelling studies, shutters and solar blinds were the most efficient ways to lower indoor temperatures, for both dwellings (Taylor et al., 2018; Escandón et al., 2019) and office buildings (Hooybergh et al., 2017). Trees, green roofs and green facades tended to have medium effectiveness (see RESIN, 2018; Figure 3.1).

Increased ventilation of buildings is a further key method of lowering indoor temperatures. For example, in low-cost housing in southern Spain, the appropriate use of natural ventilation at night by inhabitants reduced indoor temperature by up to 5 °C (Escandón et al., 2019). Active ventilation in office buildings can reduce temperatures and is modelled to decrease work hours lost by up to 90 % in RCP 8.5 scenario by the end of the 21st century (Hooybergh et al., 2017). Box 3.2 provides an example of an energy-efficient cooling and heating system in an office building in Rotterdam.

Box 3.2 Heating and cooling Rotterdam's largest office skyscraper with aquifer thermal energy storage

The Maas Tower, a 1940s office skyscraper in Rotterdam, was renovated to give it a new life, with shops on the ground floor and flexible office spaces on the upper floors. The refurbishment included the installation of an energy-efficient cooling and heating system, combining climate change adaptation and mitigation. A heat pump uses water from the River Maas and an aquifer thermal energy storage (ATES) system to supply the building with hot and cold air.

The ATES system consists of two separate underground wells for thermal energy storage. In the summer, water is extracted from the colder well and used to cool the building. This heats the water, which is then transferred to the warmer well and stored until the winter season. During winter, the warm water is pumped back into the building; the heat is extracted through the heat pump to provide heating to the building and the cold water is returned to the cold well.

ATES cost around EUR 532 000 (compared with EUR 253 000 for a conventional system), but saves around EUR 24 000 per year, so the investment payback time is around 10 years. Compared with a conventional heating and cooling system, ATES uses about 55 % less primary energy and generates half of the CO_2 emissions.

Sources: Climate-ADAPT (2016c); RVO (2020)

Maas Tower in Rotterdam © Steven Lek, Wikimedia Commons

Air conditioning is increasingly used in offices and employed by individual households, especially in the Mediterranean area, and it can be assumed that this trend will continue (De Cian et al., 2019). Extensive use of air conditioning can be seen as maladaptation (see glossary in Annex 2), as it can increase greenhouse gas emissions, emit heat outside and make it difficult to meet the peak energy demand, especially during periods in which the energy system is potentially under stress due to a shortage of water for process cooling (IEA, 2018). There is also evidence that faulty installation and maintenance of air-conditioning systems have an impact on health (Daisey et al., 2003). Using photovoltaic and thermal solar energy is a potential for cooling, especially as solar energy is available at the same time as the cooling demand (IEA, 2018; Escandón et al., 2019). Thermal cooling (see glossary in Annex 2) is more efficient than photovoltaic-fuelled systems, especially considering energy consumption over the whole life cycle of the installation (Samuel et al., 2013). District cooling, a system that produces chilled water and distributes it through insulated pipes to all buildings located in a district, is another method of increasing thermal comfort in buildings (Box 3.3). For additional information about climate-proofing of buildings against excessive heat, see Climate-ADAPT ([31]).

Box 3.3 Improving indoor thermal comfort with the use of district cooling in Paris

Energy demand for cooling in the city of Paris is increasing and is expected to make up 10 % of the city's overall energy demand by 2050, because of increasing air temperatures and growing demand for cooling within information technology installations. To use more sustainable forms of cooling, the city intends to rely increasingly on district cooling systems. These systems consist of a central plant where chilled water is produced and conveyed to buildings through a network of insulated pipes, and they are far more energy-efficient than individual cooling solutions. In Paris, the cooling network currently covers 38 % of the city, with many museums and public buildings connected. Nearly 70 % of the annual production of chilled water comes from plants situated along the Seine, using river water in heat exchange systems. This network will be extended to the entire city, and at least one further production unit using Seine water will be built. Some of the centralised cooling plants include ice storage, which can be used to satisfy daily demand peaks. The plants that do not use Seine water use electricity from renewable resources.

Sources: City of Paris (2017) and Engie (2019).

3.2.4 *Reducing energy use for cooling*

With the increased need for cooling to maintain human comfort comes increased need for energy use. Green facades have been found very effective for energy saving; green roofs, shading and passive cooling had medium levels of effectiveness, while the evidence on the effectiveness of cool roofs varied considerably (RESIN, 2018).

Green roofs, which have been researched a lot in this context, may reduce heating and cooling loads by up to 5 kWh/m^2 per year (Santamouris, 2014; Vuckovic et al., 2017). Ascione et al. (2015) quantified an energy cost reduction for a green roof on a university building in southern Italy at 2-3 %; however, combining the green roof with a passive ventilation system could reduce the cooling demand by 43 %. Therefore, the most substantial reductions in energy used for both heating and cooling may be achieved through a combination of various measures (Box 3.4).

3.2.5 *Effectiveness of urban heatwave action plans in reducing mortality*

Besides the structural adaptation options in Figure 3.1, well-designed and well-implemented heatwave action plans can successfully reduce mortality from extreme temperatures. Such heatwave plans exist in many European countries, including Austria, France, Italy, Portugal or the United Kingdom. They comprise meteorological early warning systems ensuring timely alerts, which trigger national, regional or city actions; definitions of institutional responsibilities and coordination mechanisms, and list measures to be deployed. For additional information on heat health action plans as an adaptation option see Climate-ADAPT ([32]).

The measures in heat action plans include providing vulnerable individuals with information about risk and preventive measures, accompanied in many cases by provision of cooling rooms and medical support (Climate-ADAPT, 2020; Ministero della Salute, 2019). The city of Paris has addressed the difficulty of reaching some vulnerable individuals by establishing a list of persons suggested by their doctors or relatives to be checked on and supported during heatwaves (City of Paris, 2018).

Heatwave action plans tend to be monitored, but little information is available about the effectiveness of individual measures in preventing deaths. Surveys assessing the overall efficiency of heatwave plans report, for example, that the extra mortality during heatwaves decreased by 65 % in all major Italian cities between 2013 and 2016 after the introduction of heatwave plans (de' Donato et al., 2018). In France, where

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([31]) https://climate-adapt.eea.europa.eu/help/share-your-info/general/climate-proofing-of-buildings-against-excessive-heat

([32]) https://climate-adapt.eea.europa.eu/help/share-your-info/adaptation-options/heat-health-action-plans

Box 3.4 Bioclimatic building design for energy efficiency in social housing in Zaragoza, Spain

Social housing in Spain is characterised by poor energy efficiency, resulting in uncomfortable indoor temperatures during cold winters and hot summers (Escandón et al., 2019). In Zaragoza, the EU-funded Renaissance project (part of the seventh framework programme Concerto initiative) tested a new bioclimatic design approach in two social housing neighbourhoods: a newly built eco-district on the area of a former military area (Valdespartera) and an existing social housing complex close to the city centre (El Picarral).

In Valdespartera, double orientation of dwellings allows natural ventilation and cooling. North and west facades are highly insulated and the openings are protected from the evening sun with timber lattices. South facades include large glazed areas to gain heat from the sun in winter, while overhangs provide shade for windows in the summer. Solar panels and centralised heating systems have been installed, and sewerage and watering systems are separated to save drinking water and use rainwater for maintenance of green areas. The heating consumption per dwelling is between 20 and 25 kWh/m^2 per year — a quarter of the heating consumption of conventional dwellings in Zaragoza.

The El Picarral area consists of a social housing complex built between 1940 and 1960, characterised by overall poor quality. The refurbishment of 70 dwellings and a school included increasing the thermal insulation of external walls and roofs and improving the airtightness of windows. Plumbing, hot water and sewerage systems were upgraded, and central heating was installed. These measures have reduced heating consumption to 50-60 kWh/m^2 per year.

The implemented techniques are monitored via real-time monitoring systems, and the data are used to improve the construction of buildings and to affect residents' behaviour.

Source: Saheb et al. (2019).

heatwave management plans were introduced in all major cities after the 2003 heatwave (see Box 3.5 for the example of Paris), mortality during the 2006 heatwave was 70 % lower than in 2003 (Laaidi et al., 2013).

In the light of the coronavirus disease 2019 (COVID-19) pandemic, heat action plans should be reviewed and adjusted (GHHIN, 2020). Advice such as 'leave hot apartments for public spaces', 'go to public air-conditioned locations such as cooling centres, shopping malls, and libraries', 'regularly check on vulnerable persons', 'use fans to cool rooms without air-conditioning' and 'seek urgent medical care if showing signs of heat stroke' may be in contradiction of restrictions and precautions linked to COVID-19. Therefore, effective outreach and communication to the public about heat stress during the COVID-19 pandemic is crucial to ensure that people's lives are protected from both heat stress and the virus (GHHIN, 2020).

3.2.6 Economic efficiency of measures against high temperatures

According to RESIN (2018), there is little available evidence on the cost-efficiency of measures for adaptation to heat, especially in the European context (see Box 3.1). The costs and benefits are highly location-specific, and the available knowledge is predominantly related to green infrastructure measures. For example, the benefit-to-cost ratio (BCR) of green roofs in the European context tends to be just below 1; the highest BCR for green roofs (2.4) was achieved in Belgium (Claus and Rousseau, 2012). For green facades, the costs seem to outweigh the benefits (the mean ratio for 18 European cases is 0.9). However, in some cases, green facades' BCR was over 3.3, such as in Genova, Italy (Perini and Rosasco, 2013).

When non-structural measures are considered, heatwave-warning systems emerge as one of the most cost-efficient ways of addressing the risk of heat to human lives. In Madrid, the value of statistical life and the value of a life year were used to arrive at BCRs of a heatwave-warning system ranging between 12 and 3 700, depending on the valuation method used (Chiabai et al., 2018). Similarly, in the contexts of London, Madrid and Prague, the assessment of existing heatwave-warning systems various regional climate scenarios for the period between 2035 and 2064 results in BCR ranges from 11 to 1 880 (Hunt et al., 2017). However, in order to ensure the protection of human health and the ultimate economic benefit, the effectiveness of such warnings in reaching the population and altering the behaviours needs to be high. The World Meteorological Organization and World Health Organization provide guidelines on development of heat warning systems (McGregor et al., 2015).

Box 3.5 Paris strategy to face heatwaves

The 2003 heatwave was particularly deadly in Paris, where the excess mortality rate increased by 142 %. Since 2003, several action plans and measures have been implemented at both national and local levels to reduce risks to public health from heatwaves. These actions are necessary, given that temperatures in Paris will increase by at least 2 °C, and that Parisians are likely to suffer 10-25 days above 32 °C per year by late 21st century.

The national heatwave action plan put in place in 2004 introduced a set of preventive and informative measures, which aim to protect vulnerable members of society (e.g. the isolated, the elderly and children). As part of this plan, a register called Chalex was created in Paris, where vulnerable people can self-register with a free phone call. During heatwaves, they receive a phone check-up and cooling advice, with a medical professional dispatched to their home if necessary. Vulnerable people can access air-conditioned spaces in 20 city halls, and 3 500 reusable water bottles were made available to homeless people over the summer.

Paris is also working on different ways to cool the city. Both the 2015 Paris adaptation strategy and the 2018 Paris climate action plan promote urban green and blue spaces. The city has reached the 2020 objectives of the Paris climate action plan, with 116 additional hectares of green roofs and walls developed, nine 'green streets' delivered in 2019 and more than 20 000 new trees planted. Water is also more visible thanks to the introduction of four new open-water swimming areas and 1 200 drinking fountains. During summer 2019, 80 water sprayers were active, and the opening hours of public swimming pools and parks were extended.

In summer 2019, the city also introduced 922 'cool islands', i.e. spaces with lower temperatures that are accessible and free for public use. They include several parks, museums, swimming areas, public libraries and places of worship. Thanks to these measures, the goal of the 2018 Paris climate action plan of all Parisians living within 7 minutes' walk of a cool island was almost reached in 2019. The city has developed an online map locating and providing information about the cool islands. A free mobile application (Extrema PARIS), developed in 2018, guides users to their destination via the city's cooling centres.

Moreover, the city's heatwave action plan aims to mobilise citizens to create social resilience. The community of climate volunteers, created in 2018 during the adoption of the Paris climate action plan, is made up of almost 27 000 people. Climate volunteers can access training sessions about issues related to climate change, such as adaptation and action to prevent heatwaves.

Children playing in water spraying area in Clichy-Batignolles park © Jean-Baptiste Gurliat

Outdoor swimming area on the canal de la Villette © Joséphine Brueder

Sources: City of Paris (2018, 2019a, 2019b, 2019c, 2019d); Hémon and Jougla (2003); Jouzel et al. (2014); personal communication from Julie Roussel, City of Paris (2019).

3.3 Pluvial and river flooding

Figure 3.2 presents an overview of the effectiveness of various adaptation measures in reducing the probability and impacts of flooding (RESIN, 2018). The greatest effectiveness in damage reduction is seen for measures preventing the contact between buildings and flood waters (amphibious, floating or elevated houses ([33])), but the evidence base is rather limited. Green infrastructure measures tend to be effective in intercepting rainwater and thus reducing the runoff and delaying the peak flow (Mendizabal et al., 2017). They can also store and infiltrate river flood waters (depending on the soil permeability and terrain shape). Structural measures — sewerage systems, flood protection infrastructure or water storage — also offer effective solutions. In addition, soft measures such as early warnings or flood insurance can help to avoid damage or address losses.

According to RESIN (2018), the evidence on the economic benefits and costs is rather scarce, as only relatively few studies report on benefits and costs. In addition, the costs and benefits are likely to differ between countries, and are dependent on legislation, division of responsibility, and market and insurance conditions.

3.3.1 Early warning systems

The clear leader in terms of benefit-to-cost ratio is early warning systems, which have a mean BCR of 10 (ranging between 2 and 24) according to the studies based in Europe (RESIN, 2018). In addition, the Global Commission on Adaptation (GCA) identified early warning systems as one of the most cost-efficient adaptation measures (GCA, 2019). In relation to river flooding, the benefits from the continental-scale European Flood Awareness System are estimated at around EUR 400 for every euro invested, with the BCRs higher under lower flood protection level scenarios (Pappenberger et al., 2015). In Bosnia and Herzegovina, 14 municipalities within the Vrbas river basin received communication and alarm equipment from the United Nations Development Programme in 2017 to implement an early warning system for river flooding. It was estimated that the presence of such a scheme can halve flood damage (UNDP, 2017).

In contrast to major river floods, pluvial floods in urban areas are very difficult to forecast owing to their fast onset and localised nature (Ricardo Energy & Environment, 2019). For individual households, receiving an early warning about pluvial flooding and knowing how to respond can be effective in reducing damage by allowing time to move contents upstairs, set up temporary flood protection measures or activate pumps (Rözer et al., 2016). For example, in Belgium, being aware of the risk just before the water entered the property reduced content damage from floods by 77 % for ground level and 90 % for basements (Van Ootegem et al., 2015).

Further to improving modelling and early warning systems, the involvement of citizens in flood observation can contribute to raising awareness and ultimately reducing the damage (See, 2019; Tian et al., 2019; Verbeiren et al., 2019). The FloodCitiSense project is exploring the use of low-cost sensors and citizens' observations for creating a database for urban early warning systems (Box 3.6). For an overview of the early warning systems in Europe as an option for adaptation to flooding and other climate-related hazards, see Climate-ADAPT ([34]).

3.3.2 Land use planning and relocation of human activities

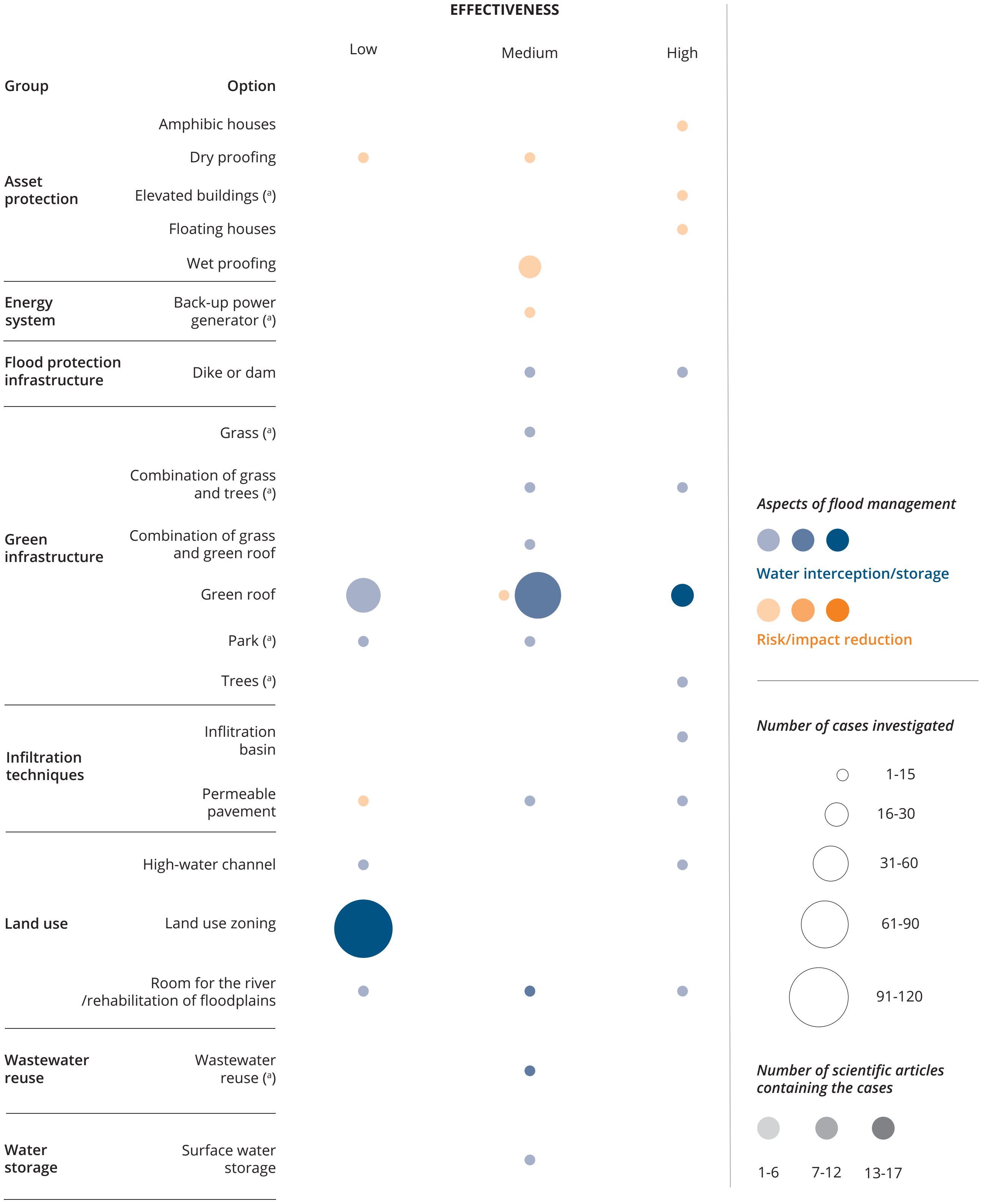
An effective way of reducing damage is 'making room for the river' (see Figure 3.2), i.e. removing sensitive land uses (e.g. housing, industry or transport; see also Section 2.3.1) from areas at risk of river flooding (Kreibich et al., 2015). However, the development of floodplains in Europe continues (see Section 2.3.2). Therefore, spatial planning that explicitly considers future flood risks is one of the key means to reduce losses. This is the case in, for example, the densely urbanised municipalities alongside the River Meuse (Beckers et al., 2013). For the Lech river in Austria, implementation of stricter land use regulations by 2030, coupled with use of property level flood resilience measures by 2030, could reduce potential flood damage by around 30 % (Thieken and DKKV, 2015). The EEA (2017d) provides examples of cost-effective floodplain restoration and management based on green infrastructure use; see also Climate-ADAPT ([35]).

([33]) For more information about this adaptation option, see: https://climate-adapt.eea.europa.eu/metadata/adaptation-options/floating-and-amphibious-housing.

([34]) https://climate-adapt.eea.europa.eu/metadata/adaptation-options/establishment-of-early-warning-systems

([35]) https://climate-adapt.eea.europa.eu/metadata/adaptation-options/rehabilitation-and-restoration-of-rivers

Figure 3.2 **Overview of effectiveness of adaptation measures: flooding**



Note: In the RESIN adaptation options database, effectiveness in terms of performance is assessed for the different measures based on different indicators of performance. The same type of measure may therefore prove to have different levels of effectiveness depending on the chosen indicator. In addition, the scale of implementation and the type of event (e.g. slow-onset event, one in 5-year event or one in 100-year event today versus in a future climate scenario) determine the effectiveness of the measures.

([a]) Results are based solely on observations from outside Europe.

Source: ETC/CCA analysis of RESIN (2018).

Box 3.6 FloodCitiSense: early warning service for urban pluvial floods

FloodCitiSense is a Joint Programming Initiative Urban Europe project that aims to develop a crowdsourced urban pluvial flood early warning service for and by citizens and city administrations, to enable better preparation and response to floods related to heavy precipitation. The application is being tested in Birmingham, Brussels and Rotterdam. Information on heavy rainfall events and pluvial flooding is crowdsourced from citizens and collected by a network of low-cost sensors and long-range technology. Combined with model predictions, data from the sensors are used to inform and warn citizens and authorities about upcoming flood events. Citizens who experience flooding can provide information (including photographs) on its location and timing. In this way, the new flood early warning service helps provide real-time information on rainfall and its risk of causing pluvial flooding.

The information on rainfall generated by the citizens and sensors can be used by city administrations to adjust official warning messages, and by scientists to improve the modelling procedures. The proof of concept was planned to be ready in 2020 and can also be applied in other cities.

Rainfall sensors on a roof in central Brussels
© Boud Verbeiren, Free University Brussels

Sources: Verbeiren et al. (2019); http://floodcitisense.webflow.io; personal communication from Boud Verbeiren, Vrije Universiteit Brussel (2019).

Relocation of people from floodplains comes with high costs, both in monetary terms, due to the necessary purchase of premises and development of new sites, and in terms of psychological and emotional effects on those being relocated. In Europe, relocation of existing residential uses from flood-prone areas has rarely been applied up to now (see for example Climate-ADAPT, 2017). The Dutch Room for the river programme involved some relocation of farmsteads linked to moving of dykes. Since 1995, the French government has set aside resources in the Barnier fund for buying or expropriating premises at high risk of flooding (Slomp et al., 2019); the fund has recently been used in the Département Alpes-Maritimes.

Land use planning can also reduce damage by setting aside land for storage of flood water. In relation to pluvial flooding, inundating a local recreation area once in 10 years has proved to be an efficient way of reducing the costs of flooding without increasing the capacity of the sewer pipes (Arnbjerg-Nielsen and Fleischer, 2009). Box 3.7 shows an example of creating space for the flood waters within densely built-up urban areas.

With regard to river flooding, the flood risk in urban areas is dependent on the land use and land cover in the river basin upstream. Thus, holistic management of flood risks at basin scale using nature-based solutions can be a cost-efficient solution reducing flood risk for urban areas and settlements downstream (Iacob et al., 2014; Climate-ADAPT, 2016i). For example, creating additional floodplains around the Scheldt tidal river flowing through Belgium and the Netherlands, protecting urban areas, has a BCR of 2.7 (Broekx et al., 2011).

3.3.3 Upgrading sewer systems

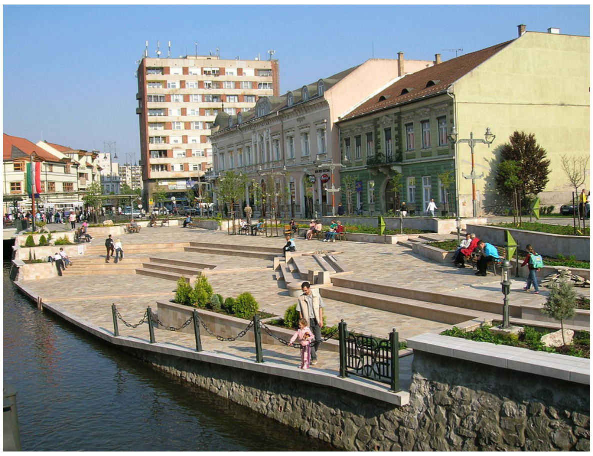
The future design of drainage systems needs to account for climate change. For example, in Denmark, the current 100-year event rainfall intensity (commonly used for infrastructure planning) is projected to become five times more likely by the end of the century (Arnbjerg-Nielsen and Fleischer, 2009). Increasing the capacity of the urban drainage infrastructure, e.g. through bigger sewer pipes, has an average BCR of 2.2 (RESIN, 2018). Separating stormwater and sanitary sewerage systems can substantially reduce the damage to residential properties and their contents from flooding, as suggested by a modelling study for Eindhoven, Netherlands (Sušnik et al., 2015). Especially in those cities where old sewerage infrastructure is combined with low levels of separation (Figure 2.5), the need for maintenance of the drainage network also opens up the opportunity to enhance sewer capacity, as well as 'piggybacking' other improvements. For example, in the Rotterdam neighbourhood Reyerdijk, the planned renovation of the sewer system will be used as an opportunity to also put in infrastructure for district heating and replace the old pavement with a water-permeable alternative or vegetation (C40 Cities, 2020a).

Box 3.7 Renovating city square as a temporary flood storage in Miskolc, Hungary

The city of Miskolc (population: 154 000) is located in north-east Hungary, in the valley of the River Sajó and the streams Hejő and Szinva. The area experienced a 15 % increase in annual precipitation between 1961 and 2015 and an increase in the intensity of heavy rainfall, resulting in quickly rising river levels and floods. The risk of flooding is exacerbated by the channelised character of the river and streams and the presence of low bridges.

The Szinva Terrace square was reconstructed in 2005. The area, previously mainly used as a car park, was turned into a multifunctional and resilient public space, functioning also as a flood retention area. The main driver of the redevelopment was the revitalisation of the city centre; however, flood risk reduction was also a factor. The Szinva Terrace is the most spectacular and expensive part of the EUR 4.7 million programme to revitalise the city centre and make it partially car-free. Most of the money was provided by EU funding and national government support; the municipality contributed 10 % itself.

The square consists of terraces and stairs that lead to the Szinva stream; the central feature is a little waterfall, lit in the evening. Thanks to its amphitheatre style, the square is used for public cultural events. It is also a popular meeting place for residents, with a fountain and vegetation providing a respite from heat in the summer. Since its construction, the square has functioned as a flood water retention area several times (in 2006, 2009 and 2019). After the flood events, there was no need for restoration, and the square was usable for residents again after cleaning.



Szinwa Terrace in dry period © Alensha

Sources: Personal communication from Zsófia Pej, Energiaklub, Hungary (2020).

3.3.4 *Sustainable urban drainage systems*

Reducing the amount of water entering urban drainage systems may lower the risk of pluvial flooding. Green roofs and infiltration trenches were found to have low, but still positive, BCRs (1 and 1.1, respectively). Wetlands tend to have somewhat higher costs than benefits (average BCR 0.7), while swales (36) and retention ponds have been found to have far higher costs than benefits (RESIN, 2018).

In Malmö, Sweden, the Augustenborg neighbourhood contains an extensive SUDS (Climate-ADAPT, 2016k), which has proven to be effective protection against flooding associated with heavy precipitation. Since the early 2000s, Augustenborg has experienced less damage from flooding than similar neighbourhoods with conventional sewer systems, also during events with extremely heavy precipitation (Sörensen and Emilsson, 2019; Sörensen, 2018), when flooding only occurred in intended areas, according to the system's design (Haghighatafshar, 2019). Sustainable urban drainage systems, combined with better water removal from the city, are also a cornerstone of the Copenhagen cloudburst management plan (Box 3.8). In Wales, adoption of SUDS was made mandatory for new developments in 2018 and it has already reduced the runoff burden on urban waste water treatment plants (Ricardo Energy & Environment, 2019).

As buildings constitute a large percentage of surface-sealed areas in cities, in many European cities one of the strategies to partially compensate for this is to install green roofs. Some cities, such as Basel or Hamburg (Climate-ADAPT, 2016d, 2016f), require green roofs on new and renovated buildings. In Newcastle, United Kingdom, citywide deployment of green roofs was modelled to reduce the incidence of pluvial flooding, the risk of traffic interruptions and related costs by 25 % (Pregnolato et al., 2016).

3.3.5 *Rainwater storage and harvesting*

Excess rainwater can be stored below or above the ground. Underground water storage has been assessed to have an average BCR of 1.3 (albeit in studies outside Europe; RESIN, 2018). Underground tanks are used in Glasgow, United Kingdom, while Copenhagen uses a mix of both surface and underground water storage systems and Malmö relies on surface storage.

Although rainwater harvesting is one of the water storage options with higher costs than benefits (average BCR 0.8; RESIN, 2018), in many cities it is encouraged on residential properties, as it has the combined benefits of reducing runoff and providing houses with a water source for gardening, car washing, toilet flushing, etc. instead of using drinking water (Box 3.9; see also Box 3.14).

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(36) Shallow, broad and vegetated channels designed to store and/or convey runoff.

Box 3.8 Systematic implementation of the cloudburst management plan in Copenhagen

To combat the impacts of extremely heavy precipitation events, the city of Copenhagen developed a cloudburst management plan in 2012, which is an offshoot of the Copenhagen climate adaptation plan. The city carried out an assessment of the costs of various measures and the residual damages to understand the financial impact of plan implementation. The assessment considered a more conventional solution (increasing the dimensions of the sewer system) and an alternative solution (utilising green infrastructure). Both solutions were found to reduce the damage cost by DKK 16 billion over the lifetime of the measures (100 years), counting both avoided damage (DKK 9 billion) and increasing revenues for the local authority in the form of tax benefits from raising property prices and employment. However, the traditional sewer solution was estimated to cost DKK 20 billion, compared with DKK 13 billion for the alternative solution. Thus, the alternative solution would result in a net gain of DKK 3 billion, compared with the net loss of DKK 4 billion with the traditional solution of DKK 4 billion. A combination of solutions was selected, including expansion of the sewer network and implementing around 300 surface projects focusing on water retention and drainage.

The implementation of the plan is scheduled to take 20 years. For each of the 60 local areas known as cloudburst branches, a masterplan is drawn up, concurrently assessing all projects in that area. Hence, between 2018 and 2022, preliminary analysis is in progress for 156 projects. This is in addition to 56 projects that had already been set in motion by 2018. In 2015, Tåsinge Plads in the Østerbro area was among the first major projects to be completed. Experience from the first summers showed that it works. In 2019, another two major projects in the same area were completed. In 2019, also Enghaveparken, a large park in the Vesterbro neighbourhood, was renovated to function as a rainwater basin.

Sources: City of Copenhagen (2015, 2018); Climate-ADAPT (2016j).

Box 3.9 Disconnecting homeowners from the municipal sewerage system in Horst aan de Maas, Netherlands

The city of Horst aan de Maas has implemented a series of measures aiming to make water and waste water management more sustainable. Such measures include disconnection of systems handling rainwater and sewage, to reduce the risk of sewage overflows. Since 2017, Horst aan de Maas has offered a subsidy (up to EUR 1 800) to homeowners for installations that allow disconnection of their roof rainwater pipes from the municipal drainage system. Citizens have three options for water storage: above-ground water tanks, underground water tanks or permeable pavements. The rainwater collected on properties can be used for watering gardens, reducing the use of drinking water. In just 6 months, 6 000 m^2 of rooftops were disconnected from the sewerage system.

Source: EGLA (2018b).

3.3.6 Flood protection infrastructure

According to European studies included in the RESIN (2018) database, dykes or dams had a mean BCR of 3.7. The city of Prague is a good example of the cost-efficiency of flood protection measures. After severe flooding in 2002, fixed and mobile barriers and safety valves in the canalisation network along the Vltava river were implemented, at a cost of EUR 146 million. The estimated benefits were calculated for a one in 500 years flood event. Avoided costs included damage to residential buildings (up to EUR 1 971 million), infrastructure and industrial buildings up to EUR 613 million, equipment up to EUR 254 million, and environmental and cultural assets up to EUR 57 million, as well as costs for evacuating citizens, cleaning and other costs, ranging between EUR 42 million (for a one in 20 years flood event) and EUR 74 million (Climate-ADAPT, 2016g).

Strengthening and raising existing dikes has favourable benefit-cost ratios, although this can transfer risk downstream (Feyen et al., 2020). It also tends to stimulate further development behind the flood barriers, which can result in catastrophic impacts in the event of their failure. Thus, raising structural flood protection has the effect of reducing the frequency of floods to below the protection standard without addressing the exposure of societies to less frequent but catastrophic floods and potentially long recovery processes (Ciscar et al., 2018).

Therefore, other adaptation options should also be implemented alongside structural protection, as for example in Cologne, Germany (Box 3.10). In Sandomierz, Poland, a hybrid approach of green and grey infrastructure measures (re-naturalisation of reservoirs and wetland restoration; expansion, reconstruction and modernisation of river embankments; restoration of dike functionalities; and reconstruction of water pump stations and water discharge channels) was applied. The total cost of the adaptation measures implemented was about EUR 217 million. The avoided flood damage to buildings was estimated to be about EUR 445 million in constant values, so the BCR was estimated at over 2 for the built environment alone (Climate-ADAPT, 2018c). For more information about dikes and dams as an adaptation option, see Climate-ADAPT (37).

Retention basins in the upper parts of river basins emerge as effective measures for mitigating flood damage in urban areas located downstream. For example, during the 2018 floods in Paris, four retention basins on the Seine lowered the water levels by 80 cm and reduced the overall damage by at least 30 % or EUR 90 million (CCR, 2018).

High-water channels tend to be highly effective in lowering water levels during floods (Figure 3.2). In Bilbao, Spain, the Deusto canal has been developed at a cost of EUR 12 million. Estimates of damage by the end of the century without adaptation measures in place vary between EUR 66 million and EUR 93 million, whereas, with the Deusto channel adaptation infrastructure in place, damage is expected to decrease to values between EUR 24 million and EUR 34 million (Abadie et al., 2017).

Box 3.10 Reducing costs of river flooding through precautionary, structural and management measures in Cologne, Germany

After two severe Rhine floods in 1993 and 1995, which caused approximately EUR 107 million of damage, the Cologne municipality decided to redefine its flood defence measures to protect the approximately 150 000 inhabitants living in flood-prone areas, as well as critical infrastructure and businesses in floodplains. An action plan called 'Flood protection Cologne' was developed to focus on both flood preparedness and extension of physical protection measures.

The implementation costs were EUR 430 million. However, the potential damage that another, more severe, flood could cause in the future would amount to up to about EUR 3.5 billion (2001 values). The protection measures implemented included the following:

- creation of retention areas within the boundaries of the municipality that can be flooded temporarily;
- measures on the ground, such as dikes and walls along the Rhine river, as well as mobile protection walls (see image) and prepared sandbags that can quickly be deployed to prevent flooding;
- annual flood prevention training with the participation of the city administration, the fire brigade and other relevant organisations;
- technical sewage flood protection, including pumping systems to keep the city dry during high-water events;
- a sewerage system headquarters to monitor and manage sewage flows during extreme events;
- a flood protection headquarters that coordinates, supports and follows up on all flood measures agreed on in the different city departments (energy, fire brigade, police, roads and transport, and rescue services).

A mobile flood protection wall © Peter Jost

Sources: Stadtentwässerungsbetriebe Köln (2019).

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(37) https://climate-adapt.eea.europa.eu/metadata/adaptation-options/adaptation-or-improvement-of-dikes-and-dams

3.3.7 *Protection of individual properties and assets*

Property level flood protection measures, such as floodgates, anti-flooding valves and airbrick covers, can be used to complement the structural flood defence measures or in areas where those are lacking. In Germany, the floods in the Elbe and Danube catchments that occurred in 2002 and 2013 resulted in average losses to flooded households of EUR 48 000, including costs for repair of damage caused to building structures. Property level flood protection measures, either permanent or temporary, have been found to reduce damage costs by 27 % (Sairam et al., 2019). In France, an even higher damage reduction effect of 50 % per flooded household was found (Poussin et al., 2015). An innovative method of protecting individual households in flood risk areas is raising them above the expected flood levels (Box 3.11).

In the case of industrial and commercial premises, transporting items to flood-safe areas, or deployment of temporary barriers preventing water from entering the building can reduce the damage potential by approximately 50 % for stock and by 28 % for equipment (Kreibich et al., 2007).

3.3.8 *Flood insurance*

Insurance against flood damage is generally considered a viable option for compensating for the financial losses caused by flooding. Yet returning to the status quo, which is the usual principle of flood insurance contracts, can result in maladaptation, as it prevents 'building back better' to adapt to future risks (Surminski et al., 2015; Hudson et al., 2016).

According to research, a risk-based insurance scheme promoting implementation of property level flood protection measures could reduce residential flood risk by 12 % in Germany and by 24 % in France, by incentivising adaptation activities. The cost of such a scheme, which combines risk-based premiums with vouchers to avoid unaffordability, would currently cost more than the value of damage it could avoid, but, by 2040, additional damages prevented would be approximately worth 150 % of the costs of the scheme in Germany and 250 % in France (Hudson et al., 2016).

Box 3.11 Raising the whole district above flood waters: local innovation in Coswig, Germany

The area of Brockwitz, a district of Coswig located by the River Elbe, has been heavily and repeatedly flooded since 2002, resulting in damage to the town centre, which is home to up to 1 000-year-old listed buildings. Consequently, in 2017 the 2-year initiative Haushebung in Überschwemmungsgebieten am Beispiel des Elbe-Dorfes Brockwitz (HUeBro) was brought to life. It aims to assess if raising the houses in the area can provide an effective alternative to dykes and other adaptation measures. Moreover, the project assesses the sustainability and broader effects of the large-scale raising of houses, while developing guidelines and best practices for similar projects. Results will be delivered by five research organisations conducting transdisciplinary assessments in 10 work packages ranging from environmental and heritage protection to spatial planning, hydrological and geotechnical factors.

The project was developed closely with local stakeholders. Through information events and feedback rounds, it provides a space for citizens to learn, discuss design possibilities and raise concerns, which has enriched the project. Moreover, buy-in was needed from several regulatory bodies and licensing authorities, while involvement of research organisations and universities was vital to legitimise the project.

The feasibility study (close to completion as of February 2020) declared the raising of the houses to be an effective adaptation measure for flooding in urban areas, providing some advantages over other adaptation measures: effective protection of listed buildings, improved quality of housing, less need for retention areas and thereby protection of valuable biotopes.

Whilst conventional flood prevention measures are often funded by the flood prevention authorities responsible, their financial support for raising houses was not available, posing a significant obstacle to implementing the project. However, in November 2019, the German federal government approved EUR 10 million funding for the project, which will be distributed from 2020 until 2026. In addition, options for financial support for individual residents from flood prevention authorities are being explored.

Flooded street in the Brockwitz district, 2013
© Coswig City

Sources: Personal communication from Olaf Lier, Coswig City (2019).

Insurance and compensation schemes for flood-related damages vary between European countries. Most countries have a form of private insurance system under which homeowners can buy coverage in case of floods (Bouwer et al., 2007; OECD, 2016). In many countries, e.g. Belgium, Denmark, France and Poland, standard residential insurance policies cover flood risk and other natural disasters; in some countries, e.g. Germany and Ireland, such coverage is offered as an option. Finally, in some countries, the public sector plays a key role, either insuring or reinsuring properties; for example, in France the public Caisse centrale de réassurance offers reinsurance for natural disaster risks (OECD, 2016; NAIAD, 2019). Iceland and Switzerland also have publicly underwritten insurance (OECD, 2016). In addition to these insurance systems, governments may also directly compensate households or businesses that suffer losses due to natural disasters (Bouwer et al., 2007; OECD, 2016). In the Netherlands, where flood insurance has been limited or not available, the government offers partial compensation for flood damage losses. But there are also cases where governments have reimbursed losses even if insurance schemes were available, e.g. in Finland, Germany and Hungary (Bouwer et al., 2007; Maccaferri et al., 2012). Where governments have intervened through ex post compensation, insurance penetration rates fall in the medium-low range (Maccaferri et al., 2012). This adds to the discussion the question of whether or not such disaster compensation reduces the incentive of property owners to take adaptive measures or buy insurance.

Flood insurance penetration rates also vary considerably among European countries, and flood losses may be insured less often than other disaster losses (OECD, 2016). In 2012, flood insurance penetration rates for households varied from about 10 % in Greece, Italy and Luxembourg, through 10-25 % in Austria and Finland, to at least 75 % in Belgium, Ireland, France and Sweden (Maccaferri et al., 2012; OECD, 2016). Iceland and Switzerland have 100 % penetration rates because schemes are mandatory. Take-up rates tend to be lower where flood insurance is provided as an optional add-on to property insurance schemes, e.g. in Austria, Germany or Portugal, while take-up rates are around 90 % in Ireland and Sweden, where flood insurance is a requirement for obtaining a mortgage (Maccaferri et al., 2012; OECD, 2016).

As part of the next EU adaptation strategy, the European Commission aims to help close the climate protection gap, i.e. reduce the share of non-insured economic losses following floods and other climate disasters; it has been estimated that a 1 % increase in insurance coverage could reduce total public costs of disaster compensation by 22 % (EC, 2020c). At the same time, the aim to increase insurance penetration rates may be challenged in the future by issues of affordability and insurability (EIOPA, 2019). For additional information on insurance as an adaptation option, see Climate-ADAPT (38).

3.3.9 Landslide risk management

Currently, most landslide risk management action in Europe is taken shortly after highly destructive landslides (Mateos et al., 2020), but preventive actions are on the rise. Databases containing information on historical landslide events have been established at national and regional levels in 28 of the EEA member and collaborating countries (Herrera et al., 2018). Such databases are used alongside susceptibility maps in landslide-prone countries, including Italy, Norway, Spain, Sweden and Switzerland. For example, aided by the Swedish Civil Contingencies Agency, landslide susceptibility has been mapped in Sweden since 1986 and the mapping now covers 157 of the 290 Swedish municipalities (Andersson-Sköld et al., 2013). These resources guide the implementation of structural measures used to stabilise ground, spatial planning, and awareness or emergency response training.

The inclusion of landslide susceptibility maps and risk assessments in local-level spatial planning was found to be a cost-effective preventative measure, based on a study of 11 Swedish municipalities in landslide-prone areas (Andersson-Sköld et al., 2013). In the highly susceptible Göta älv river valley area, stability measures, such as erosion protection and levees reducing the landslide probability by 20 % (accounting for climate change) in areas of high risk were estimated to cost EUR 550-700 million, with annual costs of around EUR 1 million for further research, maintenance and surveillance of erosion protection and processes. The value of assets protected within these high-risk areas was estimated to be EUR 900 million, which suggests that the physical measures are cost-effective in asset-rich areas (SGI, 2012). These findings are supported in a recent European-scale study, which also pointed to the importance of establishing a European-level regulatory framework to ensure that landslide risk is incorporated into urban planning, including the prevention of urban sprawl onto high-risk land (Mateos et al., 2020).

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(38) https://climate-adapt.eea.europa.eu/help/share-your-info/general/insurance-as-risk-management-tool

3.4 Coastal flooding and coastal erosion

3.4.1 Structural measures

According to a pan-European study, at least 83 % of coastal flood damage in Europe could be avoided by elevating dikes along one quarter to one third of Europe's coastline (Vousdoukas et al., 2020). The investment in dikes is economically beneficial in densely populated areas (> 500 people per square kilometre) (Feyen et al., 2020), so it is particularly relevant to cities. For around 70 % of the European coast, the costs of building dykes outweigh the benefits because of sparse population, steep morphology and/or complex coastline (Vousdoukas et al., 2020).

According to the RESIN (2018) database, dykes and dams in the European context have been found to have a relatively high BCR (3.72, based on 16 observations). The costs of dykes essentially depend on the construction height (Prahl et al., 2018) and tend to increase linearly with their size. However, specific local factors, such as implementation of wider coastal defences in an urban environment, could contribute to a non-linear increase in costs (Jonkman et al., 2013). Considering only the locations where further protection is needed, the additional average coastal defence height needed in Europe is around 1 m, ranging from 0.31-0.39 m in Malta to 2.85-3.43 m in Belgium (Vousdoukas et al., 2020). The European mean BCR of the investments in elevating dykes varies from 8.3 to 14.9; the BCR is higher for the scenarios assuming high-end greenhouse gas emissions and strong socio-economic growth (Vousdoukas et al., 2020).

Two examples from small cities in Denmark show how structural coastal protection can be integrated into existing urban areas and urban development in different ways (Box 3.12). See also Climate-ADAPT for an overview of costs and benefits of seawalls and jetties (39).

Importantly, building higher dykes may not be a sufficient strategy for the future. Currently, at the European scale, avoided flood damages and losses are almost equal for protection levels of one in 100 years and one in 300 years. However, under the extreme scenario of 2 m sea level rise, a one in 300 years protection level would almost equal the level of damage of a no-protection scenario (Mokrech et al., 2015). Future pressures on coastal zones from socio-economic development could further exacerbate damage through increased exposure of assets.

Preventing coastal erosion is one of the ways to prepare for the sea level rise. Stabilisation of coastlines is achieved mainly with beach nourishment (see Section 3.4.2) and/or hard measures such as groynes, longitudinal revetments and breakwaters (40). For example, in Portugal, around 14 % of the Atlantic coast is protected by hard structures (Marinho et al., 2019). The national coastal protection policy recommends regular reinforcement and maintenance of the existing structural protection measures, even though beach nourishment is increasingly favoured as a response and the construction of new hard structures is decreasing (Pinto et al., 2020).

3.4.2 Nature-based solutions

Beach nourishment is considered an environmentally acceptable and viable engineering alternative for shore protection and restoration (Pinto et al., 2020) (41). It can be used as a local and short-term solution (i.e. to address erosion induced by storms), or as a regional and long-term management strategy (i.e. to mitigate a tendency towards erosion and vulnerability to sea level rise) (Hamm et al., 2002; USAID, 2009). In Portugal, around 2 % of beach nourishment actions are carried out to protect existing hard structures (Pinto et al., 2020).

In the Netherlands, beach nourishment has evolved from reactive small-scale nourishments towards a proactive strategy to mitigate erosion based on foreshore nourishment to stabilise the coastline. Anticipating the need for increased sand volumes under rising sea levels, an innovative large-scale nourishment scheme called 'sand engine' was tested, which uses an artificial peninsula from which wind, waves, tides and currents redistribute sand along the coast while creating new recreational and natural areas (Borsje et al., 2017).
The feasibility and cost-effectiveness of beach nourishment strategies depend on context-specific factors, such as the extent of nearby sand resources, the distribution of assets and population along the coastline, and the physical characteristics and erosion processes at play; for example, beach nourishment may be more feasible and cost-effective in the Netherlands than in Portugal, because of the vast sand resources in the North Sea (Stronkhorst et al., 2018).

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(39) https://climate-adapt.eea.europa.eu/metadata/adaptation-options/seawalls-and-jetties

(40) See also: https://climate-adapt.eea.europa.eu/metadata/adaptation-options/groynes-breakwaters-and-artificial-reefs

(41) Although, depending on the source of the material used for nourishment, sand dredging can have impacts on seafloor ecosystems such as seagrass (Pranzini, 2018).

Box 3.12 Coastal protection strategies in small Danish cities

A new city district protecting the city centre and harbour in Fredericia, Denmark

The Danish coastal city of Fredericia is transforming 20 ha of former industrial area and harbour site into a new and attractive urban district called Kanalbyen. While bringing the city to the seafront, this new district provides protection against coastal flooding not just to the new area but also to the existing historical centre of Fredericia. The development is being carried out as a three-in-one adaptation solution, aiming to add recreational, social, aesthetic and economic value, while integrating constructions to prevent coastal flooding of the city:

1. Canals are being excavated to integrate the waterfront into the new district, making it more attractive to invest and live in the area.
2. The overall terrain of the new district is being lifted from an average of 1.9 m to 2.5 m above sea level, using the existing soil as a ground layer topped with clean soil, to seal in any contamination left from the former industrial use.
3. A dyke at the inner side of the existing harbour will reach 2.5 m above sea level, corresponding to the target level of terrain in the new district, including seating areas, cafés and green elements.


Kanalbyen © Fredericia municipality

The municipality aims to attract 2 800 new jobs and 1 200 new homes to Kanalbyen over the next 20 years. The first inhabitants moved in in 2017.

Protecting Lemvig Harbour with 'Le Mur'

Lemvig's long-term solution for protection against rising sea levels is narrowing the canal leading to the North Sea. Meanwhile, the municipality built 'Le Mur' ('The Wall') in 2012 to safeguard Lemvig harbour against storm surges, while creating a sense of place in the harbour. The concrete wall runs 320 m in a serpentine line along the harbour and is constructed to protect against 2.1 m of sea level rise. The wall has received several awards, including for innovation, as it also creates inclusive urban spaces, such as a marketplace, playgrounds and ball game areas (pétanque, beach volleyball). The wall has built-in benches and mosaics created by local schoolchildren, and creates added value for locals and tourists.

To date, the wall has protected Lemvig against coastal flooding on at least two occasions, saving the city from damage costing about DKK 30 million (EUR 4 million). The cost of implementation was DKK 18 million (EUR 2.4 million). The wall is designed as an assembly kit that can be implemented in other coastal cities.


'Le Mur' protecting Lemvig harbour © Mads Krabbe


Detail of the wall © Lemvig municipality

Sources: Global Opportunity Explorer (2018a, 2018b); https://kanalbyen.dk; https://www.danskeark.dk/content/le-mur; and direct communication from Lemvig municipality.

In the Emilia-Romagna region of Italy, the use of hard structural measures has been largely replaced by beach nourishment since the early 1980s, with a total of 8.1 million m^3 of sand from littoral and underwater deposits used from 1983 to 2007 (ARPA, 2008). These nourishment interventions were successful in reducing average shoreline retreat over the decades (Foti et al., 2020).

According to the RESIN (2018) database, beach nourishment has an average BCR of 2.6 in the European context. Based on modelling of future benefits from beach nourishment in the south-east of the United Kingdom, smaller beach nourishment schemes tend to be the most cost-efficient for short-term interventions (up to 20 years), while larger schemes are considered more cost-efficient in the longer term. In all cases the positioning of measures is crucial for their effectiveness and for the prevention of erosion processes triggered by the nourishment itself (Brown et al., 2016).

Natural coastal ecosystems based on wetlands and dunes attenuate wave heights, thus effectively diminishing impacts from storm surges. In the Lomma bay area in Skåne, Sweden, an eelgrass-planting lab showed that waves during storm events were reduced by an average of 35-40 % in eelgrass-dense sites, compared with 5-10 % reductions in sites where eelgrass is sparse (Building with Nature, 2020 (42)). Vegetation in salt marshes may reduce wave heights by up to 60 % (Fagherazzi, 2014; Möller et al., 2014; Narayan et al., 2016). Although waves progressively flatten and break the vegetation stems and thereby reduce dissipation, the marsh substrate remains stable and resistant to surface erosion under extreme events. Saltmarshes also adapt to rising sea levels through sediment capture. Saltmarshes can be several times cheaper than alternative submerged breakwaters for the same level of protection (Narayan et al., 2017), while simultaneously providing important ecosystem services in terms of biodiversity, fish production and recreation.

Limits to nature-based approaches in urban contexts are related to the large areas required for sustaining ecosystems (Calliari et al., 2019; van Wesenbeeck et al., 2017). Some studies estimate the minimum marsh width providing protection as 6 to 10 km. Furthermore, continuous marsh surface is the most effective, whereas water channels or riverbeds crossing the salt marshes convey stormwater towards the inland area (Stark et al., 2016; Narayan et al., 2017).

3.5 Drought and water scarcity

The range of drought adaptation measures in the RESIN (2018) database includes rainwater management; waste water reuse; fresh water production through desalination; and water demand management. However, the evidence on the effectiveness of measures addressing water scarcity is limited.

The cost-efficiency of various measures addressing water scarcity was assessed in the city of Barcelona (Table 3.2). The results suggest that the most cost-efficient measures are awareness-raising campaigns, followed by improvement of water resources through more efficient groundwater extraction and desalination. Water transport is the least cost-efficient measure, not only when used as an emergency measure, but also when it is a more permanent solution, such as the 80-km underwater pipeline from Turkey to Northern Cyprus (Marin et al., 2018).

Table 3.2 Unit costs of drought measures implemented in Barcelona

Measure type	Measure	Unit costs (EUR/m^3)
Demand measures: communication and awareness-raising campaigns about water saving	No welfare loss consideration	0.03
	Welfare loss consideration	1.36
Supply measures	Water shipping	32.53
	Headwater cisterns	2.3
Structural measures	Well recovery and enhancement of groundwater extraction	0.18
	Enlargement of existing desalination plant	0.61-1.30

Note: Unit cost reflects how costly it is for each of the measures to provide one additional cubic metre. Welfare losses are costs to society, including costs to producers and consumers, and taxation.

Source: Adapted from Martin-Ortega et al. (2012).

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(42) The Interreg project Building with nature brings countries of the North Sea region together to find solutions to coastal flooding and coastal erosion. Several pilots have been established in the form of living laboratories to build an evidence base on the effectiveness of nature-based solutions.

3.5.1 Measures reducing demand

Awareness raising has been proven effective in reducing water demand. For example, in the dense inner-city area of Barcelona, awareness campaigns have contributed to reducing water consumption by about 10 % between 2006 and 2011. During dry periods, additional restrictions apply to discretional water uses by both the private and the public sector. In Spanish cities, education and public awareness campaigns aimed at making more rational use of water, as well as targeted campaigns to promote the use of water-saving technologies, were the most effective measures for reducing demand (Tortajada et al., 2019). The costs of 'soft' measures, such as awareness-raising campaigns or water use bans, are quite low compared with structural measures, so they are more cost-efficient (March et al., 2013) (43).

Water prices may be regulated to reduce water consumption. However, this mechanism raises questions of equity and justice, with the poorest or largest households likely to bear the greatest economic burden. In Spanish cities, establishing different seasonal tariffs or providing discounts for low water use was found to be more effective than raising prices in reducing water use (Tortajada et al., 2019). In Portugal, a tariff regulation for urban water services is being prepared to establish the rules for defining, fixing, revising and updating tariffs for public water supply and urban waste water services.

Technological measures, such as replacement of collective water meters with individual meters, have been found to reduce per capita water consumption. In Barcelona, frequent monitoring of flow data in the water supply networks can help to identify leaks and illegal connections (Tortajada et al., 2019).

Importantly, water scarcity is usually a large-scale phenomenon, extending beyond an individual city or region. In parts of Europe the projected increases in dependency on upstream water require intensified water diplomacy efforts between countries as well as international multi-state management of river basin water resources. In the EU, this is already operational under the Water Framework Directive and in various river basin commissions, such as for the Danube, Elbe, Meuse, Oder, Rhine, Sava and others (Feyen et al., 2020).

3.5.2 Waste water reuse

Grey water collected and reused at household level, or treated waste water from waste water treatment plants, can be considered a reliable water supply, independent of seasonal drought and weather variability (EC, 2019f). Such a water supply offers alternative water resources for irrigation of lawns, urban parks and cleaning of streets. Waste water reuse emerges as a cost-efficient type of measure addressing drought, with a BCR exceeding 5 (RESIN, 2018), despite the need to ensure the highest standard of waste water treatment (Ricardo Energy & Environment, 2019). Waste water reuse is increasingly applied in Mediterranean cities, which are moving away from desalination (Box 3.13).

3.5.3 Rainwater capturing

Rainwater harvesting at the household level can meet the household needs for toilet flushing and laundry, reducing the use of drinking water. Even in areas with low precipitation (e.g. Spain), small tanks can store sufficient amounts of water to cover 100 % of these needs in single-family households (Domènech and Saurí, 2011). Subsidies are an effective way to encourage private owners to retrofit their buildings for rainwater harvesting (Domènech and Saurí, 2011; Papadaskalopoulou et al., 2015). Examples of city initiatives in Poland are described in Box 3.14. In Czechia, a national grant programme called Dešťovka (44) ('Rainwater') was opened by the Ministry of the Environment for both existing and new houses in 2017, to motivate homeowners and construction companies to capture rainwater and so to decrease the consumption of water from other sources. Since 2017, CZK 440 million (EUR 16.4 million) has been committed to the scheme. It is worth noting, though, that rainwater-harvesting systems have been found not to be cost-efficient, with 75 % of the cases in Europe having a BCR below 1 (RESIN, 2018).

Sustainable urban drainage systems can be used for replenishing groundwater at the city level, and may simultaneously address issues related to pluvial flooding (see Section 3.3). Yet, in the urban setting, there is a risk of groundwater contamination from infiltration of surface runoff if no treatment is installed. Monitoring of swales in Dutch cities found concentrations of heavy metals in the topsoil near storm water inlets (Boogaard et al., 2019). Water filtering can be achieved by using constructed wetlands with vertical water flows, saving space in urban environments. In the Spangen neighbourhood of Rotterdam, a constructed wetland provided for the storage and treatment of about 30 mm of precipitation from 4 ha of built surfaces. The purified water is subsequently stored in a sand layer at a depth of 20 m via an infiltration well. Water from this well can be used for irrigation and cooling in outdoor spaces (45).

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(43) For more information on water restrictions and consumption cuts as adaptation options, see: https://climate-adapt.eea.europa.eu/metadata/adaptation-options/water-restrictions-and-consumption-cuts.

(44) https://www.dotacedestovka.cz

(45) https://fieldfactors.com/blog/indexphp/urban-waterbuffer-is-open

Box 3.13 Waste water reuse in Mediterranean cities

In the province of **Barcelona**, the urban waste water treatment plant in **Baix de Llobregat** provides treated waste water for irrigation in agriculture, but also for watering urban green areas, washing streets and industry. The water is also used for the replenishment of coastal groundwater reserves, preventing saline intrusion, and for maintaining minimum environmental flows of the Llobregat river in particularly dry periods. Operating in a water-scarce region, this treatment plant faces challenges in ensuring sufficient water standards: pollutants arrive at the plant in higher concentrations due to the reduced dilution of waste water streams. To allow the reuse of waste water, the treatment plant needs to deploy advanced techniques to achieve a higher standard of treatment and to avoid polluting receiving watercourses when flows are reduced in dry weather (Ricardo Energy & Environment, 2019). In **Cornellà de Llobregat,** three football stadiums have been equipped with rainwater collectors. The water is used for irrigating the artificial turf football fields, saving some 90 000 m^3 per year of drinking water (EGLA, 2018a).

In **Lisbon**, treated water from two waste water treatment plants (Chelas and Alcântara) is reused for irrigation and street cleaning. A new recycled water network for irrigation of 25 % of the city parks is planned to be completed in 2022. Lisbon also aims to reduce potable water consumption by designing irrigation-free green areas containing predominantly native plant species, such as biodiverse meadows (EGCA, 2018). This initiative has been supported by a specific framework for waste water reuse, entered into force in Portugal in August 2019, accompanied by a guide for the implementation and management of water reuse projects.

Malta currently operates three water reclamation plants, providing the tertiary and final effluent treatment of the output from three urban waste water treatment plants. Reclaimed water is presently distributed for agricultural and industrial use. In 2019, circa 0.9 million m^3 of reclaimed water was made available for reuse. A 62 km distribution network extension project is under way to serve a larger customer base and meet increasing demand (personal communication from Stefan Cachia, Water Services Corporation, Malta, 2020).

In **Cyprus**, 35 waste water treatment plants clean 21 million m^3 of effluent water each year. The ambition is to increase their capacity to 80 million m^3 of treated waste water for use in farming and recreational spaces (e.g. golf courses) by 2025. Cyprus is gradually phasing out all discharging of treated waste water into the sea and will effectively close the urban water cycle by reusing all urban waste water for secondary uses, such as irrigation of green areas and replenishment of groundwater reserves. Searching for alternative water resources to desalinated water, the city of **Limassol** has become a pioneer in the implementation of sustainable urban drainage systems in Cyprus. The city has constructed four rainwater retention ponds with a total capacity of 200 000 m^3, which, while setting aside water for the urban water supply, also help to reduce pluvial flooding impacts (Papadaskalopoulou et al., 2015; Neocleous, 2018).

Box 3.14 Polish cities subsidise small-scale rainwater retention

In acknowledgement of the increasing frequency and intensity of both droughts and heavy precipitation events, several Polish cities recognise the importance of small-scale rainwater retention. Subsidies are offered to homeowners for rainwater collection systems. The aims of these programmes are to reduce the amount of municipal water used for gardening, cleaning or flushing toilets, and to limit the pressure on the sewerage systems from heavy precipitation events, and thus lower the risk of urban flooding.

In Kraków, private water retention has been subsidised since 2014. Between 2014 and 2018, the city supported 384 installations for rainwater collection and reuse, investing over PLN 1.8 million. Individuals, housing cooperations and businesses can apply for subsidies covering 50 % of the rainwater collection system costs, with a ceiling of PLN 5 000 (around EUR 1 100). In 2019, the city committed PLN 500 000 to the programme. Between January and the end of July 2019, 97 applications were made.

In Wrocław, within the Złap deszcz ('Catch the rain') programme, since August 2019 residents have been able to apply for reimbursements of 80 % of the costs of rainwater collection through either free-standing or underground containers, with a limit of PLN 5 000 (around EU 1 100). The programme is organised by the Wrocław city council in collaboration with the municipal water and sewerage company and the water knowledge centre Hydropolis. To raise awareness of the programme, the municipal water and sewerage company organised a competition, in which 100 rainwater barrels of 210 litres could be won by those sending photographs illustrating their 'eco-creativity'.

Sources: Ciszak (2019); City of Krakow (2019).

3.6 Wildfires

Wildfires in the European context are not well-evidenced in terms of effectiveness and cost-efficiency of adaptation options. As the frequency and severity of forest fires are increasing, wildfire suppression approaches become more expensive and less effective. Therefore, there is a growing need to redirect investment into preventative measures to avoid rising damage and emergency response costs (Alló and Loureiro, 2020).

Wildfire risk in the wildland-urban interface (WUI) can be reduced by addressing the human factors, fire danger and ecosystem vulnerability (Costa et al., 2020). Since most wildfires start as a result of human activity (see Section 2.7.1), awareness raising is a key measure to reduce the risk of wildfires. For example, in Portugal the Education and awareness-raising project for school population (Prosepe) was established in the 1990s and continued for more than 20 years, involving several hundred schools and thousands of teachers across the country (Nunes and Martins, 2018).

Land use planning, reducing urban sprawl into forest and brush areas, is an important measure limiting impacts of forest fires on urban areas. For example, the municipality of Esteribar in the Basque Country, Spain, considered classifying land based on the presence of forests near urban centres, creating firebreaks following recommendations by Civil Protection, duplicating access ways to vulnerable populations and regulating uses of undeveloped land to avoid activities that could cause fires (Climate-ADAPT, 2018a).

Potential for fire to spread can be addressed by land management approaches reducing fuel load and continuity. The costs of fuel removal in WUIs were estimated in the region of Taranto, Italy, and they ranged between EUR 800 and EUR 1 500 per hectare of wildland; the cost of protecting a hectare of urban area in this manner ranges between EUR 18 000 and EUR 1 000, depending on the wind and fuel load scenario (Elia et al., 2016). Calviño-Cancela et al. (2016) conclude that promoting types of land cover with low levels of fire risk provides a low-cost alternative to fuel reduction, since the land does not need to be repeatedly cleared of fuel. An innovative solution combining firebreaks with sprinklers using waste water is being adapted in Riba-roja de Túria, Spain (Box 3.15).

Extensive agricultural practices, such as using animal grazing in break areas, can also reduce the fuel load (Ruiz-Mirazo et al., 2011). Agroforestry, the practice of integrating woody vegetation and agricultural crops and/or livestock, could be another management tool to reduce wildfires in European Mediterranean countries. Agroforested areas have been found to have fewer wildfire incidents than forest, shrubland or grassland, providing evidence of the potential of agroforestry to reduce fire risk and protect ecosystems (Damianidis et al., 2020).

The selection of fire-resilient species and ecosystems represents a further adaptation option, which can be applied at the level of forest and landscape management. As mature native forests, especially deciduous, have lower ignition risk than forestry plantations in the WUI (see Section 2.7), their protection and restoration could not only benefit biodiversity but also reduce fire risk. In Greece, an independent committee appointed by

Box 3.15 Fire prevention and firefighting with reused water: the Guardian project

During the period 2000-2016, 59 forest fires were registered in the area around the city of Riba-roja de Túria (Spain). Approximately 15 000 inhabitants are potentially at risk from fires in the wildland-urban interface. The risk of forest fires could double as a result of climate change in this region.

Supported by EU funding for urban innovative actions, the city is implementing a combined strategy that will reduce fire risk and increase response capacity in case of fire outbreaks. The strategy creates a firebreak area between forests and urban areas, and implements soil and vegetation changes to increase fire resilience in the forests. Residents are informed about fire prevention and supported in increasing it with fire-resilient gardening, and in increasing household protection.

The firebreak area, which separates the forested zone from the urbanised area, is equipped with sprinkler towers, irrigation facilities, fire hydrants and high-pressure hydrant cannons covering the perimeter, which will be activated by an early warning system based on sensors. Spain being a drought-prone region, the city is creating hydraulic infrastructure that will convey water from a waste water treatment plant to fire protection installations.

A simulated image of a sprinkler camouflaged in vegetation © Guardian project

Sources: UIA — Urban Innovative Actions (2020a).

the government to review the lessons from the 2018 wildfires has proposed amending legislation to permit intervention in the management of natural vegetation on private property in WUIs (Blandford, 2019).

Fragmentation between spatial planning and civil protection is a barrier to effective wildfire risk reduction through preventative measures (Greiving et al., 2012). A more flexible and coordinated response requires a shift in approach from top-down to local-level collaboration and consensus. From 2009 to 2011, the INCA project gathered local stakeholders in Italy and Greece to address wildfire risk by seeking agreement on common objectives for hazard prevention. In the Lazio region, to reduce fire risk, the project supported regional coordination of civil protection and urban planning focusing on implementation at the local level. Measures that emerged from the project included using civil protection and urban planning data to identify vulnerable areas and infrastructure; raising awareness among relevant practitioners, such as architects, planners and engineers; regional legislative change; guidelines for local administrators to protect vulnerable areas; and training technical public sector staff to coordinate planning in line with the objectives. Given that many of the wildfire prevention approaches rely on local communities and local public officials or professionals, either for compliance or for volunteer support, it is important that the local support be gained for wildfire risk reduction strategies (Alló and Loureiro, 2020).

Once fire has occurred, early warnings may reduce the impacts. For example, the Portuguese entity responsible for civil protection, following the disastrous forest fires in 2017, has developed a national alert and warning system to the population through text messages that are received on the mobile phones active in the geographical area at risk of wildfires (as well as floods or extreme weather). Other emergency measures include interventions by fire brigades and civil protection authorities. The EU provides support in the form of the EU Civil Protection Mechanism. For example, in 2017, in order to protect the city of Ottaviano, the Italian national civil protection service asked for support from the EU Emergency Coordination Centre in Brussels. As a result, French firefighters were sent to support the Italian authorities (EC, 2018g).

Public health can also be protected by providing timely warnings and advice on how to reduce health risks during air pollution episodes associated with wildfires. Examples include staying indoors and keeping windows closed, avoiding physical activity in polluted outdoor environments, and using room air cleaners to improve indoor air quality. In particular, information and assistance should be targeted towards population groups most vulnerable to air pollution, namely the elderly, young children and those with a pre-existing respiratory or cardiovascular disease (Kollanus et al., 2017).

3.7 Windstorms

There is a paucity of studies on the effectiveness of urban adaptation measures against windstorms. Risks to urban communities and assets can be reduced through a wide variety of measures.

Soft measures include improving the accuracy of forecasting and early warning systems, strengthening emergency response, and increasing awareness of appropriate damage prevention measures and emergency actions to take before and during a windstorm.

Embedding wind-proofing in the design and planning phase of urban development could prevent damage to buildings and key infrastructure, such as power lines, hospitals and schools (Spinoni, et al., 2020). To encourage this, Eurocodes could be amended to include wind-proofing strategies to facilitate implementation across the EU. Design aspects may include building orientation, angling roof slopes to face the prevailing wind direction, shielding from surrounding buildings, and avoiding overhangs and hazardous objects in the surrounding area, such as mature vegetation and cabling.

Moving power infrastructure underground can avoid prolonged power disruptions, as was evidenced in Sweden when storm Gudrun hit in 2005; cabling in urban areas is underground, which meant power could be restored within hours, whereas it took up to 20 days to return power to rural areas because of extensive damage to above-ground power infrastructure (Gündüz et al., 2017).

Replacing vulnerable vegetation (e.g. tall conifers) and planting wind-resistant species (e.g. broadleaved trees) near homes and other assets could prevent damage to buildings and infrastructure from falling trees (Spinoni, et al., 2020). Finally, moving debris and mature vegetation away from transport infrastructure could help prevent disruptions.

3.8 Water- and vector-borne diseases

There is little evaluation of ongoing invasive vector management methods in Europe, which diminishes the opportunity to effectively address the associated risks. There is also a general lack of information in the literature about the actual or projected costs of these vector control programmes, and how to evaluate their cost-efficiency (ECDC, 2017).

Early warning systems providing active surveillance are being developed, such as the European Centre for Disease Prevention and Control Vibrio Map Viewer for the Baltic Sea region, which can compute the risk of water-borne vibrio infections using meteorological forecasts to plot environmental suitability. Public health officials can then be warned of the potential exposure and risk of infection (ECDC, 2020b).

Vector-borne diseases can be addressed with measures that limit the spread of insects, control their numbers and prevent disease outbreaks. Non-pesticide-based control measures are recommended to avoid pesticide resistance, which is exacerbated by the low number of pesticides approved for use in Europe, combined with excessive use in the past and in agriculture (ECDC, 2017). The use of other methods is recommended by the European Directive on sustainable use of pesticides (EU, 2009). Biological control methods — such as microbes, crustaceans or fish that eat mosquito larvae — may be another route to reduce the number of mosquitos (ECDC, 2017). In areas affected by outbreaks, elimination of adult mosquitoes through aerial spraying with insecticides can be considered (ECDC, 2020a).

Invasive mosquitoes tend to proliferate in small, often human-made, bodies of stagnant water, so the management or removal of those water bodies could be an effective measure. However, this may conflict with some flood control measures, such as SUDS (see Section 3.3) and thus need to be considered carefully (see also Section 3.9). Since such water bodies may be located on private property, community engagement appears to be an important factor in the successful and comprehensive implementation of such measures.

Simple protection measures, such as using mosquito nets and screens in windows and doors, can be used to prevent transmission of vector-borne diseases; in a global review of effectiveness of measures against dengue, providing houses with screens had the highest effectiveness (Bowman et al., 2016). Raising public awareness so that people can alert authorities to the appearance of invasive mosquitoes, using citizen science as a resource, is a feasible option (ECDC, 2017). In Italy, awareness and behaviour change measures are included in plans addressing West Nile virus and Usutu virus (Ministero della Salute, 2019).

3.9 Synergies and trade-offs among adaptation measures

The previous sections focused on discussing the effectiveness and cost-efficiency of various measures addressing individual climate hazards. Yet, various adaptation options can address multiple hazards simultaneously, or provide additional co-benefits to the environment, society and the economy; however, they can also exacerbate certain hazards or have negative impacts on other aspects of sustainability, leading to potential maladaptation.

> *The choice of adaptation measures should be informed by an assessment of their co-benefits and negative consequences*

3.9.1 Ensuring urban resilience through synergies

Of the various adaptation options in use, green infrastructure measures emerge as particularly strong for addressing multiple risks and providing multiple benefits. Urban green spaces — particularly trees — score highly in terms of management of high temperatures and rainwater in urban areas, but they also provide nature-protection benefits. For example, high connectivity of green infrastructure not only improves its effectiveness in addressing surface run off, but also enhancing biodiversity (Ruangpan et al., 2020).

The synergistic benefits of green spaces for climate change adaptation and human health have been recognised in the European Green Deal (EC, 2019c). Physical health is improved through the many ecosystem services that green infrastructure provides, such as air quality improvement and cooling during hot periods. There is a growing evidence base for the benefits of green spaces for mental health, including avoiding and reducing psychological stress, anxiety, depression and loneliness through providing a space for physical activity, relaxation and social interaction (e.g. Vanaken and Danckaerts, 2018; Callaghan et al., 2020). Vulnerable groups are the most affected by environmental stressors and tend to suffer from worse mental health, and yet they have the least access to green spaces (EEA, 2020c). The example of social co-benefits of SUDS in regeneration of the relatively deprived Augustenborg neighbourhood in Malmö (see ETC/CCA, 2018b) shows that green infrastructure — with the right design and location — could play a positive and significant role in socially-just adaptation to climate change (see also section 6.5.4).

'Soft' adaptation measures can establish underlying structures upon which further synergies can be based. Cross-departmental initiatives within local authorities (see Section 6.5.2) and intercity networks for shared learning (see Sections 4.3 and 4.6) improve local-level coordination and policy coherence between different levels of governance, and embed climate change adaptation and mitigation in multiple sectors, including urban and spatial planning. These underlying structures are further explored in Chapter 6.

3.9.2 Trade-offs in addressing different risks

While green infrastructure can support many synergies, it may interact negatively with risks such as water scarcity, air pollution, windstorms, forest fires and vector-borne diseases.

Firstly, green infrastructure is not immune to climate risks and can be damaged by extreme weather events. City representatives identified the natural environment to be one of the main areas affected by climate change (see Figure 2.3). For example, droughts have impacted green infrastructure in European cities (Figure 2.9) and maintaining functional green infrastructure in water-scarce conditions may require additional water and energy (for water pumping). Reusing waste water or collecting rainwater could help meet extra demand for water from green infrastructure (see Box 3.13 for examples).

Chaotic air flow at ground level in urban areas makes the interactions between green infrastructure and wind difficult to untangle (Tiwari et al., 2019). For example, trees uprooted by windstorms can cause significant human harm and economic damage (see Section 2.8), but vegetation can also be deliberately used as a windbreak to improve pedestrian comfort (Johansson and Yahia, 2020). The effect of green infrastructure on air pollution in urban areas is also much debated and depends on multiple factors, including wind, location, and vegetation size and structure (Łowicki, 2019; Xing and Brimblecombe, 2019). Vegetation can reduce local air pollution through deposition and dispersion, but it can also create pockets of increased air pollution from reduced wind speed (Riondato et al., 2020; Taleghani et al., 2020). Local-level pollution dynamics should therefore be incorporated into spatial planning of green spaces (Łowicki, 2019); for example, careful landscaping in urban parks can encourage visitors to avoid more polluted areas (Xing and Brimblecombe, 2019).

A trade-off arises between measures recommended to address heat stress and those to reduce risk of forest fires in the WUI, especially in hot dry climates. Green infrastructure can improve thermal comfort (see Section 3.2), but wildfire prevention measures include removing vegetation in the WUI and replacing fire-prone species with more resistant alternatives (see Section 3.6) (Costa et al., 2020). Similarly, restoring wetlands and riparian forests can have important cooling and water retention benefits in urbanised areas, as well as promoting biodiversity. However, stagnant water could increase the spread of vector-borne diseases. These tensions and trade-off should be considered in the design phase of green infrastructure measures to enhance their adaptation potential and minimise downsides.

Adaptation options based on grey infrastructure can be costly and inflexible. It is therefore important to understand their potential impact on risks beyond those they seek to address. For example, structural flood defences implemented in upstream areas vulnerable to flooding can displace flood risk downstream (Heritage and Entwistle, 2020). The optimisation of existing control structures, in combination with hydrological modelling and expertise, can help distribute and minimise flood risk in river networks where urban areas are exposed (Mel et al., 2020). Buildings can be configured to minimise the UHI effect through shading (see Section 3.2), but taller buildings can lead to higher energy demand from the increased lighting needs on lower floors, or may increase the risk of wind damage (Samuelson et al., 2016; Elshaer et al., 2017).

Synergies and trade-offs also arise between climate change adaptation and mitigation strategies at the local level. Adaptation measures taken to address certain risks can add to the problem. For example, air conditioning improves health and well-being during heatwaves and forest fires but adds to the energy demand in cities. Ensuring renewable energy sources could help alleviate the adverse impact of such a coping strategy, and the overall energy demand of a city can be lowered by replacing individual use of air conditioning with communal cooling spaces, as is being implemented in Paris (see Box 3.5).

During dry summers with additional tourism pressures, desalination is used to cover water demand (mainly in Mediterranean countries). However, desalination comes with high energy consumption and impacts on coastal and marine ecosystems (Papadaskalopoulou et al., 2015). Yet desalination solutions are still used in water-scarce places, for example on the Swedish island of Gotland (see Section 2.6.3). These adaptation-mitigation interactions are further explored in Section 6.5.3.

3.10 Effectiveness and cost-efficiency of adaptation measures: conclusions and outlook

As our knowledge of the scale and direction of projected climate impacts grows, in a world of limited resources the choice needs to be made: whom and what to protect, which measures to choose and how much to invest in them. Chapter 3 shows that we still know little about the effectiveness and cost-efficiency of various adaptation measures. In order to build up this knowledge and enable the well-founded selection of adaptation options, monitoring, reporting and evaluation of the implemented measures are of key importance. There is a need to move from tracking adaptation processes, towards understanding the outcomes and impacts of policies and actions (EEA, 2020d). Section 6.4 discusses monitoring of urban adaptation in more detail. Research into effectiveness and cost-efficiency of measures is also important to help build the knowledge base; to benefit from such research, cities can collaborate closely with scientists or even take 'living laboratory' approaches (see Section 6.2.2).

The key challenges to applying cost-benefit analysis in the evaluation of adaptation measures include modelling the net present value of resilience measures, assessing the value of intangibles (e.g. human lives and environmental or cultural treasures) and monetising the benefits and co-benefits of multi-purpose resilient infrastructure (Sushchenko and Schwarze, 2020). Therefore, there is a need for transparency in methods and assumptions made in assessing the cost-efficiency of measures, in relation to the timespan assessment, methods of calculation of the benefits, and whether the assessment considers only adaptation benefits or broader aspects. This is particularly pertinent in relation to green infrastructure measures, the co-benefits of which can be substantial (see Section 3.9). Some guidance on cost-benefit analysis of adaptation options can be found in the Urban Adaptation Support Tool (46).

Ideally, the evaluations of adaptation options should go beyond assessing the effectiveness of single measures against a given climate risk, to also look at their combinations and the effects of measures on other hazards, quality of life and broader environment. Some examples of synergies and trade-offs are presented in Section 3.9, and co-benefits of adaptation measures are further discussed in Section 6.5.2, but more knowledge is needed on the interactions of measures with various aspects of urban sustainability.

Despite the limited knowledge of the effectiveness and cost-efficiency of adaptation measures, some lessons can be learned. Firstly, in order to prevent damage from the future climate, the planning and construction of our cities need to change. In general, the assessment of the effectiveness and cost-efficiency of options points towards a more natural shape for cities, utilising nature-based solutions and thus bringing how cities function closer to the cycles of nature. For example, making room for the river, reusing treated waste water, allowing groundwater recharge through SUDS, shading and cooling through green spaces, and traditional land management of hinterlands to avoid accumulation of fuel in wildfire-prone areas emerge as feasible measures. However, preparing the built environment and infrastructure, e.g. sewerage systems and transport, for the unprecedented scale of future extreme weather events is also key. Section 6.5.1 discusses opportunities for integration of adaptation into urban planning.

Secondly, 'soft' adaptation measures such as awareness raising and education, with relatively little investment, can bring substantial benefits in terms of preventing some risks (e.g. limiting the incidence of forest fires) or limiting their impacts, e.g. by ensuring that citizens understand the warnings and follow the guidance before and during extreme weather events. Citizen involvement and engagement can also be a useful source of information about the occurrence of risks and damage (see Section 6.2.3).

Thirdly, while preventing the impacts of climate change in cities is key, the links to disaster risk reduction are also crucial (see also EEA, 2017a), as early warnings emerge as an effective and cost-efficient approach to reducing damage.

Finally, the options to use in adapting cities and towns need to be carefully considered in each context. For example, a relatively low level of effectiveness of an option established to date through scientific studies should not preclude including it in the catalogue of relevant adaptation options (47), as it may be the right fit for the local circumstances and budget.

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(46) https://climate-adapt.eea.europa.eu/knowledge/tools/urban-ast/step-4-2
(47) https://climate-adapt.eea.europa.eu/knowledge/tools/urban-ast/step-3-1

We need to monitor and evaluate the implemented adaptation measures to learn about their effectiveness

When choosing adaptation options, it is necessary to pay attention to their potential negative consequences to avoid maladaptation. For example, the deployment of some measures (e.g. flood defences, seawalls) may result in the displacement of risks to other areas. Other measures (desalination, air conditioning) tend to have negative environmental consequences and should be avoided in the long term.

The implications for social justice should be considered carefully when choosing the adaptation measures. For example, while water pricing can reduce the water demand, it may have negative consequences for those on lowest incomes. Subsidies for rainwater collection may benefit only house owners, and not be relevant to renters or those living in apartments; property-level flood protection or flood insurance may not be affordable to everyone. The quality of the built environment tends to be lowest among lower socio-economic status groups, and its improvement — alongside adaptation of facilities such as schools or hospitals — should be prioritised (see also Section 6.5.4).

The complexity of climate risks in urban settings and the multitude of adaptation options available call for the engagement of various stakeholders in adaptation planning and implementation. Chapter 4 explores the multi-level governance of urban adaptation to climate change in Europe.

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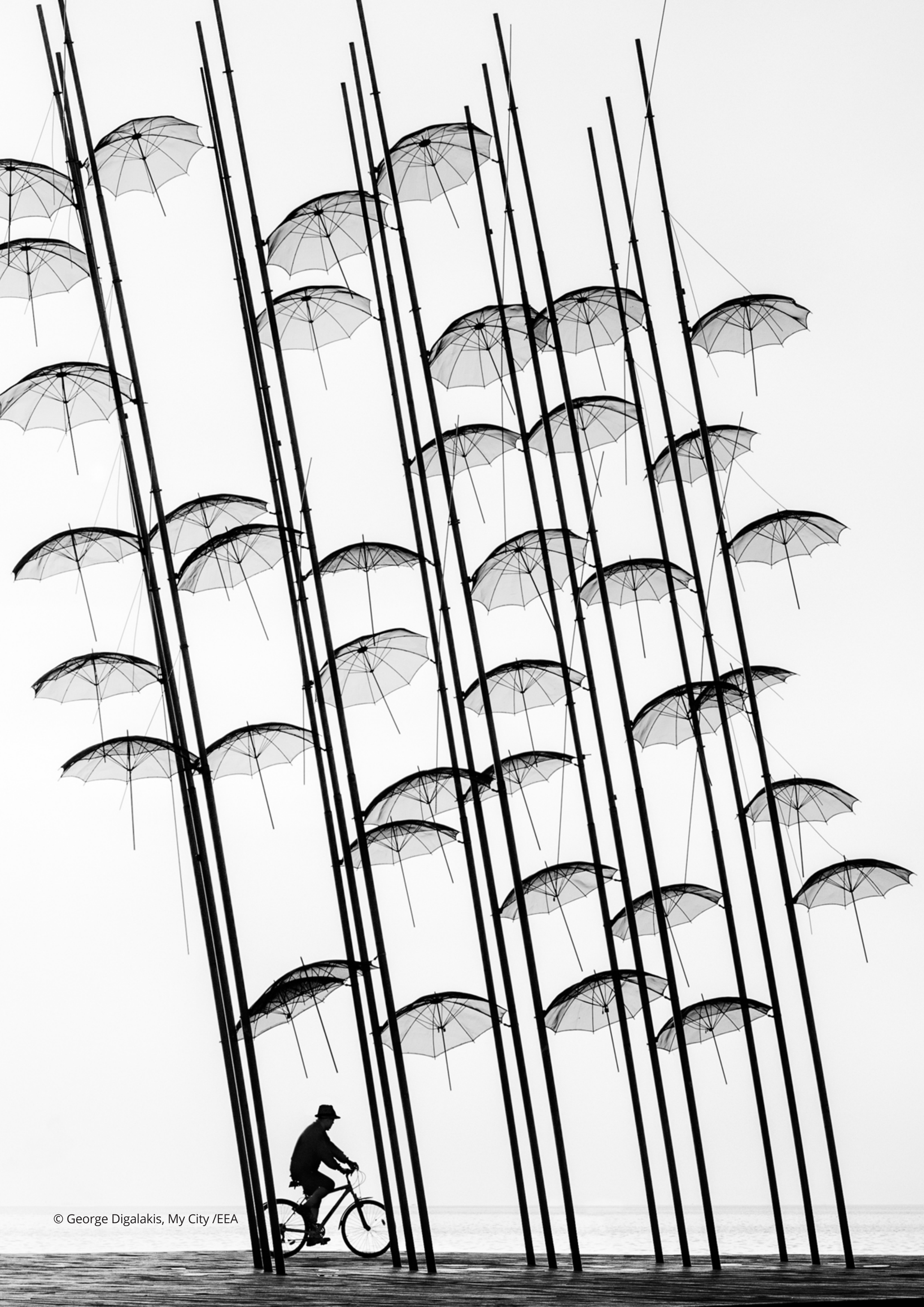

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4 Multi-level governance of urban adaptation in Europe

Key messages

- Local adaptation is embedded in a broader governance context, in which cities both are influenced by higher governance levels and can themselves drive change.
- Key international frameworks (i.e. the Paris Agreement, Agenda 2030, New Urban Agenda, Sendai Framework) encourage adaptation to climate change at the local level, with emphasis on urban areas.
- Urban adaptation to climate change is firmly anchored in EU policy through the EU adaptation strategy and its revision, with other instruments such as the Floods Directive, the green infrastructure strategy or the EU urban agenda having a supportive role.
- EU funding for climate adaptation at the local level is mainstreamed across EU sectoral policies. Several hundred cities have benefited so far from EU funding for adaptation-related research, knowledge exchange, planning and implementation of measures.
- Numerous international, European and national city networks play an important role in helping their members exchange knowledge and experiences, and providing advice, support and motivation to act on adaptation.
- Most EU Member States recognise the importance of adaptation in the urban context and identify local governments as the implementers of adaptation. Local-level adaptation planning or climate change risk assessments are mandatory in some countries.
- National-level support for cities and other local authorities for adaptation involves funding, capacity building and knowledge provision. However, the support available differs between European countries.
- Regional-level governance of adaptation plays an important role in coordinating and supporting local actions, especially for small municipalities with limited capacity and remit.

4.1 Introduction

To be planned and implemented, the adaptation measures described in the previous chapter require effective governance, i.e. organisation of government hierarchies and structures to allocate resources and to coordinate actions. According to the subsidiarity principle, policy making tasks are assigned to the lowest suitable level of administration, aiming to keep decision-making as close to citizens as possible (EEA, 2016). At the same time, local adaptation is embedded within a broader context, in which cities both are influenced by higher governance levels and can themselves drive change. The Paris Agreement stresses the importance of multi-level governance in adaptation, stating that 'Parties recognize that adaptation is a global challenge faced by all with local, subnational, national, regional and international dimensions, and that it is a key component of and makes a contribution to the long-term global response to climate change to protect people, livelihoods and ecosystems' (UNFCCC, 2015).

Understanding the complex, multi-scalar context of local adaptation policymaking, and the ways in which non-local forces influence local governments' adaptation policy choices, is crucial for effective local adaptation planning and for providing cities with the best possible support. Therefore, this chapter analyses how international and European policy frameworks recognise and drive local-level adaptation, what the collaboration between local, regional, national and European and international levels looks like, and what are the roles of international city networks and initiatives. This provides context for Chapter 5, which explores the status of adaptation policy planning and implementation in European local authorities.

4.2 International and EU policy frameworks for urban adaptation

4.2.1 International frameworks

The international policy landscape for climate change adaptation in the urban context changed significantly in 2015-2016 with the adoption of several international agreements and frameworks within the structures of the United Nations (UN), with the intention that they would reinforce each other and that stakeholders would find synergies between various policies, plans and measures. All of them highlight the importance of adaptation action and recognise the instrumental role of local authorities.

Adopted in December 2015, the Paris Agreement (UNFCCC, 2015), established the first global goal on climate change adaptation and emphasised its local dimension. The agreement recognised adaptation as a cornerstone of the global response to climate change and thus established its equal importance to mitigation actions (Magnan and Ribera, 2016).

A few months earlier, the UN General Assembly had agreed on the 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDGs). Providing an overarching framework for a better future applicable to developed and developing countries alike, the 2030 Agenda introduced Goal 11, which strives to 'make cities and human settlements inclusive, safe, resilient and sustainable'. It therefore put resilience at the forefront of the future urban development and set out a target to substantially increase the number of cities adopting and implementing policies towards adaptation to climate change and resilience to disasters by 2020 (UN, 2015b). Furthermore, in Goal 13, global leaders pledge to take urgent action to combat climate change and its impacts and to increase resilience and adaptive capacity, as well as to integrate related measures into national policies and planning.

These objectives were referred to and further specified in the New Urban Agenda, which the UN General Assembly ratified in October 2016 (UN, 2017). To implement the goal of making cities more resilient, signatory states promised to promote local climate action (including adaptation), for example by supporting the efforts of cities. States also pledged to support adaptation-planning processes, including city-level assessments of climate vulnerability and impacts, and to integrate climate change adaptation considerations into urban and territorial development and planning processes.

The Sendai Framework for Disaster Risk Reduction 2015-2030 acknowledges climate change as a driver of disaster risk and sets out a guiding principle that disaster risk reduction (DRR) requires full engagement of all state institutions at both national and local levels. It also highlights the need to empower local authorities and communities to reduce disaster risk (UN, 2015a). One of the Sendai Framework global targets is to increase the number of local DRR strategies by 2020. Member countries are required to report on the percentage of local governments that adopt and implement local disaster risk reduction strategies in line with the national DRR strategy. By 2019, 2 032 local authorities from 13 out of 37 EEA member and collaborating countries (excluding Kosovo (48) and the United Kingdom) adopted and implemented local DRR strategies in line with their national DRR strategies (personal communication from Chiara Menchise, United Nations Office for Disaster Risk Reduction, 2020).

The international frameworks tend to have an indirect impact on local adaptation, through regulation, funding and other instruments at the disposal of, for example, the EU and its Member States, as all of these agreements were negotiated and signed by national governments, with some consultation of city representatives (Valencia et al., 2019), and most actions are to be implemented by national governments. The adoption of international frameworks does not necessarily directly prompt city action on adaptation. For instance, in an analysis of the triggers leading to the development of 147 local adaptation plans in Europe, Aguiar et al. (2018) found that the United Nations Framework Convention on Climate Change process had prompted development of only 21 local adaptation plans.

4.2.2 Key European policies and initiatives

European Green Deal

In December 2019, the European Commission launched the European Green Deal (EC, 2019c) to transform Europe's economy in a way that prevents further climate change and environmental degradation. The European Green Deal is a growth strategy towards a modern, resource-efficient and competitive economy with zero net emissions of greenhouse gases by 2050 and sustainable resource use. This transformation is planned as just and inclusive. The roadmap with actions was presented to boost efficient use of resources, restore biodiversity and cut pollution. The European Green Deal outlines investments needed and financing tools. All EU actions and policies will have to contribute to the European Green Deal.

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(48) This designation is without prejudice to positions on status, and is in line with UNSCR 1244/1999 and the ICJ Opinion on the Kosovo declaration of independence.

Under the European Green Deal, the European Commission plans to adopt a new, more ambitious EU strategy on adaptation to climate change by 2021. According to the European Green Deal, future efforts on adaptation should be strengthened, continue steering public and private investments, and ensure access to data and instruments for a wide variety of stakeholders, including cities, 'to integrate climate change into their risk management practices' (EC, 2019c).

In addition, the EU Green Deal provides other opportunities to enhance climate adaptation in the urban context. The 'renovation wave' initiative encourages renovation of existing buildings, with the main goal of decarbonisation (EC, 2020g). In addition to cutting emissions by using renewable energy sources, the renovation will aim for safer and healthier buildings, thus also providing an opportunity to tackle issues related to heatwaves and flooding. The case studies from Rotterdam (Box 3.2), Zaragoza (Box 3.4) or Dresden (Box 6.18) provide examples of renovation activities helping to climate-proof buildings.

The European Green Deal also includes actions supporting biodiversity, and can therefore also play an important role to speed up the implementation of nature-based solutions. In particular, afforestation and planting trees will be encouraged.

EU strategy on adaptation to climate change

The backbone of the European adaptation policy framework is the 2013 EU strategy on adaptation to climate change (EC, 2013a; see Figure 4.1). The strategy acknowledged the importance of acting at all levels, including the local, and introduced support schemes to specifically incentivise cities to take voluntary adaptation action. To this end, the Mayors Adapt initiative was funded in 2014. In 2015, it was merged with the Covenant of Mayors to create the Covenant of Mayors for Climate and Energy. The EU strategy on adaptation to climate change also provided guidance for mainstreaming (49) climate action across EU policy (e.g. cohesion policy) and started support for the climate action subprogramme of the LIFE initiative (EC, 2013a). Many local authorities are making use of these funding options to develop adaptation plans and implement specific actions.

> *The revision of the EU adaptation strategy is an opportunity to further develop urban adaptation in Europe*

The EU adaptation strategy was evaluated in 2017-18 and was considered to be fit for purpose, even though adaptation needs had intensified and diversified. According to the implementation report by the European Commission, overall, the strategy has delivered on its objectives and progressed on each of its actions, acting as a reference point to focus and catalyse action at all levels of government (EC, 2018b). Nevertheless, progress on local adaptation varies between Member States and has been slower than originally envisaged in 2013: all cities with more than 150 000 inhabitants were originally expected to have adopted an adaptation strategy by 2020, whereas an estimated 40 % of this target was achieved by 2018 (EC, 2018b). The European Commission therefore suggests further increasing awareness as well as technical and financial assistance to local authorities, e.g. through the Covenant of Mayors initiative, and encouraging Member States to create or pursue frameworks enhancing local action, e.g. through better integration of adaptation into national and regional legal frameworks, and increased national and regional technical assistance and funding for the local level (EC, 2018b; see Sections 4.4 and 4.5).

The blueprint of the new adaptation strategy (EC, 2020c; in public consultation between May and August 2020) considers the recommendations from the evaluation, and emphasises improving knowledge of climate impacts, reinforcing planning and climate risk management, and accelerating action with focus on solutions. Specifically, in relation to cities, the new strategy aims to continue to encourage resilience building, capitalising on the success of the Covenant of Mayors initiative, and emphasises the need for cities to have better access to data to make resilience investment decisions. It also promises that adaptation and disaster risk management will be a key priority for the European Regional Development Fund and the Cohesion Fund in the period 2021-2027, with a place-based approach to improving the resilience of EU regions and cities.

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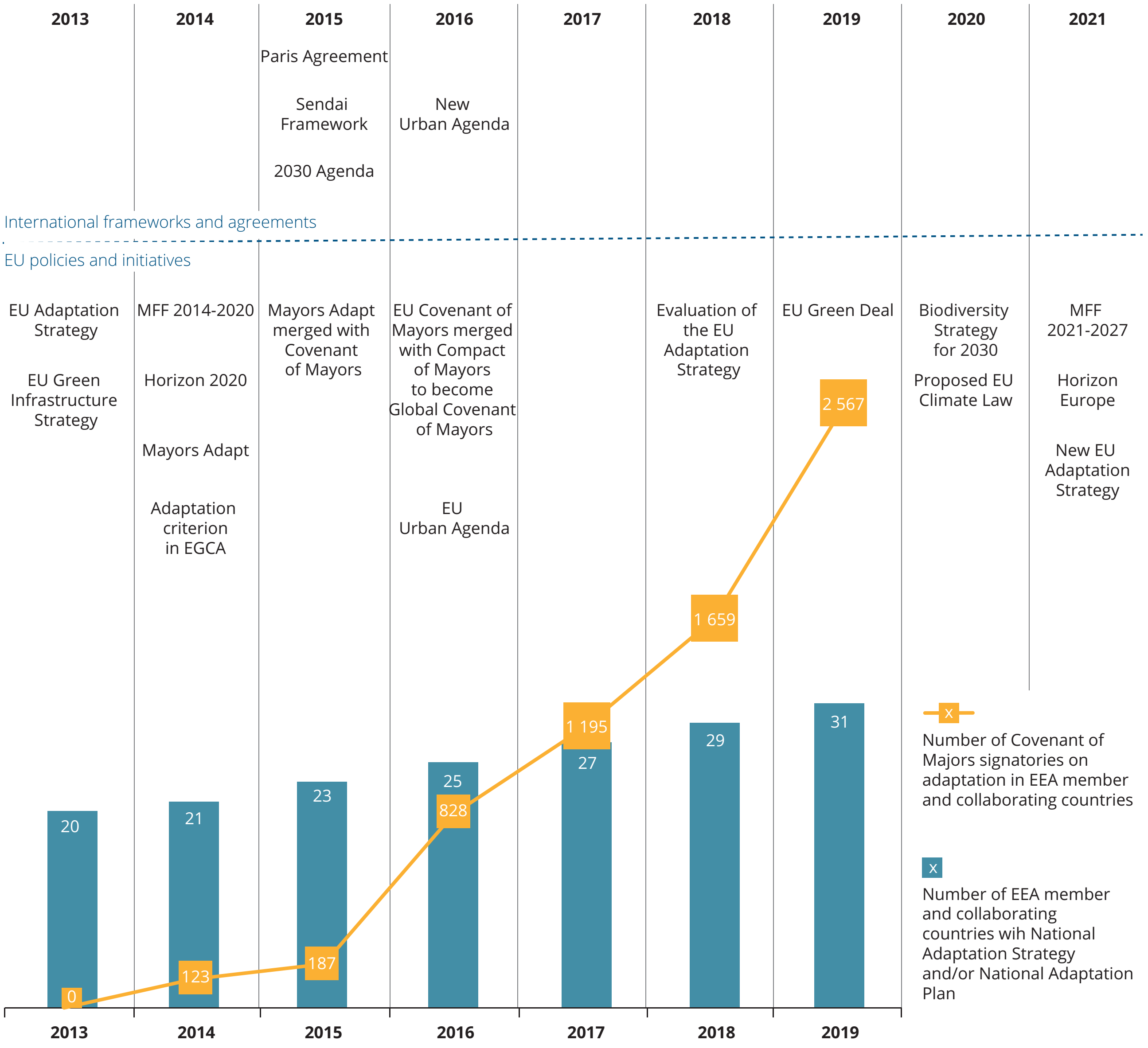
(49) Mainstreaming is the integration of climate change adaptation into related government policies in different sectors, see glossary.

Figure 4.1 **Timeline of policies, activities and milestones relevant to urban adaptation**



Source: Authors' compilation based on personal communication from Lea Kleinenkuhnen, Covenant of Mayors for Climate and Energy — Europe Office, 2020.

Governance Regulation

Under the Regulation on the Governance of the Energy Union and Climate Action (EU, 2018), EU Member States are expected to develop national energy and climate plans that provide an overview of their climate and energy policies for 10-year periods, starting with 2021-2030. In parallel, Member States are required to submit their long-term strategies for energy and the climate up to 2050. National governments are expected to include their strategies, plans and measures on adaptation to climate change in their plans. Several Member States with adaptation goals had included them in the draft plans submitted to the Commission at the end of 2018 (EC, 2019e).

Under Article 11 of the Governance Regulation, EU Member States are expected to establish multi-level climate and energy dialogues with local authorities and other stakeholders, to engage with them, discuss scenarios envisaged for climate and energy policies, and review progress. Under Article 19, by 15 March 2021, and every 2 years thereafter, Member States shall report to the Commission information on their national climate change adaptation planning and strategies, outlining implemented and planned actions to facilitate adaptation to climate change (EU, 2018). Consultation among the Member States on the implementing act specifying details of the reporting took place in early 2020 and was scheduled for adoption by the Commission in 2020. The EEA will collect the information from Member States and include it in country profiles on Climate-ADAPT (50).

The reporting under Article 19 of the Governance Regulation replaces the mechanism through which Member States used to inform the European Commission of their adaptation activities: the EU Greenhouse Gas Monitoring Mechanism Regulation (MMR) (EU, 2013). By March 2019, all Member States had responded as obliged under the MMR, describing measures undertaken for the creation of a national policy framework, identifying priority sectors and vulnerabilities and outlining the stakeholders involved (51). Local authorities emerge as important in these reports, both as stakeholders participating in the formulation of national adaptation strategies and plans and, in many cases, as those responsible for local-level implementation of national adaptation goals (see Section 4.4).

Proposed European climate law

The role of the proposed European climate law is to provide a legal basis for the European Green Deal goal of Europe being climate-neutral by 2050. The proposed climate law also includes the objective of enhancing resilience through more adaptive actions (EC, 2020h). Among other things, it requires that Member States develop and implement adaptation strategies to strengthen resilience and reduce vulnerabilities to the effects of climate change (Article 4). Subsidiarity is one of the key principles of the proposed climate law, which means that adaptation will take place at the most appropriate and cost-effective governance level. The proposed climate law clearly promotes the further development of multi-level governance, in which local authorities also play an important role, to ensure that EU targets are attained.

Climate Pact

The European Climate Pact is one of the roadmap actions of the EU Green Deal that aim to foster collaboration for climate action, at all governance levels, including local authorities (EC, 2020e). It aims to engage citizens and communities on climate-related issues, emphasising that the general public and organisations in all sectors have a role to play. Communication activities are planned to raise awareness and understanding of climate change, and to inspire and encourage behavioural change. The pact will encourage people and organisations to commit to concrete actions for mitigation and adaptation. It will also provide opportunities for online and offline learning and networking.

EU Floods Directive

Given the significant impact of flooding on cities (Section 2.4), the EU Floods Directive (EU, 2007) plays an important role in supporting countries, and therefore also cities, to prevent, protect and prepare, as well as how to recover from flooding. The directive required Member States to assess (by 2011) and map (by 2013) diverse flood risks and their impact on people and assets. Member States developed flood risk management plans in 2015. These actions were intended to be repeated every 6 years and synchronised with the Water Framework Directive. The updated flood maps were submitted recently (2020), and updated flood risk management plans are expected by 2022.

The EU Flood Directive is relevant to urban adaptation through the promotion of flood risk maps to inform and raise awareness, and of flood risk management plans to design and implement measures to reduce flood risk (EC, 2019b). The maps and management plans are often provided by Member States (e.g. Belgium and the Netherlands) as online portals and can therefore easily be accessed by urban decision-makers. However, only 15 of the 26 Member States have included climate change in the flood risk assessment thus far (EC, 2019b). In addition, only four Member States (Denmark, Finland, Slovakia and Sweden) plus the United Kingdom have developed flood risk management plans at the sub-basin or local level, directly relevant to cities. Nonetheless, by 2019, 18 of the national flood risk management plans indicated measures that have to be implemented by local authorities, importantly including land use planning and management, which are key for mitigating the risk of flooding (see Section 3.3).

Finally, the Flood Directive encourages public participation in preparing flood risk management plans. It is also expected to have contributed to better collaboration and dialogue between flood managers and civil protection agencies; however, this has not yet been evaluated.

Urban agenda for the EU

In addition to the EU adaptation strategy, the EU has also recognised adaptation as a priority topic as part of its EU urban agenda, which was launched with the Pact of Amsterdam in 2016 by the European ministers in charge of urban matters (EC, 2016b). The aim of the urban agenda is to involve urban authorities better in EU policymaking in order to improve delivery on the Union's strategic objectives for 2020. This is in recognition of the large proportion of EU legislation implemented in urban areas, and the consequent need to anticipate implementation difficulties at the local level. With the urban agenda, the EU explicitly aims to contribute to the UN 2030 Agenda for Sustainable Development (UN, 2015b) — notably Goal 11 ('Make cities and human settlements inclusive, safe, resilient and sustainable') — as well as the global new urban agenda (UN, 2017).

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(50) https://climate-adapt.eea.europa.eu/countries-regions/countries
(51) Ibid.

As one of the 12 priority themes of the urban agenda for the EU, adaptation to climate change in cities is addressed by a dedicated partnership (Box 4.1), gathering representatives from different levels of governance and other stakeholders, and intended to act as a key delivery mechanism of the agenda. The adaptation partnership defined its actions based on an analysis of pre-existing EU policies relevant to adaptation and the results of a series of surveys on bottlenecks regarding urban adaptation. The actions, originally planned to be implemented by mid-2020, aim to fill any remaining gaps as well as to scale up, adjust and better target the existing initiatives, policies and tools put forward by the EU level (Purkarthofer, 2019).

Territorial agenda

The territorial agenda of the EU is also worth mentioning. Initially adopted in 2011 by the EU ministers responsible for spatial planning and territorial development, the goal of this strategic policy document is to offer an action framework towards territorial cohesion across the EU, engaging policymakers at all governance levels. Its renewed version, to be adopted by ministers in December 2020, includes a priority axis on healthy environment, which highlights the importance of all places' resilience to the impacts of climate change (EC, 2019g).

Biodiversity strategy for 2030

In the EU biodiversity strategy for 2030 (EC, 2020d) nature-based solutions are described as essential for emission reduction and climate adaptation. In particular, ecosystem restoration is seen as a key instrument and will be subject to 'legally binding EU nature restoration targets in 2021 to restore degraded ecosystems, in particular those with the most potential to capture and store carbon and to prevent and reduce the impact of natural disasters'. In particular for the urban context, the strategy states that planting trees and deploying green infrastructure will help us to cool urban areas and mitigate the impact of natural disasters.

Green infrastructure strategy

Green Infrastructure is promoted by the EU as a way to create new ecosystems and to restore degraded ones. In the green infrastructure strategy (EC, 2013b), emphasis is placed on investing in green infrastructure solutions that boost disaster risk management and facilitate adaptation to the impacts of climate change. As cities and local authorities are on the frontline of dealing with the immediate consequences of climate-related hazards, the strategy highlights their critical role in implementing prevention measures such as green infrastructure.

European Green Capital and Green Leaf Awards

Since 2010 the European Green Capital and European Green Leaf Awards have recognised European cities and small towns that show strong commitment to urban sustainability across 12 key environmental areas. The awards are intended to highlight successful implementation of EU sustainability policy. The evolving criteria used to assess the cities reflect the changing importance of different aspects of urban sustainability. Climate change adaptation was written into the assessment framework in 2014 (linked to the publication of the EU adaptation strategy in 2013) and was afforded its own assessment category in the 2020 competition, when the 'Climate' category was divided into mitigation and adaptation. This suggests that climate adaptation is gaining importance in the assessment of cities' sustainability achievements, including the increasing prominence of climate adaptation measures in winning applications. This promotion of adaptation can extend beyond the reach of the initiative itself, as the awards are seen to foster a culture of sustainable governance that heightens ambition beyond regulation of conventional environmental problems (Gudmundsson, 2015) through, for example, sharing best practices with cities across Europe. The 2020 round of submissions (for the 2022 awards) is on the theme of 'building urban resilience', in recognition of the key role the sustainability of cities plays in addressing the environmental, social and health crises (52).

4.2.3 Key EU funding for urban adaptation

EU funding for climate adaptation is mainstreamed across EU sectoral policies. Under the 2014-2020 multiannual financial framework (MFF), it is integrated into the European Structural and Investment Funds, as well as into research and development instruments such as LIFE and Horizon 2020. Between 2014 and 2020, 20 % of the EU's budget was earmarked for climate-related expenditure (including adaptation). The European Commission proposed in 2018 to increase this proportion to 25 % of the 2021-2027 MFF (EC, 2017b). For more detailed and up-to-date information on EU funding for climate adaptation at the city level, please refer to the relevant Climate-ADAPT (53) and Covenant of Mayors (54) websites.

Several Member States use European Structural and Investment Funds, e.g. from the European Regional Development Fund or the European Agricultural Fund for Rural Development, to fund local adaptation measures. This funding is allocated through national or regional operational programmes and channelled through the managing authorities. For example,

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(52) https://ec.europa.eu/environment/europeangreencapital/news/EGCA_2022_EGLA_2021_finalists_announced.html
(53) https://climate-adapt.eea.europa.eu/eu-adaptation-policy/funding
(54) https://eumayors.eu/support/funding.html

Box 4.1 EU urban agenda Climate Adaptation Partnership and its actions

The Climate Adaptation Partnership was set up in 2017 under the coordination of the Italian city of Genoa. The members represent all governance levels, from European to local. It also involves key stakeholders engaged in urban adaptation to climate change in the EU (see Table 4.1).

Table 4.1 Members of Climate Adaptation Partnership

Member States	Local/regional authorities	European Commission	Other EU organisations
Bulgaria	Barcelona Diputación (ES)	DG Climate Action	Council of European Municipalities and Regions
France	Genova (IT)	DG Environment	Covenant of Mayors
Hungary	Glasgow (UK)	DG Regional and Urban Policy	EEA
Poland	Loulé (PT)	DG Research adn Innovation	Eurocities
	Potenza (IT)	Joint Research Centre	European Investment Bank
	Sfantu Gheorgue (RO)		Urbact
	Trondheim (NO)		

A set of 10 actions was put forward, focusing on those issues for which European-level action is most needed and adds most value. The actions contribute to the three Pact of Amsterdam objectives:

1) Better regulation:

- analysis of national multi-level urban development and planning regulations with a focus on climate adaptation.

2) Better funding:

- guidelines and toolkit for the economic analysis of adaptation projects,
- including recommendations for the operational programmes of the European Regional Development Fund to improve its accessibility for municipalities,
- a new LIFE for urban adaptation projects.

3) Better knowledge:

- improving EU municipalities' knowledge in the framework of the Copernicus Climate Change Service,
- enhancing the local content of Climate-ADAPT,
- political training on climate adaptation,
- enhancing stakeholder involvement at regional and local levels,
- promoting open access to insurance data for climate risk management,
- further engagement of national and subnational government associations as key facilitators (and relevant Covenant of Mayors supporters) to best support local authorities in their adaptation process.

Note: DG, Directorate-General.

Source: Climate Adaptation Partnership (2018).

Croatia and Hungary rely on EU financial support to fund local-level adaptation measures (EC, 2018c; Eionet, 2019). Over 70 cities, mostly in Italy, Latvia, Lithuania and Portugal, have directly benefitted from the European Regional Development Fund (ERDF) for the development and/or implementation of integrated sustainable development plans which included a focus on climate adaptation (55).

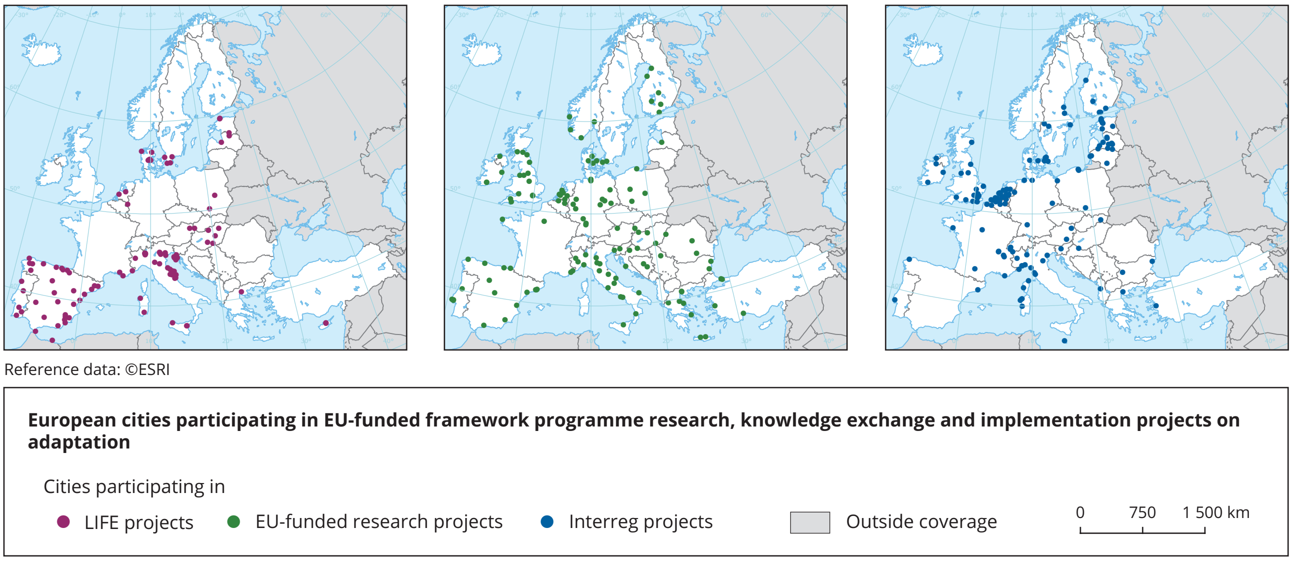
The post-2020 cohesion policy will continue to support activities in the area of climate and environment. The Cohesion Fund and the European Regional Development Fund are expected to invest more than EUR 100 billion in climate- and environment-related projects over the next 7 years (2021-2027), constituting over 30 % of the total budget (EC, 2018e).

The European cohesion policy also supports the urban innovative actions programme, under which urban authorities test how new and unproven innovative solutions work in practice. Such experiments are implemented in partnership with all the key players in one local innovation ecosystem. This programme includes a cluster of projects focused on climate adaptation and taking place in the cities of Amsterdam (see Box 5.5), Barcelona, Greater Manchester, Paris, Riba-roja de Túria (see Box 3.15) and Seville (56).

The EU funds research, knowledge exchange and implementation projects in adaptation at the local level. By June 2019, over 140 cities and other local and subnational authorities were direct beneficiaries or partners in 33 LIFE projects closely relevant to adaptation (57). Just 10 of these projects concerned individual cities; others involved several local authorities, thus incorporating a strong element of knowledge exchange. The highest numbers of cities, local and subnational authorities participating in LIFE adaptation projects were located in Italy (40) and Spain (35) (Map 4.1).

Since the fifth framework programme, over 120 cities have been partners in EU-funded research projects relevant to adaptation, including projects committed to implementing nature-based solutions to prove their multiple benefits. Some of the cities have participated in two, three or even more projects, which suggests that their involvement was advantageous (see also Box 6.4). Similarly, 128 cities have participated in 33 Interreg projects on adaptation (58) (Map 4.1), which facilitate knowledge exchange (Box 4.2). Some cities — such as Milan, Riga, Rotterdam or Thessaloniki — have participated in all three types of projects (LIFE, Interreg and research), thus benefiting from interactions with the research organisations and other cities in developing knowledge and implementing adaptation solutions.

Map 4.1 **European cities participating in EU-funded framework programme research, knowledge exchange and implementation projects on adaptation**


Reference data: ©ESRI

Note: As of June 2019.

Source: Authors' own compilation based on https://cordis.europa.eu; https://keep.eu; EC (2019d); personal communications from Giulia Facelli, Directorate-General for Research and Innovation (2019), and Bernd Decker, Executive Agency for Small and Medium-sized Enterprises (2020).

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(55) https://urban.jrc.ec.europa.eu/strat-board/#/where
(56) https://www.uia-initiative.eu/en
(57) See also https://climate-adapt.eea.europa.eu/knowledge/life-projects
(58) See also https://climate-adapt.eea.europa.eu/knowledge/interreg-projects

Many European funding programmes include a strong element on the dissemination of knowledge gained during the projects, so that a larger community of practitioners benefits from it. This is often done with the help of city networks or initiatives (see Section 4.3) and through online platforms such as Climate-ADAPT or Oppla (EU repository of nature-based solutions).

Funding to certain member states is also provided by the European Economic Area grants. For example, Portugal has used this funding to train local officers in vulnerability assessment and development of adaptation options (EC, 2018b). The European Investment Bank (EIB) also supports adaptation through, for example, the Natural Capital Finance Facility (NCFF) and URBIS (Box 4.3). NCFF, currently piloted in several European cities, is set up for projects that are expected to have a positive impact on biodiversity and/or use nature-based solutions for climate change adaptation. URBIS is a new dedicated urban advisory platform within the European Investment Advisory Hub (EIAH). It was established to provide advice to urban authorities to facilitate, accelerate and unlock urban investment projects, programmes and platforms.

Further funding opportunities for testing and implementing local and regional adaptation will become available through the new research programme Horizon Europe, guided by the European research and innovation 'missions'. The missions aim to deliver solutions to some of the greatest challenges facing our world. In particular, the missions on adaptation to climate change, including societal transformation (EC, 2020b), and on climate-neutral and smart cities (EC, 2020a) promise to support local-level adaptation. The target of the mission on adaptation is currently framed as 'to prepare Europe to deal with climate disruptions, accelerate the transition to a healthy and prosperous future within safe planetary boundaries and scale up solutions for resilience triggering transformations in society' (EC, 2020b, p.5). The target of the mission on climate-neutral cities and smart cities is achieving 100 climate neutral cities by 2030 through systemic transformation.

Box 4.2 How can cities benefit from knowledge exchange within an Interreg project?

Interreg is a funding programme under the umbrella of the European cohesion policy that implements the goal of European territorial cooperation through project funding in the fields of the environment, sustainable energy and health, among others. The programme aims to facilitate cross-border, transnational and interregional cooperation for economic, social and territorial development, as well as policy exchange and action within the EU. It has funded many climate change adaptation planning and implementation projects in EU Member States, regions and cities.

The intrinsic role of knowledge exchange in Interreg projects is demonstrated by the project Adriadapt, under the Italy-Croatia Interreg A (cross-border) 2014-2020 programme. It aims to advance the planning and monitoring of local and regional resilience and adaptation in the cooperation area, through a knowledge platform containing best practices, guidelines and harmonised and reliable data sets. The knowledge platform will be integrated and tested in cooperation with partner organisations in the participating municipalities of Udine and Cervia in Italy, the Union of the Municipalities of the Savio Valley and the city of Vodice in Croatia.

Similarly, SPONGE2020 (Interreg B, transnational programme), a participatory adaptation project in partnership with local governments and water authorities in densely built-up areas in Belgium (Flanders), France, the Netherlands and the United Kingdom (England), is designed to improve the capacity to adapt to urban flooding through the development of solutions with local stakeholders in the region. Its main outputs are the co-creation, planning, design, implementation and evaluation of adaptation solutions, a toolbox for stakeholder engagement in adaptation, and a guidance pack and action plan for participative climate adaptation strategies, which will enable knowledge exchange and transfer among partners, including Antwerp, Leiden, Rotterdam and regions in the United Kingdom and France

Sources: Interreg Europe (2019); Adriadapt (2019); SPONGE 2020 (2019).

Box 4.3 European Investment Bank loans to support green infrastructure projects in Athens

The Athens resilience strategy 2030 is central to the city's plans for its future development. The strategy aims to transform Athens into 'a responsive, embracing and inspirational city that is proud, green and citizen-led' (City of Athens, 2017, p.19). Four strategic pillars — open, green, proactive and vibrant — structure 65 actions and 53 supporting actions.

Financial support for implementation of the strategy includes a EUR 5 million loan from the EIB's Natural Capital Financing Facility (NCFF). This support finances the actions within the green pillar of the resilience strategy, such as integration of vegetation into the restoration of public squares and streets, or developing green corridors linking green areas.

Many actions in the resilience strategy will be implemented through the Athens integrated territorial investment programme, which aims to foster renewable energy and energy efficiency, green and blue infrastructure, sustainable mobility and waste management. This programme is supported by an EIB framework loan of EUR 50 million under URBIS. The total EIB loan of EUR 55 million is expected to unlock EUR 190 million of investment.

The NCFF framework loan will be combined with a EUR 1 million technical assistance component to support Athens in the preparation, implementation and monitoring of the NCFF's objectives. This loan will support 80 small-scale priority projects that are included in the municipality of Athens 2017-2020 investment plan.

Furthermore, the EIB is financing the preparation and implementation of the green pillar actions with EUR 500 000 of technical assistance, including an innovative approach to open spaces based on research *in situ*, educating municipal services and boosting investment for biodiversity and nature-based adaptation.

Sources: EIAH et al. (2019); EIB (2018, 2019).

4.3 EU and international city networks and initiatives

4.3.1 Variety of networking opportunities

Participating in international urban adaptation initiatives supports the development of an explicitly urban approach to climate change, provides cities with easy access to best practices and helps them to develop local capacity (Heidrich et al., 2016). Numerous European and international city networks organise knowledge exchange between their members on climate change adaptation (Box 4.4). Some networks are active at a global scale, such as the International Council for Local Environmental Initiatives (ICLEI) (with a regional chapter for Europe) or C40; others focus only on European cities, such as Eurocities or Climate Alliance.

While all these networks and initiatives provide support to cities on adaptation, they vary substantially in terms of access, financial contributions that they provide to or require from cities, and the types of services they offer. For example, the Covenant of Mayors is open to all local authorities free of charge, regardless of their size, on condition that they sign up to, implement and report on the commitments of the initiative in terms of greenhouse gas emission reduction, climate change adaptation and addressing energy poverty. The support that is provided to signatory cities is funded by the European Commission and coordinated by an office run by six networks of European cities and regions.

City networks that are legal entities, such as Climate Alliance, Eurocities or ICLEI, are mostly constituted in the form of associations, with local authorities paying membership fees. In addition to a fee, members often need to fulfil requirements in terms of statutes or a commitment (for example, Climate Alliance members sign up to a concrete commitment to reduce greenhouse gas emissions), or size. Full members of Eurocities, for example, usually have at least 250 000 inhabitants. Aside from capacity building and peer-exchange activities, these networks usually also represent their members politically, e.g. at the EU level, and develop proposals for third-party funded projects with and for the members. C40 cities need to be either megacities in terms of population size (at least 3 million) or gross domestic product, or innovator cities 'internationally recognized for barrier-breaking climate work' (C40 Cities, 2012), which limits the potential membership considerably.

Networks that are created as part of European projects, such as the URBACT networks, have a selective entry process through competitive calls for proposals and are thus open to only a restricted number of cities, to which they provide technical and financial support (see Section 4.3.2).

Box 4.4 Key international city networks and initiatives concerned with local adaptation

The Covenant of Mayors for Climate and Energy — Europe (European Commission) took its current shape in 2016, when the Covenant of Mayors, which started in Europe in 2008, joined forces with the Compact of Mayors to become the Global Covenant of Mayors for Climate and Energy, including the European chapter. The signatories commit to submitting a sustainable energy and climate action plan (SECAP) within 2 years after the local council decides to join the initiative, outlining the key planned actions. Since October 2015, local authorities have committed to reduce their GHG emissions by at least 40 %, increase their resilience to the impacts of climate change and secure access to sustainable and affordable energy by 2030. The support offered to signatories involves technical guidance, feedback on the SECAP and access to knowledge. Regular experience-sharing workshops and webinars are organised in various languages. The Covenant of Mayors office develops good practice case studies on adaptation in signatory cities and shares through the online library the resources developed by partner organisations and EU-funded projects. It also manages jointly with the EEA the Urban Adaptation Support Tool. There are 2 669 signatories in EEA member and collaborating countries as of April 2020, including 442 that have submitted a SECAP. https://www.covenantofmayors.eu

The **Making Cities Resilient Campaign (United Nations Office for Disaster Risk Reduction, UNDRR)** (2010-2020), aimed to work with cities, towns and local governments to increase their overall resilience to disasters by implementing risk reduction strategies. A 10-point checklist of essentials for making cities resilient served as a guide for a city's commitment to improving its resilience and was the organising principle for reporting and monitoring during the campaign. The participating local governments were expected to be proactive not only within their jurisdiction but also through sharing knowledge with others (UNISDR, 2019). As of June 2019, 645 local authorities in Europe participated. In February 2020, the new initiative 'Making Cities Resilient 2030' was proposed for launch in late 2020 (UNDRR, 2020). https://www.unisdr.org/campaign/resilientcities

The **Global Resilient Cities Network** (GRCN) carries on the foundational work of **100 Resilient Cities (Rockefeller Foundation)**, which was set up in 2013. In partnership with its global community of cities and chief resilience officers, The GRCN continues to deliver urban resilience through knowledge sharing, collaboration and collective action, seeking to inspire, foster and build resilience around the world. The GRCN's mission is to connect cities and build partnerships to design, invest and scale urban resilience solutions worldwide to help urban communities thrive in the face of acute shocks and chronic stresses. Sixteen European cities participate in the initiative. https://www.resilientcitiesnetwork.org

C40 Cities convenes networks that provide a range of services to support cities' climate change efforts. Three networks are active under the adaptation implementation initiative. The **Connecting Delta Cities Network** aims to share knowledge and experience among a dozen delta cities from around the world, including Copenhagen, London, Rotterdam and Venice. The **Cool Cities Network**, led by Athens and working in partnership with the Global Cool Cities Alliance, supports city efforts to reduce the impact of the urban heat island effect. The **Urban Flooding Network** aims to assist cities in addressing the impacts of floods and includes nine European cities. C40 provides adaptation master classes with workshops or training, tools and good practice repositories. https://www.c40.org

The **Council of European Municipalities and Regions** brings together the national associations of 130 000 local and regional governments from 41 European countries. Members meet regularly to advocate and exchange best practices on all topics. One expert group specifically focuses on climate and energy, and participates in the Climate Adaptation Partnership of the urban agenda (see Box 4.1). https://www.ccre.org

Climate Alliance is a European city network with around 1 700 members in 26 European countries. It has coordinated a working group on climate change adaptation since 2015. About 40 member cities participate in the annual meetings, sharing practical experiences, advice and knowledge. The network's secretariat regularly relays information about relevant guidance, publications and events to its members (personal communication from Lea Kleinenkuhnen, Climate Alliance, 2020). https://www.climatealliance.org

Eurocities is a European network of about 180 large member and partner cities, which provides a forum to its members to exchange information on, among other topics, nature-based solutions, cloudburst risks and water management, and discuss financial instruments for climate action. Eurocities also organises climate roundtables, where member cities can exchange experience of challenges and solutions, and gathers good examples of adaptation plans and strategies developed by member cities to inspire peers (personal communication from Heather Brooks, Eurocities, 2019). http://www.eurocities.eu

ICLEI — Local Governments for Sustainability is a global city network with around 160 members in Europe. It produces regular news about the latest developments on climate adaptation and urban resilience, and organises the annual European Urban Resilience Forum (ICLEI, 2019). https://www.iclei.org

Joining one or several of these networks or initiatives depends also on the cities' technical and financial capacities, and their expectations of the networks, but also sometimes general trends in their country or region. Many cities are members of several networks for historical reasons or in order to benefit from different offers they can receive from each of these (personal communication from Lea Kleinenkuhnen, Climate Alliance, 2020).

4.3.2 Additional European initiatives

In addition to those networks, the European cohesion policy offers opportunities to exchange experience and knowledge through programmes such as Interreg (Box 4.2) and URBACT. The URBACT programme aims to support cities to collaborate on sustainable integrated urban development. For instance, between 2016 and 2018, 11 cities from nine EU Member States (59) cooperated through the URBACT network 'Resilient Europe' with the goal of developing integrated resilience action plans. The lessons from experimenting with different solutions were shared across the network (URBACT, 2016). The C-Change network, launched in 2018, aims to transfer the city of Manchester's experience in mobilising its arts and culture sector in local climate change action to five other cities (Agueda, Gelsenkirchen, Mantua, Sibenik and Wrocław) (URBACT, 2019).

4.3.3 Twinning and pairing programmes

In addition to the activities targeted at the whole community of signatories (see Box 4.4), the Covenant of Mayors — Europe Office facilitates a twinning programme for its signatory cities, which undergo a selection process and are matched based on their needs and expertise. Between 2018 and 2020, 24 cities participated in the programme, which consisted of reciprocal visits. For example, the cities of Leeds (United Kingdom) and Breda (Netherlands) discussed the Breda water plan for climate resilience 2019-2023, which developed measures on using above-ground water storage to prevent flooding while also increasing resilience to drought and heat stress. The International Urban Cooperation programme also supports pairings between European cities and global counterparts. In October 2019, 12 of these international pairings were working on climate change adaptation (IUC, 2019). For example, the city of Bologna in Italy made use of this opportunity to apply experience from its paired city, Austin in the United States, to an urban forest plan to improve its nature-based solutions masterplan (IUC, 2018).

4.4 Relationship between the national and local levels in adaptation

4.4.1 Coordination between national and local governance levels

National adaptation policies are key for defining governance structures and arrangements that support local authorities' adaptation actions (EEA, 2020d). The proportion of local governments with adaptation strategies tends to be higher in countries with longer-established national adaptation strategies (NASs) (Heidrich et al., 2016).

Most NASs and national adaptation plans (NAPs) recognise the role of local authorities in successful adaptation action, listing cities or municipalities alongside other key sectors for adaptation. Adaptation planning at the local level is mandatory according to national regulations in Denmark, Ireland, Sweden and the United Kingdom. In France, territorial climate and energy plans (covering both adaptation and mitigation) have been mandatory for local authorities with more than 50 000 inhabitants since 2010. In 2016, when air quality was also incorporated into these plans, the obligation was extended to the French local authorities with more than 20 000 inhabitants (EC, 2018c). Local adaptation planning is also to be mandatory in Croatia.

Municipalities in some countries are obliged to carry out risk and vulnerability assessments (see the example of the Netherlands in Box 4.5). For example, since 2018 Sweden has required all municipalities to have a comprehensive plan including a risk assessment of damage to the built environment caused by climate-related events such as floods, erosion or landslides. The plan must also include the municipality's view on how such risks can be reduced or eliminated.

In other countries, local adaptation planning is enforced through the urban planning legislation, as in the case of Slovakia since 2018 (Eionet, 2019). The Slovak NAS defines precise tasks for the implementation of the local-level strategies (EC, 2018c). Similarly, adaptation is planned to be integrated into the national framework for local and regional spatial planning in Slovenia (Eionet, 2019). In Norway, new guidelines describing how the municipalities and counties can incorporate climate change adaptation work into their planning activities were adopted in 2018. The Greek NAS envisages adaptation being planned at regional and local levels, with regional adaptation strategies to define priority actions based on the specificities and characteristics of each region (see also Section 4.5).

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(59) Antwerp (Belgium), Burgas (Bulgaria), Vejle (Denmark), Ioannina, Thessaloniki (Greece), Potenza (Italy), Rotterdam (Netherlands), Katowice (Poland), Malmö (Sweden), Bristol, Glasgow (United Kingdom).

Box 4.5 Climate stress tests for Dutch municipalities

In September 2017, the Netherlands launched the Deltaplan Spatial Adaptation as part of the national Delta programme. The plan was developed through close collaboration between the national government, provinces, municipalities, waterbodies and other relevant organisations with the aim of climate-proofing the Netherlands by 2050.

The first step in the plan is to carry out municipality climate stress tests by 2020 to enable planning for appropriate adaptation measures. The stress test concept comes from the financial sector. In the adaptation context, the aim is to assess to what extent the current spatial planning can cope with the expected climate effects. In a stress test, information from the national Climate Impacts Atlas (https://www.klimaateffectatlas.nl/en) is combined with data on the location of vulnerable objects and land use functions (drinking water facilities, telecommunication, transport, healthcare facilities etc.). This gives a clear indication of how exposed the assets and functions are to the negative impacts of climate change, and how vulnerable the municipality to is flood risk, heat, drought and heavy rainfall.

Although the stress test is not mandatory, all municipalities are aligned with the ambitions of the Deltaplan and have initiated the process. The municipalities are supported from the national level with data (Climate Impact Atlas), guidelines on how to carry out the stress test and a list of consultancy agencies specialising in this type of assessment. Based on their test results, municipalities are expected to initiate a risk dialogue with citizens, local businesses and civil society organisations to agree on the accepted level of risk, and to decide on the preferred adaptation measures.

The nationally coordinated approach results in a standardised vulnerability assessment, which is likely to facilitate comparison between municipalities, help to assess national progress and support intermunicipal collaboration regarding adaptation measures. Stress tests are expected to be repeated every 6 years.

Sources: Ministry of Infrastructure and Water and Delta Commissioner (2018); Laudien et al. (2019); DPRA (2020a, 2020b).

Local authorities are crucial for the implementation of national adaptation strategies

According to the adaptation preparedness scoreboard (EC, 2018c) and countries' reports under Article 15 MMR (Eionet, 2019), nearly all EU Member States involve cities and local authorities in the design and implementation of national adaptation policies. In 12 Member States (60), this is done by including national associations of municipalities among the stakeholders consulted during the design of NASs and NAPs. During the revision the German adaptation strategy in 2015, an online consultation was conducted with cities and municipalities among other stakeholders.

The coordination between the national and local levels takes different formats: for example, in Austria, dialogue events were organised in different cities to shape the implementation of the NAP (Eionet, 2019). In Czechia, local authorities participated in consultations as stakeholders and were invited to produce written comments (EC, 2018c). While national governments interact directly with local administrations in small states (such as Luxembourg or Malta), other countries use intermediate governance levels for further coordination (see Section 4.5). In Switzerland, the implementation of the NAP follows the country's multi-level governance system. An example is its national pilot programme for adaptation, which aims to support exemplary and innovative plans by cantons, regions, cities and municipalities to concretely adapt to climate change. A number of federal offices are directly involved (e.g. the federal offices for the environment, public health, agriculture and spatial development) and support the beneficiaries to create feasible solutions. The costs are shared between all parties involved, and 81 projects have been supported since the programme's start in 2013 (FOEN, 2020a).

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(60) Bulgaria, Czechia, Denmark, Estonia, France, Greece, Ireland, Italy, Latvia, Lithuania, the Netherlands and Portugal.

4.4.2 Funding for local adaptation

Many Member States allocate parts of their national budgets to support local adaptation measures (see EEA, 2017c, for some examples). In several cases, national governments have created programmes to support the development of local adaptation plans. In Poland, cities with more than 100 000 inhabitants participated in the Ministry of the Environment's project 44MPA (co-funded by the European Cohesion Funds). The aim of the project was to develop urban adaptation action plans for the cities accounting for over 30 % of the country's population (44MPA, 2018). As of March 2020, 39 of the 44 participating cities had adopted their adaptation action plans (personal communication from Szymon Tumielewicz, Ministry of the Environment, Poland, 2019). Funding can be provided to hire additional expertise by cities, as in Germany and Slovenia (EC, 2018c) or can finance task forces, non-governmental organisations or regional offices (Eionet, 2019). National funding can also support capacity-building; for example, the Austrian Ministry for Sustainability together with the Federal States financed adaptation workshops for local and regional level staff (EC, 2018c).

When it comes to the implementation of their adaptation plans, local authorities are largely dependent on their own financial resources (see also Section 5.3). For example, Austrian municipalities are asked to cover climate adaptation implementation costs 'by prioritization and shifting within the available budget' (Eionet, 2019). However, in some countries, national government provides direct funding to implement infrastructure measures. For example, the Danish Ministry for the Environment and Food granted DKK 34.4 million (approximately EUR 4.6 million) to municipal climate-proofing projects (EC, 2018c). Portugal allocated EUR 1 million annually in 2018 and 2019 for the implementation of measures identified in municipal adaptation strategies and plans. Implementation of local adaptation in Czechia is supported through the resources of the Ministry of the Environment (EC, 2018c). In Italy, the recent Decree Law 111/2019 provides for the financing of reforestation actions in cities. In Ireland, the national Environmental Protection Agency has funded a large urban area adaptation project for the Greater Dublin region, on which researchers from Cork University collaborated with the regional authority, which is responsible for spatial planning and climate planning (MAREI, 2018). In Latvia, national co-funding for LIFE projects is available to allow local authorities to benefit from the LIFE programme without using local budgets (Box 4.6).

Several countries, including Italy, Latvia, Poland and Portugal, use revenues from auctioning carbon allowances to fund local adaptation measures (EC, 2018c). These revenues and other state-funded programmes are often channelled through state-connected green or environment funds or directly through environment ministries. For example, the Greek Green Fund, a public legal entity associated with the Ministry of Environment and Energy, supports adaptation projects such as the creation of green spaces in urban areas (Eionet, 2019).

Box 4.6 Financial and technical support for local authorities applying for LIFE funds in Latvia

The Latvian Environmental Protection Fund offers co-funding to all successful projects under the LIFE programme. Municipalities — alongside scientific institutions and non-governmental organisations — can receive up to 35 % of the eligible project costs from the national government. This system of co-funding has been functioning since 1999, with a break between 2006 and 2009. In the years without national co-funding there was a considerable fall in the number of applications to LIFE funds in Latvia. This indicates the importance of national co-financing to LIFE projects in Latvia, such as the HydroClimateStrategyRiga — integrated strategy for Riga City to adapt to the hydrological processes intensified by climate change phenomena (2010-12).

In addition, a specific LIFE project aimed to increase the volume of successful LIFE projects in Latvia by supporting the project applicants and beneficiaries. Capacity building for the LIFE programme implementation in Latvia was a LIFE project coordinated by the Ministry of Environmental Protection and Regional Development and the administration of the Latvian Environmental Protection Fund (January 2016 to December 2019). Cities were the key target audience for this project. The support offered included a helpdesk, consultations on drafting the proposals, partner search and training sessions on aspects ranging from procurement to reporting and budgeting.

Sources: https://www.lifeprogramma.lv/en; personal communication from Claire Baffert, World Wide Fund for Nature, 2019.

4.4.3 Capacity support

Having recognised a knowledge and skills gap in climate change adaptation among many local administrations (see also Section 6.1), several national governments now provide additional support to city practitioners. For example, in Denmark, a mobile task force was established by the Ministry of the Environment in 2013 to provide adaptation planning support for the local authorities, focusing specifically on solutions regarding flooding and erosion since 2017 (EC, 2018d). In order to support municipalities in dealing with the consequences of climate change, the German government promotes adaptation activities at the municipal level with the help of the Federal Environment Agency though online guides, best practice examples, information sheets and checklists (UBA-DE, 2019a). A similar kind of support is provided by the Sniffer charity in Scotland, which has been delivering the Scottish Government's climate change adaptation programme since 2011, with local authorities as one of the key target audiences. The Irish government has financed the work of four climate action regional offices, which support local authorities in fulfilling their obligation to put adaptation action in place (see Box 4.7).

External funding, such as European Economic Area grants, in some countries is channelled through national agencies for capacity-building measures for local authorities in adaptation planning. In Portugal, the ClimAdaPT.Local project (61) supported the development of 27 local adaptation strategies, ensuring consistent coverage across the country (Aguiar et al., 2018). After the project concluded in 2016, the participating municipalities created a National Network of Municipalities for Adaptation to Climate Change, which has since continued knowledge exchange through, for example, annual seminars on local adaptation (Eionet, 2019). Municipal staff in Portugal are also offered training programmes on interpreting climate data and applying it in risk and vulnerability assessments (EC, 2018c). In Poland, the Climcities project focused on capacity building for small and medium-sized cities (see Box 5.6).

In several Member States, local authorities are actively encouraged to build capacity through participation in the Covenant of Mayors and benefit from the offers of the initiative, e.g. capacity-building workshops and webinars (see also Box 4.4). The drive comes from associations of local authorities (such as in the Netherlands), non-governmental organisations (e.g. in Lithuania) or public authorities at the regional level (for example in Belgium; see also Section 4.5).

Box 4.7 Regional collaboration for urban adaptation in Ireland

In Ireland, four climate action regional offices (CAROs) support local authorities in fulfilling their obligations to develop and implement their adaptation strategies. The regional offices were established in 2018 with EUR 10 million of funding over 5 years from the national government.

Each of the four CAROs (Dublin Metropolitan, East and Midlands, Atlantic Seaboard North, and Atlantic Seaboard South) is operated by a lead local authority and encompasses involves other local authorities in the same geographical area to ensure that similar climate risks are faced in each CARO. CAROs play an important role in implementing climate actions and mainstreaming climate concerns into all local, regional and national policy. They liaise between local governments and the relevant national government departments and other agencies. Besides creating and sharing knowledge, the regional offices enable local authorities that share certain climate risks to increase consistency across their adaptation plans and to deal more effectively with cross-boundary issues. Thus, they help to create both horizontal integration between local authorities and vertical interaction between different government levels.

The governmental funding is used to establish expert teams in each centre that play a role in developing local adaptation strategies. For example, the Dublin Metropolitan CARO has collaborated on the city's climate action plan, which was signed in 2019 (O'Sullivan, 2019).

Sources: Climate-ADAPT (2018b); eLighthouse (2018); OECD (2019); O'Sullivan (2019); DCCAE (2020).

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(61) https://eeagrants.org/archive/2009-2014/projects/PT04-0007

4.4.4 Providing relevant knowledge

Almost all EEA member countries have created online climate adaptation platforms to coordinate information and knowledge sharing among municipalities (Eionet, 2019). In countries that are more experienced with adaptation and where there are more sector-related information available, such platforms tend to guide users to relevant sectoral or regional information sources (62). The Portuguese Climate Portal (Portal do Clima) was developed to promote adaptation to climate change at regional and local levels. In Germany and the Netherlands, sectoral information also includes specific knowledge, instruments and data relevant to urban climate change adaptation (Eionet, 2019). In Germany, the federal government developed the Climate Preparedness Portal (KliVo Portal), which contains quality-assured data, information and support services that relate to climate change and adaptation to climate impacts and are relevant to local actors (UBA-DE, 2020; BMU, 2020). Other knowledge portals are provided by the German Environment Agency (UBA-DE) and by research projects funded by different national ministries (see Box 4.8). In Belgium, an urban climate service centre has been integrated into the regional adaptation platform of Flanders (Eionet, 2019). The Irish government set up the climate information platform Climate Ireland. The Norwegian Climate Change Adaptation Portal has been providing information, case studies and tools since 2008; municipalities are its main target audience (63). In Sweden, the national knowledge centre for climate adaptation manages a portal (klimatanpassning.se) and functions as a knowledge broker, translating research results for practitioners. Moreover, an online game on climate adaptation has been developed and used for situated learning among local politicians, schools and others (64).

Some of these platforms, such as those in Belgium and France, also include ample information on nature-based solutions for adaptation, and Germany provides information on various adaptation measures and options (Box 4.8). In addition, in most countries, guidelines and handbooks in local languages also provide the knowledge necessary for performing risk and vulnerability assessments and designing adaptation strategies at the local level. In some cases, such as Ireland, local authorities are obliged to follow these guidelines (Eionet, 2019).

Climate services (see Annex 2 Glossary) are provided by several countries, offering information on climate risks and impacts tailored to local governments' needs. Belgium, Ireland, Latvia and Sweden provide data, impact assessments and decision-making tools, including the visualisation of climate scenarios, through dedicated online portals tailored to the municipalities' needs and scaled down to the local level. In Denmark, a nationwide Danish Climate Atlas (67) provides open access spatial data on future changes in climate impacts for municipalities. The Dutch Climate Damage Atlas (68) assembles information on the costs of damage caused by climate change (heat, drought, urban flooding and coastal/river flooding in the period 2018-50) for each municipality. In Hungary, a geo-information system called the National Adaptation Geo-information System (NAGiS) has been established to support national and local decision-making. The system presents hundreds of layers on climate adaptation, covering many affected sectors (69). In Italy, a web portal developed in the project LIFE Disaster risk reduction insurance (DERRIS) overlays various public climate hazard maps, allowing detailed assessment of local climate risks (LIFE DERRIS, 2020). The Swiss Federal Office for the Environment provides cities with a surface runoff risk map (Box 4.9). Still, according to some local practitioners, while adequate for awareness-raising, the information, provided at a relatively low resolution, may not be sufficiently detailed to support local-level planning (Laudien et al., 2019).

Box 4.8 Guidance on local adaptation measures in Germany

The database **Tatenbank**, on the climate adaptation platform of the German Environment Agency, presents examples of successful adaptation measures. It offers a forum for all interested parties to register their adaptation projects and to learn from others. The Tatenbank focuses on local and regional measures that have been or are being implemented in Germany (UBA-DE, 2013).

The climate guidance tool **Klimalotse** (65) offers online guidance that supports cities and municipalities in the development and implementation of adaptation plans and strategies, as well as the implementation of single adaptation measures (UBA-DE, 2015).

Stadtklimalotse (66) is a decision support system allowing the identification and implementation of appropriate measures for climate and adaptation in urban development, based on querying a database of more than 130 measures (TU Dortmund, 2020).

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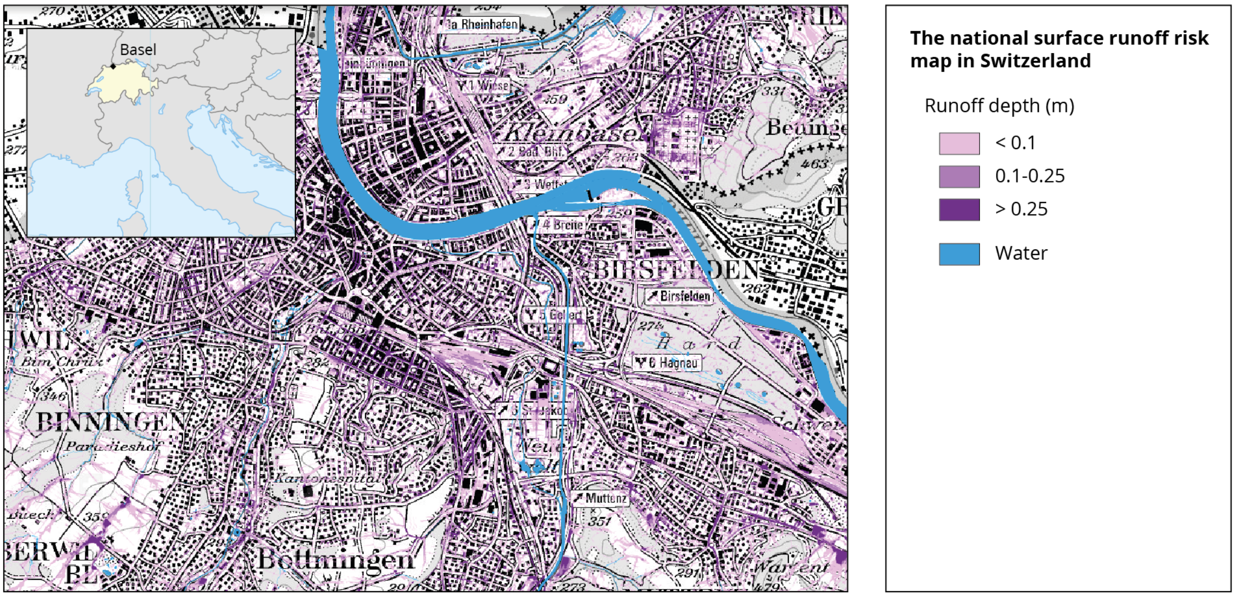
(62) For example, https://www.klimatilpasning.dk in Denmark; https://www.umweltbundesamt.de/themen/klima-energie/klimafolgen-anpassung in Germany; or https://www.climateadaptationservices.com in the Netherlands.
(63) https://climate-adapt.eea.europa.eu/countries-regions/countries/norway
(64) https://www.smhi.se/en/climate/education/adaptation-game-1.153788
(65) https://www.umweltbundesamt.de/themen/klima-energie/klimafolgen-anpassung/werkzeuge-der-anpassung/klimalotse#Elemente
(66) http://www.stadtklimalotse.net/stadtklimalotse
(67) https://en.klimatilpasning.dk/tools/climate-atlas
(68) https://climatedamageatlas.com
(69) https://nater.mbfsz.gov.hu/en

Box 4.9 The national surface runoff risk map in Switzerland

About two thirds of the buildings in Switzerland are potentially affected by surface runoff. Within the project Adaptation to extreme precipitation, the Swiss Federal Office for the Environment, in collaboration with Swiss insurance associations has created the national surface runoff risk map (see Map 4.2). The map allows local authorities, private users and investors to identify areas that potentially could be at risk of surface flooding following rare precipitation events (return period 100 years). The map shows areas at risk from surface runoff and the potential flood water depth as well as the expected flood pathways.

The map is based on scientific modelling and is intended to give professionals and the general public a first quick overview. The map requires local verification to ensure accuracy.

Map 4. **Fragment of the Swiss Federal map of surface runoff flood risk areas (FOEN, 2020b)**



Reference data: ©ESRI

Source: FOEN (2020b, 2020c).

According to the adaptation preparedness scoreboard (EC, 2018c), five Member States have explicit strategies to address knowledge gaps in local or urban adaptation. In the Netherlands and Sweden, the gaps are addressed through national research programmes. However, most countries rely on relationships with universities and research institutions (mainly for developing climate data), as is the case in France. Whereas in countries such as Germany or France the existing experience of climate adaptation has helped to identify knowledge gaps and has triggered further investments in research, smaller countries such as Malta, Portugal or Slovenia rely on European projects to build the necessary knowledge and capacity (EC, 2018e). Section 6.2 provides further information on how European cities can access and build relevant knowledge.

4.4.5 *Facilitating city-to-city support through national city networks*

National networks support the exchange of information between cities. They can be divided into three different categories:

Long-standing national networks, of which most country's local authorities are members. They work on a large array of topics, including climate change adaptation. For example, the Latvian Association of Local and Regional Governments, including in its role as supporting organisation to the Covenant of Mayors, raises its members' awareness of climate change adaptation, coordinates information exchange and organises regular events (personal communication from Eva Baños de Guisasola, Council of European Municipalities and Regions, 2020). The Swedish Association of Local Authorities and Regions coordinates a virtual network on local adaptation as a forum for dialogue and knowledge exchange for its members. It also produces a report on climate change impacts and organises a series of seminars (EC, 2018c). The German Association of Cities and Towns has included climate change adaptation in its experience exchange and advisory activities. Its expert committee on adaptation has developed a catalogue of adaptation measures in cities and identified important fields of adaptation process (Deutscher Städtetag, 2019).

Thematic networks that are specialised in climate change-related issues and usually consist of committed frontrunner cities. In Spain, a dedicated network of climate-friendly municipalities was created within the national association of municipalities in 2009 (EC, 2018c). The Norwegian Environment Agency coordinates the Front Runner Network of 14 cities, which aims to strengthen climate adaptation, locally and nationally, through developing new knowledge on climate change adaptation and exchanging expertise between participants. The Dutch city network Klimaatverbond, which works on climate change mitigation and adaptation, offers knowledge exchange on adaptation to over 160 members, while also supporting the Covenant of Mayors. The Portuguese network of municipalities working on adaptation planning (Rede de Municípios para a Adaptação Local às Alterações Climáticas) is a more recent, specialised association created in 2016. It formalises the network of the Portuguese municipalities that participated in the ClimAdaPT.Local project and offers a forum for information exchange to its members.

Other structures that are set up or coordinated by national governments, sometimes to support the implementation of NAPs or NASs. In Germany, for example, the federal government has set up forums to exchange ideas and cooperate on local adaptation to climate change. In Latvia, the Environment Ministry organises learning exchanges between Latvian and foreign municipalities (EC, 2018c).

4.5 Regional or subnational support to local adaptation

Many climate impacts extend outside the city boundaries and affect multiple sectors and actors, requiring coordination beyond the local level. Given the lack of capacity and expertise in many (especially small) municipalities (see also Chapter 5), the regional level is an intermediate step between national and local adaptation in many countries. Regional-level adaptation planning is also particularly important in adaptation planning in countries with federal structures (e.g. Belgium, Germany).

Consequently, in some places adaptation plans can be developed by regions, before being cascaded to the local level (Heidrich et al., 2016; see Box 4.10). In Germany, all 16 states have developed either separate adaptation strategies or integrated mitigation and adaptation strategies that serve as a basis and orientation for local strategies (UBA-DE, 2019b). With the aim of providing region-specific guidance to local policymakers, regional plans (at the Nomenclature des unités territoriales statistiques (NUTS) 2 level) have been developed in Greece; provincial plans (at the NUTS 3 level, including the city of Budapest) have been created in Hungary, despite the absence of national requirements for adaptation planning. Following these regional plans, approximately one third of Hungarian local authorities were expected to prepare their own strategies during 2019 (Eionet, 2019). In France, urban climate change planning seems to be dominated by mitigation policy, whereas regions deal with larger spatial units and tackle adaptation (Heidrich et al., 2016).

> *The regional level facilitates translation of national policies into local adaptation actions*

The subnational level frequently coordinates and supports local authorities in their adaptation efforts; in Sweden and Norway, this is done by county-level administrations (Eionet, 2019). In Ireland, subnational coordination mechanisms have been created in addition to the national coordination group for adaptation (Box 4.7). While there is no legal requirement for cities to develop adaptation strategies, some regional governments (e.g. Andalusia) are making climate strategies compulsory for cities over a certain population threshold (Heidrich et al., 2016).

Box 4.10 Multi-level Integration of adaptation into spatial planning in the Basque Country, Spain

In the Basque Country, the local level is explicitly recognised as a key scale for adaptation efforts in a framework of multi-level climate action. A hierarchical multi-scale climate-proof spatial planning approach has been established at three levels:

1. the Regional Spatial Planning Guidelines, which provide overarching principles, requirements and recommendations to inform local planning based on climatic and socio-economic scenarios as well as risk projections;
2. an intermediate level (supra-municipal) of integrated territorial plans for functional areas, identifying relevant vulnerabilities and risks while providing guidance and rules for climate-proof urban planning; and finally
3. local plans at municipal level, which, based on the requirements mentioned above, should consider climate adaptation in urban planning.

In the case of Greater Bilbao, the functional area territorial plan integrates climate risk information coming from the regional level. Based on the territorial plan, specific municipalities are required to respond to the identified climate risks when revising or developing their urban plans. Derived from it, a climate-mainstreaming procedure was implemented by Bilbao municipality when revising its city masterplan, requiring detailed heat stress and runoff studies in urban development and design projects.

Source: IHOBE (2019); personal communication from Efrén Feliu, Tecnalia Research and Innovation, 2020.

Individual regions also take initiative on supporting local adaptation. The Italian region of Emilia-Romagna has created a support system for climate planning, consisting of a regional coordination group and a regional climate observatory; forums for exchange among local planners, enterprises and citizens; and financial support for the drafting of local climate action plans and advice for the integration of climate action plans with urban planning instruments (Regione Emilia Romagna, 2020a, 2020b). In Saxony, Germany, the EU LIFE LOCAL ADAPT project supports small and medium-sized municipalities in improving the integration of climate adaptation measures at the local level. This is done by advising and supporting the municipalities through climate coaches and competitions as well as by providing financial support for selected adaptation measures (Sächsisches Staatsministerium für Energie, Klimaschutz, Umwelt und Landwirtschaft, 2020). The Lisbon metropolitan area climate change adaptation plan (PMAAC-AML), concluded in 2018, was co-financed by European funds (from the operational programme Sustainability and efficiency in the use of resources) and involved the 18 municipalities. The project is an example of operationalising the European and national adaptation strategies at a metropolitan scale, allowing a coherent assessment of vulnerabilities and the establishment of guidelines for the implementation of adaptation actions. The PMAAC-AML is intended as complementary to the national- and local-level approaches.

In addition, many subnational administrations and regional energy or environment agencies provide support to cities in their role as the coordinating or supporting organisations for the Covenant of Mayors. Among 190 Covenant coordinators (mostly subnational authorities) providing strategic guidance, technical and financial support to the signatories, over half offer support specifically on adaptation (Covenant of Mayors — Europe Office, 2020). This includes regional authorities in Italy, Spain and many other countries (EC, 2018c), and energy and environment agencies such as the Alba Local Energy Agency in Romania (Box 4.11). In the Walloon Region (Belgium), the Pollec programme also provides funding for cities to develop action plans for the Covenant of Mayors (EC, 2018a).

Regarding other international networks, eight regions in Europe participate in the RegionsAdapt initiative run by the Regions4 Sustainable Development network (70) (the Basque Country, Brittany, the Canary Islands, Catalonia, Lombardy, Réunion, Scotland and Wales), through which they can exchange knowledge and best practice on issues such as how to best support local authorities in their jurisdictions. In their linking position between the national and local levels, regional governments can also promote the coordination and vertical integration of policies (RegionsAdapt, 2018)

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(70) RegionsAdapt aims to accelerate ambitious climate adaptation efforts by subnational governments worldwide, to develop ambitious climate change strategies, implement concrete adaptation actions and transparently report on progress, in partnership with the reporting system of CDP, while actively contributing to United Nations Framework Convention on Climate Change processes. https://www.regions4.org/project/regionsadapt

Box 4.11 Supporting Covenant of Mayors signatories: Alba Local Energy Agency, Romania

The Covenant of Mayors is an important driver of urban adaptation policy development, especially in areas where strong supporting organisations are present. An example can be found in Romania, where the Covenant's long-term supporting organisation Alba Local Energy Agency (ALEA) established the Anergo Energy Observatory in 2015. At the time, its main goal was to collect regional energy data for Covenant of Mayors signatories in Alba County and the Centru Development Region of Romania. In the new Covenant of Mayors for Climate and Energy, Anergo has expanded its purpose to also support municipalities in delivering on their Covenant adaptation goals.

ALEA and Anergo have established a framework for collecting historical weather and climate data from various sources (e.g. Copernicus) to populate a climate database. Anergo supports municipalities in drawing up their risk and vulnerability assessments in the framework of the Covenant of Mayors. This includes establishing the baseline of existing climate adaptation policies, an in-depth analysis of weather data over the last 30 years, interpreting the data for the specific local situation and defining the most important climate and socio-economic risks and vulnerabilities within the monitoring framework for measuring adaptation progress. The first sustainable energy and climate action plans (SECAPs) based on this methodology were developed for Alba Iulia and Sebes in 2019. ALEA and Anergo plan to further expand their support to municipalities to aid them in the implementation and monitoring of local SECAPs.

Source: Personal communication from Florin Andronescu, ALEA, 2019.

4.6 Multi-level governance of urban adaptation: conclusions and outlook

As has become obvious from this chapter, considerable support exists already for adaptation to climate change in urban settings through the multi-level governance framework. The international, European-level stakeholders, and national and often regional governments acknowledge the importance of cities and towns when it comes to climate change adaptation. A number of supporting legislation and concrete schemes have been developed to facilitate and speed up adaptation planning and implementation at the local level. Many cities are self-organising their own mutual support and knowledge sharing through networks at international, national or regional scales.

However, not all cities in all countries are supported equally in their adaptation activities, and some are not in a position to work on adaptation to the extent necessary to prepare adequately for climate change impacts. To explore this further, Chapter 5 investigates the current status of local adaptation planning and implementation in Europe and sheds a light on differences in city action, e.g. based on population size or geographical location (Section 5.4). Gaps and barriers to adaptation at the local level are analysed in Chapter 6, along with developments and policy opportunities to overcome these barriers.

Even though a general trend towards collaboration between national and local levels on adaptation can be observed, the concrete implementation differs considerably between countries. National requirements that cities develop adaptation (or similar) plans seem to result in a high number of plans being produced. However, it has not been confirmed that these plans are also widely implemented (see Section 5.1.2).

When it comes to financial support, different approaches are adopted on funding cutting-edge pioneering projects or the wider implementation of already tried and tested solutions; it is often a mix of both and depends on the funds available. More research is needed to evaluate which modes of governance are the most effective in stimulating implementation of adaptive actions on the ground.

For capacity support, many countries opt for funding external expertise to help cities develop plans. Whether this facilitates the actual implementation of these plans or not still needs further research. Other countries decide to train municipal staff on all aspects of climate change adaptation. While this can help to engage municipal staff for the long haul, it may not necessarily be possible or the most efficient solution for small municipalities short of staff. It is also unclear, to what extent the lessons learned by cities in the planning and implementation of adaptation at the local level feed back into national adaptation planning.

Ultimately, the cooperation between national and local authorities depends greatly on a country's multi-level governance setup and culture, as well as available funding and priorities. At the same time, where cities had started working on adaptation before an official policy from or collaboration with the national government started, e.g. through international networks and initiatives or EU-funded projects, there is a risk that these local initiatives are not sufficiently considered in the development of national policies and support programmes. This can lead to incompatibilities between policies, the content of action plans or reporting frameworks, and diminish efficiency.

5 Taking stock of adaptation planning and action at the local level in Europe

Key messages

- There is no single comprehensive European overview of adaptation planning and action at the local government level. The paucity of coherent country reporting on local adaptation is an obstacle to understanding the status quo and taking further action at the European level.

- Many local governments in Europe have made a political commitment to climate change adaptation by joining international initiatives, with varying geographical distribution across Europe. Over a quarter of the population in EEA-38 member and collaborating countries are living in the local authorities committed to adaptation under the Covenant of Mayors for Climate and Energy.

- Local adaptation planning is time- and effort-intensive but is usually done by a limited number of civil servants in local authorities. Thus, while the number of local authorities committed to adaptation is high, adaptation planning is progressing more slowly, and implementation and monitoring of actions lag behind.

- Despite the cross-cutting nature of climate impacts, responsibility for adaptation tends to be concentrated in a single department, typically concerned with planning or the environment. Therefore, collaboration with other departments or stakeholders is necessary to secure adequate coverage of health and social issues in adaptation.

- Local budgets are the most widespread source of funding for adaptation planning and implementation. The adaptation budgets of signatories to the Covenant of Mayors tend to be rather low (median EUR 535 000). While EU funding is the largest source in total, it is used by a small number of signatories. The private sector is the third largest source of funding (after local authorities' own funds), with national funds playing a smaller role.

- A large proportion of local adaptation actions currently planned and implemented in Europe are 'soft' measures (i.e. actions aimed at developing knowledge, awareness or policy). This is because of the overall early stages of adaptation, the lower costs of such actions than green and grey infrastructure measures, as well as the remit of the local authorities.

- External stakeholders tend to participate more in adaptation planning than in the implementation phase. The private sector and citizens are the types of stakeholder most frequently engaged in planning. Further engagement of non-governmental and research organisations could enhance adaptive capacity and support adaptation activities.

- There are pronounced differences between smaller and larger local authorities in terms of their remit, budget available for adaptation (smaller local authorities have less funding) and level of stakeholder engagement. This indicates the challenges faced by small local authorities and calls for specific support for them for adaptation planning and implementation.

- Different approaches to adaptation planning and implementation exist among European regions. Western European local authorities tend to engage social care and health departments, citizens, research institutes and the private sector more frequently than other regions do. Local authorities from central and eastern Europe tend to rely heavily on their own staff — mainly in planning departments — for implementing adaptation actions, with a strong focus on infrastructure and the built environment.

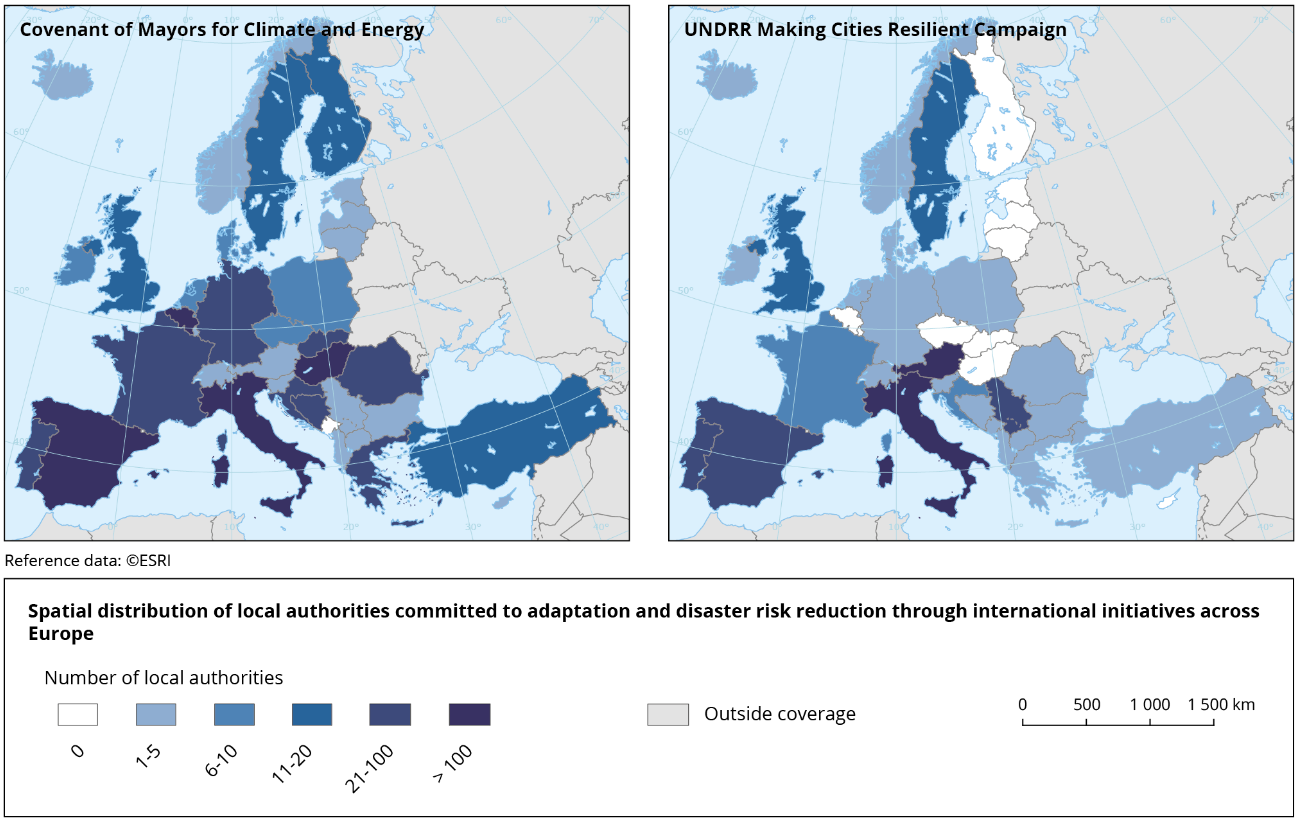
5.1 Status of local adaptation planning

In Europe, there is no single, comprehensive database of local authorities that are committed to, planning or implementing adaptation actions. The closest are the databases of the Covenant of Mayors for Climate and Energy and CDP (see Box 1.1), and various other city networks and initiatives (see Box 4.4). However, these do not cover the local authorities that act beyond the framework of international initiatives and networks, either as a result of national regulations (see Section 4.4.1) or on their own initiative. Therefore, Chapter 5 provides an approximate rather than exact picture of local adaptation planning in Europe by analysing the available information from various databases and research studies.

5.1.1 Commitment to adaptation

The number of local authorities participating in international or European initiatives has grown across Europe in the last few years (cf. EEA, 2012, 2016; and Figure 4.1). As of April 2020, nearly 123 million of the population of the EEA 38 member and collaborating countries live in local authority areas committed to adaptation under the Covenant of Mayors for Climate and Energy. The geographical distribution of the signatories varies considerably across Europe (Map 5.1). In some cases, the concentration of signatories in a given country or region can be explained by the presence of particularly active organisations supporting and coordinating the Covenant of Mayors (national ministries, provinces, regional energy and environment agencies, or city networks; see also Chapter 4). The participants in the United Nations Office for Disaster Risk Reduction (UNDRR) Making Cities Resilient campaign are concentrated in certain European countries, including Austria, the Basilicata region of Italy, Portugal and Serbia. The members of 100 Resilient Cities and C40 Cities are mainly in north-west Europe (71).

Map 5.1 Spatial distribution of local authorities committed to adaptation and disaster risk reduction through international initiatives



Reference data: ©ESRI

Notes: For information about individual local authorities see Urban Adaptation Map Viewer.

Source: Authors' own compilation based on data obtained directly from the Covenant of Mayors for Climate and Energy — Europe Office and UNDRR (as of May 2019).

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(71) See Urban Adaptation Map Viewer (https://climate-adapt.eea.europa.eu/knowledge/tools/urban-adaptation) for details on individual cities.

Signing up to international networks and initiatives is a clear signal of political will, which is an essential enabling condition for the development of local adaptation policies (Vogel and Henstra, 2015; see also Section 6.1). Political commitment can move adaptation up the local agenda; in particular, the Covenant of Mayors plays an important role in encouraging cities — particularly the smaller ones — to engage in climate action (Reckien et al., 2019). Indeed, in Portugal representatives of municipalities that are signatories to the Covenant of Mayors were found to perceive adaptation as much more important than non-signatories (Campos et al., 2017). Therefore, the widespread participation of local authorities in various initiatives indicates great potential for progressing adaptation planning and action in Europe.

5.1.2 Progressing from commitment to action

Development of adaptation action plans

Securing the political support is the first step to adaptation (72), but it takes time and effort to move from the political commitment to planning. Signatories to the Covenant of Mayors have two years to develop an action plan from joining the initiative (see Box 4.4); also, according to Albini et al. (2017), the process of development of an adaptation strategy at the local or regional level may take over 2 years. In April 2020, among the 2 669 Covenant of Mayors signatories with a climate change adaptation commitment, 442 (under 17 %) had submitted an action plan covering adaptation and none had officially reported progress (personal communication from Lea Kleinenkuhnen, Covenant of Mayors for Climate and Energy — Europe Office, 2020) (73). Just over a half of the 163 European cities reporting to CDP (see Box 1.1) had published an adaptation action plan by 2018; a plan was in progress for a further 38 cities; and 22 cities had planned to undertake work on the adaptation plan in the following 2 years. A 2018 survey among German municipalities commissioned by the German Environment Agency to assess the impact of the national adaptation strategy on the local level found that 40 % of the participating municipalities had made a political decision to adapt. However, more than 45 % of the municipalities did not have, and did not intend to have, formal instruments for climate adaptation (Hasse and Willen, 2018).

Cities also act on adaptation outside the frameworks of international initiatives. Reckien et al. (2018) concluded that around 26 % of 885 Urban Audit cities across the EU-28 had an adaptation strategy or plan. Aguiar et al. (2018) conducted a systematic literature search to identify European cities that have adaptation action plans, which found 147 plans in 20 countries. While the results from these studies differ owing to the search methodologies applied, according to both studies, the cities with adaptation action plans tended to concentrate in western Europe.

Nearly 123 million Europeans live in local authorities committed to adaptation under the Covenant of Mayors

Despite the large difference between the number of local authorities committed to acting on adaptation through their participation in various initiatives and the number of those that have adaptation action plans, local adaptation planning in Europe is progressing at a fast rate. According to Aguiar et al. (2018), the number of local adaptation strategies in cities tripled between 2011 and 2016. This is in line with the progress made in the number of EU Member States having developed national adaptation strategies (see Figure 4.1), possibly reflecting the role of national frameworks in initiating action at lower governance levels.

From adaptation planning to implementation and monitoring of actions

The reporting of the signatories to the Covenant of Mayors includes an element of self-assessment, which is organised (with some deviation) around the steps of the Urban Adaptation Support Tool (74). It offers a glimpse into the progress made by local authorities in adaptation planning, implementation and monitoring (Figure 5.1). Overall, many signatories have reported no or hardly any progress for the adaptation steps. For some, this may be because they joined the Covenant of Mayors recently, as the action plan is not required until 2 years after joining the initiative.

According to Figure 5.1, the highest proportions of the Covenant of Mayors signatories evaluated their progress as over 50 % complete for the risk and vulnerability assessment, followed by development and adoption of adaptation actions. Among the cities reporting to CDP, out of 109 cities that answered the question 'Has a climate change risk or vulnerability assessment been undertaken for your local government area?', 75 responded positively and for a further 18 the assessment was in progress.

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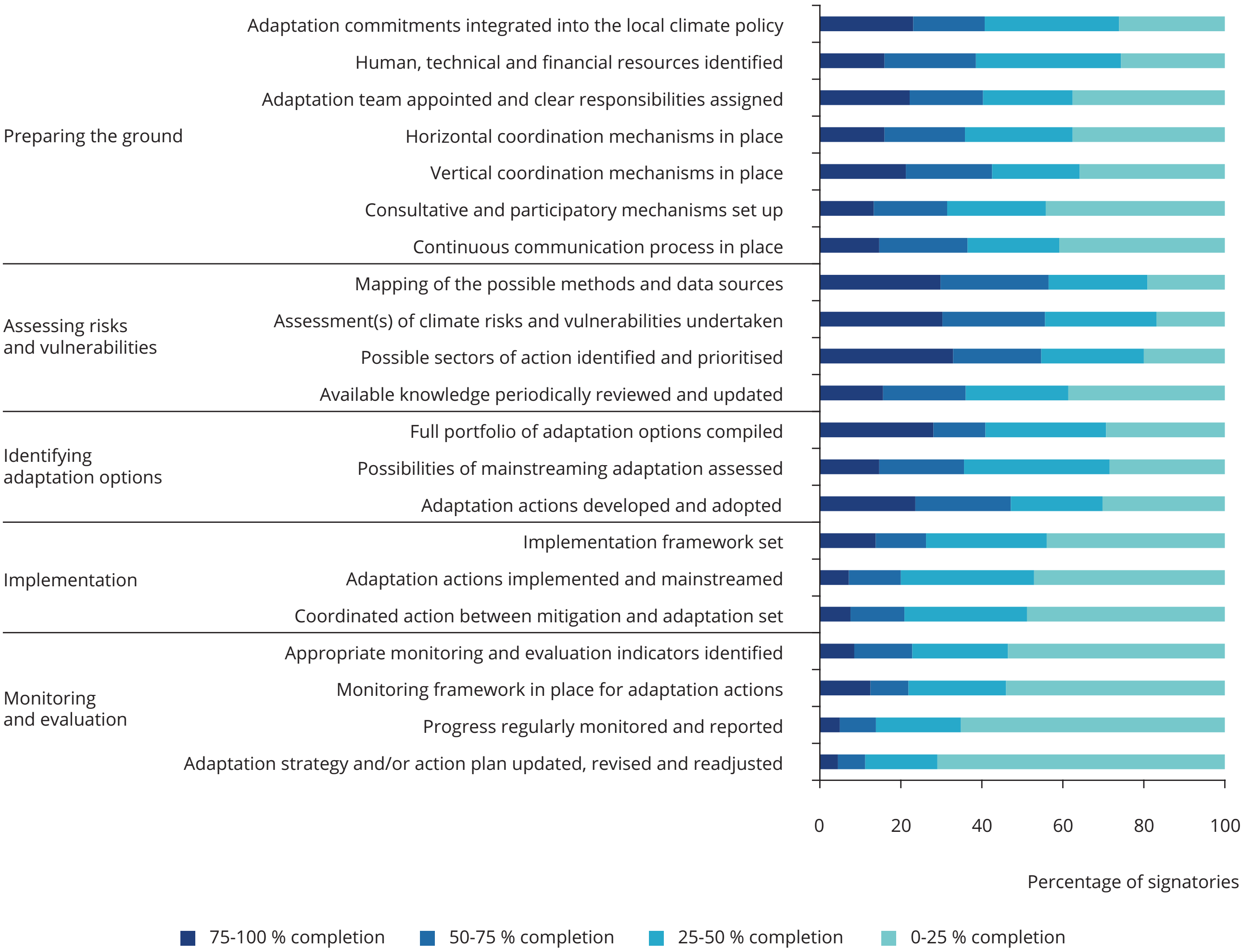
(72) For steps in adaptation planning, recommended by the Covenant of Mayors — Europe Office, see the Urban Adaptation Support Tool: https://climate-adapt.eea.europa.eu/knowledge/tools/urban-ast/step-1-0

(73) Signatory cities to the European Covenant of Mayors commit to monitor their progress every 2 years after submission of their action plan.

(74) https://climate-adapt.eea.europa.eu/knowledge/tools/urban-ast/step-0-0

Figure 5.1 **Level of progress of Covenant of Mayors signatories in adaptation planning and implementation**



Note: Based on the responses of 226 signatories from 21 EEA member and collaborating countries plus the United Kingdom that completed the Adaptation Scoreboard in their sustainable energy and climate action plans.

Source: Authors' compilation based on analysis of data extracted from Covenant of Mayors for Climate and Energy database on 19 June 2019.

The relatively low number of signatories that assessed their progress as more than 50 % complete on setting up 'consultative and participatory mechanisms' and 'horizontal coordination mechanisms' (Figure 5.1) may indicate that both the coordination between departments and local stakeholders' engagement require further development (see also Sections 5.1.3 and 5.1.4).

The number of signatories assessing their progress as more than 50 % complete reduces rapidly in the implementation and monitoring phases, compared with the earlier steps. Only around one-fifth of the signatories report good progress (over 50% completion) on implementation and mainstreaming of adaptive actions. According to Aguiar et al. (2018), based on the analysis of 147 local adaptation strategies across Europe, at least half of the municipalities had begun implementation actions. Albini et al. (2017) reports a similar proportion of city or regional governments undertaking action; 10 out of 21 investigated European sub-national authorities have begun implementation. The higher numbers found in those studies may be linked to the larger size of the authorities analysed, compared to the predominantly small Covenant of Mayors signatories. Therefore, there is an urgent need to move adaptation from the planning to implementation phase, in particular supporting smaller local authorities in their efforts.

Fewer than 5 % of signatories assessed themselves as being near completion of regularly monitoring progress or of making changes to their adaptation plans based on the results of the monitoring. This echoes the relatively little knowledge we have on the effectiveness and cost-efficiency of adaptation measures (see Chapter 3) and calls for intensified monitoring efforts.

5.1.3 Local authorities as drivers of adaptation planning

Role of local authorities in planning and implementing adaptation to climate change

Local officials perform public functions that are central to climate adaptation, such as land use regulation, building inspection, critical infrastructure protection and emergency planning. The public sector often has a duty of care over stormwater management, flood risk reduction or health-related policies, and stimulates action through regulation, incentives or subsidies. The rationales for public entities taking responsibility for adaptation are avoidance of market failure (e.g. through continuing construction in flood risk areas), security concerns (e.g. linked to emergency planning) and fairness (Mees, 2017).

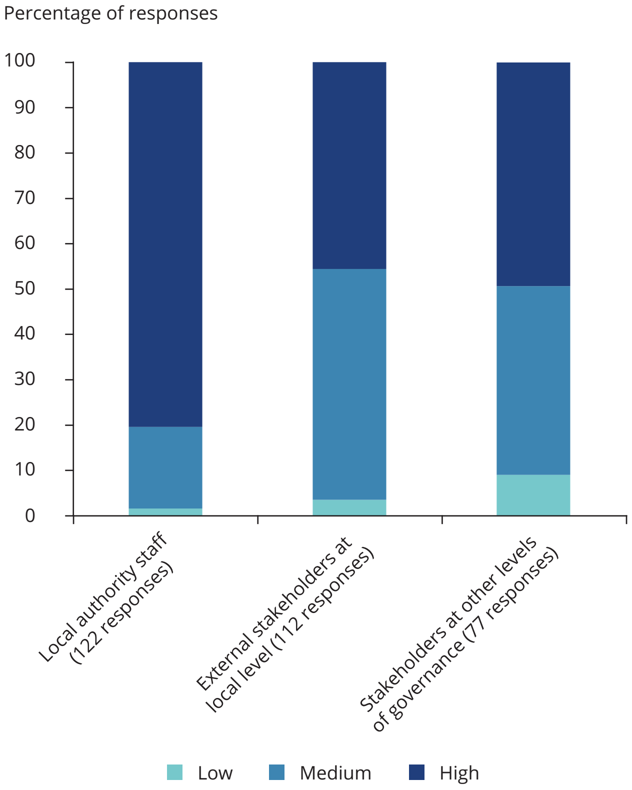
Four out of five signatories to the Covenant of Mayors emphasised high level of involvement of local authority staff in adaptation planning (Figure 5.2). However, there is some indication that the task may be allocated to very few people: in a survey of German municipalities, usually there were only 0.5-1 full-time equivalent positions (often time-limited) on adaptation; almost half of the municipalities compensated for the limited resources by hiring external experts (Hasse and Willen, 2018).

Internal division of responsibility for adaptation

Specialised climate change departments at the local authority level are a rarity. An investigation of over 100 Portuguese municipalities showed that 97 % of them did not have a specific department for handling climate change response. For 16 %, adaptation was dealt with by a department that also had other functions, and 53 % had only an environmental department (Campos et al., 2017).

Among the limited number of the Covenant of Mayors signatories that reported on the departments responsible for implementation of the planned adaptation actions, the departments most often responsible are those dealing with spatial planning, urban design, open spaces or architecture, followed by the departments concerned with environment or sustainability (Figure 5.3). In contrast, very few actions are implemented by social care or health and housing departments. Moreover, in the study conducted among municipalities in Germany, the environment and urban planning departments are most frequently involved in, and in charge of, implementing adaptation, followed by urban development and urban drainage departments. The health and social affairs departments were involved in climate adaptation activities in only a few municipalities (Hasse and Willen, 2018). The policy link between adaptation and health needs reinforcement, as recognised in the evaluation of the EU adaptation strategy (EC, 2018f).

Figure 5.2 Level of involvement of various stakeholders in adaptation planning



Note: Based on the reporting of signatories to the Covenant of Mayors for Climate and Energy from 20 EEA member and collaborating countries.

Source: Authors' compilation based on analysis of data extracted from the Covenant of Mayors for Climate and Energy database on 19 June 2019.

These findings are partly echoed in the investigation of local and regional adaptation strategies by Albini et al. (2017), which found that most strategies were developed by environmental departments, while strategy implementation was predominantly run by the planning departments. However, according to that investigation, health departments were involved in developing more than half of the adaptation strategies. Therefore, the size of the local authority may dictate which departments are involved, as smaller local authorities may not be responsible for public health or housing (see also Section 5.4.1); in some countries local authorities do not have competencies in these areas.

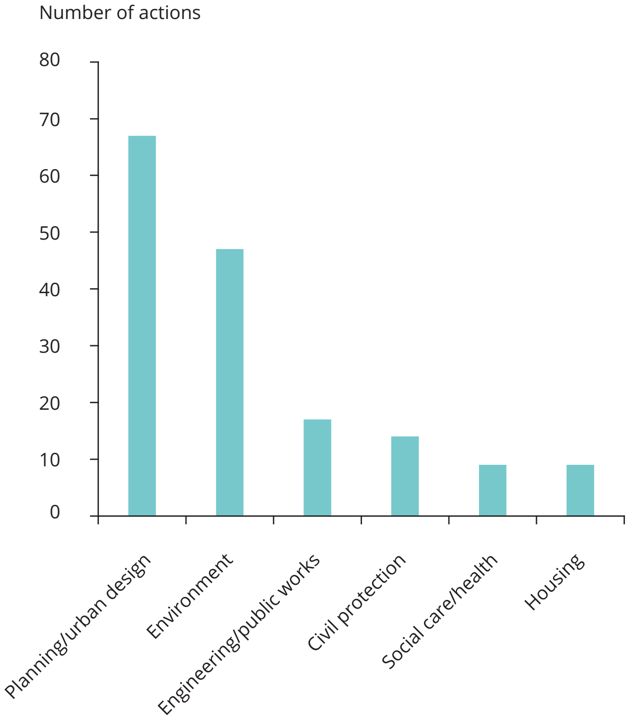
Departmental collaboration is considered beneficial for the planning and implementation of adaptation at all levels of governance (Aylett, 2015; EEA, 2017a). Two thirds of the local adaptation plans investigated by Aguiar et al. (2018) involved engaging various departments in adaptation planning and implementation, while in Germany interdepartmental working groups were less common and had been introduced or were planned in only about one third of the municipalities (Hasse and Willen, 2018). Local authorities in Scotland recognised the need to involve various departments, such as health, social care or housing, in flood risk management under the changing climate, but there was little or no collaboration in place (Kazmierczak et al., 2015). Setting up and coordinating such collaboration requires effort, especially among departments that do not traditionally have much in common. The case study from Mannheim, Germany (Box 5.1), shows how different departments' engagement in adaptation and buy-in have been secured.

5.1.4 *Stakeholder engagement in urban adaptation*

Stakeholders are individuals, groups and organisations that could be affected by policy objectives or have the power or resources to affect policy development and implementation (Bryson, 2004). Stakeholder support influences the political feasibility and perceived legitimacy of policy options.

The sharing of responsibilities among public and private stakeholders can promote joint fact-finding and social learning processes, thus raising the adaptive capacity of society to cope with climate change (Mees, 2017). In the case of flood risk management, local stakeholder involvement is seen as an important supplement to local government's capacity (e.g. knowledge and funding) required to deliver the risk reduction measures (Begg, 2018). Importantly, private entities,

Figure 5.3 Departments responsible for implementation of adaptation actions



Note: As reported for 121 actions by 27 signatories to the Covenant of Mayors for Climate and Energy from five EEA member countries (Belgium, Finland, France, Slovakia and Spain).

Source: Authors' compilation based on analysis of data extracted from the Covenant of Mayors for Climate and Energy database on 19 June 2019.

Box 5.1 Involving the different city departments through workshops and a survey in Mannheim, Germany

In the development phase of its adaptation action plan, the city of Mannheim carried out an in-depth participation process in 2018 and 2019. The process involved not only external stakeholders (citizen initiatives, thematic and residents’ associations, children and youth, etc.) but also the city administration, such as the departments for green spaces, urban development, mobility, infrastructure, health or industry, and the city-owned companies.

The starting point was a survey asking city staff about climate change impacts already experienced in the fields falling under their responsibility and in their daily work; what future challenges they foresee; and what adaptation measures staff are taking or would like to take in their daily work. The most affected sectors identified through the survey were health, green areas and air quality. The biggest challenges identified were preserving fresh air corridors (e.g. by means of the land use plan); management of open spaces (e.g. by decreasing surface sealing); and tackling heat stress.

After the survey, three workshops with city staff were organised, which focused on exploring the recognised risks and vulnerabilities, identifying goals and the measures needed to reach them, and consolidation and monitoring.

By considering the experiences and suggestions of city staff working in different departments on the development of the adaptation plan, the city managed to raise awareness across the administration staff and develop an adaptation plan that was adopted by the city council in April 2019. This plan is widely accepted and implemented in the various departments.

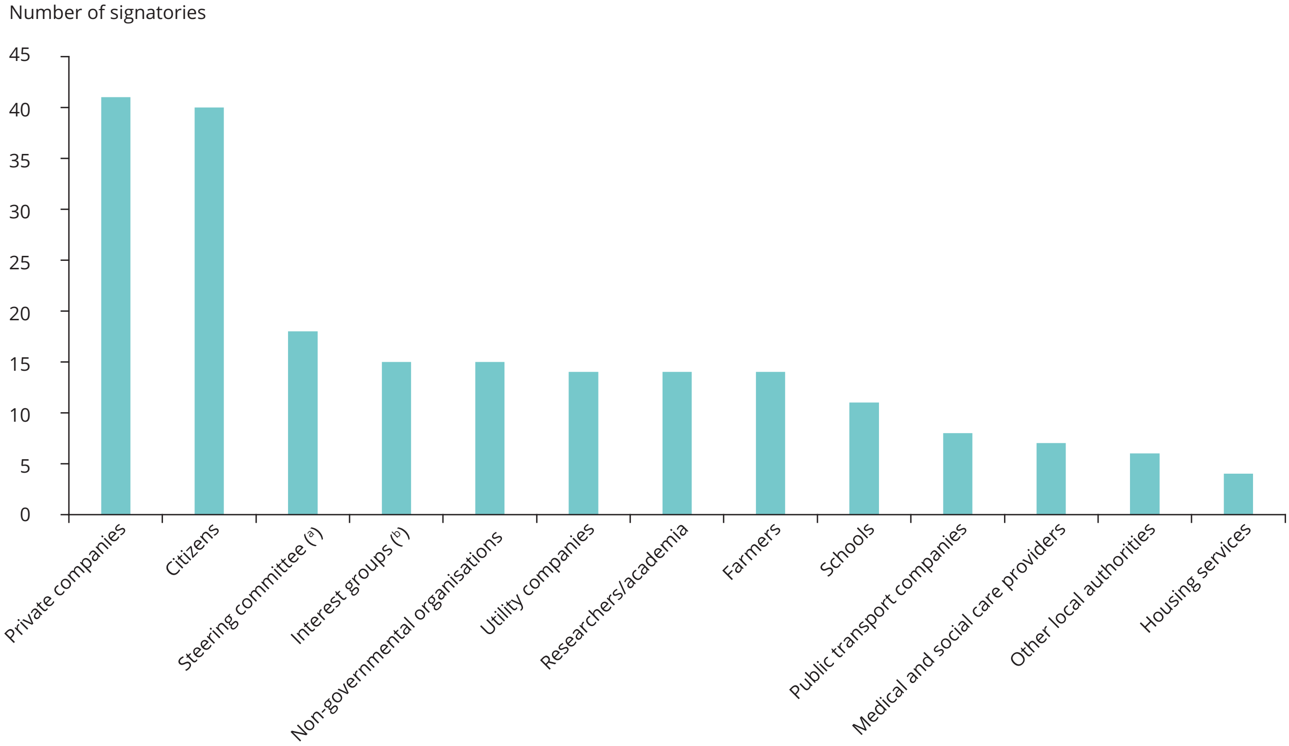
Source: Personal communication from Agnes Schönfelder, City of Mannheim, 2019; Stadt Mannheim (2019).

such as residents, developers and housing associations, are predominantly responsible for the financing, installation and maintenance of adaptation measures on private property, such as green roofs or property level flood resilience (Mees, 2017). Therefore, neglecting stakeholders' concerns can lead to poor policy performance and often policy failure (Vogel and Henstra, 2015).

Proximity to stakeholders gives local decision-makers access to knowledge about local vulnerability, enabling them to develop approaches tailored to the community needs (Aguiar et al., 2018). Public engagement is particularly effective at the local level, because the community-specific risks tangibly demonstrate the importance of taking adaptive actions (Vogel and Henstra, 2015). However, low levels of trust in local institutions may result in reluctance among the citizens, local businesses or civil society organisations to engage in adaptation activities organised by the local government. The level of trust in local institutions differs considerably between European countries; according to the European Quality of Life Survey 2016, the highest average levels of trust were expressed by respondents in Luxembourg, Austria, Denmark and Finland, and the lowest in North Macedonia, Croatia and Albania (Eurofound, 2020). Furthermore, the level of trust may differ between various social groups or locations within a country, leading to less engagement of, for example, disadvantaged groups or minorities. In addition, the understanding and perception of risk by different stakeholders plays a critical role in how individuals and institutions act to mitigate risks. It is therefore crucial to communicate climate risks effectively to various stakeholders (Santoro et al., 2019).

The current stakeholder engagement in local adaptation paints a mixed picture. Of the cities reporting to CDP (75), over 40 % had a stakeholder engagement plan in place, 20 % were in the process of preparing one and another 20 % were planning to develop such a plan in future (CDP, 2019). Aguiar et al. (2018) found extensive engagement of diverse groups in almost all local authorities that had produced adaptation action plans. The stakeholders most frequently involved were various interest groups — e.g. landowners, non-governmental organisations (NGOs), farmers' associations — the private sector, and research and academia, followed by the general public and the education sector.

Figure 5.4 **External local stakeholders involved in adaptation planning**



Notes: As reported by 113 Covenant of Mayors for Climate and Energy signatories on adaptation from 20 EEA member and collaborating countries.
(a) A committee consisting of city officials from different departments and interested citizens, as well as sometimes other stakeholders like businesses or information providers, identified mainly by signatories from Belgium.
(b) For example, landowners or various associations, identified mainly by signatories from Italy.

Source: Authors' compilation based on analysis of data extracted from Covenant of Mayors for Climate and Energy database on 19 June 2019.

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(75) A total of 61 city representatives responded to the question about stakeholder engagement.

With regard to the adaptation-planning phase, according to nearly all of the Covenant of Mayors signatories, external local stakeholders consistently were indicated to have a high or medium level of involvement in adaptation planning (see Figure 5.2). The highest number of signatories involved private sector actors, followed by citizens and various types of utility or transport companies in adaptation planning (Figure 5.4). See Box 5.2 for examples of innovative ways of engaging citizens on the subject of adaptation. An example of engagement of the insurance industry in adaptation planning in Italy is presented in Box 5.3.

Box 5.2 Examples of innovative ways of engaging citizens in adaptation

Raising awareness: gaming and virtual reality in Trondheim, Norway

Virtual reality and gaming approaches help raise awareness of climate change issues and the need to both reduce emissions and adapt to coming change. For Trondheim, Norway, the Norwegian University of Science and Technology (NTNU) developed a virtual reality application, which illustrates the effects of storm surge, pluvial flooding and sea level rise on the city centre in different climate scenarios. In the game Climate Quest in Trondheim, the player replaces cars with bicycles and chimneys with solar panels, and removes CO_2 from the atmosphere to keep the seawater levels low.

Screenshot from the virtual reality application © NTNU

Screenshot from the game Climate Quest in Trondheim © NTNU

The applications were an essential part of a 4-day exhibition entitled 'FUTURUM — the museum for the future' at NTNU in June 2019. Around 3 000 visitors (mainly Trondheim citizens), including the Crown Prince of Norway, tested the applications. The virtual reality application continues to be displayed at NTNU's science museum, which opened in September 2019. It was seen by almost 9 000 visitors up to the end of 2019. The applications were also presented at a meeting gathering stakeholders from Trøndelag county working on climate change adaptation, and at the annual meeting for researchers and stakeholders affiliated with the research programme Klima 2050.

Source: Personal communication from Jan Ketil Rød, NTNU, 2020.

Developing solutions: Climate-KIC Climathon supporting bottom-up innovations

Climate-KIC Climathon is a programme that translates climate action solutions into tangible projects, supports climate-friendly businesses and start-ups, and addresses local policy changes. Cities can volunteer to host a Climathon on a subject of their choice, whereby teams of citizens compete against each other in a 'hackathon' style 24-hour event to develop innovative solutions to challenges faced by the city. In 2018, 113 cities around the world participated. For example, in Budapest, Hungary, restructuring the existing riverbanks to improve their attractiveness was explored, while ways to improve resilience and preparedness to extreme weather events were discussed in Timisoara, Romania. In Nis, Serbia, the subject was making a climate-friendly city through green infrastructure, and in Zagreb, Croatia, options for cooling the city were developed.

Source: https://climathon.climate-kic.org

Box 5.3 Adapting small and medium-sized enterprises to climate change with the support of the insurance industry in Turin, Italy

Small and medium-sized enterprises (SMEs) are extremely vulnerable to climate risks, because they are more affected by direct losses and business interruption than larger firms. The Italian Association of Insurance Brokers estimates that 90 % of Italian SMEs that had to suspend their activities for more than 1 week owing to weather-related events went bankrupt within a year. Planning for such risks and preparing SMEs and their surrounding industrial districts is therefore crucial for avoiding long-term losses and business failure.

The EU-funded Disaster risk reduction insurance (Derris) project (2015-2018) developed a new model for public-private partnerships between insurers, local authorities and SMEs. The partnerships focused on transferring knowledge for risk assessment and management from insurers to the public and private sector, and on promoting the development of adaptation plans for industrial districts and for individual SMEs. As part of the project, the Italian insurance group UNIPOL supported 30 SMEs in six industrial areas in Turin in assessing their risk of climate-related losses and developing their company adaptation action plans.

Enterprises that participated in the project installed measures such as mobile or fixed flood protection. Routines were created for regular checking of gutters to reduce the risk of flooding, and for checking machine performance under elevated temperatures. Following information about local flood risk, one enterprise adapted its new building during its construction phase by elevating floor levels and changing the layout of walls to reduce potential damage. Many enterprises amended their organisational and management systems, for example by developing specific plans for disaster recovery, appointing personnel for monitoring emergency alerts or creating budget reserves for recovery measures.

Source: Climate-ADAPT (2020b).

Collaboration with the research community, NGOs or other local authorities on adaptation planning was less frequent among the Covenant of Mayors signatories (Figure 5.4). The cooperation among local authorities to divide tasks and coordinate efforts was practised by less than a quarter of municipalities surveyed in Germany (Hasse and Willen, 2018). This may have implications for addressing climate hazards that go beyond the borders of one local authority, and whereby actions in one location can have effects on another place (e.g. river flooding or coastal erosion, see Section 3.9).

Considering the implementation of adaptative actions, fewer than a quarter of the Covenant of Mayors signatories reported engagement of external stakeholders. Citizens were the most frequently engaged in implementation (Figure 5.5; see also Box 5.4), followed closely by entities at the higher governance level (76). Utility companies or governmental agencies, especially those concerned with water, were another key stakeholder type, followed by the broader private sector and landowners.

For nearly 40 % of actions planned by the Covenant of Mayors signatories, no involvement of external stakeholders was indicated. Over one third of actions involved one type of stakeholder, and one fifth involved two types. Fewer than 5 % of actions engaged three or more types of stakeholders. Therefore, the roles of citizens, civil society and business actors, such as project developers and housing associations, are still modest (Mees, 2017). This echoes the self-assessment of signatories (Figure 5.1), whereby relatively few local authorities reported being advanced in engagement of stakeholders. Box 5.5 shows an example of a multi-stakeholder adaptation project in Amsterdam.

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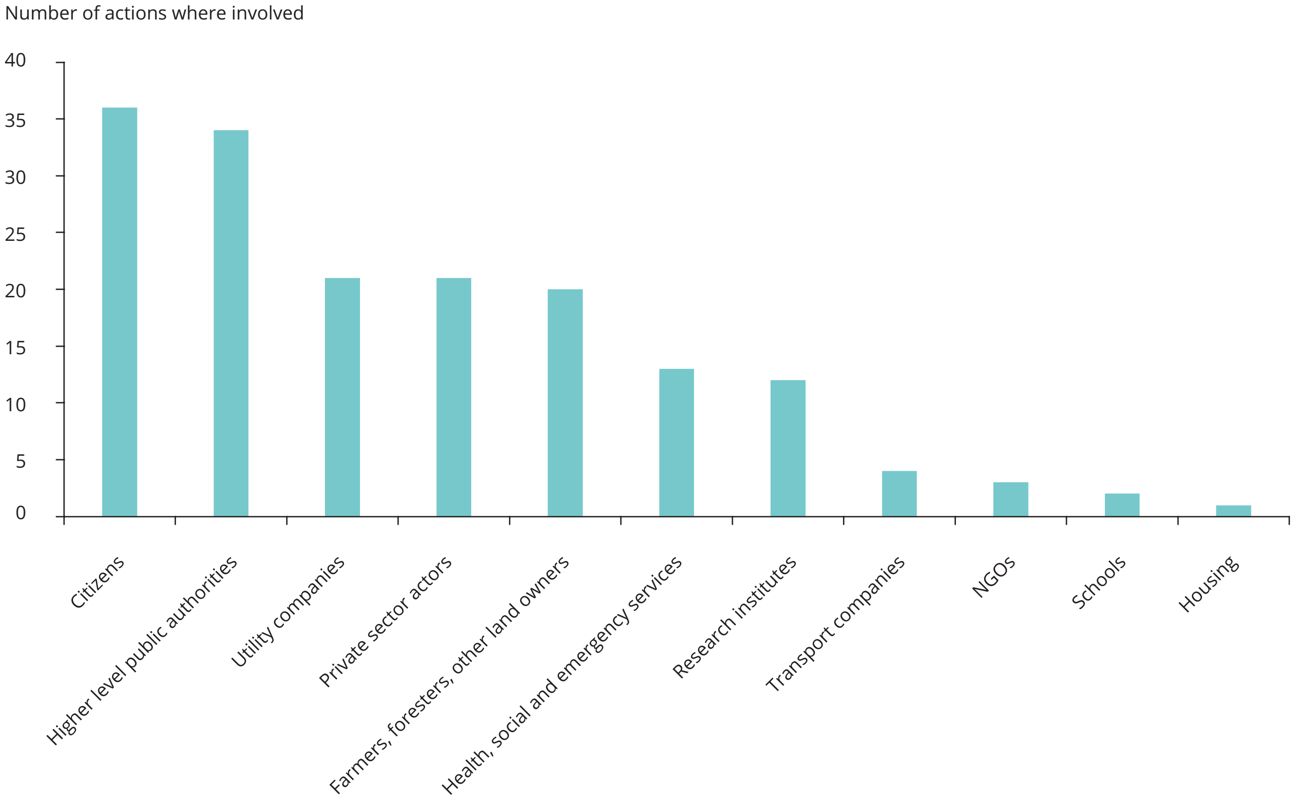
(76) This could be linked to the predominance of the small-size signatories to the Covenant of Mayors, which may have limited responsibilities and may need to rely on higher governance levels in adaptation planning and implementation.

Figure 5.5 **External stakeholders engaged in implementation of adaptation action plans**



Note: As reported by 49 Covenant of Mayors for Climate and Energy signatories on adaptation from nine EEA member and collaborating countries for 228 adaptation actions.

Source: Authors' compilation based on the analysis of data extracted from Covenant of Mayors for Climate and Energy database on 19 June 2019.

Box 5.4 Examples of innovative ways of engaging citizens in adaptation implementation

Encouraging actions on private property for public good in the Netherlands

Several municipalities in the Netherlands have hired and trained 'rainwater guardians', who advise citizens on storing rainwater and designing a 'rainproof' garden. In the city of Amersfoort, the municipality representatives go from door to door, encouraging citizens to disconnect their downspouts from the sewerage system and offering advice on alternative measures. Similarly, within the Boomgaard initiative in the municipality of Dalfsen, houses are disconnected from the sewerage system, aiming at rainwater storage within properties. The municipality informs citizens of rainwater storage solutions and provides a small budget for the creation of a legal entity for the citizen initiative (e.g. a foundation) or for hiring an expert. A further 75 Dutch municipalities participate in the programme Operation stone break (https://www.operatiesteenbreek.nl), which provides free plants to encourage citizens to remove garden paving (Mees et al., 2019).

Engaging citizens in management and maintenance of public spaces

In 2016, the city of Paris issued a 'licence to green' to all Parisians, encouraging them to plant more trees and gardens on vacant pieces of land — anything from a small strip of grass to a large community garden (Global Opportunity Explorer, 2018c). Growing food is particularly encouraged. Licences are issued for 3 years. A starter planting kit, including topsoil and seeds, is provided by the city. In return, residents agree to plant for pollinators, never use pesticides, and maintain the appearance and health of the green spaces. The city supports creative solutions, such as planters along fences or on facades, or even vegetated street furniture (Livingroofs, 2020).

The city of Legnica in Poland establishes and renovates new green areas in a joint effort with its residents. The municipal government buys trees and shrubs and offers them, free of charge, to interested parties (individual gardeners, housing cooperatives, educational institutions, road administration, real estate managers, business stakeholders and other local organisations). The plants must be collected, planted in accordance with an approved plan and taken care of. In 2017, almost 400 trees and 6 000 shrubs were planted as part of the programme (44MPA, 2019).

'Adoption' of greenery is another popular approach, which helps the local authority fund the installation and maintenance of green spaces in the city. Since 2005, citizens, private companies, non-governmental organisations or other entities in Milan have been able to adopt a flowerbed for 3-5 years. The initiative has evolved to include various types of green space. As of 2017, a total of 432 agreements had been signed, covering nearly 232 000 m^2 of green areas, amounting to EUR 1.7 million (Croci and Lucchitta, 2017). See also Box 6.9.

Stakeholder engagement can, however, be understood by the urban practitioners as many things, from information presented in media, through consultation (e.g. focus groups) or involvement in development of the strategy (e.g. participatory workshops), to various forms of collaboration and finally empowerment to decide jointly with the local authority or lead on actions. According to Albini et al. (2017), the majority of the 21 investigated regions and cities engaged the stakeholders in consultation or involvement mode, while only a third employed closer collaboration modes, suggesting that close partnerships with external stakeholders are rather rare. Guidance on the engagement of stakeholders can be found in the Urban Adaptation Support Tool (77).

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(77) https://climate-adapt.eea.europa.eu/knowledge/tools/urban-ast/step-1-6 .

Box 5.5 Collective effort of the city administration, public housing companies, small and medium-sized enterprises, and academia to provide smart blue-green roofs in Amsterdam

Within the project Resilio (Resilience network of smart innovative climate-adaptive rooftops; November 2018 to October 2021), funded through the EU Urban Innovative Actions (UIA) initiative, the city of Amsterdam aims to prepare for more intense precipitation by providing 10 000 m2 of smart blue-green roofs in social housing complexes.

On the smart blue-green roofs, rainwater can be stored under the vegetation and soil layers. A 'smart flow control' system, which is linked to the weather-forecasting system, anticipates heavy rain or dry periods, retaining or releasing the water accordingly. The roofs will be connected via a network, enabling remote regulation of rooftop water levels based on weather forecasts and water management settings. In addition, the blue-green roofs can help to alleviate the urban heat island (UHI) effect, offer additional roof insulation and enhance biodiversity. The project is a scaled-up version of the first smart blue-green roof, which was installed on building 002 in the Marineterrein innovation hub in 2017.

RESILIO aims to retrofit existing buildings in areas inhabited by residents with relatively low incomes. The apartment blocks were selected for retrofitting based on their location in flood-prone areas or places affected by the UHI effect; renovations scheduled in the maintenance programmes of social housing corporations (to avoid extra costs); and structural requirements.

The project partnership includes the city of Amsterdam, Waternet (a public water management company), three social housing companies (Stadgenoot, De Key and De Alliantie), two research institutes, a non-governmental organisation (Rooftop Revolution, promoting blue and green roofs) and two small and medium-sized enterprises (SMEs). The city of Amsterdam coordinates the project and the social housing companies are responsible for the implementation and future maintenance of the smart blue-green roofs. Of the SMEs, Metro Polder specialises in smart solutions for storing rainwater on rooftops and has an interest in further developing the blue-green roof technology. Consolidated is a green roof construction and maintenance company that has also developed a user-friendly maintenance database system to monitor the maintenance of all kinds of rooftops. Participation in the project presents them with an opportunity to strengthen their position in the roof market in Amsterdam. The role of the research institutes, Hogeschool van Amsterdam and the Environmental Institute of the Vrije Universiteit, is to explore water retention of green roofs; conduct cost-benefit and governance analysis to create a sound business case for future upscaling; and investigate ways of engaging the local communities.

The residents' buy-in is integral to the success of the project. Rooftop Revolution and the housing associations are raising awareness of the project in the neighbourhood and engaging residents living in buildings with planned blue-green roof installation. For safety reasons, the roof spaces will not immediately be accessible to the public; however, this may be possible in the longer term.

The Resilio project and UIA are alert to the opportunity for upscaling the blue-green roofs within the city and transferring the approach to other cities.

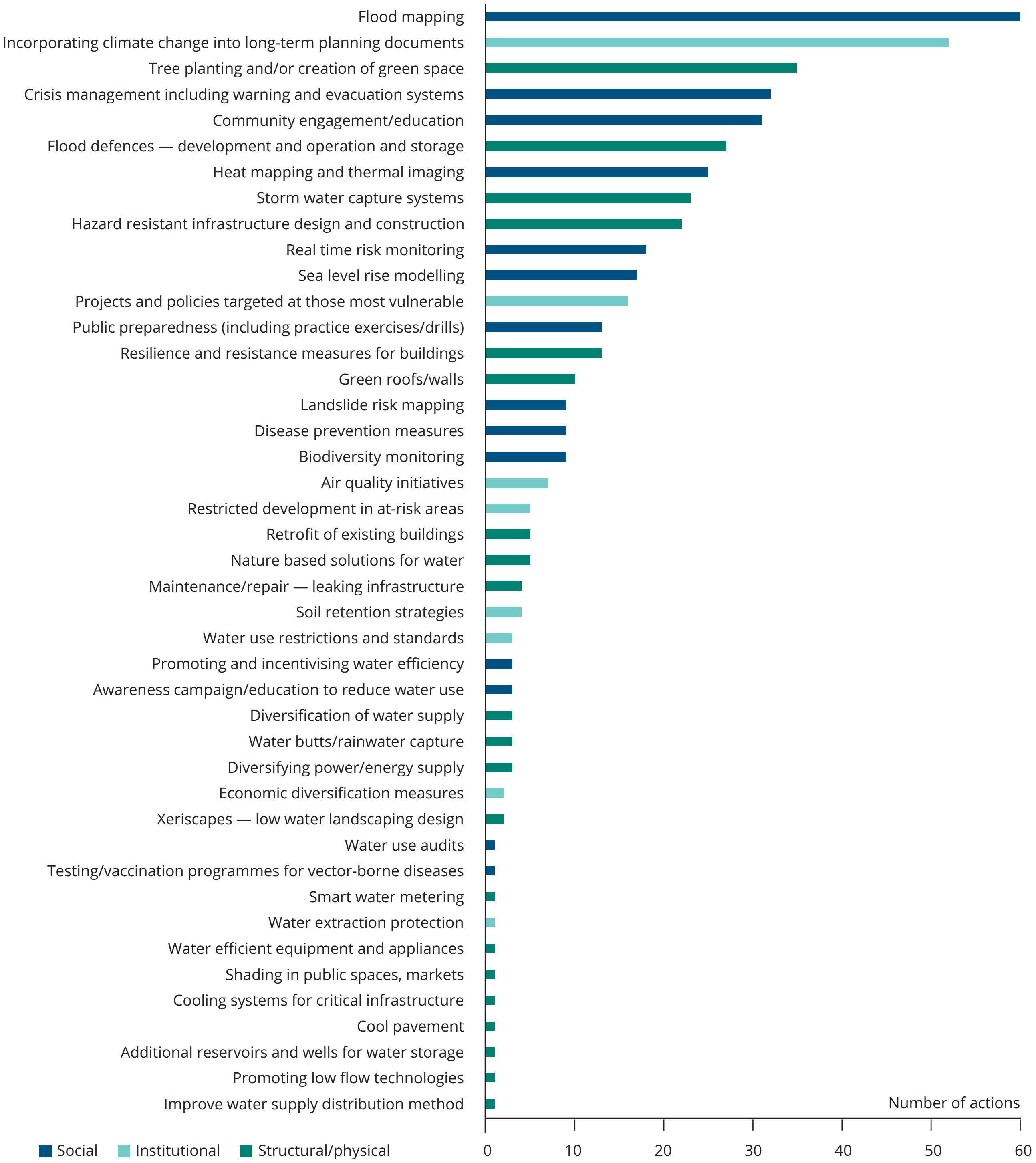
A smart blue-green roof under construction (left) and finalised (right) © Dakdokters

Sources: Personal communication from Age Niels Holstein, City of Amsterdam, and Leon Kapetas, Draxis Environmental Technologies, 2019; UIA — Urban Innovative Actions (2020b).

5.2 Adaptation actions planned and implemented across Europe

According to the CDP database (CDP, 2019), the main types of adaptation action planned by European cities concern flood risk mapping, mainstreaming adaptation, green infrastructure solutions, crisis management and community education (Figure 5.6). Referring to the IPCC (2014b) classification of adaptation options, actions from the social category are more frequently used than the structural/physical ones.

Figure 5.6 Types of adaptation actions planned by cities in Europe



Note: As reported to CDP by 155 European cities from 26 EEA member and collaborating countries and the United Kingdom. Categorised according to IPCC (2014b, p. 845)

Source: Authors' compilation based on data from CDP (2019).

The actions of Covenant of Mayors signatories most frequently address the water management, land use planning, civil protection and emergency, and health sectors (Figure 5.7), Studies looking at different samples of urban adaptation action plans report similar areas addressed by adaptive actions (Reckien et al., 2014; Aguiar et al., 2018; Campos et al., 2017).

The most frequently reported measures (around two thirds in both the CDP and Covenant of Mayors databases) are 'soft', meaning those linked to knowledge creation (e.g. through mapping or modelling studies), development of regulations or plans, awareness-raising campaigns or monitoring of risks. Around one fifth of the adaptation actions reported by cities in the CDP and Covenant of Mayors initiatives can be classified as grey infrastructure, while the green infrastructure options constitute fewer than 20 % of actions. However, in the case of C40 cities in Europe, ecosystem-based adaptation measures were found in 12 out of 14 adaptation plans (Geneletti and Zardo, 2016). These included creation of neighbourhood gardens (Paris), enhancing connectivity among existing green areas (Milan), using plants for shade in new industrial estates (Amsterdam), creating new wetland areas and ponds (Berlin), and designing green spaces to store rainwater in the event of torrential rain (Copenhagen; see also Box 3.8).

The predominance of 'soft' actions may be linked to the fact that adaptation at the local level is in its relatively early days, when the development of the knowledge, awareness and regulatory base is key. The powers of local authorities may also be important, with certain grey infrastructure actions exceeding their remit. In addition, the cost of adaptation actions may play a role. The investigation into the adaptation actions planned by the signatories to the Covenant of Mayors shows that the grey infrastructure approaches are the most expensive (median cost of 15 actions = EUR 3 700 000) and soft measures are the cheapest (median cost of 38 actions = EUR 24 000), with green infrastructure measures in between (median cost of 15 actions = EUR 70 400).

5.3 Sources of funding for local adaptation

Local authorities' own resources are the most frequently used source of funding for planning and implementing adaptation (CDP, 2019; Aguiar et al., 2018). National sources of funding are also used frequently (Tables 5.1 and 5.2; see also Section 4.4.2).

Specific research and implementation funding programmes can be key to initiating or progressing adaptation (see also Section 4.2.3), especially those allowing development of local adaptation strategies in a relatively short period. European Economic Area Grants have supported development of 27 local adaptation strategies within the ClimAdaPT.Local project in Portugal (Aguiar et al., 2018). In Latvia, local funding is also supplemented by other EU funding, including structural funds and the LIFE programme (Eionet, 2019; see also Box 4.6).

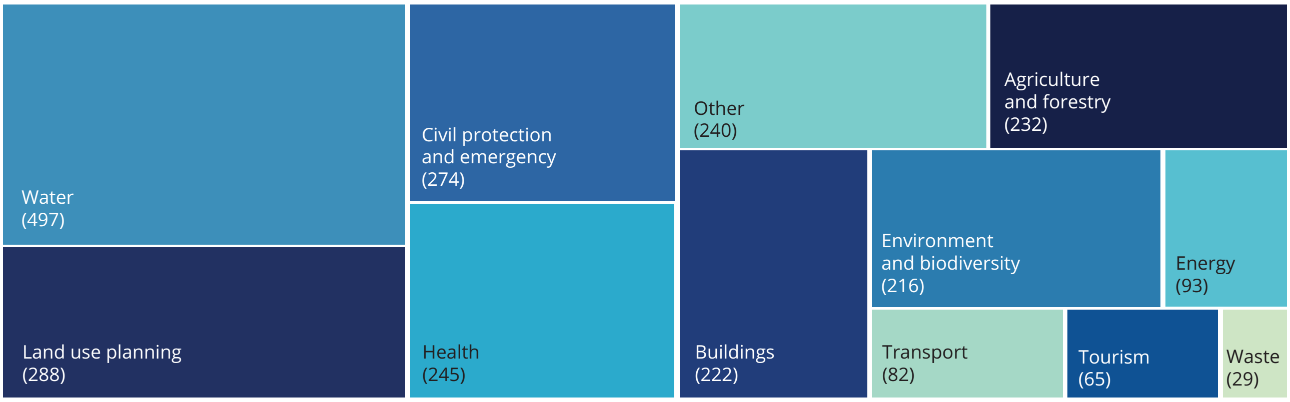
Table 5.1 Sources of funding for development or implementation of local adaptation strategies.

Funding source	Number of local adaptation strategies
Local authority	37
National level	26
Private sector	15
Research projects	10
Non-scientific projects	9
EU funds	8
Public-private partnerships	6
Property owners	5

Note: Based on the analysis of 147 local adaptation strategies across Europe.

Source: Based on Aguiar et al. (2018).

Figure 5.7 Adaptation actions planned by the Covenant of Mayors signatories, by sector



Note: As reported for 2 483 actions by 183 signatories from 14 EEA member and collaborating countries.

Source: Authors' compilation based on analysis of data extracted from Covenant of Mayors for Climate and Energy database on 19 June 2019.

Table 5.2 **Primary funding source for adaptation actions reported by cities to CDP (2019)**

Funding source	Number of actions
Local	189
National or subnational	49
Public-private partnership	14
International (official development assistance ([a]))	13
EU project (e.g. Horizon 2020, LIFE, Interreg)	10
Local public utility company ([b])	3

Note: Based on responses of 71 cities from 23 EEA member and collaborating countries and the United Kingdom reporting to CDP.

([a]) Reported by cities in Greece, Latvia, Montenegro, Portugal and Romania.

([b]) Reported by cities in Denmark.

Source: Authors' compilation based on analysis of data from CDP (2019).

A high number of the Covenant of Mayors signatories had rather low budgets for implementation of adaptation (median EUR 535 000; Table 5.3). The largest source of funding, in terms of mean value, was the EU funds, but only around 12 % of the signatories that reported on budgets had used them. The second largest pool of money was local authorities' own resources. The private sector was the third largest source of funding, with national funds playing a smaller role.

The Covenant of Mayors signatories with larger total adaptation budgets tended to report a higher number of actions planned ([78]). Comparing the signatories with the smallest and largest total implementation budgets, the bottom 20 % of local authorities, with a mean total adaptation budget of EUR 16 000, had averaged 10 planned adaptation actions and had completed two of them, while the top 20 % of signatories with a mean total implementation budget of over EUR 51 million had averaged 16 planned actions and had completed five. The signatories with the smallest own funding (bottom 20 % with a mean budget of about EUR 11 000) had reported an average of nine planned actions, while the signatories with the largest own budgets (top 20 % with mean of EUR 15 million) had on average planned 17 actions.

Table 5.3 **Funding for implementation of adaptation actions among Covenant of Mayor signatories (in EUR 1 000)**

Source	Mean	Median	Maximum	Number of signatories
Local authority	3 424	314	133 715	208
National level	812	0	61 273	24
EU	4 038	0	343 199	28
Private	1 866	0	251 521	21
Overall (including other sources)	10 855	535	597 783	209

Note: Based on reporting by 209 signatories on adaptation to the Covenant of Mayors from 21 EEA member and collaborating countries and the United Kingdom.

Source: Authors' compilation based on analysis of data extracted from Covenant of Mayors for Climate and Energy database on 19 June 2019.

([78]) With the caveat that the Covenant of Mayors signatories do not need to report on all adaptation actions. They need to only report on three key actions as a mandatory minimum requirement.

5.4 Context matters: local adaptation planning in various settings

5.4.1 Size of local authority

The smallest Covenant of Mayors signatories were somewhat less likely to have developed a sustainable energy and climate action plan (SECAP) than larger ones; while around 19 % of the signatories with over 10 000 inhabitants had a SECAP in April 2020, 15 % of the signatories with fewer than 10 000 inhabitants had a SECAP (personal communication from Lea Kleinenkuhnen, Covenant of Mayors for Climate and Energy — Europe Office, 2020).

The smaller signatories ([79]) were less likely than larger ones to set up the consultative and participatory mechanisms and foster multi-stakeholder engagement in the adaptation process (nearly half had not started or had made very limited progress). This was also observed in Denmark, where larger municipalities more frequently took advantage of networks with other governance institutions, the private sector and public associations (Jensen et al., 2016). According to Campos et al. (2017), the larger municipalities in Portugal tended to attribute more importance to climate change in municipal planning agendas compared to smaller ones. In Norway there were major differences between large and small municipalities regarding identification of vulnerabilities and risks; while 89 % of the large municipalities had analysed previous extreme weather events in the municipality, only 24 % of the small municipalities had (Klemetsen, 2019). This discrepancy emphasises the importance of mechanisms encouraging and supporting all local authorities in risk and vulnerability assessment, such as the Dutch stress test (see Box 4.5).

The smaller Covenant of Mayors signatories were more likely to plan adaptation actions in relation to agriculture and forestry, tourism and civil protection, while larger signatories were more likely to plan adaptation actions relating to land use planning. This may be due to the varying remits of different types of local authorities and their position in the governance hierarchy.

Actions of larger signatories (> 50 000 inhabitants) were more likely to target high temperatures (55 % versus 29 % for smaller signatories), which could be linked to the more pronounced urban heat island effect and poorer access to natural areas in larger cities. Larger signatories were also more likely to implement actions concerned with green infrastructure than smaller ones (25 % versus 14 %).

Unsurprisingly, the larger signatories had a larger average budget for implementation of adaptation, with the signatories smaller than 50 000 inhabitants having an average of EUR 1 million, those with between 50 000 and 250 000 inhabitants an average of EUR 24 million and those with more than 250 000 inhabitants an average of EUR 72 million. In a Danish study, larger municipalities were more able to invest the resources necessary for developing and implementing a long-term strategy to minimise the risks and costs associated with present and future climate changes (Jensen et al., 2016).

While the direct involvement of local authority staff in adaptation planning was high for signatories of all sizes (see Figure 5.2), it tended to be somewhat higher for larger signatories (90 % of signatories > 50 000 assessed the local staff involvement as high compared with 75 % of those < 50 000). For 68 % of smaller signatories the involvement of higher levels of governance was high, compared with 16 % of larger signatories. This clearly indicates the importance of a multi-scale approach to provisioning of plans and strategies from the European, through the national, to the regional level in ensuring that the smaller local authorities engage in adaptation planning (Heidrich et al., 2016). Box 5.6 presents an example of a national capacity-building for small- and medium-sized cities in Poland.

([79]) Hereafter 'smaller' refers to the Covenant of Mayors signatories with populations below 50 000 inhabitants, unless specified otherwise.

Box 5.6 Increasing adaptive capacity of small and medium cities in Poland: the Climcities project

The Climate change adaptation in small and medium size cities (Climcities) project (2016-2017) was funded by the Iceland, Norway and Liechtenstein grants (85 %) and the Polish government (15 %). The project was led by the Institute of Environmental Protection — National Research Institute and realised in cooperation with a Norwegian partner, Vista Analyse, a social science consultancy. The project concentrated on raising adaptation capacity in cities with around 50 000 to 100 000 inhabitants. Climcities focused on improving access to adaptation knowledge among the local authority officers (representing, for example, departments of the environment, spatial planning, architecture, infrastructure or crisis management). The second target group consisted of local leaders, such as activists from environmental organisations, local media journalists, and representatives of local communities and private businesses.

A series of training courses and workshops was carried out, engaging over 800 people in total. Out of those, 500 represented 80 local and other public authorities (cities, communes, voivodeships and Voivodeship Funds for Environmental Protection and Water Management). The remaining participants were citizens, as well as representatives of the private sector and non-governmental organisations. On top of the training courses, the participants had access to training materials on the project's website. Overall, the workshops and courses were assessed very favourably, and the participants' awareness of climate change and the need to implement adaptation measures in strategic planning of city development was increased.

The direct benefit of the project was that five medium-sized cities (Bełchatów, Nowy Sącz, Ostrołęka, Siedlce and Tomaszów Mazowiecki) developed adaptation strategies. The scientific and public administration experts involved in the project supported the cities through content development, presentation of the strategy at public meetings and strategic environmental impact assessment, where necessary. All five strategies were developed with public consultation. As of January 2020, one town (Tomaszów Mazowiecki) had adopted the adaptation strategy and Bełchatów was carrying out a strategic environmental assessment for the strategy. The remaining three cities were also ready to adopt their adaptation strategies.

In addition, the representatives of the five municipalities took part in a study visit to three Norwegian cities — Bærum, Oslo and Tonsberg — to discuss good practices in the use of green-blue infrastructure in climate adaptation, rainwater management, flood management, landslides and sea level rise.

Sources: Szczepański (2017); Climcities (2020); personal communication from Sylwia Waśniewska, National Centre for Emissions Management (KOBiZE), Institute of Environmental Protection — National Research Institute, Poland, 2019.

Local external stakeholders tended to be more involved in adaptation planning in the case of smaller signatories (56 % of smaller signatories selected 'high' compared with 33 % of larger signatories), suggesting that it may be easier for smaller local authorities to reach out to the local stakeholders. However, the larger signatories (> 50 000 population) were more likely to work with NGOs and civil society than the smaller signatories; this may be because the direct involvement of citizens in adaptation planning for large cities may not be feasible, so civil society organisations perform the intermediary role in public engagement in that context.

The larger signatories collaborated with research institutions much more frequently (33 % compared with 2 % of the smaller local authorities). This may indicate a gap between smaller and larger local authorities regarding access to knowledge on climate risks, vulnerabilities and adaptive actions (see also Box 6.1). For example, Campos et al. (2017) found that large Portuguese municipalities (> 50 000 inhabitants) claimed to have more information on climate change and sustainable development than smaller ones. This gap may be minimised through active involvement of the research community at the regional level; regional authorities could then help to relay the knowledge to small local authorities. For example, among the 21 regions and large cities investigated by Albini et al. (2017), 16 involved research institutions in adaptation strategy development and 11 involved them in strategy implementation. Box 5.7 provides an example of a research project specifically focused on small towns.

Box 5.7 Research supporting small towns in participatory processes aiming for higher resilience to high temperatures: GoingVis project, Germany

Climate change adaptation in small towns is currently largely overlooked in political, public and research debates as well as national adaptation frameworks. This is partially for lack of administrative capacity such as financial and human resources to address climate adaptation in smaller towns. The Governance by integrative visions (GoingVis) project aims to enhance the resilience of small towns to heatwaves by enabling locally specific social practices and behaviour. It is being implemented from 2019 to 2021 in Boizenburg/Elbe and the Elbe Elster region in Germany.

Limited resources among public administration bodies, particularly in small towns, mean that social innovations from society play a key role. GoingVis hypothesises that shared visions can provide the coordination required to build networks. Shared visions and concrete social practices for climate change adaptation (e.g. rescheduling work hours during hot periods) can be effective only when refined and initiated by the community in a comprehensive participatory process, one that includes marginalised or commonly overlooked social groups. Social practices of climate adaptation also need to be anchored in local culture, knowledge and practices and connected to broader political issues in the specific community.

The GoingVis project highlights that newly engaged citizens can act as catalysts for finding unconventional and emancipatory solutions. Therefore, the project emphasises the importance of governance through inclusive, iterative and integrated visions for local adaptation, as well as the pivotal role of behavioural adaptive measures for dealing with heat risks.

For example, one capacity-building measure for residents has been organised in the city of Boizenburg by setting up a water playground. The locals have formed a network to create this water playground themselves, by providing resources and exchanging knowledge and ideas on water, heat adaptation and its relation to Boizenburg (PLATZ-B, 2019). Surveys in both cities reveal many other examples of changed social practices in reaction to the 2018 and 2019 heatwaves. There is, however, a need for broader diffusion and community-based support to unfold the full potential of such adaptation practices.

Sources: PLATZ-B (2019); FFU (2020); personal communications from Klaus Jacob, Nicole Mahlkow and Julia Teebken, Freie Universität Berlin, 2019.

The smaller signatories tended to engage fewer internal departments and external stakeholders in the implementation of adaptation actions. Larger signatories' actions were more likely to involve the private sector compared to actions of smaller local authorities (14 % versus 4 %). The same was valid for the involvement of research institutes (10 % versus 2 %).

According to Reckien et al. (2015), only larger cities manage to develop and deliver adaptation strategies without wider support and guidance. This creates a considerable gap between smaller and larger cities, which should be addressed by providing support for cities and towns of all sizes. A potential solution to close the gap could be the creation and employment of larger planning units for climate change issues. For example, provincial or regional administrations could support small local authorities through collective actions (Heidrich et al., 2016); see also Section 4.5.

5.4.2 Geographical region

There were large regional differences among signatories to the Covenant of Mayors with regards to stakeholder engagement and adaptation planning. Considering stakeholder engagement, local authority staff were self-assessed as having the highest average involvement in central and eastern Europe. In that region, the planning departments were involved in the implementation of nearly three quarters of the actions, with no involvement of social care or health departments. In contrast, only a third of the northern European signatories' actions involved planning departments.

While citizens were involved in implementation of two thirds of actions in western Europe, only 11 % of actions in southern Europe and in central and eastern Europe involved citizens. NGOs were the most frequently involved actors in western Europe. This indicates a cultural divide between north-western and south-eastern Europe regarding the emphasis placed on societal engagement. Indeed, in research on the climate action of Portuguese municipalities, pressure from civil society was the least important factor encouraging the decision to act on climate change (Campos et al., 2017).

In addition, the private sector appears to have the highest level of participation in implementing adaptation actions in western Europe (Aguiar et al., 2018). Among the Covenant of Mayors signatories, the private sector was involved in implementing

Different approaches to local level adaptation among European regions require more research

26 % of adaptation actions in western Europe, compared with fewer than a tenth of actions in other regions.

The involvement of researchers in implementing adaptation actions was strongest in northern Europe (22 % of actions), and the weakest in the south (only 3 % of actions). The involvement of stakeholders at higher governance levels was the most frequent in southern and northern Europe, which could be linked to the small size of signatories in those regions.

Sectors targeted by adaptation actions also differ between regions. Aguiar et al. (2018) found more concern for tourism, energy and agriculture in southern Europe, higher emphasis on coastal areas and disaster risk reduction in northern Europe, and focus on business and services in eastern Europe. These results show diverse regional priorities and reflect the major vulnerabilities and hazard risks (in northern Europe), but also the importance of managing commercial risks (in the east) and prioritising the important tourism sector (in the south).

According to the Covenant of Mayors signatories' database, health and well-being tended to be firmly in focus in most regions, with at least half of the adaptation actions focusing on people. However, among the southern European signatories, only 24 % of actions focused directly on people. In that region, the emphasis was on addressing the vulnerability of resources (38 % of actions), particularly water. This may be linked to drought-related problems being more pronounced in the south than in other regions (see Section 2.5) and potentially the exclusion of health or social care from small signatories' remits. Eastern and central European signatories tended to have more actions linked to buildings and infrastructure (nearly 40 % of actions focused on them), confirming the focus on limiting commercial risks.

5.5 Taking stock of local-level adaptation: conclusions and outlook

The lack of one comprehensive overview of the adaptation planning and implementation at the local level in Europe makes it difficult to draw definite conclusions on the preparedness of European cities and towns for climate change. Investigation of the Covenant of Mayors for Climate and Energy and CDP databases is a litmus test of the state of local adaptation, but it excludes the cities active in adaptation as a result of national regulations (see Section 4.4.1), within other international networks (see Section 4.3) or on their own initiative. Regular national reporting on the proportion of cities with adaptation action plans and at the implementation stage would facilitate the understanding of the current situation in Europe. Knowledge gathered through such reporting would be particularly helpful to identify the need for support from higher governance levels (see Chapter 4).

To ensure resilience to climate change across Europe, there is a need to move from commitment to and planning of adaptation to implementation of concrete actions. The considerable effectiveness of the EU adaptation strategy (EC, 2013a) in encouraging thousands of local authorities across the EU to act on adaptation through the Covenant of Mayors initiative is clear. The new EU strategy on adaptation for climate change is an opportunity to support the implementation of adaptation by championing actions supporting access to the funding and the expertise for local authorities, in particular the smaller ones. More knowledge is needed about the cultural differences, background knowledge and preconceptions driving the local authorities in different parts of Europe in order to be able to support them effectively.

Adaptation should, however, not just be the local authority's activity but engage a broad range of stakeholders. Engaging the citizens is key for ensuring acceptance of the solutions and for tapping into local knowledge (see also Section 6.2.3). The EU policies and instruments currently in development, such as the European Climate Pact, and the European missions on adaptation and on climate-neutral and smart cities, place emphasis on the closer engagement of citizens and communities in adaptation. There is also a need to encourage modes of adaptation governance at the local level that empower participants such as civil society, the private sector and researchers. This is particularly pertinent in the context of limited resources and capacities of many of the local governments.

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6 Towards well-adapted cities and towns

Key messages

- The main opportunities for boosting local authorities' adaptation efforts lie in improving access to knowledge and funding; making effective use of land use planning regulations and tools; and facilitating both political and community engagement.
- Improving access to knowledge can be achieved through collaborating with researchers and making greater use of existing data and information sources, including citizen science, insurance claims data, and sharing knowledge with other cities.
- Additional potential sources of funding for local adaptation that can be deployed or accessed by local authorities include sustainable finance, crowdsourcing or donations, property levies and taxing schemes. Support for local authorities in accessing existing adaptation funding is key to maximising its use.
- Monitoring and evaluation of the adaptation actions implemented requires substantial improvement, as very few local authorities systematically assess their adaptation efforts.
- Climate change adaptation should be treated as an essential part of sustainable urban development. This can be done by linking it more effectively to other policy areas, especially land use planning, climate change mitigation, and health and social justice agendas.

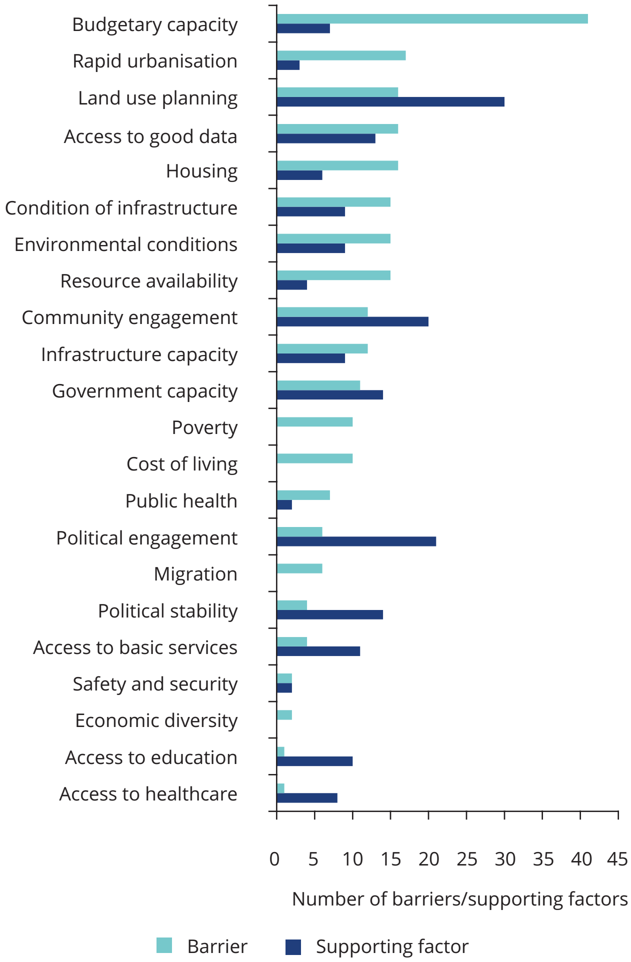
6.1 Challenges for urban adaptation in Europe

6.1.1 Limited access to financial resources

Insufficient financial resources are consistently mentioned as the key barrier by local authorities. In the 2017 survey of the Covenant of Mayors signatories, 84 % of respondents included lack of financial resources as a barrier to designing and implementing local climate action (Covenant of Mayors — Europe Office, 2017a; see also Bertoldi et al., 2020). The budgetary capacity is the main constraint listed by cities reporting to CDP (Figure 6.1). The lack of finances emerges also as the most important barrier for small municipalities (Box 6.1).

Aguiar et al. (2018) highlight a strong dependence of adaptation planning on external financial support, which particularly affects southern Europe and smaller authorities. Therefore, adequate financial and technical resources are necessary to boost local climate actions in these contexts (Pietrapertosa et al., 2019). Furthermore, the issue may be not the availability of funding but rather gaining access to it. Many local authorities are simply not aware of various funding opportunities available, do not have the necessary experience or capacity to prepare labour-intensive applications, or lack the required co-funding. Time-frames and amounts available of existing funding are not always tailored to the needs and realities of local authorities, which deters some local governments from applying (Climate Adaptation Partnership, 2018).

Figure 6.1 **Factors influencing cities' ability to adapt to climate change**



Note: As reported to CDP by 106 cities from 24 EEA member and collaborating countries and the United Kingdom.

Source: Authors' compilation based on analysis of data from CDP (2019).

6.1.2 Barriers related to knowledge

Insufficient knowledge of climate change and its impacts is a frequently encountered barrier. Access to data that are of high quality and relevant is highlighted both as a challenge and as an opportunity by cities reporting to CDP (Figure 6.1). In some cases, information is not available, or is presented at a scale inappropriate for application in cities. In other cases, the relevant people in the local authority are unaware of the information's existence, or unable to obtain it from national or regional authorities. Finally, city staff may not have the necessary skills or training to interpret the data (Climate Adaptation Partnership, 2018). In addition, just having access to data and information may not be enough to convince some local actors owing to their preconceptions about the subject. Therefore, climate change related communication needs to be adapted to the background knowledge and worldviews of target groups (Heimann, 2019).

Uncertainty, inherent to climate science, emerges as a barrier for local authorities when it comes to committing resources. In exploring the contents of 147 local adaptation plans, Aguiar et al. (2018) found uncertainty to be a barrier relatively frequently mentioned by northern European cities (15 %), while it seemed less of a constraint for cities in western or southern Europe (mentioned by 8 % and 6 %, respectively).

At the adaptation action design and selection stage, city practitioners commonly highlight that they lack knowledge about available adaptation measures and their effectiveness, as well as on their costs, benefits and co-benefits (Rendón et al., 2016). This resonates with the conclusions of Chapter 3 on the paucity of evaluation of the adaptation measures.

Technology is also a key gap limiting the success of climate adaptation efforts (UNEP, 2014); immature or high-cost technologies are reported as a substantial barrier by a high number of Covenant of Mayors signatories (Bertoldi et al., 2020). Finally, some city practitioners draw attention to the perceived oversupply of guidance and tools for certain steps of the adaptation cycle, making it difficult to decide which support to use to acquire the additional knowledge needed (Climate Adaptation Partnership, 2018).

6.1.3 Lack of human resources and capacities within the local authorities

Capacity and human resource bottlenecks in the local authority administrations are linked to many of the knowledge barriers outlined above. Technical expertise on climate change adaptation is particularly insufficient among staff in small local authorities (Reckien et al., 2015) and lack of human resources or staff capacity seems to be most relevant to municipalities in southern and eastern Europe (Aguiar et al., 2018).

Language barriers can present themselves when available information and training are only available in English. Around 30 % of respondents to the Covenant of Mayors survey were reluctant to attend learning activities (webinars, training workshops, etc.) carried out in English, with around 40 % of respondents from Belgium, France and Germany, and more than 55 % of Polish city representatives indicating they would not attend English-language events (Covenant of Mayors — Europe Office, 2017a). This emphasises the importance of national climate knowledge platforms and capacity-building programmes (see Section 4.4). Transnational initiatives such as the Covenant of Mayors offer some of their materials and events in different EU languages and, with the increasing accuracy of machine translations, this type of support could be increased.

Box 6.1 Bottlenecks and solutions for adaptation planning in small municipalities

One of the sessions at the European Urban Resilience Forum 2019 looked specifically at the barriers, triggers and ways forward for small local authorities. Based on discussions among the towns of Coswig (Germany), Urbino (Italy) and Weiz (Austria) and the regional government of Styria (Austria), and a debate with the audience, the following factors were identified.

Bottlenecks

- lack of finances;
- lack of support from regional level;
- lack of specific knowledge;
- language barriers;
- problems with identifying and obtaining information and data;
- limited numbers of staff, generating capacity problems in terms of time and knowledge pool;
- tools available at European scale not necessarily matching the small scale.

Solutions

- for the local authority:
  - participation in Covenant of Mayors,
  - networking with other small municipalities,
  - being engaged in a research project (see Box 5.7),
  - applying for implementation funding, e.g. through LIFE;
- support by higher governance levels:
  - workshops tailored to the needs of small municipalities (see also Box 5.6),
  - support in applying for funds (see also Box 4.6),
  - regional authorities' activities on information sharing and collaboration (see Box 4.7).

Note: The above reflects the views of the limited number of individuals involved in that session and cannot be seen as representative of all small municipalities in Europe.

Source: Authors' compilation based on the records of the 2019 European Urban Resilience Forum.

6.1.4 Actor-related barriers

Actor-related barriers concern personal motivations or ways of thinking among certain stakeholders. The lack of political commitment and leadership is one of the most significant barriers to successful local adaptation (Reckien et al., 2015; Figure 6.1). This is particularly marked in eastern European municipalities: according to Aguiar et al. (2018), 17 % of local adaptation plans from that region mention the lack of political commitment as a barrier, compared with 2-7 % of plans from other regions. Lack of interest in adaptation among powerful stakeholders within the municipality is another important barrier, as is the unwillingness of external stakeholders, such as citizens or companies, to engage in this topic (Rendón et al., 2016).

In contrast, strong political leadership and personal commitment of those in charge of adaptation within a municipal administration can be solid drivers of adaptation action (Reckien et al., 2015). Similarly, strong community engagement can push a local administration to act on adaptation. Both political and community engagement have been identified as crucial supportive factors for local adaptation planning by cities reporting to CDP (Figure 6.1). In recognition of the crucial role that the politicians play in the adaptation process, training sessions on local adaptation were organised for local politicians by the Climate Adaptation Partnership under the EU urban agenda (Box 6.2).

Box 6.2 Training for politicians on adaptation: Climate Adaptation Partnership under the EU urban agenda

One of the actions in the Climate Adaptation Partnership under the EU urban agenda is the training academy for politicians on adaptation to climate, led by the Council of European Municipalities and Regions in collaboration with Eurocities and the cities of Genova, Glasgow, Loulé and Potenza.

The aim of the action is to offer specific training to mayors, councillors and local political leaders on the benefits of adapting to climate change, adaptation options and measures, and engagement strategies for citizens and other stakeholders. The training aims to raise awareness of the risks and costs of inaction as well as to provide knowledge on the co-benefits of adaptation actions. The goal is that politicians decide to prioritise adaptation in public policies and deploy appropriate resources to enable action.

In 2019, two general training academy sessions were organised. On 22 May 2019, during the Urban Future Forum in Oslo, the session convened around 30 mayors, vice mayors and city representatives from Finland, Ireland, Island, Latvia, the Netherlands, Norway and Portugal as well as organisations from Hungary and Italy. On 8 October 2019, around 40 local authority representatives participated in a session during the European Week of Regions and Cities in Brussels. These general academies were supplemented by two local academies, carried out in national languages and organised back to back with important events on climate change to increase their impact. Around 60 local authority representatives took part in Glasgow on 19 June 2019 and around 20 in Genova on 26 November 2019.

The feedback received was that politicians wished to engage in ambitious strategies, involve all relevant stakeholders and strengthen links with the national governments. Some of the representatives expressed interest in joining the Covenant of Mayors. The concept of the political academy will contribute to shaping the future climate pact in the EU Green Deal.

Sources: Climate Adaptation Partnership (2018); EC (2018h); personal communication from Eva Baños de Guisasola, Council of European Municipalities and Regions (2020).

6.1.5 *Institutional context barriers*

The institutional context barriers relate to the internal management and functioning of local administrations as well as external factors. Without an internal structure accommodating adaptation and assigning clear responsibilities, adaptation policies are rarely pursued in a sustainable way (Rendón et al., 2016; Aguiar et al., 2018). Missing cross-departmental collaboration and communication, assigning the topic to a department with a weak internal position and not overseeing all adaptation policies are also highlighted as bottlenecks hindering successful adaptation action (Climate Adaptation Partnership, 2018). Section 5.1.3 indicates that the departments responsible for adaptation are currently mainly planning or environment divisions, with little engagement of other parts of the local authority.

Moreover, adaptation action can be hindered by changes in the institutional structure or a rigid hierarchical system within a city administration. Political priorities given to other issues and short-term planning are additional obstacles (Rendón et al., 2016). The mismatch between the timelines for adaptation policies that require long-term planning and short political cycles are also often mentioned by city practitioners (Climate Adaptation Partnership, 2018). Thus, political stability emerges as an important supportive factor for cities reporting to CDP (Figure 6.1).

Finally, a lack of coordination with other levels of government (see also Sections 4.4. and 4.5) as well as conflict within and between institutions can reduce efficiency in adaptation planning (Rendón et al., 2016).

6.1.6 *Physical and socio-economic characteristics of the urban areas*

Cities reporting to CDP identify several other supportive or challenging factors related to the physical and socio-economic characteristics of their urban areas, such as housing, infrastructure, levels of poverty or public health status. The example of Larissa, Greece, emphasises how a combination of physical and socio-economic aspects can be a substantial barrier to implementing adaptation measures (Box 6.3).

To facilitate adaptation planning and implementation at the local level, cities and towns need support to overcome the barriers and take advantage of opportunities. The following sections focus on opportunities to improve access to knowledge, secure funding and financing, monitor adaptation and firmly embed adaptation in the notion of sustainable development.

Box 6.3 Challenges for implementation of green roofs in the city of Larissa, Greece

Situated in central Greece, the city of Larissa (200 000 inhabitants) faces increasingly high summer temperatures, whereas winter temperatures are low and are projected to remain so in the near future. The city is expanding its green infrastructure and has explored the option of implementing green roofs. However, maintaining rooftop vegetation in a climate characterised by extreme temperatures is challenging. The plants must be able to withstand hot and dry conditions, and occasional sudden storms during summer, as well as cold and windy winters with heavy rainfall and snow.

In addition, the soil medium must be shallow, as there is little margin for additional load on the existing buildings, most of which date back to the 1970s and 1980s and were built to lower standards. As Larissa is at risk of earthquakes, ensuring the structural robustness of buildings is crucial. Furthermore, the temperature extremes lead to quick ageing of exposed materials. The local construction industry has little experience of installing green roofs, and that inexperience poses risks to buildings through, for example, potential inadequate application of the sealing layers causing leakage.

Finally, the predominant type of ownership in multi-storey buildings is that individual apartment owners have joint responsibility for common areas. This makes it difficult to reach consensus for maintenance and upgrades such as green roof installation.

Reflecting on these issues, the local authority provided a set of recommendations for installing and maintaining green roofs:

- Older buildings must have a capacity assessment to ascertain their ability to host a green roof or alternative forms of greenery (e.g. tree boxes, flowerpots, pergolas with creeping plants). The building code and anti-seismic regulation have specific rules for additions to existing buildings.

- A thorough risk assessment must be performed, evaluating tangible and intangible risks, costs and benefits. The ownership and responsibilities for maintenance must be defined before installation takes place.

- Technical works must be thoroughly studied and implemented, accounting for existing building structures (including ageing of materials) and future conditions — the stages of sealing and drainage construction must be closely monitored.

- For both existing and new buildings, incentives for owners should be set out, to include green roofs, adjusted to the specificity of the split building ownership.

Green roof on a municipal building © City of Larissa

Sources: Personal communication from Maria Nikolaidou, City of Larissa, 2019.

6.2 Improving the knowledge base

6.2.1 *Climate services for cities provided by European institutions*

Research has shown climate services to be useful in supporting decision-making in urban planning (Jones et al., 2017; Lindberg et al., 2018). At the European level, the 2015 European research and innovation roadmap for climate services provides a backbone for action (EC, 2015a). One element is the Copernicus Climate Change Service (C3S), which aims to provide a knowledge base that can support climate change mitigation and adaptation policies. It offers information about the current and past states of the climate and different projections for the coming decades. The Copernicus Climate Data Store serves as a standardised entry point providing access to data. As part of Copernicus, the Urban SIS project developed a method to downscale climate variables and impact indicators to the urban scale to support the infrastructure and health sectors in cities. The format is meant to be directly usable by local authority staff, or the experts and consultants they work with, as input for local models or calculations. The project focuses on intense rainfall and heatwaves.

However, the climate data must still be processed in order to be used (e.g. for climate risk and vulnerability assessments), which requires a certain level of expertise. Therefore, one of the actions of the Climate Adaptation Partnership under the EU urban agenda (see Box 4.1) has been to improve the awareness of European municipalities and their use of C3S, through webinars organised by the Covenant of Mayors — Europe Office and workshops carried out by the Joint Research Centre.

In addition, a set of 13 projects was funded by the EU to co-design climate services tailored to the needs of end users and to translate state-of-the-art climate knowledge and data into operational applications and tools. Two examples are the self-screening tool for climate impacts, risks and vulnerabilities through the Clarity project (80) and the Urban Climate Data Portal of the Climate-fit.City project (81).

In addition, by early 2021, the Climate-ADAPT portal aims to incorporate a user interface, whereby non-expert users can obtain Copernicus climate data for a specific location (e.g. a city), including past and projected data for different climatic variables, in the form of maps and graphs.

6.2.2 *Collaboration of cities with researchers*

Most cities need to bring in external expertise to obtain sufficient climate knowledge for adaptation planning. In some cases, researchers from local universities can support practitioners in adaptation planning. However, Section 5.1.4 shows that relatively few local authorities cooperate with researchers. Therefore, there is a need for initiatives boosting collaboration between researchers and municipalities.

Interest in joint knowledge production in the climate change adaptation context is increasing (Chapman and Hanania, 2018). It means cooperation between policymakers, scientists and other stakeholders in producing, applying and exchanging knowledge using an approach that is practice oriented, collaborative and participatory. For best results, the role of the researchers should be clarified early on in the cooperation process: whether they are mainly expected to provide data; to provide concepts to gain insight into problems or structure them; to act as mediators or process organisers; or all of the above (Hegger et al., 2012).

> *Collaboration with researchers can improve cities' access to knowledge*

Successful collaboration often happens within the framework of research projects, as was the case in Antwerp and Ostrava (Box 6.4). In Portugal, the local adaptive planning and training process started by the project ClimAdaPT.Local, including scientists from Lisbon University, was one of the most important advances in the country's adaptation policy, as it kicked off the development of more than 30 municipal strategies and plans.

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(80) https://myclimateservices.eu/en/news/how-csis-these-videos-you-learn-how-you-participate-our-climate-tool
(81) https://dataplatform.climate-fit.city/

Box 6.4 Collaboration between cities and researchers: experiences from Antwerp and Ostrava

The cities of Antwerp in Belgium and Ostrava in Czechia rely on researchers' expertise in adaptation. Antwerp cooperates closely with VITO, the Flemish Institute for Technological Research, while Ostrava collaborates with the Faculty of Science of the University of Ostrava. In both cases, the cities launched competitive tenders to contract specific expertise, and in both cases, the cooperations were financed by the cities' budgets; in Antwerp it was also supported by several European research projects.

In Antwerp, the VITO researchers were tasked to measure and model heat stress for past and future situations, and these data were used by the city's information technology (IT) department to feed into the city's websites and apps (see also Box 2.3). The University of Ostrava assessed the impacts, population vulnerability and adaptive capacity in relation to heat stress and flash floods, which were identified as the main climate-related hazards in Ostrava. In addition, the socio-demographic data were processed to prepare combined maps in the local adaptation strategy development process. The results of the cooperation were successfully integrated into Antwerp's climate2030 plan and Ostrava's climate change adaptation strategy, as well as the Ostrava strategic development plan 2017-2023.

The collaboration formats and stakeholders involved differed between the two cities. In Ostrava, the interim results were discussed at joint meetings and during two workshops with the representatives from the city districts, the public transport company and the fire rescue service. In Antwerp, a co-creative approach was used between the researchers, the city administration and the companies testing the heat forecast and alarm. The citizens were involved in evaluating and testing the first prototypes, and they mapped cool spots in one of the city's neighbourhoods.

In both cities the collaboration has continued through follow-up projects, e.g. two projects in cooperation with CzechGlobe (Global Change Research Institute of the Czech Academy of Sciences) (82) in Ostrava focused on vulnerability assessment of cities and their inhabitants to temperature extremes, and on the development of a tool for the identification and typology of locations vulnerable to thermal stress. The outputs of these projects are intended to serve as a basis for including adaptation to heat stress in the city of Ostrava's spatial planning and investment projects.

Despite the success of both collaborations, some obstacles were identified. In Antwerp, they were related to the effective communication of subtleties of climate data and technical problems linked to using real-time weather data in the city's IT infrastructure. In Ostrava, the quality of input data (e.g. digital elevation model) had implications for the development of analytical tools.

Based on these experiences, communication emerges as a key area for improvement in collaboration between researchers and city practitioners. This concerns communication between individual partners (e.g. to agree the project goals), among the city departments involved, and between city officials or scientists and citizens.

Sources: Personal communication from Rebecca Beeckman and Gert Vandermosten, city of Antwerp 2020; and from Marek Horečka and Jan Vaněk, city of Ostrava, 2020.

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(82) https://starfos.tacr.cz/cs/project/TL01000238#project-main and https://starfos.tacr.cz/en/project/TJ01000118#project-main

In some cases, the collaboration with researchers extends beyond the duration of a single project. For example, Manchester, United Kingdom, became a 'green laboratory' for adaptation research. In 2009, the University of Manchester and Manchester City Council signed a joint commitment on finding ways for urban areas to respond to climate change. Subsequently, a series of *in situ* research projects on nature-based adaptation solutions was carried out to provide answers relevant to Manchester's climate, soils, buildings and communities. The collaboration between the city council and the university continued through the Climate resilient cities and infrastructures (RESIN) Horizon 2020 project (see also Box 3.1) and through the Urban Innovative Actions project Ignition — Innovative financing and delivery of natural climate solutions (Ignition) in Greater Manchester (83).

The examples of Amsterdam (Box 5.5), Brussels (Box 3.6), Dresden (see Box 6.18), Manchester (above) and others show the 'living laboratory' approach to collaboration, whereby cities function as experimental sites for understanding the overall urban system and how it reacts to climate change. A living lab combines scientific, social and technological urban innovation into a single programme; it generates new products but also influences the behaviour of end users because they are directly involved and can observe the functioning of measures. For example, the Horizon 2020 project Urban nature labs (Unalab), focused on nature-based solutions, developed a framework and tools to implement them in other cities, based on experiences in the frontrunner cities Eindhoven, Genova and Tampere (84). The EU mission on adaptation to climate change including societal transformation plans to deploy this approach to testing adaptation solutions at the regional and community scale (EC, 2020b).

As these examples show, large research projects can bring cities and researchers together, and support knowledge developments that cities could not always afford by themselves. European and international city networks and initiatives such as the Covenant of Mayors often play a key role in spreading the knowledge created in these projects to a wider audience of cities. These networks share the findings with their members, e.g. through newsletters, dedicated mailings or webinars, and organise seminars or conferences where the research results and co-creative approaches are presented (see also Section 4.3).

Online platforms are also gaining traction when it comes to disseminating findings from research projects to a wider audience. The Climate-ADAPT platform gathers information on all European research projects on adaptation. In the area of nature-based solutions, a number of web portals and platforms have sprung up, containing many case studies, some as the results of research projects.

6.2.3 Knowledge co-creation with citizens

Involving a broad range of stakeholders expands the pool of knowledge, approaches and experiences, which also increases the likelihood of anticipating unintended effects (Luís et al., 2018). Non-scientists, including citizens, are increasingly seen as sources of knowledge that is needed for effective climate change adaptation. Local authorities can tap into citizens' knowledge to learn about their experiences of climate hazards, identify already existing solutions unknown to local authorities, or design unconventional adaptation measures. Involving citizens early in the adaptation-planning process not only offers a better knowledge base to identify risks and vulnerabilities, but also improves implementation of adaptation actions. The relevance, fairness and acceptance of adaptation actions taken by local authorities can be improved (Brink and Wamsler, 2018). One example of effective knowledge co-creation with citizens comes from the city of Prague (Box 6.5).

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(83) https://www.uia-initiative.eu/en/uia-cities/greater-manchester

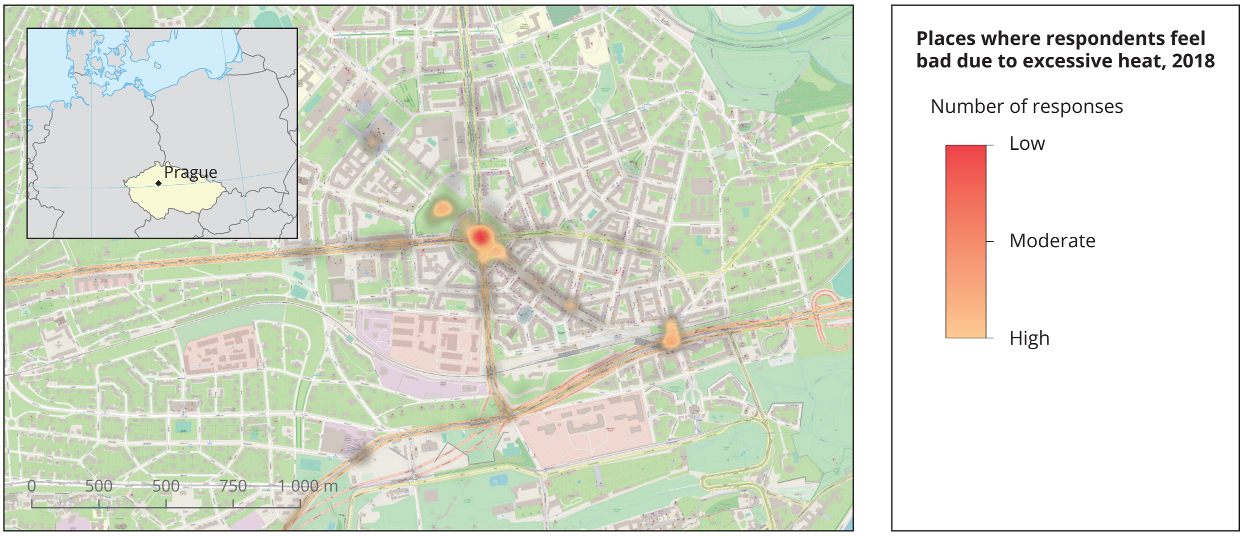
(84) https://unalab.eu/index.php/documents/d21-unalab-ull-framework

Box 6.5 Citizen science supporting climate change adaptation in Prague

In Prague district 6, together with the local authority representatives, CzechGlobe (Global Change Research Institute) used a web-based portal for citizens to map local climate impacts and adaptation options. The citizens and local stakeholders were informed about the portal through the district website, newsletter and social media channels. A meeting was also held to inform citizens of climate change impacts and to test and promote the crowdsourced adaptation mapping. Simultaneously, educational events with school children were organised, focusing on climate change risks and urban adaptation.

Respondents were asked to mark places on the online map (see Map 6.1) that were characterised by extreme heat, pleasant temperatures, insufficient rainwater retention, drought, poor air quality and lack of vegetation (on separate layers). The respondents were also encouraged to propose and locate suitable adaptation measures, based on the list of options provided through the CzechGlobe website (http://www.opatreni-adaptace.cz).

Map 6.1 Results of the crowdsourced mapping, indicating locations identified by respondents as places where they feel unwell as a result of extreme heat



Reference data: ©ESRI. Map adapted from www.pocitovemapy.cz

© Jiří Pánek, Palacký University Olomouc

During the exercise, 504 respondents (predominantly young adults with higher education) identified 7 123 locations at risk of climate impacts. Extreme heat was identified as a problem in 1 220 locations and lack of vegetation was an issue in 1 171 places; water scarcity was seen to affect 753 places. The participants unexpectedly identified public transport stop shelters with glass roofs as places with extreme heat, particularly affecting children and the elderly.

In total, 712 adaptation measures were proposed, most of them (402) connected to green infrastructure. In spring 2019, a seminar took place at the District Hall, where citizens and local non-governmental organisations were presented with the mapping results and an adaptation strategy proposal. Their feedback was included in the preparation of the district adaptation action plan, prepared in close cooperation between scientists and city district officials.

Implementation of some of the measures identified through mapping started in 2019. This included sun-reflective surfaces on the public transport stop shelters; the first tram stop shelter in Prague with a green roof was installed in October 2019. Installation of drinking fountains and water spraying is planned in the public areas that were indicated by the participants as uncomfortably hot.

The approach was a success and the same citizen mapping exercise was organised in 2019 by the Prague district 8 and the city of Žilina, Slovakia. There are plans to use this approach in other municipalities and cities in Czechia, Slovakia and possibly other countries, depending on interest.

Sources: Lorencová et al. (2019); personal communication from Mária Kazmuková, City of Prague, and Eliška K. Lorencová, Global Change Research Institute of the Czech Academy of Sciences, 2020.

However, while co-creation of knowledge with citizens is laudable, overreliance on their willingness to engage and share knowledge may exacerbate inequalities between different areas of a city, with poorer and less educated communities usually being less involved. Therefore, it is important to keep in mind equity considerations and aim to involve social groups that are less likely to engage in 'traditional' citizen participation processes (see for example Box 5.7).

The choice of topics addressed can also make a difference to attracting participants. Brink and Wamsler (2018) found that nature-based approaches can have greater potential for successful citizen engagement than physical adaptation measures, as their recreational and social use or aesthetic value is of interest to citizens. Since infrastructural (grey) adaptation measures often require specific expertise and a large amount of capital, and offer limited scope for social interaction, they might not lend themselves so easily to citizen engagement.

6.2.4 Insurance claims data as a knowledge base for adaptation planning

As explored in Chapter 2, extreme-weather related damage is expected to increase with climate change. The cost of financial and economic losses will largely fall on governments and citizens, but also on the insurance industry. Insurance companies hold a wealth of data on previously experienced damage and assets affected, which could be linked to specific weather conditions and thus help cities to prepare for such conditions in the future. For example, in Portugal, heavy losses from the high number of floods in 2014 led the Portuguese Insurance Association and the Faculty of Sciences of the University of Lisbon to develop a project that aimed to produce flood and risk maps in climate change scenarios (CIRAC) (85). However, the insurance sector and the public sector at the local level currently do not systematically share disaster loss data. This means that local risk assessments and identification of adaptation options do not benefit from knowledge collected by the insurance industry, and vice versa. This may lead to suboptimal adaptation practices, in turn causing more damage, higher recovery costs and higher premiums charged by insurers.

The role of insurance in climate change adaptation has been one of the key areas for action for the European Commission. In the EU urban agenda Climate Adaptation Partnership framework, the Directorate General for Climate Action is leading action on promoting open access to insurance data for climate risk management (see also Box 4.1). This follows on from Action 8 in the EU adaptation strategy (EC, 2013a), which is to 'Promote insurance and other financial products for resilient investment and business decisions'. Harnessing the knowledge of the insurance sector is also a focus of EU-funded research projects. For example, the platform Oasis Hub (86), developed through the H2020_insurance project, gathers data from insurers, but also other data providers, on environmental, extreme weather risks and offers the data, tools and services to any interested organisation, including local authorities.

Insurance claims data are used by local authorities in some countries; some of the most advanced actions are in Scandinavia. In Denmark, the 2011 flash floods in Copenhagen (see also Box 3.8) prompted the first loss data sharing experience between the insurer association and the city hall. A legally binding document was signed between the insurance industry and the city of Copenhagen to organise the sharing of the claims data. The pilot was extended to 70 of 98 Danish local governments/cities, covering 90 % of the Danish population. The loss data sharing was conducted in 2013 and then again in 2016, with general positive feedback from the municipalities (Box 6.6).

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(85) http://cciam.fc.ul.pt/prj/cirac/?id=1 and https://www.apseguradores.pt/pt/publica%C3%A7%C3%B5es/estudos
(86) https://h2020insurance.oasishub.co

Box 6.6 Experiences of using insurance data among Danish municipalities

In 2016, insurance claims data associated with heavy precipitation, or cloudburst (*skybrud*), events between 2010 and mid-2015 were collected from the seven largest insurance companies. The data set includes information on addresses, dates and amounts of damage compensation. Prior to collecting the data, Forsikring & Pension (the trade association for the insurers) obtained permission from the Danish Financial Supervisory Authority to disclose data.

The data collated by Forsikring & Pension were not shared with the individual insurance companies, and the data were destroyed after the association shared them with cities using secure lines. The transfer and processing of data were agreed separately with each municipality. Municipalities committed to processing data securely and confidentially and publishing results only in an anonymised form.

Feedback from the municipalities shows that data have been used for the following purposes:

- complementing the municipality's own data by identifying unknown hotspots and wider problem areas; more comprehensive and nuanced mapping of at-risk areas by including the actual cost of damage; and revision of risk maps in the context of the development of cloudburst action plans;
- prioritising interventions in a cloudburst event;
- drawing up investment plans, by considering the socio-economic benefits of climate adaptation, as well as the viability of funding adaptation in specific areas;
- in local planning cases, laying out requirements on climate adaptation measures in building and development permits;
- supporting dialogue with landowners on improvement of drainage;
- validation of the action areas in which projects have started;
- documentation related to the implementation of climate action projects.

The municipalities saw other potential uses of the insurance claims data set:

- contributing to a more realistic assessment of the economic costs of flooding;
- improving estimation of the direct costs of damage as part of socioeconomic assessments;
- identification of problems with surface runoff in areas considered for new construction or urban densification;
- planning of sewers and sewer separation, and construction of drainage basins;
- integration of data into the maintenance system of the utilities, offering information about previous flooding events, supporting development of new solutions;
- integration of insurance data with a module enabling citizens to report flooding incidents;
- eventual validation of the effect of implemented adaptation measures.

The feedback from municipalities on the data quality indicated that the data sets received would benefit from more thorough preparation and inclusion of metadata. In particular, the dates recorded were often not those of the weather events but those of the notification of the insurance company by the injured party. Data sets also included addresses located on the first floor or higher, probably because the owner's address differed from the place where the damage occurred. In some instances, the exact cause of damage was unknown. The municipalities also expressed the view that the data should be shared with them on request, rather than periodically when the top-down decision to do so is made.

As of early 2020, loss data sharing has been stopped because of insurers' concerns about breaching General Data Protection Regulation rules. However, the insurers' association continues to cooperate with municipalities and utilities in climate adaptation networks.

Source: Forsikring & Pension (2017).

In Norway, the Danish experiment was replicated as a pilot with 10 local authorities. The conditions of sharing data with municipalities were the subject of lengthy negotiations between Finance Norway and the insurance companies, the difficult issues being concerns about data confidentiality and commercial sensitivity (see Box 6.7).

Box 6.7 Applicability of insurance claims data to local adaptation planning in Norway

In Norway, in the last 10 years, insurance companies have paid annual compensation of around NOK 2 billion (about EUR 197 million) for damage to insured buildings caused by urban and river flooding. Climate scenarios for Norway warn of more frequent and intense precipitation in the future, which is likely to increase the cost of damage associated with flooding, especially in urban areas.

Information about the location and extent of the damage and losses incurred was held by the insurance companies and not shared with the municipalities. In order to open up this data source to city level decision-makers to support flood risk management and adaptation planning, Finance Norway (the industry organisation for the financial industry in Norway) started a pilot project with 10 cities in 2012, which included sharing asset level loss data held by insurers with these cities' planning and infrastructure sectors.

The feedback from the pilot cities was generally positive but opinions about the usefulness of data varied and some local authorities benefited from the insurance claims data more than others. For example, in Bærum, the damage data were largely new information for the municipality. Many of the cases included in the insurance industry's data set were damage that is not a direct responsibility of the municipality and therefore had not previously been registered. The municipality expects it could use them to identify vulnerable areas that it may have been unaware of before. In Trondheim, the data contributed to their overview of risks related to urban flooding; some areas affected by intense precipitation were identified, which were previously not seen as exposed.

However, according to the cities participating in the pilot, the cause of many of the insurance claims was not properly coded, and some claims were missing the correct address. The main conclusion of the pilot project was that access to such data would be useful for local adaptation and risk reduction planning, but only if the quality of the data were improved.

Sources: Brevik et al. (2015); UNEP (2018b); Climate-ADAPT (2020c).

In both Denmark and Norway, the municipalities generally welcomed the data, and in some cases the data have provided new information that is important for effective risk management and adaptation planning. However, from the local authorities' perspective, the lack of accuracy in the claims data in relation to date, place and cause of damage needs to be improved to make them truly beneficial as an evidence base (Forsikring & Pension, 2017; Climate-ADAPT, 2020c). In addition, the use of insurance claims information in adaptation planning is most effective if the penetration rate is very high and the claims data have good coverage. There is also a danger of social bias, whereby areas with higher insurance penetration (usually wealthier areas) have better coverage and can thus be identified as priority locations for action. Another problem with providing consistent data sets is the annual duration of insurance contracts and the movement of clients between insurance firms.

In many countries, the insurance industry is reluctant to share data owing to their commercial sensitivity and confidentiality. In Norway, the insurers were willing to provide the aggregated data (not at address level). Fears were expressed about the potential for price-fixing cartels to form and foreign companies gaining easy access to the market (Hauge et al., 2018). In addition, time and resources must be committed to extract, compile and process data. However, in Denmark insurers reported that the data-sharing exercise was a beneficial experience overall. For instance, data sharing is seen as a way to better identify areas of particularly high short-term risk, and to reduce the potential damage because it enables better adaptation planning and implementation by municipalities. The exchange of knowledge was seen to foster good cooperation between the private and public sector, boosting the role of the insurance industry as a serious partner in adaptation planning (Forsikring & Pension, 2017).

6.3 Financing adaptation

There are various ways of financing and funding local adaptation to complement the local budgets, which are the most widespread source of funding (see Section 5.3). The 2017 EEA report *Financing urban adaptation to climate change* (EEA, 2017c) provides examples of the use of European, national and private funds. The Covenant of Mayors for Climate and Energy provides an interactive funding guide (87) for signatories, coordinators and supporters of the initiative as well as academia. Information on financing and funding can also be found in the Urban Adaptation Support Tool (88). The next subsections focus on more innovative or less well-known forms of funding that could be applied to local adaptation.

6.3.1 Innovative financing methods

Given the scale of the adaptation challenge and the limited government budgets that are earmarked for adaptation (see Section 5.3), cities need multiple sources of funding. One method is to apply the existing financial mechanisms to support adaptation. For example, using financial incentives — such as tax or fee abatement schemes — can encourage property owners to invest in adaptation measures, thus reducing the financial burden on the local authority. In Germany (Box 6.8), fees for stormwater management are reduced if the rainwater from a given plot of land is not discharged into the municipal sewerage system, but captured or infiltrated into the ground. In Poland, the Water Law of 2018 requires a fee for directing rainwater into public drainage systems from owners of properties larger than 3 500 m^2 or those where over 70 % of the plot area is impermeable surfaces. The fees are reduced for property owners who install retention tanks for the rainwater (Kancelaria Sejmu, 2017). In Lisbon, exceeding the minimum required percentage of vegetated areas in public courtyards is financially promoted with tax deductions (EGCA, 2018).

Box 6.8 Stormwater fees and rainwater reuse in Germany

Further to the legal order for reducing impermeable surfaces in the German Urban Planning Law (BauGB, §179), there are financial incentives for private home owners to increase infiltration and capture rainwater. Most German local water tariff systems have split the basis for the calculation of waste water tariffs between volumes of drinking water consumed and quantities of rainwater potentially introduced into the sewerage system. This system allows the calculation of different runoff coefficients according to surface materials and degree of sealing, and the reduction of contributions for homeowners who release less water to the sewerage system. Reducing risks of pluvial flooding also has benefits for the local authorities, as they may be held liable for damage if the local sewerage system cannot cope with the increasing intensity of rainfall events.

In addition to the lower stormwater fees, some cities support homeowners' actions to reduce rainwater runoff from their properties. The city state of Bremen offers financial contributions to homeowners for desealing (EUR 20/m^2, up to a maximum of EUR 5 000) and for installations (or their upgrading) for reuse of rainwater or grey water (40 % of overall costs, up to EUR 5 000). These subventions aim to reduce the use of drinking water for flushing toilets, watering the garden or cleaning, at the same time as reducing the amount of rainwater in the sewerage syste

Sources: Groth and Buchsteiner (2018); Bremer Umwelt Beratung (2020).

Property development taxes or levies are charges placed on property developers to finance capital costs associated with development or redevelopment of an area (Merk et al., 2012). Developers are required to pay these charges to the local authority for any construction work carried out by a municipality. The capital could also help fund infrastructure investments that increase the resilience of the development area or other locations. These levies can be applied only to new areas or very rarely to areas under redevelopment and cannot, therefore, be used to replace old infrastructure.

Tax increment financing (TIF) is a form of value capture and a public financing method that is used by local authorities to borrow or issue bonds to generate the necessary capital for redevelopment, infrastructure and other community improvement projects, typically in districts in need of revitalisation. The TIF district creates a funding source for the project based on the assumption that the redevelopment will improve the general quality of the area and attract businesses and residents. In this way, property values and property taxes are increased, allowing the local authority to borrow capital

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(87) https://www.eumayors.eu/support/funding.html
(88) https://climate-adapt.eea.europa.eu/knowledge/tools/urban-ast/step-1-5

needed for any upfront investment against the expected incremental tax increase. The loan is then paid back from the additional revenue generated through the increase in property taxes (Merk et al., 2012). In the context of adaptation, TIF can be used to finance for example flood defence infrastructure, as seen with the Grangemouth Flood Prevention Scheme in Falkirk, Scotland. The total project spend is GBP 152 million, of which GBP 12.7 million is included within the TIF project (Falkirk Council, 2019). However, property taxes in some European countries form a minor part of the municipal budgets. There is also the concern that the application of TIF could create unequally distributed adaptation, with the economically disadvantaged neighbourhoods less likely to enjoy attention from the market (Root et al., 2016).

The above mechanisms can be supplemented with ad hoc ways of generating revenue, such as donations and crowdfunding. Donations are contributions made by individual persons to the provision of public goods, e.g. street trees (Box 6.9). The donors do not tend to expect a direct financial return but a non-monetary or symbolic reward (e.g. a certificate or a plaque with the donor's name). Donations can enhance a sense of ownership and personal sense of responsibility for the public space. Similarly, in the case of crowdfunding, the core idea is to obtain funding for a project from a large and diverse pool of citizens using an online platform. Crowdfunding has been used, for example, in Ghent, Belgium, to support urban greening (Climate-ADAPT, 2016e).

Box 6.9 Public donations for street trees in Berlin

The Stadtbäume für Berlin (Street trees for Berlin) campaign has since 2012 encouraged the Berlin citizens and enterprises to donate money to replace street trees that had to be cut down and that could otherwise not be replaced because of municipal budget constraints. A tree is planted if donations reach EUR 500, which is a quarter of the total cost of EUR 2 000 for the young tree and its care during the first three years. The city then covers the remaining cost.

The donors can either give the full EUR 500 needed for a tree or donate smaller amounts, which are then pooled together. When paying the full amount, donors can choose their 'personal' tree on a map and may include a plaque with their name on the tree. Donors of smaller amounts can choose in which district of the city they would like their donation to be invested. By April 2020, the citizens of Berlin had donated a total of EUR 1. 7 million and the 10 000th tree of the campaign was planted.

Newly planted tree and a poster advertising the campaign © Senatsverwaltung für Umwelt, Verkehr und Klimaschutz, Berlin

Source: Land Berlin (2020).

6.3.2 *Use of sustainable finance in adaptation at the local level*

In recent years, the financial sector has increased its focus on sustainability, particularly in relation to avoidance of fossil fuels-related investments. 'Making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development' is one of the ways the Paris Agreement aims to strengthen the global response to the threat of climate change (UNFCCC, 2015).

In the EU's policy context, sustainable finance is understood as finance to support economic growth while reducing pressures on the environment and accounting for social and governance aspects. Sustainable finance also encompasses transparency on risks related to the environmental, social and governance factors that may affect the financial system, and the mitigation of such risks through the appropriate governance of financial and corporate actors (EC, 2020i).

With the mainstreaming of sustainable finance, new financial instruments are evolving, and existing mechanisms are being adapted to the fulfilment of the Paris Agreement and broader sustainability objectives. So far, these financial instruments are predominantly applied to climate change mitigation activities, with adaptation added on (see Box 6.10). With awareness of the need to invest in adaptation measures increasing, interest is shifting to applying those financial instruments to activities in adaptation.

Box 6.10 Revolving climate fund in Almada, Portugal

In 2009, the municipality of Almada established the Almada Less Carbon Climate Fund to boost the city's investment in the implementation of local measures to address climate change. Initially, investments were focused on climate mitigation, but the fund has since supported measures that enhance adaptive capacity and promote ecosystem resilience, particularly green and blue infrastructure. The fund is managed by the Department of the Environment, Climate, Energy and Mobility, but all city departments may receive funds, which fosters cross-sectoral synergies.

In 2016, the fund was given a revolving structure, ensuring that cost savings from the implemented measures (e.g. from reduced energy consumption) are fed back into the fund. This approach ensures the fund's longevity and leverages successful projects to scale up funding for further action. To date, the Fund has invested more than EUR 1.9 million, which has reduced Almada's annual energy consumption by 3 000 MWh and saves the City Council EUR 375 000 a year in energy costs.

The mechanism facilitates the financing of climate adaptation projects, from which financial benefits may be seen only over long time periods; short-term financial gains from, for example, energy-saving measures can support adaptation that might not otherwise receive funding owing to their long payback times.

The Multi-Adapt project was funded to implement nature-based solutions addressing various climate risks, including flooding, heat and coastal erosion. Multi-Adapt restored streams (benefiting the riparian ecosystem); generated three stormwater retention basins with a combined capacity of 10 000 m^3; added 75 000 m^2 of new productive land to the network of allotments, producing 300 tonnes of fresh fruit and vegetables a year; reduced annual emissions by 400 tCO$_2$e; and created new recreational and leisure areas. The project cost EUR 440 000, with consequent annual costs of EUR 35 000 for water and maintenance. EUR 75 000 of annual revenue is expected from fees paid by the allotment users.

Sources: Freitas (2018); Infinite Solutions (2014); INTENSIFY (2019).

New sustainable financial instruments can help fund urban adaptation actions

Examples of the sustainable finance instruments applicable to adaptation at the local level include the following:

Sustainable banking and green lending are lending activities that use environmental criteria. Sustainable lending is a rapidly developing market which increasingly provides flexible solutions to individual borrowers and, smaller enterprises that wish to incorporate environmental, social and governance targets into their funding and/or invest into their own green projects to make their business model more sustainable. The specific project must be clearly articulated in the financial documentation along with the expected environmental benefits, which must be assessed, quantified, measured and reported by the borrower. In practice, sustainable provisions have been incorporated into loan agreements in several ways, such as purpose clauses, margin adjustment, third-party verification, level of green assets versus green liabilities, enforcement of covenants and breach of green contractual. Sweden has a system of green loans, whereby local authorities can borrow to fund climate adaptation and risk prevention measures (EC, 2018c). In the Netherlands, NWB Bank has issued green bonds to provide loans to local water authorities to fund projects related to flood protection and water management (Climate Bonds Initiative et al., 2019).

Green bonds are fixed-income financial instruments that are issued to raise capital from domestic and international capital markets for the implementation of environmental projects. Green bonds have four central principles: (1) use of proceeds — the issuer should declare eligible green project categories it intends to support and provide a clear definition of the environmental benefits connected to the projects financed by the proceeds; (2) process for project evaluation and selection — the issuer should outline the investment decision-making process it follows to determine the eligibility of individual investments using the green bond's proceeds; (3) management of proceeds — the proceeds should be moved to a sub-portfolio or otherwise attested to by a formal internal process that should be disclosed; (4) reporting — the issuer should report at least annually on the investments made from the proceeds, giving details of the environmental benefits accrued, with quantitative/qualitative indicators.

Currently, green bonds tied to climate resilience projects account for only 3 to 5 % of total use of proceeds (Climate Bonds Initiative et al., 2019). However, the Climate Bonds Initiative's launch of the climate resilience principles in September 2019 will inform the development of sector-specific climate resilience criteria for the Climate Bond Standard & Certification Scheme and may contribute to increased financing of climate adaptation and resilience projects (Moody's, 2020).

Globally, 13 % of the climate resilience-related green bonds in 2018 was issued by local government (Climate Bonds Initiative et al., 2019) and the public sector is seen by the finance sector as being at the forefront of adaptation to climate change. Public sector is foreseen to increasingly finance climate adaptation projects with green bond proceeds, especially in projects related to transportation and water management (Moody's, 2019). In addition, Europe is at the forefront of green bonds issuance: European issuers accounted for nearly half of 2019 global green bonds (Moody's, 2020), with France and the Netherlands in the lead (Climate Bonds Initiative et al., 2019).

Some European cities, such as Gothenburg, Malmö and Östersund in Sweden, and Paris (Box 6.11), have issued climate or green bonds. For example, Östersund municipality uses some of the net proceeds from the issue of green bonds to fund climate adaptation measures in buildings, infrastructure and sensitive habitats (Östersunds Kommun, 2017). The city of Paris uses 20 % of its 2015-issued climate bond to fund tree planting and extending its parks. However, since these measures do not generate direct revenue that can be used to pay back the bond, the revenue and costs saved from mitigation measures (e.g. from reduced energy consumption) will be used to pay back the investors.

Resilience bonds involve insurance companies and are based on the idea that avoiding catastrophes is cheaper than compensating losses and rebuilding. It works together with the co-called catastrophe (CAT) bonds and can be used to fund the development of infrastructure to mitigate the effects of catastrophic events. CAT bonds can be underwritten by a local authority with an insurance company to insure the city in case of a catastrophic event. The pay-out happens as soon as a certain criterion is met (e.g. a storm surge reaches a certain height). The resilience bond plays on the premium of the CAT bond: since the insurer has modelled and quantified the economic losses of certain climate change-related disasters, it can also model the losses that an investment helps to avoid, e.g. a flood protection wall (Ruggeri, 2017). The impact of the planned investment is then considered to lower the premium on the CAT bond accordingly. With these savings on the premium, the city frees up budget to fund the necessary protection measures.

In 2019, the European Bank for Reconstruction and Development (EBRD) launched the first ever dedicated climate resilience bond, raising USD 700 million (EUR 620 million) with the issuance. Proceeds from the EBRD's climate resilience bond can finance climate-resilient infrastructure (e.g., water, energy, transport, communications and urban infrastructure), climate-resilient business and commercial operations, and climate-resilient agriculture and ecological systems. The bond is issued in accordance with the green bond principles, as well as the new climate resilience principles (EBRD, 2019).

Box 6.11 Sustainability bond framework in Paris, France

Paris developed the sustainability bond framework in 2017: a flexible platform that allows the issuance of climate, social or sustainability bonds. The sustainability bond follows a similar approach to the climate bond issued in 2015 and includes a resilience component specifically targeting extreme climate events. This financing mechanism is EUR 320 million with a 17-year tenor and 1.375 % coupon. The lead managers are the banks Crédit Agricole CIB, HSBC and Société Générale CIB. Both the climate bond (2015) and the sustainability bond (2017) issued by the city of Paris complied with the four green bond principles.

The net proceeds of the climate, social and sustainability bonds issuance will be managed within Paris's normal treasury liquidity account in accordance with the French regulatory framework for local authorities, until the total amount of the net proceeds equals the total amount of selected eligible projects and/or until the maturity date of the bond.

The city monitors the money invested in eligible projects and assesses the climate benefits based on ex ante estimates. For climate adaptation, reporting indicators include the new surface of green areas opened to the public, the surface of new green areas on buildings (green roofs, walls and facades), and the number of trees planted.

In addition, Paris is exploring other options to finance the energy and ecological transition within its sustainability bond framework, including a 'resilience bond'. It was planned to be launched in 2020 and focus on flood prevention and reconstruction. It is meant to demonstrate innovation in infrastructure and resilience in finance. In 2017, Paris mapped its entire sewer system to better understand the projected impacts of drought and other climate changes in order to inform the creation of the resilience bond alongside other activities.

Sources: Climate-ADAPT (2016b); Mairie de Paris (2017, 2018); Environmental Finance (2018).

Impact investment funds are investments made with the intention of generating positive, measurable social and environmental impact alongside a financial return. They can be used as an alternative to direct equity investments. Through spreading assets across a variety of capital classes, risk can be diversified. Furthermore, single investments can tackle various sustainability challenges at once. Depending on the structure of the equity fund, minimum investments might be a burden for private investors. Investment management fees might reduce return on the fund. Impact Investments tend to have lower returns than traditional investments.

Results-based financing is a financing approach under which a donor or investor disburses funds to a recipient upon the achievement of a pre-agreed set of results. Results-based climate financing (RBCF) must meet the following four criteria: (1) payments are made for climate mitigation or adaptation results; (2) payments are made ex post; (3) payments are made once predefined results have been achieved; and (4) reported results have been independently verified. The immediate implication of using RBCF is that the activities it supports will need to secure prefinancing in addition to the (conditional) financing they will eventually receive through RBCF. Even though RBCF does offer some security of future financing flows to the activities it supports, the recipient still runs the risk of certain activities underperforming or not delivering the predefined results. Therefore, RBCF involves a risk transfer, leaving the recipient with greater risks than in the case of upfront financing. RBCF can be used to complement other financial instruments — such as upfront grants, loans or guarantees — and can be a vehicle for delivering the funding associated with those financial instruments.

Social impact bonds (SIBs) are multi-party, pay-for-performance/pay-for-success contracts that give investors financial returns based on the impact created by a (non-) profit organisation. They align the interests of non-profit service providers, investors and governments to improve the quality of life among individuals and communities. Their core feature is the provision of funding for upstream prevention or early intervention programmes that significantly reduce the need for subsequent and more costly remediation. Part of the savings achieved is passed on to the investors (Maduro et al., 2018). SIBs share features of both debt and equity and usually have a fixed term of 5-10 years. As the returns vary based on performance, investors bear a higher risk of losing their investment capital. In addition, there are no underlying securities, assets or secured cash flows to cover the principal. See the example of Paris (Box 6.11).

6.4 Monitoring and evaluating adaptation

Monitoring and evaluation of climate change adaptation policies at the local level is an important element in the adaptation planning and implementation cycle. Assessment of ongoing and completed measures is necessary to ensure they were implemented and reached their defined objectives. Monitoring helps to identify what works and what does not in reducing climate risks, why and for whom, thus building the knowledge base on the effectiveness of adaptation options (see Chapter 3). It also helps to uncover unforeseen negative consequences or maladaptation and adjust actions if needed. In short, monitoring and evaluation is a helpful process for local authorities to make sure that they are on the right track in their adaptation action, assess whether or not their resources are spent wisely, and assess how to correct their course if needed. Hence, the process needs to be iterative and take place over long time periods to fulfil its purpose.

6.4.1 What is being monitored and evaluated, and how?

Very few European municipalities currently monitor their adaptation policies, according to the self-assessment of the signatories to the Covenant of Mayors (Figure 5.1). According to van Minnen et al. (2018), there is currently very little monitoring of realised measures (output), their results (outcome), impact, and the effectiveness, efficiency and added value. Many cities see monitoring as a last step in the adaptation-planning process, which comes only after the implementation phase of their measures has started. To be successful, a baseline needs to be defined during the planning phase (together with specific objectives) or at the latest when selecting measures, as working with a counterfactual (what would have happened without this adaptation measure) at the end is not possible for most measures taken. While adaptation in general is a new topic for many local authorities, monitoring of strategies and actions is even less familiar.

The local authorities in their monitoring and evaluation frameworks use a variety of indicators. For example, process-related indicators help to assess the degree of completion of individual actions or the number of stakeholders involved in the completion of a certain initiative. Output-related indicators measure, for example, the number of trees planted, while outcome (or result) indicators measure the effect of the output (e.g. the improved thermal comfort of people). Impact indicators deal with the effectiveness of the intervention in terms of the broader objectives and aims (e.g. fewer people hospitalised because of heat stress) (89).

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(89) Outputs, results and impacts as understood in the 'Better regulation toolbox' (EC, 2017a), e.g. tool no 47, Evaluation criteria and questions.

Examples of cities with comprehensive monitoring of adaptation efforts include Barcelona, Berlin (Box 6.12), Copenhagen, Helsinki (EEA, 2016) and Rotterdam but some other cities also monitor their adaptation efforts. For example, the city of Munich regularly assesses if the planned adaptation measures have been implemented, if they have had the expected results and if the city's overarching objectives in terms of adaptation have been achieved thanks to the measures (Kossmann et al., 2016). The city of Bologna assesses the effectiveness of its adaptation plan against outcome indicators and completion of the actions, as well as keeping track of the implementation cost of its adaptation action plan (Covenant of Mayors — Europe Office, 2017b). The project iSCAPE (90) also helped assess and measure the effectiveness of green infrastructure in reducing UHI effect and air pollution. The Lisbon Metropolitan Area Climate Change Adaptation Plan (PMAAC-AML) comprises a system for monitoring and assessment of adaptation to climate change, a framework of monitoring indicators, a set of monitoring procedures and framework of responsibilities for the collection, processing, reporting and dissemination of monitoring indicators, and an assessment.

6.4.2 *Challenges to monitoring adaptation at the local level*

The ability to track adaptation is often challenged by the lack of measurable outcomes, outputs and impacts (including long-term and secondary effects (Aguiar et al., 2018). Unlike mitigation, there is no universal unit of measurement for adaptation (Dilling et al., 2019). Therefore, what is seen as 'successful' adaptation may vary from place to place (EEA, 2020d). At the national level, only a limited number of countries have operational adaptation indicator sets (ETC/CCA, 2018a); local-level adaptation is not well captured by national adaptation monitoring and evaluation, despite its importance for the assessment of progress towards adaptation goals at national and global levels (UNEP, 2018a).

Additional challenges to monitoring adaptation arise at the local level. General difficulties include working with the uncertainties related to future climate changes (EEA, 2015b), but also to the way societies themselves will develop. Moreover, it often proves difficult to establish the effectiveness of adaptation actions that may become measurable only in the (long-term) future,

Box 6.12 Monitoring adaptation in Berlin, Germany

Implementation of the current adaptation strategy in Berlin runs from 2017 to 2021. The city of Berlin monitors the effectiveness of adaptation measures through a set of indicators, derived from the Organisation for Economic Co-operation and Development monitoring system, which is classified into state, impact and response indicators.

The city of Berlin developed 14 state indicators, 43 impact indicators and 47 response indicators. State indicators measure the state of climatic variables, including temperature and precipitation. They serve as a basis to evaluate the success of adaptation strategies, as verification and spatial specification of climate projections, and as an indication of trends that are not yet captured by climate models. Impact indicators capture the effects of climate change on society and the environment. Currently, impact and response indicators capture data from the following action fields: buildings and urban development; health; tourism, sport and culture; environment and nature; industry and finance; traffic and infrastructure; water; energy and waste; and education. In turn, response indicators measure the success of adaptation measures. They can be divided into process indicators, which indicate the extent of achievement of adaptation measures, and result indicators, which measure the actual effect of adaptation measures.

Owing to cost, time and complexity, the process of monitoring is expected to be automated via a dedicated information system and integrated with the climate protection programme monitoring system.

Source: Reusswig et al. (2016).

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(90) https://www.iscapeproject.eu

and issues follow in attributing impacts to different causes (Klostermann et al., 2018; van Minnen et al., 2018). Establishing counterfactuals further increases the challenge of measuring the effectiveness of actions (Scott et al., 2018). Moreover, as new knowledge is likely to become available in the future, the evaluation takes place against shifting baselines. Lastly, in a multi-stakeholder context, different interested parties will have varying information needs and objectives, making developing a set of indicators that is helpful for everyone involved difficult to achieve (Klostermann et al., 2018).

Local decision-makers are not only confronted with these barriers, but often also face further issues, many of which are common in local government operations in general. These include the lack of financial and skilled human resources to carry out an effective monitoring process, as well as competing priorities at the local level. For adaptation specifically, data sets are often not readily available, and standardised approaches are missing (Scott et al., 2018). Furthermore, it can prove difficult to define concise indicators that are meaningful and robust but avoid collecting a large mass of data that would make the process too burdensome for the local administration. Gathering data by different departments and stakeholders can further complicate the process; the information monitored needs to be collated, structured and systematised in order to provide a basis for an evaluation of a plan or action (Covenant of Mayors — Europe Office, 2019).

Monitoring and evaluation at the local level can be facilitated by more knowledge on the effectiveness of measures in the urban environment, exchange of knowledge with others, and identification of examples and information relevant to a city's situation, e.g. through participation in international networks (van Minnen et al., 2018).

6.4.3 Examples of monitoring frameworks

A variety of frameworks for monitoring local climate adaptation have been developed, but it is unclear how many European local authorities follow them. Certain frameworks are linked to international policies, such as the Disaster Resilience Scorecard for Cities, which was developed by the United Nations Office for Disaster Risk Reduction (UNDRR) with the primary purpose of assisting countries and local governments in monitoring and reviewing progress and challenges in the implementation of the Sendai framework (UNDRR, 2017) (see Section 4.1). Signatory cities to the European Covenant of Mayors commit to monitor their progress every 2 years after submission of their action plan. Monitoring and evaluation is an ongoing process in the Covenant framework and is mostly done by updating previously reported data. Cities should report on the progress towards their adaptation goal(s), the staff capacity allocated for the plan implementation and the budget spent as at the time of monitoring. The risk and vulnerability assessment conducted initially can be updated to better define the relevant climate hazards, vulnerable sectors, adaptive capacity and vulnerable population groups. Optionally, signatories may define indicators to monitor progress and achievements. Information on reported adaptation actions should also be updated, in particular the progress of the action implementation and the indicators for measuring the outcomes reached. Guidance on monitoring and evaluation of adaptation is available through the Urban Adaptation Support Tool (91).

Some national governments (e.g. Germany) provide their local authorities with guidelines on monitoring and evaluation of adaptation measures. At process level, Denmark monitors local actions centrally; so does Portugal, where the national government keeps track of implementation of adaptation measures identified in strategies and plans at the national, regional and local levels (EC, 2018c).

The Italian region of Marche has developed a monitoring and evaluation framework and a tool within the LIFE Sec Adapt project that is tailored to the needs of the region's local authorities and those from its partner region, Istria in Croatia, but is still accessible to all interested parties (LIFE Sec Adapt, 2020). Other regions across Europe have developed similar approaches, often in their role as coordinators of the Covenant of Mayors.

An impact evaluation framework for nature-based solutions projects was developed under the Eklipse (Raymond et al., 2017) project. A handbook to guide impact assessments for nature-based solutions, the result of a collaboration between several Horizon 2020 projects, is expected to be published in September 2020.

Some researchers argue that standardised indicator sets may not be appropriate for measuring local impacts, and that consequently indicators that are defined locally (with a large range of stakeholders) allow better learning (Scott et al., 2018). Therefore, while this requires skills and time, the development of a framework and indicators at the regional or provincial level may be an interesting approach, since it allows pooling of scarce expertise and resources while being relatively close to the ground.

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(91) https://climate-adapt.eea.europa.eu/knowledge/tools/urban-ast/step-6-0

6.5 Adaptation as an essential aspect of sustainable urban development

6.5.1 Integrating adaptation into urban and spatial planning

Land use planning is particularly pertinent to urban adaptation (Figure 6.1) because of the spatial character of many climate impacts, the influence of characteristics of cities on the intensity of impacts from climate hazards (see Chapter 2) and the inherently future-oriented perspective of planning. The departments responsible for spatial planning or urban design were the most frequently responsible for adaptation among the Covenant of Mayors signatories (see Section 5.1.3).

However, integration between climate adaptation plans and spatial planning instruments requires further efforts, as shown by the ongoing unsustainable direction of the urban development (Section 2.10). According to the adaptation preparedness scoreboard, at the national level, in 2017 only 15 EU Member States (92) had land use, spatial or urban planning policies that explicitly addressed climate impacts, and required or encouraged adaptation (EC, 2018e), but the situation is changing. For example, since 2018, in Sweden the amended planning and building regulation has required the municipalities to assess in their masterplans the risk of damage to the built environment from climate-related landslides, erosion and floods, and propose measures to reduce or eliminate risks. The changes to the law also give municipalities the power to place demands on land permeability in the detailed planning rules. In Ireland the recently established Office of the Planning Regulator is required to evaluate how local authorities consider both adaptation and mitigation in their development plans. In Italy, since 2013, local authorities have been obliged by law to systematically manage and develop their green spaces to reduce temperatures, collect rainwater and improve environmental quality more broadly (Repubblica Italiana, 2013); in addition, the National Urban Green Strategy was adopted in 2018, and has among its objectives adaptation to climate change and heat island (Ministero Dell'ambiente e Della Tutela del Territorio e del Mare, 2018).

Urban planning can facilitate adaptation in various contexts, from city centres to rural settings. For example, in Barcelona, a new concept for the spatial organisation of the city centre, based on diverting traffic away from neighbourhoods, aims to provide a greener, cooler and more liveable environment (Box 6.13). In the Navarra region, Spain, the EGOKI project supported the integration of adaptation into land use management of small municipalities, including through land classification to prevent the spread of forest fires in rural areas surrounding the settlements or to reduce the flood risk to built-up areas, as well as through establishing regulations and construction development criteria to ensure proper ventilation, shading, vegetation and use of low-albedo materials in streets and squares (Climate-ADAPT, 2018a).

The role of spatial planning in effective design and implementation of green infrastructure solutions is key. Green infrastructure may compete with other land uses in cities that are short of space. Therefore, strong coordination with urban planning is required to ensure that the proposed green infrastructure measures are both feasible and desirable (Geneletti and Zardo, 2016). For example, the Lisbon masterplan included a study on climate guidelines for planning, which identified the need to promote conditions for suitable ventilation and reduction of the UHI effect to improve air quality and thermal comfort. This resulted in a map of the main ventilation corridors and areas exposed to wind from the sea, accompanied by guidelines preventing the ventilation areas from being blocked by new developments (EGCA, 2018). A similar approach to facilitating air movement through planning regulation has been used for several decades in Stuttgart, Germany (Climate-ADAPT, 2016h). Green space factors and points systems have been used in several European cities as a policy instrument to attain desired levels of green and blue surfaces in new property developments. This has been done, for example, in Berlin (Climate-ADAPT, 2016a), Malmö (Kruuse, 2010) and Oslo (C40 Cities, 2019). Different green and blue 'elements' are scored based on their importance for a particular function, and an area-weighted score is calculated for a proposed property development.

Urban development paradigms considering the current weather hazards and the projected impacts of climate change can be used to guide the planning of cities. For example, water-sensitive urban design (WSUD) aims to minimise the hydrological impacts of urban development on the environment. In practice, WSUD integrates the management of stormwater, supplies of groundwater and waste water to protect existing natural features and ecological processes; maintain the natural hydrologic behaviour of catchments; protect the quality of surface water and groundwater; minimise pressure on the mains water supply system; minimise waste water discharges to the natural environment; and integrate water into the landscape to enhance its visual, social, cultural and ecological value (Climate-ADAPT, 2016l).

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(92) Bulgaria, Czechia, Denmark, Finland, France, Germany, Hungary, Ireland, Latvia, Lithuania, Luxembourg, Portugal, Slovenia, Sweden and the United Kingdom.

Finally, a powerful instrument for anchoring climate change adaptation in local planning could be environmental and strategic environmental assessments, i.e. mandatory procedures for projects and plans with potential impacts on the environment. Alongside the EU adaptation strategy (EC, 2013a), in 2013 the European Commission issued guidelines for anchoring the consideration of climate change in the strategic environmental assessments (SEAs) for projects and plans (EC, 2013c). However, analysis of the implementation of the SEA Directive shows that, while consideration of climate change in SEAs has taken place to some extent, planners and local authorities continue to struggle to consider future impacts of long-term climate changes on their plans or programmes, owing to the complexity and uncertainty connected to climate projections (Larsen et al., 2013; McGuinn et al., 2019). This can be addressed by national authorities: for example, the Irish Environmental Protection Agency (EPA) provided local planners with guidelines that include recommendations to consider climate change in SEAs focusing explicitly on local spatial planning (EPA, 2020).

6.5.2 Links to various policy areas

Despite the cross-cutting nature of climate change, adaptation in cities is rarely carried out systematically across multiple sectors (Wamsler et al., 2013; see also Section 5.1.3). Nonetheless, clear links between various sectors can be found in existing adaptation action plans. For instance, the implementation of flood protection and water management actions was found to be related to urban planning, while approaches strengthening biodiversity were related to adaptation and the implementation of actions in agriculture, forests and natural areas, spatial planning and human health (Aguiar et al., 2018). The presence of these linkages calls for a more systemic and integrated approach to adaptation. Co-benefits of adaptative actions should be identified and utilised to avoid duplication of efforts among different sectors, to facilitate engagement of various stakeholders or departments, and to leverage various funding opportunities.

Box 6.13 Adapting to heat through urban planning: Barcelona's superblocks

The city of Barcelona is dense and compact. Temperatures in the city centre can be up to 8 °C higher than the surrounding areas owing to the urban heat island effect. The traffic results in noise and air pollution, with a considerable health burden on the residents, and green areas are limited.

In 2013, the Superblocks programme was designed as a new way of spatially organising the city with the aim of improving traffic efficiency, reducing greenhouse gas emissions and increasing the green areas by 1 m^2 per resident. The superblocks are neighbourhoods where road traffic is reduced nearly to zero by the introduction of traffic-free zones and speed limits. Traffic is diverted to the perimeter of the neighbourhood and the inner roads are replaced by cycling lanes and bus routes. The space that was formerly occupied by cars is being transformed into pedestrian zones, play areas and green infrastructure. Across the whole city, 503 superblocks are being considered for implementation.

Three superblocks were developed by mid-2019 and the city has committed to six more (Mueller et al., 2020). The first superblock was established in 2017 in the Poblenou neighbourhood at a cost of EUR 1.48 million. It was initially opposed by car owners and local business owners. However, upon the completion of the project, which increased the number of pedestrians and cyclists, the number of local businesses rose by 30 % and the support for the scheme increased.

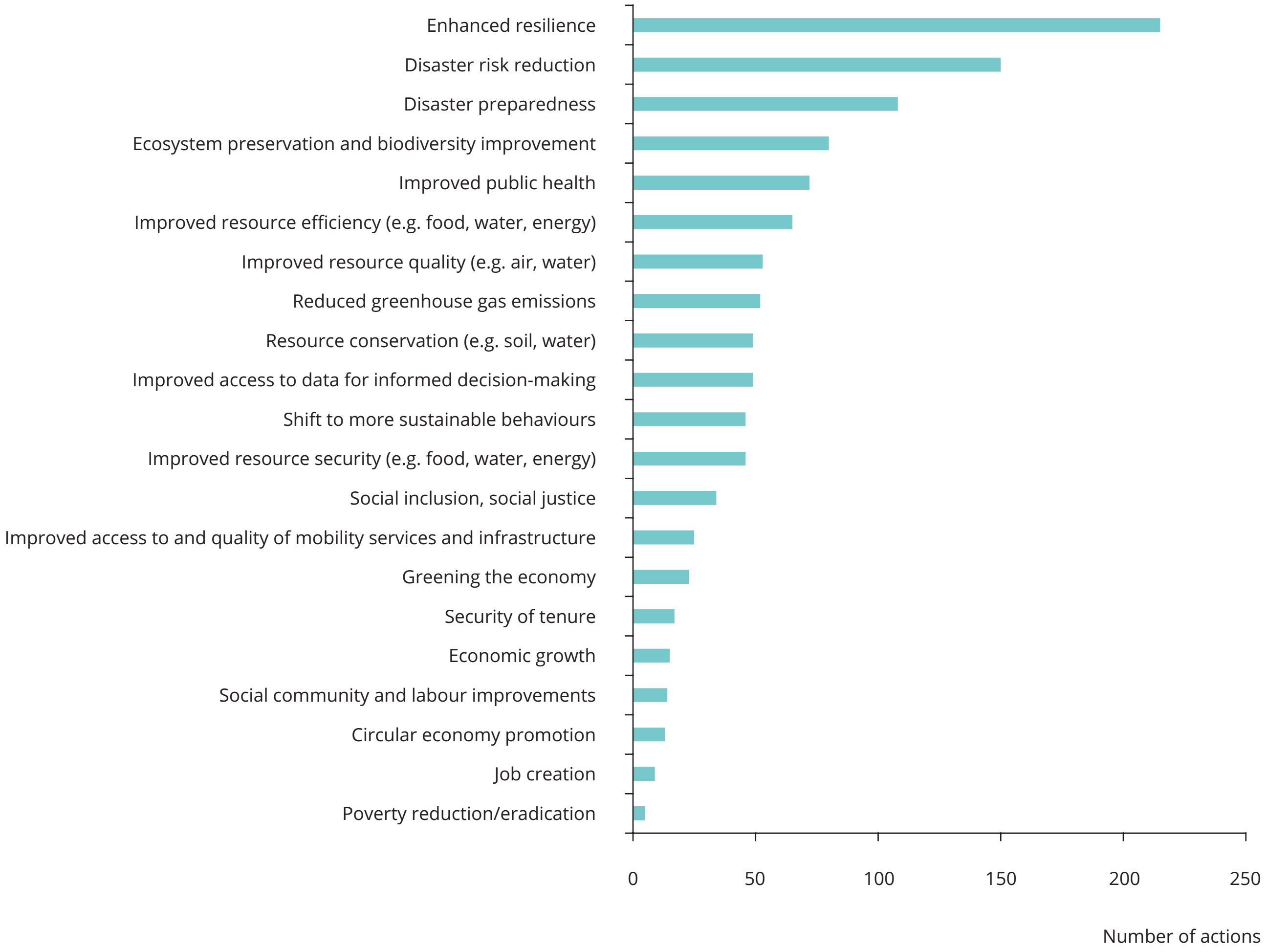
Implementation of all 503 superblocks would lead to the creation of over 23 hectares of car-free areas. The improved environment, with reduced air pollution, noise and temperatures, could prevent 667 premature deaths a year, including 117 premature deaths associated with heat.

Sources: C40 Cities (2018); Burgen (2019); Mueller et al. (2020).

Adapting to climate change by redesigning the roads in superblocks © Zvi Leve at Flickr

Cities reporting to CDP identified various co-benefits of their adaptation actions (Figure 6.2), with enhanced resilience and disaster risk reduction emerging as the most frequent co-benefits (see also EEA, 2017a). Benefits related to nature protection, health and resource management were also identified, drawing attention to the need to connect adaptation to other policy areas. Box 6.14 provides an example of rainwater management linked to circular economy and food production. However, economic co-benefits of adaptation are rarely identified by cities. This is where the main challenge for promoting adaptation actions lies: making a business case for them and linking them to economic indicators such as economic growth and number of jobs. Urban Adaptation Support Tool offers guidance on mainstreaming adaptation into urban policies and plans (93). The links between climate change adaptation and mitigation are explored in more detail in the next section.

Figure 6.2 **Co-benefits of adaptation actions**



Note: As reported to CDP by 106 cities from 24 EEA member and collaborating countries and the United Kingdom for 220 adaptation actions.

Source: Authors' compilation based on analysis of CDP (2019) database.

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(93) https://climate-adapt.eea.europa.eu/knowledge/tools/urban-ast/step-5-3

Box 6.14 Reusing grey water and rainwater for decentralised food production in Berlin

The German project Roof water-farm is a circular city experiment, in which resources are continuously recycled and regenerated. Between 2013 and 2017, the project tested sustainable and hygienically safe reuse of rainwater, grey water and black water from several apartment buildings, linking it to food production. In Berlin-Kreuzberg, a pilot installation showcases the integrated waste water treatment technology, which enables the farming of fish, fruit and vegetables by reusing treated grey water and rainwater, as well as black water as liquid fertiliser on site. Thus, the project merges rainwater management with decentralised water treatment, urban food production and educational functions. It is one of a series of small-scale projects in Berlin that strive to combine urban food production with the reuse of urban drainage and rainwater. Widespread application of such integrated systems would contribute to reducing urban water consumption and increasing drought resilience, while also creating a social space that brings communities together and contributes to capacity building. Moreover, the onsite treatment and use of rainwater, grey water and black water decreases pressure on sewerage systems during heavy rain events. Farming close to consumers also reduces transport distance and hence associated greenhouse gas emissions, noise and air pollution. Since the conclusion of the research project, the Roof water-farm has been used for educational projects.

Greenhouse at the Roof water-farm © Marc Brinkmeier

Source: http://www.roofwaterfarm.com/en

In the context of the 2020 coronavirus disease 2019 (COVID-19) crisis, the contribution of adaptation actions to increasing the overall resilience of cities is particularly important. The pandemic brought to the forefront the need to reconsider how resilient Europe is to unprecedented shocks, which may also be expected as the climate changes. The interconnections between economic, social and environmental aspects and the cascading effects of the COVID-19 crisis have shown the necessity to plan better for future risks.

The pandemic drew attention to the need to protect the most vulnerable in our society — the elderly, the frail and the sick — and emphasised the role of human solidarity in doing so, especially in the densely populated urban environments with high infection risk. The crisis also exposed the inequalities between the white-collar workers, largely able to continue working from home and receive an unchanged salary, and those in employment requiring their physical presence, who were made redundant, were furloughed or risked exposure to infection by continuing to work. Parallels can be drawn with the varying exposure and ability to continue their activities of different socio-economic groups during heatwaves, for example (such as avoiding coming to the hot city centre, working flexible hours).

The pandemic showed how important the immediate environment — our homes, cities and neighbourhoods — is for our physical and mental well-being. For example, during the lockdown period, local green spaces became spaces for physical exercise and mental restoration through contact with nature. They also enabled contact with other people at a safe distance (Samuelsson et al., 2020). This emphasises the need to consider links between the societal resilience to shocks, human health and the planning of cities.

Ensuring access to nature for the public emerged as a fundamental strategy of cities when coping with this crisis. As green infrastructure measures emerge as effective and socially acceptable options to adapt to various climate risks, the COVID-19 pandemic could give an additional boost to the nature-based solutions in cities. In addition, city authorities across Europe are introducing ambitious transport schemes, reducing car lanes to give space to public transport, pedestrians and cyclists, with the potential effects of reduced heat emissions from vehicles and greater opportunities for greening.

More time spent at home in 2020 brought attention to the quality of our built environment. The 'renovation wave' initiative (EC, 2020f), introduced under the European Green Deal (see Section 4.2.2) could usefully not only focus on the energy savings in buildings but also promote adaptation to the increasing frequency and intensity of various climate hazards (see also Section 6.5.3).

6.5.3 Towards concerted climate action: co-benefits and tensions between mitigation and adaptation

The EU adaptation strategy evaluation (EC, 2018f) identifies 'promoting links with mitigation policies at all governance levels' as one of the areas where the future adaptation strategy could deliver more. However, there are tensions between climate change mitigation and adaptation, largely associated with the risk of additional energy use for long-term adaptation actions (pumping of water out of low-lying areas etc.) or short-term coping solutions (e.g. use of air conditioning), resulting in higher emissions of greenhouse gases and, thus, maladaptation. Box 6.15 describes the efforts of the city of Rotterdam to resolve these tensions. Yet, there are also synergies; for example, both adaptation and mitigation can be addressed through refurbishment of buildings (Box 6.16; see also Boxes 3.2 and 3.4).

Urban greening provides a significant opportunity for simultaneous climate change adaptation and mitigation. The cooling qualities of urban vegetation result not only in improved thermal comfort but also in lower energy consumption for cooling. In the city of Basel, which has the highest area of green roof per capita in the world, green roofs combine increased biodiversity with adaptation and mitigation functions (reduced energy use through additional roof insulation; Climate-ADAPT, 2016f). In Lyon, France, re-greening of rue Garibaldi designed as an urban motorway in the 1960s reduced the number of car traffic lanes, calming the traffic and increasing walking and cycling. Air temperatures during the summer were reduced by around 2 °C on average close to the newly planted trees, and the temperature as perceived by people (universal thermal climate index) decreased by 9 °C (Barra, 2019; Segur, 2019). Also, sustainable urban drainage systems reduce the volume of stormwater entering the waste water collection, lowering the energy consumption in waste water treatment plants and thus their carbon footprint (Climate-ADAPT, 2016k).

In order to ensure the effectiveness of urban greening as both a mitigation and an adaptation measure, appropriate planting methods and maintenance schemes must be applied. High mortality losses among street trees may result in a net loss of street tree carbon storage over time (Smith et al., 2019); the cooling benefits provided vary among tree species (Rahman et al., 2015); and, even within the same tree species, the method of planting affects tree's evapotranspiration levels and thus cooling (Rahman et al., 2011). Older trees not only provide more shade but also store carbon more effectively, providing yet another argument for their protection (Rankovic, 2016).

Box 6.15 Resolving tensions between adaptation and mitigation in Rotterdam

With 80 % of the city below sea level, Rotterdam relies on 400 pumping stations to remove water from its polders. Those pumps are very energy-consuming, so Rotterdam has taken numerous steps to increase pumping efficiency and cut greenhouse gas (GHG) emissions. Pump operators release water to the sea by gravity flow whenever possible. Pump retrofits include green roofs, solar panels and a heat exchanger, which is linked to a cooling and heating network. These measures allowed the reduction of carbon emissions and 24 % energy savings on pumping operations, while still protecting Rotterdam from flooding.

Electric vehicle (EV) use is encouraged to improve air quality and reduce GHG emissions. One of the first EV-charging stations was constructed on the Noordereiland, an island in the Meuse river. The island is not protected by dykes, and it tends to flood once per year. As result of climate change and sea level rise, the area is expected to flood more often in the future. However, the first EV-charging stations were not waterproof and their exposure to water could cause a short circuit and power failure in the whole neighbourhood. The city of Rotterdam decided to set up only water-resistant EV-charging stations in areas that are vulnerable to flooding, which led to design innovations in EV charging stations.

Rotterdam has greened some of its tramways. They reduce the urban heat island effect and increase water retention capacity, simultaneously to carbon sequestration and reduced demand for cooling.

Flat roofs provide the opportunity for multifunctional use such as green areas, water storage and solar panels. One example of the synergies provided by multifunctional roofs is the building Peitkreet, on which a green roof is combined with solar panels. The green roof can absorb rainwater and has a temperature-regulating effect. The solar panels generate renewable energy. The cooling effect of green roofs increases the efficiency of the solar panels.

Source: C40 Cities (2020a).

Greening measures can be particularly effective for climate action if they accompany other measures. This is the case in the 25 Verde building in Turin, Italy, where a green roof and green facades are combined with heat pumps that use geothermal energy, connecting to the groundwater system through existing wells. Trees and plants on the facade deliver natural thermal regulation in both summer and winter; the deciduous species provide shade in the summer and allow sunshine to heat the building in winter (Climate-ADAPT, 2019).

Concerted mitigation and adaptation planning in Europe is rare. According to Aguiar et al. (2018), just over a quarter of the cities which combine adaptation and mitigation policy objectives in their climate change action plans explicitly consider the synergies between them. Similarly, fewer than a quarter of adaptation actions planned by the cities reporting to CDP (52 out of 220) deliver the co-benefit of reduced greenhouse gas emissions (see Figure 6.2). In the analysis of local climate action plans across Europe, Reckien et al. (2018) found that almost all joint mitigation and adaptation plans were made in France and the United Kingdom. It seems that, without national regulation, local authorities are reluctant or do not have the capacity to produce joint plans. Moreover, with mitigation plans usually produced earlier, the adaptation plan is often produced as a separate document because the mitigation plan already exists, and it can be costlier and more bureaucratic to develop an integrated plan. An additional potential barrier to the development of joint adaptation and mitigation plans is the division of expertise, in terms of both the departments dealing with the issue as well as the external stakeholders, such as consultancies.

The synergies and trade-offs of mitigation and adaptation efforts could be usefully addressed by joint climate action planning. The Covenant of Mayors — Europe Office encourages its signatories to produce sustainable energy and climate action plans (SECAPs), which include both adaptation and mitigation/energy commitments and actions, and it provides guidance and training to develop and implement them (94). SECAPs should seek and identify complementarities between mitigation and adaptation, and mainstream them into existing sectorial policies to foster synergies and optimise the use of available resources (Bertoldi et al., 2018). Consequently, a number of the provincial, regional and national organisations that used to support Covenant of Mayors signatories on climate mitigation and energy actions have expanded their support to work with these cities on both the mitigation and the adaptation parts of their plans (see also Box 4.11).

Box 6.16 Integrating climate change adaptation and mitigation measures in Bratislava-Karlova Ves municipality, Slovakia

Bratislava-Karlova Ves municipality (60 000 inhabitants) is one of Bratislava's areas that are most vulnerable to climate change impacts. The district contains housing estates of prefabricated apartment blocks surrounded by large artificial areas (car parks, wide walkways, squares) with little green space available, which makes it prone to overheating in the summer (both outdoors and indoors) and raises the need for artificial cooling. Therefore, Karlova Ves aims to introduce measures to adapt to high temperatures, while also reducing its carbon footprint, with the support of the LIFE project Developing resilient, low-carbon and more liveable urban residential area (Deliver) (2018-2023).

Public buildings account for nearly 88 % of the district administration's total energy consumption. Therefore, within the Deliver project, two public buildings — a school and a kindergarten — will be retrofitted with mitigation and adaptation measures. In addition, measures promoting biodiversity will also be included and the project will place emphasis on educational aspects, especially in the field of renewable energy. Intended adaptation measures include nature-based solutions and sustainable rainwater management. The renovation will be carried out with the use of low-carbon materials.

Involving the district communities in the decision-making processes, building their co-responsibility and raising their awareness on addressing climate change are additional goals of the project. During the first 2 years, two surveys were carried out, exploring the respondents' views and feelings about climate change. Over 600 people indicated the places where climate-related impacts (e.g. overheated open spaces, areas being flooded by rainwater) are already occurring. Two additional surveys are planned to further support spatial planning.

Finally, the project develops an online tool called Klimasken for monitoring, evaluation, management and presentation of information on adaptation and mitigation activities in the urban environment, aiming to support Covenant of Mayors signatories in SECAP preparation. This tool intends to support decision-making on adaptation and mitigation measures, covering aspects of vulnerability, exposure, sensitivity and adaptive capacity as well as emission balance, modelling and reduction of greenhouse gas emissions. Six local authorities in Slovakia and Czechia started testing the tool, which is available in Slovak, Czech and English.

Source: Personal communication from Zuzana Hudekova, Bratislava-Karlova Ves municipality, 2020; EC (2020f); LIFE — Deliver (2020).

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(94) The Covenant nevertheless also accepts the submission of separate climate change mitigation and adaptation action plans.

The C40 network's Adaptation and Mitigation Interaction Assessment Tool (AMIA) (95) enables cities to identify various potential interactions between climate adaptation and mitigation measures, highlighting opportunities for synergies and piggybacking, as well as warning against trade-offs and potential poor investments. In Paris, examples of piggybacking include providing a bike path (as a mitigation measure) on the River Seine's banks after strengthening them against flooding, and removing impermeable road surface while diverting car traffic (Barra, 2019).

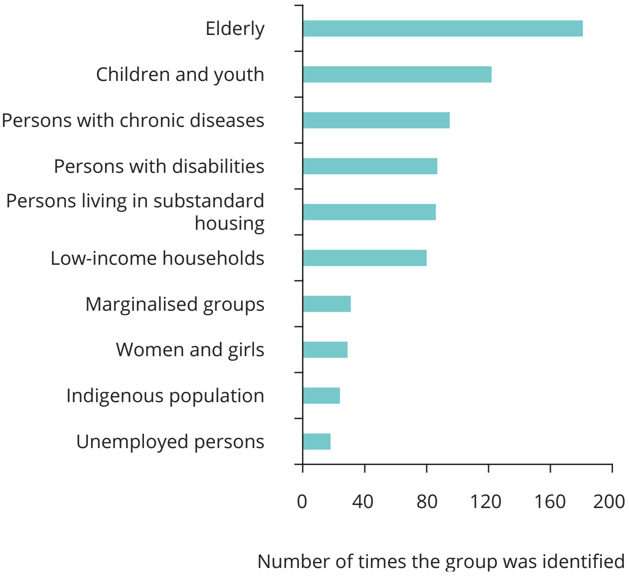
6.5.4 Socially just adaptation

Increased risk to already-vulnerable people was the second greatest social impact for the cities reporting to CDP (see Section 2.2.5). Yet, issues of equity and social justice have rarely been considered in adaptation planning and action to date (see ETC/CCA, 2018b). Many climate adaptation measures consist of technological interventions to reduce exposure of buildings and infrastructures to climate- and weather-related hazards, without accounting for the social, cultural, economic, political and institutional characteristics of cities (Nordgren et al., 2016). Such measures fail to address unequal burdens of climate impacts (Reckien et al., 2017; Torabi et al., 2018). For example, the ecosystem-based approaches in the 14 C40 cities' adaptation action plans did not consider the location of these interventions or the vulnerability of the expected beneficiaries (Geneletti and Zardo, 2016).

The evaluation of the EU adaptation strategy (EC, 2018b) draws attention to the need to carry out social vulnerability assessments, identify vulnerable groups and involve them in the design of fair adaptation policies at all governance levels, with particular emphasis on cities. In addition, the European Green Deal (EC, 2019c) is based on the principle of socially just transition, and socially just adaptation is needed to complement just mitigation efforts and avoid leaving anyone behind.

The groups most vulnerable to extreme weather events consistently emerge from research and practice as the elderly, children, those suffering from health problems or living with disabilities, and groups of lower socio-economic status (EEA, 2018a, 2020c; Figure 6.3). Examples of social vulnerability assessment and mapping exist across Europe and could be replicated (Box 6.17).

Figure 6.3 **Vulnerable groups identified as affected by climate- and weather-related hazards by representatives of European cities**



Note: The same group could be identified in relation to multiple climate- and weather-related hazards. Based on reporting of 98 cities from 22 EEA member and collaborating countries to CDP.

Source: Authors' compilation based on analysis of CDP (2019) database.

Whilst social vulnerability tends to be considered in general vulnerability assessments, consideration of vulnerable groups in participatory approaches is deficient, and implications for vulnerable groups are rarely considered in monitoring of adaptation outcomes (Reckien, 2019; Figure 6.4). Therefore, more attention must be paid to the equity aspects of adaptation. There already exist good examples of cities acting in this direction. For example, in Lisbon, the Municipal Civil Protection Service (SMPC) has developed several emergency-planning instruments. The SMPC activates a contingency plan for homeless people whenever alert levels are recorded, which is implemented by the social care department of the municipality to support the most vulnerable population (EGCA, 2018).

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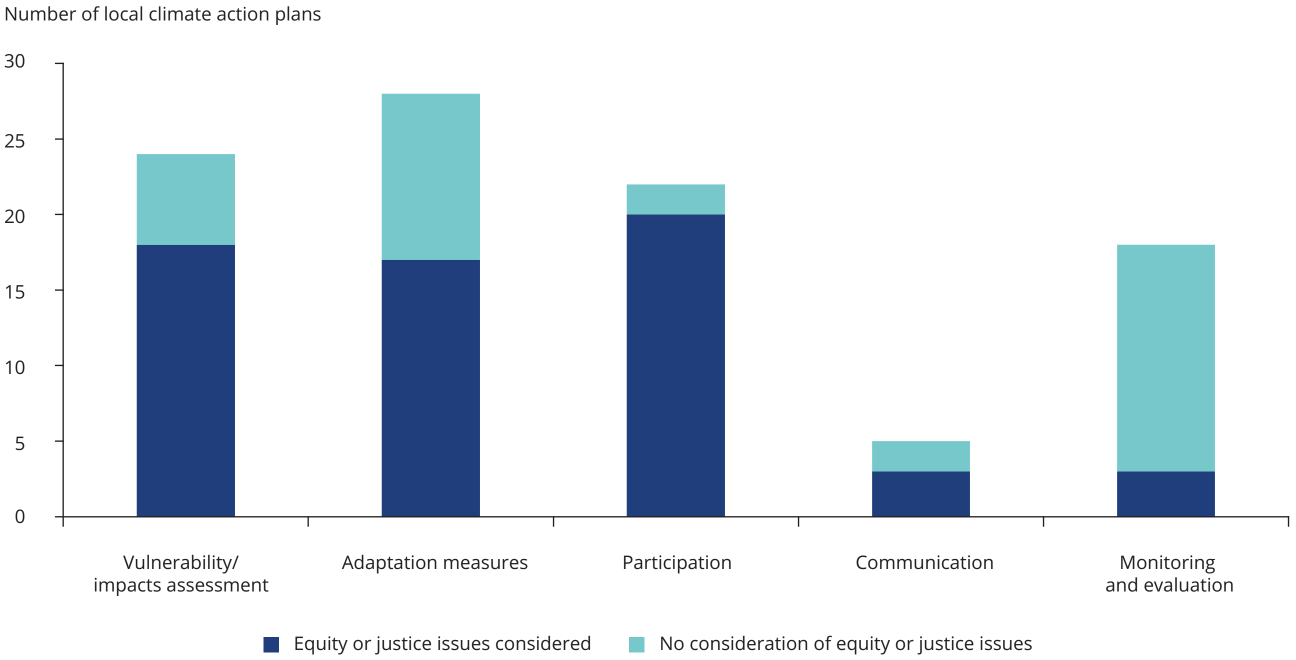
(95) https://resourcecentre.c40.org/resources/interaction-between-adaptation-and-mitigation-actions

Figure 6.4 **Consideration of vulnerable groups in local climate action plans**



Note: Based on an analysis of the contents of 28 local adaptation plans in six European countries.

Source: Reproduced from Reckien (2019).

Actions targeting vulnerable groups involve housing renovation to improve the thermal comfort, quality of life and health of the residents, including the elderly, the sick or those with lower incomes (Box 6.18; see also Box 3.4). The distribution of urban hospitals and schools with reference to UHI intensity and their location within floodplains (Boxes 2.5 and 2.6) identifies these facilities as urgent subjects for equity-focused adaptation actions. For example, three school playgrounds in Madrid have been adapted to high temperatures in pilot projects within Madrid + Natural — a public urban resilience initiative implementing nature-based solutions for climate change adaptation. Green infrastructure was used to create cool, shaded spaces. Additional benefits of the schoolyard renovations include promoting healthy habits, social integration (City of Madrid, 2019).

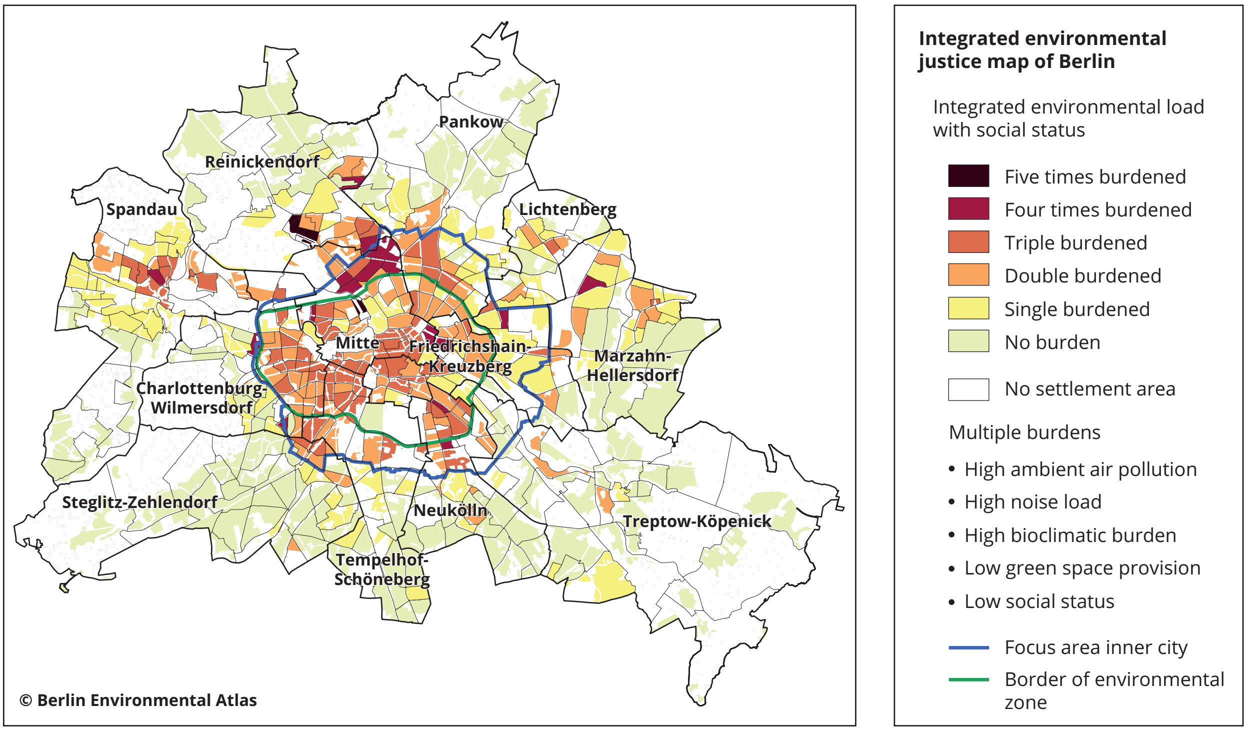
Very little is known about the effectiveness of adaptive actions in general (owing to low levels of monitoring and evaluation, and little scientific knowledge on the subject; see Chapter 3), and the distributional impacts of adaptive actions on various social groups are rarely considered. Who benefits most from adaptation requires more attention in adaptation planning, implementation and monitoring, particularly in the context of investment in structural defences, where public spending tends to be guided by cost-benefit analysis and may result in less protection for lower income groups. Furthermore, the housing market may drive lower-income groups into areas at risk of flooding through lower house prices in those areas. For example, in Rotterdam, Koks et al. (2015) find a higher proportion of low-income or single-parent households, young children, migrants and elderly people in non-embanked than embanked areas.

Finally, the affordability of adaptation measures for various groups is crucial. Property-level flood resilience measures are expensive and unaffordable for those on lower incomes (Bichard and Kazmierczak, 2012); this problem may also apply to flood insurance. Energy demand for cooling in poor-quality housing presents a conundrum in the context of the need for a just transition to a low-carbon economy. In nearly all European countries, households with the lowest incomes are less able to keep their homes cool during summer than the rest of the population (Eurostat, 2016a), with particularly high proportions of the poorest households lacking adequate cooling/heating facilities at home in Romania, Albania and Portugal (Eurofound, 2020). This raises the question of how to secure thermal comfort during increasingly hot summers without compromising the goal of greenhouse gas emissions reduction.

Box 6.17 Social vulnerability assessments allowing targeted actions at the local level

The **Berlin environmental justice index** combines neighbourhood level environmental information (levels of noise, air pollution, exposure to high temperatures, availability of green areas) with socio-economic aspects (unemployment rates, population receiving social benefits and child poverty). The index is presented spatially (Map 6.2) and is used to inform the allocation of funding for environmental improvements in neighbourhoods with the highest accumulation of environmental problems and social disadvantage (SenStadtWohn, 2015).

Map 6.2 Berlin Environmental Justice Atlas, 'Integrated environmental load including social problems'



Supporting climate-vulnerable population groups is an overarching goal of the climate adaptation strategy of the city of **Athens**. The strategy considers socio-economic and demographic aspects in assessing the impacts of climate change. For example, it assesses the adequacy of the networks of public cooling centres and public drinking water spots by overlaying them with maps of low-income households and areas with high proportion of the elderly (personal communication from Ioanna Tsalakanidou, Ministry of Environment & Energy, Greece, 2018).

In collaboration with local authorities in **Trnava** and **Košice** (Slovakia), the Carpathian Development Institute assessed the residential areas' vulnerability to high temperatures, considering the presence of older people and children and the location of facilities catering for these groups. Based on the results, adaptation strategies are being implemented in vulnerable locations, including provision of trees for shading, construction and restoration of water features and actions aiming at behaviour change (Climate-ADAPT, 2018d).

Vulnerability to high temperatures has been mapped for **Helsinki Metropolitan Region** in Finland (Kazmierczak et al., 2015) and in **Botkyrka**, Sweden (EEA, 2018a), indicating that the risk of heatwaves is also considered in adaptation planning in the Nordic countries.

Source: http://www.stadtentwicklung.berlin.de/umwelt/umweltatlas/ek901.htm

Box 6.18 Participatory adaptation of a lower income residential district in Dresden, Germany

Temperatures rising due to climate change are becoming a problem in dense urban settings, such as in high-rise building complexes made from prefabricated concrete slabs, which are present in many countries and concentrated in central and eastern Europe. In their original condition from the 1970s-1980s, the apartment blocks overheat easily on hot days. They often accommodate lower-income residents.

HeatResilientCity (2017-2020) is an interdisciplinary project aimed at developing resident-oriented heat adaptation strategies by highlighting interlinked social and climate factors. The project tests behavioural and physical adaptation measures in trial districts (Dresden-Gorbitz and Erfurt Oststadt) and is funded by the German Federal Ministry of Education and Research. It adopts an inclusive approach, bringing together representatives of the city authorities, a housing cooperative, residents and experts. This ensures that adaptation is conducted in a resident-oriented manner, which substantially increases the acceptance of proposed adaptation measures.

The project follows a 'living laboratory' approach and collects information on heat adaptation measures through thermal building simulations, expert and participatory workshops, and resident surveys, which will direct the implementation of measures. According to face-to-face surveys, three-quarters of interviewees considered sun protection on housing exteriors, such as jalousies and roller shutters as the most effective measure against heat stress. Other preferred measures for individual flats were curtains and planting of trees in front of the building. Regarding adaptation measures in the broader urban environment, around 80 % of respondents perceived shaded seating areas as useful. Air-conditioned public transport, shaded stations and bus stops, and greening streets were also largely rated as beneficial.

In 2019, the housing association Eisenbahner-Wohnungsbaugenossenschaft Dresden upgraded three 1980s apartment blocks. Based on the survey results, the following measures were implemented:

- external shutters and new windows;
- roof insulation;
- improved night ventilation by increasing the exhaust capacity in bathrooms.

Post implementation assessment found that while the individual measures had little effect on heat stress, they had a considerable effect when combined. Moreover, the behaviour of residents was found to be a key factor in regulating heat stress, as use of shading and night ventilation were shown to substantially reduce temperatures.

Residential buildings before (2018) and after renovation (2019) © S. Kunze, HTW Dresden

Sources: Personal communication from Janneke Westermann, Leibniz-Institut für ökologische Raumentwicklung (IÖR), 2019; Ortlepp and Schiela (2019); Baldin and Sinning (2019).

6.6 Towards well-adapted cities and towns: conclusions and outlook

6.6.1 Achieving better knowledge

Local decision-makers' understanding of the climate risks that the area under their jurisdiction is likely to face in the future is a prerequisite for initiating adaptation activities. While substantial steps have been made at the EU and national levels to provide climate services, there is still the need for knowledge in this area that is easy to understand and apply. The EU mission on adaptation to climate change including societal transformation (EC, 2020b) aims to foster better understanding of the exposure to climate risks. In addition, the continued maintenance and enhancement of the Climate-ADAPT platform offers the opportunity to improve access to knowledge. In particular, the ongoing development of the interface allowing non-experts to obtain climatic data from Copernicus Climate Data Store in a user-friendly manner can address the current knowledge gaps among local decision-makers on certain climate hazards.

To accurately assess the level of climate risks and potential future impacts, it is necessary to account for the currently existing adaptation and prevention measures. The development of a robust European data set of river and coastal flood defences, and areas protected by them, would facilitate understanding of the risks and enable monitoring of the proportion of the population or extent of land at risk from flooding.

A key necessary knowledge development pertains to the effectiveness and cost-efficiency of adaptation measures, which would complement the existing information collated within the RESIN library of adaptation options and on Climate-ADAPT.

The success of the Covenant of Mayors — Europe Office's communications and the training academies for local politicians in national languages under the EU urban agenda emphasises the importance of availability of information on adaptation in languages other than English. Especially in the case of small local authorities, or in locations where English is less commonly spoken, knowledge and guidance in national languages are key for progressing the adaptation agenda. This stresses the importance of national knowledge portals, climate services and training on adaptation to local authorities, and suggests a merit in translating the offers by European and international initiatives such as the Covenant of Mayors.

The European Commission's ongoing efforts to open up insurance data to municipalities for adaptation planning (e.g. under the EU urban agenda, see Box 4.1), could be complemented by striving towards national-level agreements on access to insurance data (EC, 2018e), such as exist in Denmark and Norway.

At the local level, the main opportunities for local authorities to expand their knowledge base are to make use of national and EU resources on adaptation and to engage with national and international city networks and initiatives (see Chapter 4).

Further efforts to facilitate the use of citizen science in adaptation and collaboration with local research institutes (e.g. through student placements and researcher secondments) are encouraged to develop the local knowledge on climate risks and effectiveness of adaptation measures.

6.6.2 Funding local adaptation

A quarter of the EU budget is focused on climate action. However, adaptation spending tends to be deprioritised in favour of mitigation, so explicit adaptation spending targets and transparency are needed to avoid its marginalisation. A need for clear separation between budget tracking for adaptation and mitigation spending in the EU budget has been expressed (FEPS and IEEP, 2020).

At the national level, specific adaptation funding programmes can be a source of continuous adaptation finance in addition to time-limited projects. Enabling local authorities to raise revenues for adaptation (e.g. through rainwater fees or property taxes) could help to boost adaptation budgets.

Local authorities' ability to access the funds and identify co-funding needs strengthening. The technical expertise offered to access the European Regional Development Fund (ERDF) and LIFE funds (see for example Box 4.6) is invaluable, especially for local authorities less experienced in obtaining EU funds. The secretariats of different programmes (e.g. Interreg) at the national and regional levels could support the technical aspects of applications to a greater extent. There is a need for specific funding streams catering for small municipalities, from which relatively small amounts of funding could be obtained with less administrative effort than required for larger applications.

Locally, developing schemes that either help to fund adaptation measures (e.g. through crowdfunding or donations, see Box 6.9) or partially shift responsibility for their implementation and maintenance to property owners (e.g. rainwater-harvesting systems, see Box 3.9) can be explored as quick wins.

More knowledge and experience of the use of sustainable finance mechanisms in adaptation at the local level are needed. There are a few examples of its use in Europe, but more comprehensive overview and guidance could help to boost its use.

6.6.3 *Adaptation as part of sustainable development*

As the physical shape of cities strongly affects how climate hazards translate into impacts on assets and society, there is a need for actions preventing unsustainable development into risk-prone areas, and encouraging incorporation of adaptation principles into urban planning and design (EC, 2018d).

The EU policies emerging in 2020 under the European Green Deal (EC, 2019c) offer opportunities for mainstreaming adaptation into the redevelopment and planning of cities. For example, the renovation wave can help to include resilience to climate impacts, alongside energy saving, in the refurbishment of public buildings. The EU biodiversity strategy (EC, 2020d) aims to plant 3 billion trees across Europe, with a focus on greening cities, which supports adaptation to climate change.

The new adaptation strategy could strengthen links with mitigation efforts under the governance of the energy union by emphasising the need for concerted climate action, stressing the co-benefits and highlighting the potential trade-offs that pertain to the local governance level. This is also likely to be encouraged by the activities planned under the EU mission on climate-neutral and smart cities (EC, 2020a). As highlighted in the evaluation of the EU adaptation strategy (EC, 2018f), there is an opportunity for a stronger focus on vulnerable groups in the revised version (e.g. guidance on their identification) as well as more links between adaptation and health. In addition, emphasising the links between economic performance (growth, job creation) and adaptive policy and actions is necessary to make a business case for adaptation at the local level.

The EU reporting on the Sustainable Development Goals does not currently contain indicators directly related to adaptive actions of cities. 'Population covered by the Covenant of Mayors for Climate and Energy signatories' was put on hold because of data problems detected in 2019 (Eurostat, 2019). However, if this indicator were reinstated, it could explicitly cover the population of signatories committed to adaptation actions, alongside the signatories with mitigation commitments, to emphasise the importance of adaptation.

The advancement of the EU urban agenda presents an opportunity to link adaptation to other policy areas in the urban context, for example through the development of links between the actions of the Climate Adaptation Partnership, and those of other partnerships — particularly those concerned with sustainable land use, housing or air quality, with which co-benefits can be explored. Other city-focused European Commission initiatives also offer opportunities to promote adaptation under the sustainability agenda. For example, the European Green Capital Award (EGCA) and European Green Leaf Award (EGLA) schemes help foster a culture of sustainable governance extending beyond the regulation of conventional environmental problems (Gudmundsson, 2015) through, for example, promoting good practice. Therefore, emphasising adaptation efforts as one of the key criteria in EGCA and EGLA can help to spread the message of its importance in local sustainability.

National or regional policies lend themselves to greater consideration of social equity in adaptation-related areas, such as flood risk management, insurance against natural hazards, or social care and health. There needs to be appropriate consideration of potential climate impacts on major projects or programmes and of alternative options, including green infrastructure (EC, 2018c).

Locally, engagement of departments beyond environment and spatial planning in adaptation planning and implementation can help to create links to other policy agendas. Similarly, the involvement of stakeholders concerned with mitigation, social care or economic development, as well as citizen engagement, can lead to the discovery of synergies with other actions and secure additional buy-in. Integration of socio-economic data sets into adaptation planning at all levels is likely to help in addressing social vulnerability to climate-related health impacts (Group of Chief Scientific Advisors, 2020). Last but not least, close monitoring of the adaptation outputs, outcomes and impacts is necessary not only to assess the effectiveness and cost-efficiency of the measures, but also to identify and quantify the co-benefits they provide.

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Abbreviations

AIBA	Italian Association of Insurance Brokers
ALEA	Alba Local Energy Agency
APS	Portuguese Insurance Association
ATES	Aquifer thermal energy storage
BCR	Benefit-to-cost ratio
C3S	Copernicus Climate Change Service
CARO	Climate action regional office
CAT bond	Catastrophe bond
CDP	Carbon Disclosure Project (formerly)
CEMR	Council of European Municipalities and Regions
CENIA	Czech Environmental Information Agency
CIRAC	Flood and risk maps in climate change scenarios
CLIMCITIES	Climate change adaptation in small and medium size cities
CMCC	Euro-Mediterranean Centre on Climate Change
CMIP5	Coupled Model Intercomparison Project Phase 5
CSI	City Science Initiative
DCE-AU	Danish Centre for Environment and Energy, Aarhus University
DELIVER	Developing resilient, low-carbon and more liveable urban residential area
DERRIS	Disaster risk reduction insurance
DG	Directorate General
DKK	Danish krone
DRR	Disaster risk reduction
DSI-12	12-month scale Drought Severity Index
EASME	Executive Agency for Small and medium-sized Enterprises

EBRD	European Bank for Reconstruction and Development
EEA	European Environment Agency
EFAS	European Flood Awareness System
EFFIS	European Forest Fires Information System
EGCA	European Green Capital Award
EGLA	European Green Leaf Award
EIAH	European Investment Advisory Hub
EIB	European Investment Bank
EPA	Environmental Protection Agency
ERDF	European Regional Development Fund
ESG	Environment Social Governance
ETC/CCA	European Topic Centre on Climate Change Impacts, Vulnerability and Adaptation
ETC/ULS	European Topic Centre on Urban, Land and Soil Systems
EUR	Euro
Eurostat	Statistical Office of the European Union
EV	Electric vehicle
FOEN	Federal Office for the Environment, Switzerland
GBP	Pound sterling
GCA	Global Commission on Adaptation
GDP	Gross domestic product
GDPR	General Data Protection Regulation
GHG	Greenhouse gas
GoingVis	Governance by integrative visions
GRCN	Global Resilient Cities Network

GRFU	Green Fund, Greece
H2020	Horizon 2020 framework programme
ICLEI	International Council for Local Environmental Initiatives
Ignition	Innovative financing and delivery of natural climate solutions
IPCC	Intergovernmental Panel on Climate Change
IT	Information technology
JRC	Joint Research Centre
KOBiZE	National Centre for Emissions Management, Institute of Environmental Protection — National Research Institute, Poland
MFF	Multiannual financial framework
MMR	European Union Greenhouse Gas Monitoring Mechanism Regulation
NAGiS	NAGiS - National Adaptation Geo-information System
NAP	National adaptation plan
NAS	National adaptation strategy
NCFF	Natural Capital Finance Facility
NDC	Nationally determined contribution
NECP	National Energy and Climate Plan
NGO	Non-governmental organisation
NOK	Norwegian krone
NTNU	Norwegian University of Science and Technology
NUTS	Nomenclature des unités territoriales statistiques
OSM	Open Street Map
PET	Physiological equivalent temperature
PLN	Polish zloty
PM	Particulate matter
PMAAC-AML	Lisbon metropolitan area climate change adaptation plan
PTSD	Post-traumatic stress disorder
Q10	10-year high river flow
RBCF	Results-based climate financing

RCP	Representative concentration pathway
RESILIO	Resilience network of smart innovative climate-adaptive rooftops
RESIN	Climate resilient cities and infrastructures
SDG	Sustainable Development Goal
SEA	Strategic environmental assessment
SECAP	Sustainable energy and climate action plan
SIB	Social impact bond
SMEs	Small and medium-sized enterprises
SMPC	Municipal Civil Protection Service
SUDS	Sustainable urban drainage system
SYKE	Finnish Environment Institute
TIF	Tax increment financing
UHI	Urban heat island
UIA	Urban Innovative Actions
UMZ	Urban morphological zone
UN	United Nations
UNDRR	United Nations Office for Disaster Risk Reduction
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
VITO	Flemish Institute for Technological Research
WBGT	Wet-bulb globe temperature
WEI+	Water Exploitation Index+
WENR	Wageningen Environmental Research
WFD	Water Framework Directive
WSUD	Water-sensitive urban design
WUI	Wildland-urban interface
WWF	World Wide Fund for Nature

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Annex 1

List of case studies in the report

Annex 2

Glossary

Adaptation to climate change is the process of adjusting to actual or expected changes in the climate and its effects. In human systems (e.g. urban areas), adaptation seeks to moderate or avoid harm or exploit beneficial opportunities (IPCC, 2014a).

Adaptation actions are measures considered for implementation. Adaptation action comprises protection against negative impacts of climate change, but also creating resilience, reducing vulnerability to both current and future variation in climate, and taking advantage of consequences of climatic events. There are various types of adaptation action, including anticipatory, autonomous and planned adaptation. They can be clustered in four main types:

- **Green adaptation actions** make use of nature. Examples include introducing new crop and tree varieties, allowing room for rivers to flood naturally onto floodplains and restoring wetlands.
- **Grey adaptation actions** use artificial infrastructure to reduce vulnerability to climate change and create resilience. Examples include building dykes and restoring beaches to prevent coastal erosion.
- **Soft adaptation actions** are managerial, legal and policy approaches that alter human behaviour and styles of governance. Examples include early warning systems and insurance against damage from natural disasters.
- **Combined actions** use all of the above three types. The best results often come from combining actions. For example, a combination of green and grey actions, or grey and soft actions, can address flood risk in a particular area (EEA, 2013, 2014).

Adaptation options are the array of strategies and measures that are available and appropriate for addressing the circumstances requiring action to ensure the safety of populations and security of assets in response to climate impacts. They include a wide range of actions that can be categorised as structural, institutional or social (IPCC, 2014a).

Adaptive capacity is the ability of systems (e.g. a city), institutions and other organisations to adjust to potential damage, to take advantage of opportunities or to respond to consequences (IPCC, 2014a).

Capacity building is the practice of enhancing the strengths and attributes of, and resources available to, an individual, community, society or organisation to respond to change (IPCC, 2014a).

City has no uniform definition across EU Member States. Each country has its own definition based on population size, density, functions and/or historic factors. The Organisation for Economic Co-operation and Development and the European Commission have provided a harmonised definition of cities for statistical purposes based on population density, population size and population distribution. Cities are defined as densely populated areas with at least 50 % of inhabitants living in the urban centre, where there is a population density of at least 1 500 inhabitants per km2 and a minimum population of 50 000 (Dijkstra and Poelman, 2012).

Climate in a narrow sense is usually defined as the average weather or, more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization. The relevant quantities are most often surface variables such as temperature, precipitation and wind. Climate in a wider sense is the state, including a statistical description, of the climate system (IPCC, 2014a).

Climate scenarios are plausible and often simplified representations of the future climate, based on an internally consistent set of climatological relationships that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models. Climate projections often serve as the raw material for constructing climate scenarios, but climate scenarios usually require additional information such as the observed current climate (IPCC, 2014a).

Climate change refers to a change in the state of the climate that can be identified (e.g. by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forces such as modulations of the solar cycles, volcanic eruptions, and persistent anthropogenic changes in the composition of the atmosphere or in land use. The United Nations Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.' The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition and climate variability attributable to natural causes (IPCC, 2014a).

Climate services the transformation of climate-related data — together with other relevant information — into customised products such as projections, forecasts, information, trends, economic analysis, assessments (including technology assessment), counselling on best practices, development and evaluation of solutions and any other service in relation to climate that may be of use for the society at large (EC, 2015a, p.10)

Co-benefits are the positive effects that a policy or measure with one objective might have on other objectives, irrespective of the net effect on overall social welfare. Co-benefits are often subject to uncertainty and depend on local circumstances and implementation practices, among other factors. Another name for them is ancillary benefits (IPCC, 2014a).

Cost-efficiency is the ratio of the monetary benefits to the monetary cost.

District cooling, a system that produces and disseminates chilled water via insulated pipes to all buildings located in a district, is a method of increasing thermal comfort in houses and public buildings.

Ecosystem-based adaptation is the use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people to adapt to the adverse effects of climate change. As one of the possible elements of an overall adaptation strategy, ecosystem-based adaptation uses the sustainable management, conservation and restoration of ecosystems to provide services that enable people to adapt to the impacts of climate change. It aims to maintain and increase the resilience and reduce the vulnerability of ecosystems and people in the face of the adverse effects of climate change (IUCN, 2017).

The **effectiveness** of adaptation options is their capacity to reduce the impacts of a given climate hazard.

Exposure is the presence of people, livelihoods, species or ecosystems, environmental functions, services, resources, infrastructure, or economic, social or cultural assets in places and settings that could be adversely affected (IPCC, 2014a).

An **extreme weather event** is an event that is rare at a particular place and time of year. Definitions of 'rare' vary, but an extreme weather event would normally have a 10 % or less probability of occurring. By definition, what weather counts as extreme varies from place to place. When a pattern of extreme weather persists for some time, such as a season, one may class it as an extreme climate event, especially if its average or total is itself extreme (e.g. drought or heavy rainfall over a season) (IPCC, 2014a).

The potential **floodplain** captures the area that could be flooded during a flood event with a return period of one in 100 years, as well as the river area. If flood defence structures are present, the floodplain is reduced to the flood hazard area inside those structures. For the purpose of this report, the flood hazard area is not accounted for, as data are not available. The potential floodplain area was derived by adding two spatial layers: Joint Research Centre (JRC) flood hazard map for Europe 100-year return period (JRC, 2016), based on LISFLOOD model results (Burek et al., 2013); and Copernicus Potential Riparian Zone layer from the data set Delineation of Riparian Zone (see EEA, 2019c)

Governance is the way in which government hierarchies and structures are organised to allocate resources, and to exercise control and coordination (Rhodes, 1996). Modern governance systems are thus not centralised, vertical 'command and control' but consist of dispersed networks across multiple centres of authority (Hooghe and Marks, 2003). Coordination needs to be both vertical and horizontal.

Green infrastructure is a 'strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services' (EC, 2013b). The European Commission's definition emphasises the ecosystem services provided, and the purposeful land designation and management, made with the aim of delivering a range of environmental benefits, including maintaining and improving ecological functions. 'Smart' conservation addresses impacts of urban sprawl and fragmentation, builds connectivity in ecological networks and promotes green spaces in the urban environment (including through adaptation and retrofitting) (EEA, 2015a).

Grey infrastructure means construction measures such as buildings, technical and transport infrastructure, dykes and other technical protection using engineering (EEA, 2012).

A **hazard** is the potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources (IPCC, 2014a).

Impacts are effects on natural and human systems (lives, livelihoods, health, ecosystems, economies, societies, cultures, services and infrastructure, etc.) due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system (IPCC, 2014a).

Implementation is defined as putting a public adaptation policy into effect — converting adaptation options into action. Once policymakers decide on, formulate and adopt an adaptation policy, then it is implemented, i.e. activities identified in the policy document are translated into concrete actions (EEA, 2020d).

Knowledge co-creation relates to adaptation actions and policy solutions that are based on a reciprocal exchange of knowledge, approaches and experiences, involving a broad range of stakeholders in mutual learning and knowledge generation.

Mainstreaming is the integration of climate change adaptation into related government policies in different sectors.

Maladaptation or maladaptive actions may lead to increased risk of adverse climate-related outcomes, increased vulnerability to climate change or diminished welfare, now or in the future (IPCC, 2014a).

Mitigation (of climate change) is a human intervention to reduce the sources of GHGs or trap more of them in sinks (IPCC, 2014a).

Monitoring is a continuous process of examining progress made in planning and implementing climate adaptation. This might also include monitoring the context and environment within which adaptation occurs, or drivers that shape resilience and vulnerability. The objective of monitoring is to keep track of progress made in implementing an adaptation intervention by using systematic collection of data on specified indicators and reviewing the measure in relation to its objectives and inputs, including financial resources (EEA, 2015b).

Multi-level governance, in the context of this report, means non-hierarchical forms of policymaking, involving public authorities as well as private actors, who operate at different territorial levels and acknowledge their interdependence (EEA, 2012).

A **national adaptation plan (NAP)** is a national document that articulates how a country's national adaptation strategy is to be implemented. In most cases, the NAP outlines a strategic planning process for implementing adaptation. It provides information on the goal of the adaptation measures and the next steps needed, assigns responsibilities, identifies those involved, time-frame and deadlines, etc. (EEA, 2014).

A **national adaptation strategy (NAS)** is a national document that articulates a national strategic vision with regard to adaptation in order to prepare the country for current and expected impacts of climate change. A NAS mostly summarises climate-related risks and vulnerabilities, and identifies various stakeholders and sectors as areas for action (EEA, 2020d).

Nature-based solutions to societal challenges are solutions that are inspired and supported by nature, are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions (EC, 2015b).

Nationally determined contributions (NDCs) under the Paris Agreement embody efforts by each country to reduce national emissions and adapt to the impacts of climate change. The Paris Agreement (Article 4, paragraph 2) requires each Party to prepare, communicate and maintain successive NDCs that it intends to achieve. Parties shall pursue domestic mitigation measures, with the aim of achieving the objectives of such contributions (UNFCCC, 2020).

A **percentile** is one of the 100 equal groups into which a population can be divided according to the distribution of values of a particular variable. In climate science, percentiles are often used in relation to a probability of a given scenario (low percentile, low likelihood; high percentile, high likelihood) or to describe a level of impact (low percentile, low impact; high percentile, high impact).

Planning adaptation comprises the identification, assessment and selection of adaptation options, often based on vulnerability assessments and adaptation strategies (EEA, 2016).

Regions are considered herein to be subnational administrative units. They can have different names, dimensions and degrees of relevance for local activities, depending on the specific national administrative and governance settings.

Representative concentration pathways (RCPs) describe four different 21st-century pathways of GHG emissions and atmospheric concentrations, air pollutant emissions and land use, which are based on population size, economic activity, lifestyle, energy use, land use patterns, technology and climate policy. The RCPs represent the range of GHG emissions in the wider literature well; they include a stringent mitigation scenario (RCP 2.6), two intermediate scenarios (RCP 4.5 and RCP 6.0) and one scenario with very high GHG emissions (RCP 8.5) (IPCC, 2014d).

Resilience is the capacity of social, economic and environmental systems to cope with a hazardous event or trend, responding or reorganising in ways that maintain their essential function, identity and structure, while also maintaining the capacity for adaptation, learning and transformation (IPCC, 2014a).

Risk is the potential for consequences where something of value is at stake and where the outcome is uncertain, recognising the diversity of values. A common representation of risk is the probability of the occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk results from the interaction of vulnerability, exposure and hazard (IPCC, 2014a).

Risk assessment is the qualitative or quantitative scientific estimation of risks. In the context of climate change it includes the use of climate scenarios to assess the projected climate change impacts to a system; the estimation of the probability of these impacts; and then the final estimation of the climate risk to this system (EEA, 2014; IPCC, 2014a).

Thermal cooling is a technology that uses thermally driven chillers. Solar thermal energy is harnessed to cool down gases or fluids that run through cooling systems in houses, commercial and public buildings, and business buildings. The sun supplies thermal energy at the same time as cooling is demanded. Ideally, the same system also provides hot water and space heating.

Uncertainty is a state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from imprecision in the data to ambiguously defined concepts or terminology, or uncertain projections of human behaviour (IPCC, 2014a).

Urban is used in this report as a generic term to fit with the definitions of cities and towns (see above).

Urban Audit is a project for statistical monitoring of major European cities, ongoing since 2003 at the initiative, and with the financial support, of the European Commission and Eurostat. Urban Audit aims to collect a large amount of demographic, social, economic and environmental statistics on cities and their functional urban areas (as defined by the European Commission), to provide reliable and internationally comparable information on cities for the purposes of regional and urban planning, prosperity and sustainable development. Urban Audit covers 1 007 cities (as of May 2020).

An **urban morphological zone** (UMZ) can be defined as a set of urban areas less than 200 m apart. Those urban areas are defined with land cover classes contributing to the urban tissue and function. The UMZ approximates the 'real' city form, which often does not correspond to the administrative delineation). UMZs 2012 are derived from the Copernicus Urban Atlas 2012.

The **Water Exploitation Index+** (WEI+) provides a measure of the total water use as a percentage of the renewable freshwater resources for a given territory and timescale (EEA, 2018c).

Wildland-urban interfaces can be defined as landscapes where anthropogenic urban land use and forest fuel mass come into contact (Modugno et al., 2016).

Vulnerability has a variety of definitions. In the context of this report, vulnerability is the propensity or predisposition to be adversely affected owing to a combination of and capacity to cope and adapt (IPCC, 2014a).

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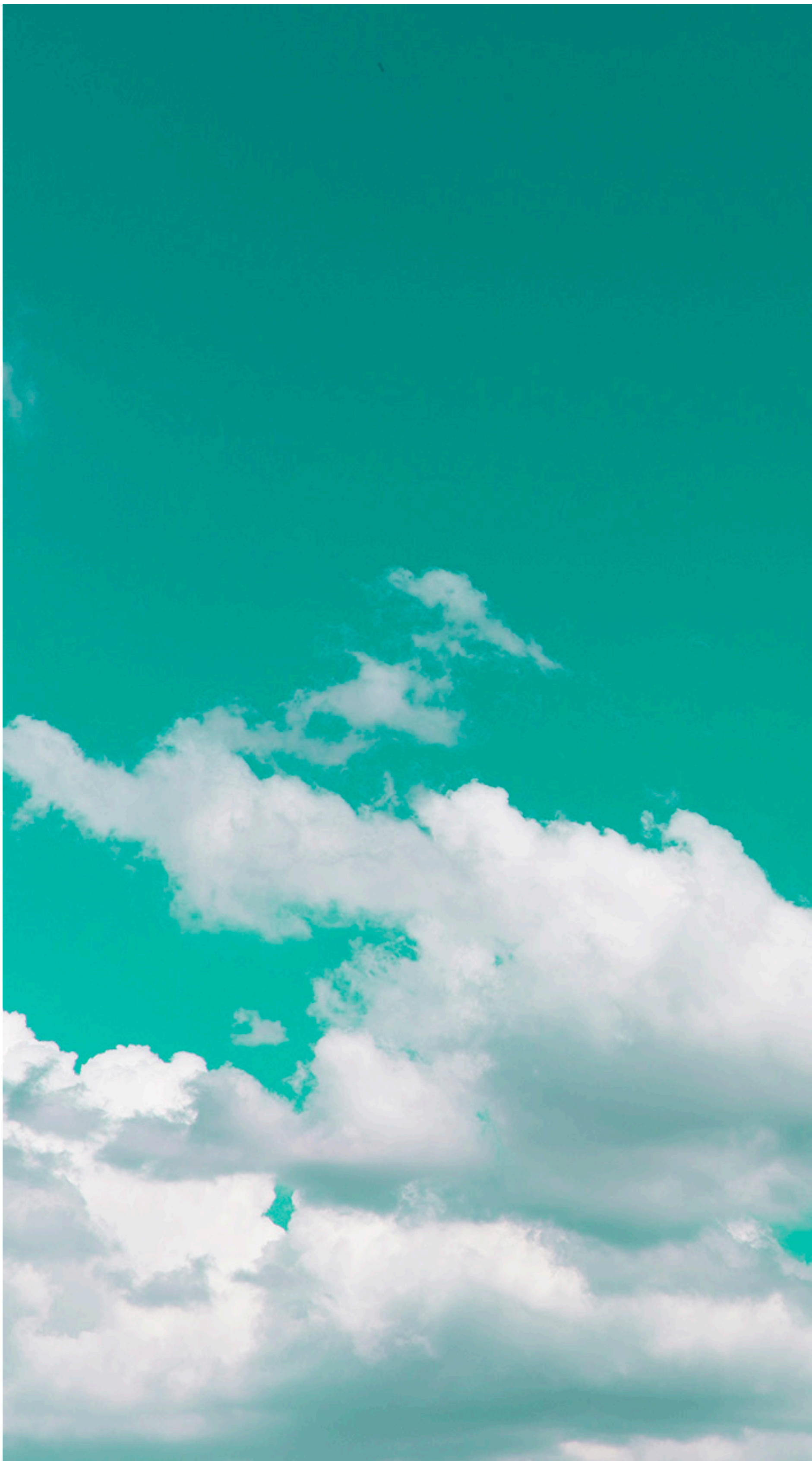

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