European Commission

Appendix 1: Literature review on impacts, risks and vulnerabilities

Adaptation Strategies for European Cities: Final Report

This is part of the Final Report of the project "Adaptation Strategies for European Cities" which has been compiled by Ricardo-AEA for the European Commission Directorate General Climate Action

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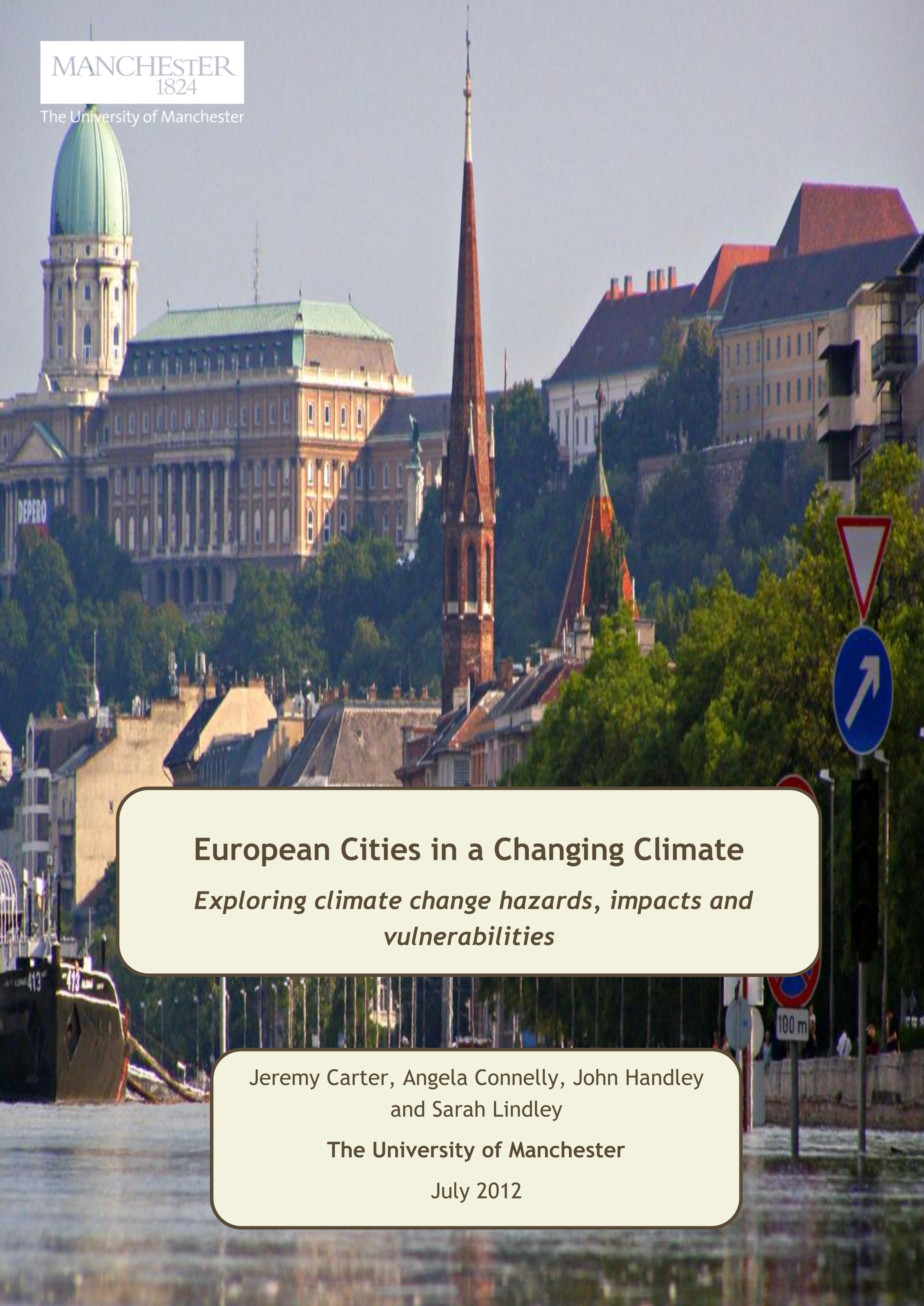

The University of Manchester

European Cities in a Changing Climate

Exploring climate change hazards, impacts and vulnerabilities

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BUDAPEST, HUNGARY, 2010 Floods

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Executive Summary

The significance of European cities

European cities are the major population centres of the continent. They are significant drivers of economic growth and innovation. They are cultural and creative hubs. The particular characteristics of European urban life bring benefits to city inhabitants. In doing so, cities have to cope with a number of challenges to sustaining and enhancing quality of life. Climate change is emerging as one of the most prominent of these. Climate change stands as a major challenge to achieving a vision centred on a secure and prosperous future for European cities.

The adaptation imperative

Taking a precautionary approach, the European Union seeks to reduce greenhouse gas emissions so as to limit the increase of global mean temperatures to no more than 2°C above pre-industrial levels (Alcamo and Olesen 2012). However, given the difficulties of addressing cumulative emissions in a timely manner, climate scientists now suggest that global mean temperatures are climbing towards 4°C above pre-industrial levels and may go beyond that level, potentially as soon as the 2060s (Betts et al 2011). Significant temperature and sea level rises are already being observed, and are found to be accelerating (Rahmstorf et al 2007), raising the threat of dangerous 'tipping points' in the global climate system being breached (Lenton et al 2008). The development of adaptation responses to this unfolding set of climate challenges appears to be essential.

Defining a city

When looking to advance the adaptation agenda in cities, particular attention must be paid to how we define a city. City definitions are important as they influence issues including how we understand the particular characteristics of cities that render them vulnerable to the changing climate. In addition, the boundaries placed around cities, particularly from an administrative perspective, set the context for both understanding the climate change hazards they may face and the scope of adaptation responses city governors can drive forwards. Some degree of standardisation and precision over how a city is defined would provide a stronger framework for climate change risk assessment and adaptation planning in European cities.

A conceptual framework

A number of conceptual frameworks exist that have been designed specifically to support adaptation planning and risk assessment. These generally cover similar issues linked to the assessment of risk, including climate change hazard, vulnerability and adaptive capacity. Clarifying understanding on adaptation issues by utilising a conceptual framework can support adaptation planning.

Within this report we focus on the framework developed as part of the Urban Climate Change Research Network (Mehrotra et al 2009, Rosenzweig et al 2011).

Following this framework, the level risk and associated negative impacts of climate change in cities (e.g. harm to human health and wellbeing, disruption to infrastructure networks) is dependent on the extent of climate hazards, the level of vulnerability of different elements to the hazard, and their capacity to adapt. An assessment of climate change risk involves understanding each of these components. *Hazards* are the weather and climate events to which a city is exposed, for example floods and heat waves. This report sees the *vulnerability* of city residents, infrastructure and the built and natural environment as a state; that is their potential for harm regardless of whether or not they experience a climate change hazard. *Adaptive capacity* then refers to the ability of city governers, businesses and residents, and associated structures and systems, to prepare for and avoid potential harm from climate change hazards. This framework indicates that climate change risk will vary between and within cities, influenced by differences in hazard, vulnerability and adaptive capacity.

Climate change hazards, vulnerabilities and impacts

Based on available research, this report provides an overview of climate hazards, vulnerabilities and impacts, focusing on those that are particularly relevant to Europe's urban areas. We begin by discussing supra-national and national data. Stemming from the desk-based review, four hazards are selected; sea-level rise, storm surges and coastal flooding; flooding from rivers; high temperatures and heat waves; and water scarcity and drought. An overview of each of these hazards is provided looking at both European scale data and, where available, information at the city-scale. By understanding the hazards, we begin to make sense of issues linked to the vulnerability of cities to the changing climate.

This review establishes that, to date, city-scale data sets on key climate hazards facing individual European cities is generally lacking. Detailed city-scale hazard data is sporadic, and where it does exist for European cities it tends to be the product of either a research enquiry or a municipal planning process. The recent report of the European Environment Agency on urban adaptation to climate change does, however, represent a significant advance (EEA 2012). It is also clear that the nature and severity of projected climate change hazards and patterns of vulnerability to these hazards varies considerably across Europe. Despite this, Europe's cities generally have access to only high level information on the potential climate change hazards that they face. Data on socio-economic factors that influence vulnerability and adaptive capacity is more comprehensive at finer scales, from the city down to constituent districts for example, although this is generally not applied within adaptation planning. Improving understanding of these issues, and the relationships between them, is needed to support adaptation strategy making, planning and resource allocation, both at strategic scales (national and EU levels) and within individual cities.

A diversity of cities and adaptation challenges

An analysis of different types of European cities according to their position within distinct climate clusters raises several broad issues of note. For example, north-western Europe contains a significant proportion of Europe's principal metropolises and regional centres. Although climate change hazards are a major threat in this area, the capacity of cities to respond is relatively high due to factors such as potential availability of financial resources, consequently lowering associated risks. In contrast, similar cities in the Mediterranean and southern central Europe are more at risk due, in part, to their lower levels of adaptive capacity (ESPON Climate 2011). There is considerable spatial diversity across Europe concerning different types of cities and the potential risks they face from the changing climate. It is important to move beyond treating cities as a homogeneous group when considering strategies to advance the adaptation agenda. The findings of this analysis are of relevance to member states and for Europe more broadly. Cities are Europe's social, economic and cultural cornerstones. Additional pressure on cities from climate change, and the associated escalation of other urban problems such as social inequality and poor air quality, is an important policy issue.

Our cities will continue to evolve and develop, as they have done for millennia. Yet, adapting to the increasing pace of climate change poses a new challenge to European cities. Policy-makers and city inhabitants must now account for climate change in planning for their long-term future and that of subsequent generations. This will go some way to enhance the territorial and social cohesion agenda of the European Commission by helping to avoid further magnification of existing regional disparities. Adaptation planning can also help to protect and enhance the economic, social and cultural competitiveness of European cities into the 21st century.

1 Introduction and context

Cities in Europe are the continent's economic powerhouse; they can be attractive and provide a good quality of life for their citizens through good urban design, employment opportunities, access to services and ease of movement. In the face of risks to these factors from climate change we could 'do nothing'. However, following the precautionary principle, it is more prudent to anticipate and plan for that change by using and sharing research and knowledge to embed climate change adaptation into policies that safeguard Europe's future prosperity and quality of life for future generations. This report aims to build knowledge and awareness around issues linked to adaptation in European cities. The opening section frames the scope and purpose of the report, and provides an outline of how it builds upon existing research undertaken by numerous European agencies and institutes.

1.1 Report scope and purpose

The *Adaptation Strategies for European Cities* (ASEC) project is working to address the challenges linked to adapting to climate change in European cities. The core aim of the project is to provide capacity building and assistance for cities in developing and implementing adaptation strategies by raising awareness throughout Europe on the importance of preparing for climate change in cities, exchanging knowledge and good practice, and developing tools and guidance for cities on adaptation. This report has been undertaken to help meet the goals of the ASEC project.

Several objectives guide this report:

- To review and synthesise the most significant available data on climate change hazards, impacts and vulnerabilities in European cities.
- To help build the evidence base and conceptual framework for delivering the ASEC project.
- To support the development of a typology of European cities, to be developed within the ASEC project, which aims to differentiate cities according to climate change impacts and adaptation needs.

The scope of this report is defined by the following broad issues:

- *Topic focus:* Hazards, impacts, vulnerabilities linking to weather and climate in European cities.
- *Impact time horizon:* Current and potential future trends and patterns in weather and climate.

- *Scale:* City level, with cities considered in their broader regional, national and European context where finer scale data is not available.
- *Sources reviewed:* The emphasis is on publically available policy and research reports. Some academic journal papers are referenced particularly for the context setting and conceptual framework discussions.

The following key questions set a framework for this report:

- Can an appropriate conceptual framework be identified to support the process of understanding adaptation to climate change in European cities?
- What does available research indicate are the key hazards, and associated impacts, linked to climate change in European cities?
- What issues influence the vulnerability of European cities to impacts linked to climate change hazards?
- Do spatial patterns characterise climate change hazards, impacts and vulnerabilities in the context of European cities?

In addressing these questions, this report draws on peer learning and builds on existing initiatives. The following sources were considered for the review:

- International agencies and organisations (e.g. Intergovernmental Panel on Climate Change, Urban Climate Change Research Network).
- European agencies (e.g. EEA, DG Regional Policy).
- Research projects targeting climate change in Europe (e.g. ESPON, PESETA, ENSEMBLES).
- National scale reports addressing relevant cross cutting issues.
- Adaptation strategies developed by EU cities.

Annex 1 includes 20 one-page synopses of key reports that informed this analysis of climate change hazards, impacts and vulnerabilities in European cities. Looking beyond these reports, there is a wealth of existing research and knowledge on issues relevant to the task of better understanding climate change hazards, impacts and vulnerabilities in European cities. The challenge is to identify and draw out the most appropriate learning to advance this agenda. A key pillar of the EU *Adapting to Climate Change* White Paper is 'developing the knowledge base' to support adaptation planning (Commission of the European Communities 2009: 7 - 8). By building the knowledge base, capacity to adapt to climate change increases. In synthesising the current state of thinking on climate change hazards, impacts and vulnerabilities in EU cities, this report can help to advance broader goals such as those linked to the White Paper.

1.2 Situating this report in the context of existing studies

Research reports continue to build upon one another in the area of European climate change hazards, impacts and vulnerabilities by identifying gaps in knowledge or by incorporating the latest data and information. Many reports are either generic or focus on the implications of climate change for different sectors (e.g. critical infrastructure), environmental resources (e.g. water) or landscapes (e.g. mountain areas). Scientists are beginning to synthesise climate change data at the European scale, but there has been little attention specifically on cities. In terms of topic focus, mostly reports focus on either hazards or vulnerability and may look at adaptive capacity (terms which are explored in chapter 3 below), but do not attempt to integrate the three adaptation elements to advance understanding of climate change risk. A recent report from the Urban Climate Change Research Network does this at the city scale (Rosenzweig et al 2011), although the focus is not exclusively on Europe. While reports generally provide relevant background information, data to support cities in assessing and responding to climate change risks locally is limited. Existing reports at the European level emphasise the lack of city-scale data on issues linked to climate change adaptation. Although this report does not fill this gap, through reviewing and synthesising existing data highlights gaps and areas where further work would be potentially useful.

Several reports commissioned by European agencies have tried to synthesise large amounts of data to understand issues linked to climate change adaptation in cities (EEA 2010a, EEA 2012, Schauser et al 2010). The European Environment Agency (EEA) does so at a wider European scale with reference to cities and urban areas (EEA 2010a), with a more targeted focus on cities in a recent report (EEA 2012). Schauser et al 2010 specifically look at vulnerability and adaptation options in urban regions. All of these reports respond to the EU white paper, *Adapting to Climate Change* (Commission of the European Communities 2009) and the EU Adaptation Strategy to be released in 2013.

The EEA's thematic assessment of adaptation to climate change forms part of its wider *European Environment: State and Outlook* synthesis report (EEA 2010a). It considers adaptation and vulnerability based on global, European and 38 country-wide assessments and contains a section on cities from a general Europe-wide perspective. There is no detailed investigation of the potential implications of climate change for cities. The report focuses on a range of climate change impact indicators and gives some recommendations on 'soft', 'green' and 'grey' adaptation options.

A recent report from the EEA on *Urban Adaptation to Climate Change in Europe* (EEA 2012) takes a closer look at the particular aspects of climate change adaptation for cities. It intends to support the forthcoming EU Adaptation Strategy by informing on the challenges of climate change for European cities, and situating these within larger policy frameworks. It also considers potential opportunities linked to adapting to the changing climate. It covers the potential direct impacts of climate change on cities alongside vulnerability and adaptive capacity, and outlines adaptation options and good practice guidance at different spatial levels. The report is accompanied by a selection of European city case studies. The EEA (2012) report represents an important advance and provides a valuable complement to this report.

A consortium of agencies looked specifically at policy responses to adaptation for European cities, drawing upon 20 geographically diverse case studies (Ecologic Institute, AEA, ICLEI and REC 2011). It used empirical evidence to evaluate existing best practice and to provide guidance to local and regional administrators and stakeholders. That report considers hazards, vulnerability and adaptive capacity. There is no explicit comparison made between cities particularly, regarding the climate change hazards that they face. The report also synthesises and compares adaptation strategies to make recommendations on their effectiveness, efficiency and transferability.

This report builds on and adds to existing studies on the theme of climate change adaptation in European cities in several ways.

- It applies a recent conceptual framework for comparative assessment of climate change impacts on cities, which clearly separates climate change hazards, vulnerability and adaptive capacity (Rosenzweig et al 2011).
- By reviewing available evidence on climate change hazards, impacts and vulnerabilities in European cities, the report highlights apparent knowledge gaps and emerging themes more broadly.
- It provides the first analysis of city types in the context of ESPON's Europe's overarching climate change regions, helping to highlight the spatial diversity of the urban adaptation agenda in Europe.
- In recognising that different cities have different adaptation challenges, it sets out a reference frame for selecting candidate cities for comparative work on the development of adaptation responses to climate change.

1.3 Report structure

Section 2 considers the position of European cities in the 21st century and policymakers' visions of a competitive, globally networked urban future. This places added emphasis on the challenge to cities posed by the 'adaptation imperative', which is underpinned by the increasing possibility of a 4°C rise in global temperatures within the 21st century. The discussion also raises questions over the way in which the 'city' is defined. Even subtle differences can strongly influence the type of data that can be collected to assist in understanding the particular characteristics of cities that render them vulnerable to the changing climate. In addition, the boundaries placed around cities, particularly from an administrative perspective, set the context for both understanding the climate change hazards that they may face and the scope of adaptation responses that city governors can drive forwards. We outline the current state of thinking and outline the definition of the city adopted for the report.

Section 3 provides a conceptual framework for understanding and advancing climate change adaptation in cities. Agreement on the definition of its constituent elements is far from unanimous. This is despite the fact that different conceptual frameworks cover similar issues linked to the assessment of risk, such as hazard or vulnerability. Clarifying the terminology on adaptation planning from a conceptual perspective provides a sound route into addressing climate change hazards, impacts and vulnerability with a specific focus on European cities, which forms the focus of sections 4 and 5 of this report.

Section 4 identifies the impacts, vulnerabilities and risks of climate change to European cities based on a desk-based review of relevant policy and research contributions. Four hazards are selected, which stand out as particularly significant risks to Europe's cities and urban areas: sea-level rise, storm surges and coastal flooding; flooding from rivers; high temperatures and heat waves; and water scarcity and drought. Each overview looks at European scale data and, where available, information at city-scale. A thorough understanding of the hazards assists in comprehending the issues linked to the vulnerability of cities to climate change. Where possible, the analyses of hazard and vulnerability are integrated to highlight the spatial dimension of climate change impacts and adaptation in European cities.

Section 5 moves to practical issues. It outlines the results of synthesising ESPON's climate change data (ESPON Climate 2011) with DG Regional Policy cities data from the Urban Audit (European Commission DG Regional Policy 2010). This offers new insights into the relationship between projected climate hazards and vulnerability to these hazards in Europe’s cities.

Section 6 reflects on the research exercise and its underlying contextual issues in order to make clear and bold recommendations for the future direction of climate change adaptation in European cities. It covers the implications of this analysis for making progress on the adaptation agenda across Europe’s urban areas, particularly on the issue of differentiating cities according to climate change risks and adaptation needs. Outputs relating to the structuring of the desk-based review and data synthesis exercise are contained in the annexes to the report.

2 European cities: challenges and definitions

Key messages from this chapter

- Cities look set to play an increasingly significant role in the 21st century.
- There is a growing consensus around the potential pace and intensity of climate change over this century, summed up by the term 'four degrees and beyond.'
- Europe's cities need to respond to the adaptation imperative posed by future climate change projections in order to protect economic competitiveness and quality of life for their citizens.
- The way that cities are defined has significant implications for understanding climate change risks and adaptation responses.
- Some degree of standardisation and precision over how a city is defined would support climate change risk assessment and adaptation planning in European cities.

2.1 European cities in the 21st Century

Two of the most significant processes set to define and shape the 21st century are continued urbanisation, and uneven patterns of globalisation (Graham and Marvin 2001). In this context, cities and urban scale governance are set to challenge the dominance of the nation state in the 21st century (Sassen 2006, Glaeser 2011). Global governance challenges, often addressed at supranational and national levels at the exclusion of cities, will increasingly need to recognise cities as key actors (Sassen 2006, Bell and De-Shalit 2011). These challenges include climate change mitigation and adaptation (Betsill and Bulkeley 2003, Sassen 2010), as cities are both a key source of carbon emissions and concentrators of people and assets at risk from the changing climate.

It has been argued that it is the 'mega city-region' that is the emerging dominant urban form of the 21st century (Hall 2009). Mega city-regions are defined as: 'a series of anything between twenty and fifty cities and towns, physically separate but functionally networked, clustering around one or more larger central cities, and drawing economic strength from a new functional division of labour' (Hall 2009: 806). Hall identifies that Europe already has a 'pentagon' of mega city-regions formed between the Greater South East region of England around London, Central Belgium, Dutch Randstad, RhineRuhr and

Rhine-Main (both in Germany) and northern Switzerland. Over the coming decades, at the level of the nation state, national and commercial capitals have significant potential to dominate, with new mega city-regions emerging in areas such as Prague, Lisbon, Madrid and Warsaw. It is at this level that local economies will compete on the global market place (Hall 2009, Bell and De-Shalit 2011). As part of these processes, the move towards the knowledge-based economy in Europe has a distinct urban dimension with innovation activity and output particularly high in the very large agglomerations: 'Cities, therefore, seem to provide favourable surroundings for the diffusion of knowledge and its application in economic activity' (European Commission DG Regional Policy 2010: 16). Indeed, Europe's major metropolises are the continents key sites of economic wealth creation, dynamism and innovation (European Commission DG Regional Policy 2010).

Over recent decades, globalisation has resulted in the successful reorientation of some city economies towards the 'knowledge economy' with changes to global production, manufacturing, distribution and consumption leading to new urban forms made possible by networked infrastructures and the logistic and new technology revolution (Graham and Marvin 2001, Sassen 2006, 2010). These patterns of economic development are uneven and, in some cases, certain cities have declined (Turok and Mykhnenko 2007). For example, some cities, typically old industrial cities that were powerhouses at the turn of the twentieth century, have not successfully restructured their economies and are now experiencing population and economic decline, a phenomenon known as *schrumpfende Stadt or* 'shrinking city' (Martinez-Fernandez et al 2012). This is particularly true of cities whose development was based on a single industry, or on the concentration of an activity in a single sector such as cities in Eastern Germany. In the United Kingdom research undertaken by the Centre for Urban Policy Studies at The University of Manchester argues that there is a 'multi-speed Britain' as different types of urban areas respond in contrasting ways to the impacts of the most recent economic downturn (Wong et al 2011), with cities such as Liverpool and Glasgow struggling to adjust their economies to suit.

Figure 1 highlights changing patterns of population density in European cities. Growth in density has tended to focus on northern and western Europe, whereas cities that have experienced falls in density broadly are concentrated in eastern and southern locations. Although urban population change clearly varies within individual member states, a spatial pattern at the European scale is apparent. Issues including differing spatial planning systems, degrees of public and private sector investment and levels of economic opportunity contribute to this contrasting situation across Europe's north-west/south-east gradient.

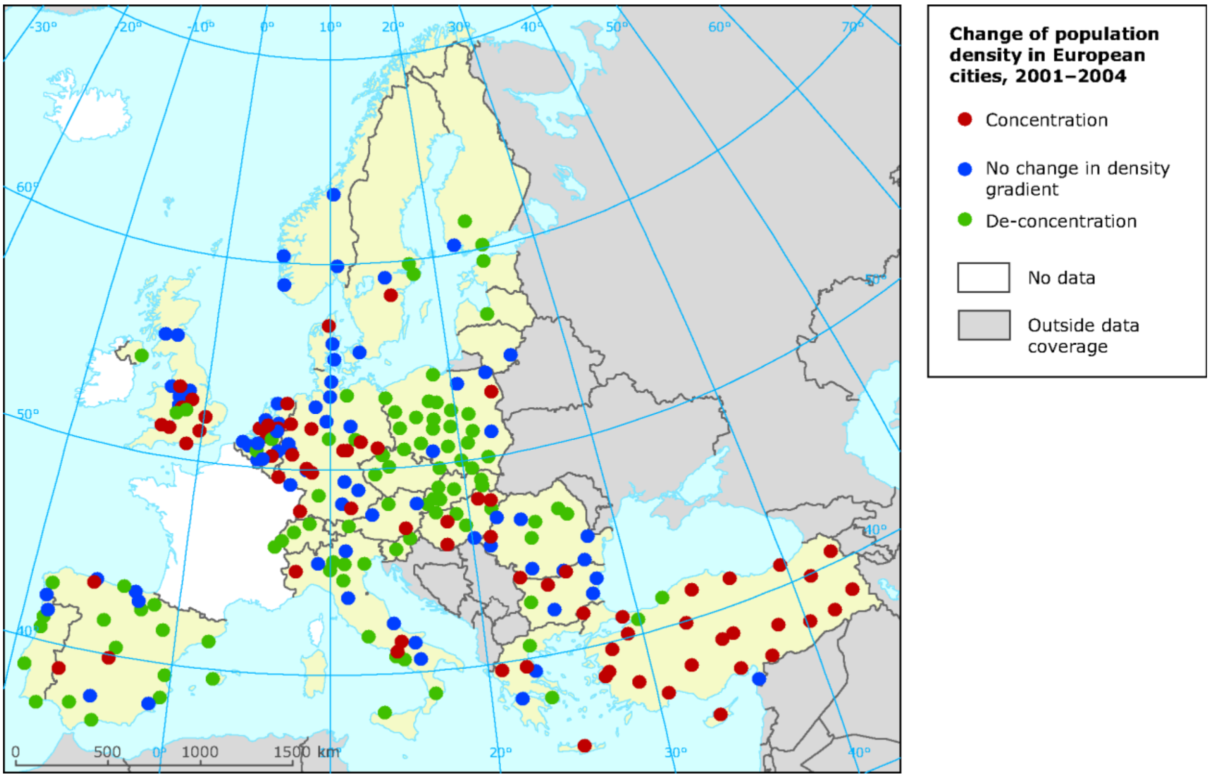


Figure 1: Population change in European cities 2001-2004 (Source: Eurostat - Urban Audit database, EEA 2009a).

Cities are Europe's major population centres. According to the United Nations Department of Economic and Social Affairs, Population Division (2008), 72% of Europe's population live in urban areas and this is likely to increase to 84% by 2050 (Kabisch and Haase 2011). Europe's growing urban population has, over recent decades, stimulated a development boom that has created significant urban sprawl with increasing attention on peri-urban zones as important spaces to consider in the context of European cities (Piorr et al 2011). Also driven by socio-economic factors, including changes in housing preference and transport modes, urban sprawl has consumed large areas of land. An area of naturally productive land three times the size of Luxembourg was lost to development between 1990 and 2000 alone (EEA 2006a). Around large cities (e.g. Paris, Brussels) and areas characterised by high rates of economic growth pre the financial crisis of 2008 (e.g. Dublin, Madrid), rates of sprawl have been especially high, and has even advanced in cities where population is shrinking (e.g. areas of Spain, Portugal and Italy) (EEA 2006a).

The EU27 population is projected to increase from 495 million on 1 January 2008 to 521 million in 2035, and thereafter gradually to decline to 506 million in 2060 (European Commission (DG ECFIN) and the Economic Policy Committee (AWG) 2009). Aside from limited short to medium term growth (principally driven by in-migration) and subsequent decline, the other key demographic feature for the EU27 is that the population is projected to grow proportionately older, with the share of the population aged 65 years and over rising from 17.1% in 2008 to 30.0% in 2060, and those aged 80 and over rising from 4.4% to 12.1% over the same period (European Commission (DG ECFIN) and the Economic Policy Committee (AWG) 2009). Likewise, the old-age dependency ratio may reach levels of more than one elderly person for every two persons of working age, or even around two for every three. This ageing is due to a combination of factors including reduction in the birth rate and better access to medical care (EUROSTAT 2011).

This so-called ‘grey wave’ is pushing south eastwards; there is a strong regional trend with the Eastern European population structure increasingly becoming older (EUROSTAT 2011). The trend towards an ageing population is most pronounced in those cities with shrinking populations whereas cities that are undergoing significant re-urbanisation, such as Paris (France), Leipzig (Germany), Ljubljana (Slovenia), Bologna (Italy) and León (Spain), inward migration is typically composed of smaller and younger households (Kabisch and Haase 2011) (see also Buzar et al 2007). Migration from within and beyond plays a key role for population growth in Europe, counterbalancing the implications of a negative natural population development in numerous regions, particularly in Eastern Europe (ESPON 2008, p. 6).

These issues are significant since population trends influence the ability of cities to adapt to climate change (Jiang and Hardee 2011). For example, studies indicate that the elderly are more vulnerable to the impacts of climate change (McMichael et al 2006). There are also questions over whether climate change will drive a wave of in-migration to European cities during this century in the form of ‘climate refugees’ from other continents (Brown 2008). Population movement to European cities may also include intra-European migration from southern and eastern to northern and western Europe. Migration, whether this is driven by climate change or other factors, has the potential to be a key force on the future of European cities influencing issues including demand for infrastructure and social services. The discussion now focuses in more detail on the challenges that the ‘adaptation imperative’ poses to European cities.

2.2 The adaptation imperative: a challenge to European cities

Extreme weather events exert a huge cost on economies and societies. Over the last thirty years the majority of Europe’s catastrophic events have been weather related, with huge economic costs (EEA 2010a). Examples include the floods of 2002 on the river Elbe (see chapter 4 for further details). With numerous lives lost and billions of Euros in damages, this was one of the key European weather events of recent years (EEA 2012). Building resilience to present day climate variability concerns maintaining the resilience of our society, financial economy and the natural economy.

As a result of policy inaction at the supranational, and in many cases at the nation state level, the world is carbonising at an unprecedented rate, not de-carbonising as the science suggests should be happening as a matter of urgency. Acknowledging the direction of emissions trajectories is an important element of appreciating the extent of potential future climate change impacts facing European cities. With recent focus on the importance of cumulative greenhouse gas emissions for understanding climate futures (Anderson and Bows 2008, Huntingford et al 2012), high levels of emissions today increase the prospect of 'dangerous' climate change, which is implicitly set at 2°C above pre-industrial levels by the Copenhagen Accord of 2009.

Since 1990, global emissions have increased by 45%, and by 30% since 2000 (Olivier et al 2011). Globally, emissions increased by 5.8% in 2010 alone, an unprecedented level in the context of the last two decades (Olivier et al 2011). China and India have led this growth in emissions, principally as a result of growing coal consumption (Olivier et al 2011). The negative effects of this escalation in emissions is compounded by the fact that political climate change targets, where they do exist, tend to be based around long term goals (e.g. reducing emissions by 80% by 2050). This is harmful in that long term targets defer action further into the future when immediate annual reductions are needed (Anderson and Bows 2008). It has also been established that the effectiveness of natural carbon sinks (e.g. oceans, forests, peat moorland) to absorb carbon dioxide has declined by 5% over the last 50 years, and this decline is set to continue (Canadell et al 2007). Consequently, at a time at which greenhouse gas emissions are accelerating, threatening to stimulate a rapid warming phase, the earth's capacity to naturally absorb these emissions is declining.

Research suggests that global mean temperatures are climbing towards 4°C above pre-industrial levels and may go beyond that level, potentially as soon as the 2060s (Betts et al 2011). Scientists are also observing significant and accelerating current temperature and sea level rise (Rahmstorf et al 2007). A study of recent climate change observations, compared to the Intergovernmental Panel on Climate Change's (IPCC) projections, found that: 'the data now available raise concerns that the climate system, in particular sea level, may be responding more quickly than climate models indicate' (Rahmstorf et al 2007: 709). Numerous examples can now be cited of shifts in climate and ecological systems that reflect these recent changes. They include the more rapid melting of Antarctic ice (Rignot et al 2008) and increased hurricane activity

(Saunders and Lea 2008). The threat of dangerous 'tipping points' in the global climate system being breached is also increasingly being discussed (Lenton et al 2008). *The Stern Review* highlights the potential economic implications, noting that abrupt and large scale climate change could lead to a 5 to 10% loss of global GDP (Stern 2007).

A report arising from a conference organised by the International Alliance of Research Universities brings together contributions from across the international climate change research community (Richardson et al 2009). It covers a broad range of recent research across the climate change agenda, and proposes the following 6 key messages:

1. Continued greenhouse gas emissions are likely to accelerate recent observed climate trends, risking abrupt or irreversible climate shifts;
2. A rise in global mean temperatures to 2°C above pre-industrial levels would likely cause major social and environmental disruption;
3. Emissions reduction strategies are urgently required. Further delay risks more severe impacts (and costly mitigation measures) in the future;
4. Equity issues cross the climate change challenge. Responding to climate change should link to broader socio-economic goals;
5. Existing tools and approaches to mitigate and adapt to climate change should now be applied, which would bring long-term benefits;
6. Societal transformation is needed to meet the climate change challenge.

This represents a strong statement from some of the world leading climate change researchers that systemic transformations are needed. It underscores the scale of the challenge facing European cities in terms of both the emissions reductions required and, if rapid action is not taken in this regard, the potential magnitude of resulting climate change impacts.

This is the climate change science and policy arena that faces the adaptation community: while scientific research findings are painting an increasingly challenging picture, the policy community and industry have yet to develop an effective response. Taken together, these warning signs add urgency to calls to reduce greenhouse gas emissions, while at the same time planning for the challenges and potential opportunities linked to the changing climate. Responding to the adaptation imperative poses a key challenge to European cities in the 21st century.

2.3 Methods of conceptualising the city

The issue of defining cities is significant for progressing adaptation policy, practice and research. Ultimately, the way that a city is defined has implications for understanding the nature of the climate change impacts it may experience, and will also influence issues linked to mobilising adaptation responses via governance structures. Some degree of standardisation and precision over how a city is defined would support climate change risk assessment and adaptation planning in European cities.

European cities have a long history and have changed size, form and political make-up to endure through millennia. Definitions of the city are elusive and will continue to evolve. For example, new forms of transport resulted in the development of commuter belts leading the town planner, Patrick Geddes, to coin the word 'conurbation' to incorporate 'this new form of population grouping' between a city and its growing hinterland (Geddes 1915: 37). Economic geographers have long grappled with analyses based on wider social and economic definitions to reflect the relationship between the core of a city and its surrounding hinterland (or travel-to-work-areas) to draw upon data from labour-market or housing-market sources, amongst others (see Robson et al 2006 for an overview).

Whatever word is chosen or however complex the definition, researchers who compare cities encounter problems of data availability and quality, in addition to different local interpretations and definitions of associated issues such as municipal boundaries. As a consequence, there is often a divergence between data gathered for European purposes and the administrative boundaries of cities to which European regional policies are typically applied. If a country is not correctly categorised, it may be unable to access certain funds (Cheshire and Magrini 2009, EUROCITIES 2011). Scale has an additional impact. National land use policy and the distances between cities can be a key variable in moulding definitions since variations in GDP per capita can reflect different national welfare policies and/or variations in economic productivity (Cheshire and Magrini 2009, see Harding et al 2010 for a discussion). Therefore, any definition of a city and the variables collected must account for local and national circumstances.

More recent work has tried to take account of technology and changing urban characteristics to refine our idea of the city and the relationships between different cities. Urban areas are increasingly connected through flows of people and information with high speed broadband, high speed rail and motorways. Rather than thinking of cities as discrete and monocentric units gathering around a strong urban core, the European landscape can be described as 'polycentric' (Hall and Pain 2006, Pain 2010). Here, physically separate core cities are nevertheless linked in a wider urban area with no obviously dominant centre; the German Rhine-Ruhr region is an often cited example. However, the distinction between monocentric and polycentric regions can be difficult where population data is used as an indicator since they have radically different urban forms owing to patterns of density but may appear to have the same population size (Eurostat 2010).

2.4 Practical collection of comparative city level data in Europe

The debate in the academic literature is reflected in the definitions of the city for the gathering of European data. The Nomenclature of Territorial Units for Statistics (NUTS) is a widely used method of dividing up the European Union into territorial units for statistical purposes. Although regularly updated, because of the availability of data, NUTS regions have usually employed a formal definition restricted to administrative regions and defined by population thresholds. NUTS data, particularly at levels 2 and 3, are used for the application of policies and to designate areas eligible for structural or special funds, and hence their relevance for European growth and development. The 3 levels of NUTS classification are outlined in Box 1.

Box 1: The different Nomenclature of Territorial Statistics (NUTS) levels

- NUTS Level 1:corresponds to major socio-economic regions (population threshold between 3 million and 7 million);
- NUTS Level 2:corresponds to basic regions for the application of regional policies (population threshold between 800, 000 and 3 million);
- NUTS Level 3: smaller regions for specific diagnoses (areas eligible for priority objective funds have mainly been classified at this level) (population threshold between 150, 000 and 800, 000).

There are comparative limitations in the NUTS approach. Firstly, the administrative boundaries of nation-states vary widely primarily as a result of their political, economic and historical development. This can hamper attempts to adequately compare between them since cities as defined within the nation state can cover widely divergent areas of land. Secondly, as they are population based, there are large variations between the surface area of a NUTS 3 region. Thirdly, there is the practice of some member states to separate a (small) city centre from the surrounding region (Eurostat 2010). Due to transportation and other infrastructure networks, cities are used by many people who commute from outside of designated political boundaries. Moreover, issues such as air pollution or management of water resources entail cities to be dependent on their hinterlands that often lie outside of the boundaries of a city's administrative unit. Consequently, the European Commission recognises that 'the administrative boundaries of cities no longer reflect the physical, social, economic, cultural or environmental reality of urban development and new forms of flexible governance needed' (European Commission Directorate General for Regional Policy 2011).

Box 2: Redefining 'Urban'

(OECD 2012: 24 – 32)

In collaboration with the European Commission, the OECD is using 1km^2 gridded population data along with land use data to redefine urban areas. This is endorsed by the European Commission as a future standard for member countries (EUROSTAT 2011). The OECD has recently incorporated relevant environmental data by applying this rural-urban method (Piacentini & Rosina 2012). However, there is the caveat that achieving a concept suitable for large cross-country comparisons may come at the expense of accurately accounting for national borders.

Step 1: Identifies contiguous or highly interconnected urban cores that are part of the same functional area;

Step 2: Identifies interconnected urban cores that are part of the same functional area (with a threshold of 15% of residents employed in the urban core);

Step 3: Defines the commuting shed or hinterland of the functional urban area.

Until recently, the OECD used political designations (OECD 2010b) where urban areas are distinguished from rural areas using the measure of population density defined within a given administrative boundary. However, the European Commission and the OECD have, over the past two years, sought to define cities functionally by developing a harmonised 'regional typology model' to ensure consistency across European Commission reports; one that aims to become internationally applicable. The OECD employ the term 'functional urban areas' based upon 'functional economic units' and the stepwise process of defining a city incorporates polycentricism discussed above. It accounts for urbanisation processes through the collection of population data as well as urban morphology. The latter is considered by the use of Urban Morphological Zones – 'a set of urban areas laying less than 200m apart' (ETC-EEA 2010: 4). These are classified by land cover relating to the urban tissue and function. Classes include continuous and discontinuous urban fabric, commercial and industrial units, green spaces and road and rail networks (see ETC-EEA 2010: 4 for the full list) The sequential steps in the OECD definition are outlined in Box 2 (for a technical account see OECD 2012: 24 – 32). The result is thought to give an accurate representation of a nation-state's 'urban system'. There are analytical and comparative possibilities too in that the new definition allows one to make a distinction between functional urban areas and compare across them. In time the emergent EU/OECD definition of functional urban areas may prove a valuable approach to defining a city for policy or comparative purposes.

At European Commission level, a number of different monitoring agencies across Europe now employ specific definitions and draw on certain datasets based on their requirements. This has lead to calls for the development of integrated monitoring approaches for urban areas across Europe. For example, the European Environment Agency suggests that the concept of 'urban metabolism' should be used as a basis for this integrated framework (Fons-Esteve et al 2008). Their delineation of a city takes a geo-spatial perspective that connects urban areas to hinterland processes and uses Urban Morphological Zones (UMZs) based on CORINE Land Cover (CLC) data. However, it recognises that this data is not always applicable to urban issues, particularly due to the synergies between population, employment and other drivers of urban processes.

2.5 Specific city definitions and data used in European reports

The EEA's report on *Urban Adaptation to Climate Change in Europe* (EEA 2012) employs GIS to integrate two datasets; the UMZs based on CLC data and also the core city definition from Urban Audit (and Urban Atlas) data. By using Urban Audit data, the EEA believe that the results are directly applicable to policymakers and politicians working in urban areas, yet the definition also pays due consideration to wider environmental and spatial drivers of urban change.

Cities of Tomorrow: *challenges, visions, ways forward* (European Commission Directorate General for Regional Policy 2011) distinguishes between the city as a political and legal entity and the city as a wider socio-economic unit. It begins by recognising that administrative boundaries are no longer appropriate as they do not encompass wider urban development processes and the functioning of a city into its hinterland. They follow the definitions of a city encompassing elements of the OECD/European Commission and ESPON approaches. In the first instance, a city is defined by certain population size and density thresholds. This can be further distinguished in terms of the Morphological Urban Area (MUA) defined by the extent of the built environment. In addition, the Functional Urban Area (FUA) is defined more widely to include commuter flows and towns and villages that are part of the urban centre's wider system. To account for the different scales of governance and a need for flexible governance, the *Cities of Tomorrow* report follows the pragmatic path and employs both terms to define cities 'as urban agglomerations in general as well as the administrative units governing them' (European Commission Directorate General for Regional Policy 2011: 2). Therefore, they follow the developing OECD/ European Commission definition to delineate a city based on:

(1) containing one or more municipalities (or LAU2);
(2) half of a city's residents live in an urban centre and;
(3) the urban centre has a minimum of 50, 000 inhabitants.

Clearly this is an area where conceptual and practical developments are moving towards a degree of standardisation. However, to allow a reasonable contemporary comparison, based on robust socio-economic data, we also chose to follow a pragmatic path focusing on good data availability and policy applicability. For these purposes, the Urban Audit (European Commission DG Regional Policy 2010) was chosen. The data and definitions have been trialled across Europe over a ten-year period and the Urban Audit definition of a city primarily rests on political boundaries in order to make its findings relevant to local and EU policymakers, although it does consider wider definitions for specific indicators. The Urban Audit, and the city typology derived for the most recent reports, is described in sections 2.6 and 2.7 below.

2.6 The Urban Audit

The way in which a city is framed will affect the breadth and depth of variables that can be considered in understanding adaptation issues, such as the vulnerability of cities and their residents to weather and climate hazards. Relevant proxy indicators for sensitivity to these hazards (a constituent element of vulnerability – see chapter 3) include socio-economic data which, as we can see, differs depending on how a city is defined. The definition of a city based on Urban Audit data is followed within this report. As outlined in the European Commission's *State of the City* reports, the Urban Audit tries to move beyond national borders to broaden city comparisons at European level observing that:

> *comparing Birmingham to Leipzig, Darmstadt to Eindhoven, Amiens to Oviedo or Poznań to Zaragoza may offer additional insight into the position these cities find themselves in, the dynamic forces at play and perspectives for the future* (European Commission Directorate General for Regional Policy 2010: 2).

Urban Audit data is coordinated by EUROSTAT under the initiative of the Directorate-General for Regional Policy at the European Commission. Beginning initially as a pilot in 1999, the number of participating cities has grown to over 300. Data is gathered voluntarily from participating cities at 3-year interval on different features of the quality of urban life in European cities. Therefore, it allows for comparisons to be made between cities with similar characteristics in terms of socio-economic data. Combined with an understanding of the climate hazards that will affect European cities, the Urban Audit city typology can assist in understanding vulnerability to climate change in cities.

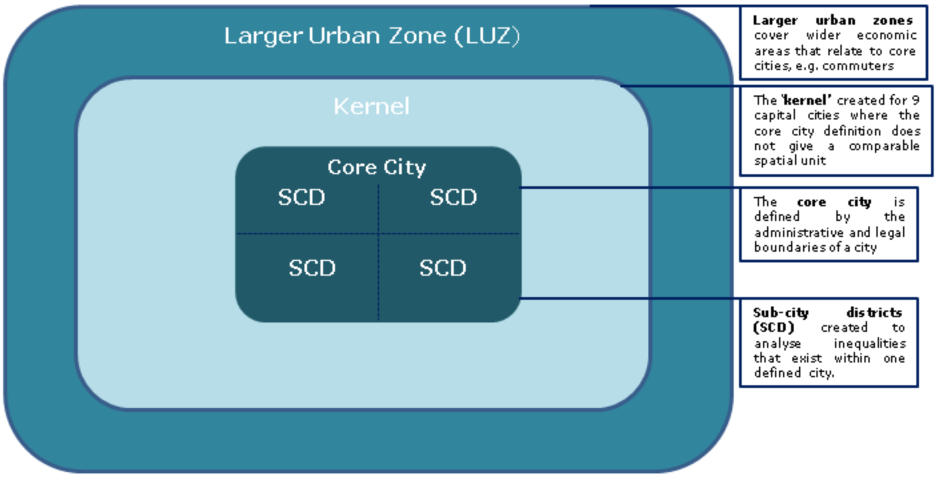


Figure 2: The four spatial levels of data collection for the Urban Audit.

Given the uneven geography of population distribution across Europe, the Urban Audit identifies different spatial levels that are appropriate for different indicators (Figures 2 and 3). For example, GDP data is better interpreted at a larger spatial level than a city's provision of services to its citizens (Eurostat 2010: 204). The 'core cities' are defined by their administrative and political boundaries so as to make recommendations that are relevant to policy-makers. Larger Urban Zones (LUZs) are functionally defined areas that extend beyond the core city and take account of commuting patterns using a predefined threshold. However, when applied to cities with wider commuting patterns or those where there are high density areas immediately adjacent to the administrative boundary (known as 'under-bounded') such as the national capitals of Paris or Lisbon, population levels in the core city and large urban zone are unduly small making it difficult to compare the spatial units across Europe's major capital cities. For this reason, the 'kernel' was developed as an additional spatial level to cover the built up area immediately surrounding the core city.

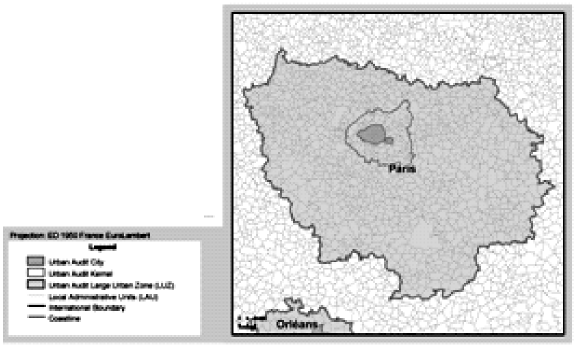


Figure 3: Spatial levels as applied to the principal metropolis of Paris, France (Source: City Maps, Urban Audit, www.urbanaudit.org)

Sub-city district (SCD) is a further subdivision of the core city according to a population criteria of between 5, 000 and a maximum 40, 000 inhabitants to allow for an analysis of spatial inequality within a city. For inner London, these sub-city districts correspond to the administrative boundaries of the London boroughs. Together, these divisions incorporate a wider definition of a city to include the difficulties of accounting for commuting patterns as well as usefully allying to legal and administrative boundaries.

2.7 The Urban Audit typology of cities (2010)

The number of cities reporting to the latest editions of the Urban Audit is limited. However, they are chosen to show a geographical cross-section across each participating country. By 2010, 320 European Union cities were included along with another 36 cities from Norway, Switzerland and Turkey. A further 'Large City Audit' collects a reduced set of 50 variables for all 'non Urban Audit' EU cities with a population over 100, 000 (European Commission DG Regional Policy 2010). The data breadth and quality of the Urban Audit is not perfect but can be considered to be robust and with decent coverage across Europe (for example, see Böhme 2009). For comparative purposes, European cities are categorised into 4 key city types with a number of sub-categories within each type:

- A: Principal metropolises
  - A1: Leading European capitals and principal metropolises
  - A2: National capitals and metropolises
- B: Regional centres
  - B1: Regional service centres
  - B2: Regional innovation centres
  - B3: Regional centres with growing population
- C: Smaller centres
  - C1: Smaller administrative centres
  - C2: Smaller centres with growing population
- D: Towns and cities of the lagging regions
  - D1: Cities in the process of structural adaption
  - D2: Less developed towns and cities

The 354 indicators used to determine, via cluster analysis, the position of a city in this typology were grouped into 9 key domains:

1 Demography
2 Social aspects
3 Economic aspects
4 Civic involvement
5 Training and education
6 Environment
7 Travel and transport
8 Information society
9 Culture and recreation

The geographical distribution of the 4 key city types is shown in Figure 4. Data on the four city types is available at the scale of the 'core city' and LUZ. Due to the benefits outlined above of defining the boundaries of cities more broadly, both in terms of providing a clearer picture of their functional economic reach and relating to understanding and responding to the adaptation imperative, the LUZ has been selected for the purposes of this report. The *State of the European Cities* city typology is used to assess the spatial connections between different city types and climate change hazards (which forms the basis of section 5 of this report).

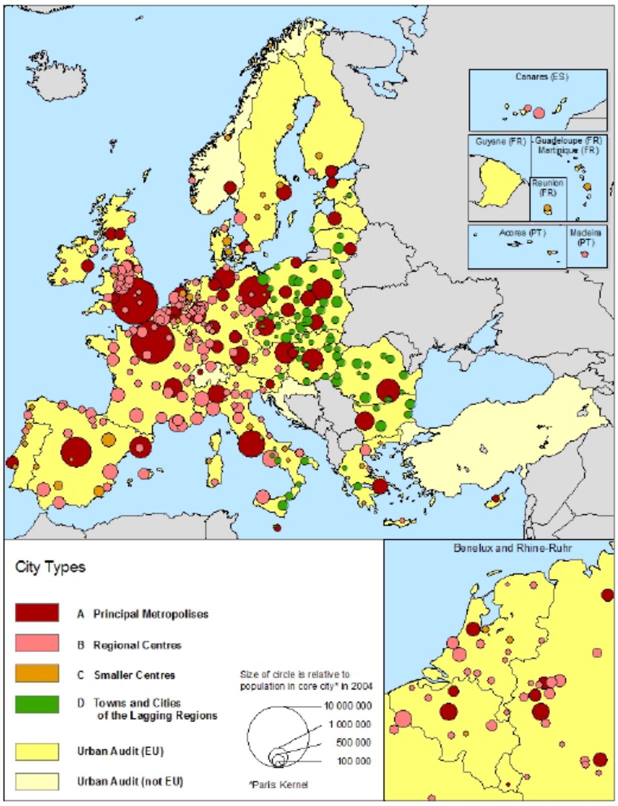


Figure 4: Geographical distribution of the Urban Audit city types (Source: European Commission DG Regional Policy 2010).

3 Understanding climate change hazards, impacts and vulnerabilities in European cities: a conceptual framework

Key messages from this chapter

- A conceptual framework can usefully highlight the different factors, and the relationships between them, framing the assessment of climate risk.
- Since there is no universally accepted conceptual framework for handling climate risk, it is necessary to explain any selected framework and define its key terms when undertaking a project of this type.
- Within this report we follow the Urban Climate Change Research Network's 'urban climate change vulnerability and risk assessment framework' (Rosenzweig et al 2011).
- Following this framework, climate change risks occur if a hazard affects a city which contains elements that are vulnerable to that hazard, whilst also having a low capacity to develop adaptation responses to the hazard.

Aiming to understand the scope of climate change hazards, impacts and vulnerabilities in European cities, raises the question: what is a city? Section 2 attends to this. Another fundamental task is to identify a conceptual framework that can highlight the different factors that form a basis for assessing climate risks in cities. As in many other sectors, conceptual frameworks are useful decision making aids for climate change adaptation. By simplifying what is a highly complex agenda into more manageable units, a good framework demonstrates the broad issues that connect climate change processes and adaptation responses. Conceptual frameworks also lend clarity to the types of data that can be gathered to support the development and implementation of adaptation responses.

As climate change adaptation has become more widely accepted within research, policy and practice, its scope has broadened. Emphasis is shifting from the development of adaptation responses based solely around managing the direct physical manifestation of climate change hazards such as flooding and heat stress, to risk-based approaches that incorporate an assessment of vulnerability and capacity to adapt to these hazards. The risks associated with a weather or climate event, or in other words the potential for a negative outcome or loss, is determined by the interaction between climate related hazards (e.g. floods), vulnerability to those hazards (e.g. of people and infrastructure) and capacity to mount an adaptation response. Since there is no universally accepted conceptual framework for handling climate risk and its components, such as vulnerability, it is necessary to explain the usage of terms when applying them in a project of this type. The following sections looks at the IPCC's and Urban Climate Change Research Network approaches to understanding climate change impacts and risk. Understanding how others have addressed the core issues and the relationships between them allows us to reflect on and situate the framework (and the definition of associated terms) used to guide this report and the ASEC project more broadly.

3.1 The IPCC conceptual framework

The IPCC places adaptation in a broad context by integrating it with mitigation as part of a balanced policy response to variability in weather and climate (see Figure 5). The IPCC's approach recognises that planned adaptation policy responses are dependent on the extent of climate change impacts and the degree of vulnerability to those impacts. The key terms forming the basis of the framework are elaborated by the IPCC (2001). It is noted that climate change impacts are difficult to identify and quantify, yet can be both beneficial and negative, and depend on issues including the magnitude and rate of climate change. Vulnerability is defined as:

> *Vulnerability is a function of the* ***sensitivity*** *of a system to changes in climate (the degree to which a system will respond to a given change in climate, including beneficial and harmful effects),* ***adaptive capacity*** *(the degree to which adjustments in practices, processes, or structures can moderate or offset the potential for damage or take advantage of opportunities created by a given change in climate), and the degree of* ***exposure*** *of the system to climatic hazards* (IPCC 2001: 89. Original emphasis).

Adaptation, which can be autonomous (self directed) or incentivised by policy making, is defined as: 'adjustments in practices, processes, or structures to take account of changing climate conditions' (IPCC 2001: 89-90).

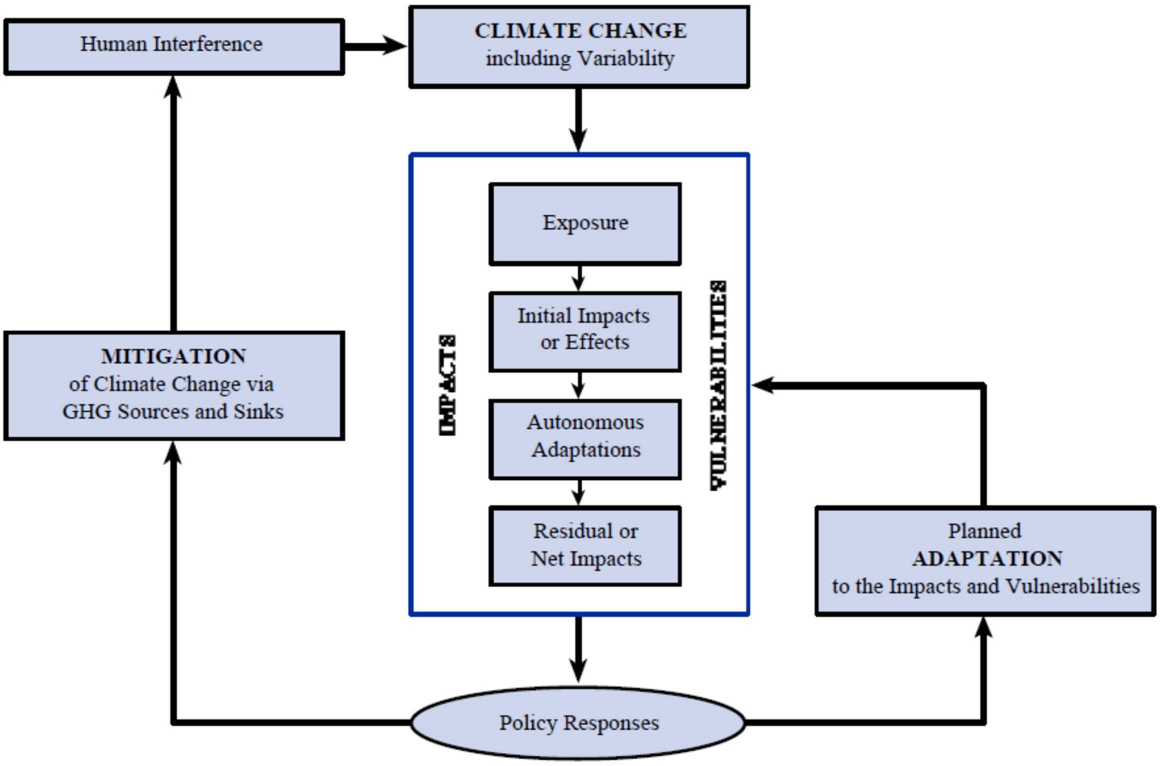


Figure 5: Places of adaptation in the climate change issue (Source: IPCC 2001; following Smit et al 1999)

An early IPCC report (Carter et al 1994) established a general framework for assessing climate change impacts. This referred to the assessment of biophysical and socio-economic impacts of climate change. Impacts were defined as:

> *...the differences over the study period between the environmental and socio-economic conditions projected to exist without climate change and those that are projected with climate change.* (Carter et al 1994: ix)

The UK Climate Impacts Programme summarises impacts as: 'A beneficial (or more usually) detrimental consequence (Willows and Connell 2003: 113). In effect, climate change impacts are the consequences arising from exposure to climate change hazards such as floods and heat waves. These impacts can be direct, which in the context of flooding, for example, are consequences such as damage to properties. Impacts can also be indirect, and following the flooding example they may include psychological trauma experienced by home owners following a flood.

3.2 The Urban Climate Change Research Network conceptual framework

The Urban Climate Change Research Network recently released their first assessment report on *Climate Change in Cities* (known as ARC3) (Rosenzweig et al 2011). They note that: '…a multidimensional approach to risk assessment is a prerequisite to effective urban development programmes that incorporate climate change responses' (Rosenzweig et al 2011: 36). In order to support such an approach they propose an 'urban climate change vulnerability and risk assessment framework' as the most appropriate method for understanding climate risks and developing adaptation strategies and responses. Based on World Bank commissioned research to develop a city-scale climate risk assessment approach, the ARC3 framework was subsequently field tested on the cities of Buenos Aires, Delhi, Lagos and New York, demonstrating applicability to cities globally (Mehrotra et al 2009). The framework is visualised in Figure 6, and is explained in greater detail within the report from which it originated (Mehotra et al 2009). It is composed of three elements which relate to climate hazards, vulnerability and adaptive capacity. These are defined within the ARC3 report as follows:

- '*Climate hazards*: such as more frequent and longer duration heat waves, greater incidence of heavy downpours, and increased and expanded coastal or riverine flooding;
- *Vulnerabilities:* due to a city's social, economic, or physical attributes such as its population size and density, topography, the percentage of its population in poverty, and the percentage of national GDP that it generates;
- *Adaptive capacity*: factors that relate to the ability of a city to act, such as availability of climate change information, resources to apply to mitigation and adaptation efforts, and the presence of effective institutions, governance, and change agents' (Rosenzweig et al 2011: xvi).

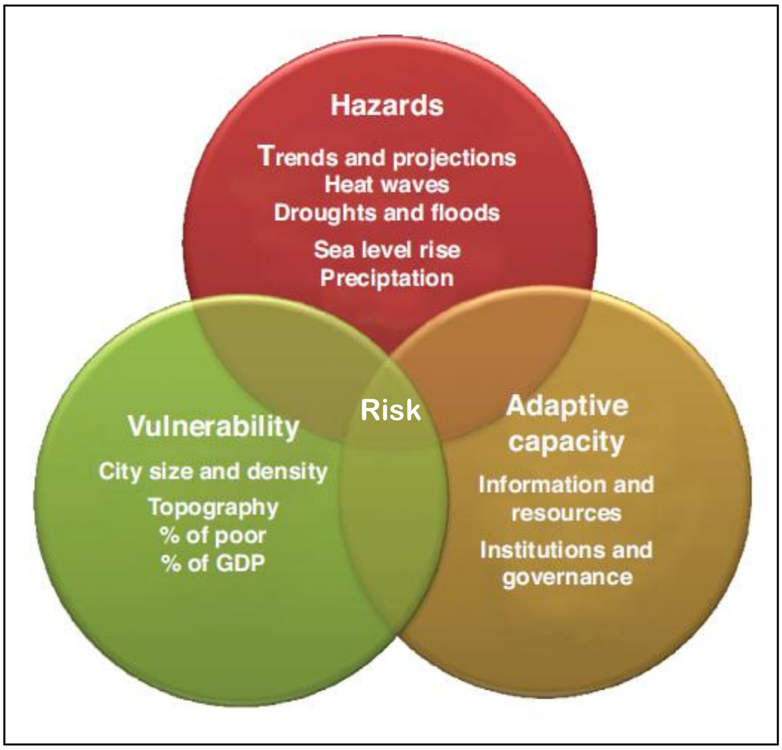


Figure 6: Urban Climate Change Vulnerability and Risk Assessment Framework (Source: Rosenzweig et al 2011; after Mehrotra et al 2009)

Since the intention of the ARC3 framework is to provide a platform for developing adaptation strategies, three distinct stages that follow its core elements are recommended as a basis for the vulnerability and risk assessment process (Rosenzweig et al 2011: 20):

1. 'Characterise the hazards associated with climate change at the city-level;
2. Identify the most vulnerable segments (people, locations, sectors) of the city; and
3. Assess the city's ability to adapt to anticipated changes in climate.'

These stages indicate the type and scope of data that can be valuable for progressing adaptation planning and strategy making. The approach is not intended to be sequential and progress can be made on the different stages in tandem. Following the ARC3 framework, climate change risks occur if a hazard affects a city which contains elements that are vulnerable to that hazard, whilst also having a low capacity to develop adaptation responses to the hazard.

3.3 Focusing on the Urban Climate Change Research Network conceptual framework

Both the IPCC and ARC3 frameworks are useful. However, with the focus of the ASEC project firmly on cities and building adaptive capacity, the ARC3 framework brings certain benefits that enhance its utility for the ASEC project. These include:

- Specific focus on city-scale climate change risk assessment.
- Applied to a number of cities globally and shown to enhance understanding of adaptation issues in these locations.
- Separates adaptive capacity from vulnerability to enable these two issues to be considered as discrete entities. This fits with ASEC project's explicit focus on building adaptive capacity in European cities. It is helpful to think about the potential vulnerability of cities to climate change hazards before factoring in adaptive capacity.
- Could usefully form the basis of the typology developed within the ASEC project to differentiate between European cities in the context of their climate change adaptation challenges.

Given the significance of the hazard, vulnerability and adaptive capacity elements of the ARC3 conceptual framework, and their prominence within this report, each element of the framework is now discussed in greater detail to draw out the underlying assumptions contained within them.

3.3.1 Hazard

In the ARC3 report, hazards are defined as:

> *'…climate induced stresses and climate-related extremes and are identified through observed trends and projections derived from global climate models (GCMs) and regional downscaling'* (Mehrotra et al 2009: 8).

The majority of climate induced hazards that affect cities arise from changes in several key variables: temperature, precipitation, wind and sea level rise. Changes in the frequency and intensity of extreme weather events (e.g. floods, heat waves) and gradual shifts in climate (e.g. subtle changes in average temperatures and precipitation patterns) are both relevant, and generate hazards that exert pressures on cities that demand different types of adaptation responses. The hazard dimension of the risk assessment framework is relatively straightforward. The term vulnerability is a more contested, and this is discussed in further detail below.

3.3.2 Vulnerability

Vulnerability is a crucial element of assessing climate change risk. Conceptual frameworks developed to support adaptation research, policy and practice (including the ARC3 and IPCC approaches) imply that once issues relating to vulnerability to climate change hazards are better understood, it will be possible to target adaptation responses to population groups, sectors and infrastructures that are particularly susceptible to damage from these hazards. From a pan-European perspective more vulnerable cities can be supported, whilst at the scale of individual cities locations or communities that are more vulnerable can be allocated resources accordingly.

While the term vulnerability receives a lot of attention in both academic and grey literature on climate change adaptation, there is no consensus over its precise meaning (Alcamo and Olesen 2012, EEA 2012). Approaches for assessing vulnerability tend to be shaped by specific research and policy contexts and are constructed using a variety of different methods (Hinkel 2011). Conclusions from the ADAM and FAVAIA projects suggest that ideas of vulnerability usually focus on measures of possible future harm irrespective of whether this harm actually occurs, but then diverge beyond that core understanding. Whilst variations in approach can be problematic it is also true that 'no one approach to vulnerability assessment fits every need' (Downing et al 2002: 1).

The EEA's report on *Urban Adaptation to Climate Change in Europe* (EEA 2012) addresses issues linked to vulnerability, focusing on cities and urban areas. The report acknowledges the lack of precision over defining vulnerability, and outlines the EEA's approach in this respect: 'While being aware of the different definitions and concepts of vulnerability, we do not use a specific definition or concept stringently in this report but rather use the term in a more generic way' (EEA 2012: 127). In order to move beyond this impasse, where there is an evident lack of clarity and consistency concerning definitions of vulnerability, Schauser et al (2010) recommends that experts are consulted to produce single components of vulnerability, which can act as a basis from which assessments can be made.

Looking more closely at the definitional differences, the ARC3 approach splits adaptive capacity from vulnerability. Similarly, the EEA also separate out adaptive capacity from vulnerability in their recent report into urban adaptation to climate change in Europe (EEA 2012). However, the IPCC consider adaptive capacity to be an element of vulnerability (alongside exposure and sensitivity). Following Mehrotra et al (2009: 10), the ARC3 distinction is useful because vulnerability is seen to relate to underlying city characteristics whereas adaptive capacity is principally determined by the ability and willingness of 'change agents' within the city to cope with climate change hazards.

As a result of these issues it is particularly important to provide a clear definition of how vulnerability is understood in the context of this report. Taking forward the ARC3 approach, this report considers vulnerability as a state. Here vulnerability is intrinsically associated with people places or things, irrespective of whether they experience a hazard that has the capacity to cause harm. It concerns the characteristics that underlie the 'elements at risk' in a city. These include physical and socio-economic factors, which influence the potential *exposure* and *sensitivity* of elements at risk to climate change hazards. Taken together, it is these exposure and sensitivity characteristics that determine levels of vulnerability to climate change hazards.

> ***Exposure:*** Physical factors such as topography, proximity to the coast and urban form (city size and density) influence the degree to which a city experiences a climate hazard (Rosenzweig et al 2011)). These also relate to factors that can act to enhance exposure to climate hazards such as proportions of different dwelling types (e.g. basement flats, tower blocks), quality of the building stock (poorly constructed buildings may be more liable to flood damage than well-constructed ones that follow relevant building codes) and the amount of greenspace (Lindley et al 2011).

> ***Sensitivity:*** Sensitivity can be expressed in terms of the basic potential for harm of the key elements at risk associated with the city. Factors including population size and age structure influence the sensitivity or susceptibility to harm of people in a city. For example, older people and those in ill-health are on average more likely to feel health effects from heat-wave events due to physiological factors. The sensitivity of other elements at risk, for example infrastructure, is influenced by factors including the quality of materials.

Understanding vulnerability requires the inherent characteristics of 'elements at risk' and their associated systems to be considered in depth. This is reinforced by Schauser et al (2010: 23) who say that:

> *Since many factors influence the vulnerability of cities and urban areas to climate change, it is important that any vulnerability assessment defines carefully and explicitly the object of investigation and the measure of vulnerability being adopted*.

ESPON Climate (2011) recognise that it is not just people and infrastructure that are at risk from climate change hazards. ESPON's approach is based around several broad categories of elements at risk including:

- Physical elements (buildings and infrastructure)
- Environmental elements (ecosystems and landscapes)
- Cultural elements (heritage sites and museums)
- Economic elements (economic sectors)
- Social elements (people, governance structures)

Some elements at risk will be more significant than others depending on the context. For example, depending on issues such as development patterns and dominant transport modes, threats to public transport infrastructure could be more serious for a city where car ownership is low.

Indicators are needed to represent the exposure and sensitivity of elements at risk from climate hazards. There are many examples of vulnerability indicator studies and projects that provide useful insights. In New York, where vulnerability assessment work is relatively advanced (Hunt and Watkiss 2011), indicators were developed for key infrastructure sectors including energy, transportation, water supply, waste and communications. Interdependencies between these sectors were also considered (Zimmerman and Faris 2010). There are other summaries of indicators for people, and whilst some of these indicators are hazard specific others may hold for multiple hazards (Lindley et al 2011). A project to assess risk of climate change in global mega-cities (Voss 2006) highlights vulnerability indicators that can be populated with existing city-scale data resources and can draw on indicators compiled for other purposes. These include building quality and density (Munich Re 2004).

3.3.3 Adaptive capacity

Adaptive capacity is a key element of the ARC3 conceptual framework. However, since adaptive capacity is the subject of a separate element of the ASEC project and is not reviewed in detail here, the concept is not elaborated beyond what is required in order to understand the scope and terminology of this report. Adaptive capacity can be defined as: '…the ability or potential of a system to respond successfully to climate variability and change' (Adger et al 2007: 727). Climate change risk assessments require due consideration of the adaptive capacity of elements at risk and their overarching systems in order to fully appreciate the extent of the potential impacts of climate change hazards.

For this report, adaptive capacity concerns the wide range of factors that can result in one city having better opportunities to prepare for, respond to and recover from climate change hazards in comparison to another city. Adaptive capacity is determined by: '…the ability and willingness of the city's key stakeholders to cope with the adverse impacts of climate change and depends on the awareness, capacity, and willingness of the change agents' (Mehrotra et al 2009: 11). The 'change agents' include government, the private sector and civil society (Mehrotra et al 2009: 11). Some of the characteristics that determine adaptive capacity have dimensions that are generic, whereas others are specific to particular climate change risk (Adger et al 2007).

Differences in the adaptive capacity of a city's population is driven by variations in awareness of climate change hazards, relative mobility, socio-economic status, length of residence time or the extent of community support (Lindely et al 2011). Adaptive capacity also relates physical infrastructure, and concerns the ability of infrastructure to absorb climate change pressure. Infrastructure such as green space has the ability to offset climate change impacts and therefore boost adaptive capacity. Assets associated with planning and management can also be considered from the perspective of a city's adaptive capacity (Engle 2011, Rosenzweig et al 2011). Governance arrangements can offset damage and enhance opportunities linked to climate change hazards, for example through developing, communicating and implementing proactive and responsive adaptation strategies and creating networks between stakeholder groups.

With the conceptual framework guiding this report outlined, and its constituent elements clarified, the following section looks in detail at issues linked to climate change hazards, impacts and vulnerability in European cities.

4 Climate change hazards, impacts and vulnerabilities: a European perspective

Key messages from this chapter

- Detailed information on projected climate hazards including flooding and heat stress is available at the pan-European scale, produced by organisations including the European Environment Agency and ESPON.
- City-scale climate hazard data is sporadic and where it does exist for European cities it tends to be the product of either a research enquiry or a municipal planning process.
- With their heavy reliance in infrastructure networks, high population densities, large numbers of poor and elderly people and major concentrations of material and cultural assets, cities are particularly vulnerable to climate change (EEA 2010, Schauser et al 2010).
- Socio-economic data sets offer decision makers a useful resource for understanding vulnerability to climate change hazards in European cities. European level sources include the Urban Audit and EUROSTAT.
- The key themes of this chapter – climate change hazards, vulnerabilities and impacts – show strong spatial variation across Europe.

This chapter considers two aspects of the ARC3 conceptual framework in detail, hazard and vulnerability, from a European perspective. This begins with a broad overview of available data from a generic pan-European perspective. This is followed by a more detailed look at four climate change hazards of particular relevance to European cities, with consideration of associated impacts and issues linked to vulnerability.

4.1 Climate change hazards: a pan-European perspective

Data on climate change hazards is available at the European scale. Significant contributions include a chapter on Europe within the IPCC's 4th Assessment report (Alcamo et al 2007), modelling work undertaken within the ClimateCost project (Christensen et al 2011), and modelling work undertaken within the ENSEMBLES project (van der Linden and Mitchell 2009). Key findings of these studies are highlighted in Box 3.

Detailed city-scale climate hazard data is sporadic and, where it does exist for European cities, tends to be the product of either a research enquiry or a municipal planning process. Examples of research outputs include a study of Greater Manchester's (UK) past and potential future climate (see Carter and Lawson 2011 for a summary and relevant links), a study of the relationship between climate change induced heat stress and human health in Cracow (Poland) (Piotrowicz 2009), and an analysis of the impacts of climate change and urbanisation on drainage in Helsingborg (Sweden) (Semadeni-Davies et al 2008). Cities, including London and Copenhagen, have produced adaptation strategies informed by an understanding of locally relevant climate change hazards (Greater London Authority 2010; City of Copenhagen 2011). In both of these cases, public environmental agencies, consultancies and academic institutions either directly supported the process of assessing climate change hazards, or their previous work was drawn upon by municipal officers.

Organisations, including ESPON and the European Environment Agency (EEA), have also produced climate change hazard data at the scale of European regions. In the case of the EEA, this relates to 7 European biogeographic regions that include the Mediterranean, north-western Europe and mountain areas (Figure 7). A high level overview is provided of key climate change hazards that are most prevalent in each biogeographic region (EEA 2010a: 39).

ESPON took a similar approach and identified key climate change hazards at the scale of broad European regions (ESPON Climate 2011). The ESPON output (Figure 8) includes five different areas identified on the basis of cluster analysis. The report notes that each of these areas, termed 'climate change clusters', consists of NUTS 3 regions that are similar in terms of projected future changes to a series of climate stimuli. The clusters, and their associated climate change profiles, are detailed in Table 1.

Box 3: European scale climate science: key research findings.

IPCC's 4th Assessment Report. Report of WGII (Alcamo et al 2007)

Working Group II of the IPCC's 4th Assessment Report, provided an overview of climate change impacts, vulnerabilities and adaptation responses at the European scale. The report highlights that Europe is already experiencing climate change impacts (e.g. to the cryosphere and ecosystems), and that recent observed changes indicate the direction of future climate change. A key IPCC message is that climate hazards will vary spatially across Europe, for example related to greater risk of droughts, fires and heat waves in the Mediterranean, central and southern Europe. Spatial differences concerning future precipitation patterns (e.g. increase in mean annual precipitation in northern Europe and a fall in southern Europe) are also noted.

ClimateCost Project (Christensen et al 2011)

This policy briefing presents the results of climate modelling work for Europe, placing the continent in the context of global climate change projections. Three greenhouse gas emission scenarios provide a basis for the modelling work; a medium-high emissions non-mitigation scenario (A1B), a mitigation scenario (E1) and a high emissions scenario (RCP8.5). Projected changes in temperature and precipitation patterns for Europe over the course of this century differ according to which emissions scenario is considered and which climate model output is selected. The briefing focuses winter and summer temperature and precipitation projections for Northern, Southern, Eastern and Western Europe. Key messages include:

- Warming is projected across Europe, with the greatest increases over land in Southern Europe (particularly the Iberian Peninsula).
- There are marked differences in projected precipitation change within Europe and across the seasons. Summers in Southern Europe could bring around half the current levels of rainfall by the end of the century. Increases in winter precipitation are projected for Northern and North Eastern Europe.
- There is considerable uncertainty in climate projections depending on the emissions scenario, climate model and time horizon chosen.

ENSEMBLES project (van der Linden and Mitchell 2009)

The climate projections generated by the ENSEMBLES project emphasise the significance in the shift in Europe's climate over the course of the 21st century. The ENSEMBLES projections offer detailed data on the future climate under several greenhouse gas emission scenarios. At the European scale, projections are provided for climate variables (temperature and precipitation) and for extreme events (e.g. heavy rainfall, droughts, heat waves). Statistical downscaling of projections for European regions and some case study countries is also provided. Key conclusions emerging from the ENSEMBLES project include:

- 'As the century progresses the projected climate moves increasingly farther away from its current state, so that by 2100 the climate of Europe will be very different than from today' (van der Linden and Mitchell 2009: 7).
- An increase in temperature extremes in the Mediterranean, with temperatures increasing by as much as 0.5°C per decade between 1950-2100 (90th percentile projection for maximum temperature).

Extreme weather events are expected to cause some of the most harmful and costly climate change impacts. Relevant findings for European cities include projected increases in extreme wind speeds in northern areas of central and western Europe.

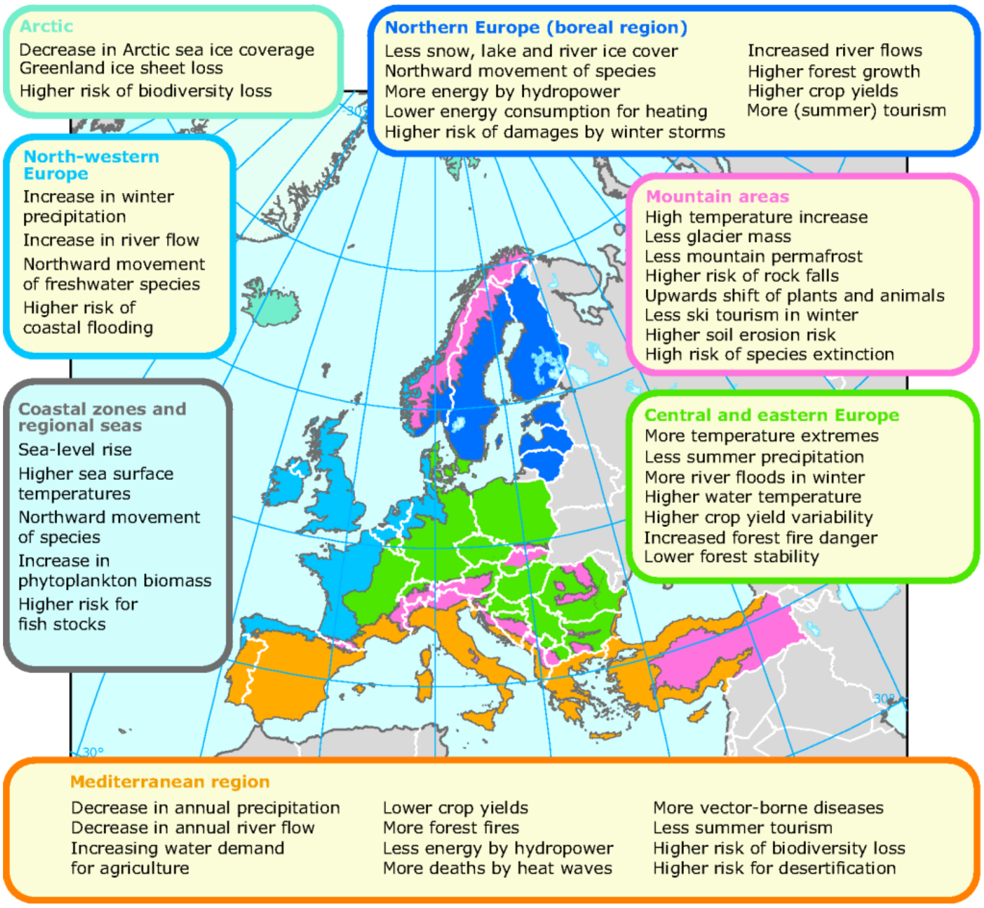


Figure 7: Key past and projected impacts and effects of climate change for the main biogeographical regions of Europe (Source: Based on EEA-JRC-WHO, 2008)

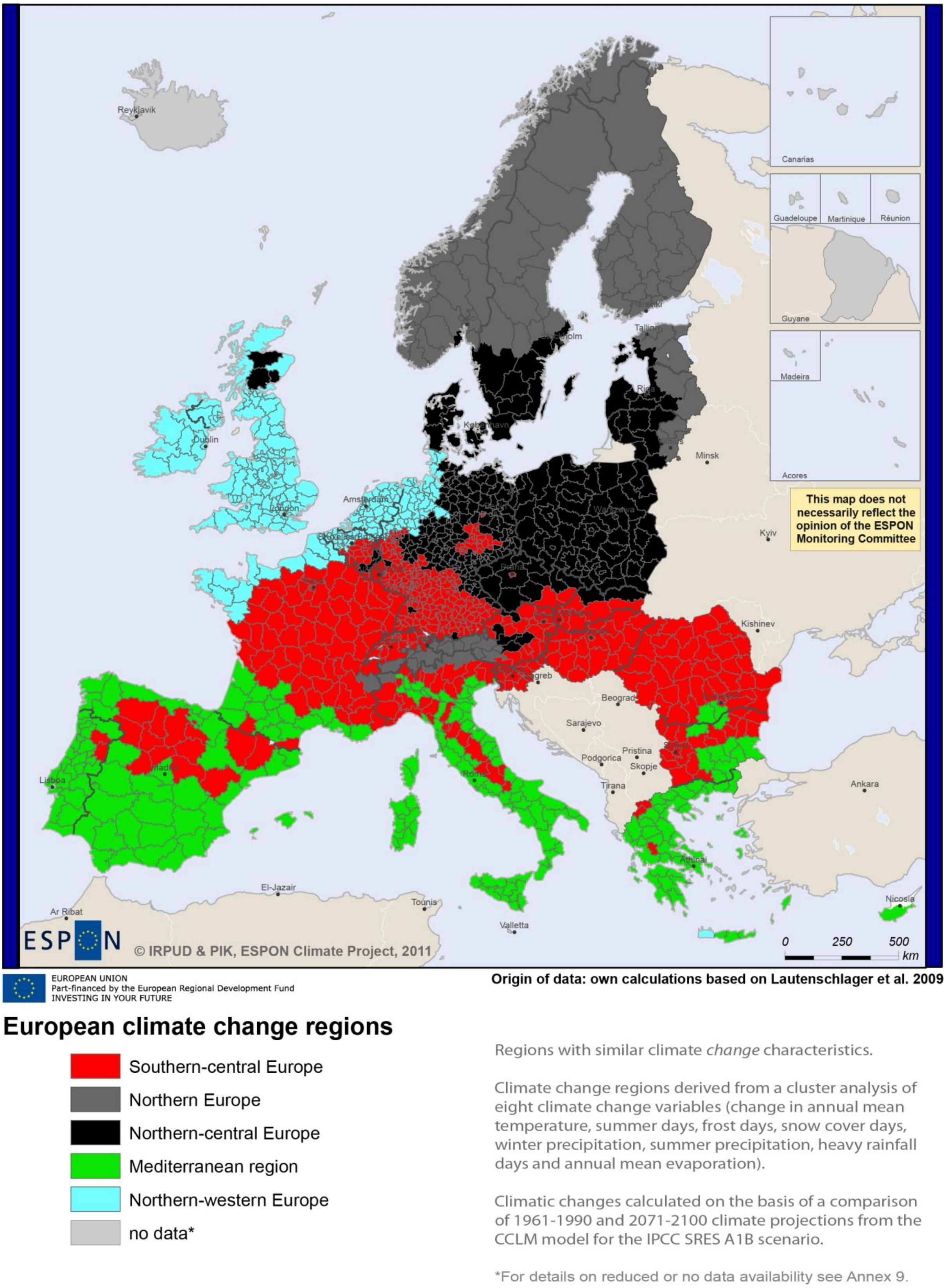


Figure 8: European Climate Change Regions (Source: ESPON Climate 2011 © ESPON, 2013)

Table 1: Different types of regions characterised by climate change based on cluster analysis (Source: ESPON Climate 2011)

Cluster/stimuli	Northern central Europe	Northern western Europe	Northern Europe	Southern central Europe	Mediterr-anean region
Change in annual mean temperature	+	+	++	++	++
Decrease in number of frost days	--	-	--	--	-
Change in annual mean number of summer days*	+	+	0	++	++
Relative change in annual mean precipitation in winter months	+	+	++	O	-
Relative change in annual mean precipitation in summer months	-	-	O	--	--
Change in annual mean number of days with heavy rainfall	O	+	+	0	-
Relative change in annual mean evaporation	+	0	+	0	-
Change in annual mean number of days with snow cover	-	0	--	0	0

Key

++ : Strong increase

+ : Increase

0: Insignificant stimulus for the characterisation of the cluster

- : Decrease

-- : Strong decrease

* - number of days with temperature over 25°C

The ESPON and EEA overviews of climate change impacts offer a broad insight into the key climate change hazards facing different European regions in the future. The EEA's biogeographical regions, which are independent of political boundaries, are designed to progress regulations and initiatives linked to flora and fauna and associated habitats and ecological networks. They nevertheless provide a useful template to visualise the spatial implications of climate change across the continent. ESPON's European Climate Change Regions were developed specifically to identify regions with similar climate change characteristics, and therefore represent a more tightly defined and rigorously evidenced spatial picture.

The available data is good enough to make broad statements about the future climate of Europe and the spatial variability of climate hazards at this scale. For example, it appears that a city in the Mediterranean is more likely to be exposed to extreme temperatures in the summer months than a city in north-western Europe. Similarly, a city in north-western Europe appears more likely to suffer from winter flooding or localised surface water flooding from high intensity rainfall events than a city in the Mediterranean.

European scale data is most useful to those who take a pan-European perspective, such as EU policy makers who need to gain a broad understanding of the variable patterns of climate change hazards facing different European regions. It has some benefits at city scale too. Climate change does have international implications, linked to issues such as food security and migration. Gaining an understanding of climate change at a continental scale can increase an individual city's perspective of their relationship to these broader issues. However, climate change impacts vary considerably at a finer scale, even within a city, according to issues such as urban densities or location (Lindley et al 2006). While European and European region-scale hazard data can usefully provide broad inferences about hazards at a city scale, cities should not use this data to provide a concrete basis for detailed planning in specific cities.

National level assessments are also available for some countries. Examples include climate change projections available for Denmark, Germany and the UK, but even these can be at a scale that offers little more to city planners than the European scale projections. The United Kingdom Climate Projections (UKCP09) (Murphy et al 2009) is one of the most sophisticated national scale climate projections suites currently available. They offer probabilistic data over seven 30-year time periods on future climate variables. Projections are available for each cell within a 25km² grid covering the UK as well as 16 administrative UK regions and 23 river basin districts. This provides a platform for UK city policymakers to identify their 25km² grid cell, and then obtain comprehensive climate change projection data for a range of variables. In practice even this scale is too coarse for the development of intra-urban adaptation strategies, with detailed adaptation planning exercises benefiting from further downscaling. Examples include research undertaken in Greater Manchester (Cavan 2011), which developed projections for several climate zones across the conurbation. However, many European countries do not have access to this type of data and their cities can often only draw on European and European regional scale data in order to be able to gain an insight into their future climate.

4.2 Vulnerability to climate change in European cities

Chapter 3 outlined the vulnerability definition followed by this report; that of vulnerability as an existing state from which hazards are experienced. In simple terms, the vulnerability of a city is determined by a combination of factors that influence the exposure and sensitivity of a city's population and assets to harm from a given climate change hazard.

With their heavy reliance on infrastructure networks, high population densities, large numbers of poor and elderly people and major concentrations of material and cultural assets, cities are particularly vulnerable to climate change (EEA 2010a, Schauser et al 2010). With the highest population density of any continent (60 persons/km² and the greatest degree of urbanisation (73% live in urban areas) (EEA 2006a, IPCC 2007), Europe faces particular challenges. Other social, economic and political processes also enhance city vulnerability such as poor governance structures or inadequate urban design (Schauser et al 2010, EEA 2012). Urban systems and infrastructures are linked together to make them interoperable meaning that a change in one system may affect the functioning of another (Wilbanks et al 2007, Schauser et al 2010).

Despite the complexities of defining vulnerability, place and context are key influences. Vulnerability therefore lends itself well to spatial analysis (for example see Lindley et al 2011). Drawing on recent research, the two core elements of vulnerability, exposure and sensitivity to climate change hazards in Europe, are considered from this perspective.

Exposure

Alcamo and Olesen (2012) provide a tentative list and high-level overview of the most vulnerable areas of Europe up to the 21st Century (Box 4). This list covers vulnerability due to exposure to hazards, and not the sensitivity of elements at risk. Cities in these areas can be regarded as being vulnerable for this reason. Wilbanks et al (2007) stress that cities (and development within them) are increasingly located in areas where exposure to climate change hazards is potentially high, for example in coastal areas, on slopes and in ravines. This occurs when land availability is reduced over time, pushing development into more marginal locations. Socio-economic changes can influence a city's level of exposure to climate change hazards. For example, population pressures can increase the number of houses built in flood prone areas (EEA 2012).

Box 4: The most vulnerable areas of Europe up to the end of the 21st century

(Source: Alcamo and Olesen 2012: 209)

- The particular stretches of Europe's coastline facing a growing risk of flooding and erosion owing to increased storminess and sea level rise; particularly vulnerable areas existing along the south coast of the North Sea, in the Baltic Sea region and along low-lying coastal stretches of the Mediterranean, Adriatic and Black Sea.
- The Mediterranean regions, which is threatened by a combination of warmer and drier conditions leading to longer and more frequent droughts, aggravated water scarcity, declining crop productivity, and higher fire risk.
- Mountainous regions subject to stress due to increasing temperatures, a shift in the form of precipitation from snowfall to rainfall, reduced snow cover, melting permafrost, accelerated glacier melting, changing river hydrology, destabilised slopes and more frequent rock falls.
- The cities of Europe, particularly in its central and southern parts, which will be increasingly exposed to warmer average summer temperatures and short term heat waves as in 2003.
- Agriculture in south eastern Europe, where higher summer temperatures and more frequent droughts will greatly reduce crop yields, but where winters remain too cold to allow for crop growth.
- Lower-lying, densely populated areas along rivers throughout much of Europe, which are threatened by more frequent flooding due to the increasing volume and intensity of winter precipitation.
- The Arctic and sub-Arctic regions, where large areas of permafrost will disappear and infrastructure and housing will need to be rebuilt, and current ecosystems are greatly threatened.

It is clear that levels of exposure to climate change hazards in cities can be altered by issues linked to urban form and design. The following quote from the EEA brings this issue to the fore:

> *The vulnerability of cities depends critically on the way urban areas are built. Urban design, and ultimately land cover and land usage, can aggravate climate change impacts, for example through soil sealing contributing to the heat island effect and flooding caused by water run-off* (EEA 2012: 23).

Schauser et al (2010) highlight the role of urban green space in this context, noting that vegetation cover influences the hydrological cycle and temperatures in cities. Higher levels of green space can therefore lower levels of exposure to high temperatures (through shading and evapo-transpiration) and surface water flooding (through increasing infiltration capacity) (Gill et al 2007). In effect, the design of cities creates 'unique micro-climates' that affect climate variables including temperature and wind (EEA 2012), with the physical structure of urban areas influencing their vulnerability to climate change (EEA 2010a).

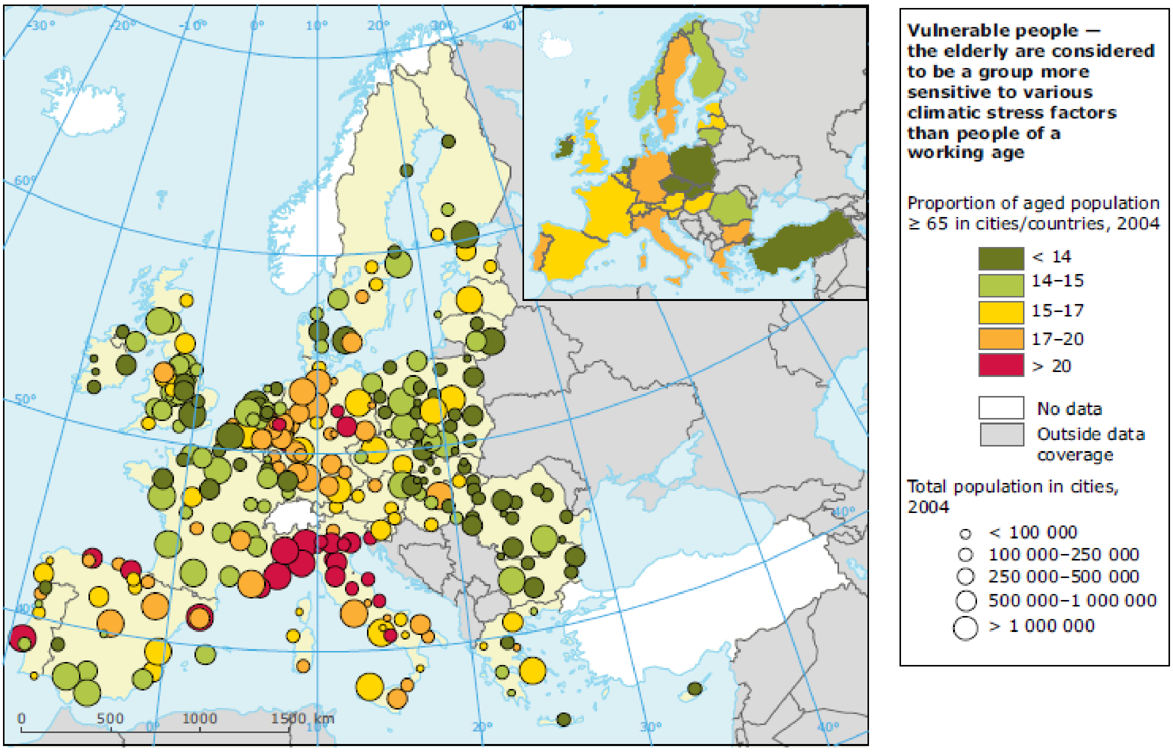
> *While urban areas will generally experience the same exposures to climate change as surrounding regions, the urban setting can alter this as well as any potential local impacts* (EEA 2012: 6).

The urban heat island effect, where cities are warmer than their surrounding hinterlands, is a key example of this feature of urban areas (Gartland 2008). The impacts associated with heat stress are, as a result, intensified in urban areas. At a finer scale, building type and even location within a particular building can influence levels of exposure to climate change hazards. For example residents in top floor flats are at greater threat of exposure to heat stress, whilst residents in basement apartments are more likely to be exposed to flood waters (Lindley at al 2011).

Sensitivity

The issue of vulnerability to climate hazards such as heat stress covers not only urban form and design, but also characteristics of the element at risk from this climate change hazard. In terms of people, factors influencing sensitivity to heat include age and physical and mental health status (Lindley et al 2011, EEA 2012). Generally, the same factors also influence sensitivity to flood risk (Lindley et al 2011, EEA 2012). The EEA have mapped the proportion of elderly people in

European cities, a group considered to be vulnerable to climate change hazards more generally (Figure 9). Spatial patterns are revealed, including the high numbers of elderly people in southern France and northern Italy.



Note: Total population in cities; proportion of population aged ≥ 65.
Data for Bulgaria, Cyprus, Czech Republic, Finland, France, Ireland and Latvia are from 2001.

Source: Eurostat, Urban Audit database, 2004.

Figure 9: Vulnerable people in Europe's cities (Source: EEA 2012)

ESPON's indicator on 'social sensitivity', based on indicators including public health and personal mobility, highlights areas of Europe where the population is particularly prone to the effects of climate change from hazards including floods, storm surges and heat waves (Figure 10). The areas of Europe with the highest social sensitivity include coastal regions in the Netherlands, Belgium, Spain and Italy.

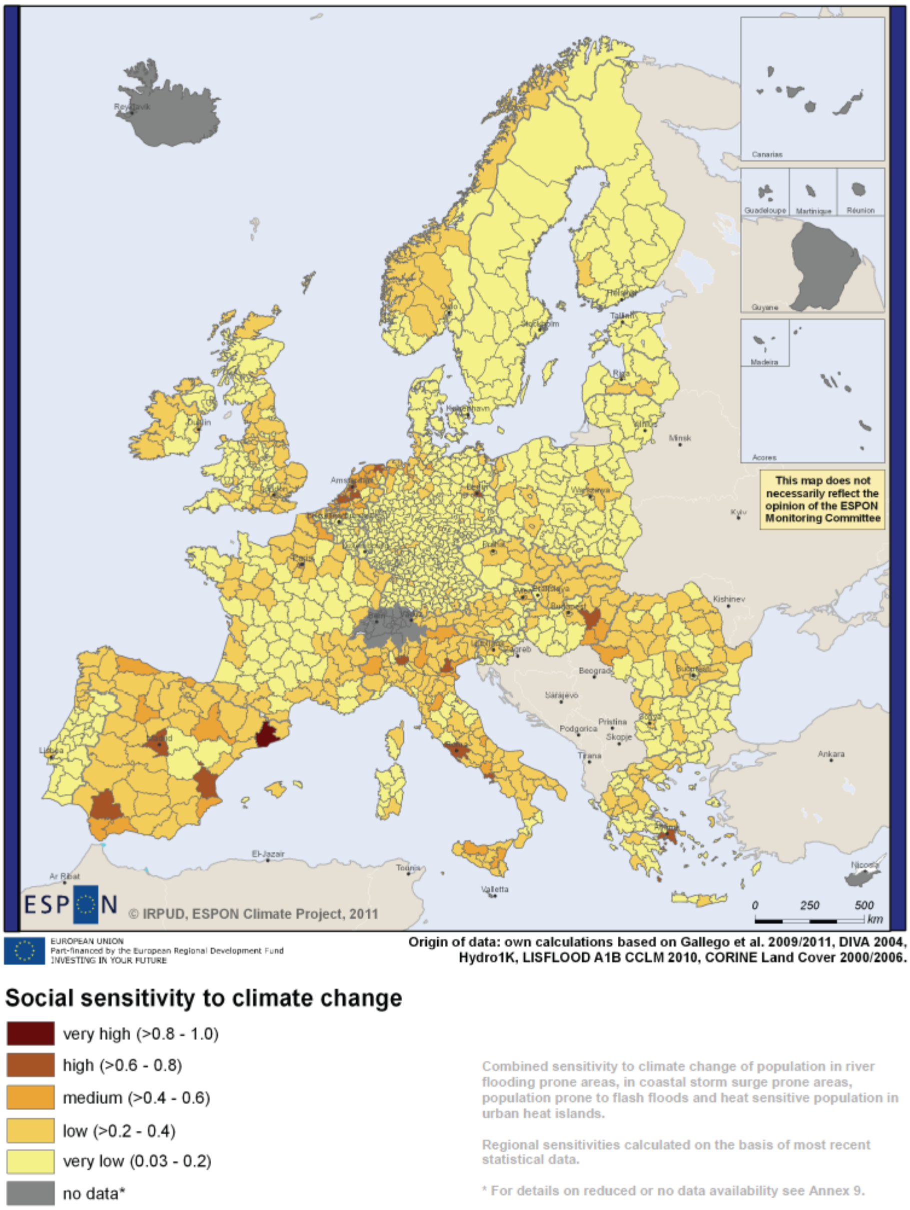


Figure 10: Combined social sensitivity to climate change (Source: ESPON Climate 2011)

Taking a wider perspective on vulnerability to climate change, it is clear that it connects to issues of social justice and inequality. As poorer and disadvantaged members of society often disproportionately shoulder the impacts of climate change (Semenza et al 1996, Tapsell et al 2002), reducing this potential threat can help to advance social goals in terms of recognising and acting upon the apparent inequality in terms of vulnerability to climate impacts.

4.3 Assessing vulnerability in European cities

Recent reports by European agencies and organisations have progressed the consideration of vulnerability to climate change in the context of European cities (Schauser et al 2010, EEA 2012). For example, Schauser et al (2010) reviewed available literature and research outputs to test and assess the feasibility of climate change-related vulnerability indicators for urban areas. They compare different models of vulnerability indicators and note the influence of data issues on the potential effectiveness of vulnerability assessments. They also looked at various attempts to apply and map these indicators in urban regions based on existing research.

Vulnerability assessments at the city-scale must initially understand which elements of cities affect their ability to function effectively. Important in this regard are, physical, environmental, social, economic and cultural actors, entities and systems (and the connections between them). These are described as 'elements at risk and are discussed in chapter 3. It is then necessary to consider indicators that reflect the susceptibility of these elements to harm caused by climate hazards. Conceptually, these indicators link to the exposure and sensitivity of the elements at risk. In comparison to climate change hazards, relevant city-scale data on indicators connected to climate change vulnerability is more comprehensive. However, for certain climate hazards such as heat and fluvial floods there is a greater level of consensus on representative indicators, whereas this is not the case for hazards such as water scarcity and drought and pluvial flooding (Schauser et al 2010).

Socio-economic data sets offer decision makers a useful resource for understanding vulnerability to climate change hazards in European cities. European level sources include the Urban Audit and EUROSTAT. Census data is available at national levels. The 336 variables in the Urban Audit are useful in this respect. The nine indicator domains that form the basis of the Urban Audit (see section 2.6) cover aspects linked to assessing vulnerability to climate change hazards, although principally concerning sensitivity and not exposure. Similarly, indicators developed for other purposes, such as sustainability measures, may also provide a route into gathering data to assess a city's vulnerability to climate change. However, this is also generally sensitivity-related. For reasons of data availability, as noted by Schauser et al (2010), vulnerability indicators tend to miss the exposure aspect although examples do exist including insurance claims per year and numbers of planning approvals given for new developments within known hazard zones (Jacob et al 2010).

The diversity of factors influencing the vulnerability of cities to climate change presents a complex picture to those looking to understand the issue in more detail. The core issues underlying vulnerability, exposure and sensitivity, also interact. For example, building quality (insulation, availability of cooling) combines with the sensitivity of its residents (age, health) to determine vulnerability levels. The IPCC acknowledge that further work is needed, whilst also pointing out the challenges that this poses to researchers:

> *Further elucidation of this concept [vulnerability] requires highly interdisciplinary, integrative approaches that are able to capture bio-geophysical and socio-economic processes* (Schneider et al 2007: 804).

Adding to this complexity, factors that influence vulnerability of cities to climate change can shift rapidly. Not only is the climate changing, but so are the elements at risk from climate hazards. Changes within cities have the potential to exacerbate or moderate vulnerability (Schneider et al 2007). For example, an aging population may increase the proportion of a city's population that is vulnerable to heat waves, while future development and growth in urban areas could increase the number of people and assets potentially exposed to flooding (EEA 2012).

4.4 Climate change in European cities: a focus on specific themes

Moving beyond the generic pan-European data outlined above, this section looks in greater detail at selected hazards and associated vulnerabilities and impacts. The hazards are:

- Sea level rise, storm surges and coastal flooding.
- Flooding from rivers.
- High temperatures and heat waves.
- Water scarcity and drought.

These are selected for several reasons. Firstly, they are felt across wide geographic areas and will potentially influence a large number of European cities. Thematically, recent reports in this area have taken a similar focus. For example, the EEA's (2012) report on urban adaptation in Europe focused on heat, flooding and water scarcity and droughts. Clearly, other climate hazards are prevalent at a European scale. They including changes in the frequency and intensity of storms (including high winds) and wild fires, and the influence of climate change on ground stability (subsidence, landslides etc), surface water flooding, water quality and air quality. However, these hazards have not received the same degree of attention, and Schauser et al (2010) note that associated vulnerability indicators have not been developed at the appropriate scale to progress their understanding at the city scale. Issues such as difficulties in quantifying projections for key variables such as wind speed (Murphy et al 2009) act as barriers. These hazards will variously impact on cities and should therefore ideally receive additional attention from researchers, policy makers and practitioners to enable more comprehensive analyses to be undertaken.

An overview of each of the selected four hazards is provided looking at European scale data and, where available, information at the city-scale. Data and insights into factors influencing the vulnerability of 'elements at risk' to these different hazards are also highlighted. Both recorded and potential impacts linked to the four hazard themes are considered where data is available. In the context of this report, and following the ARC3 framework, impacts occur where a sensitive element at risk is exposed to a climate hazard, and the 'change agents' have insufficient capacity to moderate the effect of the hazard.

4.4.1 Sea level rise, storm surges and coastal flooding

Historically, the importance of port cities found along the European coast has resulted in high population densities, concentrations of economic assets and activities, which combine with their sensitive ecosystems to render them particularly vulnerable to this climate change hazard (Brown et al 2011, Ciscar 2009). There are strong connections between sea level rise, storm surges and coastal flooding. In Europe, the negative effects of sea level rise on populations (and infrastructure, assets and biodiversity) will be principally felt in association with coastal storm surge events (ESPON Climate 2011), which in turn results in coastal flooding. Due to the heat storing capacity of the oceans, the world is committed to significant sea level rise over the coming centuries due to thermal expansion alone (Richardson et al 2011). Continuing greenhouse gas emissions this century will inexorably commit the world to higher sea level rise in the next. The European Environment Agency notes that the impacts of sea level rise are expected to be 'overwhelmingly negative' (EEA 2010a: 16).

Sea level rise, storm surges and coastal flooding: key impacts for European cities

Potential impacts in coastal areas include coastal flooding (with implications for people, buildings and infrastructure), coastal erosion, saline intrusion to aquifers and agricultural land and damage to coastal biodiversity and ecosystems (EEA 2008). The extent of these impacts in the future depends on the climate change scenario chosen (and therefore the severity of the hazard), the degree to which elements at risk are exposed to the hazard, and the extent of future adaptation responses. The case of the 1953 North Sea floods, which resulted in particularly serious impacts in the Dutch province of Zeeland, highlights the implications of coastal flooding and storm surges (see box 5). Here a particularly severe hazard event affected an area with high exposure to such events due to its concentration of development on low lying land, and resulted in major impacts to people, property and infrastructure. The subsequent legislative and engineering response of the Netherlands to addressing a future hazard of this kind is a classic example of building adaptive capacity.

Projections within the IPCC's 4th Assessment Report put potential global sea level rise (including the contribution from melting ice caps) at between 0.18 and 0.76 metres by the end of this century depending on the chosen scenario (IPCC 2007). However, it is now apparent that sea levels are rising at a pace above that projected by the IPCC (Richardson et al 2009). In Europe, sea levels have risen by 3.1mm per year over the last 15 years, which is significantly above the global average for this period of 1.7mm per year (EEA 2008). Further, the pace of increase has been rising over recent decades, with sea levels a metre above

1990 levels by 2100 now being considered a possibility by some scientists (Richardson et al 2011). Indeed, the European Environment Agency note that the IPCC's sea level rise projections may be too low (EEA 2008). Although future sea levels are uncertain, due to lack of understanding of factors including ice sheet melt and the trajectory of future greenhouse gas emissions pathways, significant sea level rise during the course of this century beyond the upper end of the IPCC's projections cannot be discounted (Hansen 2007). This will put considerable pressure on European coastal cities and, since they function as important trade hubs with strong networks and connections to inland cities, they too will be affected. Moreover, resulting changes in economic geography and associated migration effects could pressure infrastructure and services in non-coastal cities.

From a European perspective, sea level rise around the upper levels of the IPCC's projections would be potentially catastrophic for some locations. Indeed, in Europe, the land one metre or less above sea level equates to an area roughly the size of Greece (EEA 2010a). 12% of the EU's coastal zone (that is land within 10km of the coast) is 5 metres or less above sea level, with the North Sea and Atlantic coasts currently having greatest of exposure to resulting coastal flooding (EEA 2006b). 38.5% of the population of the EU 27 countries lives within 50km of the coast (European Commission Directorate-General Regional Policy 2009). Potential exposure to coastal flooding is therefore very high. It has been estimated that, at a European scale, one metre of sea level rise would lead to 139, 000 km² of land area and 13.6 million people affected by coastal flooding, with €305.2 billion losses in GDP (Anthoff et al 2006).

The implications of sea level rise in the future have been studied within some research projects working at the European scale. Brown et al (2011) project that by 2080, under a medium to high emissions scenario, 250,000 people may be flooded annually due to sea level rise, storm surges and associated coastal flooding. By this point, up to 438,000 people may need to relocate inland due to annual flooding in coastal zones (Brown et al 2011). The levels of future damages associated with sea level rise, including number of people flooded and amounts of land inundated, depend on issues including geographical location, the vulnerability of receptors, the extent of adaptation responses and the climate change scenario chosen. The latter issue is highlighted by the PESETA (Projection of Economic impacts of climate change in Sectors of the European Union based on boTtom-up Analysis) project (Ciscar 2009).

Box 5

Storm Surges – The North Sea Floods, 1953

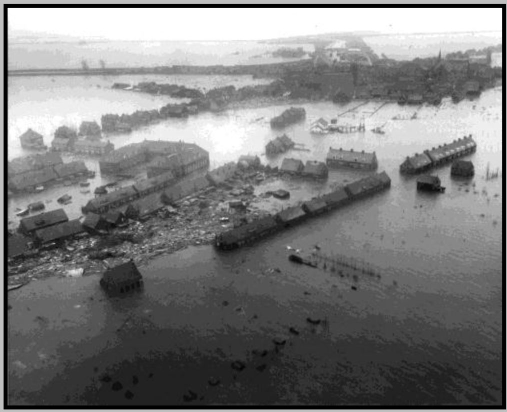


Figure 11: Oude-Tonge on the island of Goeree-Overflakkee, The Netherlands. Viewed from a U.S. Army helicopter. US National Archives and Records Administration, cataloged under the ARC Identifier (National Archives Identifier) 541705.

Two-thirds of the Netherlands is at risk of flooding and 52 per cent of inhabitants live below sea level, which has clear implications for projected sea level rise (McRobie et al 2005). Historical examples exemplify the potential gravity of the circumstances. In 1953, a severe storm track reached the Dutch coast during high tide resulting in a series of storm surges that, at their highest point, reached 4.55m above 'Normal Amsterdam Water Level'. Although similar weather and tidal patterns are seen in the United Kingdom, the Dutch coast experiences these differently because of its position and form of the coastline (Gerritsen 2005)

Existing flood protection measures were quickly breached, particularly in the province of Zeeland. The total area flooded was 165,000 hectares with 1, 836 human casualties as a direct result. Approximately 100, 000 people were evacuated. The damage to buildings, dikes and other infrastructure was enormous and took many years to rectify. Gerritsen (2005) indicates that the human exposure to stress continued long after the event.

Recognition that insufficient flood protection measures and a general lack of preparedness worsened the impacts of the storm surge eventually led to the establishment of the Delta Commission and the Delta Works engineering project to improve flood defences. The international reinsurer, Munich Re, believes that a similar event, with a statistical return period of 100 years or more, remains a significant potential threat particularly in regard to the enormous value and high population density around the North Sea coast line (Berz 2005).

Table 2, which draws on data from the PESETA project, includes the number of people flooded in different regions of Europe by 2085 under five different climate change scenarios. The 'A2 ECHAM4 high SLR' scenario assumes an increase in sea level of 0.88m. For their sea level rise analysis, the PESETA project took a reference year of 1995, which puts the number of people across the EU currently at risk from coastal flooding at 36, 000. Table 2 demonstrates that even under the lowest emissions scenario this figure rises to 775, 000 by 2085, although this assumes no adaptation response in the interim. This table also highlights the regional differences in number of people affected by flooding across the continent. Although there are differences according to the climate change scenario, central northern Europe and southern Europe appear to be potentially most severely affected by coastal flooding over the coming decades. It is worth noting that the high sea level rise scenario used within the PESETA project is somewhat above the upper end of the IPCCs 2007 projections, but less than statements from others (such as Richardson et al 2011). Richardson et al (2011) suggest that sea level rise of one metre by the end of this century is possible.

Studies that have addressed the economics of climate adaptation in coastal areas have tended to focus on sea level rise (Policy Research Corporation for the Directorate-General for Maritime Affairs and Fisheries 2009). The economic impact of sea level rise linked to climate change in Europe, and associated impacts such as coastal erosion and salt water intrusion, are placed at €11 billion by 2050s (mid estimate) and as high as €25 billion by the 2080s. Under higher sea level rise scenarios these costs rise dramatically, for example to €156 billion under a 1 metre sea level rise scenario (Brown et al 2011). It is worth noting that this degree of sea level rise should not be regarded as a remote possibility (Hansen 2007, Richardson et al 2011).

Table 2: Number of people flooded (1000s/year) in selected climate change scenarios with high climate sensitivity, without adaptation by 2085 (Source: Ciscar 2009)

	Climate change scenarios				
	B2 HadAM3h 2.5ºC	**A2 HadAM3h 3.9ºC**	**B2 ECHAM4 4.1ºC**	**A2 ECHAM4 5.4ºC**	**A2 ECHAM4 high SLR**
Northern Europe People flooded (1000s/year)	20	40	20	56	272
British Isles People flooded (1000s/year)	70	136	86	207	1,279
Central Europe North People flooded (1000s/year)	345	450	347	459	2,398
Central Europe South People flooded (1000s/year)	82	144	85	158	512
Southern Europe People flooded (1000s/year)	258	456	313	474	1,091
EU People flooded (1000s/year)	**775**	**1,225**	**851**	**1,353**	**5,552**

Future sea level rise, storm surges and coastal flooding in Europe: a spatial perspective

There are clear spatial patterns concerning the severity of potential impacts associated with coastal flooding in Europe. Significant factors that influence the vulnerability of a location to this climate hazard include altitude above sea level, tidal ranges, population density and concentrations of infrastructure and built environment assets (European Commission Directorate-General Regional Policy 2009). These factors relate to both the exposure and sensitivity of coastal locations. Several studies have attempted to highlight the spatial implications of sea level rise at a European scale. The EEA (2010b) indicates that France, Latvia, the Netherlands and the United Kingdom face the most serious threat. Associated economic costs, relating principally to coastal flooding and saline intrusion, are expected to be the highest in the Netherlands, followed by France, Germany and the United Kingdom (EEA 2010b). The bulk of assets potentially exposed to sea level rise and coastal flooding concentrate in three cities: Amsterdam, London and Rotterdam (EEA 2010b).

At a finer spatial scale, ESPON (ESPON Climate 2011) looked at the distribution of impacts linked to sea level rise and coastal flooding in NUTS 3 regions. Key findings include that exposure to coastal storm surges is highest in the Netherlands and Belgium, and locations including north eastern Italy, western France and eastern England. Potential impacts on populations are also generally highest in these areas, particularly the coastal lowlands of Netherlands and Belgium. Projecting forward to 2100, these general patterns prevail. Spatial patterns of distribution of damages and costs linked to sea level rise vary widely across Europe, with the north-west of the continent having the highest potential damages (Brown et al 2011). The majority of reports and studies hazard remain at European regional level and do not consider individual cities. Nevertheless, several studies that have focused on cities in this context.

A report from the OECD (Nicholls et al 2008) looks at the current (based on 2005 data) and potential future (based on 2070 scenario projections) impacts of coastal flooding on populations and assets in key global port cities. Data for European cities that are covered by this report are included in Table 3. Based on 2005 data, Amsterdam and Rotterdam are in the top 10 of a total of 136 port cities with more than one million inhabitants when measured against assets exposed to coastal flooding. By 2070 numbers of people and value of assets in port cities exposed to coastal flooding increases worldwide due to multiple factors including climate change and urbanisation. The report also emphasises that exposure to sea level rise does not automatically translate into impacts. Impacts may be high where sensitive population and assets are potentially exposed, but actual impacts may be much less in the event of flooding due to protection offered by coastal defences.

Table 3: European port cities over 1 million population: current and future exposure to coastal flooding (Source: Nicholls et al 2008)

City	**Current climate + current population/assets**				**Future climate + future population/assets**			
	Exposed pop (000)	**Exposed pop ranking**	**Exposed assets (US$bn)**	**Exposed assets ranking**	**Exposed pop (000)**	**Exposed pop ranking**	**Exposed assets (US$bn)**	**Exposed assets ranking**
Amsterdam	839	15	128.33	6	1425	24	843.70	14
Athens	3	127	0.28	118	5	132	2.19	127
Barcelona	11	108	1.41	81	20	116	10.38	94
Copenhagen	25	82	4.42	53	47	91	31.48	73
Dublin	16	95	3.26	62	43	94	33.38	72
Hamburg	261	37	39.39	18	255	60	127.27	44
Helsinki	6	119	1	89	13	121	7.74	100
Lisbon	40	71	3.88	57	90	77	33.43	71
Marseille	14	102	2.04	78	21	115	9.89	97
Naples	2	131	0.33	117	5	133	2.47	126
Porto	14	103	1.33	82	22	114	8.17	98
Rotterdam	732	17	114.89	7	1404	25	825.68	15
Stockholm	3	128	0.39	115	8	130	4.58	115

An investigation of the economic impacts of sea level rise and storm surges in Copenhagen found that the city is currently not at high risk of coastal flooding (Hallegatte et al 2008). Nevertheless, in a future scenario twinning 50cm of sea level rise and a 1:120 year storm surge event, and where flood protection is inadequate, economic costs could run to €5 billion. Protecting the city with high dykes is therefore recommended, and is promoted as an adaptation response with high net economic benefits in terms of costs avoided.

Hallegatte et al (2008) note that most world cities do not exhibit the same characteristics as Copenhagen in this respect; that is low level of potential exposure to sea level rise/storm surges and high levels of protection to these hazards. Climate change will enhance what are already high risks in many cities to unacceptable levels, with comprehensive adaptation responses therefore needed to stymie the damaging consequences for people and assets. Furthermore, projected warming this century will have very significant long term effects on sea level rise, the implications of which should therefore ideally be considered over timescales beyond the end of this century.

4.4.2 River flooding

Damaging floods result from an interaction of biophysical and socio-economic factors. In Europe, river floods are principally associated with long spells or intense bursts of precipitation in the winter months, and snow melt leading to high river levels in the spring months (ESPON Climate 2011). Human activity, linked to land use and socio-economic change, has a significant bearing on the frequency and magnitude of river floods (EEA 2009b, ESPON Climate 2011). Europe’s major cities are often situated along rivers, due to their historic value as transport routes which continues into the present day (ESPON Climate 2011). Many cities carry with them a legacy of development sited in areas at risk of flooding, often more so where development pressure has been high over recent decades. This enhances their potential exposure to river floods. The changing climate and the projected increases in frequency and intensity of floods in some parts of Europe therefore pose particular challenges for Europe’s cities.

> *People living in river valleys are one of the most sensitive population groups in regard to climate change. This is because climatic and resulting hydrological changes taking place in entire river basins accumulate and are ‘channelled’ through the rivers. In a way rivers can thus be considered amplifiers and transporters of climate change effects* (ESPON Climate 2011: 56).

River floods: key impacts for European cities

According to existing observations, flooding is one of the most significant natural hazards in Europe in terms of economic losses (EEA 2010b). Two-thirds of economic losses from all natural disasters occurring in Europe between 1998 and 2009 came from floods and storms. This is due to the large area that these events can cover (EEA 2010b) and also the concentration of people and assets in river valleys (ESPON Climate 2011). Not only do river floods inflict huge socio-economic damage to Europe's cities (Pitt 2008, EEA 2010b) but they are also a source of social and psychological distress for their inhabitants. Across the continent, river floods were responsible for 1, 100 deaths and affected more than 3 million people between 1998 and 2009. Over €60 billion in direct economic losses (based on 2009 values) were linked to flooding over this period. Dresden was particularly badly affected by floods in 2002. Box 6 provides further details of this event. An unprecedented flood resulted in major impacts to people, infrastructure, agriculture and cultural assets, which were highly vulnerable to flooding due to their exposed location.

Box 6

Flooding of the River Elbe – Dresden, 2002

Figure 12: The Semper Opera House in Dresden during floods, August 2002. Source: Feuerwehr Dresden

The river Elbe flows into Germany from the Czech Republic, and has many significant cities on its banks including Prague and Dresden. In August 2002, 100 to 200 mm of rainfall was recorded over three days, around two to four times the monthly average. The water level of the River Elbe in the historic city of Dresden reached 940 cm, exceeding the previous high mark by 63 cm (Kundzewicz et al 2005).

The resultant floods severely affected people, buildings and infrastructure in Dresden. Over 300, 000 people were affected, with a total of 27 deaths. Dresden's central train station was flooded to a depth of 1.5 m. Residents barricaded the streets with sandbags in order to protect the city's cultural monuments, such as the Semper Opera and the Zwinger Gallery (Kundzewicz et al 2005).

Existing flood defence measures were unable to cope with the severity of the flood. It is regarded as the most expensive natural hazard in Germany in recent years. Financial losses accrued from decreased business productivity and damage to private and commercial property, as well as the costs linked to the damage to homes and infrastructure. The combined flood damage was estimated to be €9.2 billion (Kundzewicz et al 2005). In Dresden, losses to residential buildings alone totalled €304 million (Kreibich and Thieken 2009). There was also significant harm caused to agriculture and thousands of fish died (Mueller 2003).

Trends suggest that the financial and human impacts of river floods have increased across Europe (EEA 2010a, EEA 2010b, ESPON Climate 2011). Socio-economic and land use changes linked to rising populations, higher levels of wealth and greater exposure of people and assets in locations prone to flooding are key underlying factors (Barredo 2009, EEA 2010b). Climate change does not yet stand out as a contributory factor (ESPON Climate 2011). However, studies from the University of Oxford found that the 2000 flood events in the UK were made more likely by increases in greenhouse gases and associated climate change (Pall et al 2011).

The focus of flooding studies has tended to be on people and economic impacts. The implications of flooding for infrastructure have generally not been researched in as much detail, although there are exceptions (URS Corporation Limited 2009, RAE 2011). Maintaining continuity in the provision of services offered by different infrastructures is central to the effective functioning of cities. These include energy, transport, water supply and waste water treatment infrastructure, all of which are vulnerable to flooding (URS Corporation Limited 2009).

Transport networks are crucial to any city's productivity, communication and competitiveness, and can be severely impaired by flood events. Floods can also damage electricity transmission and distribution networks. Water abstraction and waste water treatment infrastructure is often sited near to rivers due to the need for ready access to untreated freshwater, making them one of the first infrastructures to be impacted by river flooding (Wilbanks et al 2007). There are also important interdependencies between infrastructures, for example water supply and energy that are threatened by floods. Ultimately, many key urban infrastructures are fixed assets with long life spans, yet were not designed to be resilient to the pressures that the changing climate is projected to impose on them. Indeed, much infrastructure was designed to standards that assume that climate remained a constant (Ecologic Institute et al 2011). In some UK cities, for example, there is a legacy of Victorian era urban water supply and waste water treatment pipe work. This is worrying, and adaptation of critical infrastructure has the potential to be a particularly challenging issue for cities in the coming decades. There is a clear need to align understanding of climate change risk and adaptation with infrastructure projects and sectors.

Future river flooding in Europe: a spatial perspective

Increases in annual river flows have been observed in northern Europe, with decreases in southern Europe, with these trend projected to continue over the 21st century (EEA 2010b). Analysis of recent major floods reveals some spatial concentration of events. Twenty-six major flood disasters were recorded between 2003 and 2009, with the countries affected most frequently being Romania (six major floods), United Kingdom (five major floods) and Italy (four major floods) (EEA 2010a). Over this period economic losses were highest in the United Kingdom (€5 billion), Switzerland (€2.3 billion), Romania (€2.2 billion) and France €1.6 billion) (EEA 2010b).

Climate change is projected to influence the frequency, intensity and spatial patterns of river flooding. Studies have looked at potential future changes to seasonal patterns of river flooding and the extent of associated impacts. From a broad perspective, in north-western, central and eastern Europe, projections for river flooding indicate increasing frequency and duration of spring and winter river flooding (EEA 2010a).

The PESETA project (Ciscar 2009) established that many parts of Europe can expect to see an increase in frequency of 100 year return river discharge levels. This will increase the probability of river floods, particularly in parts of western and eastern Europe where present day '100-year floods' will become more frequent and intense over the course of this century (Dankers and Feyen 2008, 2009). By the end of the century, inundation depths are projected to increase as a result of climate change in some regions, in northern Italy and eastern Romania for example (ESPON Climate 2011). At a more local scale, negative impacts linked to river floods will increase with climate change. Estimates for the Upper Danube show that economic damages from a 100-year flood event could increase by 19% under the IPCC's lower emissions scenario, and by 40% under their higher emissions scenario by 2100 (European Commission, Directorate-General Regional Policy 2009).

However, in some parts of central and north-eastern Europe (for example Germany, Poland, and Hungary), research indicates that a combination of warmer winters, shorter snow seasons and reduced snow melt will reduce peak spring discharge, lessening the threat of river flooding with inundation depths projected to decline by the end of the century (Ciscar 2009, Dankers and Feyen 2008, 2009, EEA 2008, ESPON Climate 2011).

A study by Hiederer et al (2009) looked at the percentage of land in European cities that would be exposed to flooding under the IPCC's A2 scenario. Figure 13 presents the findings of this research. There are a number of cities in the Netherlands, Belgium, Poland and Romania where over 10% of urban land is exposed to potential floods, which contributes to increasing levels of vulnerability to floods in these areas.

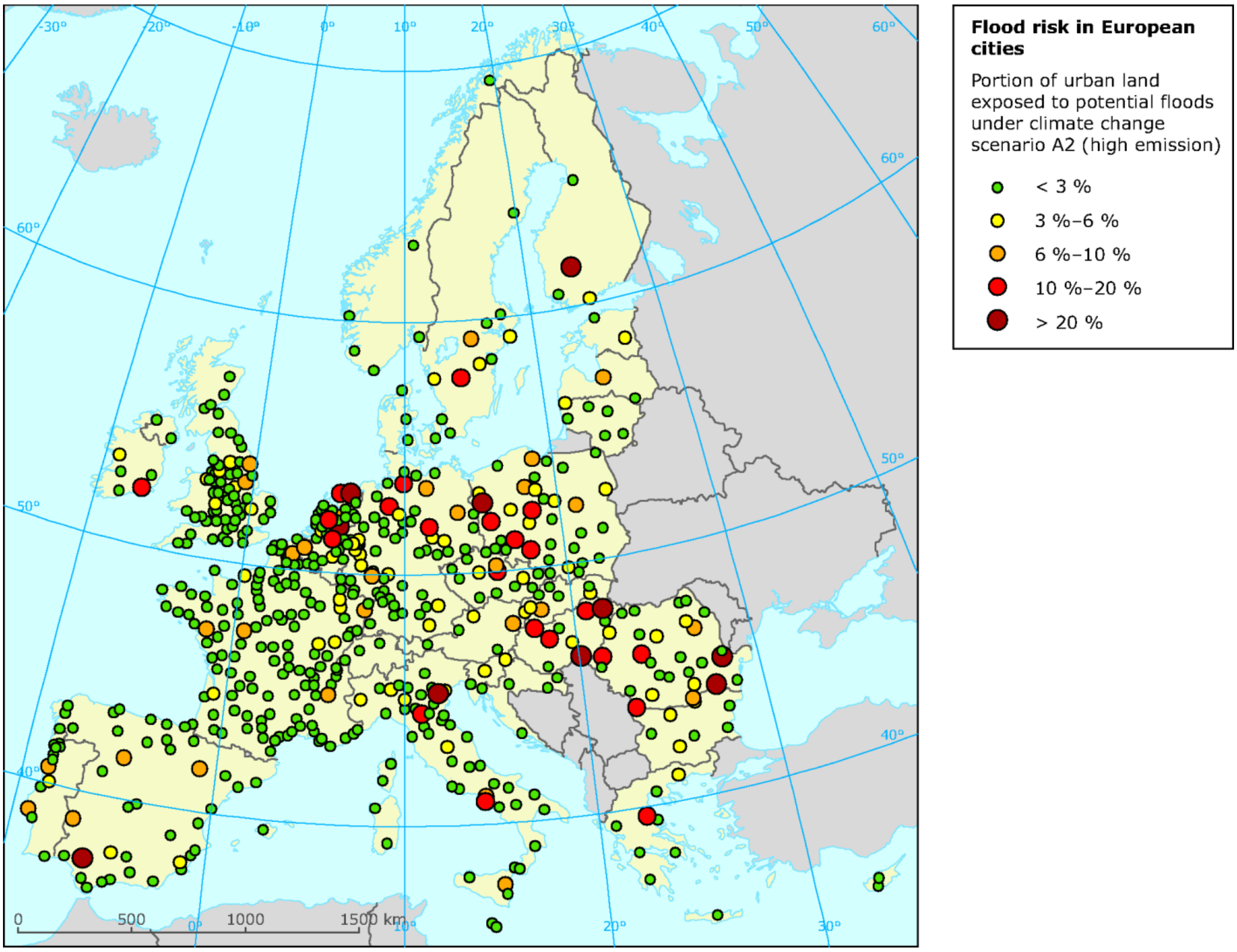


Figure 13: Climate change impacts – exposure to flood risk under the climate change scenario A2 (Source EEA 2009b. Map based on Lavalle et al 2005)

As part of the PESETA project, a 'river flood impact assessment' was undertaken that incorporated a modelling approach to assess economic damages and levels of population exposed under future climate change conditions (Ciscar 2009). At the European scale, Ciscar (2009) estimate that between 250, 000 and 400, 000 more people are projected to be exposed to river flooding by the 2080s than at present (based on a 1960-1990 baseline). Much of this increase is accounted for by central Europe and the British Isles. In terms of economic impacts, it is these regions that are again expected to see the most significant escalation of damages over the course of this century due to their high levels of potential exposure to river floods. Within Europe as a whole, economic damages linked to river flooding are projected to more than double by the 2080s under the higher climate change scenarios (against a 1960-1990 baseline). This is regarded as an underestimate as the modelling approach did not take into account growth in population or increase in the value of assets exposed to floods (EEA 2008**,** Ciscar 2009). Projected impacts of river flooding on people and assets discussed above generally do not take into account possible future adaptation responses and future enhancements of adaptive capacity, and are therefore *potential* rather than actual impacts.

It is clear that the negative impacts linked to river flooding differ considerably according to location and associated levels of exposure to flood hazards. Projected patterns of impacts also vary depending on which climate change scenario is considered. Figure 14 demonstrates that differences are seen both in terms of greenhouse gas emissions scenario selected (the IPCC's B2 - lower emissions - and A2 - higher emissions - scenarios are shown in this figure) but also depending on the climate model used to make the future projections. However, generally, higher emissions scenarios bring increased future river discharges, particularly in central and western Europe and the British Isles. Differences can also be observed depending on which future time slice is considered (Alcamo et al 2007).

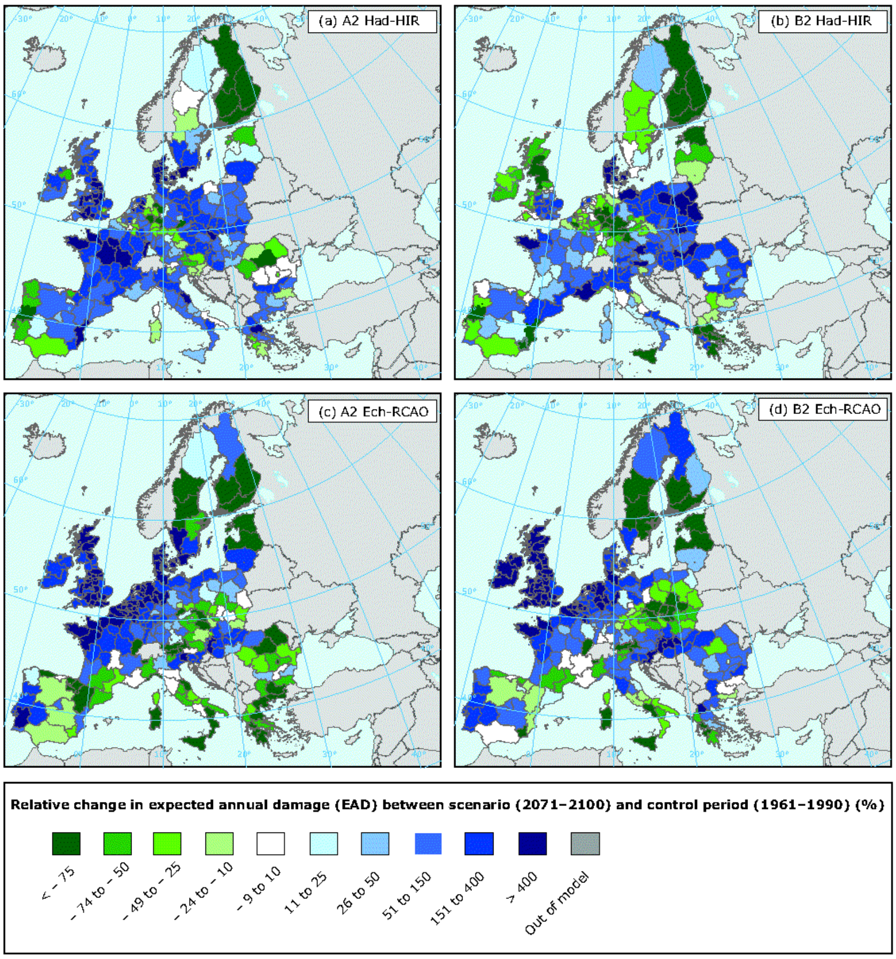


Figure 14: Expected impact of climate change on future riverine flood damage (Source EEA 2010a. Based on Feyen et al 2011)

In Europe, as a consequence of pressures linked to population growth, development has taken place in areas at exposed to flooding (EEA 2009a). This will increase the potential scale of impacts in the future. Of particular concern is additional urbanisation in locations with the potential to be more frequently exposed to floods as a result of the changing climate, for example in northern, central and eastern Europe (Alcamo et al 2007).

Urban development and densification also influences hydrology in urban areas; often reducing infiltration and increasing surface water runoff. Although this section has focused on flooding from rivers, it is important to note that surface water flooding, also sometimes referred to as pluvial, nuisance or intra-urban flooding, is a significant emerging risk to urban infrastructures and populations. This is caused by intense rainfall events that overwhelm the capacity of sewage and drainage systems (Evans et al 2004, White 2010). The impact of surface water floods is often very localised and can happen with little warning. The negative impacts this type of flooding are compounded by the fact that the flood waters are often mixed with sewage, which brings additional health risks. The number of properties at risk of intra-urban flooding in the UK is projected to increase approximately four fold by the 2080s (Evans et al 2004). The likelihood is that without the development of appropriate adaptation responses, this form of flooding will increase across European cities more generally. Schauser et al (2010: 83) found very little information on surface water flooding although city-scale research is evident in Malmö, Rotterdam and London. Further research at the scale of European cities would be valuable in order to better understand this increasingly prevalent climate hazard.

4.4.3 High temperatures and heat waves

As heat waves and high temperature events are measured relative to climatic conditions in any particular location, a universally applicable definition does not exist (EEA 2010b). Nevertheless, it is broadly understood that cities are generally more exposed to heat waves than their surrounding peri-urban areas and rural hinterlands, hence increasing their vulnerability to these events. This is as a result of the 'urban heat island effect' (Gartland 2008, Rosenzweig et al 2011), which is projected to intensify due to climate change (Wilby 2007). A number of factors contribute to this effect; urban infrastructures and residents act as sources of heat, hard surfaces and built structures absorb and retain heat releasing it at night time, reduced vegetation cover due to urbanisation lowers evaporative cooling and the built environment acts as an obstacle to wind flow which would otherwise dissipate hot air. Mediterranean cities are densely compacted and so heat island effects are particularly prominent in these areas (ESPON Climate 2011).

High temperatures and heat waves: key impacts for European cities

Europe currently suffers from heat (and cold) related mortality, sometimes at relatively moderate temperatures but particularly during heat wave events (Alcamo et al 2007). A review of the incidence and implications of natural hazards in Europe identified heat waves as the most significant threat to human health, highlighting the 2003 European heat wave and the estimated 70, 000 excess deaths associated with this event (EEA 2010a). In terms of loss of human life, heat waves are by far the most significant type of natural hazard impacting on Europe (Schauser et al 2010). For every 1°C increase above location-specific thresholds, mortality risk increases by 0.2 to 5.5%, with prolonged heat waves having an impact 1.5 to 5 times greater than short term events (EEA-JRC-WHO 2008). Cities have varying temperature thresholds above which heat related mortality is seen to increase; for example 32.7°C for Athens and 21.7°C for Stockholm (EEA 2012). A study of nine large European cities as part of the EuroHEAT project found that heat waves resulted in a 7.6% to 33.6% increase in mortality levels depending on location (D'Ippoliti et al 2010, WHO 2009). It is clear that the extent of heat wave impacts is determined by local factors including the sensitivity of the population and the density of urban areas.

Vulnerable groups include the elderly, who are sensitive to heat stress due to factors including that capacity to regulate body temperature reduces with age. Also, mobility declines diminishing control that the elderly have over their environment for example to access fluids or open windows. Young children are also sensitive to heat stress for physiological reasons (Commission for the European Communities 2009, EEA 2010a, Schauser et al 2010). The 2003

European heat wave was particularly severe in Paris, where new temperature records were set. Details of this event are provided in Box 7. Analysis of the impacts of the Paris heat wave emphasises the sensitivity of the elderly to heat stress. It also highlights that the characteristics of residential property influences mortality rates. Residents, typically of lower socio-economic status, living in small poorly insulated accommodation had higher exposure to heat and were, therefore, more vulnerable. This emphasises the importance of building design and public space provision in the context of reducing heat stress.

The elderly constitute a growing proportion of Europe's total population, with an estimated 58 million additional people over the age of 65 by 2050 (ESPON Climate 2011). This demographic change, in association with the changing climate, is a key public health issue for European cities over the coming decades. Without the development of adaptation responses, a higher incidence of heat waves poses major risks to human health and heat-related deaths are likely to increase (Alcamo et al 2007). By 2071-2100, under a 3°C mean global temperature increase scenario, a net rise of 86, 000 annual heat related deaths is projected across Europe (from a 1961-1990 baseline) (EEA-JRC-WHO 2008).

Increases in heat-related mortality will be offset to some degree by reductions in cold-related deaths, which are also an issue in Europe especially for vulnerable groups in the mid-latitudes of the continent (Alcamo et al 2007). Indeed, by the 2020s, the fall in cold related deaths is likely to exceed the increase in heat related deaths. However, by the 2080s, according to certain model projections the opposite balance is more likely as heat waves exert an increasing toll on human health (Ciscar et al 2009). Despite the focus on the increased frequency of heat waves and resulting heat-induced impacts on human health, it is also important not to overlook cold-related mortality, which remains a significant public health issue in Europe (Analitis et al 2008).

Over time, humans will adapt to increasing heat stress, acclimatising to higher temperatures, which may moderate the potential negative effects on human health to a certain extent (Schauser et al 2010). Ultimately, as is the case with other climate change hazards, the extent of heat wave impacts on human health depends on factors including the magnitude and duration of the event, the vulnerability of the population and the effectiveness of adaptation responses.

Impacts on human health arising from heat-induced reductions in air quality, especially concerning ozone, are another concern for European cities (Kamal-Chaoui and Robert 2009, EEA 2010a). From a public health perspective, the spread of infectious diseases is widely linked to higher temperatures. Social disorder also becomes more prevalent in heat wave and high temperature situations (Schauser et al 2010). Aside from increased deaths, greater hospital admissions linked to heat waves and high temperatures will pressure hospital and community care services.

Box 7

Heat waves – Paris, 2003

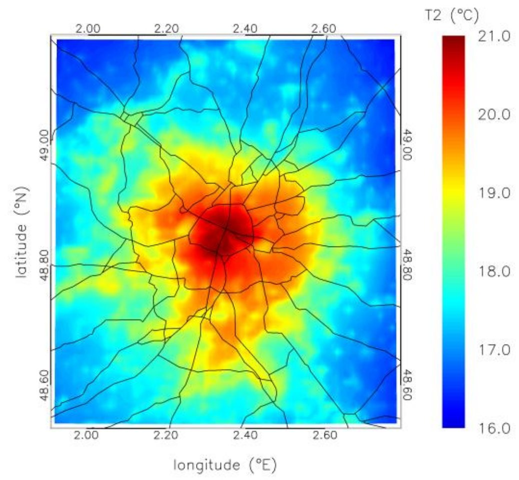


Figure 15: The image shows 2-m air temperature at 22:00 UT, averaged for the period May-September 2003 (Source: VITO/Planetek/ESA, koen.deridder@vito.be).

Europe experienced temperature extremes during 2003 as the result of persistent anticyclonic conditions throughout the summer period (Black et al 2004). In Paris, temperatures were the highest recorded since records began in 1873. The urban heat island effect intensified temperatures in the city. Modelling has shown that a heat island was centred on downtown Paris during the night. In the daytime, the dense residential and industrial suburbs also showed temperature spikes (Laaidi et al 2011). The metropolitan area experienced nine consecutive days with temperature reaching 38°C in daytime, and increases from 20°C to 25°C in night time at the peak of the heat wave. The highest temperature recorded during the episode was 40°C on 12th August (Dousset et al 2011).

The number of consecutive hot days and the added effects of negligible night time cooling are believed to have contributed to excess deaths. In Paris and its surrounding areas, there were around 150% more deaths than the average; mortality rates returned closer to the average once temperatures began to decrease (Poumadère et al 2005). The majority of deaths occurred in the elderly and those who lived alone. Dwelling characteristics were also significant. Those living in dwellings that were either exposed to the sun, had poor insulation, or a small surface area suffered disproportionately.

As well as human health, other receptors were critically affected by the high temperatures. Accompanying the heat waves was a lack of rainfall leading to low water levels. Combined with a heightened energy demand for cooling, France’s major electricity provider (EdF) agreed for 16 nuclear reactors to operate outside of their normal legal temperature ranges as well as operating at a reduced capacity because of insufficient means to cool them (Poumadère et al 2005).

Looking beyond impacts on human health, higher temperatures will have implications for the operation and maintenance of transport infrastructure, including buckling rail tracks and melting road surfaces. This is an important consideration for cities, which rely on effective transport networks for moving people and goods. Further, a key cause of vehicle breakdown is overheating (URS Corporation Limited 2009). Heat stress may also stimulate a modal shift, with public transport users opting for private air conditioned vehicles, for example where underground metro systems become uncomfortably hot during the summer months (URS Corporation Limited 2009). Interdependencies between infrastructures threaten cascading failures when climate change events such as heat waves occur (RAE 2011). For example, the efficient operation of electricity sub-stations and transformers is jeopardised by high temperatures (URS Corporation Limited 2009), which could reduce the capacity of urban areas to provide cooling and maintain water supplies in the event of a heat wave. This would have severe implications for human health.

As energy demand is influenced, in part, by outside temperatures, climate change has significant implications for the use of energy for heating and cooling in cities (EEA 2010a). Broadly, demand for heating in winter will decline whilst demand for cooling in the summer will rise, bringing net costs to some areas (southern Europe) and net benefits to others (northern Europe). Seasonal changes in peak energy demand are likely to be seen, as are changes in patterns of diurnal demand. Alcamo et al (2007) discuss European research on this issue.

Future high temperatures and heat waves in Europe: a spatial perspective

In recent decades high temperature extremes have become more frequent and cold temperature extremes less common over Europe (EEA 2010b), driven by the warming climate that Europe has experienced over recent decades (EEA-JRC-WHO 2008). Climate change induced increases in temperatures and reductions in summer precipitation raise the chance of a greater incidence of high temperatures and heat waves in Europe over the 21st century (Alcamo et al 2007, EEA 2010b). Many cities can expect more frequent and prolonged heat waves than they have been accustomed to in the past (Rosenzweig et al 2011).

More frequent heat waves are a particular threat for cities in central and southern regions (Alcamo et al 2007, EEA 2009a, EEA 2010b, ESPON Climate 2011). Under the IPCC's A2 scenario, by the end of the 21st century, central Europe will be exposed to the same number of hot days as currently seen in Spain and Sicily (Beniston et al 2007). The ENSEMBLES projections (RCM scenario) (van der Linden et al 2009) imply twice as many days over 40°C in southern Europe by the end of the century than occur today. Potential increases in mortality rates (under a 3.9°C climate change scenario) are particularly prominent for countries in the Mediterranean and south-eastern Europe, with northern and north-western Europe least exposed to this risk (Ciscar 2009). Scandinavian and Baltic countries are projected to benefit most from projected falls in cold related mortality.

The potential for exposure of urban areas in Spain to heat waves in the future is a particular concern, although the threat is relevant to urban agglomerations in the south of Europe more generally (ESPON Climate 2011). Further unchecked development in these areas, leading to a densification of the urban environment, should therefore be cautioned against as this would enhance exposure of populations and infrastructure to heat waves and high temperatures (ESPON Climate 2011).

Although heat waves are projected to be most extreme in central and southern regions, climate models project increased heat wave frequency and duration across many parts of Europe (McGregor et al 2005). It is notable that the European heat wave of 2003 was responsible for a large number of additional deaths in cities including Paris and London (UNEP/DEWA/GRID 2004). This highlights the problems associated with placing hard spatial boundaries around climate and weather projections, and the corresponding need to acknowledge that extreme events such as heat waves are a threat across a wide range of European locations. Figure 16 visualises the southward shift of major European cities under a changed climate to emphasise that all cities will be required to adapt to changed temperature regimes over the 21st century.

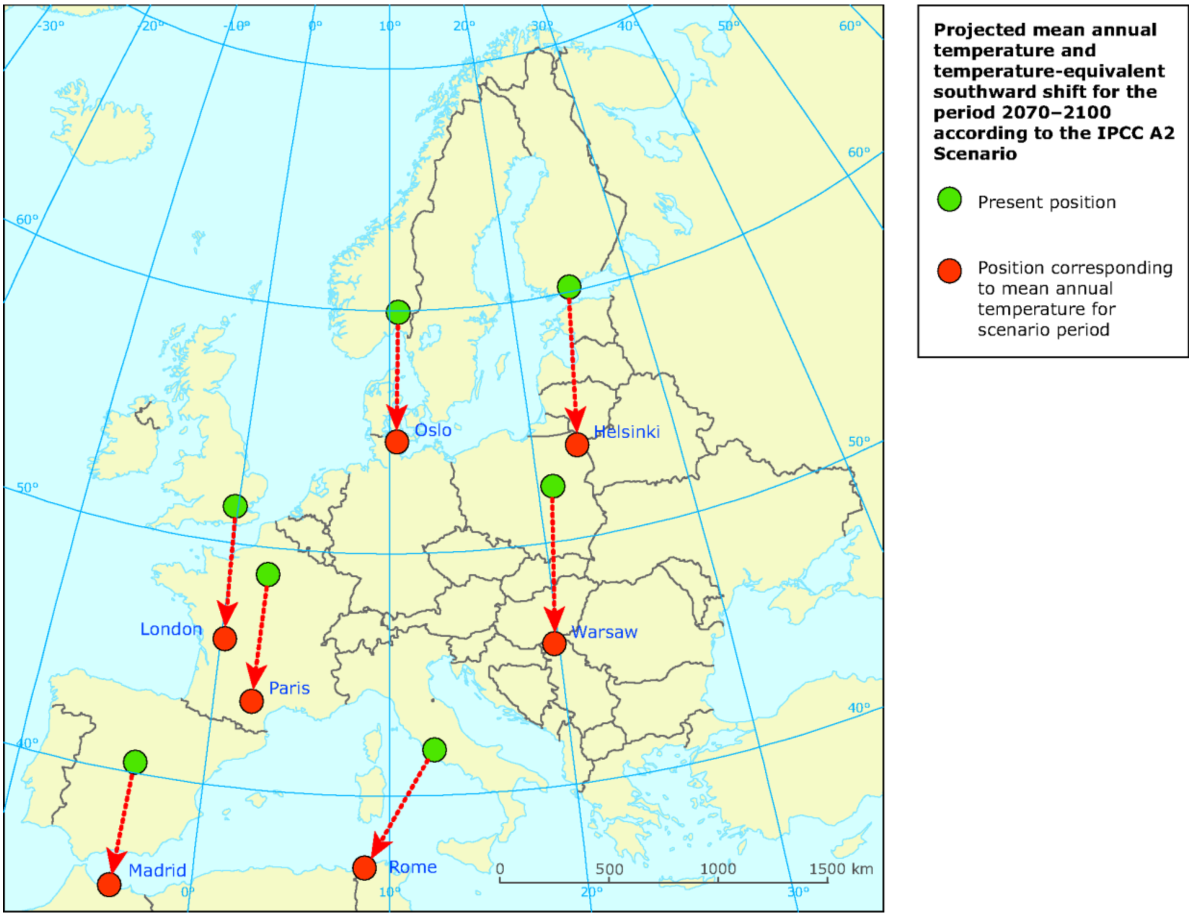


Figure 16: Apparent southward shift of European cities due to climate change, 2071-2100 (Source: EEA 2009a).

4.4.4 Water scarcity and drought

Drought and water scarcity are separate yet interrelated phenomenon, and are therefore difficult to differentiate. The EEA defines drought as: 'a sustained and extensive occurrence of below average water availability, caused by climate variability' (EEA 2008: 53). They are often wide ranging and diffuse events, with long lead in times. Water scarcity, on the other hand, generally acts to exacerbate the impacts of droughts and 'reflects conditions of long-term imbalances between water availability and demands' (EEA 2008: 53).

In some areas of Europe, as a result of drought and over-abstraction, the balance between levels of water abstraction and availability is now at a critical level. The area affected by water scarcity and drought in Europe doubled to 13% between 1976–1990 and 1991–2006 (EEA 2010b). Across Europe, abstracted water is currently used by the energy sector (44%), agriculture (24%), public water supply (21%) and industry (11%) (EEA 2009a). Despite water being relatively abundant in the continent as a whole, this hazard occurs because much of the rainfall is to the sparsely populated north whereas many major cities are in the drier south.

Nevertheless, in Europe, water scarcity and drought can affect both high and low rainfall areas (EEA 2010b), and these hazards currently affect many parts of Europe. Sporadic water shortages do feature in northern Europe, principally during dry years and the summer months (EEA 2010a). However, the EEA question whether this situation may be changing, as higher temperatures (and resulting increases in evaporation) coupled with lower rainfall threaten to increase water scarcity and drought hazards over more of Europe:

> *Until now, most Europeans have been insulated from the social, economic and environmental impacts of severe water shortages. But as demand increases and the global climate changes, is Europe becoming more susceptible?* (EEA 2009a: 5).

Water shortage and drought are a particular threat to cities. Cities rely on water supplies, often imported from far into their surrounding hinterlands, for a wide range of uses. Water scarcity and drought threaten to impinge on the future growth and development of European cities, regardless of their location. Where cities are growing in population and development is intensifying, demand for water will generally increase. It appears likely that in some cities, particularly in southern and eastern Europe, that any additional growth will occur in a context of reduced water availability driven by climate change. Further, many European cities currently rely upon ageing water infrastructure designed for historical weather patterns, which would be difficult and expensive to upgrade or replace (Kamal-Chaoui and Robert 2009, Ecologic Institute et al 2011). In some cases, as a result of changing climate regimes, this may nevertheless be necessary.

The drought in the Catalunya region of Spain in 2008 impacted heavily on its principal city, Barcelona (see Box 8). This case shows how a combination of one of Spain's worst droughts in decades, which brought water shortages at a time of escalating demand for water from a range of sectors, led to major economic and social impacts. Adaptation strategies were instituted as a result in order to reduce the risks associated with similar events in the future.

Water scarcity and drought: key impacts for European cities

Droughts bring social, environmental and economic impacts, with direct and indirect implications for cities (EEA 2010a). Kallis (2008) argues that droughts affect more people than any other climatic hazard. The extent of impacts depends on the duration and intensity of events (the hazard), the vulnerability of the receptors exposed to them and the degree of capacity to mount a response. Water scarcity and droughts have significant financial impacts. Between the periods 1976-1990 and 1991-2006, average annual financial impact of droughts doubled, to €6.2 billion per year in the latter period (EEA 2010b).

Key impacts of droughts on public water supplies include reductions in water availability, which can in some cases can lead to rationing and increasing water prices. This has social implications, particularly for people on low incomes who are sensitive to droughts for this reason. Water scarcity and droughts also pose significant public health issues for cities. In urban areas low river flows can lead to eutrophication of water course, bringing negative health and amenity impacts. Also, the benefits of green infrastructure for moderating high temperatures in urban areas (through evapo-transpiration) can be threatened in conditions where water supplies for irrigation are impaired.

Box 8

Drought and Water Scarcity – Barcelona, 2008

Figure 17: Drought conditions in Spain, 2008. Image licensed under Creative Commons. Owned by The Italian Voice, Available from Flickr.com http://www.flickr.com/photos/desiitaly/1299201815/

During 2007 and 2008, Spain's Catalunya region received little rainfall during what became regarded as one of Spain's severest droughts in decades (World Meteorological Organisation, 2009). Barcelona is Catalunya's capital and the second largest city in Spain. It is a significant tourist destination with a strong cultural tradition. Water resources in the Catalunya region dropped to 21 per cent capacity by early 2008, resulting in difficulties of providing water for drinking, irrigation and generating electricity for the expanding population (Martin-Ortega & Markandya 2009). At an estimated cost of €22 million, fresh water was imported from Tarragona in southern Catalunya, Marseille and Almeria (European Environment Agency (EEA), 2009). Delicate political negotiations regarding the water imports occasionally became tense between municipalities, and was reported in the media as the 'Water Wars' (Nash 2008).

The direct costs of the drought have been estimated at €878.09 million with indirect costs from loss of productivity reaching €358.47 million. This is in addition to the non-marketable welfare costs such as those on human health (Martin-Ortega and Markandya, 2009).

In response to the risk of future events of this nature, Barcelona has developed a long term water supply strategy and encourages water conservation. Desalination plants have been constructed although these consume high amounts of energy and are an example of mal-adaptation (OECD 2008: 59)

Many of the key services and functions on which cities and their residents depend are threatened by water scarcity and drought. The energy sector is particularly vulnerable to droughts, due to reduced water availability for hydropower and water abstraction for cooling power stations. In some circumstances electricity plants may be forced to close temporarily, for example where limit values for cooling water are exceeded (ESPON Climate 2011). Alongside energy, agriculture is the other key sector that is heavily reliant on freshwater supplies. In southern Europe, 80% of abstracted water is used for agriculture (EEA 2009a). Reduced water supplies may therefore lessen crop yields, with impacts on food prices. Although most of European agriculture occurs in peri-urban and rural areas, through processes like this, the effect of climate change on agricultural production will have direct implications for urban residents.

River navigation, common for freight transportation in some regions, is dependant on reliable river flow levels. Droughts can also lead to soil shrinkage and subsidence, particularly where clay-based soils are present, potentially causing problems for buildings and transport infrastructure. Lower rainfall and higher temperatures would also increase the frequency of forest fires, with substantial potential damages to forests in areas such as the Mediterranean (ESPON Climate 2011). Forest fires may worsen air quality in nearby cities and urban areas, and reduce opportunities for recreation in some cases. These are examples of potential indirect impacts of water scarcity and drought on cities, which also include pressures on urban biodiversity through reduced river flows and associated rising concentrations of water-borne pollutants.

Future water scarcity and drought in Europe: a spatial perspective

Changes in the hydrological cycle over recent decades, including observed increases in precipitation in northern Europe and reductions in the south, may be linked to climate change (EEA 2010b). Recorded changes have been substantial. The 20th century saw increases in precipitation of between 10-40% in northern Europe and falls of up to 20% in southern Europe (EEA-JRC-WHO 2008). It is likely that changes in the climate have already led to a rise in the frequency and intensity of droughts over the continent (EEA-JRC-WHO 2008).

Annual runoff, which will in part influence future water availability and the frequency and duration of droughts, is projected to change by the 2020s with projected reductions of up to 23% in parts of southern Europe. By the 2070s this figure could be 36%, with today’s 100 year droughts occurring every 50 years (or less) in southern and eastern Europe (Alcamo et al 2007). Such changes to the hydrological cycle, including higher temperatures (and associated increases in evaporation) and longer periods without rain, are likely to create water scarcity and drought hazards that are worse than they are today (Alcamo et al 2007, EEA-JRC-WHO 2008). When droughts do occur, climate change projections indicate that they will be longer in duration and more severe than at present (EEA-JRC-WHO 2008, EEA 2010a). Climate change has the potential to exacerbate negative impacts linked to water scarcity and drought in the future.

The areas that currently suffer from water shortage and drought are those that are projected to become increasingly exposed to these events over the course of the century; essentially southern and south-eastern Europe. However, this does not mean that other areas of Europe will escape droughts in the future. Figure 18 highlights locations that were exposed to droughts between 2002 and 2008. This clearly demonstrates that droughts are not only specific to southern and south-eastern Europe with recent episodes occurring in northern Europe too. Figure 18 also illustrates the large scale at which droughts operate.

In the future, droughts may influence many parts of Europe, although they are projected to be more frequent and intense in the south and east (Alcamo et al 2007, EEA-JRC-WHO 2008, EEA 2010a, EEA 2010b). Alcamo et al (2007: 548) highlight the Iberian Peninsula, the Alps, the eastern Adriatic seaboard and southern Greece as areas particularly at risk of longer duration droughts that start earlier in the year. Lower minimum river flows are likely across the continent, particularly in the summer, and droughts prompted by low river flow are projected to become more frequent and intense, not only in southern and south-eastern Europe but also the United Kingdom, France, Benelux, Italy and western Germany (EEA-JRC-WHO 2008). As a consequence, the number of people living in water-stressed river basins is projected to increase (EEA 2010a).

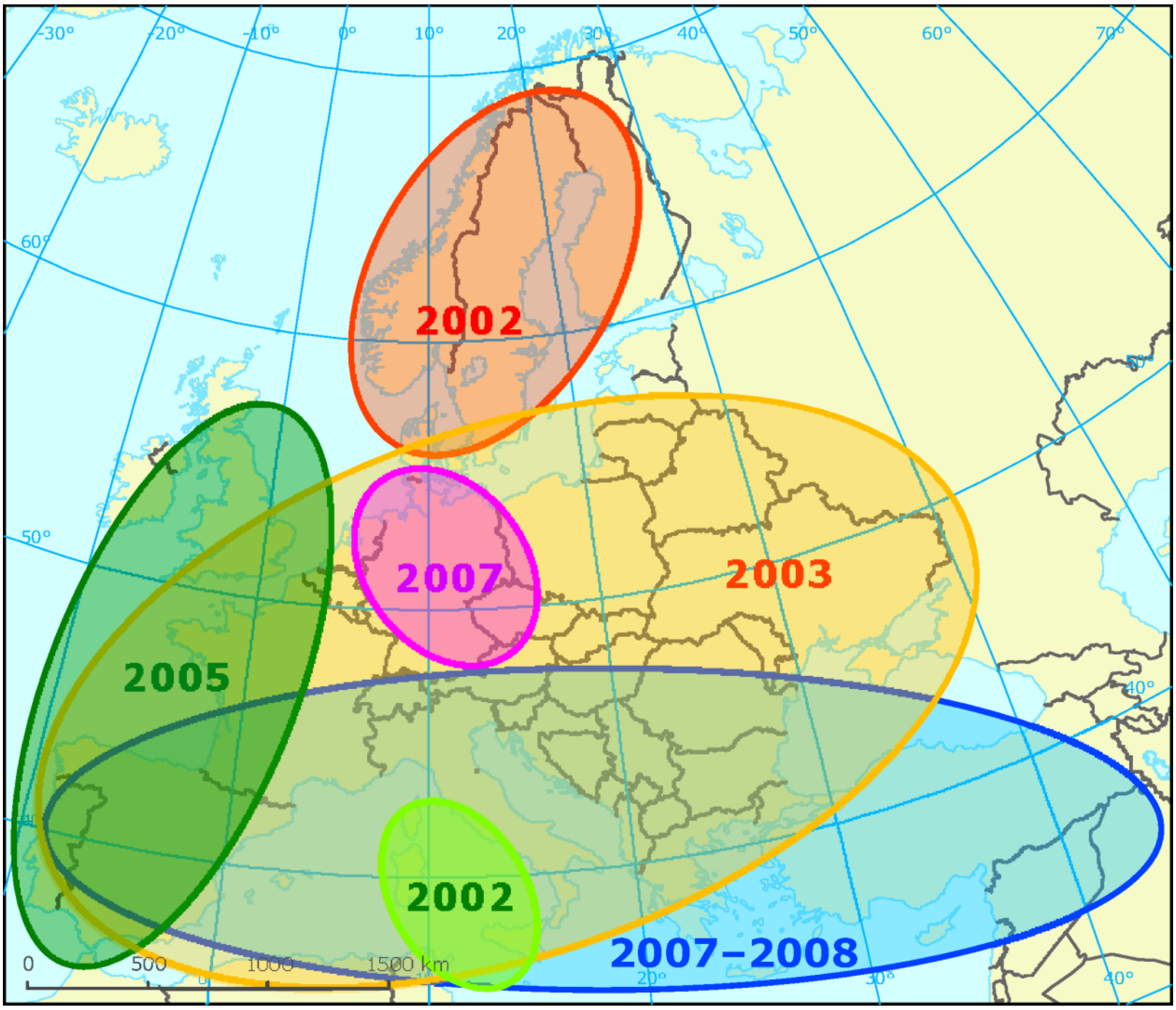


Figure 18: Main droughts in Europe between 2000 and 2009 (Source: EEA 2010a)

Drought and water stress in the Mediterranean (coupled with more frequent and intense heat waves) could make this region less liveable in the future (European Commission Directorate-General Regional Policy 2009). This may reduce the economic backbone of tourism revenue that supports many Mediterranean coastal areas, with potential implications for the future prosperity of cities and urban areas in this region. Competition for water between sectors and uses will be a key feature of the future of freshwater supplies (Kamal-Chaoui and Robert 2009). In Europe, it is probable that direct human uses for water, such as for tourism and daily life in urban areas, will win at the expense of water for irrigation, potentially leading to lower agricultural yields (European Commission Directorate-General Regional Policy 2009). This provides an example of the complex processes that look set to characterise the relationship between European cities and water resources over the course of this century.

Even though climate change threatens to significantly reduce available water supplies in parts of Europe, the EEA projects stable or declining water demand because of low population growth, technological efficiencies and little growth in areas taken by irrigated land (EEA 2010b). In effect, the EEA believes that capacity of societies to respond to water shortage and drought will increase. Since the 1990’s, water use has been declining in Europe, and principally as a result of more efficient use of water for electricity generation, it is projected to fall by a further 11% by 2030 (EEA 2010b). However, this does not mean that cities can discount the implications of climate change for water scarcity and drought. Indeed, many river basins will face increasing water stress and cities, being key users of water resources via the demand of their populations for energy and food, are intimately linked to water supply networks. It is also apparent that climate change itself will influence future water demand. Household and agricultural use of water in northern Europe is likely to rise under a warming climate, with areas such as Ireland seeing increased demand for irrigation (Alcamo et al 2007).The problem of water shortage will be particularly acute in growth areas, for example south-east England, where climate change and increasing population are identified as the main threats to water supply (Environment Agency 2012).

4.5 Current understanding of climate change hazards, vulnerabilities and impacts in European cities

Each of the climate change hazards covered in section 4 of this report pose a significant threat to the growth and development of European cities over the coming decades. However, although there are exceptions, there is generally a poor availability of city-scale data on these hazards. Many cities must rely on data produced at higher spatial scales, drawing on work such as ESPON's study to identify similar climate change regions across Europe (ESPON Climate 2011). This study provides cities with a useful insight into projected changes in climate variables, and where more spatially detailed data cannot be accessed, it offers valuable background information on climate change hazards so enabling cities to progress adaptation goals. In some cases, national and regional hazard data can be accessed to provide cities with more detail, for example outputs from the UK Climate Impacts Programme (Murphy et al 2009). However, climate change hazards are often experienced locally and in spatially variable patterns, for example in terms of areas of a city exposed to flooding or extremes of heat. Climate change projections produced at higher scales can therefore only highlight broad changes in climate variables, which risks missing the local subtleties that characterise levels of exposure to climate change hazards. To advance understanding at the local level, cities are left with the option of commissioning research individually to explore potential exposure to hazards at a finer scale.

There is a large gap between potential and actual climate change impacts in European cities. It is difficult to imagine, barring a catastrophic reduction in the availability of capital, that large cities such as Amsterdam, Rotterdam or London would not continue to maintain and enhance coastal protection schemes in the face of rising sea levels and increased frequency of coastal storm surges. Nevertheless, the risk to such cities from extreme weather events, such as storm surges amplified by high tides and high winds, cannot be discounted. Increasing development activity in areas protected by flood defences magnifies potential risks, and demands the careful consideration of the robustness of flood defences under the changing climate.

Amsterdam, Rotterdam and London are examples of cities that would be likely to develop concerted adaptation responses to such climate change hazards. The impacts associated with not acting would be simply too great and their capacity to invest would be high. This might not be the case, however, in cities that are less economically prosperous. Here the gap between potential and actual impacts would be much narrower. Richardson et al (2011) note that although it is feasible to respond to sea level rise through actions such as raising sea walls, and locating urban and coastal infrastructure in less vulnerable locations, this will require political acceptance of sea level rise driven by climate change, allocation of significant resources, and social support for transformational change in coastal zones.

Even though they have not been assessed in detail within this review, it is important to acknowledge the international dimensions of climate change for European cities. The international impacts of climate change on the political, economic and social interests of European countries will also affect their cities. Cities often link to global networks of people, goods and services that are essential to their effective functioning. Climate induced threats to these networks would have major implications for cities. At a global scale, impacts on food security, financial/business sectors (and hence employment), and infrastructure internationally (airports, ports, oil refineries) would all affect European cities. A report by the UK Government's Office for Science (Foresight 2011) considers the implications of global climate change for the UK. Their key message is that global impacts (i.e. those occurring outside the UK) could be as significant for the country as the impacts of climate change directly affecting the UK.

There is an emerging understanding of what makes cities and their constituent elements vulnerable to climate change hazards. For a variety of socio-economic and biophysical reasons, not all cities (nor districts and neighbourhoods within them) are equally vulnerable to climate change hazards. Hazards will have different impacts on populations and infrastructures depending on a wide range of often interconnected issues such as their proximity to the coast, demographic profile or economic strength. Some sources of socio-economic city-scale data do address these issues (e.g. the Urban Audit, EUROSTAT data) and create a basis from which to assess vulnerability to European climate change hazards.

The key themes of this chapter – climate change hazards, vulnerabilities and impacts – show strong spatial variation across Europe. Patterns of adaptive capacity are similarly diverse (ESPON Climate 2011). Following the ARC3 conceptual framework, climate change risk will therefore vary within and between cities. Ultimately, data is needed to assess climate change risk in cities (and hence their adaptation needs). However, it appears that data is not sufficiently comprehensive at this scale, and will therefore support a city-scale assessment of just some of the true range of factors affecting the extent of hazards, vulnerability and adaptive capacity of cities across Europe.

This section shows that major climate related hazards already have significant implications for European cities, and these are projected to intensify over the coming decades. It is also clear that there is a strong spatial component in terms of hazard intensity and vulnerability. While many impacts are location specific and individual cities will need to carry out their own risk assessment, it is possible to say something about the future climate hazard profile of different geographic regions. We explore this in tandem with information on city types in these regions in the next section.

5 Climate change in European cities: highlighting the spatial dimension

Key messages from this chapter

- This analysis synthesises ESPON climate change data with the Urban Audit city typology to build understanding of the relationship between projected climate hazards and vulnerability and adaptive capacity to these hazards in Europe's cities.
- A significant number of Europe's cities (that are covered by the Urban Audit) are located in areas where potential exposure to climate hazards is high (i.e. the Mediterranean and Southern Central Europe).
- Different European cities not only face varying climate hazards, but also display different levels of vulnerability and capacity to adapt. There is a need to move beyond treating cities as one homogeneous group when considering climate change impacts and adaptation.
- Patterns of climate change risk appear to match spatial socio-economic imbalances at the European scale, and may act to worsen these disparities.

Although there is an emerging body of research on European climate change hazards, vulnerabilities and impacts, this rarely addresses cities specifically. A pan-European overview of the position of different cities in the context of projected climate change does not exist. In response to this gap, this section synthesises data sets on projected climate change hazards (drawing on ESPON's climate change clusters 2011) and European city type (based on the Urban Audit city typology 2010) by drawing on the core elements of the ARC3 conceptual framework: hazard, vulnerability and adaptive capacity. Hazards are considered using ESPON data (supported by insights on key European climate hazards contained in chapter 4) and the Urban Audit city typology is used as a basis for a broad consideration of vulnerability and adaptive capacity at the city-scale.

Although the Urban Audit is designed to allow objective comparisons to be made between the EU cities covered by the data set, it is limited to coverage of only 328 cities in total (See Sections 2.5 and 2.6 for a discussion). It does, however, include cities in all EU countries. The sample is, therefore, of sufficient size from which to derive a broad assessment of the distribution of different city types across the continent for the purposes of this synthesis. Indeed, we do not provide a detailed analysis for individual cities but focus on highlighting the issues emerging from the spatial relationship, at the European scale, between different types of cities and the climate change hazards that they are projected to face. More detailed research into individual cities would be valuable and could support the development of responses to address the issues raised by this analysis.

5.1 Climate hazards data

Although detailed city-scale climate change projections are rare, data is available to produce a broad picture of key climate hazards facing different European cities. ESPON's report on climate change in European regions (ESPON Climate 2011) identifies 5 'climate change clusters' representing areas of Europe that have similar future climate change projection profiles (see Figure 8). The clusters, which were developed via statistical analysis using available climate change projections data, offer a useful basis from which to consider climate change hazards in Europe. Their spatial focus, at the NUTS 3 region scale, enables European cities to determine which cluster they sit within. The ESPON data focuses on projected changes to climate variables linked to temperature and precipitation, and as such does not directly address hazards such as flooding, heat stress or drought. However, looking at the ESPON projections alongside available data on key climate related hazards (Section 4), changes in the frequency and intensity of hazards such as these (flooding, heat stress and drought) at the scale of the 5 ESPON climate clusters can be broadly understood. Sea level rise, storm surge and coastal flooding are not covered in ESPON's climate hazard profiles.

5.2 A typology of European cities

The *State of European Cities Report* (European Commission DG Regional Policy 2010) developed a city typology (see Section 2 for more details). It looks beyond cities as a single entity and differentiates between 4 principal city types (which are broken into a further 9 sub-categories). The typology clarifies that Europe's cities fall into broad categories that are distinguished using statistical methods according to their basic structural characteristics based on Urban Audit data. The city types are as follows:

- A: Principal metropolises
    - A1: Leading European capitals and principal metropolises
    - A2: National capitals and metropolises
- B: Regional centres
    - B1: Regional service centres
    - B2: Regional innovation centres
    - B3: Regional centres with growing population
- C: Smaller centres
    - C1: Smaller administrative centres
    - C2: Smaller centres with growing population
- D: Towns and cities of the lagging regions
    - D1: Cities in the process of structural adaption
    - D2: Less developed towns and cities

Though cities differ considerably, the Urban Audit city typology clarifies that different groups broadly share similar characteristics in terms of their demographic profiles, employment rate and GDP per head of population (European Commission DG Regional Policy 2010). Consequently, the typology allows for comparisons to be made between cities with similar basic structural characteristics (European Commission DG Regional Policy 2010).

Vulnerability to climate change hazards differs from city to city according to a range of factors, as does their capacity to adapt to these hazards. Factors relate to issues including their socio-economic profiles and governance structures, all of which are dealt with in Urban Audit data and the typology derived from it. Though imperfect, this enables a broad consideration of vulnerability indicators and adaptive capacity at the level of European cities. Table 4 includes relevant data linked to the four principal city types. This demonstrates, for example, that population density is much higher in principal metropolises than smaller centres, hence increasing the potential exposure of residents to heat stress. Moreover, towns and cities of the lagging regions have the lowest percentage of elderly and young people, which makes their overall population less vulnerable to heat stress.

Table 4: Indicators for the four principal Urban Audit city types (data for Larger Urban Zones) (Source: European Commission DG Regional Policy 2010).

Indicator	Principal metropolises	Regional centres	Smaller centres	Towns and cities of the lagging regions
Total resident population	2,213,046	628,848	236,604	295,739
% of population < 5	4.9	5.0	5.3	4.6
% of population > 75	6.8	7.7	7.2	5.3
Share of nationals	87.8	93	96.1	98.5
Highly qualified working age population (%)	22	22.5	22.7	16.2
Population density (people per km²)	804	674	181	482

Figure 19 clearly demonstrates that larger cities (i.e. principal metropolises and regional centres) have higher levels of economic prosperity than smaller cities (i.e. smaller cities and regional centres). Due to their higher GDP levels and better access to financial resources principal metropolises will generally have higher levels of adaptive capacity than, for example, towns and cities in the lagging regions. As a result, they may be better able to proactively adapt to climate change hazards and mount an effective recovery when extreme events do occur. Further, policy makers may perceive metropolises, and their concentrations of people and assets, to be at higher risk and hence act to develop adaptation strategies and responses. We do not claim to provide a detailed assessment of vulnerability and adaptive capacity based on the Urban Audit city data. Instead, the aim is to highlight that different types of cities exhibit characteristics that in turn influence their degree of vulnerability and level of adaptive capacity to climate change hazards.

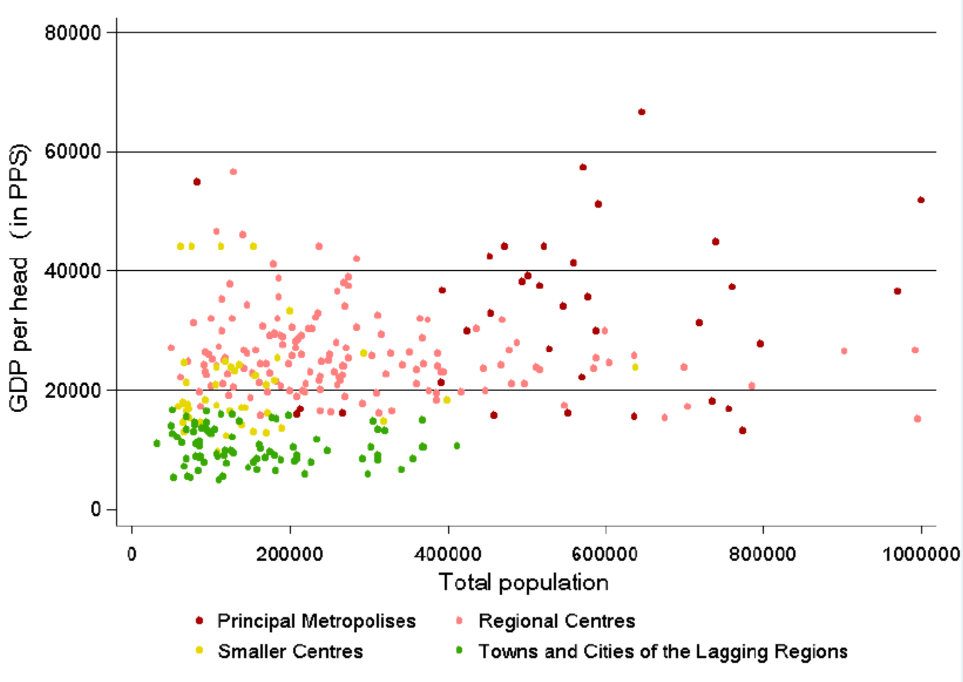


Figure 19: Economic prosperity and city size (Source: European Commission: DG Regional Policy 2010)

Aside from varying levels of vulnerability and adaptive capacity, the other key factor that will influence a city's risk of climate change impacts is the frequency and intensity of climate change hazards that they experience. The following section integrates ESPON climate data with the Urban Audit city typology in order bring these different elements together.

5.3 Integrating climate hazard and city type data

Integrating the ESPON climate data with the Urban Audit city typology generates new insights into climate change in European cities. 329 cities are covered within the *State of European Cities Report*[1]. Table 5 shows the distribution of these cities across the ESPON climate zones. Table 5 demonstrates that over half of the cities covered by the Urban Audit are in the southern central and Mediterranean regions. Alcamo and Olson (2012) emphasise that these regions are particularly vulnerable to climate change due to their high levels of exposure to hazards including heat stress and droughts.

[1] No data is available for six sites including those in French Guyana (located in South America); Malta and the Canary Islands.

Table 5: Distribution of EU Urban Audit cities across the ESPON climate zones (2011)

Climate Zone	Number of Cities	% of Cities
Southern-central Europe	102	31.67%
Mediterranean	72	22.36%
North-western Europe	67	20.81%
Northern-central Europe	63	19.57%
Northern Europe	18	5.59%
Total	322	100%

The city typology emphasises the need to avoid treating European cities as one homogeneous group. The city typology provides a more nuanced perspective of European cities, highlighting four broad types that differ significantly from one and other in a number of ways. Table 6 and Figure 20 present the results of an analysis of the city types across the ESPON climate change clusters (Annex 2 includes the data on which this analysis is based). Table 6 shows the percentage (numbers in parenthesis) distribution of each city type across the climate clusters. This emphasises that the clusters have different characteristics in respect of the breakdown of city types they contain. Each of the five ESPON climate clusters are now discussed individually to draw out key points relating to their climate change hazard and city type profiles.

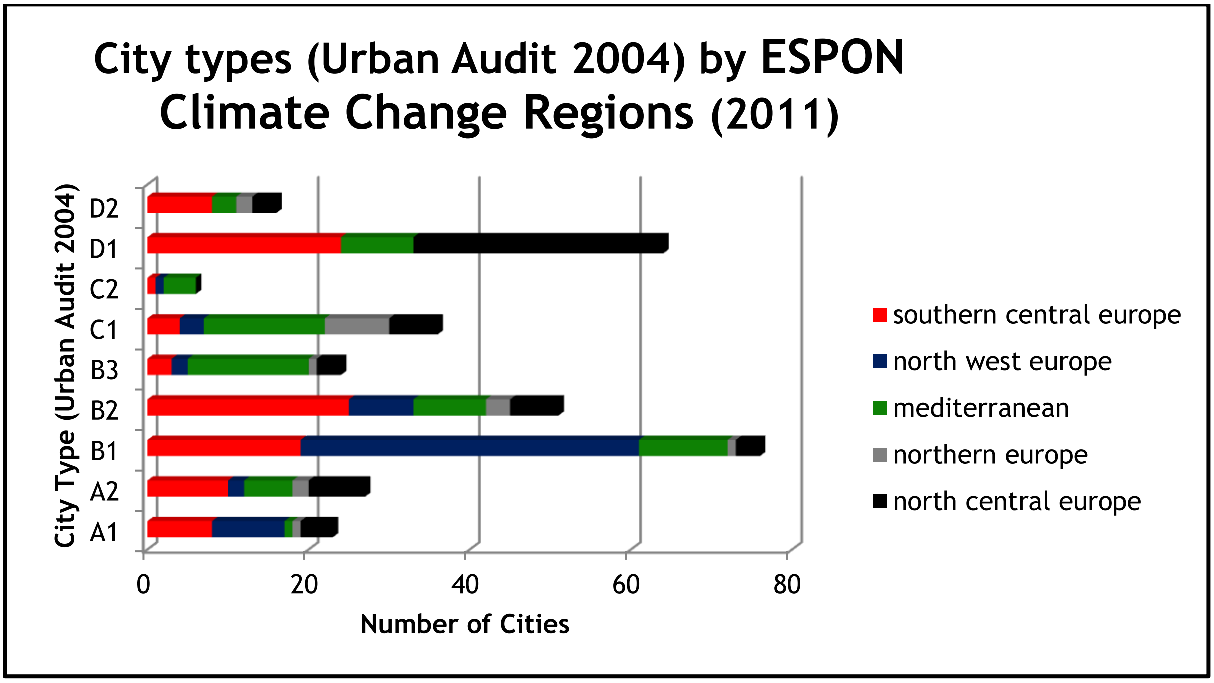


Figure 20: Urban Audit city types (full list) according to ESPON climate change regions

Table 6: Distribution of Urban Audit city types across each climate zone expressed as a % (no.)

Notes: (1) Classification of City Types drawn from the European Commission. 2010. Second State of European Cities Report.(2) Climate Zone data drawn from ESPON and IRPUD. 2011. *Climate Change and Territorial Effects on Regions and Local Economies in Europe*. ESPON & IRPUD, TU Dortmund University. Thanks to Marjan van Herwijnen (ESPON) for sharing their data.

	Climate Zone				
	Southern Central Europe	**North West Europe**	**Mediterranean**	**Northern Europe**	**North Central Europe**
	% (no.) of urban audit city type in climate zone				
Urban Audit City Type					
Principal Metropolises (A)	**36 (18)**	**22 (11)**	**14 (7)**	**6 (3)**	**22 (11)**
Leading European Capitals and Metropolises (A1)	34.7 (8)	39.1 (9)	4.3 (1)	4.3 (1)	17.4 (4)
National Capitals and Metropolises (A2)	37 (10)	7.4 (2)	22.2 (6)	7.4 (2)	25.9 (7)
Regional Centres (B)	**31.1 (47)**	**34.4 (52)**	**22.6 (34)**	**3.3 (5)**	**7.9 (12)**
Regional Service Centres (B1)	25.3 (19)	56 (42)	13.3 (10)	1.4 (1)	4 (3)
Regional Innovation Centres (B2)	49 (25)	15.7 (8)	17.6 (9)	5.9 (3)	11.8 (6)
Regional Centres with Growing Population (B3)	12.5 (3)	8.3 (2)	62.5 (15)	4.167 (1)	12.5 (3)
Smaller Centres (C)	**11.9 (5)**	**9.5 (4)**	**45.2 (19)**	**19 (8)**	**14.3 (6)**
Smaller Administrative Centres (C1)	11.1 (4)	8.3 (3)	41.7 (15)	22.2 (8)	16.7 (6)
Smaller Centres with Growing Population (C2)	16.6 (1)	16.6 (1)	66.7 (4)	0	0
Towns and Cities of the Lagging Regions (D)	**40 (32)**	**0**	**15 (12)**	**2.5 (2)**	**42.5 (34)**
Cities in the Process of Structural Adaptation (D1)	37.5 (24)	0	14.1 (9)	0	48.4 (31)
Less developed towns and cities (D2)	50 (8)	0	18.8 (3)	12.5 (2)	18.8 (3)

5.3.1 Northern Europe

Box 9 includes details of the climate characteristics of Northern Europe, and the city types contained within this area. The ESPON Climate outputs (ESPON Climate 2011), supplemented by additional insights contained in Section 4, generally indicate that projected changes to key climate change hazards in northern Europe include:

- Increased risk of heat stress in cities.
- Reduction in cold weather events.
- Increased threat of flooding (river flooding and surface water flooding) particularly during the winter months.

Analysis of the profile of city types contained in the Northern Europe climate cluster demonstrates that:

- Northern Europe contains by far the smallest number of Urban Audit cities of any ESPON climate region (5.6% of the total).
- A large proportion of cities (44.4 %) are smaller administrative centres. This represents almost a quarter of Europe’s total of this city type.
- Aside from smaller administrative centres, Northern Europe contains a small percentage of Europe’s different Urban Audit city types (across the full range of city types).

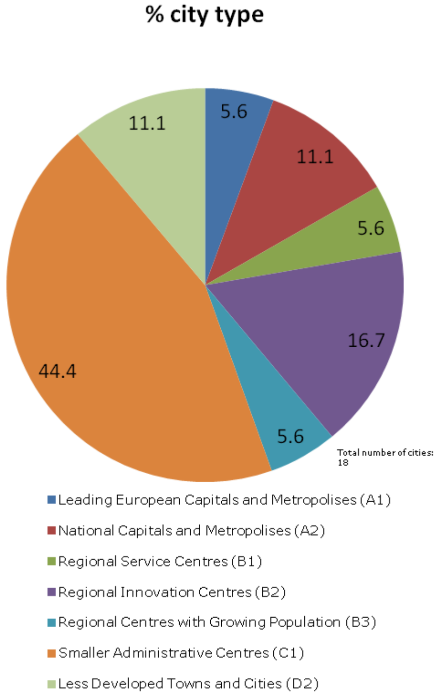
Box 9: Northern Europe – climate characteristics and city types (Sources: ESPON Climate 2011 and DG Regional Policy 2011)

NORTHERN EUROPE

CLIMATE CHARACTERISTICS

Cluster/ Stimuli	Characteristic
Change in annual mean temperature	++
Decrease in number of frost days	--
Change in annual mean number of summer days*	0
Relative change in annual mean precipitation in winter months	++
Relative change in annual mean precipitation in summer months	0
Change in annual mean number of days with heavy rainfall	+
Relative change in annual mean evaporation	+
Change in annual mean number of days with snow cover	--

Key
++: strong increase
+: increase
0: insignificant stimulus for characterisation of cluster
-: Decrease
-- strong decrease
*: number of days with temperature over 25°C



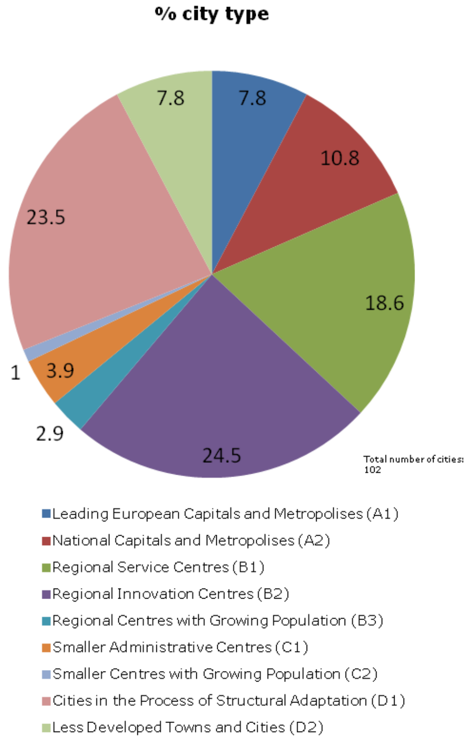
Box 10: Southern-central Europe – climate characteristics and city types (Sources: ESPON Climate 2011 and DG Regional Policy 2011)

SOUTHERN CENTRAL EUROPE

CLIMATE CHARACTERISTICS

Cluster/ Stimuli	Characteristic
Change in annual mean temperature	+
Decrease in number of frost days	--
Change in annual mean number of summer days*	+
Relative change in annual mean precipitation in winter months	+
Relative change in annual mean precipitation in summer months	-
Change in annual mean number of days with heavy rainfall	0
Relative change in annual mean evaporation	+
Change in annual mean number of days with snow cover	-

Key
++: strong increase
+: increase
0: insignificant stimulus for characterisation of cluster
-: Decrease
-- strong decrease
*: number of days with temperature over 25°C



5.3.2 Southern-central Europe

Box 10 includes details of the climate characteristics of Southern Central Europe, and the city types contained within this area. Prominent projected changes to key climate change hazards in Southern Central Europe include:

- Reductions in the number of cold events and days with snow cover.
- Increased threat of heat stress during the summer months.
- Higher chance of droughts and water shortages, particularly during the summer months.
- Increased threat of flooding (river flooding and surface water flooding).

Analysis of the profile of city types contained in the Southern-central Europe climate cluster demonstrates that:

- This area contains the largest number of Urban Audit cities of any of ESPON's five climate regions (31.67%).
- A large proportion of Europe's leading capitals and metropolises are found in southern-central Europe (34.7%).
- Southern-central Europe contains 49% of the Urban Audits regional innovation centres, and 25.3% of its regional service centres. Regional centres make up almost half of the cities in this area.
- This area accounts for a large number of the Urban Audit's towns and cities of the lagging regions (40%). Southern Central Europe contains half of Europe's less developed towns and cities and 37% of cities in the process of structural adaptation.

5.3.3 Northern-central Europe

Box 11 includes details of the climate characteristics of Northern-central Europe, and the city types contained within this area. Generally, the changing patterns of key climate change hazards in Northern-central Europe include:

- Reductions in the number of cold events and days with snow cover.
- Increased threat of heat stress during the summer months.
- Higher chance of droughts and water shortages, particularly during the summer months.

- Increased threat of flooding (river flooding and surface water flooding).
- Some areas (e.g. the Baltic States and Northern Germany) face threats associated with sea level rise.

Analysis of the profile of city types contained in the Northern-central Europe climate cluster demonstrates that:

- Northern-central Europe contains just under 20% of Europe's Urban Audit cities.
- This area contains a largest number of the Urban Audits towns and cities of the lagging regions (42.5%). 54% of cities in Northern Central Europe fall into this type.
- Northern Central Europe houses many of the Urban Audit cities in the process of structural adaptation (48.4%).
- This area contains almost a quarter of the Urban Audit's principal metropolises, but relatively few of its regional centres (7.9%).

5.3.4 North-western Europe

Box 12 includes details of the climate characteristics of North-western Europe, and the city types contained within this area. For North-western Europe, projected changes to patterns of key climate change hazards include:

- A decrease in the number of winter cold events.
- Increased threat of heat stress during the summer months.
- Potential for more droughts and water shortages, particularly during the summer months.
- Increased threat of flooding (river flooding and surface water flooding).
- Greater threats associated with sea level rise and storm surges in areas including the UK and the Netherlands.

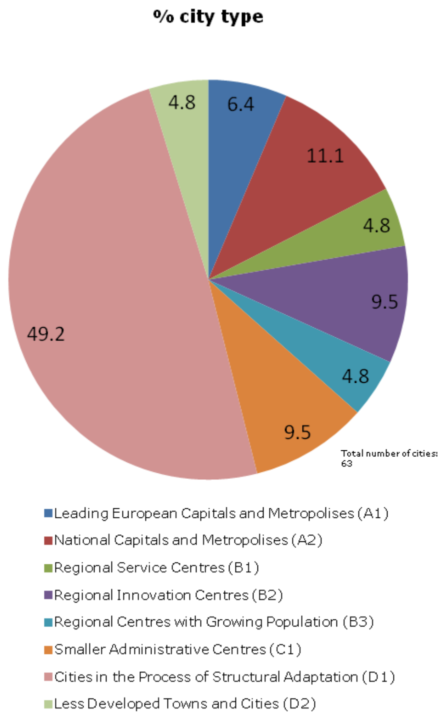
Box 11: Northern -central Europe – climate characteristics and city types (Sources: ESPON Climate 2011 and European Commission DG Regional Policy 2011)

NORTHERN CENTRAL EUROPE

CLIMATE CHARACTERISTICS

Cluster/ Stimuli	Characteristic
Change in annual mean temperature	+
Decrease in number of frost days	--
Change in annual mean number of summer days*	+
Relative change in annual mean precipitation in winter months	+
Relative change in annual mean precipitation in summer months	-
Change in annual mean number of days with heavy rainfall	0
Relative change in annual mean evaporation	+
Change in annual mean number of days with snow cover	-

Key
++: strong increase
+: increase
0: insignificant stimulus for characterisation of cluster
-: Decrease
-- strong decrease
*: number of days with temperature over 25°C



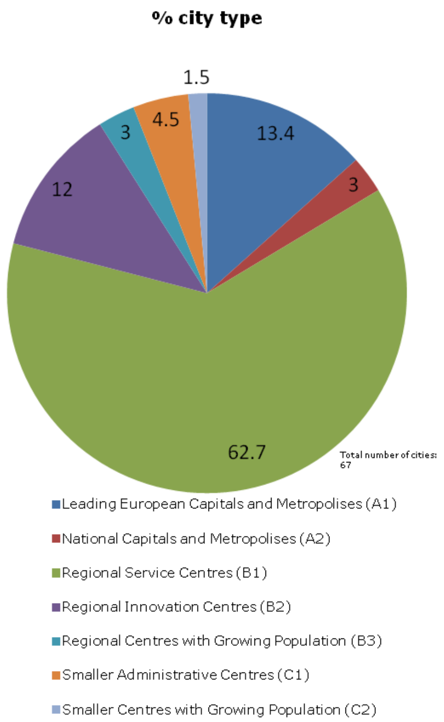
Box 12: North-western Europe – climate characteristics and city types (Sources: ESPON Climate 2011 and European Commission DG Regional Policy 2011)

NORTH WESTERN EUROPE

CLIMATE CHARACTERISTICS

Cluster/ Stimuli	Characteristic
Change in annual mean temperature	+
Decrease in number of frost days	-
Change in annual mean number of summer days*	+
Relative change in annual mean precipitation in winter months	+
Relative change in annual mean precipitation in summer months	-
Change in annual mean number of days with heavy rainfall	+
Relative change in annual mean evaporation	0
Change in annual mean number of days with snow cover	0

Key
++: strong increase
+: increase
0: insignificant stimulus for characterisation of cluster
-: Decrease
-- strong decrease
*: number of days with temperature over 25°C



Analysis of the profile of city types contained in the North-western Europe climate cluster demonstrates that:

- A large proportion of Europe's leading capitals and metropolises are found in North-western Europe (39.1%).
- This area has a particularly high percentage of regional centres (77.7% of the total number of cities in this climate cluster). Many of these are regional service centres (56% of the Urban Audit's total for Europe).
- North Western Europe includes none of the Urban Audit's towns and cities of the lagging regions, and a small fraction of its smaller centres (9.5%).

5.3.5 Mediterranean

Box 13 includes details of the climate characteristics of the Mediterranean, and the city types contained within this area. Based on ESPON's climate data (ESPON Climate 2011) and insights contained in chapter 4, broadly, projected changes to patterns of key climate change hazards in the Mediterranean include:

- Strong increase in heat stress events.
- Strong increase in drought and water shortages, particularly during the summer months.
- Threats linked to sea level rise in some areas, for example North Eastern Italy.
- Increased risk of flash flooding linked to intense precipitation events.

Analysis of the profile of city types contained in the Mediterranean climate cluster demonstrates that:

- 45% of the Urban Audit's smaller centres are in the Mediterranean, including the majority of smaller centres with growing populations (66.7%).
- Contains 62.5% of the Urban Audit's regional centres with a growing population.
- The Mediterranean has a relatively small percentage (14%) of the Urban Audit's principal metropolises.

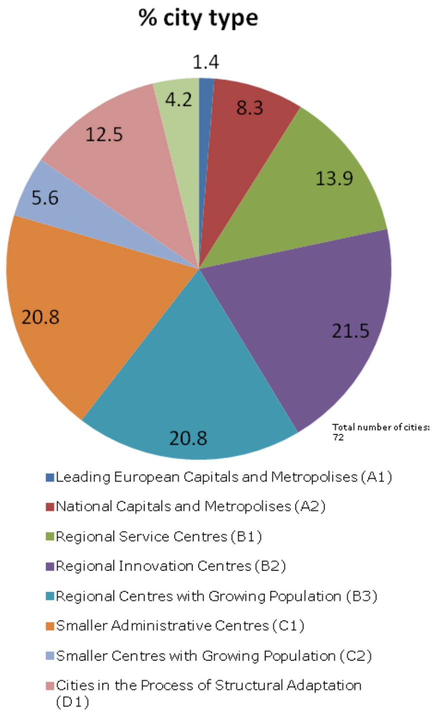
Box 13: Mediterranean – climate characteristics and city types (Sources: ESPON Climate 2011 and European Commission DG Regional Policy 2011)

MEDITERRANEAN

CLIMATE CHARACTERISTICS

Cluster/ Stimuli	Characteristic
Change in annual mean temperature	++
Decrease in number of frost days	-
Change in annual mean number of summer days*	++
Relative change in annual mean precipitation in winter months	-
Relative change in annual mean precipitation in summer months	--
Change in annual mean number of days with heavy rainfall	-
Relative change in annual mean evaporation	-
Change in annual mean number of days with snow cover	0

Key
++: strong increase
+: increase
0: insignificant stimulus for characterisation of cluster
-: Decrease
-- strong decrease
*: number of days with temperature over 25°C



Understanding the types of cities that are similar in respect of issues such as the climate hazards that they are projected to face and their overarching socio-economic characteristics can support adaptation planning and policy making at strategic scales. Separating European cities into broad types and situating them within distinct climate clusters, as this analysis has done, can support the process of gaining a better understanding of their contrasting and in some cases complementary adaptation challenges.

In the context of climate change in European cities, a picture of a north-south split has emerged from this analysis. Whilst the Mediterranean and Southern Central Europe are particularly threatened by severe climate change hazards, especially those linked to heat stress and drought, they are also areas that have high concentrations of smaller and less prosperous cities. In effect, climate change hazards are potentially high, yet capacity to adapt may be relatively low due to factors such as lower levels of resources to commit to adaptation strategies and responses. Although projected climate change hazards are significant for Northern and Western Europe, cities in these areas are generally larger and possibly better resourced. Patterns of climate change risk appear to match spatial socio-economic imbalances at the European scale, and may act to worsen these disparities. Nevertheless, caution must be exercised in making overly simplistic conclusions. It is clear that cities across Europe are at risk from climate change in different ways, and appropriate adaptation strategies across the continent are needed.

Principal metropolises can be regarded as the 'keystone species' of the European urban landscape. They can be distinguished from other European cities across a range of indicators, in terms of their population size, economic strength and sector diversity, and degree of innovation and dynamism (DG Regional Policy 2010). Climate change hazards in these cities could have a disproportionately large negative impact in comparison to other city types. Due to their strategic significance, where resources are available, the likelihood is that over time adaptation strategies will be developed to respond to the threat of climate change hazards in principal metropolises, particularly in northern and western Europe. These parts of Europe have higher levels of adaptive capacity than the Mediterranean for example (ESPON Climate 2011). The examples of London, Rotterdam and Copenhagen, which are already underway with adaptation planning processes, demonstrates that this is happening in practice in north western Europe. Principal metropolises in areas such as the Mediterranean and Southern Central Europe must also mount effective adaptation responses to reduce the risks associated with the climate change hazards that they face.

ESPON focuses on five generic determinants of adaptive capacity in assessing associated spatial patterns across Europe's NUTS3 regions: knowledge and awareness, technology, infrastructure, institutions, and economic resources (ESPON Climate 2011). They identify that adaptive capacity is generally lower in southern and eastern Europe than northern and western Europe (ESPON Climate 2011). Although the ESPON analysis focuses on NUT3 regions, it is assumed that their key conclusions on adaptive capacity also broadly stand for the cities situated in these regions. Adaptive capacity influences the level of risk associated with climate change hazards. As a result, although significant climate change impacts are projected for northern and western Europe, the capacity of these regions to mobilise adaptation responses lessens their overall level of climate risk. However, there is a question mark over whether adaptation planning and action will proceed proactively, following the precautionary principle, or occur in response to the experience of extreme weather events. Conversely, potential climate risks are greater for cities in the Mediterranean and southern central Europe due to the combination of high hazard exposure and relatively low levels of adaptive capacity. This is likely to be particularly true for smaller and less prosperous cities in these regions.

The Urban Audit city typology provides a current snapshot of the type and distribution of a sample of Europe's cities. In the same way that is necessary to apply a futures perspective to the European climate, it is useful to reflect on the potential for change in the landscape of cities over the coming decades. The city typology makes reference to cities with growing populations, many of which are in the Mediterranean. It also covers cities in the process of structural adaptation, with the majority being in northern and southern central Europe. In cities such as these there is the potential for dynamic change in their economic profiles and a greater intensity of urban development activity to accommodate growth. Without attention to climate change adaptation measures, this could potentially increase levels of exposure to hazards, particularly heat stress. For cities where capacity to adapt is relatively low, escalating exposure to climate change hazards over the coming decades (for example through increasing densities) is a threat to urban quality of life and future development potential.

It is important to emphasise that due to the local nature of climate change impacts within cities, which are influenced by fine scale patterns of vulnerability to climate change hazards and adaptive capacity, climate change projections at national and regional scales can only give a broad indication of climate change risks facing specific cities. Similarly, vulnerability may be lower and adaptive capacity higher within particular neighbourhoods in a city, lessening the potential risks linked to climate hazards. This influences how the results of this analysis should be interpreted, and where they can be most usefully applied. The value of this analysis is principally at the strategic level; for policy makers and practitioners working at the European, national and regional scales. Here, policy responses and resources could be allocated to address risks to certain groups of cities where the need is potentially greatest. The findings are not intended to directly inform city-scale planning and development, although cities may benefit from understanding their relative degree of climate risk and could be encouraged to learn from similar peer cities where adaptation responses are being developed.

6 European cities in a changing climate: conclusions and recommendations

Cities are frequently cited as problem generators for many reasons including lack of social cohesion, and high disparities in income, health and wellbeing. Yet, solutions to these problems often reside in the positive aspects that characterise cities; they remain Europe's main drivers of economic growth and employment, social change and innovation (European Commission Directorate General for Regional Policy (DG Regional Policy) 2010, 2011). Moreover, although frequently cited as the source of many environmental problems, for example, due to their major contribution to greenhouse gas emissions (OECD 2010a), others indicate that density and good transport networks in cities such as London and Barcelona mean that they emit less carbon per capita than their national averages (Dodman 2009).

As concentrators of people and assets, cities must also sit at the vanguard of the climate change adaptation agenda. If climate change impacts are left to steadily erode the functionality of cities, reducing their effectiveness as sources of cultural diversity, innovation and wealth creation, the competitiveness of Europe on the global stage will suffer. The extent of climate change impacts projected for the 21st century ensures that European cities face a future shaped in no small part by responding to the adaptation imperative. Given these multiple drivers, there is little doubt that climate change adaptation in European cities is set to intensify, although the pace and intensity of related activity remains to be seen.

This report has touched upon a range of issues linked to climate change hazards, impacts and vulnerabilities in European cities. European cities are highly susceptible to climate change impacts due to their concentrations of physical infrastructure and human populations (EEA 2010a, EEA 2012). Despite this fact, adaptation strategies to respond to climate change risks have only recently started to find their way into city policy and plan making (Carter 2011). Addressing the key issues raised by this report, there follows a series of conclusions and associated recommendations that aim to support individuals and organisations engaged in adaptation capacity building and action. These are targeted at strategic policy makers (at European, national and regional scales), European cities and the ASEC project (and by extension other projects looking at climate change risk and adaptation in cities).

6.1. Key conclusions and recommendations: strategic policy makers

City definitions: climate change adaptation connections

Due to the focus of this report on climate change hazards and vulnerabilities in European cities, attention has been paid to the basic question of how to define a city. Chapter 2 emphasises that there is a number of ways of in which this question can be answered, looking at cities in land use, administrative and functional economic terms for example. Recently, the European Commission and OECD's 'regional typology model' (OECD 2012) has incorporated land use and population data, recognising cities as urban systems.

In the context of climate change adaptation, two relevant themes emerge. The first concerns the spatial 'footprint' of cities from a physical perspective. Whether cities are defined in administrative or functional economic terms, as core cities or larger urban zones for example, each implies a spatial dimension. Cities will be perceived as covering a larger or smaller area depending on which definition or approach is taken. The issue of scale is significant in terms of climate change hazards; the more broadly a city is defined, the greater the potential for exposure to climate change hazards. Further, broader definitions connect cities to substantial hinterlands that provide functions linked to environmental and ecosystem services. In the context of adaptation these include water supply, flood water storage, food production and cool air flow. The second theme linking to the issue of spatial scale relates to socio-economic and demographic characteristics. Depending on how a city is defined, indicators including its population and average per capita income will vary. This is relevant due to the connections between these issues and notions of understanding sensitivity to climate change hazards.

Expanding on these two themes, the definition of a city influences the adaptation agenda in various ways including:

- *Identifying and prioritising climate change hazards:* The nature and scale of the climate hazards to which a city is exposed will differ according to city definition. A core city will have a different hazard profile than a larger urban zone in this respect. A geographically wider definition will generally bring into scope a broader range of landscapes and land uses, and may encompass, for example, flood risk zones that are not present within the boundaries of the core city.
- *Understanding the vulnerability of people and infrastructure:* As socio-economic and demographic indicators will vary according to which city definition is chosen, so too will measures of vulnerability of people and

communities to climate change hazards. Similarly, the types and volume of infrastructure potentially exposed to climate change hazards will differ according to the boundaries that are set. The vulnerability profile of cities is therefore dependant, in part, on how the city itself is defined.

- *Developing and implementing adaptation responses:* Some adaptation responses linking to issues such as flood risk management or cool air transfer become available to decision makers where the boundaries of cities are defined more broadly. Trans-boundary adaptation responses are also possible where cities are defined not as just the core city under the jurisdiction of one municipal authority, but as a collection of districts falling within the same functional economic area. It is at these scales that natural process connected to air flows and the water cycle can be more effectively managed.

Agencies and organisations engaged in this agenda could usefully clarify their understanding of how cities are defined when addressing issues linked to climate change adaptation.

Enhancing the availability of spatial data at the city scale

This report has demonstrated that available data and reports provide a basis to make broad statements about the future climate of Europe and the spatial variability of climate hazards at this scale. For example, it appears that a city in the Mediterranean is more likely to be exposed to extreme temperatures in the summer months than a city in north-western Europe. Similarly, a city in north-western Europe appears more likely to suffer from winter flooding or localised surface water flooding from high intensity rainfall events than a city in the Mediterranean. Beyond this, drawing on publically available data sets, it is difficult for cities to make more locally specific statements about the climate change hazards that they face. This issue is made more complex by the fact that exposure and sensitivity to climate change hazards differ at a fine scale within a city. There is a role for European agencies and organisations in supporting the development of more comprehensive city scale spatial data sets on issues linked to climate change hazards, and the exposure and sensitivity of European cities to these hazards. This would provide a stronger basis for the development of targeted adaptation responses at the city-scale.

Acknowledging and responding to spatial diversity

The core elements of the climate change adaptation agenda – hazards, vulnerability and adaptive capacity - are spatially diverse. For example, for a variety of socio-economic and biophysical reasons, not all cities (nor districts and neighbourhoods within them) are equally vulnerable to climate change hazards. Hazards will have different impacts on populations and infrastructures depending on a wide range of often interconnected issues such as their proximity to the coast, demographic profile or economic strength. There is a corresponding need to understand more about this diversity from a spatial perspective in order to advance adaptation in European cities. Ultimately, as noted by the OECD:

> 'Adaptation will…need to be tailored to local and regional contexts that drive vulnerability and adaptive capacity' (OECD 2010a: p. 29).

This report emphasises that climate hazards vary spatially across Europe, for example related to greater exposure to droughts, fires and heat waves in the Mediterranean, central and southern Europe. Spatial differences to future precipitation patterns and associated flood risk (e.g. increase in mean annual precipitation in northern Europe and a fall in southern Europe) are also apparent (Alcamo et al 2007). This hazard diversity is visualised through outputs such as ESPON's 'climate change clusters' (ESPON Climate 2011). It is also apparent that a climate change hazard of a given intensity will impact differently depending on which 'type' of city it hits. Following the terminology of the Urban Audit city typology, a smaller centre situated inland in the Mediterranean clearly faces very different climate change adaptation challenges than a principal metropolis in a coastal area in north-western Europe. This relates not only to the climate change hazards that they are projected to face, but also to their level of vulnerability and capacity to adapt to these hazards. The nature of adaptation strategies will need to be correspondingly varied. A key message for policy makers is to develop ways of looking beyond cities as a homogenous group when developing adaptation policy and strategy.

It is also significant that an overall assessment of Europe's adaptive capacity shows a distinct north-south split in this respect, with the Mediterranean and south eastern Europe displaying relatively low levels of adaptive capacity (ESPON Climate 2011). As hazards are also projected to be intense in these areas, climate change could therefore act to worsen the prevalent socio-economic imbalances at the European scale in the future. This presents a strong argument for the development of high level policy and the targeted allocation of resources to reduce this risk.

Promoting early adaptation action in European cities

Acknowledgement of several issues demonstrates that the development of urban adaptation strategies and responses in the short term is going to be necessary. Firstly, European cities already suffer from the impacts of extreme weather and climate. Adaptation strategies are therefore needed to stem the erosion of long term resilience and adaptive capacity that arises from urban areas being impacted by hazards associated with weather and climate extremes. Indeed, it can take urban areas years to recover from serious floods for example, diverting resources from more productive uses (including investing in proactive long term adaptation responses). It is also apparent that some climate change impacts (for example sea level rise) are being experienced more quickly than projected (Rahmstorf et al 2007), in addition to there being several global 'tipping points' that raise the risk of accelerating climate change (Lenton et al 2008). Further, risks associated with climate change beyond Europe's borders may have significant implications for daily life in European cities in the shorter term.

The precautionary approach therefore dictates that early adaptation action is most appropriate, particularly where this supports the achievement of other policy goals such as greenhouse gas emission reduction or biodiversity conservation. It is also important to acknowledge that certain adaptation responses are not 'quick fixes' and can require years and sometimes decades of planning, implementation and maturation; developing green infrastructure networks in urban areas and re-locating critical energy infrastructure at risk of coastal flooding are good examples. The slow turnover of the building stock in many European cities, which often hold considerable heritage value, highlights that urban planners cannot wait for new development opportunities to implement adaptation responses. Ongoing retrofitting of the urban form for the changing climate is therefore a necessity. Arguments such as these have the potential to stimulate the mobilisation of resources and political commitment to respond to the adaptation imperative over the coming years.

6.2. Key conclusions and recommendations: European cities

Apply a conceptual framework to support adaptation planning

A conceptual framework can be a useful decision making aid for developing climate change adaptation strategies and responses. By simplifying what is a highly complex agenda into more manageable units, a good framework demonstrates the broad issues that connect climate change processes and adaptation responses. Conceptual frameworks also specify the types of data that can usefully be gathered to support the assessment of climate risk and the development and implementation of adaptation responses. Following the AR3C framework outlined in this report (Rosenzweig et al 2011) it is recommended that cities:

- Determine the hazards associated with climate change that are most prevalent within their city;
- Identify the most vulnerable receptors (people, places, things) within their city;
- Assess the city's ability to adapt to projected changes in their climate.

Following this approach provides cities with a platform to develop targeted adaptation responses to the most prevalent risks.

Develop alliances to better understand spatial data and adaptation responses at the city scale

While European region scale data can usefully provide broad inferences about climate change hazards at a city scale, cities should not use this data as a basis for detailed adaptation planning locally. Climate change projections produced at higher scales can only highlight broad projections for climate variables, and risk missing the local subtleties that characterise exposure to hazards at finer scales. Cities should be encouraged to develop a stronger spatial understanding of their exposure and sensitivity to these hazards. Cities could usefully look to develop alliances, for example with research institutes and consultancies, in order to develop a more refined picture of potential climate change hazards. The conclusions within this report relating to the spatial diversity of issues linked to climate change risk also offer a basis to develop city networks twinning partners sharing similar characteristics. These can be encouraged to foster valuable mutual learning, and co-production of knowledge and responses to the adaptation imperative. When cities can more clearly appreciate the climate change risks they face, the development of locally appropriate and spatially targeted adaptation strategies and responses can proceed more effectively and efficiently.

6.3. Key conclusions and recommendations: the ASEC project

There follows a set of conclusions and recommendations arising from this review that are targeted to the ASEC project, from where this report originated. It is useful to note that these recommendations are also broadly relevant to other adaptation research programmes.

Developing a typology matching cities and their adaptation challenges

An aim of the ASEC project is to develop a typology matching cities and their adaptation challenges. The ASEC project recognises that a typology can be beneficial for driving forward the adaptation agenda in European cities noting that:

> "….different cities will face similar problems because they share characteristics, be they non-climate context or climate dependent. A typology will help to classify European cities according to these variables."

The ASEC project states that it is essential to the success of the project as a whole that the typology is built on a strong conceptual understanding of the adaptation process. An early task for this review was therefore to identify an appropriate conceptual framework to base the development of the project typology around. The ARC3 approach was proposed for this purpose (see section 3) which considers climate change hazards, vulnerabilities and adaptive capacity as the essential elements of developing adaptation responses.

This review has uncovered challenges to developing of a typology of this sort. These centre on issues of data availability and quality. Operationalising a typology relies on data inputs to differentiate cities. This review has established that measuring some of the factors linked to assessing climate change risk in cities (and hence their adaptation needs) is difficult and it is highly likely that currently available data will support the assessment of just some of the true range of issues affecting the extent of hazards, vulnerability and adaptive capacity of cities across Europe. Further, existing data sets that offer such data, such as the Urban Audit, cover a limited (yet representative) sample of European cities. Also, where data can be accessed, its quality can vary and it may not always be possible to compare data sets available for different cities where these originate from different sources.

Nevertheless, this report has demonstrated that at a relatively broad-brush level, cities can be distinguished according to issues including their socio-economic and demographic characteristics, and the climate change hazards that they are projected to experience in the future. It is apparent that there exists a range of city types, in terms of their shared or contrasting adaptation challenges, and it is possible that most European cities could be placed into a broad 'type' in this respect. This could be broadly based around Urban Audit city types and ESPON Climate clusters. These insights can be useful in supporting the process of developing groups of cities to engage in training and capacity building exercises, which forms the focus of the next recommendation.

Selecting cities for training and capacity building clusters

The ASEC project aims to select a sample of 21 cities to engage in an adaptation training and capacity building exercise. Due to the range of climate change hazards and city types within Europe, it cannot be expected that all possible permutations will be covered. Nevertheless, an important stage in the project is to select an appropriate group of cities to engage in this way, and this review emphasises that there are several potential approaches to making this selection. The question is which approach to follow. Ideally cities should be selected according to a combination of issues linking to climate change hazards, vulnerabilities and adaptive capacity. Focusing on one issue alone risks missing important connections between cities concerning their shared adaptation challenges.

A geographical focus may facilitate a grouping of cities projected to face similar climate change hazards in the future. However, different cities in broadly similar locations (for example coastal areas in north west Europe or inland areas in the Mediterranean) will still face different hazards as a consequence of local issues such as topography, altitude, proximity to the coast and rivers, or urban form. Indeed, heat stress will not be equally prevalent in all Mediterranean cities, despite the projections for increasing frequency and duration of heat waves across this region.

Understanding climate hazards is one aspect of adapting to the changing climate. A city’s capacity to respond is also crucial. The impacts of a hazard event of a similar magnitude in two different cities will depend on factors including their socio-economic and demographic profiles, and the extent to which they have developed adaptation strategies and implemented adaptation responses in the past. In selecting an appropriate sample of cities it is important to be mindful of these issues.

Ultimately, matching similar types of cities (using the Urban Audit typology as a guide) could be a valuable approach to guide the process of grouping cities for training and peer learning. If a city does not fall under the Urban Audit, it will be necessary to judge which broad group it falls into based on comparison of available socio-economic data against the characteristics of the Urban Audit city types. The nature of hazards facing cities within each group will clearly differ. Nevertheless, the factors influencing the approach taken to developing adaptation responses will exhibit similarities in terms of issues such as population size and economic strength. Following the Urban Audit city typology, within a capacity building exercise, bringing together a principal metropolis and a smaller centre from the same climate change region may be less productive than one that includes two smaller centres from different climate change regions. For instance, a principal metropolis and a city of the lagging regions situated in a coastal zone both at risk from sea level rise are likely to face a very different range of options in developing strategies and responses to a rapidly changing climate.

7 References

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8 Annex 1: Summaries of the short listed reports.

The following 20 reports were selected for detailed analysis to inform this report based upon certain criteria. The first was whether or not the report was widely accessible, therefore discounting published academic papers since these often require institutional access or payment. Secondly, the report had to be directly relevant to climate change in EU cities. So, many of the sources include European agencies such as the EEA. Lastly, certain reports could be included that were not ostensibly linked to EU cities, for example those linked to adaptation conceptual frameworks.

Each overview includes publication details, geographical focus and the hazards covered along with a brief description and a bulleted list highlighting its relevance to climate change impacts and adaptation in European cities. At the end of this annex is a list of the reports with an overview of their scope and coverage in a comparative perspective.

1. Europe. Climate Change 2007: Impacts, Adaptation and Vulnerability

Intergovernmental Panel on Climate Change (IPCC)
2007

Publication details: 39 pages, executive summary included

Geographical focus: Europe, with reference to specific regions and countries where relevant

Hazards covered: wide range of climate hazards

Brief Description

This chapter, contained within the report of Working Group II of the IPCC's 4th Assessment, provides an overview of climate change impacts, vulnerabilities and adaptation responses at the European scale. It highlights that Europe is already experiencing climate change impacts (e.g. to the cryosphere and ecosystems), and that recent observed changes indicate the direction of future climate change. A key IPCC message is that climate hazards will vary spatially across Europe, for example related to greater risk of droughts, fires and heat waves in the Mediterranean, central and southern Europe. Spatial differences to future precipitation patterns (e.g. increase in mean annual precipitation in northern Europe and a fall in southern Europe) are also noted. Impacts on a range of different economic sectors are identified, including energy, transport, tourism and agriculture. Implications for ecosystems, species and human health are also discussed.

Links to climate impacts and adaptation in European cities

- Emphasises that Europe's climate is already changing, with impacts felt across a range of sectors.
- Adaptation in European cities should build responses to current climate patterns and associated extreme events.
- Importance of taking a spatial perspective to the assessment of climate hazards and vulnerabilities at the European scale: 'Impacts of climate change will vary substantially from region to region, and from sector to sector within regions' (p.544).
- Adaptive capacity will vary according to location. Some cities will be in a better position to address the challenges and potential opportunities linked to the changing climate.
- An integrated approach to responding to the changing climate is proposed, ideally one that recognises, and does not conflict with, sustainable development goals.

URL

http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg2_report_impacts_adaptation_and_vulnerability.htm

2. International Dimensions of Climate Change Final Project Report

Foresight (The UK Government Office for Science)

2011

Publication details: 127 pages, executive summary included

Geographical focus: country (UK)

Hazards covered: the report focuses in the international impacts of climate change on the UK

Brief Description

The report considers the implications of global climate change for the UK. The key message is that global impacts (i.e. those occurring in countries other than the UK) could be as significant as the impacts of climate change directly affecting the UK. These include that climate change could stimulate international instability, negatively affect UK financial and business interests, threaten resources and infrastructure on which the UK depends and have global health implications that could influence the UK. Associated challenges (and in some cases opportunities linked to developing responses to adapt to climate change) should not be considered in isolation, and should instead be seen as linked to other policy agendas. The report notes that uncertainties around future climate change and its impacts should not be taken as a reason for policy inaction, and a risk-based approach is advised.

Links to climate impacts and adaptation in European cities

- The international impacts of climate change on the political, economic and social interests of European countries will also affect their cities. These impacts could be as significant as the direct impact of climate change in cities (e.g. flooding, heat waves).
- Cities often link to global networks of people, goods and services that are essential to their effective functioning. Climate-induced threats to these networks would have major implications for cities. At a global scale, impacts on food security, financial/business sectors (and hence employment), and infrastructure internationally (airports, ports, oil refineries) would affect European cities.
- Risk-based adaptation responses to these impacts would change the form and function of European cities, potentially making them more resilient to external climate shocks.

URL

http://www.bis.gov.uk/foresight/our-work/projects/published-projects/international-dimensions-of-climate-change/reports-and-publications

3. European and Global Climate Change Projections: Discussion of Climate Change Model Outputs, Scenarios and Uncertainty in the EC RTD ClimateCost Project

Christensen, O. B, Goodess, C. M. Harris, I, and Watkiss, P.

2011

Publication details: 28 pages, key messages included

Geographical focus: Global, Europe

Hazards covered: temperature, precipitation

Brief Description

This policy briefing presents the results of climate modelling work for Europe, placing the continent in the context of global climate change projections. Three greenhouse gas emissions scenarios provide a basis for the modelling work; a medium-high emissions non-mitigation scenario (A1B), a mitigation scenario (E1) and a high emissions scenario (RCP8.5). Projected changes in temperature and precipitation patterns for Europe over the course of this century differ according to which emissions scenario is considered and which climate model output is selected. The briefing focuses winter and summer temperature and precipitation projections for Northern, Southern, Eastern and Western Europe. Key messages include:

- Warming is projected across Europe, with the greatest increases over land in Southern Europe (particularly the Iberian Peninsula).
- There are marked differences in projected precipitation change within Europe and across the seasons. Summers in Southern Europe could bring around half the current levels of rainfall by the end of the century. Increases in winter precipitation are projected for Northern and North Eastern Europe.
- There is considerable uncertainty in climate projections depending on the emissions scenario, climate model and time horizon chosen.

Links to climate impacts and adaptation in European cities

- The report stresses that the uncertainty characterising future climate change projections should not be seen as a reason for inaction and that robust strategies to prepare for uncertain futures are needed.
- It is important to focus on regionally specific climate change projections data when developing adaptation responses.
- The low emissions scenario still projects significant climate change, for example related to summer temperatures (up to 3°C increase by the end of the century).
- Even in a future where radical mitigation action is taken, cities will need to remain focused on developing adaptation responses.

URL

www.climatecost.cc/images/Policy_brief_1_Projections_05_lowres.pdf

4. Climate change: global risks, challenges & decisions. Synthesis Report from Copenhagen 2009, 10-12 March

University of Copenhagen

2009

Publication details: 39 pages, executive summary included

Geographical focus: global

Hazards covered: wide range of climate hazards

Brief Description

This report, arising from a conference organised by the International Alliance of Research Universities, brings together contributions from across the international climate change research community. It covers a broad range of recent research, and proposes 6 key messages. These are:

1. Continued greenhouse gas emissions are likely to accelerate recent observed climate trends, risking abrupt or irreversible climate shifts;
2. A rise in global mean temperatures to 2°C above pre-industrial levels would likely cause major social and environmental disruption;
3. Emissions reduction strategies are urgently required. Delay risks more severe impacts (and costly mitigation measures) in the future;
4. Equity issues cross the climate change challenge. Responding to climate change should link to broader socio-economic goals;
5. Existing tools and approaches to mitigate and adapt to climate change should now be applied, which would bring long-term benefits;
6. Societal transformation is needed to meet the climate change challenge.

Links to climate impacts and adaptation in European cities

- The report represents a strong statement from some of the world leading climate change researchers that systemic transformations are needed to meet this challenge.
- The report underscores the scale of the challenge facing European cities. This concerns the emissions reductions required, and if rapid action is not taken in this regard, the risk of major climate change impacts.
- The report highlights that cities are responsible for around 75% of human greenhouse gas emissions, are home to over half of the world's population and are particularly vulnerable to climate change impacts. As a result the report emphasises that "…the battle against climate change will be won or lost in cities." (p.30)

URL

http://climatecongress.ku.dk/pdf/synthesisreport

5. Climate change impacts in Europe. Final report of the PESETA research project

European Commission Joint Research Centre

2009

Publication details: 114 pages, executive summary included

Geographical focus: Europe, with a focus on 5 geographical regions

Hazards covered: flooding, sea level rise, heat stress

Brief Description

The report notes a knowledge gap regarding the potential impacts of climate change on Europe's environment, economy and population, to which the PESETA project aimed to respond. Five 'impact categories' were considered: agriculture, coastal floods, river systems, tourism and human health. These issues were considered across five regions: Southern Europe, Central Europe South, Central Europe North, British Isles and Northern Europe. The impacts of climate change differ according to issues including location and time horizon considered. Significant findings include:

- More than double the number of people exposed to river flooding by the 2080s, particularly in Central Europe and the British Isles, compared to 1961-1990 figures.
- Without adaptation measures, the number of people affected by sea flooding rises from 36,000 (1995 figure) to 775,000 to 5.5 million depending on the scenario considered.
- By the 2080's, levels of heat-related mortality increase whilst levels of cold-related mortality decrease.
- By the 2080's, under a high emissions and high sea level rise scenario, costs of climate change to Europe's economy are estimated at around €65billion.

Links to climate impacts and adaptation in European cities

- Negative impacts on assets and people in cities are set to increases, particularly as a result of flooding from rivers and the sea.
- Some regions could benefit from climate change, for example related to improved tourism potential and reduced incidence of cold related deaths. Quality of life in some cities may therefore increase.
- Enhanced understanding of the geographical and sectoral impacts of climate change can help cities develop better targeted adaptation strategies.
- Economic damages are expected to be greatest in Southern Europe and Central Europe North. Cities in these regions therefore look to be at particular risk.

URL

http://www.climatecost.cc/images/Policy_brief_2_Coastal_10_lowres.pdf

6. Impacts of Europe's changing climate: 2008 indicator-based assessment

European Environment Agency

2008

Publication details: 246 pages, executive summary included

Geographical focus: Europe

Hazards covered: wide range of climate hazards

Brief Description

This report covers past and projected climate change and related impacts at the European scale, and demonstrates these issues via the use of indicators. The aim is to identify vulnerable regions and sectors across Europe in order to inform the development of adaptation responses. Indicators relate to a range of climate change hazard themes linked to the atmosphere and climate (e.g. changes in precipitation and the intensity of precipitation extremes). The direct impacts of these hazards are also considered, for example concerning flooding, droughts and water quality. The indicators also address climate change impacts on different sectors, including biodiversity, agriculture and human health. Where appropriate these indicators are mapped. The indicator maps demonstrate that spatial patterns of climate change impacts and vulnerabilities vary widely across Europe. An economic assessment of the costs of past and projected climate change impacts emphasises the associated financial implications linked to issues such as flooding and agricultural productivity. Although uncertainties in climate change data are acknowledged, the report concludes that adaptation is needed to increase the resilience of human and natural systems to future climate change.

Links to climate impacts and adaptation in European cities

- Covers a range of different indicators linked to climate change impacts and vulnerabilities in urban areas, highlighting the cross-sectoral nature of climate change impacts and adaptation responses.
- Demonstrates that past and current climate change trends are having visible impacts on European cities.
- Past and current trends generally reflect the direction of future climate change projections.
- Critical connections between key sectors within and beyond cities, for example energy supply, water supply and transport, will be put under pressure by the changing climate.
- Climate change is identified as a threat to public health. Protecting vulnerable populations is therefore important, an issue that is particularly relevant to cities.

URL

http://www.eea.europa.eu/publications/eea_report_2008_4

7. Adapting to Climate Change

European Environment Agency

2010

Publication details: 52 pages, summary included

Geographical focus: Europe, with a focus on Europe's biogeographical regions

Hazards covered: wide range of climate hazards, particularly heat waves, flooding and drought

Brief Description

Undertaken as one of the thematic assessments of the European environment state and outlook 2010, this report focuses on key climate change vulnerabilities from a European perspective. Vulnerable regions are identified as the Mediterranean basin, north-western and central-eastern Europe and the Arctic. Coastal zones, areas prone to flooding, mountain areas and cities are also highlighted. It is noted that the majority of observed and potential future climate change impacts are expected to be negative.

Even in the event of global temperature rises remaining 2°C or below pre-industrial levels, it is suggested that adaptation strategies will be needed. 'Vigorous adaptation' is called for, and the report makes it clear that policy makers should focus on addressing the adverse impacts of climate change, where proactive action is needed, leaving potential beneficial impacts of climate change to autonomous adaptation and the private sector. As vulnerability to climate change in Europe differs spatially and sectorally, the report notes that adaptation is therefore location and context specific.

Links to climate impacts and adaptation in European cities

- European cities are highlighted as being particularly vulnerable to climate change impacts due to their concentrations of physical infrastructure and human populations.
- Heat waves, flooding (coastal and riverine) and droughts are identified as particularly relevant to European cities, with potential implications for sectors including infrastructure (water, energy, buildings and transport), health and the economy.
- Socio-economic drivers, such as urban sprawl and soil sealing, intensify climate change impacts by altering runoff patterns and aggravating the heat island effect. Urban planning is needed to avoid such impacts worsening in the future.
- Climate change impacts will in turn have implications for settlement patterns, for example through stimulating 'managed retreat' from flood prone coastal zones.

URL

http://www.eea.europa.eu/soer/europe/adapting-to-climate-change

8. Climate Change and Territorial Effects on Regions and Local Economies, Final Report Version 31/5/2011, Scientific report

ESPON and IRPUD

2011

Publication details: 291 pages

Geographical focus: Europe, with a focus on regions (NUTS 3)

Hazards covered: A range of direct impacts lined to changing temperature and rainfall patterns

Brief Description

This report offers a pan-European vulnerability assessment, undertaken with the aim of identifying regional typologies of climate change exposure, sensitivity, impact and vulnerability. The research underpinning the report is based on the recognition that these elements of the climate change agenda are spatially diverse, and the corresponding need to understand more about this diversity from a spatial perspective in order to advance adaptation. The data contained in the report offers an evidence-based framework around which a territorial response to climate change impacts can be built. This includes mapping of climate change indicators (e.g. related to changes in temperature and precipitation variables), leading to the identification of five European climate change regions which each share similar future climate change characteristics. Europe's administrative regions are also mapped according to their sensitivity to climate change (based on physical, environmental, social, cultural and economic indicators) and according to the potential impacts of climate change (physical, social, economic etc). Regional capacities to adapt to climate change are also mapped, looking at issues including economic resources and infrastructure quality. Data on exposure, sensitivity and adaptive capacity are integrated to map the overall vulnerability of European regions to climate change.

Links to climate impacts and adaptation in European cities

- The report offers cities the opportunity to develop locally relevant adaptation strategies based on a better understanding of the climate change challenges they face.
- Potential impacts of climate change (river flooding and sea level rise) on settlements are mapped, identifying high impacts for coastal regions (e.g. the Netherlands, Belgium) and regions facing multiple climate hazards (e.g. Northern Italy, Western France).
- Agglomerations, particularly in the South, are noted as being vulnerable to urban heat.
- An overall assessment of Europe's vulnerability to climate change shows a distinct north-south split, with the Mediterranean and South-Eastern Europe most vulnerable.
- Patterns of climate change vulnerability appear to match spatial socio-economic imbalances at the European scale.

URL

http://www.espon.eu/export/sites/default/Documents/Projects/AppliedResearch/CLIMATE/ESPON_Climate_Final_Report-Part_C-ScientificReport.pdf

9. Cities and Climate Change

OECD

2010

Publication details: 278 pages, executive summary included

Geographical focus: global

Hazards covered: wide range of climate hazards

Brief Description

'Adaptation will…need to be tailored to local and regional contexts that drive vulnerability and adaptive capacity (p. 29)'

This report synthesises a large body of OECD work on climate change impacts and vulnerabilities in cities. It discusses climate impacts specific to urban areas and takes on board that urban population and infrastructure are increasingly at risk to detrimental effects of climate change. Urban infrastructure is a key area since much of it is already in place, and may therefore need to be retrofitted. The impacts of rising temperatures and sea levels, as well as changing precipitation patterns, should be considered when planning new urban infrastructure, although long lead times render this a complex exercise

The report looks at urban multi-level governance, noting that adaptation policies at the local level have lagged behind mitigation actions. Cities and urban planning provide a key entry point to act on the adaptation agenda and reduce vulnerabilities. For example, vulnerability to storm and hurricane risks can be reduced through spatial planning and land management. That land-use change occurs over decades and urban buildings typically last 50 to 100 years, if not longer, make this a complex exercise.

Links to climate impacts and adaptation in European cities

- Cities provide an appropriate scale to develop innovative policy solutions that can be scaled up into regional or national programmes, or to provide a laboratory for national pilot programmes on the urban level.
- Need for land-use and spatial planning to address urban sprawl and density
- Need for inter-municipal strategies to climate adaptation as impacts will cut across administrative boundaries.
- Climate change impacts are often localised, thus effective responses require region specific.
- Vulnerability assessments model potential local damage in scenarios of flooding, rising sea levels, heat extremes, and other expected climate change impacts.
- Coastal cities and poorer cities are more vulnerable to climate change

URL

http://www.oecd-ilibrary.org/docserver/download/fulltext/0410081e.pdf?expires=1331140090&id=id&accname=ocid177243&checksum=385D874BB856104C1BD7720D68A86CFD

10. Climate Change and Cities: First Assessment Report of the Urban Climate Change Research Network

OECD

2011

Publication details: Executive summary only online, 9 pages

Geographical focus: global

Hazards covered: wide range of climate hazards

Brief Description

This report covers cities in the developed and developing world, using climate science and socio-economic research to facilitate the mapping of a city's vulnerability to climate hazards. It also considers how cities can develop both their adaptation and mitigation capacity to deal with climate change over different timescales.

It uses a new conceptual framework for assessing risk and vulnerability that differs from the standard IPCC approach. The UCCRN climate change vulnerability and risk assessment framework is comprised of three distinct and overlapping sets of indicators: *Climate hazards* facing the city, such as more frequent and longer duration heat waves, greater incidence of heavy downpours, and increased and expanded coastal or riverine flooding; *Vulnerabilities* due to a city's social, economic, or physical attributes such as its population size and density, topography, the percentage of its population in poverty, and the percentage of national GDP that it generates; *Adaptive capacity aspects*, factors that relate to the ability of a city to act, such as availability of climate change information, resources to apply to mitigation and adaptation efforts, and the presence of effective institutions, governance, and change agents.

Links to climate impacts and adaptation in European cities

- Provides a specific way of incorporating adaptive capacity into city-scale climate change vulnerability and risk assessments.
- Identifies the need to consider sectoral implications and cross-cutting issues in tandem with one another.
- Emphasises that Cities need to incorporate climate science, adaptation strategies, and mitigation actions into daily decision-making and long term plans and investments.
- Cities, often acting as research hubs, can provide the grounds for testing innovative policy strategies.

URL

http://uccrn.org/documents/ARC3_Executive_Summary.pdf

11. Assessing key vulnerabilities and the risk from climate change

Intergovernmental Panel on Climate Change

2007

Publication details: 32 pages, inc. executive summary

Geographical focus: global

Hazards covered: wide range of climate hazards

Brief Description

This section of the IPCC's 4th Assessment Report identifies key vulnerabilities to climate change based on known and normative indicators. The criteria for assessing vulnerability are magnitude of impacts; timing of impacts; persistence and reversibility of impacts; likelihood (estimates of uncertainty) of impacts and vulnerabilities; confidence in those estimates; potential for adaptation; distributional aspects of impacts and vulnerabilities; importance of the system(s) at risk.

Although it does not address cities and urban areas specifically, the report identifies key vulnerabilities under five categories. These can be considered in relation to their effects on urban areas and are: global social systems; regional systems; global biological systems; geophysical systems and extreme events.

The report considers the developing world as being more susceptible to climate impacts than nations in, for example Europe. However, it identifies that drought and drying in the Mediterranean, increasing frequency and intensity of extreme heat events, as well as concentrations of air pollutants, such as ozone, may increase mortality and morbidity in urban areas and increase their vulnerability to the changing climate.

Links to climate impacts and adaptation in European cities

- There is a need to consider how key climate change vulnerabilities in other regions at a global scale may impact on European cities.
- Although the report identifies key vulnerabilities, the responses of human and natural systems to climate change impacts, both autonomous and anticipatory, will need to be considered when assessing overall future climate risk.
- There is considerable potential for adaptation to climate change via market and social systems, dependent on the costs and institutional capacities to adapt.
- Where the potential for adaptation is much lower, for example in certain biological and geophysical systems, mitigation strategies will need to be elevated.

URL

http://www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4-wg2-chapter19.pdf

12. Ensuring quality of life in Europe's cities and towns: tackling the environmental challenges driven by European and global change

European Environment Agency

2009

Publication details: 110 pages

Geographical focus: European cities

Hazards covered: all, particularly river and surface water flooding; drought

Brief Description

This report considers climate change as one of six key drivers that will affect quality of life in Europe's cities in the future. Climate change is considered along with Demographic changes; Consumption and urban lifestyles; Urbanisation; Air pollution and noise and Cohesion policy. The report illustrates how different conceptions of quality of life influence the quality of life of others, and provides ideas for ways to meet the challenges that lie ahead; and by doing so aims to support individuals and politicians to discover a balanced concept for quality of life compatible with sustainable development.

The report notes that concrete action on adaptation is still very limited. Barriers to adaptation these include (1) Individual cities may feel that acting alone will have limited effect and that they are not in a position to implement all the changes they need to make. The actions taken by cities also depend on national actions and actions by other cities and regions worldwide. (2) Coordination of many different sectors and actors poses another challenge (3) there are low levels of awareness in cities of the concrete impacts of climate change and what they must do to adapt to the impacts. (4) Current policy lacks sufficient level of long term commitment, in particular economic to initiate the necessary measures, (5) few cities have experience of implementing measures that allow adaptation to the 'new' climate change conditions.

URL

http://www.eea.europa.eu/publications/quality-of-life-in-Europes-cities-and-towns

13. The Impacts and Economic Costs of Sea-Level Rise in Europe and the Costs and Benefits of Adaptation. Summary of Results from the EC RTD ClimateCost Project. Technical Policy Briefing Note, 2.

S. Brown, R.J. Nicholls, A. Vafeidis, J. Hinkel and P. Watkiss

2011

Publication details: 44 pages, key messages included

Geographical focus: Europe

Hazards covered: River (estuary) flooding, coastal flooding, sea-level rise

Brief Description

Part of a wider volume of published work under the ClimateCost programme, this policy briefing analyses the potential cost and impacts of sea level rise in Europe. It models this for various scenarios to provide an overview of a European-wide assessment of the impacts and economic costs of sea-level rise, covering coastal floods and flooding around estuaries. It considers three European geographic regions, based on GDP: OECD countries, Eastern European and former USSR countries.

The report covers the impacts in terms of number of people at risk of flooding, different socio-economic scenarios and the extent of impacts based upon the uptake of adaptation options. It highlights a strong spatial distribution of impacts across the EU. Looking at the annual damage costs, it reports these at national scale, taking account of topography, size of economy, length of coastline and existence of strong flood defences. It estimates that for several different scenarios of sea-level rise, countries in north-west Europe have the greatest potential damages and costs, although many of these countries are nevertheless preparing well for the changing climate.

Links to climate impacts and adaptation in European cities

- Cities located on the coast line or in estuaries in north-west Europe have the greatest potential damages and costs, although many of these countries are the most prepared for climate change in the European Union.
- Climate and socio-economic uncertainty make a difference to the nature of future adaptation responses. This uncertainty needs to be considered as part of integrated and flexible approaches.
- The most appropriate response to sea-level rise cities in coastal areas is a combination of adaptation (to deal with the inevitable rise) and mitigation (to limit the long-term rise to a manageable level).
- More detailed, local scale assessments are required to assess and reduce risk to vulnerable areas, including the development of local adaptation plans.

URL

http://www.climatecost.cc/images/Policy_brief_2_Coastal_10_lowres.pdf

14. Adapting Energy, Transport and Water Infrastructure to the Long-term Impacts of Climate Change.

URS (Ltd.) Corporation

2010

Publication details: 144 pages, executive summary included

Geographical focus: UK

Hazards covered: wide range of climate hazards

Brief Description

URS Corporation Limited (URS) was commissioned by the UK Department for Environment, Food and Rural Affairs (Defra) report on the risks and operational implications of long-term climate change to infrastructure in the energy, water and transport sectors. The report identifies key related infrastructure elements that are vulnerable to climate change impacts, and proposes adaptation options based on the analysis of risks.

Although technical solutions will vary considerably across each sector, the report concluded that new infrastructure in all sectors face certain common issues. Responses entail the identification of the likely impact of long-term climate change impacts on new infrastructure and examining the possible acceptable minimum level of resilience to these impacts; providing new or revised advice/constraints on infrastructure design and/or construction; statute and/or regulation to ensure any interconnectivities and/or interdependencies between infrastructure types are properly addressed for the design life of the infrastructure; and, if necessary, financial controls and undertakings to ensure any operating costs are covered; again for the duration of the life of the infrastructure.

Links to climate impacts and adaptation in European cities

- Cities are home to large concentrations of infrastructure, and are dependent on this for their effective functioning. Adapting infrastructure to climate change is needed.
- Stresses the interdependency between sectors and infrastructure types.
- Need for flexible adaptation options that can be modified in light of the uncertainties linked to understanding future climate change impacts.
- Need for long-term time horizons in planning and design of infrastructure.
- Cities will need to adapt in response to statute and regulation on infrastructure and address vulnerability of infrastructure through adequate planning policy mechanisms.

URL

http://archive.defra.gov.uk/environment/climate/documents/infrastructure-full-report.pdf

15. Improving public health responses to extreme weather/heat-waves – EuroHEAT

WHO Regional Office for Europe

2009

Publication details: 70 pages

Geographical focus: European

Hazards covered: extreme cold, heat waves, drought

Brief Description

Following the serious health and social problems posed by the 2003 heat waves, the Fourth Ministerial Conference on Environment and Health initiated a wide scale project to understand the impacts to weather extremes, particularly heatwaves, in order to improve the public health response.

This report summarises the research. Adverse health effects of hot weather and heat-waves are largely preventable, at least under current climate conditions. Prevention requires a range of actions at different levels, including health system preparedness coordinated with meteorological early warning systems, timely public and medical advice and improvements to housing and urban planning.

Significantly, it notes that long spells of hot weather have most impact in larger, highly populated cities such as Europe's principle metropolises of London and Paris. Future years should focus on how effective these actions have been in preventing heat-related mortality, particularly amongst the most vulnerable.

Links to climate impacts and adaptation in European cities

- Need to address reducing exposure to heat waves through urban planning and building design.
- Longer duration heat waves cause greater impacts, particularly in densely populated cities such as London and Paris.
- European cities need to monitor whether policies in place are reducing exposure.
- Reports mainly focus on heat waves – less information regarding mortality under extremely cold conditions.

URL

http://ccsl.iccip.net/e92474.pdf

16. The UK Climate Change Risk Assessment 2012 Evidence Report

HM Government, UK

2012

Publication details: 488 pages, separate summary report available

Geographical focus: UK

Hazards covered: wide range of climate hazards, especially flooding and heat waves.

Brief Description:

As a result of the national Climate Change Act (2008), the UK will undertake an independent analysis of climate change risks every five years. The first is published in 2012 and feeds into the country's National Adaptation Plan (2013).

This Evidence Base report (in conjunction with a shorter overview) gathered reports from eleven different sectors in the UK. Rather than synthesising existing research, the CCRA compares around 100 different climate risks. The resulting risk assessment considers these across the five identified themes of agriculture and forestry; biophysical impacts; business; health and well-being; buildings and infrastructure and natural environment. It assesses the priority of risk based on considering magnitude of consequences for the 2050s, confidence in the risk and urgency.

Although it contains some national and regional comparisons and considers the international dimensions of climate change, the results should not be used for re-analysis or interpretation at a local or site-specific scale. The CCRA is intended to support policy-makers at national level in planning for climate change. Nevertheless, it provides a useful framework for city-scale adaptation and looks at options for adaptation planning.

Links to climate impacts and adaptation in European cities

- Rising temperatures and changing precipitation levels pose the greatest potential risks to urban environments in the UK.
- Adaptation planning needs to be mainstreamed in all sectors affected by climate change.
- High priority risks include overheating of buildings, infrastructure and the potential health risks; flood risk to buildings, people and the economy; water resource scarcity. These risks all link closely to the future of cities.
- Notes a knowledge gap in understanding the interdependency between sectors and how different factors combine to increase the potential risks in urban environments.

URL

http://randd.defra.gov.uk/Document.aspx?Document=TheUKCCRA2012EvidenceReport.pdf

17. Copenhagen: climate adaption plan.

City of Copenhagen

2011

Publication details: 16 pages

Geographical focus: City of Copenhagen

Hazards covered: Urban flooding, sea-level rise, urban heat island

Brief Description

The City of Copenhagen is amongst the 'frontrunners' leading on climate change adaptation. The adaptation plan gives details of the three levels of adaptation. The first, with the highest priority, is to prevent damage where there is a high indication of risk. The second, where damage is unavoidable, responses seek to minimise the costs of damage. The third level – of lower priority – is to reduce the vulnerability of key receptors to damage.

The plan mainly addresses adapting to increased precipitation frequency and intensity and heat waves. The adaptation options proposed include technical, hard-end solutions, such as managing rainwater runoff locally and increasing levels of green space cover.

The calculations and forecasts in the plan are based on the best available knowledge of the future climate. However, to reflect uncertainty, the plan will be revised on an ongoing basis so that adaptation initiatives respond to technological development and take place step by step, so that the measures initiated are able to reflect the latest knowledge in the field.

The plan's guidelines and recommendations are incorporated into a Municipal Plan to ensure that climate adaptation becomes a natural part of Copenhagen's ongoing development.

Links to climate impacts and adaptation in European cities

- Good exemplar city demonstrating a proactive response to developing climate adaptation strategies.
- As a proactive city, the plan highlights how adaptation should already be incorporated into the planning and development system. This has implications for cities who have less well-established adaptation plans
- Covers the technical solutions to 'live with water' and cope with sea-level rise and urban flooding.
- Provides a robust economic argument for timely and preventative measures for adaptation to the changing climate, although notes the real need to think about financing measures to improve adaptive capacity.

URL

http://kk.sites.itera.dk/apps/kk_publikationer/pdf/794_kZEjcvbgJt.pdf

18. Urban Regions: Vulnerabilities, Vulnerability Assessments by Indicators and Adaptation Options for Climate Change Impacts: Scoping Study

ETC/ACC Technical Paper 2010/12

2010

Publication details: 208 pages

Geographical focus: Europe

Hazards covered: wide range of climate hazards

Brief Description

This report pulls together the conceptual background to urban vulnerability to climate change; the data, approaches and indicators currently available; and the evaluation of specific approaches. It also provides an overview of adaptation activities in European cities.

The report tries to address the value of existing vulnerability indicators and to assess whether ongoing projects or initiatives help with conceptual gaps, data gaps and other relevant gaps on this issue. It also considers what can be done in the short term, and recommends what the first steps are in making progress on identifying indicators for assessing vulnerability to climate change?

The ten exiting indicators, which exhibit varying degrees of data quality are: High temperatures; decreased precipitation and water scarcity; wild fires; heavy precipitation and fluvial floods; intensive precipitation and urban drainage; sea level rise; saltwater intrusion; ground instability and erosion; wind storms; and vector borne diseases. It makes recommendations for the future development of a consistent set of vulnerability indicators for urban regions in Europe.

Links to climate impacts and adaptation in European cities

- Cities depend on their surrounding hinterlands for essential services, and information on wider (urban, suburban and surrounding rural) areas should be considered when developing adaptation strategies.
- Physical and socio-economic characteristics of a city influence its sensitivity to harm from climate change impacts. There is a need to derive a typology of cities, based on integrating quantifiable characteristics (such as density and green spaces) with a vulnerability assessment for the urban population in order to compare adaptive capacity.
- Urban areas and cities in Europe are facing different climate threats and the vulnerability of urban regions is highly influenced by their geographic situation.

URL

http://acm.eionet.europa.eu/reports/docs/ETCACC_TP_2010_12_Urban_CC_Vuln_Ada

19. Industry, Settlement and Society

Intergovernmental Panel on Climate Change,
2007

Publication details: 34 pages, executive summary included

Geographical focus: Global

Hazards covered: wide range of climate hazards

Brief Description

This section of the IPCC's 4th Assessment Report identifies current vulnerabilities to climate change in the urbanised world. Combining these with observations on future climate trends and the potential impacts arising from these in urban areas, the chapter goes on to indicate the key areas where adaptation is particularly imperative.

The report finds that urban areas (or industrial settlements) are most vulnerable to extreme weather events, yet finds that preparation for this climate change risk is not adequately integrated into current policies. Stating those issues for which there are high confidence levels, the IPCC report emphasises the geographical distribution of climate change risks, with coastal areas being especially vulnerable. Also, it is noted that the associated social and economic costs are likely to rise in the future. Nevertheless, room for adaptation in urban areas is considerable, although local adaptation needs to be supported by links to national and global action.

Links to climate impacts and adaptation in European cities

- European cities in coastal areas are particularly vulnerable to floods.
- Climate-change impacts, adaptive capacities, and vulnerabilities are context-specific, and are related to the characteristics and development pathways of the location or sector involved.
- European cities need to adapt in anticipation of higher frequency of more extreme weather events.
- Consideration should be paid to tracing indirect impacts of climate change in urban areas.
- Possible negative impacts of climate change pose risks of higher total *monetary* damages in industrialised areas of the developed world, such as Europe.

URL:
http://www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4-wg2-chapter7.pdf

20. Urban adaptation to climate change in Europe: challenges and opportunities for cities together with supportive national and European policies

European Environment Agency (EEA) report: no. 02/2012

2012

Publication details: 143 pages, stakeholder summary included

Geographical focus: European, cities

Impacts covered: Heat waves, coastal flooding, river flooding, urban flooding, coastal erosion, water scarcity and drought

Brief Description

This report is intended to support the 2013 EU Adaptation strategy by informing the challenges of climate change for European cities, and situating these within larger policy frameworks. It also considers potential opportunities linked to adapting to the changing climate. It covers the potential direct impacts of climate change on cities in terms of vulnerability and adaptive capacity and considers factors such as geographical position, urban design, size, wealth and governance system. In doing so, it outlines a range of 'grey', 'green' and 'soft' adaptation options and good practice guidance at different spatial levels. The report is accompanied by a selection of European city case studies. This analysis should input into future assessments on the indirect impacts of climate change on equity and quality life issues.

The report draws upon the EEA's use of Urban Morphological Zones (UMZ), ESPON's climate mapping and Urban Audit data. However, given that this does not cover all indicators linked to vulnerability and adaptive capacity, it draws upon the EEA Urban Atlas to consider green and blue space as well as user perception studies on indicators measuring trust or commitment to address climate change. Cities are defined by their morphological delineation according to urban land use classes which intersects with the core city (administrative) delineation defined by Urban Audit.

Links to climate impacts and adaptation in European cities

- Covers the direct impacts of climate change to Europe's urban areas in order to target good practice guidance and outline the issues for multi-level governance.
- Considerable thought needs to be given to planning for climate change and governance structures at appropriate spatial levels.
- European level is a good scale to outline strategies, provide an overview of key challenges, opportunities and to provide supporting information.
- The EEA report includes indicators influencing adaptive capacity such as green and blue infrastructure.

URL:

http://www.eea.europa.eu/publications/urban-adaptation-to-climate-change

Report Overview

This table indicates the scope and coverage of each short-listed report. The checklist gives an indication of the geographical scale of each report (that is whether it looks at European, national, regional or city scale); the climate hazard or vulnerable sector addressed

	Geographical Scale							Climate Hazards												Vulnerable Sectors				
Report Number and Title	Global	Europe	Country-specific	European Administrative Regions	European Biogeographic Regions	City-generic	City-specific	River flooding	Coastal flooding	Urban flooding	Sea level rise	Ground instability	Drought	Heat waves	Cold events	Storm events	Wild fire	Water quality	Air quality	Physical	Environmental	Social	Cultural	Economic
1. Europe. Climate Change 2007: Impacts, Adaptation and Vulnerability	*								*		*					*				*	*	*		*
2. International Dimensions of Climate Change	*		*					*	*		*		*	*		*				*		*		*
3. European and Global Climate Change Projections	*	*			*																			
4. Climate change: global risks, challenges & decisions		*	*		*	*		*	*		*		*	*	*	*	*			*	*	*		*
5. Climate change impacts in Europe		*			*			*	*											*		*		*
6. Impacts of Europe's changing climate— 2008 indicator-based assessment		*	*		*			*	*		*		*	*	*	*	*	*		*	*	*		*
7. Adapting to Climate Change SOER Thematic Assessment		*			*	*		*	*		*	*	*	*		*	*		*	*	*	*		*
8. Climate Change and Territorial Effects on Regions and Local Economies		*		*	*															*	*	*	*	*
9. OECD (2010) Cities and Climate Change	*					*		*	*		*	*	*	*		*	*	*	*	*	*	*		*
10. Climate Change and Cities First Assessment Report of the Urban Climate Change Research Network	*					*		*	*	*	*		*	*		*	*	*	*	*	*	*		
11. Assessing Key Vulnerabilities from IPCC (2007)	*							*	*	*	*		*			*		*		*	*	*		*
12. Ensuring quality of life in Europe's cities and towns		*	*			*	*	*	*	*			*	*	*			*	*	*	*	*	*	*

Report Number and Title	Geographical Scale							Climate Hazards												Vulnerable Sectors				
	Global	Europe	Country-specific	European Administrative Regions	European Biogeographic Regions	City-generic	City-specific	River flooding	Coastal flooding	Urban flooding	Sea level rise	Ground instability	Drought	Heat waves	Cold events	Storm events	Wild fire	Water quality	Air quality	Physical	Environmental	Social	Cultural	Economic
13. The Impacts and Economic Costs of Sea-Level Rise in Europe and the Costs and Benefits of Adaptation. Summary of Results from the EC RTD ClimateCost Project		*	*					*	*		*							*		*	*			*
14. Adapting Energy, Transport and Water Infrastructure to the Long-term Impacts of Climate Change			*					*	*	*		*	*		*	*				*				*
15. Improving public health responses to extreme weather/heat-waves – EuroHEAT		*	*			*	*						*	*	*		*			*		*		
16. UK Climate Change Risk Assessment 2012			*					*	*	*	*	*	*	*	*	*		*	*	*	*	*	*	*
17. City of Copenhagen Climate Change Plan			*				*		*	*	*			*		*		*	*	*	*	*	*	*
18. Urban Regions: Vulnerabilities, Vulnerability Assessments by Indicators and Adaptation Options for Climate Change Impacts: Scoping Study		*				*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
19. Industry, settlement and society. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change	*					*			*	*	*	*				*		*	*	*	*	*		*
20. Urban adaptation to climate change in Europe: challenges and opportunities for cities together with supportive national and European policies				*		*	*	*	*	*	*		*	*				*		*	*	*		*

9 Annex 2: City Type (DG Regional Policy 2010) climate change region (ESPON Climate 2011) analysis

Section 5 highlights the spatial variability of climate change hazards, impacts and vulnerability in European cities. It draws on ESPON's (2011) *Climate Change and Territorial Effects on Regions and Local Economies* and the city types data from the European Urban Audit (DG Regional Policy 2010) – this table formed the basis for that analysis.

City	City Type	Southern-central Europe	Northern Europe	Northern-central Europe	Mediterranean region	Northern-western Europe	no data
Amsterdam	A1					Northern-western Europe	
Bremen	A1					Northern-western Europe	
Bristol	A1					Northern-western Europe	
Bruxelles	A1					Northern-western Europe	
Dublin	A1					Northern-western Europe	
Dusseldorf	A1	Southern-central Europe					
Edinburgh	A1					Northern-western Europe	
Frankfurt am Main	A1	Southern-central Europe					
Glasgow	A1					Northern-western Europe	
Hamburg	A1			Northern-central europe			
Hannover	A1					Northern-western Europe	
Helsinki	A1		Northern Europe				
København	A1			Northern-central europe			
Köln	A1	Southern-central Europe					
London	A1					Northern-western Europe	
Luxembourg	A1	Southern-central Europe					
Milano	A1				Mediterranean region		

City	City Type	Southern-central Europe	Northern Europe	Northern-central Europe	Mediterranean region	Northern-western Europe	no data
München	A1	Southern-central Europe					
München	A1	Southern-central Europe					
Nürnberg	A1			Northern-central europe			
Oslo	A1		Northern Europe				
Paris	A1	Southern-central Europe					
Stockholm	A1			Northern-central europe			
Stuttgart	A1	Southern-central Europe					
Wien	A1	Southern-central Europe					
Antwerpen	A2					Northern-western Europe	
Athina	A2				Mediterranean region		
Barcelona	A2				Mediterranean region		
Berlin	A2	Southern-central Europe					
Bern	A2	Southern-central Europe					
Bratislava	A2	Southern-central Europe					
Bucuresti	A2	Southern-central Europe					
Budapest	A2	Southern-central Europe					
Essen	A2	Southern-central Europe					
Gdańsk	A2			Northern-central europe			
Kraków	A2			Northern-central europe			
Leeds	A2					Northern-western Europe	
Lefkosia	A2				Mediterranean region		
Lisboa	A2				Mediterranean region		
Ljubljana	A2	Southern-central Europe					
Łódz	A2			Northern-central europe			
Lyon	A2	Southern-central Europe					
Madrid	A2				Mediterranean region		

City	City Type	Southern-central Europe	Northern Europe	Northern-central Europe	Mediterranean region	Northern-western Europe	no data
Poznan	A2			Northern-central europe			
Praha	A2	Southern-central Europe					
Riga	A2			Northern-central europe			
Roma	A2				Mediterranean region		
Sofia	A2	Southern-central Europe					
Tallinn	A2		Northern Europe				
Valletta	A2						No data
Vilnius	A2		Northern Europe				
Warszawa	A2			Northern-central europe			
Wroclaw	A2			Northern-central europe			
Aalborg	B1			Northern-central europe			
Aix-en-Provence	B1				Mediterranean region		
Amiens	B1					Northern-western Europe	
Arnhem	B1					Northern-western Europe	
Belfast	B1					Northern-western Europe	
Bergen	B1		Northern Europe				
Besançon	B1	Southern-central Europe					
Birmingham	B1					Northern-western Europe	
Bonn	B1	Southern-central Europe					
Bordeaux	B1				Mediterranean region		
Bradford	B1					Northern-western Europe	
Breda	B1					**Northern-western Europe**	
Brescia	B1				**Mediterranean region**		
Caen	B1					Northern-western Europe	
Cardiff	B1					Northern-western Europe	
Charleroi	B1	Southern-central Europe					

City	City Type	Southern-central Europe	Northern Europe	Northern-central Europe	Mediterranean region	Northern-western Europe	no data
Clermont-Ferrand	B1	Southern-central Europe					
Cork	B1					Northern-western Europe	
Coventry	B1					Northern-western Europe	
Dijon	B1	Southern-central Europe					
Eindhoven	B1					Northern-western Europe	
Enschede	B1					Northern-western Europe	
Exeter	B1					Northern-western Europe	
Funchal	B1						No data
Galway	B1					Northern-western Europe	
Gent	B1					Northern-western Europe	
Göteborg	B1			Northern-central europe			
Gravesham	B1					Northern-western Europe	
Grenoble	B1	Southern-central Europe					
Irakleio	B1				Mediterranean region		
Kingston-upon-Hull	B1					Northern-western Europe	
Lausanne	B1	Southern-central Europe					
Le Havre	B1					Northern-western Europe	
Leeuwarden	B1					Northern-western Europe	
Leicester	B1					Northern-western Europe	
Lens-Liéven	B1					Northern-western Europe	
Liège	B1	Southern-central Europe					
Lille	B1					Northern-western Europe	
Limerick	B1					Northern-western Europe	
Limoges	B1	Southern-central Europe					
Lincoln	B1					Northern-western Europe	
Liverpool	B1					Northern-western Europe	
Malmö	B1			Northern-central europe			

City	City Type	Southern-central Europe	Northern Europe	Northern-central Europe	Mediterranean region	Northern-western Europe	no data
Manchester	B1					Northern-western Europe	
Marseille	B1				Mediterranean region		
Metz	B1	Southern-central Europe					
Montpellier	B1				Mediterranean region		
Nancy	B1	Southern-central Europe					
Nantes	B1					Northern-western Europe	
Napoli	B1				Mediterranean region		
Newcastle-upon-Tyne	B1					Northern-western Europe	
Nice	B1	Southern-central Europe					
Nottingham	B1					Northern-western Europe	
Oporto	B1				Mediterranean region		
Orléans	B1	Southern-central Europe					
Palermo	B1				Mediterranean region		
Poitiers	B1	Southern-central Europe					
Portsmouth	B1					Northern-western Europe	
Reims	B1	Southern-central Europe					
Rennes	B1					Northern-western Europe	
Rotterdam	B1					Northern-western Europe	
Rouen	B1					Northern-western Europe	
Saint-Etienne	B1	Southern-central Europe					
s'Gravenhage	B1					Northern-western Europe	
Sheffield	B1					Northern-western Europe	
Stevenage	B1					Northern-western Europe	
Stoke-on-Trent	B1					Northern-western Europe	
Strasbourg	B1	Southern-central Europe					
Tilburg	B1					Northern-western Europe	

City	City Type	Southern-central Europe	Northern Europe	Northern-central Europe	Mediterranean region	Northern-western Europe	no data
Toulon	B1				Mediterranean region		
Toulouse	B1				Mediterranean region		
Tours	B1	Southern-central Europe					
Utrecht	B1					Northern-western Europe	
Wirral	B1					Northern-western Europe	
Wolverhampton	B1					Northern-western Europe	
Worcester	B1					Northern-western Europe	
Aberdeen	B2					Northern-western Europe	
Ancona	B2				Mediterranean region		
Augsburg	B2	Southern-central Europe					
Bari	B2				Mediterranean region		
Bielefeld	B2					Northern-western Europe	
Bochum	B2	Southern-central Europe					
Bologna	B2				Mediterranean region		
Brugge	B2					Northern-western Europe	
Cagliari	B2				Mediterranean region		
Cambridge	B2					Northern-western Europe	
Cremona	B2				Mediterranean region		
Darmstadt	B2	Southern-central Europe					
Dortmund	B2	Southern-central Europe					
Erfurt	B2			Northern-central europe			
Firenze	B2	Southern-central Europe					
Freiburg im Breisgau	B2	Southern-central Europe					
Genève	B2	Southern-central Europe					
Genova	B2	Southern-central Europe					

City	City Type	Southern-central Europe	Northern Europe	Northern-central Europe	Mediterranean region	Northern-western Europe	no data
Göttingen	B2		Northern Europe				
Graz	B2	Southern-central Europe					
Halle an der Saale	B2			Northern-central europe			
Heerlen	B2					Northern-western Europe	
Karlsruhe	B2	Southern-central Europe					
Kiel	B2			Northern-central europe			
Koblenz	B2	Southern-central Europe					
Leipzig	B2	Southern-central Europe					
Madgeburg	B2			Northern-central europe			
Mainz	B2	Southern-central Europe					
Modena	B2	Southern-central Europe					
Moers	B2					Northern-western Europe	
Mönchengladbach	B2					Northern-western Europe	
Mülheim a.d.Ruhr	B2					Northern-western Europe	
Oulu	B2		Northern Europe				
Padova	B2				Mediterranean region		
Pescara	B2	Southern-central Europe					
Plzen	B2			Northern-central europe			
Regensburg	B2	Southern-central Europe					
Saarbrücken	B2	Southern-central Europe					
Schwerin	B2			Northern-central europe			
Torino	B2	Southern-central Europe					
Trento	B2	Southern-central Europe					
Trier	B2	Southern-central Europe					
Trieste	B2	Southern-central Europe					
Turku	B2		Northern Europe				

City	City Type	Southern-central Europe	Northern Europe	Northern-central Europe	Mediterranean region	Northern-western Europe	no data
Venezia	B2				Mediterranean region		
Verona	B2	Southern-central Europe					
Vigo	B2				Mediterranean region		
Volos	B2				Mediterranean region		
Wiesbaden	B2	Southern-central Europe					
Wuppertal	B2	Southern-central Europe					
Zürich	B2	Southern-central Europe					
Alicante	B3				Mediterranean region		
Bilbao	B3				Mediterranean region		
Dresden	B3			Northern-central europe			
Gijón	B3				Mediterranean region		
Groningen	B3					Northern-western Europe	
Innsbruck	B3		Northern Europe				
Las Palmas	B3				Mediterranean region		
L'Hospitalet de Llobregat	B3				Mediterranean region		
Linz	B3	Southern-central Europe					
Logroño	B3	Southern-central Europe					
Málaga	B3				Mediterranean region		
Nijmegen	B3					Northern-western Europe	
Oviedo	B3				Mediterranean region		
Palma di Mallorca	B3				Mediterranean region		
Pamplona/Iruña	B3				Mediterranean region		
Potsdam	B3			Northern-central europe			
Salzburg	B3			Northern-central europe			

City	City Type	Southern-central Europe	Northern Europe	Northern-central Europe	Mediterranean region	Northern-western Europe	no data
Santa Cruz de Tenerife	B3				Mediterranean region		
Santander	B3				Mediterranean region		
Sevilla	B3				Mediterranean region		
Thessaloniki	B3				Mediterranean region		
Valencia	B3				Mediterranean region		
Valladolid	B3	Southern-central Europe					
Vitoria/Gasteiz	B3				Mediterranean region		
Aarhus	C1			Northern-central europe			
Apeldoorn	C1					Northern-western Europe	
Aveiro	C1				Mediterranean region		
Badajoz	C1				Mediterranean region		
Coimbra	C1				Mediterranean region		
Córdoba	C1				Mediterranean region		
Derry	C1					Northern-western Europe	
Faro	C1				Mediterranean region		
Foggia	C1				Mediterranean region		
Frankfurt (Oder)	C1			Northern-central europe			
Jönköping	C1			Northern-central europe			
Kalamata	C1				Mediterranean region		
Kavala	C1				Mediterranean region		
Kecskemét	C1	Southern-central Europe					
Kristiansand	C1		Northern Europe				
L'Aquila	C1	Southern-central Europe					

City	City Type	Southern-central Europe	Northern Europe	Northern-central Europe	Mediterranean region	Northern-western Europe	no data
Linköping	C1			Northern-central europe			
Murcia	C1				Mediterranean region		
Namur	C1	Southern-central Europe					
Odense	C1			Northern-central europe			
Örebro	C1		Northern Europe				
Perugia	C1	Southern-central Europe					
Ponta Delgada	C1						No data
Potenza	C1				Mediterranean region		
Santiago de Compostela	C1				Mediterranean region		
Sassari	C1				Mediterranean region		
Stavanger	C1		Northern Europe				
Tampere	C1		Northern Europe				
Toledo	C1				Mediterranean region		
Tromsø	C1		Northern Europe				
Trondheim	C1		Northern Europe				
Umeå	C1		Northern Europe				
Uppsala	C1		Northern Europe				
Weimar	C1			Northern-central europe			
Wrexham	C1					Northern-western Europe	
Zaragoza	C1				Mediterranean region		
Ajaccio	C2				Mediterranean region		
Almere	C2					Northern-western Europe	
Braga	C2				Mediterranean region		
Fort-de-France	C2						No data

City	City Type	Southern-central Europe	Northern Europe	Northern-central Europe	Mediterranean region	Northern-western Europe	no data
Larisa	C2				Mediterranean region		
Pointe-a-Pitre	C2						No data
Saint Denis	C2	Southern-central Europe					
Setubal	C2				Mediterranean region		
Alba Iulia	D1	Southern-central Europe					
Arad	D1	Southern-central Europe					
Banská Bystrica	D1	Southern-central Europe					
Bialystok	D1			Northern-central europe			
Brno	D1	Southern-central Europe					
Bydgoszcz	D1			Northern-central europe			
Campobasso	D1	Southern-central Europe					
Caserta	D1				Mediterranean region		
Catania	D1				Mediterranean region		
Catanzaro	D1				Mediterranean region		
Ceske Budejovice	D1			Northern-central europe			
Cluj-Napoca	D1	Southern-central Europe					
Częstochowa	D1			Northern-central europe			
Debrecen	D1	Southern-central Europe					
Gorzów Wielkopolski	D1			Northern-central europe			
Gozo	D1						No data
Győr	D1	Southern-central Europe					
Hradec Kralove	D1			Northern-central europe			
Ioannia	D1				Mediterranean region		
Jelenia Góra	D1			Northern-central europe			
Jihlava	D1			Northern-central europe			
Kalisz	D1			Northern-central europe			

City	City Type	Southern-central Europe	Northern Europe	Northern-central Europe	Mediterranean region	Northern-western Europe	no data
Karlovy Vary	D1			Northern-central europe			
Katowice	D1			Northern-central europe			
Kaunas	D1			Northern-central europe			
Kielce	D1			Northern-central europe			
Kładno	D1			Northern-central europe			
Konin	D1			Northern-central europe			
Kosice	D1	Southern-central Europe					
Koszalin	D1			Northern-central europe			
Liberec	D1			Northern-central europe			
Liepaja	D1			Northern-central europe			
Lublin	D1			Northern-central europe			
Maribor	D1	Southern-central Europe					
Miskolc	D1	Southern-central Europe					
Nitra	D1	Southern-central Europe					
Nyíregyháza	D1	Southern-central Europe					
Olomouc	D1			Northern-central europe			
Olstyn	D1			Northern-central europe			
Opole	D1			Northern-central europe			
Oradea	D1	Southern-central Europe					
Ostrava	D1			Northern-central europe			
Panevezys	D1			Northern-central europe			
Pardubice	D1			Northern-central europe			
Patra	D1				Mediterranean region		
Pécs	D1	Southern-central Europe					
Pleven	D1				Mediterranean region		
Plock	D1			Northern-central europe			
Prešov	D1	Southern-central Europe					

City	City Type	Southern-central Europe	Northern Europe	Northern-central Europe	Mediterranean region	Northern-western Europe	no data
Reggio di Calabria	D1				Mediterranean region		
Rzeszów	D1			Northern-central europe			
Salerno	D1				Mediterranean region		
Sibiu	D1	Southern-central Europe					
Szczecin	D1			Northern-central europe			
Szeged	D1	Southern-central Europe					
Székesfehérvár	D1	Southern-central Europe					
Taranto	D1				Mediterranean region		
Timisoara	D1	Southern-central Europe					
Toruń	D1			Northern-central europe			
Trencin	D1	Southern-central Europe					
Trnava	D1	Southern-central Europe					
Usti nad Labem	D1			Northern-central europe			
Zielona Góra	D1			Northern-central europe			
Žilina	D1	Southern-central Europe					
Zlin	D1	Southern-central Europe					
Zory	D1			Northern-central europe			
Bacau	D2	Southern-central Europe					
Braila	D2	Southern-central Europe					
Burgas	D2				Mediterranean region		
Calarasi	D2	Southern-central Europe					
Craiova	D2	Southern-central Europe					
Giurgiu	D2	Southern-central Europe					
Nowy Sącz	D2			Northern-central europe			
Pietra Neamt	D2	Southern-central Europe					
Plovdiv	D2				Mediterranean region		

City	City Type	Southern-central Europe	Northern Europe	Northern-central Europe	Mediterranean region	Northern-western Europe	no data
Radom	D2			Northern-central europe			
Ruse	D2				Mediterranean region		
Suwalki	D2			Northern-central europe			
Târgu Mures	D2	Southern-central Europe					
Tartu	D2		Northern Europe				
Varna	D2	Southern-central Europe					