Urban Vulnerability Indicators

A joint report of ETC-CCA and ETC-SIA

ETC-CCA and ETC-SIA Technical Report 01/2012

18 December 2012

Rob Swart, Jaume Fons, Willemien Geertsema, Bert van Hove, Mirko Gregor, Miroslav Havranek, Cor Jacobs, Aleksandra Kazmierczak, Kerstin Krellenberg, Christian Kuhlicke, and Lasse Peltonen

European Topic Centre on Climate Change
Impacts, Vulnerability and Adaptation

The European Topic Centre on Climate Change Impacts, Vulnerability and Adaptation(ETC CCA) (partners: CMCC, Alterra, AU-NERI, CUNI, FFCUL, MetOffice, SYKE, THETIS, UFZ, UKCIP, UoM, UPM. ZAMG)

and

The European Topic Centre on Spatial Information and Analysis (ETC SIA)(partners: UMA, UAB, Alterra, FÖMI, GeoVille, GISAT, EAA, con terra, DDNI, Ifgi , IGN, IFN-FI, ISPRA, NERI, REDIAM, SCM, UHI, UJF-LIS-Steamer, UWE)

are consortia of European institutes under contract of the European Environment Agency

COVER PHOTOS: SHUTTERSTOCK

Layout/editing: Rob Swart/Willemien Geertsema (Alterra), Aleksandra Kazmierczak (University of Manchester)

Legal notice

Copyright notice

Information about the ETC/CCA is available on the internet. It can be accessed at http://cca.eionet.europa.eu/

Information about the ETC/SIA is available on the internet. It can be accessed at http://sia.eionet.europa.eu/

Author affiliations:

Rob Swart, Alterra
Jaume Fons, UAB
Willemien Geertsema, Alterra
Bert van Hove, Alterra
Mirko Gregor, Geoville
Miroslav Havranek, CUNI
Cor Jacobs, Alterra
Aleksandra Kazmierczak, University of Manchester
Kerstin Krellenberg, UFZ
Christian Kuhlicke, UFZ
Lasse Peltonen, SYKE

EEA Project managers:

EEA – Birgit Georgi

Phone: +4551220001

Email: Birgit.Georgi@eea.europa.eu

Website: http://cca.eionet.europa.eu/

Contents

Executive summary

As a follow-up to the 2010 ETC/ACC scoping study on vulnerabilities to climate change hazards in urban regions and the 2012 EEA report on urban adaptation to climate change, a collaborative project between the ETC Climate Change Adaptation and ETC Spatial Information and Analysis was started in 2012 to further develop and implement a system of urban vulnerability indicators. This Technical Paper reports on this collaboration. The aim of the paper is to propose a system of urban vulnerability indicators, which allows assessing where European cities stand in terms of vulnerability and adaptation, and where certain problems cluster. The proposed indicator set can serve different stakeholders that are relevant in a multi-level approach towards urban adaptation. This includes the European and national level (getting an overview of the situation and the trends regarding urban vulnerability and adaptation in Europe, identifying hotspots and problem clusters to develop programmes of targeted support, identifying positive developments, which can be analysed for success factors and lessons to be learnt, as a monitoring tool to provide input to policy effectiveness evaluations) as well as at the local and regional level (getting an indication on how the situation of the own city is within the broader national and European picture, identifying cities with similar characteristics that can serve as role models, exchange and cooperation partners; encouraging further investigation of the situation with more detailed regional and local data and knowledge).

A structure is proposed for organizing urban vulnerability indicators according to exposure, sensitivity and response capacity, an elaboration of the vulnerability definitions used by the IPCC and the EEA in an urban context. Indicators are elaborated for heat, floods, water scarcity and droughts, and forest fires. Proposals for outdoor thermal comfort indices and for calculating appropriate urban delineations are elaborated in more detail. For a comprehensive coverage of exposure, next to climatic drivers also hydrological and morphological factors can play a role (for floods) as well as human factors (e.g., soil sealing). For sensitivity, the paper proposes to distinguish between population, economic assets in the urban area, and dependency of the cities on external services (critical infrastructure). Response indicators are proposed to include both anticipatory factors as well as indicators for coping capacity, distinguishing between awareness, ability and action indicators. While many of the proposed indicators have already been implemented or can be implemented at short notice, for other indicators additional work would be needed, such as for indicators describing the dependency of cities on external services. While for some indicators the link between the value of the indicator and the actual vulnerability is rather direct and unambiguous, other indicators are just proxies for which the actual evidence that they determine vulnerability in a European context is yet missing, such as indicators that would capture the sensitivity and response capacity of specific groups for floods and forest fires. The paper also addresses crosscutting issues, which can lead to confusion, such as areas/cities with high sensitivity to more than one hazard, recurrent indicators (appearing in more than one hazard), and indicators with different messages in a different context. The paper ends with a number of recommendations for further work. Fact sheets for the proposed priority indicators are included in the annexes.

1 Introduction

1.1 Background

Climate change is already happening in Europe. Temperatures and sea levels are rising, precipitation patterns are changing, and some extreme weather events are happening more frequently, resulting in hazards such as heat waves, floods and droughts. Even if strong climate mitigation policies were implemented, climate would continue to change substantially in the future. These serious challenges require adaptation now. In 2013 the European Commission will publish a European adaptation strategy. Furthermore, the current proposal for the EU Multi-annual Financial Framework for the period 2014-2020 foresees a much higher share – 20% - of the budget for climate change action.

Urban adaptation will be a key element of the implementation of the new EU adaptation strategy. Europe is a ‘Union of cities’. Around three quarters of its population live in cities. They are the places where most people will experience climate change hazards in everyday life. Urban adaptation is not only important to sustain quality of life in cities but also to keep them functioning as key drivers of the European economy and wealth generation. Cities are not isolated places but are strongly linked to other cities and rural areas and dependent on services provided by these external regions like water, energy, food, areas for biodiversity and ecosystem services. Furthermore, cities are embedded in a system of national and European legislation, planning and finance.

Cities matter for Europe and Europe matters for cities. Adaptation is place-based and most adaptation measures need to be planned and implemented at the local or regional level. The strong interlinkages of cities make a supportive national and European framework key to successful and effective urban adaptation. National and European support can, in particular, increase cities’ general capacity to cope with and adapt to climate change hazards. One of the pillars for a multi-level governance approach to urban adaptation is an appropriate knowledge base. A first European-wide assessment and analysis of the situation is provided in the recent EEA report ‘Urban adaptation to climate change’ (EEA, 2012a).

1.2 Objective

Building on the EEA report on urban adaptation to climate change (EEA, 2012a), the aim of this technical paper is to propose a system of urban vulnerability indicators, which allows assessing where European cities stand in terms of vulnerability and adaptation, and where certain problems cluster. It shall, from a European perspective, provide a first indication of what action is needed where. It shall thus serve as a starting point for further in depth exploration by European, national and local stakeholders. The focus of this paper is on the European scale, but the aim is that the indicators provided are useful at regional or local level as well. On the European level this paper proposes a limited set of indicators that can be used for a broad overview of the vulnerability of cities. For more in-depth insight in the vulnerability of cities and to identify trends in vulnerability, additional indicators are identified. This report will describe the indicators as well as the effort needed for the development of the indicators.

1.3 Approach

This paper builds on the results of the EEA report on urban adaptation to climate change (EEA, 2012a) which provided an assessment of urban vulnerability to climate change in Europe based on a couple of indicators. This paper develops the framework and the indicators further towards a set which can serve for regular reporting, given that data is provided continuously. It focuses on specific climate change challenges with a specific urban component – heat, flooding, water scarcity and forest fires. Indictors for climate change hazards not specifically related to urban issues are presented in detail in the parallel

EEA report 'Climate change, impacts and vulnerability in Europe - An indicator-based report' (EEA, 2012b).

Not all aspects of climate change vulnerability and adaptation can be described by quantitative indicators, and limited data availability further constrains the development of urban vulnerability and adaptation indicators. While the number of indicators presented in this paper is limited, the paper highlights the gaps and limitations. For example, when the indicators are to be used for development of regional urban adaptation strategies, the indicators need to be complemented by additional local and/or qualitative information.

1.4 Using the proposed indicators set

The proposed indicator set can serve different stakeholders that are relevant in a multi-level approach towards urban adaptation:

European and national level:

- getting an overview of the situation and the trends regarding urban vulnerability and adaptation in Europe, important to implement the European and national adaptation strategies and to ensure the objectives of the EU 2020 strategy towards a smart, green and inclusive Europe;
- identifying hotspots and problem clusters to develop programmes of targeted support, e.g. through Structural Funds, LIFE or INTERREG projects, knowledge provision, via Climate-ADAPT, national systems and programmes of capacity building;
- identifying positive developments, which can be analysed for success factors and lessons to be learnt;
- as a monitoring tool, providing input to policy effectiveness evaluations.

Local and regional level:

- getting an indication on how the situation of the own city is within the broader national and European picture;
- identifying cities with similar characteristics that can serve as role models, exchange and cooperation partners;
- encouraging further investigation of the situation with more detailed regional and local data and knowledge

1.5 Outlook

This report is not a final end product on urban vulnerability indicators. It can be carried forward in different ways. The indicators proposed in this paper will be integrated into the European Climate Adaptation Platform, Climate-Adapt (http://climate-adapt.eea.europa.eu/). Climate-Adapt is not only a key knowledge base for the European adaptation strategy, national and local action; it can also serve as a communication platform for interaction between stakeholders at different level. Eye on Earth provides another interactive open source platform with broad participation options and the potential to create unique information with the combination of citizen science (http://www.eyeonearth.org/). EEA will further explore the potential of Eye on Earth. The indicators proposed in this paper and the underlying framework are developed in such a way that the indicators and the framework can be updated, extended and further tailored to user needs and new sources of information over time.

1.6 Guide to this report

Noting that many adaptation and vulnerability concepts and frameworks exist in parallel, this paper chooses for practical reasons a very simple framework consisting of exposure, sensitivity and response capacity. The focus of this report is on describing the framework in which the indicators are embedded and their interlinkages.

Many frameworks have been developed to define adaptation and vulnerability as well as the links between these concepts. Chapter 2 describes the framework in which the indicators are embedded and its the theoretical background and how it is used in this report. Chapter 3 focuses on generic response indicators. Chapters 4-7 explore relevant indicators. The final chapters will discuss the interaction between climatic hazards and formulate recommendations on further work. In the Annex factsheets of the indicators are given, methodological background information and a comprehensive indicator table.

2 Concepts, definitions and relationships

2.1 Different ways of framing vulnerability

The objective of the EEA is to develop a system of urban vulnerability indicators. There is a large and still growing literature on the concept of vulnerability to climate change and the many ways of defining and quantifying it. This paper follows the practice of most climate change- related publications of the EEA by applying the definition of vulnerability from the IPCC Fourth Assessment Report (IPCC, 2007)(1). According to this definition, vulnerability is dependent on exposure to climate change, the sensitivity and the adaptive capacity of the affected system(see Figure 2.1).Other vulnerability definitions put a different emphasis on the three composing elements, but can all be captured under the more generic umbrella of “a measure of possible future harm”, where the meaning of harm needs to be defined for the specific case considered (Hinkel, 2011).

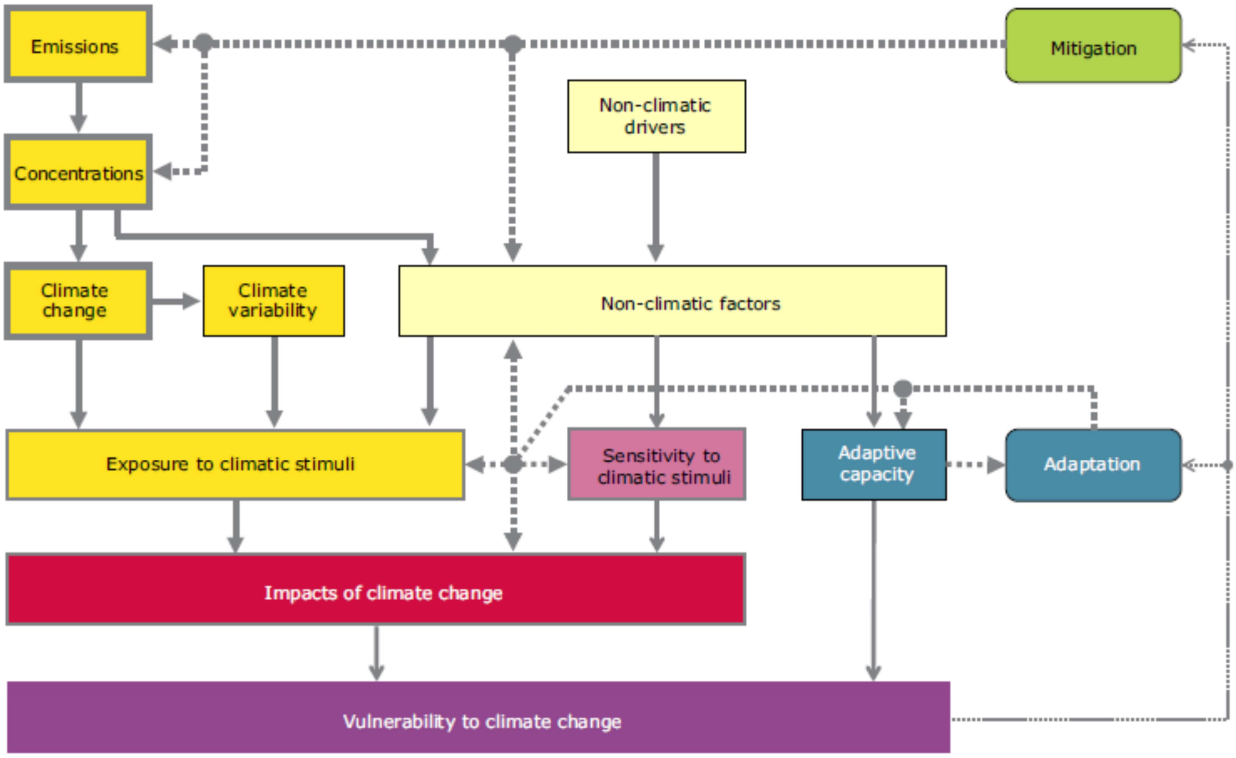


Figure 2.1. IPCC Vulnerability framework. Adaptation action can reduce vulnerability in three ways: decreasing exposure (e.g. by changing human drivers like soil sealing), decreasing sensitivity (e.g. by avoiding high value economic assets in flood-prone areas) and increasing response capacity (e.g. by developing an adaptation strategy). Source: EEA, 2012b

---

[1] In many other areas, the EEA applies the ‘DPSIR’ approach which distinguishes driving forces, pressures, states, impacts and responses to indicators for several environmental issues. However this approach is considered to be less suitable to structure a vulnerability indicator system, because vulnerability is not clearly linked to the DPSIR components.

The terms in the Figure 2.1 can be framed in different ways, which is a frequent source of confusion in interdisciplinary climate change risk assessments (e.g., see IPCC, 2012). Figure 2.2 captures the definition of vulnerability and risk in the disaster risk community, while Figure 2.3 attempts to reconcile these two perspectives.

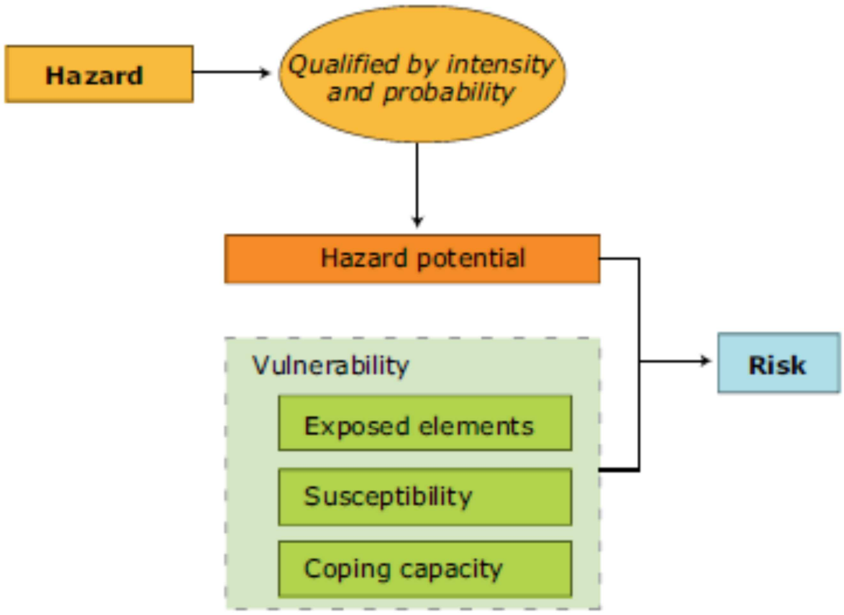


Figure 2.2 The concepts of risk and vulnerability in the risk-hazard framework (EEA, 2012b)

As Kuhlicke et al. (2012) note, different methods are suitable for the assessment of the various components of the Figure 2.1 scheme. An indicator-based approach is most suitable for the assessment of exposure, scenario approaches or agent-based modelling are more relevant for the assessment of sensitivity (or "susceptibility"), and interviews, self-assessment or focus groups are most effective for assessment of adaptive capacity. In practice this means that indicators for sensitivity and adaptive capacity have to be developed, communicated and interpreted with particular caution, since they could give an indirect, partial, or even misleading message. Hinkel (2012) suggests that of 6 possible applications of vulnerability indicators (identification of mitigation targets, identification of vulnerable people, regions or sectors, awareness raising, allocation of adaptation funds, monitoring of adaptation policy performance, and conducting scientific research), they may only be meaningful for the identification of vulnerable people, regions or sectors at local scales. While one might argue that other applications might be meaningful in specific settings (e.g. participatory process in which the background and qualification of the indicators can be presented and debated), it is clear that the development and communication of urban vulnerability indicators in the context of Europe-wide EEA reports and other communication requires the utmost care with respect to explaining what the visualized indicators mean and for which purposes they can or cannot be used. At best, urban vulnerability indicators presented at a Europe-wide level give some indication about potential vulnerability in cities. For example, a high share of soil sealing may not be a serious problem if the capacity of the urban drainage system is generously designed, and equally a high share of elderly people may not necessarily imply high vulnerability to heat waves in cities with well-managed health and senior citizen's care institutions, well-cooled buildings and ample green infrastructure (provision of green spaces). For a further discussion of other frameworks, see EEA (2012b, Section 1.7).

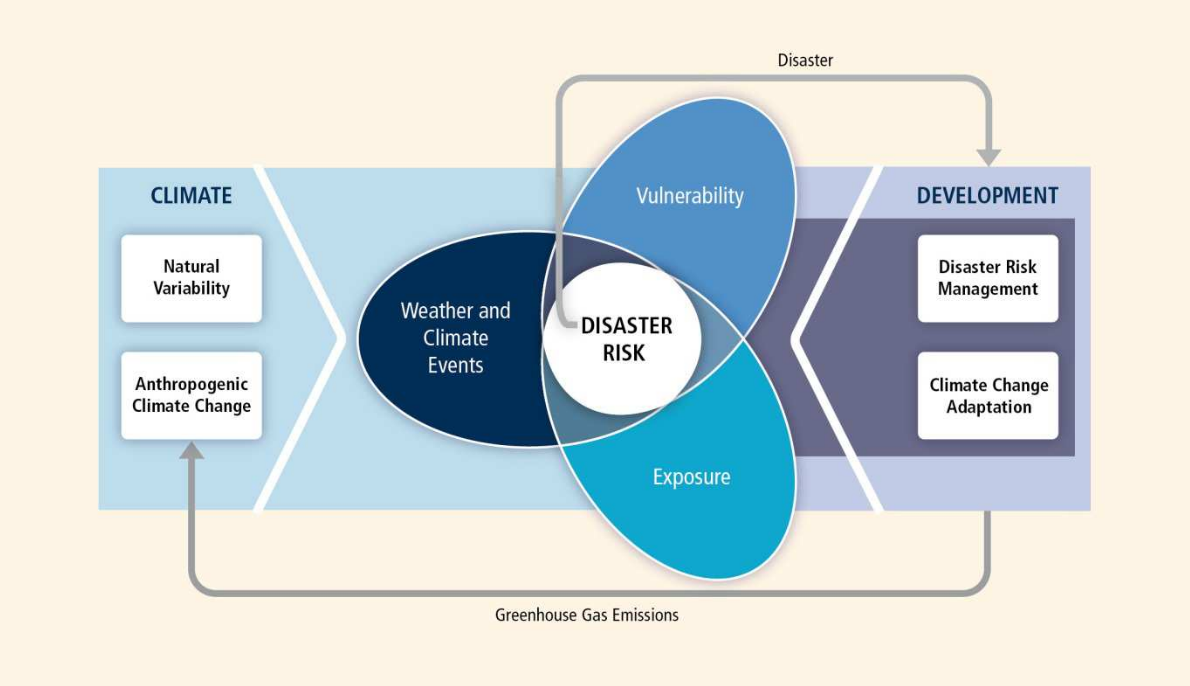


Figure 2.3 Links between climate change and disaster risk (source: IPCC, 1012)

In the context of EEA indicators, it is relevant to note that vulnerability is often considered from a spatial perspective. According to Füssel (2007), a situation is vulnerable when it is possible to identify 1) the system at issue with spatial reference; 2) the specific attribute or property at threat; 3) the specific hazard with respect to temporal reference. Thus, analyses of vulnerability often relate to place-specific natural or socio-economic systems, such as cities. Hinkel (2011) argues that vulnerability analyses are most useful at the local level, where they take into account the spatial specificity. The spatial specificity is taken further in analyses of response: specific spatial systems and their attributes at threat are characterised by context-specific response capacity and are subject to specific responses. However, as we step back from singular local response measures towards understanding the contextual factors enabling those responses at the city-scale, we can see that some capacities are not specific to single climate change induced hazards, but they enable multiple response measures. This is further elaborated in the next chapter.

2.2 Proposed structure and definitions for a system of urban vulnerability indicators

In this paper, we propose to follow the EEA practice based on the IPCC definitions but amend it slightly in two ways. Figure 2.4 amends an earlier EEA Figure in two ways. First, coping capacity is distinguished from adaptive capacity. In this framework, coping capacity refers to the current ability to respond to the short-term effects of an extreme climate-related event, while adaptive capacity refers to the longer-term capacity to plan for preventing and/or managing the impacts of climate change (Omann et al., 2010). Both concepts are subsumed under the term response capacity, which is further categorized into awareness, ability and action, and discussed in more detail in chapter 3.

Figure 2.4 shows that concepts like vulnerability, sensitivity and adaptive capacity have various determining factors. In principle, indicators can be combined by defining an index or a composite indicator. For example, ESPON (2011) developed such indices for climate change vulnerability by combining different indicators and applying weighting factors determined by an expert panel. EEA decided not to develop composite indicators for its system of urban vulnerability indicators, because the combination of indicators hides the information on the factors that eventually determine the vulnerability and depends on subjective weighting of the determinants. Furthermore, the quantitative information required to calculate the composite indicator is limited and of diverse quality. Therefore, it would not be possible to draw robust policy messages on the basis of a composite indicator.

Second, while sensitivity relates to the level of impacts for a given exposure, in the recent EEA report on urban vulnerability (EEA, 2012a) it is acknowledged that exposure is not only influenced by climatic factors, but also by morphological factors (e.g. topography influencing wind speed and direction, for heat), hydrological factors (river basin characteristics, for floods) or human factors (e.g. soil sealing for both heat and floods). In Figure 2.4, we amended Figure 2.1 and the definitions accordingly (Box 2.1).

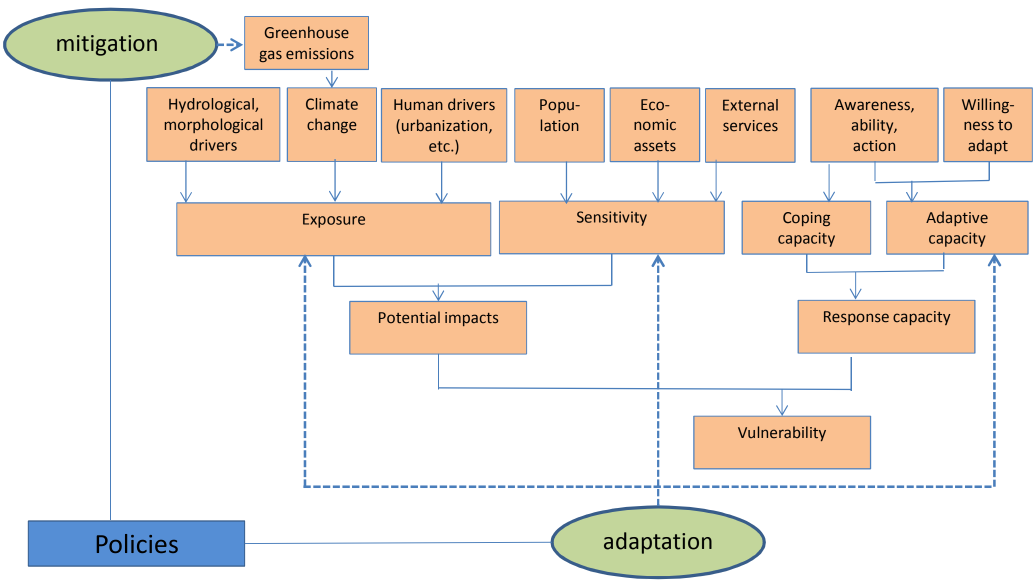


Figure 2.4. Adaptation action can reduce vulnerability in three ways: by decreasing exposure (e.g. by changing human drivers like soil sealing), by decreasing sensitivity (e.g. by avoiding high value economic assets in flood-prone areas) and by increasing adaptive capacity (e.g. by developing an adaptation strategy). Note: the directions of the arrows do not reflect the sign of the relationship.

Box 2.1. Definitions of relevant terms as used in this report

Adaptive capacity describes the ability of a system to adjust to climate change (including climate variability and extremes) to moderate damages, to take advantage of opportunities, or to cope with the consequences.

Coping capacity refers to the manner in which people and organisations use existingresources to achieve various beneficial ends during unusual, abnormal, and adverse conditions of a disaster event or process. The strengthening of coping capacities usually builds resilience to withstand the effects of natural and other hazards.

Exposure is the degree, duration, and/or extent in which the system is in contact with, or subject to, a perturbation, such as climate change. Exposure can be influenced by climatic, hydrological, morphological and human factors.

Resilience describes the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to adapt to stress and change.

Response capacity combines short term coping and longer term adaptive capacity, covering both capacitieswhich are specific to particular climatic threats as well as generic.

Risk is the combination of the probability of an event and its negative consequences. The word has two distinctive connotations: in popular usage the emphasis is usually placed on the concept of chance or possibility, such as in "the risk of an accident"; whereas in technical settings the emphasis is usually placed on the consequences, in terms of "potential losses" for some particular cause, place and period.

Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. It depends on biophysical factors, social factors or a combination of both.

Vulnerability in this report is defined as the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is then a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its response capacity.

2.3 Applying the proposed structure for a limited set of urban vulnerability indicators

In order to facilitate the communication of the complexities of vulnerability information, we propose a simple structure with a limited number of relevant climate-related risks, types of factors that determine sensitivity for each risk, and types of responses. Table 2.1 provides a quick overview of the structure and the main indicators which are elaborated in chapter 3-7, and the fact sheets in Annex 4.

2.3.1 Exposure

Exposure indicators cover four climatic hazards: heat waves (including the urban heat island effect), floods (including flooding by high river run-off, by sea level rise and from drainage systems overwhelmed by local high intensity precipitation), water scarcity and droughts, and forest fires(threatening peri-urban areas). We do not propose developing storm-related indicators (other than flooding from sea level rise combined with storm surges) because it is very uncertain how the frequency and intensity of storms may change at the local level. Indicators cover climatic drivers, hydrological and morphological drivers (for flooding and heat-related risks, respectively) as well as human drivers.

2.3.2 Sensitivity

Sensitivity indicators cover three categories ("receptors of exposure"): sensitivity of the population, sensitivity of the economic assets within the city (e.g. built environment) and sensitivity of the city's functioning to disturbances in crucial external services (provision of energy, water and transport). While in some cases, sensitivity may be captured by a generic indicator (e.g. older and less wealthy people are in average more sensitive to both heat waves and flood risks than younger and more affluent people), most sensitivity indicators are specific to a specific climatic hazard.

2.3.3 Response capacity

There are many ways to develop and structure a set of response indicators:

- by the system responding to climate change: human response capacity (e.g. represented by education level), institutional capacity (the level of commitment of the city government), financial capacity (average income per capita, financial resources available);
- anticipatory versus reactive response capacity: capacity to respond to extreme events (short-term coping capacity) and ability to adapt and prevent potential negative consequences of climate change (long-term adaptive capacity);
- specific vs. generic response capacity (e.g., investments made only for specific hazards versus an integrated institutionalized emergency plan);
- response capacity vs. actual response indicators (e.g., investments in planning and education versus past investments in flood risk prevention).

The development of a comprehensive set of response indicators that captures all these possible types of response capacity is neither desirable nor feasible. Europe-wide data are lacking for many of these aspects, and the relationship between some available indicators and the message they can provide is weak (e.g. education levels in general) or confusing (high income levels and economic assets in a city imply high absolute risks but also high response capacity). In chapter 3, a framework for generic response indicators is further developed. Those indicators are important for several climate hazards, so they are valid across at least two of the climatic effects (heat, flooding, droughts or forest fires, in this paper). Hazard specific response indicators are covered in chapters 4-7.

2.3.4 Urban delineations

A basic decision to be taken at the beginning of the production of urban indicators is to identify the appropriate reference units that define on the one hand "urban area" and the "urban surrounding", and on the other hand "green" (e.g., parks) and "red" (built-up) spaces within the "urban area" and the "urban surrounding". In general one can differentiate between 3 types of urban delineations: physical/morphological delineation; functional delineation and administrative. For heat-related indicators, the "urban area" is proposed to be defined by the Urban Morphological Zone (UMZ) inside the Urban Atlas/Audit core city (CC), cut-off at the core city boundaries, a combination of morphological and administrative delineation. Annex 1describes this proposal for the urban delineation for the purpose of EEA urban vulnerability indicators in detail. For forest fires, a different delineation is used (see chapter 8).

2.4 Discussion

Table 2.1 shows the proposed indicators and indicates the feasibility of implementing them in the short, medium and long term. The following chapters discuss the indicators for the various types of climatic hazards in detail. Dozens if not hundreds of indicators are conceivable that do have some bearing on the vulnerability of European cities to climate change by drawing on the vast amount of data from meteorological observation systems and climate modelling as well as from socio-economic statistics data (e.g. Schauser et al., 2010). Indicators for regular reporting require a careful selection that balances the effort required to produce and maintain the set of indicators with the objective to serve the target audience as effectively as possible. A limited number of indicators would be sufficient for high-level EEA reports on a general European level (e.g., SOER and Europe Environment reports). Their main purpose would be to get an overview of the situation (first objective for European and national level, see Chapter 1).

The indicators in Table 2.1 (which are elaborated in the following chapters) are candidates for inclusion in EEA's indicator system for application in urban-focused publications and web pages. Some indicators require more careful presentation than others, because the message they provide may differ according to the context in which they are used. E.g., income levels in urban areas determine the sensitive capital as well as the response capacity. Similarly, green infrastructure is sensitive to climate change (heat and droughts), but enhances response capacity (lowering temperatures and providing water storage capacity or overflow and infiltration areas).See also chapter 8 for a discussion on these crosscutting issues. The most readily available response indicators provide only proximate indication of response capacity, since with the possible exception of heat and related water scarcity issues, plausible conclusions from research demonstrating such links in Europe are as yet missing. At the same time, hazard-specific indicators of response indicators may have a stronger link with actual response capacity, but data at a sufficiently wide scale are as yet missing. The table also suggests that meaningful and feasible indicators which would illustrate urban vulnerability to disruption of external services c.q. critical infrastructure, are still missing, but would be very relevant for further work.

Table 2.1: System of urban vulnerability indicators; indication of development time: ■ short term/done, ■ medium term, ■ long term

	Exposure			Sensitivity				Response capacity			
	Climatic drivers	Hydro-/morpholo-gical drivers	Human drivers	Social	Economic	External services and infrastructure	Biophysical	Generic			Hazard specific ([3])
								Awareness	Ability	Action	
Heat	Combined hot days/tropical nights	Share of urban green spaces incl. fringes([1])	Population density (proxy UHI)	% population > 65 yrs		Cooling water demand	Low priority compared to UHI ([1])	Education level	Dwellings without basic amenities	GDP/cap	(Policies to) increase % green space
	Effective Temp (Thermal comfort)			% low income households				Awareness of climate change	Hospital beds	Effec-tiveness gover-nance	(Policies to) decrease soil sealing
				Demographic dependency ratio				Equity/risk perception ([2])	Health (life expectancy)	Insurance penetration	(Policies to) decrease dependency
Floods	Area prone to flooding (fluvial and coastal floods)		% soil sealing (pluvial floods)	Flood-prone population	Industrial/ commercial flood-prone	Transport infrastructure flood-prone		See heat ([2])			(Policies to) increase % green space/ soil sealing,
											Technical flood defenses
											Early warning policies
Water scarcity/ droughts	Standard Precipitation Index		Water exploitation index	Water use/cap.			Share green space ([2])	See heat([2])			Water supply diversity, efficiency
				Sensitive groups see heat above							Water cuts ([2])
Forest fires	Fire probability index			% residential in high risk zone	% buildings in high risk zone	% transport infras. in high risk zone	Share green space([2])	See heat([2])			Accessibility in peri-urban areas
				% population > 65 in high risk zone	% industrial/ commercial high risk zone						

[1]green space decreasing the UHI is considered as more important than sensitivity of vegetation itself; [2]suggests low priority - weak link with demonstrable vulnerability or confusing message; [3] this column is not exhaustive: in principle, if data were available on policies reducing exposure and sensitivity, these would all qualify.

3 Indicators of generic response capacity

3.1 Introduction

This chapter introduces the concept of response capacity, which is the ability of the urban areas to respond to climate change hazards. The response capacity can be classified into anticipatory (encompassing preparation before the climate event) and reactive (relating to the ability to cope during the climate event and its aftermath). Further, the response capacity can be either generic, reflecting the ability of the city to cope with different types of climate hazards, or specific - related to individual climate hazards (such as flooding or heat waves). This chapter discusses the different dimensions of response capacity and proposes a set of generic response capacity indicators, which can tell us the potential of the city to deal well with the climate hazards (Table 3.2). The specific response capacity indicators, relating to the individual climate hazards are discussed in chapter 4-7.

3.2 Specific and generic response capacity

The Intergovernmental Panel on Climate Change recently presented a simplified definition of vulnerability as "the propensity or predisposition to be adversely affected" (IPCC, 2012). The three critical elements of vulnerability are:

- exposure to perturbations - climate change and variability,
- the sensitivity of systems (either human and natural),
- system’s adaptive capacity (see chapter 2; Box 2.1). As discussed in chapter 2, in this report, we use the notion of response capacity instead of adaptive capacity, capturing both the anticipatory adaptation and capacity to cope during extreme weather events and in their aftermath.

This report adopts the IPPC’s distinction between the generic and specific response (cf adaptive) capacity (IPCC 2007). Generic adaptive capacity refers to the general ability of a system to respond to climate change; in the context of urban areas, it is predominantly related to the levels of development in terms of economic, technological and social spheres of a society. For example, high levels of poverty and socio-economic inequality can reduce the capacity to adapt to a range of different hazards (Adger et al., 2004). The generic perspective has been used in the ESPON climate report (ESPON, 2011) and the EEA urban report (EEA, 2012a). Specific capacity relates to capacity of the urban area (with its inhabitants and institutions) to respond to a specific climate change hazard, for example, drought or a flood (see chapters 4-7).

The response capacity can be divided into the anticipatory adaptation (planning and preparation in advance of climate hazards) as well as the ability to respond to, cope with or recover from the climate hazards as they happen, termed reactive adaptation (IPCC 2001). For instance, the number of hospital bed available in a city relates to reactive adaptation since they are needed immediately in a an extreme-weather event, such as heat waves or flooding, while planning to increase the capacity of hospitals to cope with the increased admissions during heat waves can increase the anticipatory response capacity. Also, research efforts improving the understanding of climate and related hazards and helping to forecast their occurrence can increase the anticipatory response capacity.

The dimensions of response capacity are summarised in Table 3.1.The indicators discussed in the remaining part of this chapter relate to the second column of table 3.1 (the generic response capacity indicators). The indicators of specific anticipatory capacity are covered in chapters 4-7.

Table 3.1: Dimensions of response capacity (adapted from ESPON, 2011)

	Generic **(all climate hazards)** **Chapter 3, Table 3.2**	**Specific** **(one climate hazard)** **Chapters 4-7**
Anticipatory • long term • in advance of climate hazards	*Generic anticipatory capacity* General ability for long-term anticipatory adaptation (e.g. availability of financial resources for adaptive actions)	*Specific anticipatory capacity* Long-term anticipatory strategies addressing specific climate stimuli (e.g. long term flood risk management strategies)
Reactive (coping) • short term • responsive to climate hazards	*Generic coping capacity* Generic capacities addressing immediate effects of climate hazards (e.g. presence of early warning systems and appropriate provision of medical facilities to cope with a variety of events)	*Specific coping capacity* Short-term coping strategies to specific hazardous events (e.g. flood emergency preparedness, dispatching temporary flood resilience measures for individual properties

In addition, we propose to adopt the three-dimensional understanding of response capacity, including the following aspects:

- ***Awareness,*** which is needed to recognise the problem of the changing climate and the need of adaptation;
- ***Ability***, reflecting the enabling factors of adaptation (e.g. presence of infrastructure or technological know-how, or the physical ability of individuals to cope with the climate hazard);
- ***Action,*** which refers to factors crucial for the adaptation measures to take place.

These dimensions were originally adopted in the ATEAM project (Schröter et al., 2004). They were also used in ESPON (Greiving et al., 2011) and in the recent EEA report on urban vulnerability (EEA, 2012a).

3.3 Measuring response capacity

Direct measures of 'adaptation success' are difficult to find, due to the relative novelty of the adaptation agenda and hence few examples of adaptation measures implementation. Therefore, the response capacity rather than the actual response may be easier to measure. It needs to be emphasised that response capacity represents the potential for adaptation rather than actual successful adaptation (Adger et al., 2004). Nonetheless, whilst high response capacity may not directly translate into efficient disaster management, measuring the response capacity helps to approximate how places are likely to deal with climate hazards. It can also be useful in comparing how different locations, for example different cities in Europe, may fare in the face of the changing climate. Response capacity is assessed with the use of indicators and proxies.

The use of indicators in relation to climate change adaptation has been criticised due to the ambiguity of the concepts such as 'vulnerability' or 'response capacity' (Juhola et al.,2012). In this report we aim to avoid this criticism by clearly defining the terms used (see chapter 2). We also aim to avoid the criticism of an inappropriate, or biased choice of indicators (Juhola et al., 2012) by providing information about their relevance, feasibility and credibility (see table 3.2, tables in chapters 4-7 and the extensive factsheets in Annex 4). We also acknowledge that response capacity is highly context-specific and varies between different countries and even between cities in the same country. It is virtually impossible to discern between the relative importance of economic, technological or institutional capacity in terms of enhancing response capacity. For example, less technologically advanced cities may still have high response capacity due to the high levels of trust in local communities resulting in their self-help capacity. This is why we treat the indicators separately rather than try to combine them into one index. Despite the criticism, indicator-based studies still allow for advances in the state of knowledge of the complex socio-ecological phenomena such as adaptation of cities to climate change (Malone and Engle 2011). The indicators simplify complex realities and are valuable tools for communication. They can be seen as starting point for discussion and further analysis of response capacity.

3.4 Indicators of response capacity

As highlighted in chapter 2 (table 2.1), the response capacity indicators can relate to human, institutional, financial and infrastructure aspects of the urban system. For example, Adger et al. (2004) suggested human health status, governance and level of education as important factors of human vulnerability; and GDP, income equality, regulatory quality, and rule of law as potentially useful proxies of response capacity. Christopherson et al. (2010) discussed factors that have been important for the economic viability of regions in the face of economic and other perturbations (thus also those related to the changing climate), including 1) strength of the regional innovation system, 2) factors supporting a 'learning region', 3) a modern productive infrastructure (e.g. transport, broadband provision), 4) a skilled workforce, 5) a supportive financial system with 'patient capital' and 6) a diversified economy not overly reliant on a single industry. Whilst the institutional and governance aspects are difficult to measure, the aspects of resilient urban governance has been found to include (1) decentralisation and autonomy, (2) accountability and transparency, (3) responsiveness and flexibility, (4) participation and inclusion and (5) experience and support(Tanner et al, 2009).

The response capacity indicators, including those relating to the factors described above, can be classified under the three dimensions of response capacity: awareness, ability and action (see Table 3.2). Indicators of awareness relate to the knowledge base, education levels of the local population, but also values such as equality and perceptions of climate change as a problem. These attributes link with the question of social limits to adaptation (Adger et al., 2009). Ability refers to physical infrastructure and technological development as enabling factors for adaptation. Human health is also included there as a generic but crucial determinant of the capacity to respond. The dimension of action depends on factors such as availability of financial resources and presence of relevant institutions and appropriate governance structures. This last dimension has been divided here into capacity for action and actual response. The emphasis is on the former, since documentation on actual adaptation measures taking place in European cities is still limited. Nonetheless, we propose to record the emergence of the adaptation strategies and adaptation measures as an important proxy of the response capacity.

Table 3.2 reflects mainly the anticipatory dimension of the response capacity (see Table 3.1); the anticipatory response measures are necessary for the development and occurrence of the reactive measures. The indicators represent the human, institutional, financial and infrastructure aspects of response capacity. Whilst in the summary table 2.1, only the indicators with relatively high relevance, feasibility and credibility have been included, the list presented in table 3.2 is more comprehensive. The proposed list of indicators also considers the fact that the scales of response capacity are either not independent or separate from each other (Smit and Wandel, 2006); different capacities are important at different scales of governance (Juholo and Westerhoff, 2011). In particular, the national level capacities, such as central government effectiveness, affect the response capacity at the city level (Kern and Alber, 2008; Kern and Bulkeley, 2009; Keskitalo, 2010; Robinson and Berkes, 2011). Consequently, the proposed list of indicators includes the index of the national level government effectiveness and an indicator reflecting the national data on insurance penetration (Table 3.2). For more information about the individual indicators see factsheets in Annex 4.

Aspect of response capacity	Indicator	Relevance	Feasibility / Source	Credibility
Awareness				
Human: Education	Proportion of population aged 15-64 qualified at tertiary level	The level of education may reflect awareness of the climate change problem and suggest that the population is open to a variety of adaptation solutions.	Urban Audit	Medium: indirect link with climate change[1]
Institutional: Equity	Percentage of elected city representatives who are women	The representation of women in cities may reflect a more equal society, which could be more aware of the need to protect vulnerable people.	Urban Audit	Low: weak link with climate change [1]
Human: Awareness of climate change	Perception of the city population that the authorities are committed to fight against climate change	The awareness of the city authorities and the population indicate higher response capacity.	Urban Audit	High: a direct link with climate change[1]
Human: Risk perception	Risk perceptions of European citizens	Relates to food and food chain risks, but could be used as a proxy for other risks.	Eurobaro-meter	Low: weak link with climate change[1]
Ability				
Infrastructure: Built environment	Proportion of dwellings lacking basic amenities	The worse the housing situation, the lower the response capacity. Poorer housing is likely to be more affected by extreme weather events.	Urban Audit	Medium: indirect link with climate change[1]
Financial/human: innovation	R&D expenditure, personnel and patent applications	The R&D expenditure indicates how technologically advanced the city is; this may indicate greater ability to develop technological response solutions.	ESPON	Low: weak link with climate change ESPON. Not used in EEA report due to lack of coverage – check data & updates.
Human: Technology	Percentage of households with Internet access at home.	Internet access may increase the access to information about climate change hazards and enable users to exchange information with others.	Urban Audit	Low: weak link withclimate change
Human: Health	Life expectancy at birth for males and females	The healthier the population, the higher the response capacity.	Urban Audit	Medium: poor physical health is linked to lower ability to cope with extreme weather events.
Infrastructure: Hospital beds	Number of hospital beds / 1000 inhabitants	The more hospital beds, the higher city's response capacity in the case of an extreme weather event	Urban Audit	High: direct link to emergency response. Not used in EEA report due to data quality / coverage (check for updates needed)
Action: Generic capacity to act				

Human: Demographic dependency	Relationship of non-working age population to working age population	The higher the proportion of potentially state-dependent, or family-dependent people, the lower the response capacity.	Urban Audit	Medium: indirect link with climate change[1]
Financial: GDP per capita	GDP per capita in European Cities	The richer the society, the higher the response capacity	Urban Audit	High: financial capacity is strongly linked to climate change[1]
Financial: Insurance penetration	Insurance penetration as proportion of national GDP	Insurance penetration reflects the overall level of insured lives and properties in a country, reflecting some degree of preparedness.	National level figures, CEA data	Medium: whilst in some countries flood insurance is available, in others (e.g. The Netherlands) it is not. [1]
Human: Social capital	Most people can be trusted (synthetic index 0-100)	Higher levels of trust increase the probability that city residents will work together in the case of emergency.	Urban Audit perceptions survey data	Low: weak link with climate change[1]
Institutional: Government effectiveness	National rankings on government effectiveness	The more effective government, the higher the response capacity	World Bank	Medium: indirect link with climate change[1]
Human: Political participation	Percentage of registered electorate voting in local elections	The more voters, the higher the trust of the citizens in the institutions and the higher the effectiveness of the institutions and citizens working together in response to climate change.	Urban Audit	Low: weak link with climate change [1]
Action: Actual response				
Actual adaptation at the city level	Urban adaptation strategies & measures	The presence of urban adaptation strategies and measures	COST action on urban adaptation; results not yet published; EU Cities Adapt	Relatively high: direct link with climate change.
National measures	National adaptation strategy	Presence of a national strategy suggests a presence of supportive governance framework in which the city can develop its own adaptations measures.	UNFCCC	Medium: indirect link to city policies.

Table 3.2. Generic response capacity indicators. Scientific evidence is provided in factsheets in Annex 4.
[1] Indicator previously used in the 2012 Report 'Urban adaptation to climate change in Europe' (EEA 2012a)

3.5 Further directions for research

Future research should focus on development of indicators in relation to actual response action. Developing European data on progress in local adaptation measures and their effectiveness is clearly a field where more work needs to be done. Studies on adaptation strategy development at national (Swart et al., 2009) and regional (Ribeiro et al., 2009) levels have been conducted, but similar local level assessments have not been concluded. The ongoing work under the COST framework is looking at Urban Audit Cities' adaptation strategies, yet the results are not available yet. Juxtaposing the actual response indicators with the existing indicators of response capacity would help to explore the relationship between the potential response capacity and the actual response, and thus validate the indicators presented in Table 3.2.

4 Heat waves

This chapter provides a discussion on the indicators for exposure, sensitivity (economic assets, population, dependency on external services), and response capacity/resilience (institutional, financial, green infrastructure) related to heat waves in urban environments. Table 4.1 provides a summary of the indicators in terms of relevance (message), feasibility (Europe-wide availability of data) and credibility (reliability of data source). The discussion below elaborates the indicators and identifies some gaps in knowledge and possible future work. In the Annex 4 a more detailed fact sheet for each selected indicator, elaborating the information in the table and providing data sources, has been included. We note that WHO in collaboration with DG Sanco in the CEHAPIS project developed a set ofhealth indicators (categorized into exposure, effect, action), complementary to the vulnerability indicators discussed in this paper (WHO, 2011).

4.1 Exposure

Hot days and tropical nights

Climate projections indicate that the frequency and intensity of heat waves will increase in Europe in the coming decades. These projections are in line with the trends observed during the last decades. Particularly the Iberian peninsula and Mediterranean region are affected (Fischer and Schär, 2010; Schär et al. 2004). The consequences of trends in warm spells or heat waves are more severe in cities because of the urban heat island (UHI) effect.

The consecutive occurrence of hot days (maximum temperature, T_{max} > 35 °C) and tropical nights (minimum temperature, T_{min} >20 °C) has been found to explain spatial and temporal variance in excess mortality during recent heat waves. Under these conditions, there is no relief of cool nights and subsequent exhaustion leads to a larger impact (Grize et al., 2005; Kovats and Hajat, 2008; Dousset et al., 2011). Therefore, the number of combined tropical nights and hot days has been used as an exposure indicator for heat stress by the European Environment Agency (EEA, 2012a). This is a proxy indicator and specific local thresholds can be different, e.g. mortality rates decrease after different thresholds in different cities. Also, this indicator has been derived from standard climatological data, that is, the climatological quantities apply to rural areas. Because of the UHI effect, in particular T_{min} may become higher in cities. Thus, T_{min} in this indicator underestimates the hazard in cities, and should be corrected or complemented with an indicator for the strength of the urban heat island. Such an indicator can be based on the characteristics of the urban fabric, such as population density and share of green space per city. Because the quantitative relationship between the UHI and population density is better established than between the UHI and green space, we propose to use population density relation to adjust urban temperature (see Annex 4 for more details). Since an UHI indicator such as green space can also be regarded as a structural sensitivity indicator it will also be discussed in that context below.

Outdoor thermal comfort indicator

Most of the impacts of temperature extremes on human health not only relate to individual hot days but are strongly affected by other factors. Whether or not citizens feel comfortable with the urban micro-climate they encounter depends on a complex interaction between physical, physiological, behavioural and psychological factors.

For the assessment of the thermal exposure of the human body the integral effects of all thermal parameters have to be taken into account. Like explained in Annex 2, there are two main classes of thermal comfort indices. The first class contains sophisticated bio-meteorological indices, like the predicted mean vote (PMV), the physiologically equivalent temperature (PET), and the recently developed Universal Thermal Climate Index (UTCI). These are based upon models for the human heat balance and are called indirect indices. They consider all relevant meteorological parameters, as well as important physiological factors (Fanger, 1970, Höppe, 1999; Blazejczyk et al., 2012). However, since bio-meteorological indices rely on many variables, some of which may be difficult to obtain, and since these indices may be quite complex, they are difficult to apply as a European-wide indicator for thermal comfort. By contrast, the second class contains so-called direct indices that are easily computed from standard meteorological parameters, including output from climate models like from the ENSEMBLES multi-model scenario experiment (see, e.g., Fischer and Schär, 2010). Many of these empirically derived indices, like the discomfort index (Thom, 1959), wet-bulb-globe-temperature (WBGT), apparent temperature (Steadman, 1979), and wind-chill index (Steadman 1971) are being used to describe thermal comfort. Though often used, these indices consider only some of the relevant meteorological parameters. Moreover, they do not take into account thermal physiology. See Annex 2 for more details on outdoor thermal comfort indices.

The study by Blazejczk et al. (2012) and our own analyses (Annex 2) suggests that the simple, direct indices Effective Temperature (ET) and Apparent Temperature (AT), which are both based on air temperature, water vapour pressure and wind speed, can be regarded as a reasonable proxy for the much more sophisticated UTCI. ET and AT are therefore suitable exposure indices for outdoor thermal comfort in cities, with a somewhat better behaviour of ET.

Both ET and AT can be computed from meteorological observations or weather and climate model output. A post-processing step may be required to arrive at a single and simple index that describes a longer period of time, for example, a climatological period of 30 years. This could be a simple statistic like the number of days a given threshold has been or will be exceeded. This threshold could be chosen to represent, for example, "severe night time heat stress." The actual indicator will then become "the (annual) number of days with severe night time heat stress."

The Urban Heat Island effect (UHI)

However, it should be stressed that both indicators underestimate the exposure to heat within cities if they are derived from standard meteorological data that do not include the effect of the UHI. Rather large underestimations during night-time may be made, particularly during clear and calm summer periods when the UHI is strongest. For this, a correction could be made by relating the (potential) nocturnal UHI to urban features of a city, for example to the percentage urban green (Steeneveld et al. 2011). During day time, differences in air temperature between urban and rural areas are rather small ($\Delta T < 1 - 2$ °C). The same is true for differences in water vapour pressure of the air. This implies that during day time, AT or ET values calculated from standard meteorological data are probably slightly underestimating those values for cities. The dynamics of the UHI may require it to be estimated on an hourly to 6-hourly basis, depending on the temporal resolution of the input data, in order to generate a correction that can be used along with in the post-processing of AT or ET data.

The UHI intensity is a dynamical feature that depends on the weather conditions. It may be required to estimate the behaviour of the UHI for the correction of the exposure indicators for the urban environment, for example when a statistical index needs to be established. A relatively simple methodology has been proposed by Oke (1998). Here, the maximum UHI intensity is obtained from a characterization of the urban fabric and the thermal inertia of the surroundings. This maximum UHI is then adjusted to obtain actual UHI strength on an hourly basis using wind speed and cloud cover to account for the weather as well as a day-night rhythm. The details and feasibility of such a method in the present context need to be further examined.

The UHI intensity in a particular city results from the interaction of many factors, on different spatial and temporal scales. Latitude or climate zone, the topography and the distance to large water bodies determine the 'background' urban climate on the meso-scale while city size, urban design and structure related factors as well as population related factors (anthropogenic heat production, pollution) affect UHI intensity on the meso to micro scales. A distinction can be made between controllable and uncontrollable or natural factors. In addition, a categorization can be made between temporary effects, such as wind speed and cloud cover, (quasi-)permanent effects such as green spaces, building material, and geometry (sky view factor, aspect ratio), and cyclic effects such as solar radiation and anthropogenic heat sources. Population density provides a reasonable initial estimate for UHI at the city level (Steeneveld et al. 2011). It can be used as a proxy for the density of the built environment. Anthropogenic heat production is also related to population density. Therefore, population density may serve as a biophysical sensitivity indicator for the potential UHI of a city. Population density values are available for the Urban Audit cities from the Urban Audit database. In case other reference units are to be used the population density can be calculated using the population disaggregation grid available from the JRC (1km²)([2]) divided by the surface area of the reference unit.

Share of urban green spaces and edge length between green space and red space

While we propose adjust the temperature indicators for the UHI using population density as a proxy, we do know that also green spaces have a cooling effect, even if we cannot quantify this generically for European cities. We therefore propose to also include an indicator for green space to highlight its importance. It is a well-known and documented fact that the land surface temperature and the share of vegetation are related to each other (Chen et al., 2006; Jusuf et al., 2007; Gabor and Jombach, 2009; Klok et al., 2012). The ameliorating thermal effect induced by green spaces inside the warm urban microclimate of densely populated cities can improve the thermal comfort, as well as the overall health and living conditions of their inhabitants. The effect of green infrastructure on UHI is primarily provided by shading and evapotranspiration. The processes behind this function are:

- Vegetation provides cooling through evapotranspiration, at least when there is no water stress (drought).
- Vegetation provides shade, especially trees. Even single trees can be effective in providing shade. Parks and urban forests are more effective. Shading provided by the vegetation also affects the human energy balance directly (see Exposure Indicators).

In cities, most notably, the cooling effect of vegetated surfaces is replaced by storage of heat in impervious engineered surfaces. Consequently, the more urban green spaces a city still contains and the better distributed these green spaces are, the lesser the impact of the UHI effect. Indeed, for cities in the Netherlands, Steeneveld et al. (2011) found that an increase in the percentage of surface area covered with green vegetation reduces the maximum UHI intensity significantly. The cooling effect of vegetation can be identified at different scales, from buildings (green and blue roofs, green walls), streets (trees, tree rows), to regions and complete cities (parks, green lanes, etc). Cooling effects of parks have been observed at distances up to 500 m or more (Bowler et al., 2010). Also green spaces at the fringes of the

---

[2] http://www.eea.europa.eu/data-and-maps/data/population-density-disaggregated-with-corine-land-cover-2000-2/

cities provide beneficial effects in terms of recreational and cooling functions. The urban fringe is hence also accounted for in this study.

These aspects will be analysed by two indicators, (i) the share of urban green spaces, and (ii) the edge lengths between green and built up (i.e. "red") space. Water ("blue") areas are not included since they have a less clear effect on the UHI. The land use data source is the GMES Urban Atlas data base([3]), which provides reliable, inter-comparable, high-resolution land use maps for 305 Large Urban Zones and their surroundings for the reference year 2006. The selection of classes contained in the urban green spaces is based on their relevance for the Urban Heat Island effect, i.e. agricultural areas and forests are included as well. The share of urban green spaces is calculated for on the one hand the Urban Morphological Zone (UMZ([4])) of the city and on the other hand a buffer that is created around the UMZ. The buffer has a width of 5km and should account for the fringe of the urban areas.

The edge lengths between the green spaces and the remaining "red" space of the cities provides an indication about the distribution of urban green spaces such that one can interpret that a large edge length in a city indicates a relatively high number of green patches with borders to the sealed parts of the urban fabric made up of residential and commercial/industrial/public buildings. The edge lengths are calculated for the red-green edges within the UMZ and between UMZ and the associated buffer.

Effects of open water on the UHI remain unclear. Most studies assume a cooling effect of water bodies, which is intuitively right. However once water is warmed due to heat waves or high temperatures, it may become a source of warmer air during lower temperatures. Some recent measurements of ambient air temperature at street level showed no effect of open water on air temperature or even an increased temperature close to water (Steeneveld et al. 2011). The high thermal inertia of water bodies is a possible explanation for this. Though water temperature responds slowly to forcing during the day, it also cools down slowly, which means that large water bodies may support the UHI effect at night.

Wind provides urban ventilation. Information about prevailing winds and wind flows carrying cooler air from surrounding forests or sea, together with information about the geometry of the city (high buildings, infrastructure, trees, etc.)([5]) is also relevant in urban sensitivity. However, the climatic and geometric information required to assess effects of so-called ventilation paths is extremely city-specific and using this information requires detailed high-level postprocessing (Ren et al., 2010). Although this has been done for individual cities with some success (Ren et al., 2010; Ren et al., 2012), a general, European-wide biophysical indicator referring to urban ventilation seems as yet unfeasible. Here, we suggest adjusting the existing indicator for the share of green space used by the EEA in the recent report on urban adaptation ('Share of green and blue urban areas') by excluding the area of water bodies and including the edge density red/green as a proxy for the distribution.

---

[3] http://www.eea.europa.eu/data-and-maps/data/urban-atlas

[4] http://www.eea.europa.eu/data-and-maps/data/urban-morphological-zones-2000-umz2000-f1v0

[5] The geometry of the city is determined by the 3D spatial distribution of high rise buildings, parks, infrastructure, etc, the orientation of street patterns and building patterns related to the surroundings and the geomorphology/relief of the city. Urban geometry is relevant for the sensitivity for the impact of heat waves, as it influences the wind as well as the provision of shade. Wind in the urban area provides cooling from urban heat. Building structures and street patterns influence wind speed and direction. Also high rise buildings and narrow streets may block out direct sunlight; and thus provide a cool environment on street level. Urban geometry can stimulate ventilation at street level or on the other hand block winds. Examples include cooling wind from hills around or in cities and the position of parks and trees..

We note that a different interpretation of green space would be that the share and the distribution of urban green in a city affects the biophysical sensitivity for the potential UHI of a city as a whole. However, we discuss it as an exposure indicator here, because this is more consistent with the structure of Figure 2.4, and it distinguishes it from the sensitivity of the vegetation itself.

4.2 Sensitivity

To assess the sensitivity of a city to heat waves biophysical and social sensitivity indicators can be distinguished. Many of the social and biophysical sensitivity indicators are available from the Urban Audit database maintained by Eurostat([6]) and the Urban Atlas. For several selected indicators (e.g. green space, total population, population density) data from 2008 and even 2011 are available, but not covering all European countries. Since the Urban Audit data undergo a quality control procedure before being published these data are supposed to be reliable (exceptions exist). Their easy availability from the online database also makes them feasible to produce. A possible indicator for biophysical sensitivity in the context of the UHI for the city as a whole,would be the area of green space (a city with more green can be considered as less sensitive). We note that from the alternative perspective of local vulnerability within a city, green space with its cooling effect could also be considered as an indicator of exposure. At the same time, also vegetation is sensitive to heat. Green spaces in cities exposed to heat (and droughts), such as in southern Europe, can loose some of their greenness, which would decrease its effectiveness in reducing the UHI. The size of this effect is unknown and would require more research. In the context of this paper, we subjectively value the decreasing effect of green space on the UHI as more important than the sensitivity of vegetation itself to heat and propose to use green space as a positive indicator (the higher the better). See chapter 8 for a more in-depth discussion of such crosscutting issues.

Social sensitivity indicators

Demographic/age dependency

Life expectancy and the ageing of population in Europe are increasing. Possible indicators for age are the share of the population older than 65 or the ageing index, defined as the ratio of the population older than 60 years to that 0–14 years old. Senior citizens are in average more sensitive to heat because of intrinsic changes in the thermo-regulatory system and because of the use of drugs that interfere with normal homeostasis. Heat mortality risk varies by both age and sex. Epidemiological studies of heat-related mortality show a larger effect in the elderly; the risk increases with increasing age above about 50 years. Children and babies also have in average a limited ability to thermo-regulate and are also more at risk of dehydration than are adults. Child deaths from heat stroke occurred in France during the heat waves in 2003 and 2006 (Kovats and Hajat, 2008). However, up to date, time-series and episode analyses indicate no significant excess in mortality of children due to heat waves. Although there are exceptions, overall mortality in this group is generally low in industrialized countries. In the United States, less than 4% of all persons dying from heat caused by weather conditions are aged 4 years or younger (Centers for Disease Control and Prevention, 2002). Following the practice of earlier EEA reports, we recommend to take the share of the population as indicator, rather than the ageing index.

([6])http://www.urbanaudit.org/DataAccessed.aspx and http://epp.eurostat.ec.europa.eu/portal/page/portal/region_cities/city_urban/data_cities/tables_sub1

Whether women or men are more at risk of dying in a heat wave, remains unclear. A European study by WHO states that: “Epidemiological studies indicate that risk in men and women does not differ significantly”(WHO, 2004). However, in contrast, Kovats and Hajat (2008) state that the majority of European studies have shown that women are more at risk of dying in a heat wave (Kovats and Hajat, 2008). Social factors have also been found to be important. There may be some physiological reasons for an increased risk in elderly women, but social factors are also important. In Paris, the heat risk increased for unmarried men, but not unmarried women (Carson et al. , 2006). In the United States, elderly men are more at risk in heat waves than women, and this was particularly apparent in the Chicago heat wave events (Semenza et al. 1996, Whitman et al. ,1997). This vulnerability may be related to the level of social isolation among elderly men (Naughton et al., 2002; Semenza et al., 1996,1999). Men are also more at risk of heatstroke mortality because they are more likely to be active in hot weather (CDC, 2006). In addition to the ageing index, the demographic dependency can also be used as a secondary indicator, which is defined as the ratio of the number of people at working age (20-64 years old) to younger (< 20 years old) and older (over 65 years) people. The demographic dependency index is available from the Urban Audit database, which, however is not gender specific. For gender specificity, the proportion of male or female lone-pensioner households of the urban audit may be used as a proxy for sensitive elderly males or females, but since the literature is inconclusive about gender-specific sensitivity to heat, we do not recommend to use these indicators for this purpose. The physical and social isolation of elderly people further increases their vulnerability to dying during a heat-wave (Klinenberg, 2003).

Other possible age thresholds

Many studies mention an age of 65 years and older for the increase in sensitivity for high temperatures to heat. However, this age threshold is often a predetermined age and therefore, it remains unclear at which age above 65 years the sensitivity really increases. Up to date, only a few studies have analysed this in more detail. For instance, an analysis of the impact of the 2003 heat wave for Greater London shows a clear increase in daily mortality among elderly above an age of 75 years whereas no notable effect for the group elderly with an age between 65 and 74 years was observed (Kovats and Hajat, 2008). More or less similar results were obtained in a study of the 1999 Chicago heat wave (Centers for Disease Control and Prevention, 2002). Nevertheless, we propose to follow the usage of a 65 year threshold that WHO (2004) uses as an indicator for excess mortality due to heat waves.

Share of people with lower socio-economic status

People with lower socio-economic status, or migrants, may be more sensitive to heat-related mortality because of poorer-quality housing and a lack of air-conditioning. Also people with lower educational levels seem to be more vulnerable (Reid et al., 2009). Populations in more deprived areas within a city are also more likely to be exposed to other risk factors for heat-related death. Several studies that investigated heat-related mortality rates in different neighbourhoods reveal the importance of socio-economic factors (Semenza et al., 1996, 1999; Smoyer, 1998a, b, Reid et al., 2009). It should be noted that some indicators such as the ones related to poverty or social exclusion are also relevant for climate-related problems other than heat. The Urban Audit includes various indicators that relate to the economic circumstances of the population (e.g., levels of per capita income, unemployment, ratio of first to fourth quintile earnings, percentage of households with less than half the national average income, dependency on social security, etc.). There are no studies available that provide a quantitativelink between particular indicators of socio-economic status and climate change response capacity. Therefore, we – to some extent arbitrarily - propose to select the percentage of households with less than half the national average to capture vulnerability related to social inequity. Here, we focus on sensitivity. We note that the share of people with low socio-economic status can also be seen as an indicator of response capacity, as discussed in the previous chapter. In chapter 8, the implications of these crosscutting issues are further explored.

Economic sensitivity indicators

As an indicator for the sensitivity of the external services for urban areas we propose to, in the future, explore the feasibility of using the cooling water demand of power plants serving cities, which information is not readily available. Similarly, we did not identify a meaningful indicator for describing sensitivity of a city in economic terms, since few economic activities are directly affected by heat other than maybe through a decreased productivity of the work force.

External services and infrastructure sensitivity e indicators

Whilst it is recognised that elements of infrastructure, in particular transport (roads and railways) may be sensitive to high temperatures, no relevant indicators have been identified.

Biophysical sensitivity indicators

While we acknowledge that vegetation itself is sensitive to heat, we consider this to be less important than the cooling effect of green infrastructure, and hence do not recommend to use it as a sensitivity indicator, to avoid confusion (see also chapter 8).

4.3 Response capacity

Responses can target three elements of vulnerability, exposure, sensitivity and response capacity. Chapter 3 discusses *generic indicators for response capacity*, which would be equally relevant for different climatic hazards, noting that we do not have quantitative evidence how important the links with actual climate change vulnerability are. Many of the generic response capacity indicators are discussed in the previous chapter and available from the Urban Audit database maintained by Eurostat([7]). For several selected indicators (e.g. education, hospital beds, social trust and commitment to climate change; the latter two coming from the last perception survey) data from 2008 and even 2011 are available, but not covering all countries. Since the Urban Audit data undergo a quality control procedure before being published these data are supposed to be reliable (exceptions exist). Their easy availability from the online database also makes them feasible to produce.

For *exposure or sensitivity indicators*, policies to change the associated aspect of exposure or sensitivity would represent responses. E.g. policies to decrease the dependency level of in particular the old (and maybe also young) people by stimulating the attractiveness of living in the city by the working age would be a response indicator, while the dependency level itself represents a sensitivity indicator. Policies to increase the share of green space would be a response indicator, while the share of green space would be an exposure indicator. In the context of heat, it would also be relevant to include the existence of heat action plans (like in Paris), but this information is not available at a European level. In general, information on policies or investments is not available from the urban audit, neither for specific climate hazards, such as heat, nor for generic policies. One might use the *changes in* the sensitivity or some

[7] http://www.urbanaudit.org/DataAccessed.aspx and http://epp.eurostat.ec.europa.eu/portal/page/portal/region_cities/city_urban/data_cities/tables_sub1

exposure indicators as response indicators, assuming that these changes relate to policy interventions. Examples include observed changes in the share of urban green space (using the same data sources as for determining the share of green space as a factor affecting the UHI), observed changes in soil sealing or dependency ratio. This may be an issue for future work.

Table 4.1 summarises the recommended exposure, sensitivity and response capacity indicators in relation to the hazard of heat waves.

Table 4.1. Summary of indicators proposed for urban heat vulnerability

Theme: Heat	**Proposed urban climate vulnerability indicator for EEA indicator system**	**Relevance (what is the message, implication of indicator values)**	**Feasibility (data availability, when and from where)**	**Credibility (reliability of data source, how sure are we of relationship with hazards)**	**Remarks**
Exposure	CHT: combined number of hot days (T_{max} >35 °C) and tropical nights (T_{min} >20 °C)	The higher the value, the higher the effects on health, thermal comfort, and economic productivity	CHT can be calculated from data obtained by: • Climate model simulations : present-day and future projections from ENSEMBLES project: http://ensemblesrt3.dmi.dk • Observations: E-OBS : http://eca.knmi.nl • Reanalysis data: ERA-40: http://www.ecmfw.int/research/era/do/get/era-40	Most of the databases to be used are the result of peer reviewed projects Meteorological data are subject to quality control	
	Effective Temperature for thermal comfort (ET): frequency distribution number of days exceeding threshold values for ET	The higher the value, the higher the effects on health, thermal comfort, and economic productivity	ET can be calculated from data obtained by: • Climate model simulations : present-day and future projections from ENSEMBLES project: http://ensemblesrt3.dmi.dk • Observations: E-OBS : http://eca.knmi.nl • Reanalysis data: ERA-40: http://www.ecmfw.int/research/era/do/get/era-40	Most of the databases to be used are the result of peer reviewed projects Meteorological data are subject to quality control •	
	Population density	The higher the population density, the higher the density of the built environment and the higher the (potential) UHI	Urban audit database (Eurostat) http://www.eea.europa.eu/data-and-maps/data/population-density-disaggregated-with-corine-land-cover-2000-2/	Data undergo quality control procedure before being published and are supposed to be reliable	
	Share of urban green spaces including the urban fringe	The higher the share of green, and the higher the green edge lengths, the	Urban Atlas http://www.eea.europa.eu/data-and-maps/data/urban-atlas	GMES Urban Atlas data base provides reliable, inter-comparable, high-resolution	The high heat capacity of water makes it difficult to establish a

		lower the (potential) UHI and hence health impact	http://www.eea.europa.eu/data-and-maps/data/urban-morphological-zones-2000-umz2000-f1v0	land use maps for 305 Large Urban Zones and their surroundings for the reference year 2006. The share of urban green spaces is calculated for the Urban Morphological Zone (UMZ) of the city on the one hand and a buffer that is created around the UMZ on the other hand. The buffer has a width of 5 km and should account for the effect of the fringe of the urban areas.	relationship with open water. Therefore, we propose to adjust the existing indicator used by the EEA by excluding the area of water bodies
	The edge density between green and non-green (i.e. “red”) space	The larger the value representing the length of green edges, the lower the (potential) UHI and hence health impact	Urban Atlas http://www.eea.europa.eu/data-and-maps/data/urban-atlas		
Sensitivity: Social	1. Share of senior citizens with age >65 years 2. Demographic dependency (ratio >65 and <20) 3. Share of poor people, e.g. percentage of households with less than half the national average income	The higher the share of senior or poor citizens, or the higher the dependency ratio, the higher the impacts	Urban audit database (Eurostat)		The literature is inconclusive as to the age where the sensitivity starts to increase rapidly Various indicators are available from the urban audit to capture poverty
Sensitivity: Economic	Cooling water demand	The higher the cooling water demand in the urban area, the higher the sensitivity of the urban power supply	Data not available at the city level		
Response	For generic response indicators: see chapter 2 For specific response indicators: no information is available about heat plans. As a proxy, *changes in* the sensitivity and some exposure indicators above could be considered, assuming that these changes would be the result of policies. This is for future work.				

5 Floods

5.1 Introduction

Recent research indicates that losses caused by flooding have mainly socio-economic character (Barredo, 2009). In particular, high concentration of population and economic wealth in cities and the ongoing processes of urbanisation may lead to further increases in economic losses (Bouwer, 2011), most likely further exacerbated by the consequences of climate change (EEA 2010). Different scenarios indicate that by 2080 between 250.000 and 400.000 additional people will be exposed to the risk of river flooding in Europe; when coastal flooding is consider, the number of people at risk could increase to 775.000 - 5,5 million people, majority of them located in cities (Ciscar et al., 2011; European Environment Agency, 2012a).

The interrelation of urbanisation and floods is at least twofold. First, increasing urbanisation often results in an expansion of impermeable areas, whereby the higher proportion of sealed soils result in an increased runoff volume and a decreased response time of a catchment, causing higher peak flows. Second, urbanisation can also have other implications for vulnerability as quite often urban areas expand into flood risk areas (European Environment Agency, 2012a; Hildén et al., 2012).

This chapter provides a discussion on the urban flood indicators that have been determined as the most relevant to the aspects of exposure, sensitivity, and response capacity. They have been selected out of a long list of indicators (see Table 5.1) that summarizes all identified flood vulnerability indicators in terms of relevance (message), feasibility (Europe-wide availability of data) and credibility (reliability of data source). The following discussion elaborates the selected indicators and identifies some gaps in knowledge and possible future work. Annex 4 includes a more detailed fact sheet for each selected indicator, elaborating the information in table 5.1.

5.2 Exposure

Area potentially affected by flooding/inundation

One of most relevant indicators for urban vulnerability to flooding is exposure. Exposure indicates the urban areas potentially at the risk of flooding. In a more general sense, exposure is "describing the relationship of elements at risk to the hazard and is therefore somehow a bridging element" (Fuchs et al., 2011, 615). It represents the interface of processes related to the flood hazard as well as processes and structures related to the layout and extent of urban areas itself. Information on exposure serves as basic information for all subsequent indicators.

To assess the exposure, there is a need for information on the flood hazard and the different sources of flooding as well as on the urban area itself.

1. *Flood hazard*. A flood means "the temporary covering by water of land not normally covered by water" (Flood Directive, Article 2/1). Although any further classification of floods is somewhat arbitrary, the following distinction between the different kinds of floods is considered as quite useful (quoted from Hildén et al., 2012, 6):
   - ***Fluvial flooding*** occurs when water levels in a channel, lake or reservoir rise so that water covers nearby areas, which normally are dry land. Such an event may result from heavy or persistent rain, snowmelt or ice jam, sometimes also by debris jam, landslide or other blockage of the channel. Flooding can be a regular feature of the yearly hydrological cycle, but rivers have different patterns of flow and the severity of

flooding varies. Antecedent conditions (soil moisture, groundwater stage) may also considerably affect the severity of the flood. Forecasting fluvial floods is generally easier than for other flood types.

- ***Pluvial flooding*** is caused by intense localised rainfall. Pluvial floods often cause damages in urban environments in combination with overflowing sewers and high runoff in small catchments. Urban pluvial floods often arise due to a combination of land sealing and insufficient capacities of sewers and drainage systems. They are difficult to predict due to the difficulty in predicting local rainfall patterns, lack of data on the actual hydrological status, and the short lead-times.
- ***Coastal flooding*** occurs when sea level exceeds normal levels due to storm surges, exceptional tides or tsunamis. Flooding in deltas and river mouths may be caused by a combination of fluvial flooding with storm surges or otherwise exceptionally high sea level. Forecasting is difficult but risk analyses can be performed using models. Coastal flooding due to sea level rise, storm surges or tsunamis is covered in the (forthcoming) EEA report on coasts.
- ***Groundwater flooding*** arises when underground water emerges in excessive quantities from either point or diffuse locations. This can be a consequence of e.g. persistent rains, high sea levels or land subsidence. If adequate data exist on groundwater flow, forecasting is feasible.
- ***Flash flooding*** is characterised by very rapid inundation. Some pluvial floods can be classified as flash floods, particularly if heavy rain in the upper part of the catchment creates flood wave surges downstream, where it may not have rained at all. In addition to pluvial origin, there are many other causes of flash floods: river or lake outbursts (linked e.g. to landslides or ice jams), overflowing of karstic formations, dam-breaks and snow-slush flows. The forecasting of flash floods is often extremely difficult, due to the same factors as mentioned under pluvial flooding.

While the first three flood types are characterised by their source (rivers, rainfall, sea) and the first two may occur almost everywhere in Europe, the risk of flash floods is highest in Europe in Mediterranean and mountain areas, while coastal flooding has caused the largest damages in low-lying areas around the North Sea (Hildén et al., 2012).

2. Urban area. The extent of urban areas exposed to the risk of flooding within a city can be expressed in relative terms (i.e. proportion of urban areas exposed to the risk of flooding in relation to the overall urban area) and is primarily a function of the topography and different land uses and land cover of an urban area in relation to the source of the hazard (e.g. a flat topography usually results in a higher percentage of areas at the risk of flooding compared to a more contoured topography; sealed surfaces increase the hazard compared to permeable surfaces).

Reliable information and data on pluvial, groundwater and flash floods are difficult to obtain (see above), whereas rainfall precipitation events and how they change as a consequence of climate change might be used as a proxy (admittedly a vague one) to better understand whether pluvial and/or flash floods might increase in urban areas. The most relevant and feasible exposure information at a large scale such as for a European assessment can be produced with regards to fluvial flooding and coastal flooding([8]).

Fluvial flooding indicators

In practice, there are two ways of assessing the exposure of an urban area to the risk of fluvial flooding, i.e. obtaining spatial information about the extent of inundation. Firstly, the data about the morphological form of the city can be combined with the information about the statistical return periods of flooding (e.g. with a probability once every hundred years) in order to understand how certain water levels translate into the spatial extension of flood events. Secondly, the morphological form information can be combined with absolute water depths (e.g. one meter water depth) .

Pluvial flooding indicators

For pluvial flooding, it is proposed to use the degree of soil sealing as a proxy indicator, as soil sealing increases the runoff by decreasing the soil retention and infiltration of rain water; for fluvial flooding, soil sealing within the city is likely to play a marginal role. The information on rainfall intensity at the local level, especially in terms of the future projections of precipitation, is insufficiently reliable to be used as an indicator of exposure for pluvial flooding for a set of European cities, also due to the resolution of the regional climate models being too coarse for a meaningful analysis for individual cities. Whilst the larger scales of rainfall intensity projections could be considered, more research is required as to how these could be used. The adequacy of the local information on sewerage or drainage systems is currently unknown.

Coastal flooding indicator

Assessing the exposure of urban areas to the risk to coastal flooding depends again on information about statistical return rates or absolute water depths as consequence of incremental change (e.g. climate change) or as result of sudden water levels changes (e.g. tsunamis or storm surges). As a consequence of climate change, the return rates might change resulting in more frequent flood events and/or in higher water levels (EEA, 2012a). However, exposure might change due to socio-economic or demographic changes resulting in urban sprawl, re-urbanisation processes or even in shrinkage.

5.3 Sensitivity

By adding information about the sensitivity of an urban area to the risk of flooding, the picture of flood risk becomes more nuanced and diversified. In line with the approach to sensitivity outlined in Chapter 2, we propose to distinguish between three different categories of sensitivity indicators: sensitivity of the population to the risk of flooding, sensitivity of the economic assets within the city and sensitivity of the city's functioning to disturbances in external services that are the city's lifelines (provision of energy, water, transport).

[8] For individual cities or neighbourhoods detailed analyses can be made for pluvial floods which take into account the local sewerage c.q. rainwater disposal system capacity.

Social sensitivity indicators

Population potentially affected by the risk of flooding

The loss of human life is surely one of the most severe negative impacts caused by flood events, but also the physical and mental health consequences, as well as wider social impacts contribute significantly to the overall vulnerability of an urban population. At the same time, there is no clear picture of the underlying social causes that influence and define social sensitivity to the risk of flooding. While it is usually assumed that specific characteristics, such as age, income, gender, educational background and other variables would have a significant impact on the sensitivity of people to the risk of flooding, recent research results from a European cross-cultural analysis indicate that such assumptions are not easily verifiable. The study concludes "there was not a common set of previously assumed social vulnerability indicators […] that proved to be valid in a cross-country perspective across all phases of the disaster cycle" (Kuhlicke et al., 2011, 799). This view is backed-up by other studies (e.g. Tapsell et al. 2011).

Taking these research findings into consideration, the proposed indicator of social sensitivity is restricted to providing information on the quantity and spatial distribution of population within an urban area. The most feasible way of implementing this indicator is considering residential areas affected by the risk of flooding and include officially registered citizens within the areas exposed to the hazard of flooding. This indicator serves as a proxy for the expected number of residents prone to the risk of flooding; however, it is virtually impossible to assess what proportion of these people would be actually at their location of residence in the event of flooding.

However, ideally this indicator would need to be further specified in two ways. Firstly, the diversity of residential areas could be taken into account. It makes a considerable difference whether a residential area includes by one-storey or by multi-storey houses. In the latter case population density might appear considerably higher in the assessment outputs compared to those vulnerable in the case of an actual flood, as only ground floors and possibly first floors would be directly affected. Yet, although not directly affected by the immediate consequences of the flood, higher floors are still affected by the consequences of the flood: they might be confronted with restricted access to their apartments, shortage of drinking water, inundated basements, etc. Thus, whilst not perfect, the indicator provides information about the sheer number of residents that need to be dealt with in case of emergency response, and helps to identify urban areas characterized by a particularly dense population concentration (hot spots of vulnerability). Furthermore, the indicator can be used in longitudinal studies to assess whether over time residential areas spread into flood exposed areas (e.g. as a result of urban sprawl), or whether they retreat from such areas due to planning restrictions or demographic change (shrinkage of urban areas). Secondly, the indicator could be further qualified by also including non-residential persons (e.g. tourists, temporary workers) who stay for a certain time within an urban area (e.g., if information on number of hotel beds, or other proxies would be available).

Economic sensitivity indicators

Industrial/commercial area affected by the risk of flooding

Floods affect not only the urban residents; they quite often also have severe impacts on businesses and entire industries. The impact usually takes place on three different levels. The first level is the immediate physical impact on the factory or office, including building structure, interiors and equipment. The business cannot operate until the flood waters have receded and the premises are restored to a functioning level. This results in secondary impacts, such as loss of production. A car company, for instance, will no longer be able to produce cars (outputs) and will face monetary losses.

This might result on a third level in the reduction of productivity of the entire supply chain, as the suppliers might no longer be able to produce outputs on which other industries depend.

As a result, assessing the sensitivity of industries and companies to the impact of flooding is anything but trivial. The assessment procedures depend largely on the scale of assessment (Green et al., 2011; Lequeux and Ciavola, 2012). For a Europe-wide approach is seems feasible to develop an indicator that only includes information about the spatial extent of commercial/industrial areas in cities and to what extent they are exposed to the risk of flooding, thus relating to the first level of impacts. A higher proportion of such areas in a city would indicate its increased vulnerability.

However, the indicator would neither provide information on the economic sensitivity of an urban area nor on the relevance that individual companies/industries or the entire city might have within regional, national or global supply and interdependency networks (Sassen, 1991). Therefore, this basic indicator could be further developed in two directions:

- Aggregated indicators for socio-economic sensitivity. A socio-economic sensitivity indicator would provide an overview on the aggregated economic sensitivity represented by different land use types such as industrial and commercial areas, residential buildings, transport, administration and services as well as sport, recreation and garden allotments that are exposed to flooding (Adger, 1999). Land use could be a criterion serving as a proxy to evaluate the overall financial losses expectable in a city (Filatova et al., 2009 quoted in Kubal et al. 2009, 1886).
- Role and function of city on the regional, national, European as well as on the global scale. This indicator would be interesting but is yet to be developed.

External services and infrastructure sensitivity indicators

Sensitivity of (critical) infrastructure

Infrastructures are an important basis of urban life which is densely networked and defined by a highly differentiated society. Graham and Marvin (2001) therefore propose the "splintering urbanism" thesis, arguing that the current "organizational, institutional, economic and technical unbundling of infrastructure systems is reshaping social and spatial relations in cities and the relationship between cities and their infrastructure" (Graham and Marvin, 2001 cited in in Moss 2008, 437). Infrastructures in urban areas provide services that ensure a high standard of living and economic productivity. The different types of infrastructure include both the technical structures and the social and emergency systems in cities (cf. also Fekete 2011, Lenz 2009):

- transport and traffic related infrastructure (% by type in LUZ);
- water related infrastructure (e.g. drinking water supply, sewage);
- electricity related infrastructure (e.g. grids, power plants etc.);
- social infrastructure (e.g. schools, kindergarten, nursery homes, hospitals,);
- emergency related infrastructure (e.g. fire departments, police stations, other relevant public institutions etc.);

The critical character of urban infrastructures becomes most evident in case of their failure, when services and resources are suddenly not available anymore (Fekete 2011, 15). The failure of critical infrastructure means a substantial disturbance of public life and undermines the security of service supply (Lenz 2009, 19). The sensitivity of critical infrastructure depends on two overarching elements (based on Fekete 2011):

- The quantity of elements or nodes of infrastructure as well as critical number of services provided by that infrastructure. If a flood reaches a certain water level or a certain spatial extent, this will seriously affect an infrastructure system upon which other infrastructures, business, industries and urban populations depend;
- The duration of outage of an infrastructure which depends, among others, on the speed of onset, and the average time to restore its functionality.

Assessing the sensitivity of infrastructure to the risk of flooding is a challenging task as data is quite often not publically available since many infrastructures are operated privately. Furthermore, the sensitivity of infrastructure depends critically on the physical condition of the very structures, which should ideally be assessed on a case-by-case basis. Therefore, on a European scale, it is proposed to assess the sensitivity of infrastructure by recording the presence of infrastructures in areas prone to the risk of flooding. A high proportion of such kind of infrastructure in flood prone areas means an increased vulnerability of an urban area; this takes into account the fact that if infrastructure is affected by flooding, the consequences could also be felt in the wider urban area, depending on given elements of infrastructure.

Biophysical sensitivity indicators

For floods, we do not propose any indicators for biophysical sensitivity indicators

5.4 Response capacity

Chapter 3 discusses generic response indicators. The measures and strategies increasing the specific response capacity of cities to flooding can be classified into structural and non-structural measures (Schanze 2009) or into grey, green and soft measures (European Environment Agency, 2012a). The response capacity measures include as follows (Hildén et al., 2012):

- spatial planning: restricting development in floodplains as much as possible;
- constructional measures: ensuring appropriately adapted construction methods in areas prone to flooding;
- risk acceptance: making financial provisions (backed by insurance);
- behavioural adaptation: communicating risk, preparing the residents and businesses for flooding, and practicing how to cope with flood-related emergencies;
- information systems: alarming, warning and informing about impending events;
- increasing natural water retention in catchment areas and reducing land sealing;
- technical flood protection: constructional facilities for water retention (dams, storage, reservoirs, dykes, flood polders).

It is proposed here to differentiate response capacity indicators into those contributing to awareness, ability and action, in line with the typology in chapter 3. While it is challenging to identify specific indicators of awareness and action that could be meaningful and easy to collect at the European level, it is feasible to identify some indicators with regard to "ability", which includes physical infrastructure and technological development that enable urban areas to prevent the impact of flooding or adapt to its consequences.

Technical flood protection measures

Dikes, dams, walls, storm water storage systems, and sewage systems play a major role in responding with different capacities to flood hazard taking into account that absolute flood protection is impossible and buildings already located in flood prone areas need to be protected. Usually these measures are constructed following a certain design standard providing protection for events with a given statistical return period. In Germany, for instance, many dikes are designed to prevent flooding with a statistical return rate 1 in 100 years. In the Netherlands, design standards are considerably higher (e.g. 1 in 1000 years). In the European context, these measures ensure a durable protection against many flood events and allow settlement in flood plains as well as economic development and prosperity. At the same time, the development behind the dikes in "flood secured" areas may increase the overall exposure of a city. In case of a major flood exceeding the designed protection standard, or in case of a failure of the existing measure (e.g. due to bad maintenance of a dike), the damage might even higher than in the case of unprotected areas, due to a higher numbers of people living in the presumably "secure" area). This is known as the "levee-effect".

In this sense, the indicator on the existence of technical flood protection measures is ambivalent: it indicates the reduction of exposure of protected areas with regard to the events that it is designed for, assuming the appropriate maintenance of the flood defence; at the same time, it may contribute to an increasing exposure in protected areas, exactly because citizens, organisations and business have a (false) sense of security. However, the indicator serves as a proxy of how well a city is protected against the impacts of certain evens with a given statistical return period. For a specific run-off return period, the larger the proportion of the residential and commercial areas that are protected with technical measures, the less vulnerable the city is. In this sense, the existence of technical flood protection measures in urban areas prone serves as a general proxy for how many residents and businesses as well as industries are not exposed to the risk of flooding because of the existence of technical measures.

Early warning related activities (monitoring system or emergency plans)

In the case of flooding resulting from intensive rainfall, the existence of (web-based) early warning systems or emergency plans can involve the prediction of expected water levels, based on detailed data and models regarding precipitation and water levels, and thereby serve as a general proxy for copying with the occurrence of flood. Of outmost importance in this context is the continuous update of the input data in order to guarantee an effective forecast with adequate warning times, a stable, user-friendly operation of models and a reliable forecast to allow for adequately communicating the occurrence of the hazard to the relevant population.

The European Floods Portal brings together information on river floods and flood risk in Europe, resulting from ongoing research within the "Floods" Action at the Joint Research Centre (JRC) of the European Commission, as well as using publicly available information from EU countries (http://floods.jrc.ec.europa.eu/). The European Floods Awareness System (EFAS) is an early flood warning system complementary to national and regional systems. It provides the national hydrological and/or meteorological institutes and the European Commission with information on possible river flooding to occur within the next 3 or more days.

Change of the proportion of urban green spaces / soil sealing

The capacity of soils and vegetation to retain water is an important factor in flood prevention as it reduces peak discharges across river basins (European Environment Agency, 2012a). The manner in which the agricultural and forestry land is used is therefore relevant to flood risk management at the watershed scale. Furthermore, green spaces reduce the surface water runoff after intense rainfall by increased infiltration. Thus, a low availability of vegetated areas (also referred to as green infrastructure) and the increasing proportion of built-up areas are expected to increase the occurrence of flooding (Lundy & Wade, 2011; Kazmierczak & Carter, 2010). The increase of the overall amount of green spaces at the watershed level can thereby be determined as an important adaptive response to fluvial floods. For pluvial floods, decreasing the degree of soil sealing within the actual urban area in favour of green areas or permeable soil surfaces, would be an important response indicator.

However, this overall indicator can only serve as a general proxy for the capacity for flood protection, as the specific benefits of different types of green spaces (considering different soil and vegetation types) need further specification. Also, it is important to investigate the connectivity of the green spaces to rivers and water bodies as buffers or retention zones reducing peak-flows. If they are not connected within cities, these effects are rather negligible in the context of the river flooding as they cannot be used in a controlled manner to control peak flows. Nonetheless, they may still be effective in reducing the risk of pluvial flooding and it seems legitimate to state that the more urban green spaces a city contains, the higher its capacity to adapt to the increased risk of flooding.

Table 5.1 summarises the recommended exposure, sensitivity and response capacity indicators in relation to the hazard of flooding.

Table 5.1. Summary of indicators proposed for flooding

Theme: Heat	**Proposed urban climate vulnerability indicator for EEA indicator system**	**Relevance (what is the message, implication of indicator values)**	**Feasibility (data availability, when and from where)**	**Credibility (reliability of data source, how sure are we of relationship with hazards)**
Exposure	Area potentially affected by flooding (fluvial and costal)	Indicates the surface areas prone to the risk of flooding in urban areas (statistically 1/100 years), indicates the amount of risk prone areas, high proportion of areas prone to flooding means increased vulnerability.	Risk of flooding can be calculated from data obtained by: - Climate model simulations: present day and future projections from LISFLOOD model: http://floods.jrc.ec.europa.eu/lisflood-model.html Exposed area can be calculated by a "volume model" (see EEA 2012) indicating the difference between modelled water level and the digital elevation model.	Data sources are state-of-the-art; LISFLOOD results involve potential fluvial floods (neither local flood defences nor pluvial or coastal floods are included)
	Degree of soil sealing (pluvial flooding)	The more impervious surface, the more storm water to be disposed off.	Indicator maintained by the EEA http://www.eea.europa.eu/data-and-maps/data/eea-fast-track-service-precursor-on-land-monitoring-degree-of-soil-sealing-100m-1	Soil sealing may say something about the amount of water to be disposed of, it doesn't say much about flooding because the local drainage system may be well developed.
Sensitivity: social	Share of population potentially affected by the risk of flooding	Indicates the geographical expansion of residential areas prone to the risk of flooding; serves as a general proxy for expected number of residents prone to the risk of flooding, higher share means increased vulnerability	Sensitivity can be calculated based on Corine Land Cover information and the Urban Atlas – in the implementation phase the best sources should be chosen http://sia.eionet.europa.eu/CLC2006 http://www.eea.europa.eu/data-and-maps/data/urban-atlas Of relevance is information on the category "settlement".	Data is available on a European scale, but not very detailed regarding its spatial resolution and its differentiation; however, still the only data set that might be used (cf. also http://www.floodsite.net/html/partner_area/project_docs/T9_06_01_Flood_damage_guidelines_D9_1_v1_0_p01.pdf

Sensitivity: economic	Industrial/commercial area affected by the risk of flooding	Indicates the geographical expansion of commercial/ industrial areas prone to the risk of flooding; serves as a general proxy for expected losses in productivity, higher share within the city means increased vulnerability	Sensitivity can be calculated based on the urban atlas or the Corine Land Cover information http://www.eea.europa.eu/data-and-maps/data/urban-atlas http://sia.eionet.europa.eu/CLC2006 Of relevance is information on the category "industries".	Data is available on a European scale, but not very detailed regarding its spatial resolution and its differentiation; however, still the only data set that might be used (cf. also http://www.floodsite.net/html/partner_area/project_docs/T9_06_01_Flood_damage_guidelines_D9_1_v1_0_p01.pdf
Sensitivity: external services and infrastructure	(Critical) infrastructure affected by the risk of flooding	Indicates the existence of in urban areas prone to the risk of flooding; high proportion of such kind of infrastructure in flood prone areas means increased vulnerability and this not only for the very region but also for the larger urban area, as it might depended on the services provided by the at risk infrastructure.	Sensitivity can be calculated based on Corine Land Cover information http://sia.eionet.europa.eu/CLC2006 However, information is only available with regard to traffic related infrastructure. Not sure about other infrastructure related aspects. Additional information can be gathered in the Urban Atlas: http://www.eea.europa.eu/data-and-maps/data/urban-atlas Additionally, there seems to be information available on flooded treatment plans as well as on power plants exposed on ECRINS (however, not quite sure about information) http://projects.eionet.europa.eu/ecrins	Data is available on a European scale, but not very detailed regarding its spatial resolution and its differentiation; however, still the only data set that might be used (cf. also http://www.floodsite.net/html/partner_area/project_docs/T9_06_01_Flood_damage_guidelines_D9_1_v1_0_p01.pdf
Response	Technical flood protection measures	Indicates the existence of technical flood protection measures in urban areas prone to the risk of flooding; serves as a general proxy for indicated the proportion or residential/ commercial/ industrial areas that are	Needs to be specified.	If information about local flood protection measures (public as well as private) would be collected locally for a sufficiently large number of cities, it would enhance the relevance of the indicator, and

		protected for certain events (depending on the design standard), the higher the proportion the lower the vulnerability of a city		could also be used to improve LISFLOOD
	Early warning related activities (monitoring system or emergency plans)	In the case of flooding Early warning system can predict expected water and serve as a general proxy for copying with the occurrence of flood; Emergency plans can help in order to help evacuation activities and thereby enhance the overall coping capacities of cities.	Information on early warning systems are available at: http://floods.jrc.ec.europa.eu/ The European Floods Awareness System (EFAS) is an early flood warning system complimentary to national and regional systems	It is difficult to agree on responsibilities of maintenance and updating data but if existing European portals will be used and further developed with lower higher resolution the problem could be solved.
	Change in the proportion of soil sealing Change in the proportion of urban green spaces	Indicates the *change in* the level of soil sealing and the amount of green space in urban areas that can serve as important area for protecting other uses from flooding (due to infiltration and retention function)	Up-to-date information on green spaces. Can be derived from (CORINE land cover maps http://www.eea.europa.eu/publications/COR0-landcover or from the GMES Urban Atlas http://www.eea.europa.eu/data-and-maps/data/urban-atlas. Shape files are available for download. Spatial resolution varies. Soil sealing: EEA FTSP on Land Monitoring – Degree of soil sealing 100m http://www.eea.europa.eu/data-and-maps/data/eea-fast-track-service-precursor-on-land-monitoring-degree-of-soil-sealing-100m-1	Depends largely on the quality and feasibility of data, more difficult is the distinction between different type of green spaces and the estimation of the positive effects

6 Droughts and water scarcity

6.1 Introduction

Projected changes in climate indicate a shift of precipitation patterns in Europe. Precipitation deficit and precipitation surplus are likely to increase frequencies of floods in northern and northeastern Europe, while southern and southeastern Europe is likely to be affected by significantly increased frequency of droughts (e.g. Lehner et al. 2006;European Environment Agency, 2008).

This chapter provides a discussion on the indicators for exposure, sensitivity (under the headings of human population, economic assets and external services) and response capacity related to water scarcity and droughts in urban environments. Table 6.1 provides a summary of the suggested indicators in terms of their relevance (message), feasibility (Europe-wide availability of data) and credibility (reliability of data source). The discussion below elaborates the indicators and identifies some gaps in knowledge and possible future work. In the Annex 4 a more detailed fact sheet for each selected indicator, elaborating the information in the table and providing data sources, has been included.

6.2 Exposure

Exposure to droughts and water scarcity is the degree to which an urban system is exposed to long-term water unavailability. This affects the reliability of long-term water supply to the city. The most common categorisation of droughts distinguishes between meteorological, agricultural, hydrological and socio-economic drought (Dracup et al., 1980), all of which originate from lack of precipitation. Meteorological drought is usually initialised by below-average precipitation. Should this pattern last longer, moisture levels in the soil will start to drop and a meteorological drought will initiate an agricultural drought. Agricultural drought can cause severe impacts on crops and ecosystems, which subsequently lead to complex impact patterns on food supply and socio-economic systems through various pathways. Prolonged precipitation deficit may lead to a hydrological drought. Hydrological drought is defined as a drop of water levels below the long-term average in surface and ground water aquifers. Hydrological drought impacts include reduced water supply to cities and problems for inland water transport. The final type of drought is socioeconomic drought. This type is defined as the failure of a water supply system to deliver sufficient water to the population, due to various reasons (e.g. water poverty, technical limitations). Guha-Sapir et al. (2012) estimated damage from climate-induced droughts worldwide to reach 14.2 billion USD in 2011([9]), but almost all of this damage occurred outside of Europe. Whilst precipitation deficit is the predominant driver for agricultural, hydrological

[9] It should be noted that reported damages from climatological disasters are often underestimated due to a lack of standardized methods for quantifying and reporting losses. Also, there is no standardized method how to disentangle impact pathway that propagate through economic system due to changes in supply chains, migration, security etc.

and socioeconomic droughts, these drought types can also be caused or exacerbated by unsustainable land use, excessive water withdrawals or socioeconomic conditions in the city.

Likelihood of occurrence of the meteorological drought

While meteorological drought (precipitation deficit) does not threaten urban systems directly, it usually precedes the other types of drought that do have direct impact on urban systems. Therefore, we argue that the precipitation deficit is a good proxy exposure indicator for water scarcity and droughts, and that regional drought indicators are useful proxies for the urban areas in the associated regions. There is a number of ways how precipitation deficit can be measured (see, e.g. Heim 2002). One of the commonly used metrics to monitor precipitation irregularities is the SPI (Standardized Precipitation Index). The Standardized Precipitation Index (SPI) is an indicator for lack or surplus of precipitation in given cumulative period according to the baseline period. It measures the difference of precipitation from the mean divided by the standard deviation, with the mean and standard deviation being determined from the climate record (McKee et al. 1993). SPI is commonly monitored by meteorological services in EU member states, as well as by the European Drought Observatory at JRC. The SPI-n is a statistical indicator comparing the total precipitation received at a particular location during a period of n months with the long-term rainfall distribution for the same period of time at that location. SPI is calculated on a monthly basis for a moving window of n months, where n indicates the rainfall accumulation period, which is typically 1, 3, 6, 9, 12, 24 or 48 months. The corresponding SPIs are denoted as SPI-1, SPI-3, SPI-6, etc. In our case SPI-12 reflects 12 months SPI, which according to literature (McKee et al., 1993) is a proxy for hydrological drought. SPI-12 compares accumulated precipitation in the preceding 12 months to the average precipitation over the same preceding months in baseline period (usually 1961-1990 or 1971 - 2000) and the results are presented in the form of standard deviation. SPI ranges between +2 and -2. SPI lower than -1.5 indicates severe to extreme dryness (McKee et al., 1993).

While SPI is a useful indicator for assessment of the immediate exposure to droughts, there is a need for a long term, forward-looking indicator of exposure. To provide better metrics to the cities, allowing them to monitor their changing exposure, we suggest to use a SPI derivate that captures the likelihood of drought events in a selected period. Suppose we are studying dryness in last 30 year (1982-2012) and we would like to see if there is high or low likelihood for extreme dry event across Europe. We calculate SPI-12 at specific location or grid point for each month between 1982 and 2012 (based on the ECA&D (E-OBS) precipitation datasets) and count how many times SPI-12 was lower than -1.5. This will range between 0 and 360 (30 years * 12 months) and the likelihood (the number of dry events divided by the total number of possible events [360]) will be between 0 and 100 %. Figure 6.1 presents the likelihood of meteorological drought across Europe at the NUTS3 level.

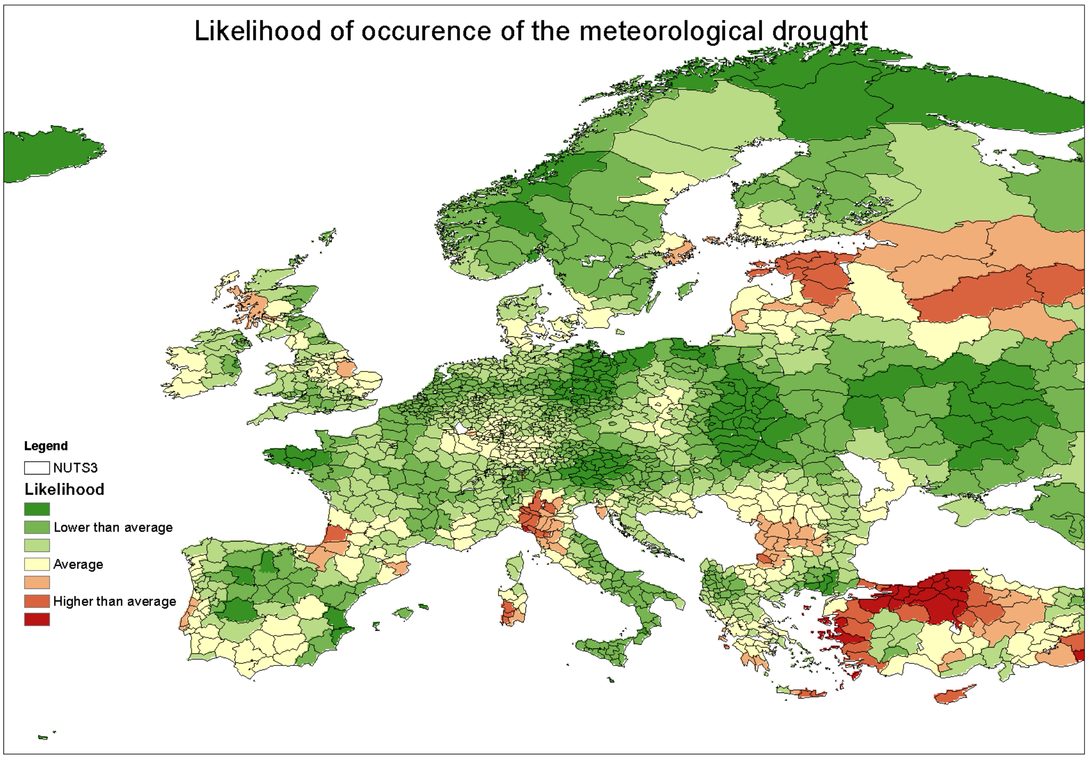


Figure 6.1: Likelihood of occurrence of the meteorological drought for the period 1989-2008 (Blaz Kurnik, EEA, personal communication)

Water availability and Water Exploitation Index

Most of the time, urban water supply systems are not directly dependent on precipitation. The majority of European cities draw their water supply either from surface or from ground water reservoirs. Therefore, one of the exposure indicators in this particular theme should deal with the problem of water availability. Water availability in physical terms can be simply described as the amount of water in a given time and given place. For individual river catchments, this can be estimated by based on information about runoff and evapotranspiration. For simplification purposes, total runoff from catchments is sometimes used as a metric for water availability. Additional metrics can involve water availability in a river basin, divided by the population in that river basin. However, for the urban localities this indicator may be misleading as large cities often draw water from distant aquifers or they withdraw water simultaneously from different river basins.

The Water Exploitation Index (WEI) is a metric that can be used to describe the exposure of cities to droughts and water scarcity. Water scarcity is a situation where there is insufficient water to satisfy normal requirements and is often induced by droughts. WEI is a standard EEA indicator (CS018), defined as the mean annual total abstraction of fresh water, divided by the long-term average of freshwater resources. It describes the pressure that the abstraction puts on water resources. In the case of urban areas, it would identify those cities that are located in areas of high water abstraction in relation to their freshwater resources, which may therefore be prone to problems of water scarcity and droughts. In the standard WEI, the long-term average freshwater resource is derived from the long-term average precipitation minus the long-term average evapotranspiration plus the long-term average inflow from neighbouring countries (EEA, 2012c).

Usability of WEI as an exposure indicator for the cities is associated with some problems. Firstly, the spatial resolution of the current indicator (country or river basin) is too coarse to be used in a meaningful way for cities. The second problem is related to the "water abstraction" for energy use, which captures water that is used for cooling in energy production. In reality this water is largely returned to the natural environment: some through evaporation but majority to water bodies. Whilst this water has a higher temperature, it is suitable for further usage. The third problem is that WEI includes only surface freshwater but cities are often at least partly dependent on underground resources. Therefore, the WEI only provides some insights into water scarcity and droughts exposure. However, it is a well-established and readily available indicator.

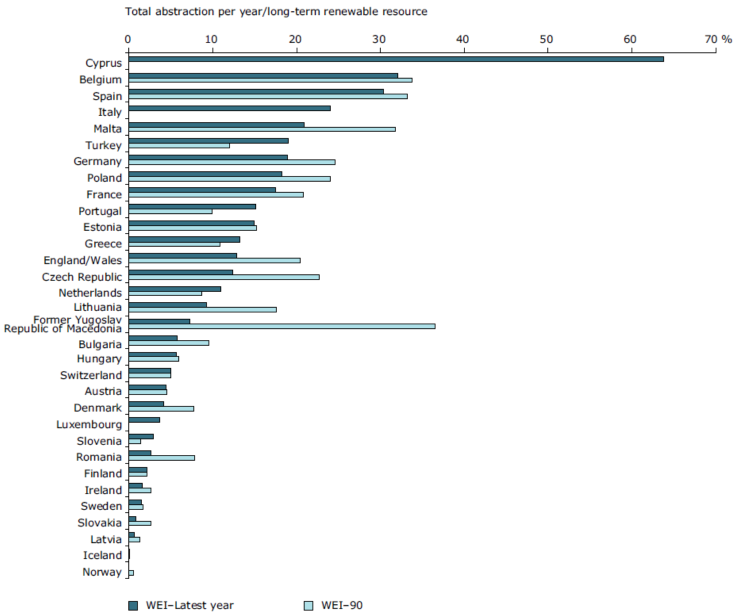


Figure 6.2: Water exploitation index, Europe, (EEA, CS 018, 2010[10])

6.3 Sensitivity

A system sensitive to water scarcity generally has a high water demand and the proposed indicators aim to capture this association. Urban systems that are more sensitive to droughts and water scarcity

[10] assessment from 31 Aug 2010.For particular countries, the values are from the following years(WEI Latest year, WEI-90): Cyprus (2007); Belgium (2005, 1994); Spain (2006, 1991); Italy (1998); Malta (2007, 1990); Turkey (2001, 1990); Germany (2004, 1991); Poland (2005, 1990); France (2006, 1991); Portugal (1998, 1990); Estonia (2007, 1990); Greece (2007, 1990); UK* (England/Wales) (2006, 1990); Czech Republic (2007, 1990); The Netherlands (2006, 1990); Lithuania (2007, 1990); FYR, of Macedonia (1990, 2007); Bulgaria (2007, 1990); Hungary (2002, 1992); Switzerland (2006, 1990); Austria (1999, 1990); Denmark (2004, 1990); Luxembourg (1999); Slovenia (2007, 1990); Romania (2007, 1990); Finland (1999, 1990); Ireland (2007, 1994); Sweden (2007, 1990); Slovakia (2007, 1990), Latvia (2007, 1991); Iceland (2005, 1992); Norway (1985)
Source : http://www.eea.europa.eu/data-and-maps/indicators/use-of-freshwater-resources/use-of-freshwater-resources-assessment-2

are those with a large provision of green spaces (due to the need for watering); a high proportion of children and the elderly in the population; and large number of water-sensitive industries (such as food and beverages production). In addition, the sensitivity to droughts and water scarcity is also affected by the city's reliance on only one source of water supply. The indicators proposed in this section reflect the total amount of water consumption, presence of sensitive demographic groups and diversity of supply.

Social sensitivity indicators

Per capita water use

The more water a city uses, the more sensitive to disruption or incremental decrease of its supply it is. Large urban areas in Europe are entirely dependent on centralised water supply that can ensure appropriate water quantity and quality for the city population; however, smaller cities, towns and villages, often still have a certain share of self-supply (private wells and boreholes). Supply of water per capita seems to be an appropriate indicator for water use. Even if high per capita water use may imply more water use for non-essential purposes (watering of lawns, washing cars) and would allow for maintaining water supply for a more limited set of more essential purposes (drinking, food preparation), for practical reasons we propose not to distinguish between essential and non-essential uses. Water use per capita in a country is a standard indicator that can be derived from Eurostat statistics. In the Urban Audit, indicator "EN3003V Total consumption of water" divided by indicator "DE1001V Total resident population" should give a relatively accurate picture of "per capita" consumption of water in the city.

Share of sensitive population groups

Water scarcity and droughts can be particularly stressful for sensitive groups in the city population. As a period of water scarcity can be accompanied by increased temperatures, there is a synergy effect with scarcity of drinking water and thermal discomfort (see also Chapters 4 and 8). Sensitive groups might be older people, those with increased water demand (infirm people) and people with physical disabilities. Water scarcity can be induced by a failure of the supply system. As it is heavy to carry (e.g. from cisterns temporarily supplying the city or its parts with water), those less physically able (older people, children and those in poor health) may be more sensitive. When water availability to people is associated with its affordability of water, another sensitive group may be low-income households who spend considerable amount of their income on water (situation described as "water poverty"). Although, like in the case of floods, there is no evidence clearly indicating such specific sensitivity for droughts, the link with heat seems to justify to use the same indicators for sensitive groups as presented in chapter 4 in relation to heat stress.

Economic sensitivity indicators

In the context of economic sensitivity of water scarcity and droughts, the share of highly water-intensive industries would be a possible indicator. Information on this is however not available at the European scale for cities.

External services and infrastructure sensitivity indicators

Efficiency of water supply systems

The efficiency of a water supply system decreases its sensitivity to water scarcity. A water loss in water supply systems (WSS) is associated with a number of factors: leakage in the network from poorly sealed pipes; losses in user installations before the water is metered; sometimes the consumption differences between quantities used (measured) and those not measured are also counted as losses. In Europe, losses in water distribution systems range from 15% in well-managed networks up to 75% in ill-managed networks (EEA, 2001). The indicator for measuring losses in the water supply system is not well developed, but several approaches are proposed (EEA, 2001, which we consider more specific about these issues than later publications, such as EEA, 2012c:

- Efficiency ratio: this ratio uses only measured values and compares the measured delivery volumes to end users with the volume released into the network by the supplier, but it does not take into account the total volumes involved (it is not used to compare different networks).
- Net efficiency ratio: this ratio takes into account all types of water uses (measured, unmeasured and maintenance). It can be erroneous, if there is an inappropriate use of maintenance volumes, which increase the net efficiency value.
- Linear leakage index: the physical state of networks can be compared by relating the lost volumes to the length of the network.

Whilst all WSS operators gather the information necessary to calculate these indicators for their internal purposes, this data is currently not publically available. Therefore, we suggest not to use these indicators for reporting until the data is available or other indicators are developed.

Diversity of water supply

Urban areas that are supplied from different water sources are less sensitive to water scarcity and droughts than those relying on one source of water supply. Most of the big European cities have a diverse water supply. There is no unified approach how to measure diversity in water supply. Measuring the richness of water resources that supply the city is one possibility; the indicator would simply quantify how many different water sources are used. Another option is to use diversity indices such as the Shannon-Wiener Index (SW Index). This indicator is used in ecology for measuring biodiversity, where it reflects a number of different species and how evenly the numbers of individuals are distributed among the different types of species. However, it also has been applied to measure the diversity of energy supplies; thus, it could be also applicable to the urban water supply diversity.

In this context, the SW index is the sum of the proportion of water from a given source multiplied by the logarithm of the proportion of water from a given source:

$$H' = -\sum_{i=1}^{S} p_i \ln p_i$$

, where p_i is the proportion of water supply coming from the ith source.

The minus sign at the beginning of the equation ensures that the value of the index is always positive. The index increases as the number of different supply sources increases. Complete dependence of one water source yields an indicator of 0 (since ln1 = 0), whereas for cities with more than seven various sources (and their equal proportion in the total water supply) the indicator can be higher than 2.

Whilst this indicator corresponds well to the sensitivity of cities to water scarcity and droughts, it is still underdeveloped in terms of data and method. Until further research is conducted, we suggest not using it as a priority indicator.

Biophysical sensitivity indicators

Green spaces and green infrastructure, if managed and watered, increase consumption of water and therefore make cities more vulnerable in case of water scarcity and drought events. This vulnerability can be lessened by the selection of drought-resilient species and by the design of green spaces (e.g. by including rainwater reservoirs in them). We have also discussed this indicator in the context of heat, but in that context we considered the role of green spaces in reducing the Urban Heat Island effect to be more important (more green is positive) than their sensitivity. Therefore, also for the problem of drought, we propose not to use green space as an indicator for sensitivity, because it would suggest that the more green, the more vulnerable a city would be, while we consider the effect of green space on reducing the UHI as more important. At the same time, when including green space as an indicator of vulnerability in the sense of “the more green, the less vulnerable a city is for heat”, this message should be complemented by a remark that this refers to the cooling effect of green space, and not to the sensitivity of vegetation itself to heat (or drought). City managers can decrease this sensitivity by selecting more drought-resistant species. See also Chapter 8 for a discussion on such crosscutting themes.

6.4 Response capacity

Whilst meteorological droughts are not an imminent problem for the cities, agricultural droughts - although most of the time they have an impact outside of the city boundaries – can have a direct impact on urban green spaces and green infrastructure. Hydrological droughts in areas around the city often lead to socioeconomic drought, which has a direct impact on the urban system. The capacity of urban areas to prepare for, tackle, and cope with, various types of drought differs significantly between cities, but in general the possibilities of responding to droughts are limited.

A meteorological drought in cities is accompanied by decreased moisture in the air and increased air pollution from dust and particulate matter. This can be tackled by a temporary decrease of sources of particulate matter in the city (e.g. transport regulation) or by increasing moisture in the city (e.g. by water spraying or increased water cleaning of streets). Increased water consumption during meteorological drought can however aggravate the situation and trigger other types of drought.

Agricultural drought that damages city parks and other green spaces can be tackled by a smart selection of species when designing parks, or by increased watering of these areas during the drought period. Increased watering can mitigate impacts of dry season on the green infrastructure, but it increases the pressure on city water reservoirs and can trigger hydrological drought.

Hydrological drought directly threatens city reservoirs, and cities are usually in a position to regulate the rate of water abstraction through soft and hard measures. To decrease the probability of hydrological drought, cities can build artificial water reservoirs or diversify their supply. Failure to regulate water abstraction during hydrological drought can lead to socioeconomic drought, which is sometimes the last link in the causality chain, starting with unusually long periods of dry weather and ending with insufficient supply of drinking water in the public supply system.

Water rationing and water cuts

One of the immediate responses to the pressure exerted on the urban water supply systems by water scarcity is to moderate water use. Moderation can take the form of "soft" suggestions from the city hall to cut excessive water use. An example is hosepipe ban in the UK - an official restriction on the use of hosepipes in gardens during a water shortage, breaching of which results in a fine.

Hard regulation – so called water rationing – is a more strict approach that allows the water supplier to directly control how much water is used and distributed. Whilst water rationing may lead to socioeconomic drought, it could prevent a total failure of the water supply system.

A potential response indicator could be the number of water rationing cases obtained from the Urban Audit (EN3008V). This indicator presents the number of days per year when water was rationed - it should include the scheduled water cuts due to shortage, e.g. hosepipe bans, but exclude the rationing due to maintenance or repair, which are highly infrequent and seldom impact on quality of life. Complementary to this, the Urban Audit indicator Water cuts (EN3009V) can be used to cover scheduled and unscheduled cuts in the central provision of water. This indicator covers water cuts lasting more than 12 hours, or affecting more than 10% of the population of the city.

These two indicators could provide a certain insight how the water supply in city is regulated and how often it is restricted. However, data for those indicators that are part of urban audit indices are incomplete and their quality varies. Also, water cuts depend very much on political decisions and might also be result of a very poor water infrastructure and management already in non-drought times. Cities which have a good water management and do not need to cut under droughts do not necessarily have a lower responsive capacity. Therefore, our suggestion is to further improve the data quality before these indicators can be presented in any EEA report. However, the currently existing data can still be used to identify case studies illustrating water rationing.

Existing water scarcity or drought plans would be a good response indicator, but such information is unavailable. Table 6.1 summarises the recommended exposure, sensitivity and response capacity indicators in relation to the hazard of droughts and water scarcity.

Table 6.1. Summary of indicators proposed for water scarcity and drought

Theme: Water scarcity/ Droughts	**Proposed urban climate vulnerability indicator for EEA indicator system**	**Relevance (what is the message, implication of indicator values)**	**Feasibility (data availability, when and from where)**	**Credibility (reliability of data source, how sure are we of relationship with hazards)**	**Remarks**
Exposure	Likelihood of occurrence of the meteorological drought	The higher the likelihood, the higher the exposure WS/D event	Data are based on JRC – EDO and mathematically converted to the likelihood by EEA. Data are available for whole Europe as well as other parts of the world if needed.	High	For application in urban areas fine resolution should be used
	Water exploitation index (WEI)	Higher WEI means higher exposure to WS/D event	Core EEA indicator (CSI 018) - Use of freshwater resources	Medium	Currently WEI is available on country level and on river basin level. Application for local level needs further development.
Sensitivity: social	Water use per capita	The higher the water use per capita, the higher sensitivity to WS/D events.	EurostatUrbanAuditstandardindicator EN3003V	Medium	Data have gaps and possibility of "background noise" (e.g. industrial consumption, tourism influence).
	Share of sensitive population groups	See chapter 4			
Response	Water rationing and water cuts	Dubious – it needs more detailed interpretation - presence of rationing shows response but it does not necessary indicate additional response capacity.	Data are available in Urban Audit EN3008V and EN3009V however data set is incomplete.	Low Rationing and cuts are often politically motivated and this indicator may be a response rather than describing capacity.	Data need additional verification or and possible further development from data provider.

7 Forest fires

7.1 Introduction

The impact of climate change on forest fires in Europe has been widely described (Lindner et al., 2008; EEA, 2012a). However, the present and future impacts of forest fires on urban areas, at a European scale, are rarely considered, despite the fact that in Southern Europe wildfires involving settlements are becoming more and more frequent, because of the increasing number of houses and infrastructure located within, and adjacent to, areas prone to wildfires (Marzano et al., 2008). This problem has mainly been addressed from the fire risk management perspective, at the regional level, as exemplified by the projects Wildland-Urban Interface Fire Risk Management (WARM([11]), FP5 Programme) and Fire Paradox([12]) (FP6). Finally, the MOVE([13]) project (FP7) delivered a web-based indicator database where forest fires are included with special reference to human health and dwellings.

This chapter provides a discussion on the indicators for exposure, sensitivity (under the headings of human population, economic assets and external services) and response capacity related to forest firest. Table 7.1 provides a summary of the suggested indicators in terms of their relevance (message), feasibility (Europe-wide availability of data) and credibility (reliability of data source). The discussion below elaborates the indicators and identifies some gaps in knowledge and possible future work. In the Annex 4, a more detailed fact sheet for each selected indicator, elaborating the information in the table and providing data sources, has been included.

7.2 Exposure

Fire probability index

Although it is generally recognized that the occurrence of forest fires in Europe is mainly caused by anthropogenic factors, the total burned area varies significantly from year to year largely due to weather conditions. Climate factors that determine fire risk are well known and relate to the occurrence and length of dry and hot summers (Bassi et al., 2008). These climate conditions decrease the water content in plants, leading to the increased inflammability of vegetation. Climate change projections in the Mediterranean areas indicate an increase in air temperature, heat waves and dry spells, and a decrease in summer rainfall, suggesting a future increment in water deficit. This in turn may lead to an increase in ignition probability and fire propagation during the summer period. Fire danger is also expected to increase in the boreal and central European regions (Lindner et al., 2008).

---

[11] http://www.fria.gr/WARM/warmProceedings.htm

[12] http://www.fireparadox.org/technical_guide_wildland_urban_interfaces.php?PHPSESSID=3c3fd5f3937a8d45025870daf24335bb

[13] http://www.gi4drr.org/move/move_query/index_hi.html

Several indices have been developed in order to summarise the climatic conditions that determine the fire danger. The Fire Weather Index (FWI, Van Wagner 1987) is the fire danger assessment method most widely applied all over the world (San Miguel-Ayanz et al. 2003). It is also used by the European Forest Fire Information System (EFFIS) in order to provide a harmonized European-wide assessment of daily fire danger.

One application of the FWI is the Seasonal Severity Rating which aggregates the daily rating over a period of time. This indicator has been developed by JRC and used in the latest update of the EEA report Climate change, impacts and vulnerability in Europe (2012b). This index, aggregated on a seasonal basis, summarises the overall fire potential of a given year due to meteorological conditions.

7.3 Sensitivity

The land development in the last decades, in particular urban sprawl, mean that the built-up areas are encroaching into semi-natural and natural areas, including those prone to wildfires. Whilst part of this process is related to the trend of having second homes in the countryside, the number of permanent residents in these peri-urban areas has been steadily increasing. In some cases, these peri-urban areas offer cheap housing for lower income families.

As discussed in Chapter 2, three different categories of sensitivity indicators can be distinguished: sensitivity of the population to the risk of fires, sensitivity of the economic assets in the peri-urban areas and sensitivity of the city's functioning to disturbances in external services that are the city's lifelines (mainly provision of energy and transport).

Given the character of the forest fires, it is key to define the object of the analysis: urban areas, peri-urban areas, or both. It is clear that the direct and main impacts of forest fires will be at the city-nature interface. However, large cities (e.g. Athens) can also be exposed to indirect effects of forest fires by disruption of services, or by smoke, which can reach several kilometres. However, as these indirect effects are difficult to measure and evaluate using the existing information (although indicators on proximity to areas of high risk could be developed for cities), the main focus is recommended to be on peri-urban areas. Peri-urban areas are identified as follows:

- peri-urban areas are characterised by their lower density (of population and built-up areas), and discontinuity compared to the core city. However, peri-urban areas maintain links and are located in the proximity of the core city.
- the UMZ will be the reference of the city since this delineation characterises the larger continuous built-up area (with its limitations). See also Annex 2 for a discussion on the delineation of urban areas.
- peri-urban areas will be delineated as follows:
    - a buffer of 20 km outside the border of the UMZ.
    - a buffer inward the UMZ, proportional to the degree of soil sealing. It is generally accepted that vulnerability to fires is higher in low density settlements due to a higher proportion of flammable vegetation in the area.

Social sensitivity indicators

Percentage of residents in high risk area

People living in the peri-urban areas are those most exposed to direct impacts of forest fire. Frequently, a distinction is made between permanent and floating population, i.e. temporary residents staying in second homes and tourist establishments. However, as the summer season is the season with the higher fire risk and higher occupancy rates in the peri-urban areas, both types of peri-urban residents should be considered in order to estimate the resource needed in the case of evacuation (transport and temporary shelter) and the number of people affected by e.g. psychological trauma.

The existing data on population (Eurostat) does not provide sufficient information to estimate the floating population, consequently the indicator can only identify the percentage of permanent residents that are in a high risk area. Since the information on population is available at 1 km grid, it is possible to identify at which distance of the core city a fixed proportion of the population is at high risk (for example 50%). Given the resolution (1 km), this analysis would only be meaningful for larger cities (and metropolitan areas).

It is recommended to explore, at least for case studies, the availability of information on floating population, since its inclusion multiplies the total population in these high risk areas by a factor of 4 or 5 in relation to the permanent population (own estimations of Province of Barcelona). National statistics in Spain could probably provide enough information to develop a test case study. In addition, experts on tourism in the ETC/SIA can provide additional references and check the scientific soundness of the proposed approach.

Percentage of population over 65 years

Inhalation of forest fire smoke is estimated to cause approximately 5000 deaths per year in Western and Central Europe (Johnston et al., 2012); people suffering from cardiovascular diseases are the most vulnerable. Since the information about cardiovascular health is usually not available at large scales, the population above 65 years is taken as a proxy (e.g. following the MOVE project). However, it needs to be checked with WHO, if it would be justified to use this indicator in this context.

A critical issue is the spatial disaggregation of the population above 65 years since this information is usually provided at administrative level. The Urban Atlas provides detailed demographic statistics both for the core city and the Larger Urban Zone (LUZ). This information can provide an indication of the age distribution inside the city and the periphery. It is suggested to have a close link with DG Regio (RegioGIS) and the ESPON database project (M4D), since they are developing methodologies in the same direction. Moreover, the increased availability of socio-economic statistics at grid level (see European Forum for Geostatistics) needs to be taken into consideration. Even if the data is available only for a few countries it would be useful to incorporate test areas with a greater level of detail into the assessment as a demonstration of the usability of this type of information.

Economic sensitivity indicators

Percentage of buildings in high risk zones

Since the indicators focus on the urban dimension, not all areas at high risk of forest fire are considered. Consequently, economic losses related to agriculture and forests are not included.

Residential areas in high risk zones are most exposed to fire damage, which have serious consequences. For example, forest fires in Greece in 2007 caused thousands of people to lose their homes (Bassi et al., 2008). The sensitivity of settlements is usually related to its structure (lower density increases the sensitivity). In that sense, the use of the peri-urban area as a relevant unit, following the approach described above, relates to this lower density of the built-up area and the higher degree of isolation of buildings. Other factors increasing sensitivity of the settlements are the characteristics of the surrounding vegetation, as well as topographic aspects (Marzano et al, 2008).

This indicator could be further developed considering two different data sources which provide different time scales:

- JRC has developed scenarios for future fire risk and corresponding development of built-up area based on the Community Land Modeler. The major constraint is the grid cell size, 25 km, and the classification of land uses (currently no differentiation between residential and industrial). Currently JRC is also exploring the possibility to run the model at higher resolution, but the results are unlikely to be available in the short term. The advantage of this approach is that it will provide future projections of changes in both land cover and climate (not just future impacts under current conditions of land use). Therefore, it is recommended to strengthen the cooperation with JRC in that area in order to identify the feasibility of running the model at higher resolutions.
- The Urban Atlas can be used as a source of information about land use under current fire risk, and also future projections (see exposure indicator). This approach allows to differentiate land uses at higher resolution. However, it is based on actual land use and does not take into account the interactions between topographic aspects and vegetation. This is a pragmatic approach, but not without some limitations.

Percentage of industrial/commercial in high risk zones

In terms of economic damage, forest fires have a stronger impact on residential areas than on industrial and commercial areas (Marzano et al, 2008). The reason is that the development of industrial and commercial areas has more strict regulations (especially in terms of fire protection) and is characterised by better planning than housing (in particular second homes). In addition, industrial and commercial facilities tend to aggregate in areas with easy access to infrastructure and are less isolated, therefore are more accessible by the emergency services.

The issues on data availability discussed for the previous indicator also apply here. Therefore, the use of the Urban Atlas is a short-term and feasible, but not optimal option. The comparison of both land use-related indicators (residential vs. industrial/commercial use) would provide some indication on the differential vulnerability related to past regulations and planning.

External services and infrastructure sensitivity indicators

Percentage of transport infrastructure in high risk zones

The impact on transport infrastructure has several consequences:

- increased difficulty to access the exposed area (increased risk);
- disruption of transport networks causing possible isolation of other areas not directly affected by the fire (indirect effect);
- economic loss (damage to the infrastructure).

This indicator presents the amount of infrastructure in the area and thus reflects the economic losses rather than issues of accessibility. It is based on existing data on roads and rail (GISCO, the Eurostat service which promotes and stimulates the use of GIS within the European Statistical System and the Commission).

Biophysical sensitivity indicators

We do not propose any biophysical sensitivity indicators for water scarcity and droughts.

7.4 Response capacity

Most of the responses to increased risk of forest fires relate to forest management and there is a great range of the adaptation measures and scales of implementation (Keskitalo, 2011). In most cases, a reactive approach is taken, and a consistent/coordinated framework of measures is often lacking (European Forestry Commission, 2010). In addition, there is no database with information about the investments on forest fire protection at the European level. However, it is estimated that the Mediterranean countries which belong to the EU, invest more than 2.5 billion euro per year in prevention and suppression, of which 60% is invested in equipment, personnel and forest fire suppression operations, and the rest is used in preventive work.

Accessibility in peri-urban areas

Accessibility is a key factor reducing the vulnerability; for example, evacuation plans include an assessment of accessibility.

The indicator will calculate the percentage of built-up areas where more than 75% of infrastructure connecting them to other areas is located in a high risk area. This indicator does not take into account either the topographic components that would modulate the fire risk, or vegetation types, since these would require a more complex modelling.

Expenditure on forest fire prevention

Currently there is no comprehensive European data supporting this indicator. However, there are national statistics in Spain, France and Italy that could provide some information. It is important to identify the expenditure on improved risk communication and protection of urban areas – at least based on the data available for the countries mentioned above. It would also be relevant to establish contact with the MOVE project([14]).

Information about existing early warning systems or fire evaluation plans would be useful response indicator, but is unavailable at the European level.

Table 7.1 summarises the recommended exposure, sensitivity and response capacity indicators in relation to the hazard of forest fires.

[1414] http://www.gi4drr.org/move/move_query/index_hi.html

Table 7.1. Summary of indicators proposed for forest fire

Theme: Forest fires	Proposed urban climate vulnerability indicator for EEA indicator system	Relevance (what is the message, implication of indicator values)	Feasibility (data availability, when and from where)	Credibility (reliability of data source, how sure are we of relationship with hazards)	Remarks
Exposure	Fire probability index	The higher the value, the higher the probability of occurrence of a forest fire.	http://forest.jrc.ec.europa.eu/forest-fires/fire-danger-rating http://www.eea.europa.eu/data-and-maps/figures/projected-meteorological-forest-fire-danger	The methodology is the result of peer reviewed international projects and widely used for fire risk management (at national and international levels). Source data is subject to quality control	Resolution is too coarse for previse assessments (25 km grid), although large forest fires occur at this scale. Possibility to use current risk and projected risk as well.
Sensivity: social	% of residents in high risk area	The higher the share of resident in high risk area, the higher the (potential) impact of a fire. It also shows to what extent there is a need for a better planning or investment.	http://epp.eurostat.ec.europa.eu/portal/page/portal/gisco_Geographical_information_maps/popups/references/population_distribution_demography http://www.eea.europa.eu/data-and-maps/data/urban-atlas	Eurostat. Population data (2006) at 1 km grid. Data has been derived by two different procedures depending on the country: bottom-up (aggregation from census statistics), which is highly reliable; and top-down (disaggregation from national statistics), which has more errors (see Barredo, 2005). GMES Urban Atlas data base provides reliable, inter-comparable, high-resolution land use maps for 305 Large Urban Zones and their surroundings for the reference year 2006.	This indicator only relates to permanent residents, not to floating population which is highly relevant. However, there is not enough idata to disaggregate the information on floating population (tourists, second homes) at the spatial resolution of the analysis.
	% of population > 65 years	It is assumed that people over 65 years old area more sensitive to smoke.	Urban audit database (Eurostat) http://www.urbanaudit.org/DataAccessed.aspxhttp://epp.eurostat.ec.europa.eu/portal/page/portal/region_cities/city_urban/data_cities/tables_sub1 http://www.eea.europa.eu/data-and-maps/data/population-density-disaggregated-with-	Data needs to undergo quality control procedure before being published in order to be reliable	The literature is inconclusive as to the age where the sensitivity starts to increase rapidly.

			corine-land-cover-2000-2/ GMES Urban Atlas http://www.eea.europa.eu/data-and-maps/data/urban-atlas	GMES Urban Atlas data base provides reliable, inter-comparable, high-resolution land use maps for 305 Large Urban Zones and their surroundings for the reference year 2006.	
Sensitivity: economic	Percentage of built-up areain high risk zones	The higher the share of buildings in high risk area, the higher the (potential) of economic losses (and potential impact on the number of homeless people)	GMES Urban Atlas http://www.eea.europa.eu/data-and-maps/data/urban-atlas	GMES Urban Atlas database provides reliable, inter-comparable, high-resolution land use maps for 305 Large Urban Zones and their surroundings for the reference year 2006.	There is an alternative data source based on modeling, which provides future scenarios (JRC). However, the resolution and differentiation of land uses remain issues which require further work/cooperation with JRC. Current proposal excludes interaction with vegetation and topographic features.
	Percentage of industrial/commercial land use in high risk zones	The higher the share of industrial/commercial land use in high risk areas, the higher the (potential) economic losses (due to direct and indirect impact, i.e. inaccessibility for a period of time)	GMES Urban Atlas http://www.eea.europa.eu/data-and-maps/data/urban-atlas	GMES Urban Atlas database provides reliable, inter-comparable, high-resolution land use maps for 305 Large Urban Zones and their surroundings for the reference year 2006.	There is an alternative data source based on modeling, which provides future scenarios (JRC). However, the resolution and differentiation of land uses remain issues which require further work/cooperation with JRC. Current proposal excludes interaction with vegetation and topographic features.
	Percentage of transport infrastructure in high risk zones	The higher the percentage, the higher the direct and indirect impacts (increased difficulty to access the exposed area, isolation of other areas, damage to	GISCO (http://epp.eurostat.ec.europa.eu/portal/page/portal/gisco_Geographical_information_maps/geodata/reference)	This is the reference data for transport infrastructure in Europe provided by Eurostat.	

		infrastructure)			
Response capacity	Accessibility of peri-urban areas	Peri-urban areas are the most vulnerable to fires. Accessibility shows the ability of certain area to respond in case of a fire (e.g. access to services, possibility of evacuation).	GISCO (http://epp.eurostat.ec.europa.eu/portal/page/portal/gisco_Geographical_information_maps/geodata/reference)	This is the reference data for transport infrastructure in Europe provided by Eurostat.	

8 Interaction of climatic hazards

8.1 Introduction

In chapters 4-7 indicators related to different climatic hazards have been presented independently. In chapter 3 generic indicators for response capacity were discussed, with a focus on the socio-economic domain. Those generic indicators are relevant for different climatic hazards simultaneously. In this chapter we will further discuss the consequences of interaction between climatic hazards. One of the issues is the fact that also certain exposure and sensitivity indicators are linked to more than one climate hazard (e.g. soil sealing affects both heat and floods exposure, the share of low-income population relates to sensitivity to most hazards) . The compounded effects can lead to new domains. A new domain is entered when the system has not recovered from the first disturbance before a second perturbation occurs, leading the system to a new condition. Under climate change, these compounded effects may be unprecedented and unpredictable. In addition, some hazards are strongly linked, like heat waves and forest fires, resulting in a multiplying effect.

As with the generic indicators for response capacity, we saw in the former chapters sensitivity indicators that appear in more than one hazard. Other indicators had different messages in a different context. The complexity arising from these multiple relations between indicators and hazards is discussed in this chapter.

In order to approach this complexity we focus on three aspects:

- Areas/cities with high sensitivity to more than one hazard
- Recurrent indicators (appearing in more than one hazard)
- Indicators with different messages in a different context

8.2 Cities and areas in cities with high sensitivity to more than one hazard

In previous chapters, different hazards have been analysed independently. However, at least three of these hazards are strongly linked: heat, droughts and forest fires. In general, they all have relations with less precipitation and higher temperatures in summer. However, the resulting vulnerability assessment would require a more complex analysis of the exposure factors in order to identify under which circumstances each hazard would occur and if a related probability can be established for the future. A likely situation is that a city may be exposed to different hazards successively. Then, the impacts may accumulate over time resulting in an increased vulnerability. An analysis of the synergy, trade-offs and other interactions between the impact of different hazards is needed to understand the combined effects.

The current framework provides a starting point to deal with the combined effects of different hazards. At this stage, where priority indicators need to be consolidated, it is too premature to implement such analysis. However, it needs to be developed in a second stage, since it adds another dimension that probably will require the reinforcement of the responses – or even the need of a different kind of response. Therefore, a simple and pragmatic approach is presented in this document. Since the proposal is very simple, it could be tested once the headline indicators are developed, in order to have a first glimpse on the soundness of the results. Ideally, the results should then also be checked against local experts (e.g., via EIONET) in order to have an expert judgement, in addition to the theoretical scientific soundness.

The indicators provided in previous sections will allow to identify which cities and areas are more vulnerable than others to each particular hazard. Therefore it is relevant to identify cities that are highly vulnerable to more than one hazard. The analysis can be developed for each dimension: exposure, sensitivity and response.

Since the current approach is based on individual indicators, and there is more than one indicator per dimension and hazard, the following scoring system is proposed:

- Rank cities according to the degree of vulnerability for each individual indicator. Classes can be defined by quartiles.
- For each hazard and dimension extract the average of rankings from individual indicators.
- Group cities according to the number of hazards for which the ranking results in high vulnerability.

As can be seen, the result will be highly dependent on which indicators are used (and to a lesser extent the number of indicators). However, this is unavoidable when combining several indicators or deriving composite indexes (OECD, 2009). Therefore the choices of headline indicators presented in the previous chapters are very important.

As mentioned before, interaction between indicators, either multiplying the effects or weakening the effects, is not yet in this quick scan of multiple vulnerabilities. Nevertheless, it gives a first impression and an indication of cities that may adaptation measures most urgently.

8.3 Indicators that appear in more than one hazard

Looking at the different hazards, it is clear that some indicators appear recurrently. Chapter 3 already addresses the issue of general response indicators from the socio-economic domain, which are relevant for all hazards and provide the generic capacities to cope with the vulnerability of the city. In this section we will focus on the other dimensions: exposure, sensitivity and other specific response indicators.

Not surprisingly exposure indicators are the most specific ones: each indicator only appears in one single hazard. It is logical since these indicators characterise each climatic hazard, which has its own specific components. Consequently, most of the indicators that appear in more than one climatic hazard correspond to sensitivity and, to a lesser extent, specific response (table 8.1).

The analysis of recurrent indicators can provide a deeper insight on those components of the system that have a greater influence in the complete cycle of exposure, sensitivity, responses and feedbacks. reflects that there are some elements that integrate to a certain extent critical components of the system. In particular, from table 8.1, it is apparent that the share of urban green spaces is the most repeated one. This is because the green component of the city delineates areas with a functioning closer to natural ecosystems. Consequently its composition, size and distribution pattern within (and around) the city has influence on the water cycle (floods, droughts), flux of gases, biodiversity and air circulation, among others. Many of those functions are linked to the ecosystem services and multifunctionality approach which provides useful instruments for city planning. Indeed, looking at city planning from the multifunctional perspective ensures appropriate identification of synergies between different components. In practical terms it means that urban green spaces could be planned taking into account air quality, noise attenuation, leisure, but also vulnerability to climate change. Therefore it is advised to relate this indicator not exclusively with climate change adaptation, but to create synergy with other sectors in developments on a Green Infrastructure strategy. Finally, the indicator has its specificities depending on the climate hazard, which is described in next section.

Table 8.1. Examples of indicators that are relevant for more than one hazard

Indicator	**Heat waves**	**Floods**	**Water scarcity**	**Forest fires**
Soil sealing	•	•		
Share of urban green space	•	•	•	•
Percentage of residential area in high risk zone		•		•
Percentage of commercial are in high risk zone		•		•
Percentage of sensitive population	•		•	
Percentage of infrastructure in high risk zone		•		•
Population in high risk area		•		•
Expenditure devoted to risk prevention		•		•

Another indicator related to several hazards is soil sealing. Soil sealing could be considered as the reverse of green infrastructure in terms of land cover (simplified view built-up/non built-up) and associated properties. Moreover, soil sealing is a good indicator of urban sprawl, which is an important driver of some hazards (e.g. floods).For heat, population density is used for correction of the UHI rather than soil sealing.

Another group of indicators that appear in more than one hazard relate to floods and forest fires. These indicators have in common the physical disruption of the city. Consequently the sensitivity of economic assets will be similar in concept although spatially segregated in most cases.

This crosscheck of recurrent indicators also makes the different nature of water scarcity and droughts apparent, compared to other climatic hazards discussed in this paper. Indeed, water scarcity, and to a lesser extent drought, are less dependent on the biophysical structure of the city and more related to the regional context (climate, water availability) and technology (water infrastructure).

8.4 Indicators with different messages in a different context

From chapter 2, it is clear that it is difficult to derive a coherent and pragmatic framework of urban vulnerability indicators given the inherent complexity, interaction of multiple factors and feedbacks. Therefore, when developing such framework, from time to time one faces the question of the right position of a certain indicator, either in exposure, sensitivity or response. Moreover, it also happens that an indicator that appears in more than one hazard can be allocated to a different dimension of vulnerability. This reflects that the dividing lines between exposure, sensitivity and response are not always strict.

The sometimes fuzzy line between sensitivity and response, the identification of recurrent indicators and the role of indicators representing key components of a system, all make it logical that under different threats/contexts the same indicator provides different (complementary) messages.

To face this challenge, we have further analysed the indicators that presented potential conflicts considering:

- Review of the definitions in light of the sensitivity-response dilemma
- Better identification and description of the context;.

Solving the Sensitivity – Response dilemma

One of the first conflicts identified is related to a group of indicators which are labelled as both sensitivity and response capacity (e.g., green space, poor people, water efficiency/diversity). According to the definition adopted in this project sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate related stimuli. Response capacity is conducive to actual adaptive responses. Response indicators are differentiated between awareness, ability and action. The previously mentioned indicators where conflicts arise when labelling them as sensitivity or response indicators, could fit either under ability or action (not awareness). However, when considering the 'action' perspective, if we only measure the current status of the indicator, it does not necessarily reflect the real action taken or planned. For example, urban green spaces could be the result of good planning, or just the areas left after (uncontrolled) urban development. It is clear that the idea of planned or intended action is not necessarily reflected by the indicator when we only observe the status at a certain point on the time line. Consequently, the last dimension for confusion would be the 'ability' perspective. According to the definition provided in chapter 3, ability refers mainly to physical infrastructure and technological development as enabling factors for adaptation. Here the differences are more subtle. Again the current status does not necessarily provide an indication on the ability. Taking the example of urban green spaces, a better indicator of ability would be the potential to extend or increase the accessibility of existing urban green spaces. In that sense, the idea of intended, planned or potential action is always present. As a conclusion, the following rules are proposed:

- The ***static dimension*** of the indicator could represent the ***sensitivity***. When the indicator reflects the situation at one point in time, it reflects the current status, and, accordingly, the sensitivity to a particular climatic hazard.
- ***Changes*** in these indicators over time, or city plans to change this (if known), can be regarded as ***response*** indicators.

Indicators in context: Green infrastructure

Green infrastructure in urban areas is relevant for both mitigation and adaptation. And it is also relevant for the vulnerability of cities for different climate impacts. The message of green infrastructure differs with the context. A large share of urban green spaces decreases the sensitivity of cities, both for heat waves and for flooding (chapters 4 and 5). When taking measures to increase the response capacity of cities to climate change, an increase of the green spaces can serve two targets: making the city less vulnerable to flooding as well as less vulnerable to heat, making it very much a no-regret measure. The effectiveness of the measures can be increased when taking spatial variation of the climate hazards into account (e.g. flooding related to depressions and lower lying areas).

Green infrastructure is relevant for climate change mitigation, because of its function for carbon sequestration. The cooling effect of green infrastructure (including green roofs, green walls, trees, etc.) indirectly also decreases the demand for artificial cooling by air conditioners and thus decreases the dependency on external (fossil) energy and the production of heat. The magnitude of this mitigating effect is not very well known.

At the same time the green spaces, and the biodiversity that depends on it, can be sensitive themselves. An urban environment is generally warmer, water supply for vegetation is less robust, and sometimes dependent on human provision of water. Trees, animals and other organisms are vulnerable, especially for water scarcity and forest fires. The extent to which they are vulnerable depends on the plant and animal species and the management of the green spaces (e.g. build-up of fuel wood).

Many of these context-related issues are related to spatial variation within the cities. The relevant scale is not necessarily identical to the whole city.

9 Recommendations and future work

In 2012, the EEA report 'Urban adaptation to climate change in Europe' was published which included a number of urban vulnerability indicators for Europe as they happened to be available at that time. These indicators provided an interesting but incomplete picture of the vulnerability of European cities to climate change. The current paper explores options for a more comprehensive set of indicators, which would capture the exposure of cities to climate change, their sensitivity and their level of preparedness c.q. adaptive capacity, for four climatic hazards: heat; floods; water scarcity and droughts; and forest fires. The indicators discussed in this paper vary in terms of the relevance for climate change adaptation and the feasibility of quantifying them for a sufficient number of European cities. We recommend four activities for further work:

1. ***Implement the recommendations of this paper and test the indicators***. The paper recommends to further develop a number of urban vulnerability indicators, based on the current understanding of the feasibility to implement them at a European scale. Future work should focus on actually implementing these indicators, visualize them, discuss them with staff of the EEA and the European Commission and other users of this information (do the indicators provide a message relevant for European and national climate adaptation policy?), and finally, prioritize them for inclusion in future EEA products. Prioritization is considered necessary, since for some climate risks and for some elements of the exposure-sensitivity-adaptive capacity chain more than one indicator has been proposed, while for regular maintenance in the EEA system the number of indicators can only be limited. Testing does not only involve the selection of indicators, but also their definition and the way they are calculated, e.g. in terms or urban delineation, which may be different for different hazards (e.g. involving the peri-urban areas for forest fire risk).

2. ***Fill priority gaps***. From the discussions in this paper we derive a number of gaps that should be addressed:
   - *Further analyse the relevance and feasibility of socio-economic indicators*, which often have relevance for more than one climatic hazard, but often have only a partial and often context specific relationship with vulnerability to climate change. Some indicators may give multiple messages, e.g. related to both adaptive capacity and sensitivity. Actual cases demonstrating (differences in) response capacity would be helpful and could be identified in the context of Climate-ADAPT.
   - *Develop indicators for the dependency of cities on external services*, or critical infrastructure, like energy, water, communication and transportation.
   - *Evaluate the possibilities for including forward looking information*. The current paper focuses on urban indicators describing the current vulnerability, while for EEA assessments like the SOER and periodic impact assessment reports also forward information (scenarios) is relevant and possibly available for some of the indicators.
   - *Hydrological, morphological and human drivers of exposure.* For floods and heat, in addition to climatic factors, also hydrological and morphological factors play a role, respectively. It is as yet unclear if these drivers can be quantified at the European level.

3. ***Compare the urban vulnerability indicators with other indicator sets***, notably the JRC work. The indicators proposed in this paper have not explicitly taken into account the development of urban indicators by other organizations. This includes JRC's European Database of Vulnerabilities (EVDAB), which is expected to also include composite indices. This paper also did not include

indicators with only national, regional or local coverage, like the ones included in the 2010 ETC/ACC Technical Paper “Urban Regions: Vulnerabilities, Vulnerability Assessments by Indicators and Adaptation Options for Climate Change Impacts” (Schauser et al., 2010). Comparing the proposed indicators with these other sets may lead to improvement of the system, and would in fact serve a quality control purpose.

4. ***Integrate the indicator information into the EEA indicator system and Climate-ADAPT***. After the implementation and testing of the proposed indicators, a selection can be recommended for further development and inclusion in the EEA system of environmental indicators, possibly including the Core Set of Indicators. The indicators can then also be included and highlighted on the urban pages of Climate-ADAPT. Collaboration with main data providers like EUROSTAT (Urban Audit), GMES/EEA (Urban Atlas, soil sealing) and EEA work on spatial data, such as ECRONS, Eye-on-Earth and work on land use and population, should be consolidated.

10 References

Adger, W.N. (1999) Social vulnerability to climate change and extremes in coastal Vietnam. World Development 27, 249-269.

Adger, W.N., N. Brooks, G. Bentham, M. Agnew and S. Eriksen (2004). New indicators of vulnerability and adaptive capacity. Tyndall centre Technical report 7 Tyndall Centre for Climate Change Research, Norwich.

Adger, W.N., S. Dessai, M. Goulden, M. Hulme, I. Lorenzoni, D.R. Nelson, L.O. Naess, J. Wolf and A. Wreford (2009). Are there social limits to adaptation to climate change? Climatic Change 93, 335-54.

Barredo, J. I. (2009). Normalised flood losses in Europe: 1970-2006. Natural Hazards Earth System Sciences, 9, 97-104.

Bassi, S., Kettunen, M., & Cavalieri, S. (2008) Forest fires: causes and contributing factors in

Europe. IP/A/ENVI/ST/2007–15 PE 401.003. Policy Department, Economic and

Scientific Policy, European Parliament, Brussels, Belgium.

Blazejczyk, K., Epstein, Y., Jendritzky, G., Staiger, H., and Tinz, B. (2012). Comparison of UTCI to selected thermal indices. Int. J. Biometeorol. 56:515–535.

Bouwer, L. M. (2011). Have disaster losses increased due to anthropogenic climate change? Bulletin of the American Meteorological Society, 92(1), 39-46.

Carson C, Hajat S, Armstrong B, et al. (2006). Declining vulnerability to temperature-related mortality in London over the 20th century. Am. J. Epidemiol. 164:77e84.

CDC (2006). Heat-Related Deaths—United States, 1999–2003. MMWR 55:796–798.

Chen, X.L., Zhao, H.M., LI, P.X., Yin, Z.Y. (2006). Remote sensing image based analysis of the relationship between urban heat island and land use/cover changes – Remote Sensing of Environment 104: 133-146.

Christopherson, S., J. Michie and P. Tyler (2010). Regional resilience: theoretical and empirical perspectives. Cambridge Journal of Regions, Economy and Society 3, 3-10.

Ciscar, J.C., Iglesias, A., Feyen, L., Szabo, L., Van Regemorter, D., Amelung, B., Nicholls, R., Watkiss, P., Christensen, O.B., Dankers, R., Garrote, L., Goodess, C.M., Hunt, A., Moreno, A., Richards, J., Soria, A. (2011) Physical and economic consequences of climate change in Europe. Proceedings of the National Academy of Sciences 108, 1678-2683.Bassi, S., Kettunen, M., Kampa, E., Cavalieri, S. (2008). FOREST FIRES: causes and contributing factors in Europe. Study IP/A/ENVI/ST/2007-15 . European Parliament, Brussels.

CLIMATE ADAPT http://climate-adapt.eea.europa.eu/

Dousset, B., Gourmelon, F., Laaidi, K., Zeghnoun, A., Giraudet, E., Bretin, P., Mauri, E. and Vandentorren, S. (2011). Satellite monitoring of summer heat waves in the Paris metropolitan area. Int. J. Clim. 31:313–323.

Dracup, John A., Kil Seong Lee, a Edwin G. Paulson Jr. (1980). „On the definition of droughts“. Water Resources Research 16 (2): 297–302. doi:10.1029/WR016i002p00297

ESPON (2011). ESPON Climate - Climate Change and Territorial Effects on Regions and Local Economies. ESPON Luxemburg.

European Environment Agency (2001). Sustainable water use in Europe Part 2: Demand management. Copenhagen.

European Environment Agency (2008). Impacts of Europe’s changing climate: 2008 indicator-based assessment; joint EEA-JRC-WHO report. Luxembourg: Office for Official Publ. of the European Communities.

European Environment Agency (2012a). Urban adaptation to climate change in Europe - Challenges and opportunities for cities together with supportive national and European policies. EEA Report No 2/2012

European Environment Agency (2012b). Climate change, impacts and vulnerability in Europe - An indicator-based report, EEA Report No 12/2012

European Environment Agency (2012c). Towards efficient use of water resources in Europe. EEA Report No 1/2012

EYEONEARTH http://www.eyeonearth.org/en-us/Pages/Home.aspx

Fanger, P.O. (1970). Thermal Comfort. Analysis and Application in Environment Engineering. Danish Technical Press, Copenhagen.

Fekete, A. (2011) Common Criteria for the Assessment of Critical Infrastructures. International Journal of Disaster Risk Science. 2(1), 15-24.

Fischer, E.M. and Schär, C. (2010). Consistent geographical patterns of changes in high-impact European heat waves. Nature Geoscience, Published online: 16 May 2010, DOI: 10.1038/NGEO866, 1 – 6

Fuchs, S., Kuhlicke, C., Meyer, V. (2011) Editorial for the special issue: vulnerability to natural hazards - the challenge of integration. Natural Hazards 58, 609-619.

Füssel, H.-M. (2007) Vulnerability: A generally applicable conceptual framework for climate change research. Global Environmental Change 17, 155-67.

Gabor and Jombach (2009). The relation between the biological activity and the land surface temperature in Budapest. App. Ecology and Environm. Research 7:241-251.

Graham, S., Marvin, S. (2001) Splintering urbanism. Networked infrastructures, technological mobilities and the urban condition. Routledge, London/New York.

Green, C., Viavattene, C., Thompson, P., (2011) ConHaz Report: guidance for assessing flood losses. Middlesex University

Greiving, S. et al.,2011. Climate change and territorial effects on regions and local economies. Final report. Applied research 2013/1/4., ESPON & IRPUD TU Dortmund, Dortmund.

Grize, L., Huss, A., Thommen, O., Schindler, C. and Braun-Fahrländer, C., (2005). Heat wave 2003 and mortality in Switzerland. Swiss Medical Weekly 135:200–205.

Guha-Sapir, Debby, Femke Vos, Regina Below, a Sylvain Ponserre (2012). „Annual Disaster Statistical Review 2011 The numbers and trends“. CRED.

Heim, R. (2002). „A Review of Twentieth-Century Drought Indices Used in the United States“ 83 (8): 1149–1165.

Hildén, M., Dankers, R., Kjeldsen, T., Hannaford, J., Kuhlicke, C., Kuusisto, E., Makropoulos, C., te Linde, A., Ludwig, F., Luther, J., Wolters, H., (2012) Floods: vulnerability, risks and management - a joint report of ETC CCA and ICM, in: European Environment Agency: European Topic Centre on Climate Change - Impacts, V.a.A. (Ed.), ETC CCA / ICM Technical Papers.

Hinkel, J., (2011). “Indicators of vulnerability and adaptive capacity”: towards a clarification of the science policy interface. Global Environmental Change, 21, 198–208.

Hinkel, J., (2012). Climate impacts: from numbers to stories, in K. Hasselmann, C. Jaeger, D. Mangalagiu, G. Leipold and E. Henning, (Eds.), Action for Climate: Beyond the Zero-Sum Game, Earthscan, London, forthcoming (cited in PROVIA Guidance).

Höppe, P. (1999). The physiological equivalent temperature—a universal index for the biometeorological assessment of the thermal environment. Int. J. Biometeorol. 43:71–75.

IPCC, 2001. Climate Change 2001: Impacts, Adaptation, and Vu l n e r a b i l i t y, Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change.J.J. McCarthy, O.F. Canziani, N.A. Leary, D.J. Dokken and K.S. White, Eds., Cambridge University Press., Cambridge, 1032 pp.

IPCC (2007). Climate Change 2007: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. (Parry, M.L.; Canziani, O.F.; Palutikof, J.P.; van der Linden, P.J.; and Hanson, C.E., eds). Cambridge University Press, ISBN 978-0-521-88010-7 (pb: 978-0-521-70597-4).

IPCC (2012). Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK, and New York, NY, USA, 582 pp.

Johnston, F. H., Henderson, S. B., Chen, Y., Randerson, J. T., Marlier, M., DeFries, R. S., Kinney, P., Bowman, D. M. J. S., Brauer, M. (2012). Estimated Global Mortality Attributable to Smoke from Landscape Fires, Environmental Health Perspectives, 120(5), p.695–701.

Juhola, S. and L. Westerhoff (2011). Challenges of adaptation to climate change across multiple scales: a case study of network governance cin two European countries. Environmental cScience & Policy 14(3): 239-247

Juhola, S., L. Peltonen and P. Niemi (2012). The ability of Nordic countries to adapt to climate change: assessing adaptive capacity at the regional level. Local Environment 17, 717-34.

Jusuf, S.K.l., Wong, N.H., Hagen, E., Anggoro, R., Hong, Y. (2007). The influence of land use on the urban heat island in Singapore. Habitat International 31: 232-242.

Kazmierczak, A. and Carter, J. (2010) Adaptation to climate change using green and blue infrastructure. A database of case studies, Manchester University

Kern, K. and G. Alber (2008). Governing Climate Change in Cities: Modes of Urban Climate Governance in Multi-level Systems. OECD International Conference: Competitive Cities and Climate Change, 9-10 October 2008- Milan, Italy.

Kern, K. and H. Bulkeley (2009). Cities, Europeanization and Multi-level Governance: Governing Climate Change through Transnational Municipal Networks. JCMS: Journal of Common Market Studies 47, 309-32.

Keskitalo, E. C. H. (2011). How Can Forest Management Adapt to Climate Change? Possibilities in Different Forestry Systems, Forests, 2(1), p.415–430.

Keskitalo, E.C.H. (2010). Conclusion: The Development of Adaptive Capacity and Adaptation Meaures in European Countries. In E.C.H. Keskitalo (ed.), Developing Adaptation Policy and Practice in Europe: Multi-level Governance of Climate Change, Springer, Dordrecht, 339-66.

Klinenberg E. (2003). Review of heat wave: autopsy of disaster in Chicago. N. Engl. J. Med. 348:666e7.

Klok, L., Zwart, S., Verhagen, H., & Mauri, E. (2012). The surface heat island of Rotterdam and its relationship with urban surface. Resources, Conservation and Recycling. doi: 10.1016/j.resconrec.2012.01.009.

Kovats, R. S. and Hajat, S. (2008). Heat stress and public health: A critical review. Annual Review of Public Health 29:41–55.

Kubal, C., Haase, D., Meyer, V., & Scheuer, S. (2009). Integrated urban flood risk assessment: adapting a multicriteria approach to a city. Natural Hazards and Earth System Sciences, 9, 1887-1895.

Kuhlicke, C., K. Krellenberg, S. Kabisch, and Annette Steinfüher (2012). Urban Vulnerability under Conditions of Global Environmental Change. Conceptual Reflections and Empirical Case Examples of Growing and Shrinking Cities. In: Auteur: Kabisch, S. A.K. Kunath and P. Schweizer-Ries , 2012. Vulnerability, Risks, and Complexity: Impacts of Global Change on Human Habitats. Series on Advances in People-Environment Studies. Hogrefe Publishing ISBN: 9781616764357

Kuhlicke, C., Scolobig, A., Tapsell, S., Steinführer, A., & De Marchi, B. (2011). Contextualising social vulnerability: findings from case studies across Europe. Natural Hazards, 58(2), 789-810.

Lehner, B., P. Döll, J. Alcamo, T. Henrichs, and F. Kaspar (2006). „Estimating the Impact of Global Change on Flood and Drought Risks in Europe: A Continental, Integrated Analysis“. Climatic Change 75 (3) (duben): 273–299. doi:10.1007/s10584-006-6338-4.

Lenz, S. (2009) Vulnerabilität kritischer Infrastrukturen. Herausgegeben durch das Bundesamt für Bevölkerungsschutz und KatastrophenhilfeLequeux, Q., Ciavola, P., (2012) ConHaz-Report: methods for estimating the costs of coastal hazards. UniFe.

Lindner, M., Garcia-Gonzalo, J., Kolström, M., Green, T., Reguera, R., Maroschek, M., Seidl, R., Lexer, M. J., Netherer, S., Schopf, A., Kremer, A., Delzon, S., Barbati, A., Marchetti, M. Corona, P., (2008). Impacts of Climate Change on European Forests and Options for Adaptation. Report to the European Commission Directorate-General for Agriculture and Rural Development, European Forest Institute, Joensuu, Finland

Lundy, L. and R. Wade (2011). Integrating sciences to sustain urban ecosystem services. Progress in Physical Geography October 2011 35: 653-669, doi:10.1177/0309133311422464 Malone, E.L. and N.L. Engle (2011) Evaluating regional vulnerability to climate change: purposes and methods. Wiley Interdisciplinary Reviews: Climate Change 2, 462-74.

Marzano, R., Camia, A., Bovio, G. (2008). Wildland-Urban Interface Analyses for Fire Management Planning. In: Proceedings of the Second International Symposium on Fire Economics, Planning, and Policy: A Global View, Gen. Tech. Rep., U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA.

McKee, T.B., N.J. Doesken, and J. Kleist (1993). „The relationship of drought frequency and duration to time scales. In: Preprints, Eighth Conference on Applied Climatology (Anaheim, California), 179-184.“

Moss, T. (2008) ‘Cold spots’ of Urban Infrastructure: ‘Shrinking’ Processes in Eastern Germany and the Modern Infrastructural Ideal. In: International Journal of Urban and Regional Research 32/2, 436-451

Naughton, M.P. , Henderson, A. Mirabelli, M.C., Kaiser, R. Wilhelm, J.L. Kieszak, S.M., Rubin, C.H., McGeehin, M.A. (2002). Heat-Related Mortality During a 1999 Heat Wave in Chicago. Am J. Prev. Med. 22(4): 221-227.

Naughton, M.P., Henderson, A., Mirabelli, M.C., Kaiser, R., Wilhelm, J.L., Kieszak, S.M., Rubin, C.H. and McGeehin, M.A. (2002). Heat-related mortality during a 1999 heat wave in Chicago. American Journal of Preventive Medicine 22: 221-227.

Oke, T.R. (1998). An Algorithmic Scheme to Estimate Hourly Heat Island Magnitude. Preprints of the AMS Second Urban Environment Symposium, 80-83.

Omann, I., J. Jäger, S. Grünberger and J. Wesely (2010). Report on the development of the conceptual framework for the vulnerability assessment. CLIMSAVE FP7 project

Reid, C.E., M. S. O’Neill, C.J. Gronlund, S.J. Brines, D.G. Brown, A.V. Diez-Roux, and J. Schwartz (2009). Mapping Community Determinants of Heat Vulnerability. Environ Health Perspect. 2009 November; 117(11): 1730–1736

Ren, C., Ng, E., Katzschner, L. (2010). Urban climatic map studies: a review. International Journal of Climatology, doi:10.1002/joc.2237.

Ren, C., T. Spit, S. Lenzholzer, H. L. S. Yim, B. Heusinkveld, B. van Hove, L. Chen, S. Kupski, R. Burghardt and L. Katzschner (2012). Urban Climate Map System for Dutch spatial planning. International Journal of Applied Earth Observation and Geoinformation 18, 207-221.

Ribeiro, M.M., C. Losenno, T. Dworak, E. Massey, R. Swart, M. Benzie and C. Laaser (2009) Design of guidelines for the elaboration of Regional Climate Change Adaptations Strategies. Tender DG ENV. G.1/ETU/2008/0093r. Ecologic, Berlin.

Robinson, L.W. and F. Berkes (2011). Multi-level participation for building adaptive capacity: Formal agency-community interactions in northern Kenya. Global Environmental Change 21, 1185-94.

San Miguel-Ayanz, J., Carlson, J.D., Alexander, M., Tolhurst, K., Morgan, G., Sneeuwjagt, R. and Dudley, M. (2003). Current Methods to Assess Fire Danger Potential. In: Wildland Fire Danger Estimation and Mapping. The Role of Remote Sensing Data (E. Chuvieco, Ed.). World Scientific Publishing, Singapore, pp. 21-61.

Sassen, S. (1991) The global city: New York, London, Tokyo. Princeton University Press, Princeton.

Schanze J.; Hutter, G.; Penning-Rowsell, E.; Nachtnebel, H.-P.; Meyer. V.; Werritty, A.; Harries T.; Holzmann, H.; Jessel, B.; Koeniger, P.; Kuhlicke, C.; Neuhold, C.; Olfert, A.; Parker D.; Schildt, A. (2008), Systematisation, Evaluation and Context Conditions of Structural and Non-structural Measures for Flood Risk Reduction, FLOOD-ERA Joint Report, published by ERA-NET CRUE, London, S. 203. http://www.crue-eranet.net/partner_area/documents/FLOOD-ERA_Joint_Report_FINAL_web.pdf

Schär, C., Vidale, P. L., Lüthi, D., Frei, C., Häberli, C., Liniger, M. A. and Appenzeller, C. (2004). The role of increasing temperature variability in European summer heatwaves. Nature, 427:332–336

Schauser, I., S. Otto, S. Schneiderbauer, A. Harvey, N. Hodgson, H. Robrecht, D. Morchain, J. Schrander, M. Khovanskaia, G. Celikyilmaz-Aydemir, A. Prutsch, and S. McCallum (2010). Urban Regions: Vulnerabilities, Vulnerability Assessments by Indicators and Adaptation Options for Climate Change Impacts. ETC/ACC Technical Paper 2010/12.

Schröter, D. et al. (2004). ATEAM final report. Section 5 and 6 and Annex 1 to 6. Detailed report, related to overall project duration. Reporting period: 01.01.2001–30.06.2004., Potsdam Institute for Climate Impact Research, Potsdam.

Semenza, J.C., McCullough, J., Flanders, D.W., McGeehin, M.A., Lumpkin, J.R. (1999). Excess hospital admissions during the 1995 heat wave in Chicago. Am. J. Prev. Med. 16:269–277.

Semenza, J.C., Rubin, H.C., Falter, K.H., Selanikio, J.D., Flanders, D.W., Wilhelm, J.L. (1996). Risk factors for heat-related mortality during the July 1995 heat wave in Chicago. N. Engl. J. Med. 335:84–90.

Smit, B. and J. Wandel (2006). Adaptation, adaptive capacity and vulnerability. Global Environmental Change 16, 282-292.

Smoyer K.E. (1998a). A comparative analysis of heat waves and associated mortality in St. Louis, Missouri 1980 and 1995. Int. J. Biomet. 42:44–50.

Smoyer K.E. (1998b). Putting risk in its place: methodological considerations for investigating extreme event health risks. Social Science and Medicine 47:1809–1824.

Steadman R., (1971). Indices of wind chill of clothed persons. J. Appl. Meteorol. 10:674–683.

Steadman R.G., (1979). The assessment of sultriness. Part I: A temperature-humidity index based on human physiology and clothing science. J. Appl. Meteorol. 18:861–873.

Steeneveld, G.J., Koopmans S., , Heusinkveld, B.G., van Hove, L.W.A. and Holtslag, A.A.M. (2011). Quantifyingeffects and outdoor human comfort in relation to urban morphology by exploring observations from hobby-meteorologists in the Netherlands. J. Geophys. Res.116, D20129, 14pp., doi: 10.1029/2011 JDO15988.

Swart, R., R. Biesbroek, S. Binnerup, T.R. Carter, C. Cowan, T. Henrichs, S. Loquen, H. Mela, M. Morecroft, M. Reese and D. Rey (2009). Europe Adapts to Climate Change. Comparing National Adaptation Strategies. Partnership for European Environmental Research (PEER), Helsinki.

Tanner, T., T. Mitchell, E. Polack and B. Guenther (2009) Urban Governance for Adaptation: Assessing Climate Change Resilience in Ten Asian Cities. IDS Working Papers 2009, 01-47.

Tapsell, S; McCarthy, S; Faulkner, H & Alexander, M (2010): Social Vulnerability and Natural Hazards. CapHaz-Net WP4 Report, Flood Hazard Research Centre – FHRC, Middlesex University, London (available at: http://caphaz-net.org/outcomes-results/CapHaz-Net_WP4_Social-Vulnerability.pdf).

Thom E.C. (1959). The discomfort Index. Weatherwise 12:57–60.

Van Wagner, C.E. (1987). Development and structure of the Canadian Forest Fire Weather Index System. Canadian Forestry Service, Ottawa, Ontario. Forestry Technical Report 35. 37 p.

Whitman S., Good G., Donoghue E.R., Benbow, N., Shou, W., and Mou, S. (1997). Mortality in Chicago attributed to the July 1995 heat wave. Am. J. Public Health 87:1515e18

WHO (2004). Heat waves: risks and responses. Health and Global environmental change series, no 2. 124 pp.

WHO (2011). Tools for the monitoring of Parma Conference commitments. Report of a meeting Bonn, Germany, 25-26 November 2010. WHO Regional Office for Europe, Bonn

Annex 1: Urban delineations

As described in more detail in the fact sheets in Annex 4 the two indicators “Share of urban green spaces” and “Distribution of urban green spaces” (approximated by the edge lengths and density between “green” and non-green (i.e. “red”) areas) aim at supporting the assessment of heat-related impacts on urban areas, their direct surroundings and the respective populations.

Heat waves have been the most prominent hazard causing human fatalities over the past decades (EEA, 2010a). The impact of heat waves is particularly strong in cities and towns. The so-called ‘Urban Heat Island’ (UHI) describes the increased temperature of the urban air compared to its rural surroundings. It is a well-known and documented fact that the land surface temperature and the share of vegetation are related to each other (Chen et al., 2006; Jusuf et al., 2007; Gabor and Jombach, 2009; Klok et al., 2011). The ameliorating thermal effect induced by green spaces inside the warm urban microclimate of densely populated cities can improve the thermal comfort, as well as the overall health and living conditions of their inhabitants. The effect of green infrastructure on UHI is primarily provided by shading and evapotranspiration.

The basic decision to be taken at the beginning of the indicator production is to identify the appropriate reference units that define on the one hand “urban area” and the “urban surrounding”, and on the other hand “green” and “red” spaces within the “urban area” and the “urban surrounding”.

In general one can differentiate between 3 types of urban delineations:

- **Physical/morphological delineation**. It is assumed that land use/land cover reflects the human activity in a particular area of the territory. Then, urban areas are delineated considering the continuity/proximity of certain land use/cover classes. One objection to this type of delineation is that they are not relevant anymore to study urban sprawl, since the recent urban extensions are located far from the densely and continuously urbanized core. However, this methodology provides a consistent basis to extend the analysis beyond its boundaries by the use of buffers. Moreover, the resulting boundaries of the urban area are strongly linked to the evolution of the city: rapid growth is reflected in measurable changes in the city border.
- **Functional**. Urban areas can be characterised by their density of population. In fact, the higher density of population is encountered within cities. Following this basic principle urban areas are delineated according to population density profiles. In addition other properties or “functions” of the city can be measured and integrated into the definition of the urban area. For example trips patterns related to the daily life of citizens (working, shopping, recreation) are used to define sub-urban areas, residential, core businesses-city,...
- **Administrative**. The administrative delineation of urban areas is based on historical process related to the evolution of the administration and existing tools for planning. The most detailed information usually is provided by administrative boundaries of a city.

Two ways of delineating a city boundary are considered for the current work, (i) the administrative "core city" used as an approximation of the city in the Urban Audit15, and (ii) the morphological "Urban Morphological Zones" produced for the EEA16. While the Urban Audit core city is the administrative reference unit for many socio-economic indicators considered relevant for the report (with all the known weaknesses that administrative boundaries have when it comes to European comparisons, e.g. different scales), the urban morphological zones better reflect the physical outline of the cities.

To take advantage of both reference units (accepted and coded reference for European socio-economic indicators on the one and the better representation of the real city boundary on the other hand), both data sets have been combined by applying GIS geo-processing techniques.

The most important is the city level. To ensure that this level is directly relevant to policy makers and politicians, political boundaries were used to define the city level. In many countries these boundaries are clearly established and well-known. As a result, for most cities the boundary used in the Urban Audit corresponds to the general perception of that city. In most countries the core city corresponds to LAU2 level.17

An Urban Morphological Zone (UMZ) can be defined as "a set of urban areas laying less than 200m apart". Those urban areas are defined from land cover classes contributing to the urban tissue and function. UMZ are derived from CORINE Land Cover (CLC) by using urban core classes (residential, industrial and commercial, urban green spaces) and adding enlarged core classes in case they fulfil certain neighbourhood conditions to the core classes.18

[15] http://www.urbanaudit.org/help.aspx
[16] http://www.eea.europa.eu/data-and-maps/data/urban-morphological-zones-2000-umz2000-f1v0
[17] http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-BD-04-002/EN/KS-BD-04-002-EN.PDF
[18] http://www.eea.europa.eu/data-and-maps/data/urban-morphological-zones-2000-umz2000-f1v0/, methodology description

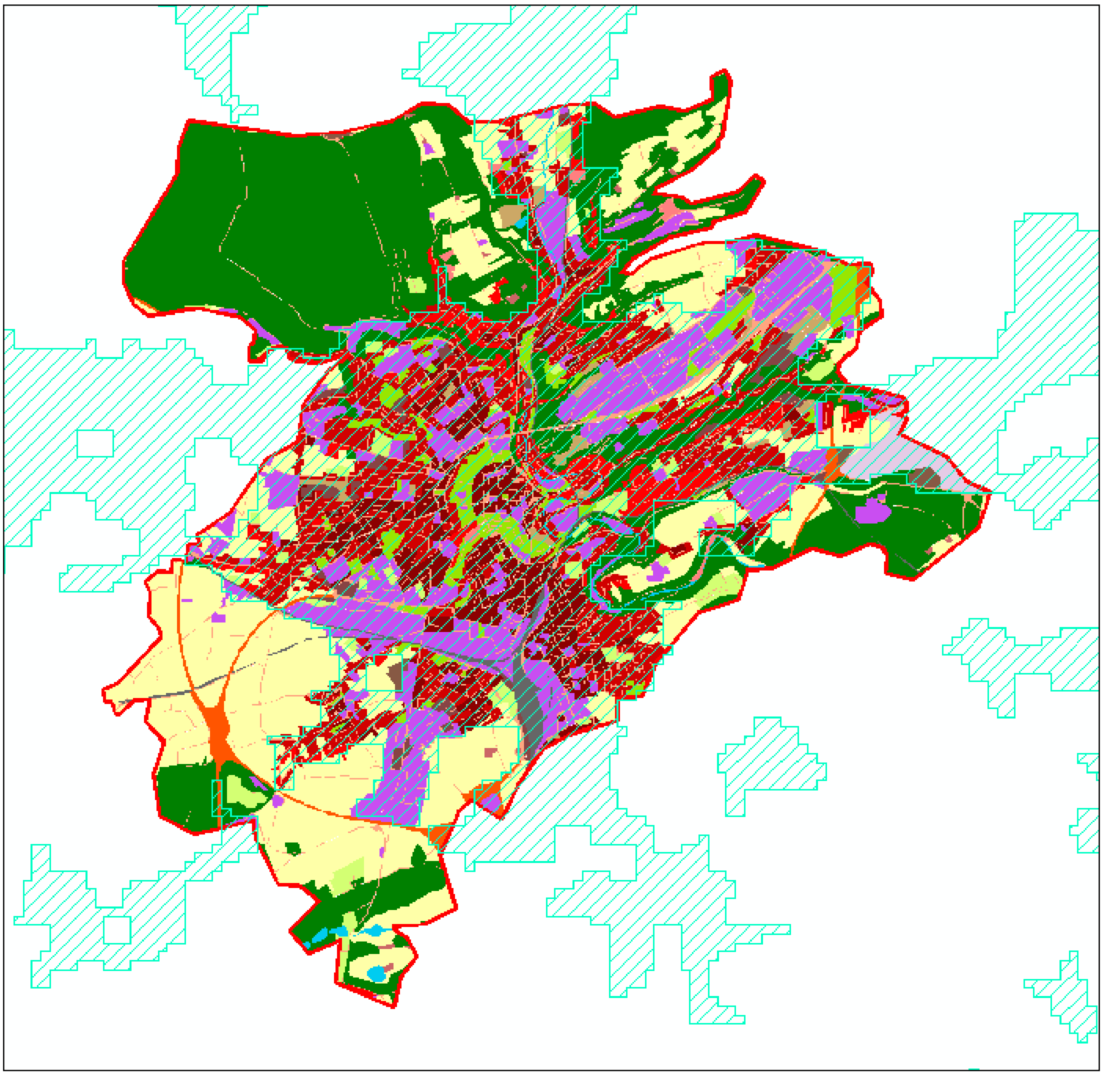


Figure A2.1: Urban Atlas map of the core city of Luxembourg, UMZ objects on top in cyan-coloured hatching

Both data sets are available as shape files. The “urban area” is defined by the Urban Morphological Zone (UMZ) inside the Urban Atlas/Audit core city (CC) (cut-off at the core city boundaries). First both data sets are overlaid, subsequently the UMZ which contain much more objects than the core city layer are clipped by the outlines of the core cities. The result is an UMZ layer that only contains those UMZ objects that are located within the core cities. UMZ objects that cross the core city boundaries are cut off along the borders. The last processing step is the creation of one UMZ per core city, so that all UMZ objects located within the core city become one object (they are not physically connected, but logically, i.e. they possess only one object ID).

Those “UMZ within the core city” objects build the basic spatial reference unit for the computation of further indicators for the spatial unit “urban area”, in particular for the extraction of the Urban Atlas information.

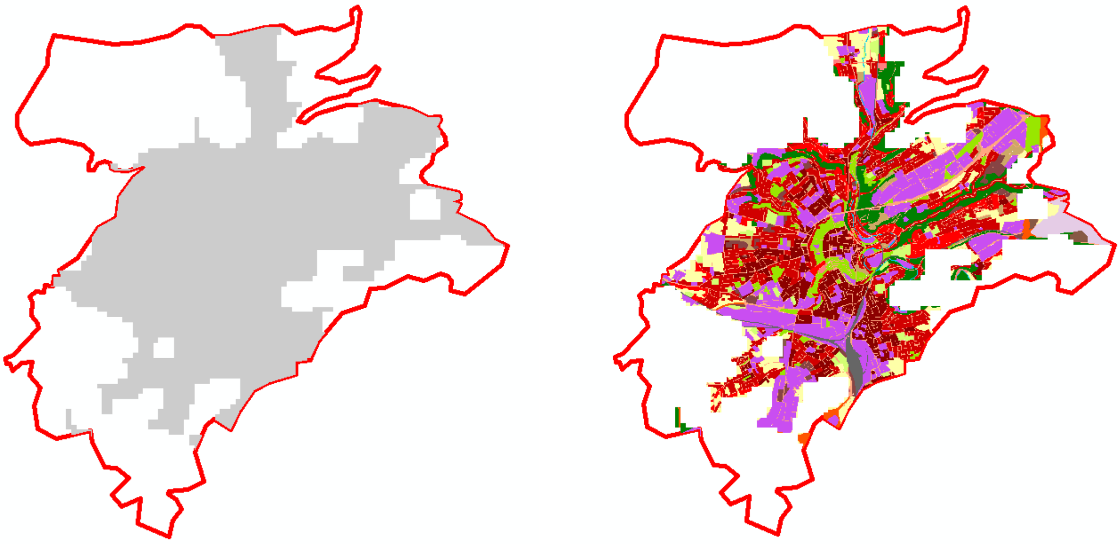
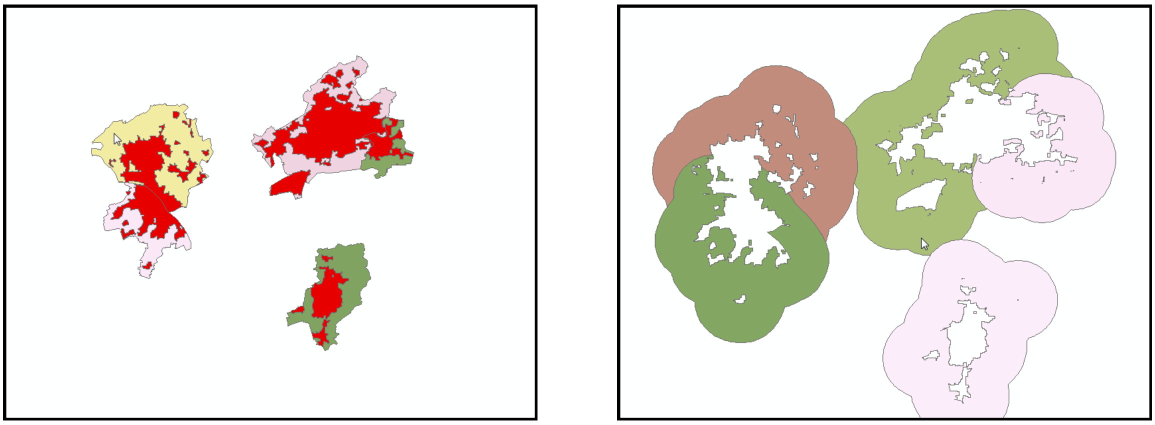


Figure A2.2: Workflow illustration; core city of Luxembourg in red on the left, containing the UMZ which are located inside the core city in grey; the resulting Urban Atlas map inside the "UMZ within core city" on the right

The "urban surrounding", that should account for the urban fringe, is represented by a buffer of 5km around the "urban area", i.e. the UMZ that is cut off at the CC boundaries, whereby the buffer is not clipped to the core city boundaries; where cities are adjacent or located in vicinity to each other overlaps of buffer areas can occur which are not removed (cf. FigureA2.3).



FigureA2.3: Illustrations of (i) UMZ within the core city (red areas within the coloured areas on the left), and (ii) buffers of the core city UMZ on the right

Thematically, the classes "green spaces" and "red spaces" are defined based on the Urban Atlas nomenclature, as outlined in Figure A2.4 below. An additional "blue spaces" class is defined since blue areas do not belong to artificial, often sealed urban classes, but do according to recent research also not provide significant cooling effects for urban areas. The land use data source is the GMES Urban Atlas data base19, which provides reliable, inter-comparable, high-resolution land use maps for

[19] http://www.eea.europa.eu/data-and-maps/data/urban-atlas

305 Large Urban Zones and their surroundings for the reference year 2006. The selection of classes contained in the urban green spaces is based on their relevance for the Urban Heat Island effect, i.e. agricultural areas and forests are included as well.

CODE	Urban Atlas classes
11100	Continuous Urban Fabric (S.L. > 80%)
11210	Discontinuous Dense Urban Fabric (S.L. : 50% - 80%)
11220	Discontinuous Medium Density Urban Fabric (S.L. : 30% - 50%)
11230	Discontinuous Low Density Urban Fabric (S.L. : 10% - 30%)
11240	Discontinuous Very Low Density Urban Fabric (S.L. < 10%)
11300	Isolated Structures
12100	Industrial, commercial, public, military and private units
12210	Fast transit roads and associated land
12220	Other roads and associated land
12230	Railways and associated land
12300	Port areas
12400	Airports
13100	Mineral extraction and dump sites
13300	Construction sites
13400	Land without current use
14100	Urban green spaces
14200	Sports and leisure facilities
20000	Agricultural areas, semi-natural areas and wetlands
30000	Forests
50000	Water bodies

Figure A2.4: Nomenclature defining the “green”, “red” and “blue” spaces

The extracted polygons are grouped to create a “green” class. Afterwards, the total area of all “green” patches is summed up and its share calculated

1. in relation to the total area of the UMZ (within the core city); and
2. in relation to the buffer of 5km around the UMZ.

For the map production the values are classified into 4 classes and presented as coloured dots on the map: green dots represent cities with a high or relatively higher share of green and blue urban areas, red and orange dots correspond to cities with a low share.

Intra-urban edges are computed within the UMZ between the red and the green spaces and summed up to result in a total edge length value per city. Afterwards, the relation of the total edge length to the reference area (UMZ or buffer) is computed to get an edge density value.

Annex 2 Outdoor thermal comfort indices

Whether or not citizens feel comfortable with the urban micro climate (outdoor) they encounter, depends on a complex interaction between physical, physiological, behavioral, and psychological factors. For the assessment of the thermal influence of the environment on the human body, the integral effects of all thermal parameters have to be taken into account. A large number of indices have been proposed to define thermal comfort. These can be grouped into direct and indirect approaches. The direct (or "empirical") approaches are based on direct measurements of environmental variables: e.g. apparent temperature (AT) (Steadman 1984), the operative temperature (Blazejczyk et al. 1998), and the wet-bulb globe temperature (WBGT) (Yaglou and Minard 1957). The indirect indices are based on calculations involving the heat balance equation for the human body (so called "rationale indices"). In this note, first a short overview of relevant thermal comfort indices will be presented, followed by an advice about the thermal comfort index. Emphasis will be on the impact of heat stress on human health.

A3.1. Direct indices

Direct indices are simple methods based on thresholds of air temperature (mean, maximum or minimum) or a combination of air temperature and a measure of humidity, sometimes with consideration of exceedance time.

A3.1.1 Apparent temperature

An apparent temperature (AT) is an adjustment to the ambient temperature, to assess "how hot it actually feels", taking into account effect of atmospheric humidity. AT was developed by Steadman (1979a, b) and is based on physiological studies of evaporative skin cooling for various combinations of ambient temperature and humidity. The AT equals the actual air temperature when the dew-point temperature is 14 °C. At higher dew-points, the AT exceeds the actual temperature and measures the increased physiological heat stress and discomfort associated with humidity that is higher than comfortable. When the dew-point is less than 14 °C, the apparent temperature is less than the actual air temperature and measures the reduced stress and increased comfort associated with lower humidity and greater evaporative skin cooling. AT is valid over a wide range of temperatures. A simple hot weather version of the AT is known as the heat index (HI, see section 1.2).

There are many different versions of apparent temperature. Here we use an approximated version that is commonly used by The Australian Bureau of Meteorology and that is an approximation of a mathematical model of heat balance of the human body (www.bom.gov.au/info/thermal_stress/, 16 March 2011). It takes the air humidity and wind speed into account:

$$\mathrm{AT} = \mathrm{T_a} + 0.33 v_p - 0.70 \mathrm{w_s} - 4.00 \qquad (1)$$

Where

Ta = dry bulb temperature (°C)

vp = water vapour pressure (hPa)

ws = wind speed (m s-1)

The vapour pressure can be calculated from the temperature and relative humidity using the equation:

$$v_p = \frac{RH}{100} x\ 6.105\ xexp\big(17.27\ xT_a/(237.7 + T_a)\big) \qquad (2)$$

Where RH is % relative humidity

(Source: Norms of apparent temperature in Australia, Aust. Met. Mag., 1994, Vol 43, 1-16)

A.3.1.2. Heat index and mean heat index

Just like the AT the heat index (HI) combines air temperature and relative humidity to determine an apparent temperature. The HI is widely used in the United States. The United States National Oceanic and Atmospheric Administration (NOAA) issues heat warnings for the entire United States based on the mean heat index. It is calculated according to a polynomial function:

$$\mathrm{HI} = -8.784695 + 1.61139411\ \mathrm{T_a} + 2.338549\ \mathrm{RH} - 0.14611605\ \mathrm{T_a}\ \mathrm{RH} - 1.2308094\ 10^{-2}\mathrm{T_a^2} - 1.6424828\ 10^{-2}\mathrm{RH}^2 + 2.211732 10^{-3}\mathrm{T_a^2}\mathrm{RH} + 7.2546 10^{-4}\mathrm{T_a}\mathrm{RH}^2 - 3.582\ 10^{-6}\mathrm{T_a^2}\mathrm{RH}^2 \qquad (3)$$

Where: Ta is air temperature in C, and RH is relative humidity rounded to its integer value in %.

Ideally the apparent temperature is calculated from the daily maximum temperature and the simultaneous relative humidity. If the latter is not available, the daily minimum relative humidity can be used, which at first approximation coincides with the maximum temperature in the diurnal cycle.

The mean heat index is an average of the heat index from the hottest and coldest times of each day and is therefore more representative of the entire 24-hour period than a single daily maximum value. Forecasts are provided routinely for conditions 3 to 7 days in advance on the web site of NOAA. When severe conditions are forecast within 2 days, NOAA issues an alert (more severe than a warning) to the public and relevant agencies (http://www.hpc.ncep.noaa.gov/heat_index.shtml , 29 October 2003).

Table A3.1. Heat Index thresholds

Heat Index (°C)	Category	Possible heat disorders for people in high risk groups
27-32	Caution	Fatigue possible with prolonged exposure and/or physical activity
32-41	Extreme caution	Sunstroke, muscle cramps, and/or heat exhaustion possible with prolonged exposure and/or physical activity
41-54	Danger	Sunstroke, muscle cramps, and/or heat exhaustion likely. Heatstroke possible with prolonged exposure and/or physical activity
≥54	Extreme danger	Heat stroke or sunstroke likely

A.3.1.3Effective temperature

The effective temperature index was originally established to provide a method of determining the relative effects of temperature and humidity on comfort (Houghton and Yaglou, 1923). The index was further mathematically developed by Missenard (1933) taking the organism's thermoregulatory capacity (warm and cold perception) into account. The ET is still in use in Germany. Li and Chan (2000) have adapted the Missenard formula and named it Normal Effective Temperature (NET). The Net is routinely monitored by Hong Kong Observatory. The original Missenard equation is:

$$ET = 37 - \frac{37 - T}{0.68 - 0.0014\,RH + \frac{1}{1.76 + 1.4 w_s^{0.75}}} - 0.29\,T(1 - 0.01\,RH) \qquad (4)$$

Where ws is wind speed (in m s-1) at 1.2 m above the ground.

Several assessment scales have been developed for ET. Table A3.2 shows the thresholds for ET that are in use in Central Europe the following thresholds

Table A3.2. Thresholds for Effective Temperature

ET ranges (°C)	Thermal stress
>27	Hot
23-27	Warm
21-23	Comfortable
17-21	Fresh
9-17	Cool
1-9	Cold
< 1	Very cold

A3.1.4 Wet-bulb globe temperature

The wet-bulb globe temperature (WBGT) is the thermal comfort index most widely used throughout the world. It was developed by the US Navy as part of a study on heat-related injuries during military training (Yaglou and Minard, 1957). It is determined by weighting of the measured dry-bulb temperature, natural (un-aspirated) wet-bulb temperature and the measured black- globe temperature. However, in practice the globe temperature is rarely measured. Instead, a simplified version can be used based on air temperature and water vapour pressure (www.bom.gov.au/info/thermal_stress/, 16 March 2011):

$$WBGT = 0.567\,T_a + 0.393\,v_p + 3.94 \qquad (5)$$

Where Ta is air temperature in °C, and vp the water vapour pressure (hPa)

We used this approximation to assess outdoor thermal comfort for Dutch cities using data provided by hobby meteorologists (Steeneveld et al., 2011). Table 3 gives the ranges of WBGT with recommendations for outdoor activity.

Table A3.3. WBGT thresholds (source: www.bom.gov.au/info/thermal_stress/, 16 March 2011)

WBGT (°C)	Recommended sporting activity
< 18	Unlimited
18-23	Keep alert for possible increases in the index and for symptoms of heat stress
23-28	Active exercise for unacclimatized persons should be curtailed
28-30	Active exercise for all but the well-acclimated should be curtailed
>30	All training should be stopped

A.3.2. Indirect indices

Indirect indices include all important meteorological and physiological parameters that needed to better describe the physiological heat load: air temperature, water vapour pressure, wind velocity and short- and long-wave radiant fluxes. They are derived from heat budget (energy balance) models that take all mechanisms of heat exchange into account and are therefore thermo-physiologically relevant to individual exposures and experiences. Most of the approaches refer to a reference environment in which the perception of cold and/or heat would be the same as under the actual conditions.

A3.2.1 Standard effective temperature (SEN)

The standard effective temperature (SET) is defined as the equivalent air temperature of an isothermal environment at 50% RH at which a person wearing clothing standardized for the activity concerned, experience the same heat stress and thermoregulatory strain as in the actual environment. SET uses skin temperature and skin wetness as the limiting conditions which are derived from a model of human physiology (Gagge et al. 1971,1986).

A3.2.2 Predicted mean vote and perceived temperature

The predicted mean vote (PMV) index predicts the mean response of a larger group of people according to the ASHRAE thermal sensation scale. It was developed by Fanger (1970) and is based on a complete heat budget model of the human body with simple approaches considering skin temperature and sweat rate. The output parameter is a 8-point scale of thermal sensation (see Table 4). The predicted mean vote is still very popular for assessing indoor climate.

Fanger's PMV equation is the basis for the Klima-Michel-model (Jendritzky 1990; Jendritzy et al. 1979), an operational thermal assessment procedure, that is used by the German Meteorological service (Deutscher Wetterdienst, DWD). The output parameter is perceived temperature (PT, °C) that is a more comprehensible measure by the public than PMV. To date, DWD is the only national weather service to run a complete heat budget model on a routine basis specifically for applications in human biometeorology.

A3.2.3 Physiological equivalent temperature

The physiological equivalent temperature (PET in °C) is a variation on the PMV (Höppe 1984,1999). PET provides the equivalent temperature of an isothermal reference environment with a water vapor pressure of 12 hPa (50% at 20 °C) and light air (0.1 m s-1), at which the heat balance of a reference person is maintained with core and skin temperature equal to those under the conditions being assessed. 'Standard calculations' are based on a man of 35 years old, with a length of 1.75 m and weight of 75 kg, standing in the sun, with a clothing factor 0.9 and with a heat production of 80 W.

Table A3.4. Ranges of Predicted Mean Vote (PMV) and Physiological Equivalent Temperature (PET) for different grades of thermal perception by human beings and physiological stress on human beings: internal heat production: 80 W, heat transfer resistance of clothing: 0.9 clo (Höppe 1984,1999; Matzarakis et al. 1999)

PMV*	PET** (°C)	Thermal perception	Grade of physiological stress
-3.5	4	Very cold	Extreme cold stress
-2.5	8	Cold	Strong cold stress
-1.5	13	Cool	Moderate cold stress
-0.5	18	Slightly cool	Slight cold stress
0.5	23	Comfortable	No thermal stress
1.5	29	Slightly warm	Slight heat stress
2.5	35	Warm	Moderate heat stress
3.5	41	Hot	Strong heat stress
>3.5		Very hot	Extreme heat stress

A3.2.4 Universal thermal climate index

Recently a new thermal comfort was proposed, the Universal Thermal Climate Index (UTCI). It is the outcome of the European COST Action 730 (Cooperation in Science and Technical Development) project which brought together scientists from 19 European countries plus experts from Australia, Canada, Israel and New Zealand. The UCTI is expressed as an equivalent ambient temperature of a reference environment providing the same physiological response of a reference person as the actual environment. UTCI was developed conceptually as an Equivalent Temperature (ET). Thus, for any combination of air temperature, wind, radiation, and humidity, UTCI is defined as the air temperature in the reference condition which would elicit the same dynamic response of the physiological model.

A 10 points stress assessment scale from “extreme heat stress” to “extreme cold stress” was defined (Table A3.5).

Table A3.5. UTCI equivalent temperature ranges and perceived thermal stress (source: Bröde et al. 2012)

UTCI range (°C)	Stress category
Above +46	Extreme heat stress
+38 to +46	Very strong heat stress
+32 to +38	Strong heat stress
+26 to +32	Moderate heat stress
+9 to +26	Not thermal stress
+9 to 0	Slight cold stress
0 to -13	Moderate cold stress
-13 to -27	Strong cold stress
-27 to -40	Very strong cold stress
Below -40	Extreme cold stress

A3.3 Comparison of thermal comfort indices

Obviously, the indirect indices represent thermal comfort in specific climates, weather, and locations much better because they take thermal physiology of human beings into account. However, because they depend on many variables, indirect indices are more complex and therefore, more difficult to implement for daily use. The direct approaches, in contrast, are more user-friendly and applicable. They consider only some of the standard meteorological parameters (air temperature, RH or vapour pressure, wind speed) and are, therefore, easy to calculate from weather and climate data. For instance, Fischer and Schär (2010) used datasets provided by high-resolution regional climate models (RCMs) to calculate the Heat Index.

Blazejczyk et al. (2012) compared UTCI with most of the other indices listed here. The analysis is based on three groups of data; global data-set, a 20-year weather database from Freiburg (Germany), and datasets obtained from measurement campaigns within the frame work of COST-730 at different locations (Svalbard archipelago, Negev Desert, Madagascar, Warsaw). Strong correlations (r2 > 0.96) were found with other indices derived from human heat balance models (Table A3.6). Correlations with the direct indices such as WBGT and HI appeared to be very weak. However, in contrast, rather strong correlations were found for AT and ET.

Table A3.6. Relationships between Universal Thermal Climate Index and other indices (source: Blazejczyk et al. (2012).

Index	Slope	R-squared (%)
AT	0.716	95.35
HIa	0.444	39.72
ET(NEC)	0.947	96.97
WBGTa	0.381	42.46
SET	1.021	97.54
PMV	-	98.12
PET	-	96.42

a - calculated for air temperature > 20 °C

We did a preliminary analysis for the correlations between UTCI and ET or AT, partly similar to that of Blazejczyk et al. (2012), in order to get an impression about their suitability as an universal indicator. Also we made a comparison between UTCI and WBGT. For this analysis we used datasets (year 2011) from the urban monitoring stations Centre and South in Rotterdam and from a reference rural monitoring station, north of Rotterdam. Besides a variable for air temperature and humidity, both the ET and AT equation contain a variable for wind velocity. It is a standard variable in datasets provided by WMO sites that are usually located in rural areas. However, observational data of wind speed in the urban environment are scarce. The available datasets indicate that the wind speed provided by the WMO sites poorly represent wind speeds in the urban environment. The latter are strongly variable and particularly at days with high temperatures, significantly reduced relative to the ones of the surrounding rural area. Similarly, wind speed data from climate models do not represent urban areas. For these reasons, calculations were carried out (1) taking the measured wind speeds into account, and (2) for a fixed low wind speed of 1 m s-1. Figure 1 shows the obtained relationships between UTCI and ET or AT for the rural reference site. A strong correlation (r2 = 0.94) for ET is found when the wind speeds are taken into account, which is in accordance with the results of Blazejczyk et al. (2012). A weaker correlation for AT was found (r2 = 0.79). The correlations become obviously weaker when a fixed wind speed is used in the calculations of ET and AT (ET2 and AT2 respectively). In general, better correlations for the urban datasets are obtained as is shown e.g. in Figures A3.2. The correlations between UTCI and ET2 or AT2 assessed for the urban data are even better than those found for the reference ET and AT data (i.e. taking the wind velocity into account). In particular ET and ET2 are nearly linearly related to UTCI. This implies that the assessment scale for UTCI could be applied to ET or ET2 as well, with relatively simple adjustments. Like in Blazejczyk et al. (2012) we find that the relationship between AT or AT2 and UTCI comes with a lower slope of the linear regression line. Furthermore, the data distribution seems and is slightly more none-linear than in the case of ET and ET2. In particular the latter characteristics makes appliation of the UTCI classification to AT or AT2 slightly less attractive.

Figure A3.3 shows the results for the comparison between UTCI and WBGT. In contrast to the results of Blazejczyk et al. (2012), better correlations were found. Nevertheless, we also conclude that – taking UTCI as the reference – the ET indices outperform WBGT.

Table A3.7. Relationships between UTCI and ET, AT and WBGT. Calculations were carried out for datasets obtained from urban monitoring stations in Rotterdam (Centre, South) and for a monitoring station in the rural reference site, north of Rotterdam (51°58’55.17”N, 4°25’45.31”O). ET2 and AT2 constant wind speed of 1 m s-1 used in the calculations. The urban stations, labelled as Rotterdam-Centre and –South, represent the densely built commercial area and the densely built up living neighbourhood, respectively (coordinates: 51°55’24.18”N, 4°28’10.35”O; 51°55’31.41”N, respectively).

Direct index	**Reference**		**Centre**		**South**	
	slope	R-squared	Slope	R-squared	slope	R-squared
ET	0.76	0.94	0.86	0.96	0.87	0.96
ET2	0.59	0.69	0.87	0.91	0.96	0.95
AT	0.69	0.79	0.86	0.96	1.06	0.95
AT2	0.65	0.71	0.96	0.90	1.06	0.95
WBGT	0.43	0.71	0.62	0.87	0.69	0.92

A3.4 Conclusion

It can be concluded from the results of Blazejczyk et al. (2012) and our own results that the simple indices ET and AT give a reasonable indication for outdoor thermal comfort. In particular ET seems to perform rather well in comparison with UTCI. Our analysis suggests that this is also true when a constant, low wind velocity of 1 m s-1 is used for the calculation of ET or AT. This implies that datasets containing at least air temperature and humidity (water vapour pressure or RH) are suited to estimate ET or AT with suffucient accuracy, although inclusion of wind speed will increase the performance. The fact that ET is nearly linearly related to UTCI implies that the assessment scale for UTCI can be applied to ET as well, with relatively simple adjustments to the class boundaries.

References

Blazejczyk, K., Epstein, Y., Jendritzky, G., Staiger, H., and Tinz, B. (2012). Comparison of UTCI to selected thermal indices. Int J Biometeorol (2012) 56:515–535 DOI 10.1007/s00484-011-0453-2.

Bröde, P., Fiala, D., Błażejczyk, K., Holmér, I., Jendritzky, G., Kampmann, B., Tinz, B., and Havenith, G. (2012). Deriving the operational procedure for the Universal Thermal Climate Index (UTCI) Int J Biometeorol (2012) 56:481–494. DOI 10.1007/s00484-011-0454-1

Fanger, P.O. (1970). Thermal Comfort. Analysis and Application in Environment Engineering. Danish Technical Press, Copenhagen.

Fischer, E.M. and Schär, C. (2010). Consistent geographical patterns of changes in high-impact European heat waves. Nature Geoscience, Published online: 16 May 2010, DOI: 10.1038/NGEO866, 1 - 6.

Höppe, P. (1984). Die Energiebilanz des Menschen. Wiss Mittl Meteorol Inst Uni München 49.

Höppe, P. (1999). The physiological equivalent temperature—a universal index for the biometeorological assessment of the thermal environment. Int J Biometeorol 43:71–75.

Houghton, F.C., Yaglou C.P. (1923). Determining equal comfort lines. J Am Soc Heat Vent Eng 29:165–176.

Jendritzky, G. (1990). Bioklimatische Bewertungsgrundlage der Räume am Beispiel von mesoskaligen Bioklimakarten. In: Jendritzky G, Schirmer H, Menz G, Schmidt-Kessen Methode zur raumbezogenen Bewertung der thermischen Komponente im Bioklima des Menschen (Fortgeschriebenes Klima-Michel-Modell). Akad Raumforschung Landesplanung, Hannover, Beiträge 114: 7–69

Jendritzky, G., Sönning, W., Swantes, H.J. (1979). Ein objektives Bewertungsverfahren zur Beschreibung des thermischen Milieus in der Stadt und Landschaftsplanung ("Klima-Michel-Modell"). Beiträge d. Akad. f. Raumforschung und Landesplanung, 28, Hannover.

Li, P.W. and Chan, S.T. (2000). Application of a weather stress index for alerting the public to stressful weather in Hong Kong. Meteorol Appl 7:369–375.

Missenard, F.A. (1933). Température effective d'une atmosphere Généralisation température résultante d'un milieu. In: Encyclopédie Industrielle et Commerciale, Etude physiologique et technique de la ventilation. Librerie de l'Enseignement Technique, Paris, pp 131–185

Steadman, R.G. (1984). A universal scale of apparent temperature. J Appl Meteorol Climatol 23:1674–1687.

Steadman, R.G. (1979). The assessment of sultriness. Part I: A temperature-humidity index based on human physiology and clothing science. J Appl Meteorol 18:861–873.

Steeneveld, G.J., Koopmans S., , Heusinkveld, B.G., van Hove, L.W.A. and Holtslag, A.A.M. (2011). Quantifying urban heat island effects and outdoor human comfort in relation to urban morphology by exploring observations from hobby-meteorologists in the Netherlands. J. Geophys. Res.116, D20129, 14pp., doi: 10.1029/2011 JDO15988.

Yaglou, C.P. and Minard, D. (1957). Control of heat casualties at military training centers. Am Med Assoc Arch Ind Health 16:302–316

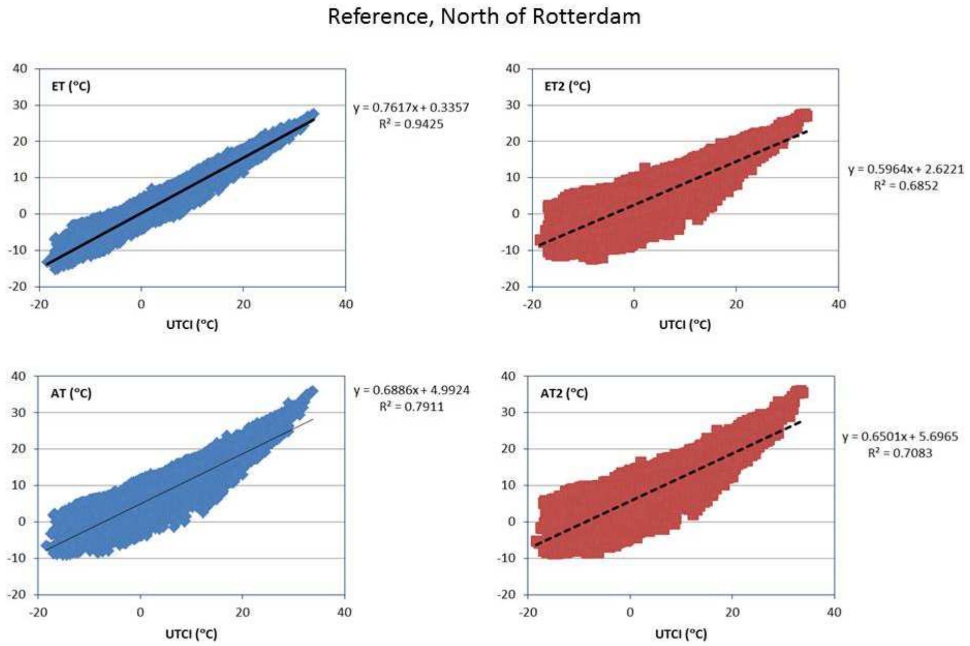


Figure A3.1. UTCI versus Effective Temperature (ET) and Apparent Temperature (AT) for the rural reference site, north of Rotterdam. Right panels: ET2 and AT2 calculated with fixed wind velocity of 1 m s-1.

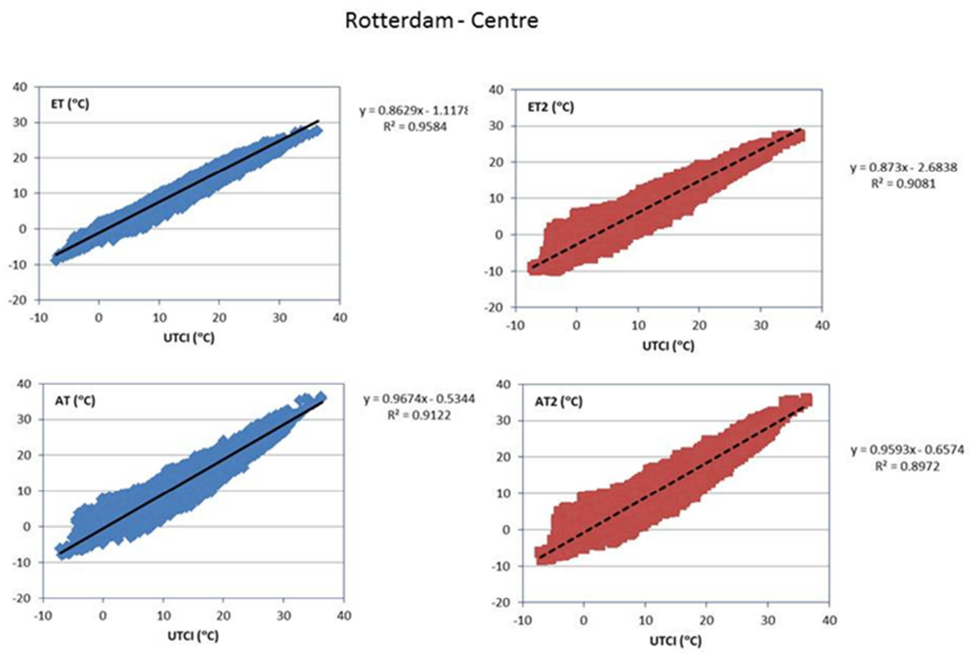


Figure A3.2. UTCI versus Effective Temperature (ET) and Apparent Temperature (AT) for the Centre of Rotterdam. Right panels: ET2 and AT2 calculated with fixed wind velocity of 1 m s-1.

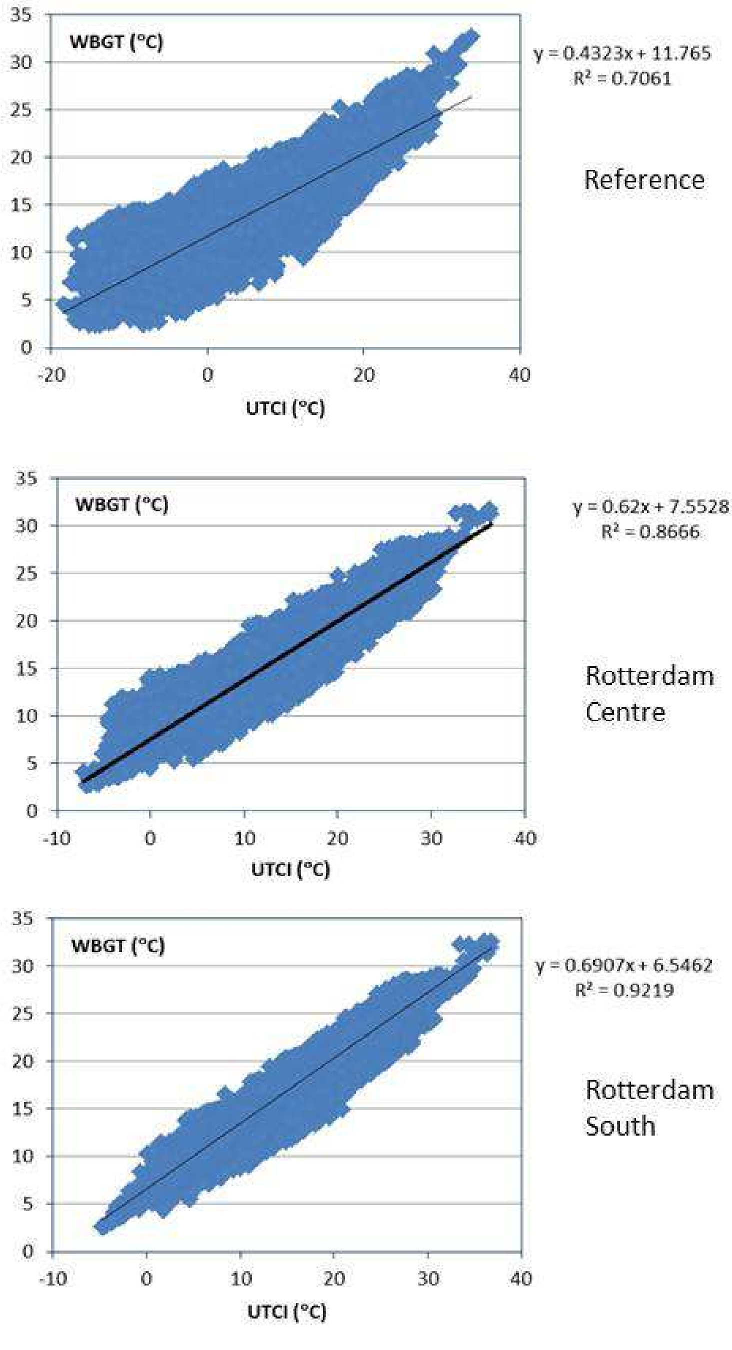
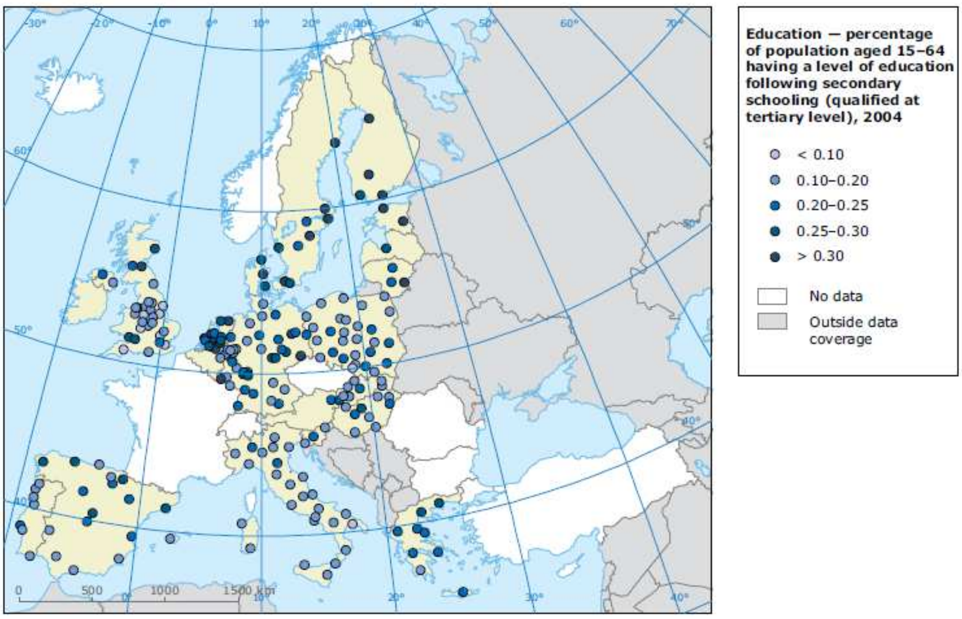


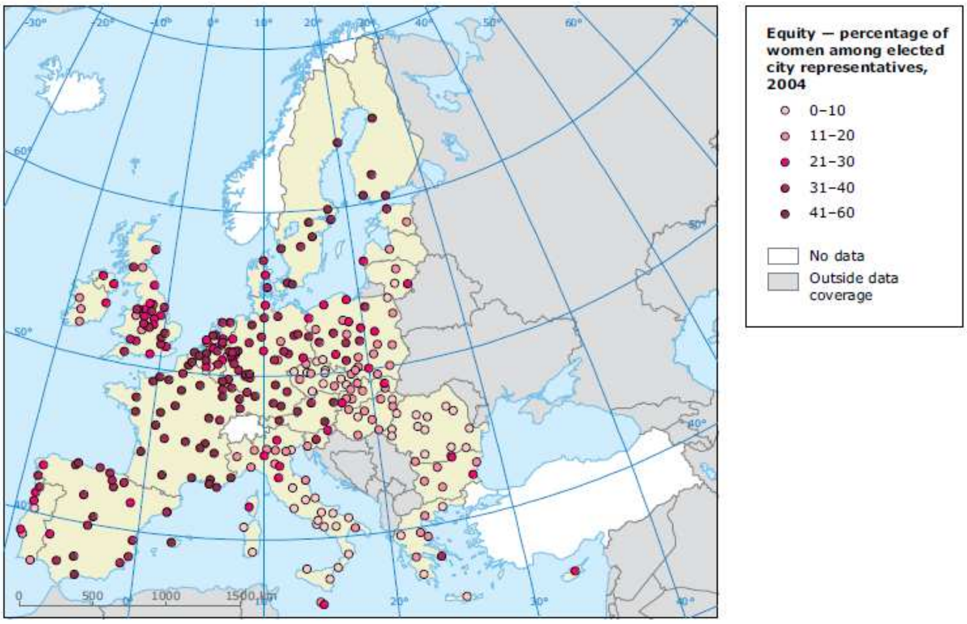
Figure A3.3. UTCI vs. WBGT

Annex 3 Fact sheets

Generic response indicators

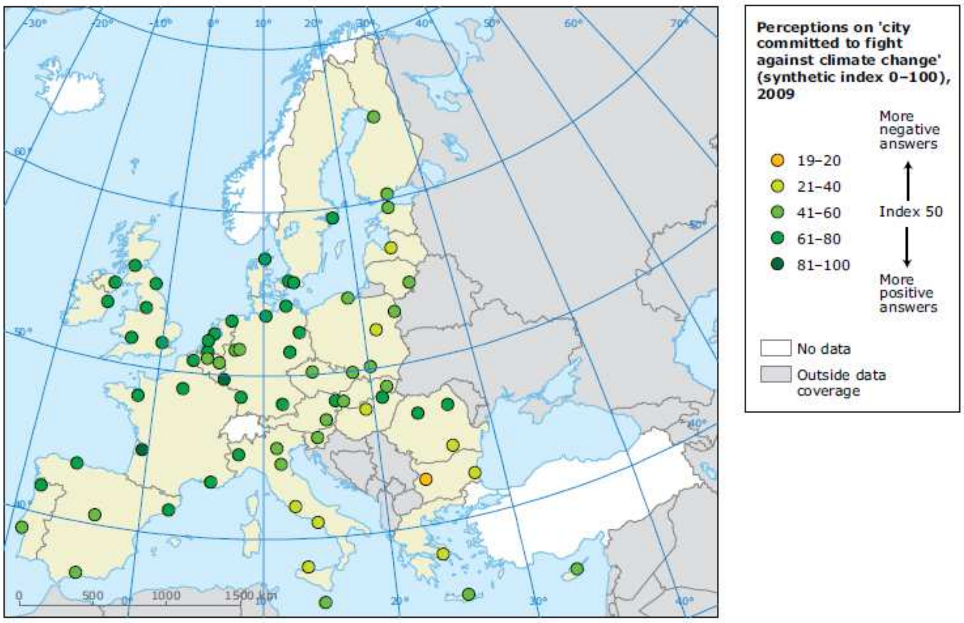
Indicator	Education
Key question	What is the likely awareness of climate change issues among the city's population? What is the level of education of the city's population?
Climatic hazard	All
Dimensions	Response capacity: awareness
Definition	Proportion (%) of population aged 15-64 qualified at tertiary level (ISCED 5-6) living in Urban Audit cities (cities in EU27, except BG, BE, CZ, FR, IE, MT, RO).
Rationale and context	In general, locations with higher levels of stores of human knowledge are considered to have greater adaptive capacity than those with lesser levels of knowledge and education, e.g. developing nations and those in transition (Smit and Pilosova, 2001). The level of scepticism about climate change may decline with the increasing level of education (Whitmarsh, 2011). However, it was also observed by this author that political views also strongly affect the scepticism and uncertainty about climate change. Weber (2010) believes that at least for some people, better (environmental) science and statistics education can create the familiarity with the scientific presentation of climate change information and thus increase their understanding of the issue.
Data requirements and sources	Source: Urban Atlas
Processing	Extraction from the Urban Audit database.
Example	 **Note:** Data for Finland, Italy, Poland, Portugal, Slovenia, Slovakia and Spain are from 2001. **Source:** Eurostat Urban Audit database, 2004. Source: EEA (2012)

Feasibility	Easy
Scientific evidence	(Scientific) justification provided in the field “rationale and context”. References: Smit, B. and Pilifosova, O. (2001) Adaptation to Climate Change in the Context of Sustainable Development and Equity in McCarthy, J.J., Canziani, O., Leary, A., Dokken, D.J. and White, K.S. (Eds.), Climate Change 2001: Impacts, Adaptation and Vulnerability. IPCC Working Group II, Cambridge University Press, Cambridge: pp. 877–912 Whitmarsh, L. (2011) Scepticism and uncertainty about climate change: dimensions, determinants and change over time. Global Environmental Change 21(2) 690-700. Weber, E.U. (2010) Wiley interdisciplinary Reviews: Climate Change 1(3): 332-342.

Indicator	Equity
Key question	To what extent voices of all members of the society are represented at the city level? To what extent are the more vulnerable groups included in decision making?
Climatic hazard	All
Dimensions	Response capacity: awareness
Definition	Percentage of women among elected city representatives
Rationale and context	Building adaptive capacity in cities requires involving all members of society. The percentage of women among elected city representatives may be used as an indication, to what extent the decision makers involve the more vulnerable members of the society and are aware of their problems. One of the central aspects of any participatory planning is including both men and women. Gender differences, being a key component of the political, social, economic and cultural characteristics of a society, need to be considered as a strategic entry point for identifying roles and responsibilities within a community (Lambrou and Piana, 2006). Adaptive capacity of a system may be regarded as a function not only of the availability of resources but of accessto those resources by decision makers and vulnerable subsectors of a population (Kelly and Adger, 1999). According to IPCC (Smit and Pilosova, 2001), adaptive capacity is greater if social institutions and arrangements governing the allocation of power and access to resources within a given location assure that access to resources is equitably distributed; the entitlement to use resources by different sections of the society influences their response capacity.
Data requirements and sources	Sources: Urban Audit
Processing	Extraction from the Urban Audit database
Example	 **Note:** Data for Czech Republic, Greece, Hungary, Lithuania, the Netherlands, Slovenia and partially Belgium are from 2001. **Source:** Eurostat, Urban Audit database, 2004.

	Source: EEA (2012)
Feasibility	Easy
Scientific evidence	(Scientific) justification provided in the field “rationale and context”. References: Lambrou, Y. And Piana, G. (2006) Gender: the missing component of the response to climate change. Food and Agriculture organisation of the United Nations, available at: http://www.eldis.org/vfile/upload/1/document/0708/DOC21057.pdf Kelly**,** P. and W.N. Adger, 1999: *Assessing Vulnerability to Climate Change and Facilitating Adaptation*. Working Paper GEC 99–07, Centre for Social and Economic Research on the Global Environment, University of East Anglia, Norwich, United Kingdom. Smit, B. and Pilifosova, O. (2001) Adaptation to Climate Change in the Context of Sustainable Development and Equity in McCarthy, J.J., Canziani, O., Leary, A., Dokken, D.J. and White, K.S. (Eds.), Climate Change 2001: Impacts, Adaptation and Vulnerability. IPCC Working Group II, Cambridge University Press, Cambridge: pp. 877–912

Indicator	Perception of the city population that the authorities are committed to fight against climate change
Key question	To what extent are the local authorities aware of and interested in climate change issues?
Climatic hazard	All
Dimensions	Response capacity: awareness
Definition	The Perception Survey on the quality of life in European cities aimed at measuring local perceptions in 75 cities in the EU, Croatia and Turkey. The data are based on surveys/interviews of randomly selected citizens.
Rationale and context	The indicator is based on the assumption that city's awareness of the issues of climate change leads not only to greater chance of action on climate mitigation but also on adaptation. This seems to be justified, as cities committed to other sustainability issues tend to acknowledge the need for adaptation. Carmin et al (2012) carried out a global survey among cities in the ICLEI – Local Governments for Sustainability association. They found that 79% of the cities observed changes in weather or occurrence of natural hazards that they attribute to climate change; 68% reported that they are pursuing adaptation planning.
Data requirements and sources	Source: Urban Audit Perceptions Survey 2009
Processing	The Perception Survey on the quality of life in European cities aimed at measuring local perceptions in 75 cities in the EU, Croatia and Turkey. The data are based on surveys/interviews of randomly selected citizens. The information is provided as « synthetic index ». From the perception survey data, an index was calculated by subtracting the negative answers from the positive ones and dividing the result by the total number of answers ("very much agree" and "quite agree" are counted as positive answers, whereas "very much disagree" and "quite disagree" are negative answers).This initial index has a minimum of -1 and a maximum of +1. To make it easier to use, the index was then multiplied by 50 and 50 then added to the result. The resulting index covers values between 0 and 100. A value above 50 means positive answers predominate; below 50, there are more negative answers.

<table>
<tr><td>Example</td><td>

Source: DG REGIO/Eurostat: Urban Perception survey 2010; data 2009.
Source: EEA (2012)</td></tr>
<tr><td>Feasibility</td><td>Easy</td></tr>
<tr><td>Scientific evidence</td><td>(Scientific) justification provided in the field “rationale and context”.

Reference:

Carmin, J., Nadkami, N. And Rhie, C. (2012) progress and challenges in urban climate adaptation planning: results of a global survey. MIT, Cambridge, MA. Available at: http://web.mit.edu/jcarmin/www/carmin/Urban%20Adaptation%20Report%20FINAL.pdf</td></tr>
</table>

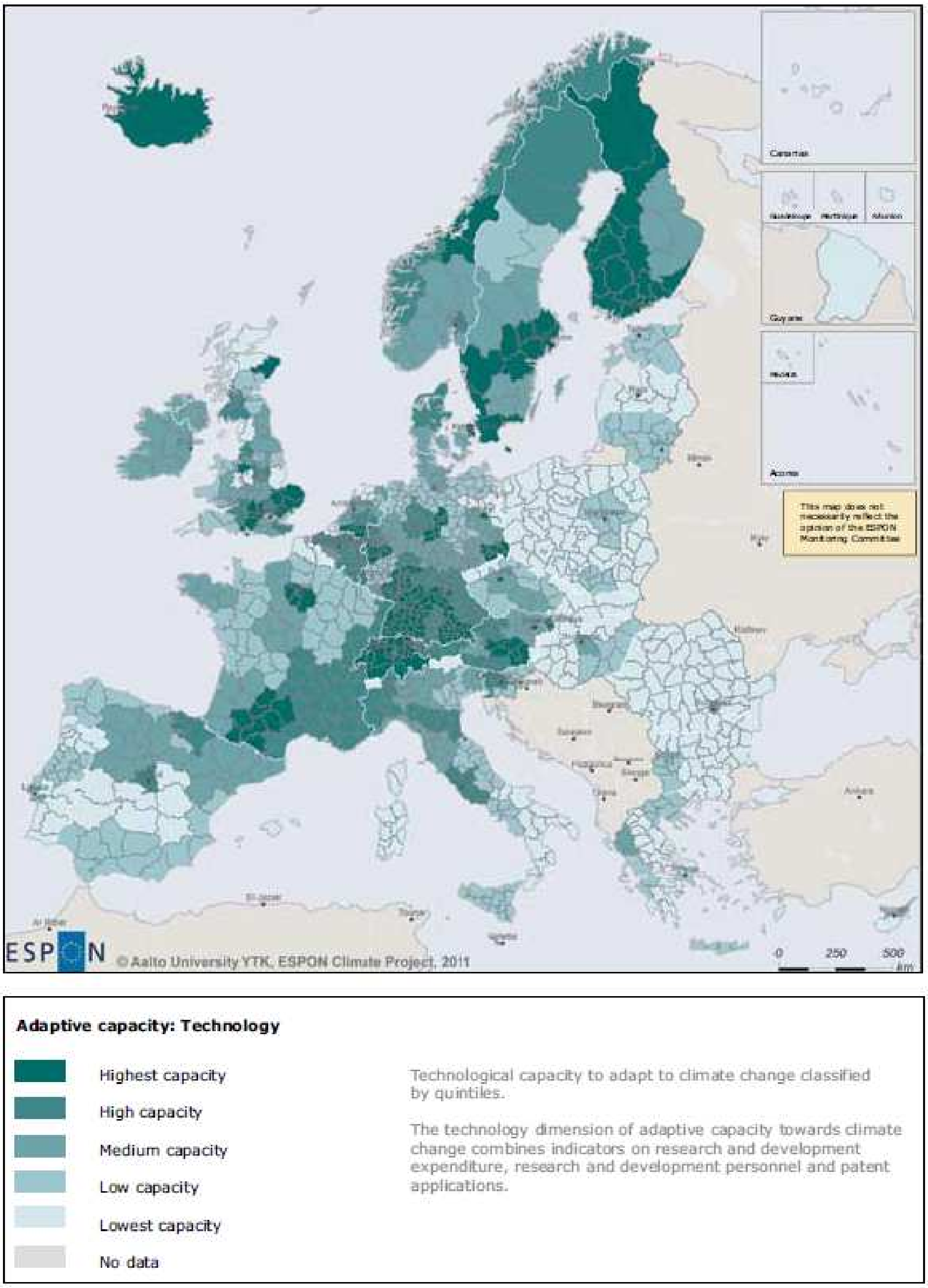
Indicator	Risk perceptions of European citizens
Key question	To what extent are the European citizens aware of the environmental risks? To what extent are the European citizens aware of the risks associated with climate change?
Climatic hazard	All
Dimensions	Response capacity: awareness
Definition	In the absence of Europe-wide surveys on the perception of risks associated with climate change, the presented indicator refers to the perceived risks associated with food. The survey (Special Eurobarometer 354, wave 73.5) was carried out on a representative sample of 26.691 individuals, age 15 or over in all 27 Member States in 2010. The responses of those surveyed represent the views of over 500 million European consumers. It follows that a 1% value represents the views of 5 million consumers, thus even small percentage values represent the views of a large number of people. For more detail see: http://www.efsa.europa.eu/en/riskcommunication/riskperception.htm
Rationale and context	An assumption is being made here that awareness of the risks associated with food reflects the awareness of risks associated with climate change. This may be correct in some cases; however, the food-related risks are much more immediate to people than those associated with climate change. Nonetheless, no indicators associated with the perception of climate change risks are available at the European scale. In the context of climate change adaptation, the perception that there is a risk is a prerequisite for taking adaptive actions. Grothmann and Patt (2005: 203) developed a theoretical "model of private proactive adaptation to climate change". The model starts from risk appraisal, or assessment of the probability and severity of impact. Only when the perceived hazard exceeds a certain threshold does the individual carry out the adaptation appraisal, which includes an assessment of their belief in the effectiveness of the actions, the perceived ability to carry out the adaptive responses, and the perceived cost of the action. Depending on the outcomes of this appraisal, adaptation actions are implemented or not. Similarly, Lamond and Proverbs (2009) identified the mental steps that need to be completed by a flood plain resident who wants to implement flood-protection measures. These include awareness of the risk, the perception that the risk is sufficient to warrant action, and owning the problem rather than expecting an outside agency to solve it. Once this is achieved, the person needs knowledge of the solution, resources to implement it, and a belief that the solution is effective and beneficial. These models are illustrated by some empirical studies. A study of elderly people's perceptions of heat wave risks suggests that this relatively vulnerable group does little to adapt, because it does not perceive its vulnerability (Wolf et al. 2009). Research in Norway, for example, shows that in situations where no risk is perceived, little if any action to adapt is undertaken (O'Brien et al. 2006).
Data requirements and sources	http://www.efsa.europa.eu/en/riskcommunication/riskperception.htm
Processing	
Example	

Feasibility	Easy
Scientific evidence	(Scientific) justification provided in the field "rationale and context". References: Grothmann T, Patt A (2005) Adaptive capacity and human cognition: the process of individual adaptation to climate change. Glob Environ Chang Part A 15:199–213 Lamond JE, Proverbs DG (2009) Resilience to flooding: lessons from international comparison. Urban Des Plan 162:63–70 O'Brien KL, Eriksen S, Sygna L, Naess LO (2006) Questioning complacency: climate change impacts, vulnerability, and adaptation in Norway. Ambio 35(2):50–56 Wolf, J., Adger, W.N., Lorenzoni, I., Abrahamson, V., Raine, R. (2010) "Social capital, individual responses to heat waves and climate change adaptation: An empirical study of two UK cities", *Global Environmental Change*20(1): 44-52.

Indicator	Proportion of dwellings lacking basic amenities
Key question	To what extent the housing in cities is of good quality/ To what extent can it withstand extreme weather events and provide appropriate living environment for vulnerable populations>
Climatic hazard	All
Dimensions	Response capacity: ability
Definition	Proportion of dwellings lacking basic amenities
Rationale and context	Absence of basic amenities may have serious implications for example during recovering from flood events. Diarrhoea and upset stomachs can be passed from person to person in cramped conditions with insufficient access to sanitary installations and fresh water and (Tapsell et al., 2002). The lack of amenities can be used as a proxy for the general state of the building, which may affect how it copes with extreme weather events. Solid masonry buildings can withstand flooding without suffering major structural damage, while lightweight constructions may be more easily damaged (Sanders and Phillipson, 2003). Housing without basic amenities may also be inappropriately insulated, and thus prone to overheating; it has been found that wall insulation in particular reduces the temperatures inside houses (Porritt et al., 2010). In the European context, flats in tower blocks or old townhouses may be among the dwellings without the basic amenities and of poor quality. Flats can be poorly ventilated and the top floor may be overheating due to the poor roof insulation; extremely high temperatures in top-floor apartments were the reason for a significant number of deaths in Paris during the 2003 heatwave (Poumadere et al., 2005). The high proportion of housing without basic amenities and of low quality has been previously used as one of the indicators of the overall city's vulnerability in the assessment of global cities' vulnerability to climate change (De Sherbinin et al., 2007).
Data requirements and sources	Source: Urban Audit SA1018V or SA1001V
Processing	Extraction from the Urban Audit database
Example	
Feasibility	Easy
Scientific evidence	(Scientific) justification provided in the field "rationale and context". References: De Sherbinin, A., Schiller, A and Pulsipher, A. 2007. The vulnerability of global cities to climate hazards. Environment and Urbanisation 19(1): 39-64. Porritt, S.M., Shao, L., Cropper, P.C. and Goodier, C.I. (2010) Building orientation and occupancy patterns and their effect on interventions to reduce overheating in dwellings during heatwaves. Proceedings of Conference: *IESD PhD Conference: Energy and Sustainable Development,*Institute of Energy and Sustainable Development, De Montfort University, Leicester, UK, 21st May 2010. Tapsell, S.M., Penning-Rowsell, E.C., Tunstall, S.M. and Wilson, T.L. (2002) Vulnerability to flooding: health and social dimensions*Phil. Trans. R. Soc. Lond. A*

	360, 1511-1525 Sanders, C.H., Phillipson, M.C., 2003. UK adaptation strategy and technical measures: the impacts of climate change on buildings. *Building Research & Information*, 31, 210-221.

Indicator	Research & Development (R&D) expenditure, personnel and patent applications
Key question	What is the technological know-how in the city? What is the potential for finding innovative adaptation solutions in the city?
Climatic hazard	All
Dimensions	Response capacity: ability
Definition	The indicator is a composite of 3 indicators: - R&D expenditure as % of GDP, - number of R&D personnel - number of patent application per The values of the indicator are presented in 5 classes and presented per NUTS 3 unit.
Rationale and context	According to IPPC, many of the adaptive strategies identified as possible in the management of climate change directly or indirectly involve technology (e.g., warning systems, protective structures, settlement and relocation or redesign, flood control measures).Hence, a community's current level of technology and its ability to develop technologies are important determinants of adaptive capacity. Lack of technology has the potential to seriously impede a nation's ability to implement adaptation options by limiting the range of possible responses. Moreover, openness to the development and utilization of new technologies for sustainable extraction, use, and development of natural resources is key to strengthening adaptive (Smit and Pilifosova, 2001).
Data requirements and sources	Source: ESPON Climate project
Processing	The indicator is calculated as normalised average of research and development expenditure as % of GDP, number of research and development personnel and number of patent applications

<table>
<tr><td>Example</td><td>


Source: Greiving et al., 2011; © ESPON, 2013.

Source: EEA, 2012</td></tr>
<tr><td>Feasibility</td><td>Easy</td></tr>
<tr><td>Scientific evidence</td><td>(Scientific) justification provided in the field “rationale and context”.</td></tr>
</table>

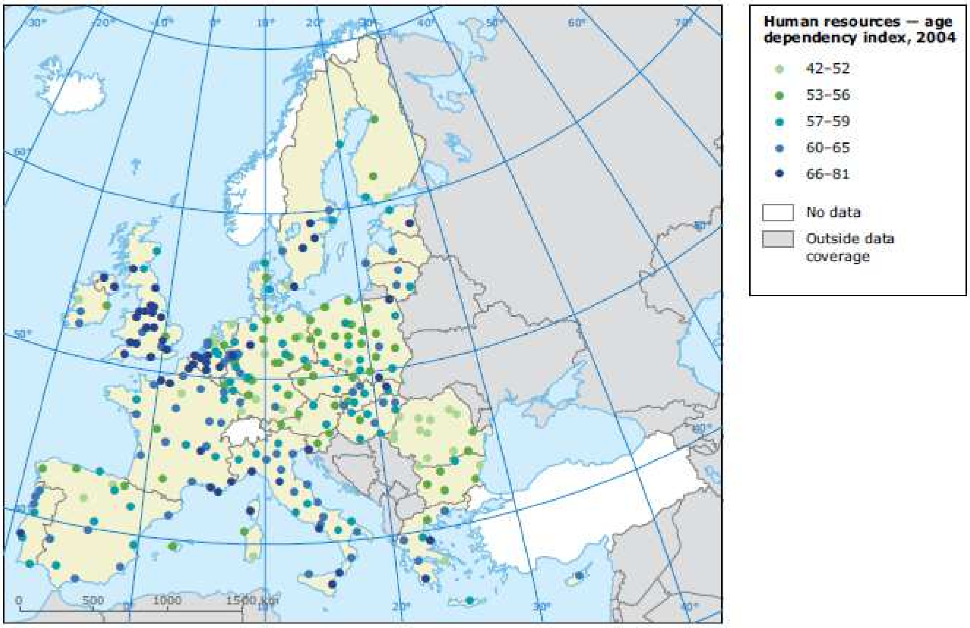
Indicator	Percentage of households with Internet access at home.
Key question	What is the level of technological advancement in the city? What is the capacity of the residents to communicate online? To what extent the residents have access to information provided online?
Climatic hazard	All
Dimensions	Response capacity: ability
Definition	Percentage of households with Internet access at home.
Rationale and context	Those without strong social networks and unfamiliar with their area (for example, as a result of short residence in the area or renting) may have less access to information (Cutter et al., 2003). For them being able to access information online may increase their ability to respond in the case of a climate event. Access to internet can also allow people to contact their friends and relatives in an event of emergency and reduced their isolation. Social networks have been proven to be crucial lifelines in climate-related extreme events; people living alone are the most frequent victims (e.g. Poumadere et al., 2005). For example, the 1995 heat wave in Chicago, anything that facilitated social contact was associated with a decreased risk of death (Semenza et al., 1996).
Data requirements and sources	Urban Audit
Processing	Extraction from the Urban Audit database
Example	
Feasibility	Easy
Scientific evidence	(Scientific) justification provided in the field “rationale and context”. References: Poumadere, M., Mays, C., Le Mer, S. and BlongR. (2005) The 2003 HeatWave in France: Dangerous Climate ChangeHere and Now. Risk Analysis 25(6): 1483-1494. Semenza JC, Rubin CH, Falter KH, Selanikio JD, Flanders WD, Howe HL, Wilhelm JL (1996) Heat-related deaths during the July 1995 heat wave in Chicago. The **New England Journal of Medicine**335**:**84-90. Smit, B. and Pilifosova, O. (2001) Adaptation to Climate Change in the Context of Sustainable Development and Equity in McCarthy, J.J., Canziani, O., Leary, A., Dokken, D.J. and White, K.S. (Eds.), Climate Change 2001: Impacts, Adaptation and Vulnerability. IPCC Working Group II, Cambridge University Press, Cambridge: pp. 877–912

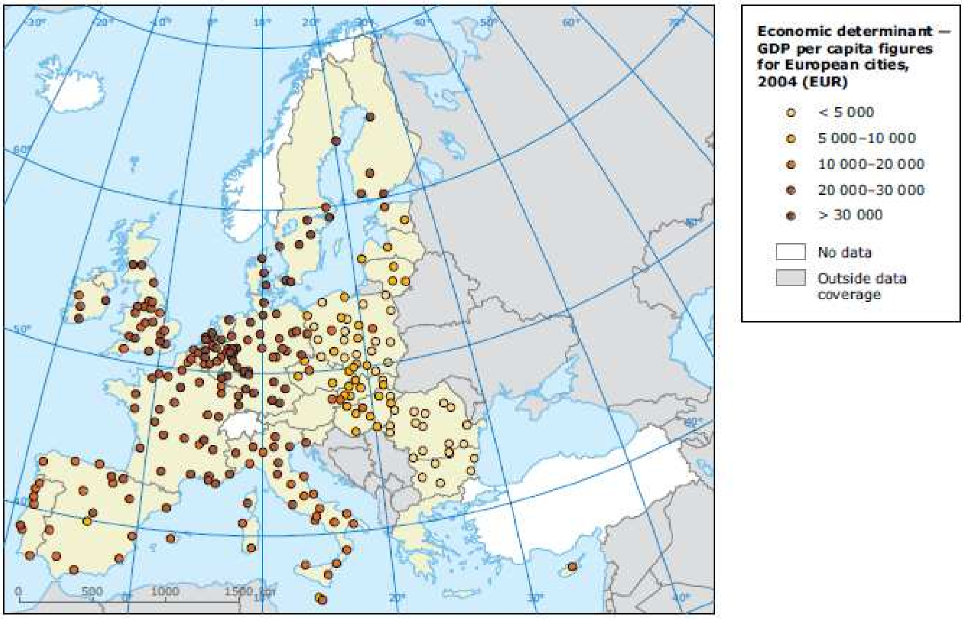
Indicator	Life expectancy at birth for males and females
Key question	What is the health status of the residents in the city?
Climatic hazard	All
Dimensions	Response capacity: ability
Definition	Life expectancy at birth for males and females
Rationale and context	The capacity of people to act in the event of natural disasters and extreme weather can be negatively affected by their pre-existing health problems (Rygel et al., 2006). Post-flood mortality and incidence of flood-related diseases (e.g. those associated with contaminated water) is significantly higher when the flood victims suffer from preexisting health problems. Flooding may limit access to medicine, or make it impossible to receive medical attention in good time. People with pre-existing medical conditions are at increased risk of hospitalisation during hot weather. The medical conditions include cardiovascular and respiratory diseases, diabetes, renal diseases, nervous system disorders, Parkinson's disease, emphysema and epilepsy (McGeehin and Mirabelli, 2001). Medications that potentially affect renal function, the body's ability to sweat, thermoregulation or electrolyte balance can make this group more vulnerable to the effects of heat (NHS, 2009). Those with Alzheimer's disease, a disability, or bed-bound have diminished ability to adapt to high temperatures, due to either of lower awareness of their circumstances, or inability to take actions to adapt to hot weather (Semenza et al., 1999). In addition, flooding and heat waves puts a strain on hospitals and emergency departments, and less urgent health problems may be put on hold, possibly exacerbating the existing health problems (see the indicator on the number of hospital beds).
Data requirements and sources	Source: Urban Audit (SA2001I)
Processing	Extraction from the Urban Audit database
Example	
Feasibility	Easy
Scientific evidence	(Scientific) justification provided in the field "rationale and context". Reference: McGeehin, M.A. and Mirabelli, M. 2001. The potential impacts of climate variability and change on temperature-related morbidity and mortality in the United States. Environmental Health Perspectives 109(supplement 2): 185-189. Semenza JC, McCullough JE, Flanders WD, McGeehin MA, Lumpkin JR. 1999. Excess hospital admissions during the July 1995 heatwave in Chicago Am J Prev Med 16:269–277 NHS (2009) Heatwave plan for England. NHS, London. Rygel, L., O'Sullivan, D., Yarnal, B., 2006. A method for constructing a social vulnerability index: an application to hurricane storm surges in a developed

	country. Mitigation and Adaptation Strategies for Global Change 11: 741-764.

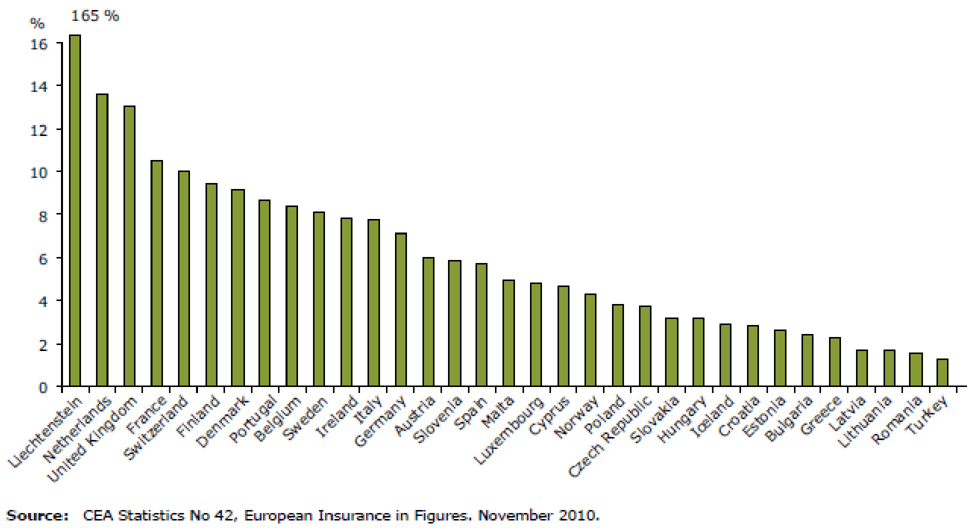
Indicator	Number of hospital beds / 1000 inhabitants
Key question	What is the ability of the city to provide health care for its residents during and after extreme weather events?
Climatic hazard	All
Dimensions	Response capacity: ability
Definition	Number of hospital beds / 1000 inhabitants
Rationale and context	The number of hospital beds reflects the ability of the city to cope during and after extreme weather events associated with climate change. For example, research shows increased admissions to hospitals during heat waves (Kovats et al., 2004); flooding also causes health problems. Disasters also may overwhelm health and nursing facilities that are forced to manage not only injuries caused by the disaster, but also chronic conditions in persons who have been unable to obtain the normal care needed to manage their conditions at home due to the disaster (Fernandez et al., 2002). Thus, having a buffer in the number of hospital beds available makes cities better prepared for extreme weather.
Data requirements and sources	Source: Urban Audit
Processing	Extraction from the Urban Audit database
Example	
Feasibility	Easy
Scientific evidence	(Scientific) justification provided in the field “rationale and context”. References: Fernandez, L.S. Byard, D., Lin, C.-C., Benson, S. and Barbera, J.A. (2002) Frail elderly as disaster victims: emergency management strategies. Prehospital and Disaster Medicine 17(2): 67-74 Kovats, R.S., Hajat, S., Wilkinson, P. (2004) Contrasting patterns of mortality and hospital admissions during hot weather and heat waves in Greater London, UK. Occupational and Environmental Medicine 61(11): 893-898.

Indicator	Demographic dependency
Key question	What is the ability of the city's population to cope independently in the event of climate hazard? What is the potential pressure on city's emergency and social care systems associated with the need to provide assistance to elderly and underage population?
Climatic hazard	All
Dimensions	Response capacity: action
Definition	The Demographic Dependency Index data represents the number of people under 20 years old and over 65 years old divided by the number of people 20-65 years old.
Rationale and context	For this index the proportion of the young and older citizens is related to the working age population. This reflects the proportion of the population which is potentially depended either on the state's support (e.g. pensioners) or on their families. The high proportion of people outside the working age can be a burden on country's and city's financial resources; these people may also require additional support in form of health and social during extreme weather events. During heat waves and flooding the older people and children tend to be disproportionately affected in terms of their physical health (Clark et al., 1998; Cutter et al., 2003; Fernandez et al., 2002); also they have been found to suffer considerable psychological trauma following flood events (Fernandez et al., 2002; Rygel et al., 2006; Tapsell et al., 2002). In addition, their carer's (e.g. parents of children) are faced with an additional responsibility and may be less efficient at the preparation for, coping during, and recovering after hazards (Clark et al., 1998; Cutter et al., 2003; Tapsell et al., 2002). In addition, those dependent on the state for accommodation (e.g. those in nursing and care homes) have been found to be more frequent victims of heat waves than those living at home (Kovats and Ebi, 2006; Hajat et al., 2006).
Data requirements and sources	Source: Urban Audit. The reference year is 2004; data for BG, CZ, FR, IE, CY, LV, FI is from 2001.
Processing	The calculation result is multiplied by 100 and represented as percentage value giving the share of young and old people compared to the working age population.

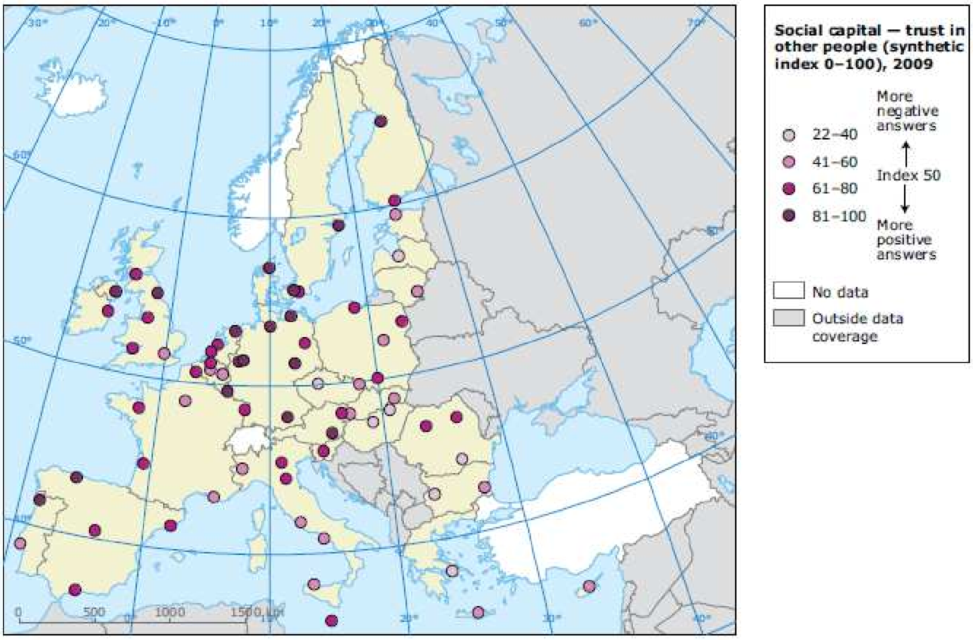
Example	 **Note:** The number of people under 20 years old and over 65 years old is divided by the number of people 20–65 years old and multiplied by 100. Data for Bulgaria, Cyprus, Czech Republic, Finland, France, Ireland and Latvia are for 2001. **Source:** Eurostat Urban Audit database, 2004. Source: EEA (2012)
Feasibility	Easy
Scientific evidence	(Scientific) justification provided in the field “rationale and context”. References: Kovats, R.S. and Ebi, K.L. (2006) heatwaves and public health in Europe. European Journal of Public Health 16 (6): 592-599. Hajat, S., Kovats, R.S. and Lachowycz, K. 2006. Heat-related and cold-related deaths in England and Wales: who is at risk? Occupational and Environmental medicine 64: 93-100. Clark, G., Moser, S., Ratick, S., Dow, K., Meyer, W., Emani, S., Jin, W., Kasperson, J., Kasperson, R., Schwarz, H.E. (1998) Assessing the vulnerability of coastal communities to extreme storms: The case of Revere, MA, USA. Mitigation and Adaptation Strategies for Global Change3: 59–82. Cutter, S.L., Boruff, B.J., Shirley, W.L., (2003) Social vulnerability to environmental hazards. Social Science Quarterly 84, 242-261.

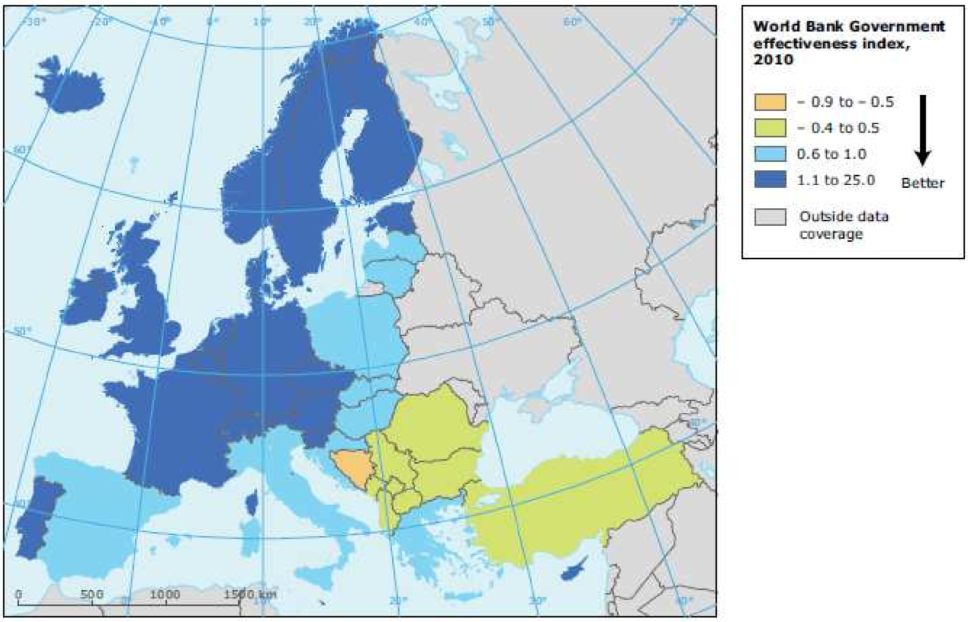
Indicator	GDP per capita in European cities
Key question	What is the ability of the city to cope financially in the event of extreme weather? What is the ability of a city to mobilise extra resources to respond to climate change events?
Climatic hazard	All
Dimensions	Response capacity: action
Definition	GDP per capita in European cities
Rationale and context	According to IPCC, the economic condition of locations, whether expressed as the economic assets, capital resources, financial means, wealth, or poverty, clearly is a determinant of adaptive capacity. It is widely accepted that wealthy nations are better prepared to bear the costs of adaptation to climate change hazards and risks than poorer nations (Smit and Pilifosova, 2001). This could be extended to cities: The wealthier cities may have higher ability to mobilise financial resources in the case of emergency. Also, the wealthy residents require less state/city support than the poorer ones.
Data requirements and sources	Source: Urban Audit. The reference year is 2004; due to data quality issues data from 2001 are used for ES (EC2001I)
Processing	The GDP data have been extracted from the Urban Audit database.
Example	 **Note:** Data for Spain are from 2001 due to data-quality issues. **Source:** Eurostat, Urban Audit database, 2004. Source: EEA (2012)
Feasibility	Easy
Scientific evidence	(Scientific) justification provided in the field "rationale and context". References: Smit, B. and Pilifosova, O. (2001) Adaptation to Climate Change in the Context of Sustainable Development and Equity in McCarthy, J.J., Canziani, O., Leary, A., Dokken, D.J. and White, K.S. (Eds.), Climate Change 2001: Impacts, Adaptation

	and Vulnerability. IPCC Working Group II, Cambridge University Press, Cambridge: pp. 877–912

Indicator	Insurance penetration as proportion of national GDP
Key question	What proportion of assets is insured in a given country?
Climatic hazard	All
Dimensions	Response capacity: action
Definition	Insurance penetration is calculated as the percentage of total insurance premiums to gross domestic product.
Rationale and context	The proportioned of insured residents and businesses reflects the preparedness for extreme weather events. According to IPCC, more extensive penetration of or access to insurance increases the ability of countries to adapt to climate change (Vellinga and Mills, 2001).
Data requirements and sources	http://www.insuranceeurope.eu/
Processing	
Example	 Source: EEA (2012)
Feasibility	Easy
Scientific evidence	(Scientific) justification provided in the field "rationale and context". References: Vellinga, P. V., E. Mills, L. Bouwer, G. Berz, S. Huq, L. Kozak, J. Paultikof, B. Schanzenbacker, S. Shida, G. Soler, C. Benson, P. Bidan, J. Bruce, P. Huyck, G. Lemcke, A. Peara, R. Radevsky, C. van Schoubroeck, A. Dlugolecki. (2001) Insurance and Other Financial Services. Chapter 8 in ***Climate Change 2001: Impacts, Vulnerability, and Adaptation***. Intergovernmental Panel on Climate Change, United Nations and World Meteorological Organization, Geneva.

Indicator	Social capital
Key question	What is the capacity of the city residents to respond together in an event of extreme weather? What is the potential for the self-help within city's neighbourhoods and communities?
Climatic hazard	All
Dimensions	Response capacity: action
Definition	The indicator reflects the perception of the cities' population on their trust in other people living in the city. The Perception Survey on the quality of life in European cities aimed at measuring local perceptions in 75 cities in the EU, Croatia and Turkey. The data are based on surveys/interviews of randomly selected citizens.
Rationale and context	Reviews of social capital indicate that the presence of bridging social capital (links between distinct groups), bonding social capital (relationships between individuals who share social identity) or linking social capital (networks of trust across authority gradients) may, albeit not necessarily, lead to an increase in resilience in societies, and that both are associated with survival and recovery from natural disasters (Wolf et al 2010). There are studies showing that people living in high crime rates may be at higher risk to overheating, as they are scared to leave their windows open at night (Klinenberg, 2002). Similarly, not trusting others may cause people to stay in a flooded area to avoid looting. Thus, higher levels of trust can contribute to the response capacity, as they enable people to act in the case of extreme weather events.
Data requirements and sources	Source: 2009 Urban Audit Perceptions Survey
Processing	The information is provided as « synthetic index ». From the perception survey data, an index was calculated by subtracting the negative answers from the positive ones and dividing the result by the total number of answers ("very much agree" and "quite agree" are counted as positive answers, whereas "very much disagree" and "quite disagree" are negative answers).This initial index has a minimum of -1 and a maximum of +1. To make it easier to use, the index was then multiplied by 50 and 50 then added to the result. The resulting index covers values between 0 and 100. A value above 50 means positive answers predominate; below 50, there are more negative answers.

Example	 Source: DG REGIO/Eurostat: Urban Perception survey 2010; data 2009. Source: EEA (2012)
Feasibility	Easy
Scientific evidence	(Scientific) justification provided in the field “rationale and context”. References: Klinenberg, E. (2002) *Heatwave: A Social Autopsy of Disaster in Chicago*. Chicago, IL: University of Chicago Press Wolf, J., Adger, N., Lorenzoni, I., Abrahamson, V. And Raine, R. (2010). Social capital, individual responses to heat waves and climate change adaptation: An empirical study of two UK cities. Global Environmental Change 20(1): 44-52.

Indicator	National government effectiveness
Key question	How effective is the national government in the opinion of country's citizens? How good the government is at formulating policies and providing public and civil services?
Climatic hazard	All
Dimensions	Response capacity: action
Definition	The Worldwide Governance Indicators report on six broad dimensions of governance for over 200 countries over the period 1996 to 2010. One of the dimensions is government effectiveness, which encompasses the population's perception of the quality of public and civil services and their degree of independence from political pressures; the quality of policy formulation and implementation; and the credibility of the government's commitment to such policies.
Rationale and context	Adger et al (2004) suggest government effectiveness as one of good governance/institutional indicators of adaptive (cf. response) capacity.
Data requirements and sources	Source: World Bank
Processing	The data for the EEA report have been extracted from the World Bank database for the reference year 2010, cut by all countries that do not belong to EEA-38 (Kosovo is not officially accepted by World Bank) and mapped per country.
Example	 Source: World Bank, 2012. Source: EEA (2012)
Feasibility	Easy
Scientific evidence	(Scientific) justification provided in the field "rationale and context".

Indicator	Political participation
Key question	What is the level of engagement between the city's residents and the local authorities? To what extent do the residents trust their local authorities?
Climatic hazard	All
Dimensions	Response capacity: action
Definition	Percentage of registered electorate voting in local elections
Rationale and context	'Voice and accountability' is one of the governance-related factors of adaptive capacity listed by Adger et al (2004); one of the ways in which it is possible to assess whether residents in a given location can voice their preferences is to find out whether there are democratic processes in place, and to what extent people participate in these. In addition, there seems to be an association between voting activity and attitudes to climate change adaptation. For example, Whitmarsh (2008) found that non-voters were significantly less likely to consider climate change a personal threat or to take action out of concern for it. However, the actual political views are also relevant. Whitmarsh (2011) found that those of more conservative views are more likely to be skeptical about climate change (see also 'Education' generic response indicator).
Data requirements and sources	Source: Urban Audit (CI1009I)
Processing	Extraction from the Urban Audit database
Example	
Feasibility	Easy
Scientific evidence	Scientific justification provided in the field "rationale and context". Reference: Whitmarsh, L. (2008) Are flood victims more concerned about climate change than other people? The role of direct experience in risk perception and behavioural response. Journal of Risk Research 11(3): 351-374.

Indicator	Urban adaptation strategies & measures
Key question	Is there an adaptations strategy at the city level which would help to coordinate responses to climate change?
Climatic hazard	All
Dimensions	Response capacity: action
Definition	Presence of an climate change adaptation strategy at the city level.
Rationale and context	Presence of an adaptations strategy at the city level suggests the commitment of the local authority to respond to climate change hazards.
Data requirements and sources	COST Action TU0902 or EU cities adapt project
Processing	
Example	
Feasibility	Easy
Scientific evidence	(Scientific) justification provided in the field “rationale and context”.

Indicator	National adaptation strategy
Key question	Is there an adaptation strategy at the national level which would help to coordinate responses to climate change and support cities in their actions?
Climatic hazard	All
Dimensions	Response capacity: action
Definition	Presence of a national adaptation strategy.
Rationale and context	Presence of a national strategy suggests a presence of supportive governance framework in which the city can develop its own adaptations measures. National adaptation strategies have become a key instrument determining how to integrate adaptation as a policy aim (Keskitalo, 2010). These strategies can embed local action into the national context and link cities and regions. They can set the framework by developing national legislation and creating a variety of standards and incentives (Swart et al., 2009). National governments can climate-proof national legislation and policy and mainstream adaptation into different areas whilst ensuring that national policies are also coherent and supportive for local adaptation (Corfee-Morlot et al., 2009). However, the presence of national strategies does not automatically mean that there are adaptive actions, or higher adaptive capacity, at the city scale. Studies show a gap between local, bottom-up adaptation and national adaptation strategies. For example in Finland, local and regional adaptation strategies and measures develop independently with very little linkages to national adaptation strategies. The national focus undermined regional and local perspectives, making the strategy less interesting for local actors (Juhola, 2010).
Data requirements and sources	UNFCCC
Processing	
Example	
Feasibility	Easy
Scientific evidence	(Scientific) justification provided in the field “rationale and context”. References: Juhola, S., 2010,'Mainstreaming Climate Change Adaptation: The Case of Multi-level Governance in Finland', in: Keskitalo, E. C. H. (ed.) *Developing adaptation policy and practice in Europe: Multi-level governance of climate change*, Springer, Dordrecht. Keskitalo, E. C. H. (ed.) (2010) *Developing adaptation policy and practice in Europe: multi-level governance of climate change*, Springer, Dordrecht, New York.

Indicators relating to specific climate hazards

Indicator	**Number of hot days and tropical nights in cities**
Key question	What is the exposure to excess heat in European cities and how will it alter in the next decades due to climate change?
Climatic hazard	Heat waves/Extremely warm weather conditions
Dimensions	Exposure
Definition	The average number of days with a maximum temperature of 35°C or more, followed or preceded by a night with a minimum temperature of 20°C or more, taking into account the Urban Heat Island effect, and occurring in the period April-September.
Rationale and context	Extremely warm weather conditions have been the most prominent hazard causing human fatalities over the past decades (EEA, 2008). The 2003 summer European heat wave alone has caused up to 70 000 excess deaths over four months in Central and Western Europe. An increased mortality is the most drastic impact of heat waves; however, exposure to hot weather can have various other impacts on human health and well-being, ranging from “bad mood”, feeling discomfort and getting sick. The impacts of summer days are extra felt in cities and towns because of the ‘Urban Heat Island’ (UHI) effect. Air temperature differences between urban areas and rural surroundings can be up to 10°C or more (Oke, 1982). Differences a re particularly high during night-time. The consecutive occurrence of hot days (maximum temperature, Tmax > 35 °C) and tropical nights (minimum temperature, Tmin >20 °C) has been found to explain spatial and temporal variation in excess mortality during recent heat waves. Under these conditions, there is no relief of cool nights and subsequent exhaustion leads to a larger impact (Grize et al., 2005; Kovats and Hajat, 2008; Dousset et al., 2011). Therefore, we propose to select the combined number of hot days (Tmax > 35 °C) and tropical nights (Tmin >20 °C) as heat exposure indicator.
Specification of data	Basic prerequisites for the indicator: The summer season is from 1 April to September; the usual 3 calendar months (June, July, August) are extended to include additional time period when heat waves may occur. Meteorological variables: Maximum and minimum values of diurnal air temperature City features population density and share of green space per city (UMZ) are used to estimate the potential UHI effect.

Data requirements and sources	The combined number of hot days and tropical nights (CHT) can be calculated from data obtained from various sources: • Gridded meteorological observations (station data) (present-day) European Climate Assessment&Data (ECA&D) project: E-OBS : http://eca.knmi.nl • Reanalysis products, available from institutes worldwide (present-day). The use of the ECMWF ERA-Interim product is recommended: ERA-Interim: http://data portal.ecmwf.int/data/d/interim_full_daily/ • Climate model projections (present-day and future): present-day and future projections from ENSEMBLES project: http://ensemblesrt3.dmi.dk • City features for population density and share of green space: Urban audit database (Eurostat) and Urban Atlas (GMES / EEA) http://www.urbanaudit.org/DataAccessed.aspxhttp://epp.eurostat.ec.europa.eu/portal/page/portal/region_cities/city_urban/data_cities/tables_sub1 http://www.eea.europa.eu/data-and-maps/data/population-density-disaggregated-with-corine-land-cover-2000-2/ http://www.eea.europa.eu/data-and-maps/data/urban-atlas http://www.eea.europa.eu/data-and-maps/data/urban-morphological-zones-2006-umz2006-f3v0
Processing	RCMs generate values for daily maximum, minimum and average air temperatures, typically on a 25 x 25 km resolution. The number of tropical days (> 35 °C) followed by tropical nights (> 20 °C) should be counted.Neither observations and reanalyses data, nor RCMs take the urban landscape into account. Therefore a correction for daily nocturnal UHI intensity is proposed. For now, until a more general relationship is available, we use the relationship between UHI and population density assessed by Steeneveld et al. 2011: $UHI_{med} = 0.1822\, xP_d^{0.2996} (r^2 = 0.55)(1)$, where UHImed is the median UHI in K and Pd is the population density of the core city in inhabitants per km2. The nocturnal UHI estimated for each city is added to the daily minimum temperatures obtained from the RCMs to estimate the daily minimum temperature in a city. Steeneveld et al. (2011) found also a quantitative relationship between UHI and % green cover. However, due to a lack of data this relationship is less certain and therefore, not proposed here, though many studies show the mitigating effect of urban green.
Feasibility	Most of the databases to be used are free licensed and also already available on the internet. Furthermore, most data undergo quality control procedure before being published and are supposed to be reliable.
Scientific evidence	Dousset, B., Gourmelon, F., Laaidi, K., Zeghnoun, A., Giraudet, E., Bretin, P., Mauri, E. and Vandentorren, S., 2011, 'Satellite monitoring of summer heat waves in the Paris metropolitan area', International Journal of Climatology, 31(2) 313–

	323. European Environment Agency, 2008. Impacts of Europe's changing climate: 2008 indicator-based assessment; joint EEA-JRC-WHO report. Luxembourg: Office for Official Publ. of the European Communities. Grize, L., Huss, A., Thommen, O., Schindler, C. and Braun-Fahrländer, C., 2005, 'Heat wave 2003 and mortality in Switzerland', Swiss Medical Weekly, 135(13–14) 200–205. Kovats, R. S. and Hajat, Shakoor, 2008, 'Heat stress and public health: A critical review', Annual Review of Public Health, 29(1) 41–55. Li, P.W. and Chan, S.T. (2000). Application of a weather stress index for alerting the public to stressful weather in Hong Kong. Meteorol Appl 7:369–375. Oke, T.R., 1982 The energetic basis of the urban heat island. Quart. J. R. Met. Soc., 108, pp. 1-24 Steeneveld, G.J., Koopmans S., , Heusinkveld, B.G., van Hove, L.W.A. and Holtslag, A.A.M., 2011. Quantifying urban heat island effects and outdoor human comfort in relation to urban morphology by exploring observations from hobby-meteorologists in the Netherlands. J. Geophys. Res.116, D20129, 14pp., doi: 10.1029/2011 JDO15988.

Indicator	**Thermal comfort index - Number of days with potentially strong heat discomfort**
Key question	What will be the potential impact on outdoor thermal comfort of citizens?
Climatic hazard	Heat waves/Extremely warm weather conditions
Dimensions	Exposure
Definition	The average number of days with a maximum effective temperature (ET) of 27°C or more, taking into account the Urban Heat Island effect, and occurring in the period April-September.
Rationale and context	Whether citizens feel comfortable or not within the urban micro climate depends not only on temperature, but on a complex interaction between physical, physiological, behavioural, and psychological factors. For the assessment of the thermal exposure of the human body, the integral effects of all thermal parameters have to be taken into account. Empirically derived indices, like the discomfort index (Thom, 1959), wet-bulb-globe-temperature (WBGT), apparent temperature (Steadman, 1979), and wind-chill index (Steadman 1971) are being used to describe thermal comfort. Though often used, these indices, consider only a limited number of the relevant meteorological parameters. Furthermore, they generally do not take into account thermal physiology. More sophisticated bio-meteorological indices, like the predicted mean vote (PMV), the physiologically equivalent temperature (PET), and the recently developed Universal Thermal Comfort Index (UTCI) are based upon models for the human heat balance which use all relevant meteorological parameters, as well as physiological factors as input (Fanger, 1970; Höppe 1999; Matzarakis et al., 2010; Fiala, 2012). These models rely on many variables, some of which may be difficult to obtain in practice for large regions. therefore, they are less suited to apply as an European-wide indicator for thermal comfort. We propose to use Effective Temperature (ET) as a thermal comfort index thatcan be considered as an alternative exposure indicator. ET is a relatively simple, direct index containing air temperature, water vapour pressure and wind speed. Results of Blazejczk et al. (2012) suggest that ET can be regarded as a reasonable proxy for the much more sophisticated UTCI. In particular during night-time, the air temperature and therefore ET in cities can be affected by the Urban Heat Island (UHI). We propose to take this effect into account as well. The potential for UHI can be estimated from population density.
Specification of data	**Meteorological variables:** • Maximum and minimum of diurnal air temperatures • Maximum and minimum relative air humidity • Daily average values of wind velocity **City features** as population density and share of green space per city (UMZ) are

	used to estimate the potential UHI effect.
Data requirements and sources	The Effective Temperature (ET) can be calculated from data obtained by: • Gridded metrological observations (station data) (present-day) European Climate Assessment Data (ECA&D) project: E-OBS : http://eca.knmi.nl • Reanalysis products, available from institutes worldwide (present-day). The use of the ECMWF ERA-Interim product is recommended: ERA-Interim: http://data portal.ecmwf.int/data/d/interim_full_daily/ • Climate model projections (present-day and future): present-day and future projections from ENSEMBLES project: http://ensemblesrt3.dmi.dk • City features for population density and share of green space: Urban audit database (Eurostat) and Urban Atlas (GMES / EEA) http://www.urbanaudit.org/DataAccessed.aspxhttp://epp.eurostat.ec.europa.eu/portal/page/portal/region_cities/city_urban/data_cities/tables_sub1 http://www.eea.europa.eu/data-and-maps/data/population-density-disaggregated-with-corine-land-cover-2000-2/ http://www.eea.europa.eu/data-and-maps/data/urban-atlas http://www.eea.europa.eu/data-and-maps/data/urban-morphological-zones-2006-umz2006-f3v0
Processing	Neither observations and reanalyses data, nor RCMs take the urban landscape into account. Therefore a correction for daily nocturnal UHI intensity is proposed. For now, until a more general relationship is available, we use the relationship between UHI and population density assessed by Steeneveld et al. 2011: $UHI_{med} = 0.1822\, xP_d^{0.2996} (r^2 = 0.55) (1)$ where UHImed is the median UHI in K and Pd is the population density of the core city in inhabitants per km2. Steeneveld et al. (2011) found also a quantitative relationship between UHI and % green cover. However, due to a lack of data this relationship is less certain and therefore, not proposed here, though many studies show the importance of urban green in mitigating heat in the urban environment. The nocturnal UHI estimated for each city is added to the daily minimum temperatures obtained from the RCMs to estimate the daily minimum temperature in a city. To assess the potential impact on outdoor thermal comfort and heat stress, daily maximum (daytime) and minimum (night time) effective temperatures for cities are estimated according to: $\mathrm{ET} = 37 - \frac{37 - \mathrm{T_{air}}}{0.68 - 0.0014\,\mathrm{RH} + \frac{1}{1.76 + 1.4 w_s^{0.75}}} - 0.29\, T_{air} (1 - 0.01\,\mathrm{RH}) \qquad (2)$

where Tair is the air temperature, RH the relative humidity (%) of the air and ws the average wind speed (m/s). The maximum RH should be combined with the minumum T, since maximum RH usually occurs during the night. For now, we assume that RHs in the urban outdoor areas are not much different from those in the rural surroundings. Observational data of wind speed in the urban environment are scarce. The available datasets indicate that the wind speeds in the urban environment are much lower than in the rural surroundings. Particularly at hot days, wind speeds are usually low (< 2 m s-1). Preliminary estimations (see annex 2) show that only a small error is made by filling in a fixed wind speed of 1 m s-1 for urban areas in equation (3).

Table 2 shows the thresholds for ET that are in use in Central Europe:

Table 2. Thresholds for Effective Temperature

ET ranges (°C)	Thermal stress
>27	Hot
23-27	Warm
21-23	Comfortable
17-21	Fresh
9-17	Cool
1-9	Cold
< 1	Very cold

Feasibility

Most of the databases to be used are free licensed and also already available on the internet. Furthermore, most data undergo quality control procedure before being published and are supposed to be reliable.

Sometimes, RH is not available directly. In those cases it can be computed from the atmospheric moisture variable that is actually made available, such as dew-point temperature.

Scientific evidence

Blazejczyk, K., Epstein, Y., Jendritzky, G., Staiger, H., and Tinz, B. (2012). Comparison of UTCI to selected thermal indices. Int J Biometeorol (2012) 56:515–535 DOI 10.1007/s00484-011-0453-2.

Fanger PO (1970) Thermal comfort—analysis and applications in environmental engineering. McGraw Hill, New York, pp 19–43.

Fiala, D., G. Havenith, P. Bröde , B. Kampmann, G. Jendritzky, 2012: UTCI-Fiala multi-node model of human heat transfer and temperature regulation. Int. J. Biometerol., 56(3), 429-4

Fischer, E.M. and Schär, C. (2010). Consistent geographical patterns of changes in high-impact European heat waves. Nature Geoscience, Published online: 16 May 2010, DOI: 10.1038/NGEO866, 1 - 6.

Grize, L., Huss, A., Thommen, O., Schindler, C. and Braun-Fahrländer, C., 2005, 'Heat wave 2003 and mortality in Switzerland', Swiss Medical Weekly, 135(13–14) 200–205.

Höppe, P. (1999). The physiological equivalent temperature – a universal index for the biometeorological assessment of the thermal environment. Int. J. Biometeorol. 43, 71-75.

Kovats, R. S. and Hajat, Shakoor, 2008, 'Heat stress and public health: A critical review', Annual Review of Public Health, 29(1) 41–55.

Li, P.W. and Chan, S.T. (2000). Application of a weather stress index for alerting the public to stressful weather in Hong Kong. Meteorol Appl 7:369–375.

Matzarakis, A., Rutz, F., and Mayer, H. (2010). Modelling radiation fluxes in simple and complex environments: basics of the RayMan model. Int. J. Biometeorol. 54: 131-139.

Missenard, F.A. (1933). Température effective d’une atmosphere Généralisation température résultante d’un milieu. In: Encyclopédie Industrielle et Commerciale, Etude physiologique et technique de la ventilation. Librerie de l’Enseignement Technique, Paris, pp 131–185

Steadman, R.G. (1971) Indices of windchill of clothed persons. J. Appl Meteorol 10:674–683.

Steadman, R.G. (1979) The assessment of sultriness. Part I. A temperature-humidity index based on human physiology and clothing science. J Appl Meteorol 18:861–873

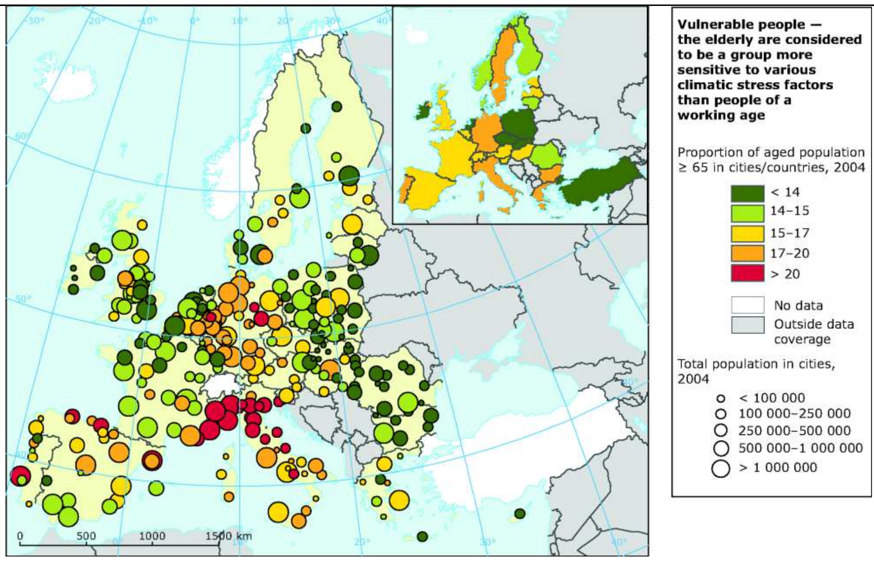
Steeneveld, G.J., Koopmans S., , Heusinkveld, B.G., van Hove, L.W.A. and Holtslag, A.A.M. (2011). Quantifying urban heat island effects and outdoor human comfort in relation to urban morphology by exploring observations from hobby-meteorologists in the Netherlands. J. Geophys. Res.116, D20129, 14pp., doi: 10.1029/2011 JDO15988.

Thom EC (1959). The discomfort Index. Weatherwise 12:57–60.

Indicator	**Share of low-income households**
Key question	What is the current and future sensitivity of the urban population to excessive heat?
Climatic hazard	Heat waves/Extremely warm weather conditions
Dimensions	Sensitivity (state) Response (change)
Definition	Proportion of households in a city with an income less than half of the national average income for households in the country [%]
Rationale and context	Low-income households may be more sensitive to heat-related mortality (WHO, 2004; Reid et al., 2009; Schauser et al., 2010). For 11 large eastern US cities in 1973–1994, Curriero et al. (2002) found that the percentage people living in poverty was associated with increased mortality effects of high temperature. A modest increase in risk of heat-related death was observed for those making less than (versus more than) $10,000 during the 1999 Chicago heat wave (Naughton et al., 2002). In Seoul, Korea, people of low income had higher mortality rates during hot weather (Kim and Joh, 2006). The increased risk may be due to poor quality of housing and lack of air conditioning, as well as lack of access to resources and transportation. U.S. studies indicate that air conditioning is an important protective factor for heat related mortality in the USA (Semenza et al., 1996; Naughton et al., 2002). Individuals on low incomes are also more likely to have a chronic disease or other medical risk factors, such as obesity or mental illness, which will increase the risk of heat-related mortality (Kovats and Hajat, 2008). So far, most studies on the influence of socio-economic factors have been conducted for cities in the US. There is a lack of information for European cities. Stafoggia et al. (2006) analysed heat-related mortality for four Italian cities and reported a higher risk in low-income groups. e propose to select the percentage of households with less than half the national average as a social sensitivity indicator to heat-related mortality. This may be arbitrary, but the same would apply to other possible indicators, since no evidence basis exists linking such specific indicators to heat sensitivity.
Data requirements and sources	The urban audit database includes various socio-economic indicators of among which percentage of households with less than half the national average income. http://www.urbanaudit.org/DataAccessed.aspxhttp://epp.eurostat.ec.europa.eu/portal/page/portal/region_cities/city_urban/data_cities/tables_sub1
Processing	Take from Urban Audit
Feasibility	Easy for current status; currently no projections available
Scientific evidence	Eurostat, 2008, 'Population projections 2008–2060 — from 2015, deaths projected to outnumber births in the EU-27', Eurostat, Luxembourg. Kim, Y., and S. Joh, 2006. A vulnerability study of the low-income elderly in the

	context of high temperature and mortality in Seoul, Korea. Sci Total Environ 371(1-3): 82-88. Kovats, R. S. and Hajat, S., 2008. Heat stress and public health: A critical review. Annual Review of Public Health 29:41–55. Reid, C. E. , M. S. O'Neill, C. J. Gronlund, S. J. Brines, D. G. Brown, A. V. Diez-Roux, and J Schwartz (2009). Mapping Community Determinants of Heat Vulnerability. Environmental Health Perspectives 117(11), pp. 1730-1736. Stafoggia M, Forastiere F, Agostini D, Biggeri A, Bisanti L, et al. 2006. Vulnerability to heat-related mortality: a multi-city population based case-crossover analysis. Epidemiology 17:315–23 Schauser, I., Otto, S., Schneiderbauer, S., Harvey, A., Hodgson, N., Robrecht, H., Morchain, D., Schrander, J.-J., Khovanskaia, M., Celikyilmaz-Aydemir, G., Prutsch, A. and McCallum, S., 2010, Urban regions: vulnerabilities, vulnerability assessments by indicators and adaptation options for climate change impacts — Scoping study, ETC/ACC Technical Paper, European Topic Centre on Air and Climate Change, Bilthoven. WHO, 2004. Heat waves: risks and responses. Health and Global environmental change series, no 2. 124 pp.

Indicator	**Share of urban population with an age of 65 years or older**
Key question	What is the current and future sensitivity of the urban population to excessive heat?
Climatic hazard	Heat waves/Extremely warm weather conditions; Floods Droughts and water scarcity
Dimensions	Sensitivity
Definition	The proportion of people in a city with an age of 65 or older [%]
Rationale and context	Senior citizens are more sensitive to heat because of intrinsic changes in the thermo-regulatory system and because of the use of drugs that interfere with normal homeostasis. Many epidemiological studies mention 65 years or older as the age above which the sensitivity to heat starts to increase. However, this age threshold is often predetermined and it is not entirely clear yet at which age above 65 years the sensitivity really increases. Also, it remains unclear whether women or men are more at risk of dying in a heat wave (Kovats and Hajat, 2008; Reid et al, 2009; WHO, 2004). However, in practice mortality rates during heat waves are found to be associated with the share of population with an age over 65 years (Kovats and Hajat, 2008). Despite the shortcomings, we therefore propose to use the share of an urban population with an age of 65 years and older as an 'overall' sensitivity indicator to heat This population group currently constitutes about 17.1% of the total population of Europe, but this share is expected to rise to 30% by the year 2060. The share of people aged 80 years or older (4.4% in 2008) will even nearly triple by 2060 (Schauser et al., 2010; Eurostat, 2008). Obviously, this demographic trend will lead to an increased sensitivity to heat. However, demographic developments of cities may deviate from regional trends. No European wide demographic projections at city level are available yet and consequently, it is not well possible to project how the sensitivity will change in the next decades. Other indicators may be possible, such as lone pensioner households, but it is not clear what additional information that would provide.
Data requirements and sources	Demographic information is available from the urban audit database. The database is however not gender specific. If information on future demographic developments of particular cities is available, this can be used to make future projections. As such, an indication about the change in sensitivity to heat can be obtained. http://www.urbanaudit.org/DataAccessed.aspxhttp://epp.eurostat.ec.europa.eu/portal/page/portal/region_cities/city_urban/data_cities/tables_sub1
Processing	The proportion of aged population ≥65 in cities can be classified (see legenda in figure below).

Example (if available)	
Feasibility	Easy for current data; currently not available for projections.
Scientific evidence	Eurostat, 2008, 'Population projections 2008–2060 — from 2015, deaths projected to outnumber births in the EU-27', Eurostat, Luxembourg. Kovats, R. S. and Hajat, S. (2008). Heat stress and public health: A critical review. Annual Review of Public Health 29:41–55. Reid, C. E. , M. S. O'Neill, C. J. Gronlund, S. J. Brines, D. G. Brown, A. V. Diez-Roux, and J Schwartz (2009). Mapping Community Determinants of Heat Vulnerability. Environmental Health Perspectives 117(11), pp. 1730-1736. Schauser, I., Otto, S., Schneiderbauer, S., Harvey, A., Hodgson, N., Robrecht, H., Morchain, D., Schrander, J.-J., Khovanskaia, M., Celikyilmaz-Aydemir, G., Prutsch, A. and McCallum, S., 2010, Urban regions: vulnerabilities, vulnerability assessments by indicators and adaptation options for climate change impacts — Scoping study, ETC/ACC Technical Paper, European Topic Centre on Air and Climate Change, Bilthoven. WHO, 2004. Heat waves: risks and responses. Health and Global environmental change series, no 2. 124 pp.

Indicator	**Early warning related activities (monitoring system or emergency plans)**
Key question	If there is yet any monitoring system or emergency plan available, who could/should be responsible to develop and establish it? How can the maintenance and the update of the activities be guaranteed?
Climatic hazard	Floods
Dimensions	response capacity
Definition	Presence of systems improving the response to flooding, including warning systems or emergency plans.
Rationale and context	In the case of flooding as a response to intensive rainfalls the existence of (web-based) early warning system can predict expected water levels based on detailed data and models, and thereby serve as a general proxy for copying with the occurrence of flood. Of outmost importance in this context is the continuous update of the input data in order to guarantee an effective forecast with adequate warning times, a stable, user-friendly operation of models and a reliable forecast to allow for an adequate copying of the population with the occurrence of the hazard. Emergency plans can help in order to help evacuation activities and thereby enhance the overall coping capacities as there is guided information provided of how to protect from losses.
Data requirements and sources	For establishing a monitoring system detailed data and models on precipitation and water levels is necessary. For establishing emergency plans detailed information is needed on risk prone areas and transport infrastructure. The European Floods Portal brings together information on river floods and flood risk in Europe, resulting from ongoing research within the “Floods” Action at the Joint Research Centre (JRC) of the European Commission, as well as from public available information from EU countries: http://floods.jrc.ec.europa.eu/ The European Floods Awareness System (EFAS) is an early flood warning system complimentary to national and regional systems. It provides the national institutes and the European Commission with information on possible river flooding to occur within the next 3 or more days.
Processing	Use existing dynamic GIS-based Web applications in order to combine different input data.

Indicator	**Distribution of urban green spaces**
Key question	How resilient is a city regarding heat waves? Is the distribution of urban green and blue spaces adequate to provide necessary cooling for cities and their residents? Do urban green spaces increase the thermal comfort in cities and alleviate stress to vulnerable citizens (the elderly and the very young, those with health problems)?
Climatic hazard	Heat waves
Dimensions	Exposure Response capacity (changing distribution of green space)
Definition	The indicator provides the edge density per km² of edges/boundaries between green and red (built-up) areas of the cities, by that representing a proxy for the distribution of urban green spaces [m/ha]
Rationale and context	Heat waves have been the most prominent hazard causing human fatalities over the past decades (EEA, 2012a). The 2003 summer European heat wave alone has caused up to 70 000 excess deaths over four month in Central and Western Europe. An increased mortality is the most drastic impact of heat waves; however, exposure to hot weather can have various other impacts on human health and well-being, ranging from “bad mood”, feeling discomfort and getting sick. The impact of heat waves is particularly strong in cities and towns. The so-called ‘Urban Heat Island’ (UHI) describes the increased temperature of the urban air compared to its rural surroundings. The temperature difference can be up to 10°C or more (Oke, 1982). The difference is in particular high at night time. It is a well-known and documented fact that the land surface temperature and the share of vegetation are related to each other (Chen et al., 2006; Jusuf et al., 2007; Gabor and Jombach, 2009; Klok et al., 2012). The ameliorating thermal effect induced by green spaces inside the warm urban microclimate of densely populated cities can improve the thermal comfort, as well as the overall health and living conditions of their inhabitants. The effect of urban green spaces on UHI is primarily provided by shading and evapotranspiration. In cities, most notably, the cooling effect of vegetated surfaces is replaced by storage of heat in impervious engineered surfaces. Consequently, the more urban green spaces a city still contains and the better distributed these green spaces are, the lesser the impact of the UHI effect. Indeed, for cities in the Netherlands, Steeneveld et al. (2011) found that an increase in the percentage of surface area covered with green vegetation decreases the maximum UHI intensity significantly. The cooling effect of vegetation can be identified at different scales, from buildings (green and blue roofs, green walls), streets (trees, tree rows), to regions and

	complete cities (parks, green lanes, etc). Cooling effects of parks have been observed at distances up to 500 m or more (Bowler et al., 2010). Also green spaces at the fringes of the cities provide beneficial effects in terms of recreational and cooling functions. These aspects will be analysed by two indicators, (i) the share of urban green spaces (see separate indicator factsheet), and (ii) the edge density between green and non-green (i.e. “red”) space as a proxy for the distribution of green spaces. The land use data source is the GMES Urban Atlas data base[20], which provides reliable, inter-comparable, high-resolution land use maps for 305 Large Urban Zones and their surroundings for the reference year 2006. The selection of classes contained in the urban green spaces is based on their relevance for the Urban Heat Island effect, i.e. agricultural areas and forests are included as well. The share of urban green spaces is calculated for on the one hand the Urban Morphological Zone (UMZ[21]) of the city and on the other hand a buffer that is created around the UMZ. The buffer has a width of 5km and should account for the fringe of the urban areas. Although the effect of size and connectivity of parks on the cooling effect are not very well known[22], the distribution of urban green spaces provides relevant information related to the response capacity to heat for several reasons: Improved accessibility for citizens Shorter distances between green and blue urban areas improve the connectivity and hence provide higher chances for biodiversity maintenance, green infrastructure elements More equally distributed cooling effect, especially for the cooling effect in the surroundings of parks and other green spaces. The edge density between the green spaces and the remaining “red” space of the cities is computed based on the total edge lengths and related to a homogeneous reference unit to account for the varying sizes of European cities. The edge density provides an indication about the distribution of urban green spaces such that one can interpret that a high edge density in a city indicates a relatively high number of green patches with borders to the sealed parts of the urban fabric made up of residential and commercial/industrial/public buildings. The edge lengths and derived density are calculated for the red-green edges within the UMZ inside the core city. It can be concluded that the status information of the share and the distribution of urban green in a city can be used as an overall biophysical sensitivity indicator for

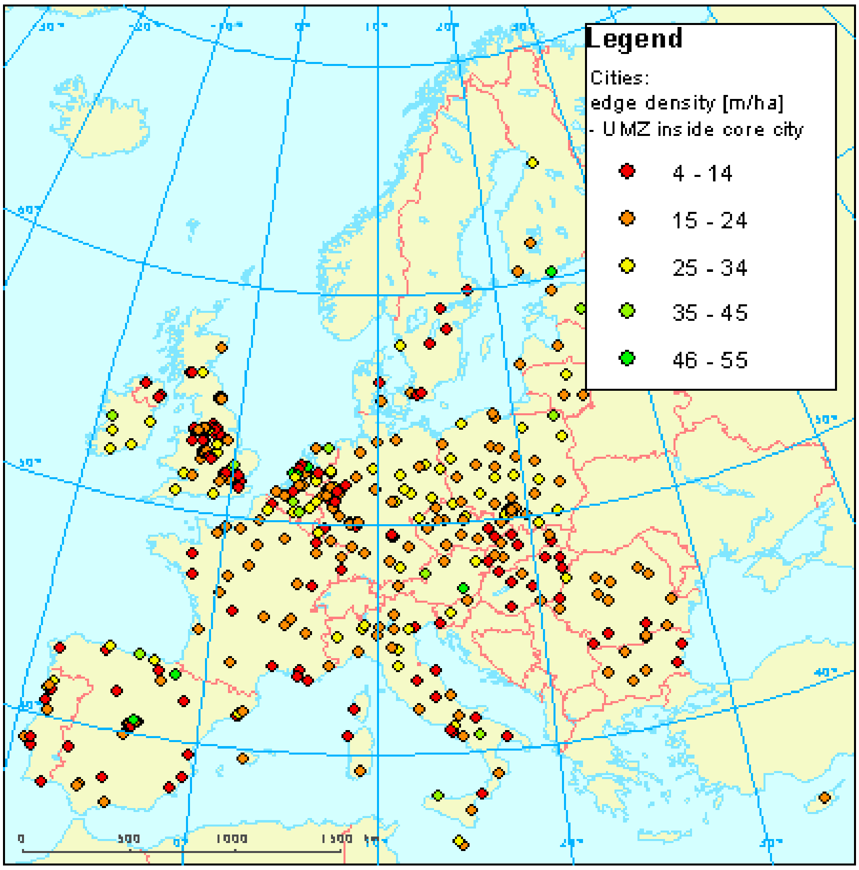
[20] http://www.eea.europa.eu/data-and-maps/data/urban-atlas
[21] http://www.eea.europa.eu/data-and-maps/data/urban-morphological-zones-2000-umz2000-f1v0
[22] An analysis of the effect of area, spatial structure and/or distribution of green spaces on the UHI effect across several cities (preferably across Europe has not yet been done). Such an analysis would help to identify good indicators.

	the potential UHI of a city, while change information would belong to response capacity.
Data requirements and sources	GMES Urban Atlas to extract the relevant classes and produce the maps of urban green spaces from which the statistics can be computed. Data available for download from the EEA data service: http://www.eea.europa.eu/data-and-maps/data/urban-atlas. Urban Morphological Zones as reference unit for the city morphology (as best approximation of the "real" city form, which is often not corresponding to the administrative delineation), available from the EEA data service: http://www.eea.europa.eu/data-and-maps/data/urban-morphological-zones-2000-umz2000-f1v0. NB: In the current processing we use all UMZ patches which are located within the core city boundaries.
Processing	Basic reference units for the processing are the UMZ inside the core city which function as a representation of the "real" city. In addition, to account for the urban fringe a buffer of 5km is computed around the UMZ, which can also exceed the core city boundary. By consequence, two strata are created: (i) "green" and (ii) "red". Urban green spaces are extracted from the Urban Atlas product, i.e. values for 369 core cities are available. The following selection has been made, all listed classes are components of the urban green spaces:

CODE	Urban Atlas classes
11230	Discontinuous Low Density Urban Fabric (S.L. : 10% - 30%)
11240	Discontinuous Very Low Density Urban Fabric (S.L. < 10%)
14100	Urban green spaces
14200	Sports and leisure facilities
20000	Agricultural areas, semi-natural areas and wetlands
30000	Forests

In the current context, we suggest adjusting the existing indicator used by the EEA in the recent report on urban adaptation ('Share of green and blue urban areas') by excluding the area of water bodies.

Intra-urban edges are computed within the UMZ between the red and the green spaces and summed up to result in a total edge length value per city. Afterwards, the total edge length is put in relation to the reference surface area and converted into an edge density, this to account for the varying sizes of the European cities.

	For the map production the values are classified into 5 classes and presented as coloured dots on the map: green dots represent cities with a high or relatively higher edge density, red and orange dots correspond to cities with a low edge density.
Example	
Feasibility	Easy
Scientific evidence	Bowler, D.E.; Lisette M Buyung-Ali, Teri M Knight and Andrew S Pullin (2010): A systematic review of evidence for the added benefits to health of exposure to natural environments. BMC Public Health 2010, 10:456 Chen, X.L., Zhao, H.M., LI, P.X., Yin, Z.Y. (2006): Remote sensing image based analysis of the relationship between urban heat island and land use/cover changes – Remote Sensing of Environment 104: 133-146. EEA (2012a). Urban adaptation to climate change in Europe - Challenges and opportunities for cities together with supportive national and European policies. European Environment Agency Report No 2/2012, Copenhagen, Denmark. Gabor and Jombach (2009). The relation between the biological activity and the land surface temperature in Budapest. App. Ecology and Environm. Research 7:241-251.

	Jusuf, S.K.l., Wong, N.H., Hagen, E., Anggoro, R., Hong, Y. (2007). The influence of land use on the urban heat island in Singapore. Habitat International 31: 232-242. Klok, L., Zwart, S., Verhagen, H., & Mauri, E. (2012). The surface heat island of Rotterdam and its relationship with urban surface. Resources, Conservation and Recycling. doi: 10.1016/j.resconrec.2012.01.009. Oke, T. R. (1982): "The energetic basis of the urban heat island". Quarterly Journal of the Royal Meteorological Society 108 (455): 1–24. Steeneveld, G.J., Koopmans S., , Heusinkveld, B.G., van Hove, L.W.A. and Holtslag, A.A.M. (2011). Quantifyingeffects and outdoor human comfort in relation to urban morphology by exploring observations from hobby-meteorologists in the Netherlands. J. Geophys. Res.116, D20129, 14pp.

Indicator	**Share of urban green space**
Key question	How resilient is a city regarding heat waves? Is the share of green and blue urban space sufficient to provide necessary cooling for cities and their residents? Do urban green spaces increase the thermal comfort in cities and alleviate stress to vulnerable citizens (elderly and very young, disease-prone)?
Climatic hazard	Heat waves, floods, droughts and water scarcity
Dimensions	Exposure Response capacity (change in the proportion of urban green space)
Definition	The indicator presents the fraction of green spaces in European cities for two units (core city, fringes) [%]
Rationale and context	Heat waves have been the most prominent hazard causing human fatalities over the past decades (EEA, 2012a). The 2003 summer European heat wave alone has caused up to 70 000 excess deaths over four month in Central and Western Europe. An increased mortality is the most drastic impact of heat waves; however, exposure to hot weather can have various other impacts on human health and well-being, ranging from “bad mood”, feeling discomfort and getting sick. The impact of heat waves is particularly strong in cities and towns. The so-called ‘Urban Heat Island’ (UHI) describes the increased temperature of the urban air compared to its rural surroundings. The temperature difference can be up to 10°C or more (Oke, 1982). The difference is in particular high at night time. It is a well-known and documented fact that the land surface temperature and the share of vegetation are related to each other (Chen et al., 2006; Jusuf et al., 2007; Gabor and Jombach, 2009; Klok et al., 2012). The ameliorating thermal effect induced by green spaces inside the warm urban microclimate of densely populated cities can improve the thermal comfort, as well as the overall health and living conditions of their inhabitants. The effect of green infrastructure on UHI is primarily provided by shading and evapotranspiration. In cities, most notably, the cooling effect of vegetated surfaces is replaced by storage of heat in impervious engineered surfaces. Consequently, the more urban green spaces a city still contains and the better distributed these green spaces are, the lesser the impact of the UHI effect. Indeed, for cities in the Netherlands, Steeneveld et al. (2011) found that an increase in the percentage of surface area covered with green vegetation decreases the maximum UHI intensity significantly. The cooling effect of vegetation can be identified at different scales, from buildings (green and blue roofs, green walls), streets (trees, tree rows), to regions and complete cities (parks, green lanes, etc). Cooling effects of parks have been observed at distances up to 500 m or more (Bowler et al., 2010). Also green spaces at the fringes of the cities provide beneficial effects in terms of recreational and cooling functions.. The urban fringe is hence also accounted for in this study. These aspects will be analysed by two indicators, (i) the share of urban green spaces, and (ii) the edge density between green and non-green (i.e. “red”) space as a

<table>
<tr><td></td><td>proxy for the distribution of green spaces. The land use data source is the GMES Urban Atlas data base[23], which provides reliable, inter-comparable, high-resolution land use maps for 305 Large Urban Zones and their surroundings for the reference year 2006. The selection of classes contained in the urban green spaces is based on their relevance for the Urban Heat Island effect, i.e. agricultural areas and forests are included as well. The share of urban green spaces is calculated for on the one hand the Urban Morphological Zone (UMZ[24]) of the city and on the other hand a buffer that is created around the UMZ. The buffer has a width of 5km and should account for the fringe of the urban areas.

It can be concluded that the status information of the share and the distribution of urban green in a city can be used as an overall biophysical sensitivity indicator for the potential UHI of a city, while change information would belong to response capacity.</td></tr>
<tr><td>Data requirements and sources</td><td>GMES Urban Atlas to extract the relevant classes and produce the maps of urban green spaces from which the statistics can be computed. Data available for download from the EEA data service: http://www.eea.europa.eu/data-and-maps/data/urban-atlas.

Urban Morphological Zones as reference unit for the city morphology (as best approximation of the “real” city form, which is often not corresponding to the administrative delineation), available from the EEA data service: http://www.eea.europa.eu/data-and-maps/data/urban-morphological-zones-2000-umz2000-f1v0. NB: In the current processing we use all UMZ patches which are located within the core city boundaries.</td></tr>
<tr><td>Processing</td><td>Basic reference unit for the processing are the UMZ inside the core city which function as a representation of the “real” city. In addition, to account for the urban fringe a buffer of 5km is computed around the UMZ, which can also exceed the core city boundary. By consequence, two strata are created: (i) “green” and (ii) “red”.

Urban green spaces are extracted from the Urban Atlas product, i.e. values for 369 core cities are available. The following selection has been made, all listed classes are components of the urban green spaces:

<table><tr><th>CODE</th><th>Urban Atlas classes</th></tr><tr><td>11230</td><td>Discontinuous Low Density Urban Fabric (S.L. : 10% - 30%)</td></tr><tr><td>11240</td><td>Discontinuous Very Low Density Urban Fabric (S.L. < 10%)</td></tr></table></td></tr>
</table>

[23] http://www.eea.europa.eu/data-and-maps/data/urban-atlas
[24] http://www.eea.europa.eu/data-and-maps/data/urban-morphological-zones-2000-umz2000-f1v0

14100	Urban green spaces	
14200	Sports and leisure facilities	
20000	Agricultural areas, semi-natural areas and wetlands	
30000	Forests	

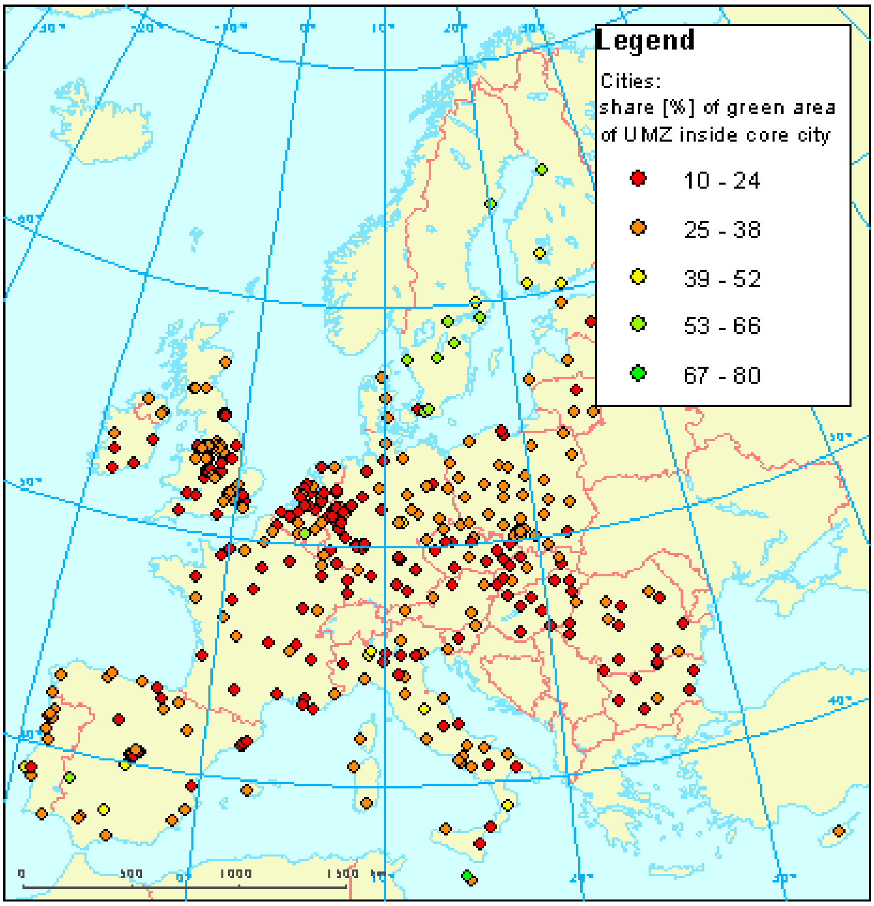
Here, we suggest adjusting the existing indicator used by the EEA in the recent report on urban adaptation (‘Share of green and blue urban areas’) by excluding the area of water bodies.

The extracted polygons are grouped into to create a “green” class. Afterwards, the total area of all “green” patches is summed up and its share calculated

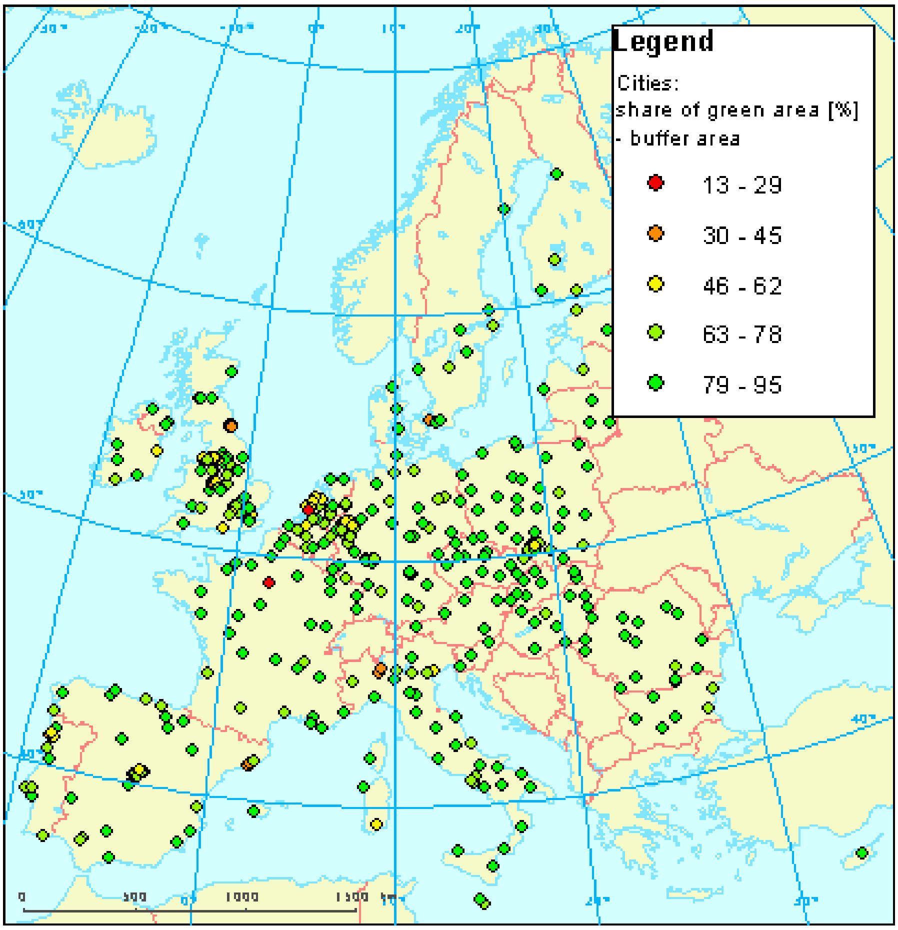
in relation to the total area of the UMZ (within the core city); and

in relation to the buffer of 5km around the UMZ.

For the map production the values are classified into 5 classes and presented as coloured dots on the map: green dots represent cities with a high or relatively higher share of green and blue urban areas, red and orange dots correspond to cities with a low share.

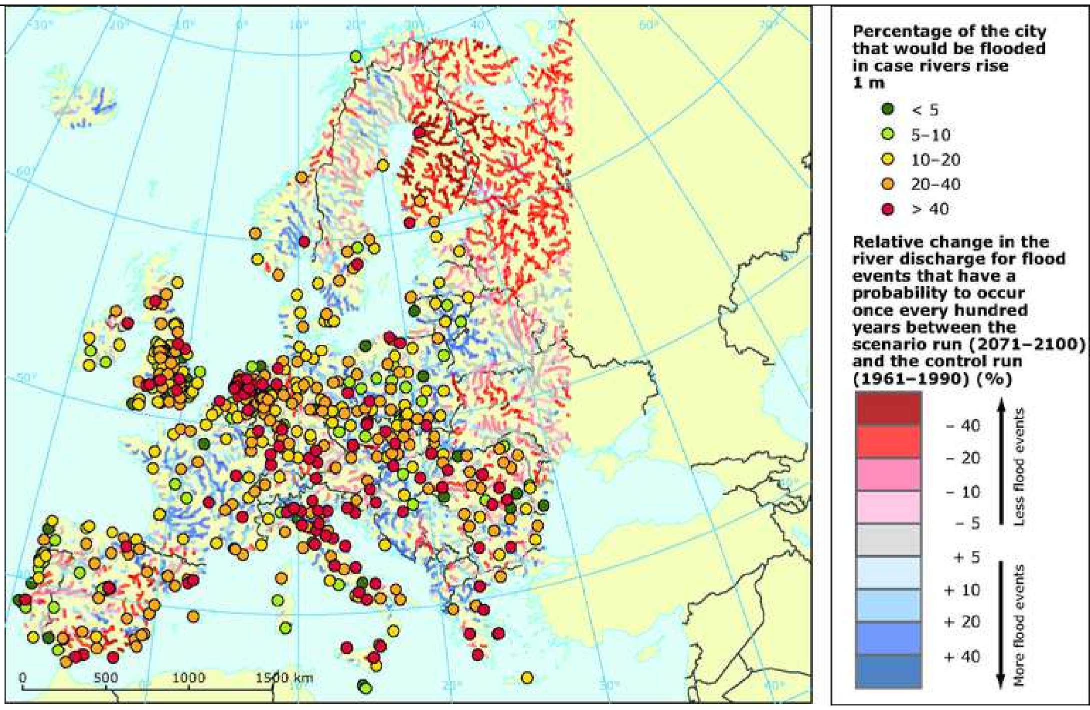
<table>
<tr>
<td>Example</td>
<td>


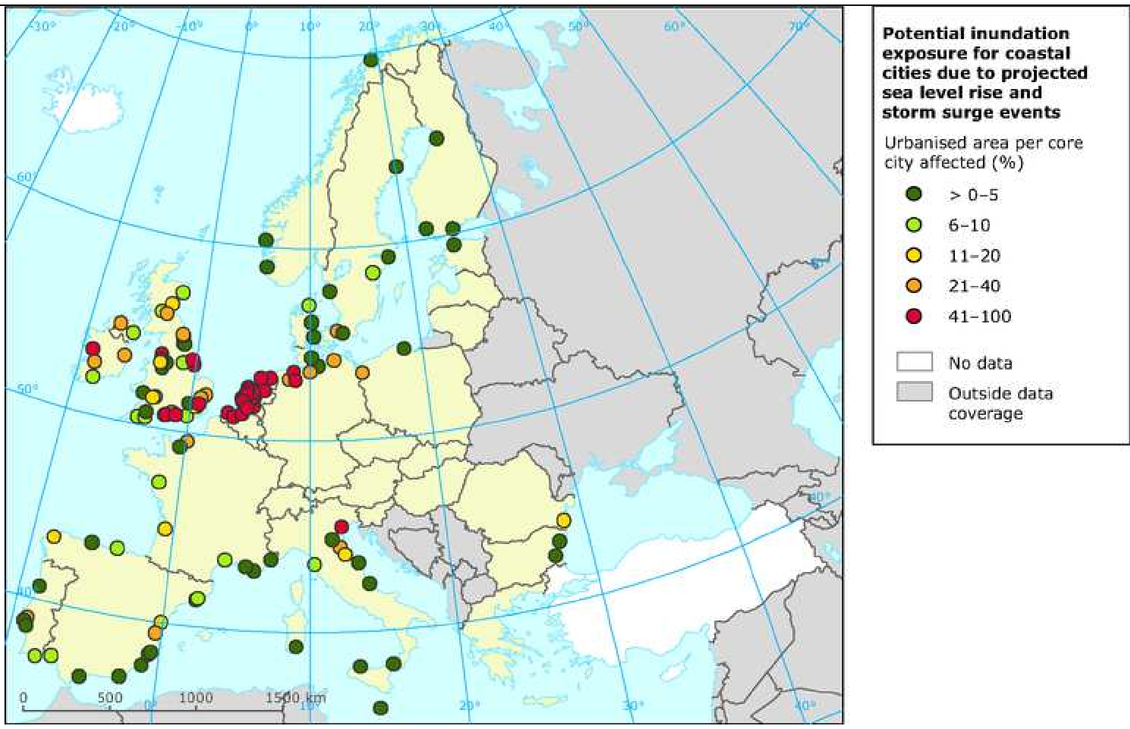
</td>
</tr>
</table>

	
Feasibility	Easy
Scientific evidence	Bowler, D.E.; Lisette M Buyung-Ali, Teri M Knight and Andrew S Pullin (2010): A systematic review of evidence for the added benefits to health of exposure to natural environments. BMC Public Health 2010, 10:456 Chen, X.L., Zhao, H.M., LI, P.X., Yin, Z.Y. (2006): Remote sensing image based analysis of the relationship between urban heat island and land use/cover changes – Remote Sensing of Environment 104: 133-146. EEA (2012a). Urban adaptation to climate change in Europe - Challenges and opportunities for cities together with supportive national and European policies. European Environment Agency Report No 2/2012, Copenhagen, Denmark. Gabor and Jombach (2009). The relation between the biological activity and the land surface temperature in Budapest. App. Ecology and Environm. Research 7:241-251. Jusuf, S.K.l., Wong, N.H., Hagen, E., Anggoro, R., Hong, Y. (2007). The influence of land use on the urban heat island in Singapore. Habitat International 31: 232-

	242. Klok, L., Zwart, S., Verhagen, H., & Mauri, E. (2012). The surface heat island of Rotterdam and its relationship with urban surface. Resources, Conservation and Recycling. doi: 10.1016/j.resconrec.2012.01.009. Oke, T. R. (1982): "The energetic basis of the urban heat island". Quarterly Journal of the Royal Meteorological Society 108 (455): 1–24. Steeneveld, G.J., Koopmans S., , Heusinkveld, B.G., van Hove, L.W.A. and Holtslag, A.A.M. (2011). Quantifyingeffects and outdoor human comfort in relation to urban morphology by exploring observations from hobby-meteorologists in the Netherlands. J. Geophys. Res.116, D20129, 14pp.

Indicator	**Area potentially affected by flooding/inundation**
Key question	How resilient is a city regarding flooding? How large is the area potentially exposed to the risk of fl Are potentially flood affected areas increasing or decreasing because of climate change and/or urbar dynamics (e.g. urban sprawls or shrinkage)?
Climatic threat	Floods
Dimensions	Exposure
Rationale and context	Flood events are a complex amalgam of climatic, meteorological, hydrological and societal facto still cause the highest economic damages in Europe among all natural hazards. The reasons there manifold and relate among others to socio-economic developments and increasing settlement in floo areas as well as urbanisations processes (Barredo 2009). At the same time are urban areas, particularly prone to the impact of floods as they are defin population density, a high intensity of economic activities and infrastructure that provide not only for the immediate urban population, but also for population beyond the city limits. For the successful development of effective flood management and climate change adaptation meas strategies an identification of areas exposed to the risk of flooding. Exposure indicates the urb potentially exposed to the risk of flooding and specifies the areas subject to a potential damage or l more general sense exposure is “describing the relationship of elements at risk to the hazard and is t somehow a bridging element” (Fuchs et al., 2011, 615) at the interface of processes related to t hazard as well as processes and structures related to the layout and extent of urban areas itself. Info on exposure serves as basic information for all subsequent indicators. To assess the exposure, there is information needed on the (1) flood hazards and its different so flooding as well as on (2) urban areas itself. Ad (1): A flood means “the temporary covering by land not normally covered by water” (Flood Directive, Article 2/1). Although any further classific floods is somewhat arbitrary, the following distinction between the different kinds of floods is consi quite useful (quoted from Hildén et al., 2012, 6): Fluvial flooding occurs when water levels in a lake or reservoir rise so that water covers nearby areas, which normally are dry land. Pluvial flo caused by intense localised rainfall. Pluvial floods often cause damages in urban environm combination with overflowing sewers and high runoff in small catchments. Coastal flooding occu sea level exceeds normal levels due to storm surges, exceptional tides or tsunamis. Flooding in de river mouths may be caused by a combination of fluvial flooding with storm surges or o exceptionally high sea level. Groundwater flooding arises when underground water emerges in e quantities from either point or diffuse locations. Flash flooding is characterised by very rapid inu Ad (2): The extent of urban areas indicates areas that are exposed the risk of flooding within a city. be expressed in relative terms (i.e. proportion of urban areas exposed to the risk of flooding in relati overall urban area) and is primarily a function of the topography of an urban areas in relation to th of the hazard (e.g. a flat topography usually results in a higher percentage compared to a more co topography). Reliable information and data on pluvial, groundwater and flash floods are difficult to obtain (see whereas rainfall precipitation events and how they change as a consequence of climate change r used as a proxy (admittedly a vague one) to better understand whether pluvial and/or flash floo increase in urban areas. The most relevant and feasible exposure information can be produced with to fluvial flooding and coastal flooding (see above). Additionally we proposed to use for pluvial the degree of soil sealing as a proxy indicator, which is already maintained by the EEA.
Data requirements and sources	Fluvial flooding: risk of flooding can be calculated from data obtained by: Climate model simulation instance the present day and future projections derived from LISFLOOD model:

	http://floods.jrc.ec.europa.eu/lisflood-model.html Data on coastal flooding is available at: http://www.eea.europa.eu/data-and-maps/figures/potential-inundation-exposure-for-coastal
Processing	**Fluvial flooding**. Procedure should follow the steps outlined by the EEA (2012): http://www.eea.europa.eu/data-and-maps/figures/percentage-of-the-city-that 1) Potential flood areas by 1 m water rise were delineated for all Europe according to ETC/LUSI (20 Cities were defined by clipping UMZs inside Core City of Urban Audit. 3) Resulting layers of step 1 step 2 were crossed and, for each city (accordign definition in step 2) intersected area was calculatec each city, flooded area (step 3) was divided by total area (part of the UMZ inside the core city of Url Audit) in order to obtain the percentage. 5) Percentages obtained from the cities were grouped by qu in order to represent groups of cities in the map. Note: Flood protection measures should not be considered in the calculation. **Coastal flooding indicator***:* in principle the procedure should the same as with regard to fluvial f by using input data on sudden (storm surges) or creeping sea-level rise due to climate change f following source. The methodology and data is available at: http://www.eea.europa.eu/data-and-maps/figures/potential-inundation-exposure-for-coastal Again, technical measures should not be considered in this calculation.
Example (if available)	 http://www.eea.europa.eu/data-and-maps/figures/percentage-of-the-city-that

	 http://www.eea.europa.eu/data-and-maps/figures/potential-inundation-exposure-for-coastal
Feasibility	Reliable information and data on pluvial, groundwater and flash floods are difficult to obtain (see whereas rainfall precipitation events and how they change as a consequence of climate change r used as a proxy (admittedly a vague one) to better understand whether pluvial and/or flash floo increase in urban areas. The most relevant and feasible exposure information can be produced with to fluvial flooding and coastal flooding (see above).
Scientific evidence	(Scientific) justification provided in the field “rationale and context”.

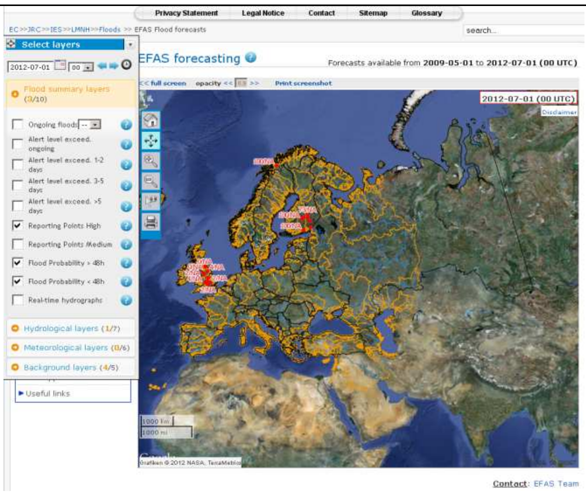
Indicator	**Population potentially affected by the risk of flooding**
Key question	How many people are exposed to the risk of flooding in an urban area? Where are hotspots that need particular attention in case of emergency?
Climatic threat	Floods
Dimensions	Sensitivity
Rationale and context	The loss of human life is surely one of the most severe negative impacts caused by flood events, but also the physical and mental consequences as well as wider social impacts contribute significantly to the overall vulnerability of an urban area. At the same time, there is no clear picture at hand about what are underlying social causes that influence and define social sensitivity to the risk of flooding. While it is usually assumed that specific characteristics, such as age, income, gender educational background and other variables would have a significant impact on the sensitivity of people to the risk of flooding, recent research results from a European cross-cultural analysis indicate that such assumptions are not easily verifiable (Kuhlicke et al., 2011, Tapsell et al. 2011). Against the background of these results, the indicator of social sensitivity is restricted to giving an overview on the quantity and spatial distribution of population within an urban area. The most feasible way of doing this is considering residential areas affected by the risk of flooding and include officially registered citizens in an urban area exposed to the risk of flooding. This indicator serves thus as proxy for expected number of residents prone to the risk of flooding.
Data requirements and sources	Information is needed on the extent of the areas exposed to different kinds of flood hazards. Therefore the output layer of the indicator "area potentially affected by the risk of flooding" should be used (see above). Additionally information on population density is needed in order to identify areas within the UMZ that are densely populated and thus particularly sensitive. http://www.eea.europa.eu/data-and-maps/data/population-density-disaggregated-with-corine-land-cover-2000-1 Data is available 100 m x 100 m. Each pixel value is the estimated density of inhab/km2. Note however that a pixel is 100 m x 100 m, ie 1 hectare. The pixel value should hence be divided by 100 in order not to overestimate the population density.
Processing	1) Output layer from exposure indicator (fluvial and sea-level rise) should be crossed with the population density layer in order to determine areas with high population density and thus high sensitivity.
Example (if available)	
Feasibility	Easy
Scientific evidence	(Scientific) justification provided in the field "rationale and context".

Indicator	**Industrial/commercial area affected by the risk of flooding**
Key question	How sensitive is an urban area to an impact of flood events? Which areas are economically particularly affected?
Climatic threat	Floods
Dimensions	Sensitivity
Rationale and context	Floods not only affect the population of citizens; they quite often have severe impacts on companies and entire industries. The impact usually takes place on three different levels: The first level is immediate impact on the physical structure of a factory or office as well as its interiors and production equipment. As long as the physical space is flooded or as long it is not restored to a functioning level, a company is not able to work or an industrial site not able to produce. This results in secondary impacts as production might no longer be possible. A car company, for instance, will no longer be able to produce cars (outputs) in monetary losses. This might result on a third level in the reduction of productivity in dependent entities as suppliers might no longer be able to produce pieced on which other industries depend. However, assessing the sensitivity of industries and companies to the impact of flooding is anything than trivial, whereas the assessment procedures depends largely on the scale of assessment (Green et al., 2011; Lequeux and Ciavola, 2012). For a European approach is seems therefore feasible to develop an indicator that only includes information about commercial and industrial areas exposed to the risk of flooding in urban areas. This indicator simply specifies the geographical expansion of commercial/industrial and serves as a general proxy to what extent industrial/commercial areas are exposed to the risk of flooding, whereas a higher share of such areas would mean in increased vulnerability of a given city. The indicator would neither provide information on the economic sensitivity of an urban area nor of the relevance individual companies/industries or the entire city might have within regional, national or global networks of exchange and interdependency (Sassen, 1991).
Data requirements and sources	Information is needed on the extent of the areas exposed to different kinds of flood hazards. Therefore the output layer of the indicator “area potentially affected by the risk of flooding” should be used (see above). Additionally information on the extent of commercial and industrial areas in a city is needed. Data can be obtained from the Urban Atlas’s Core Zone 121 – Industrial or commercial units http://www.eea.europa.eu/data-and-maps/data/urban-morphological-zones-2006-umz2006-f3v0
Processing	(1) Output layer from exposure indicator (fluvial and sea-level rise) should be crossed with the commercial/industrial layer, (2) For each city, exposed commercial/industrial area should be divided by total exposed area (outcome of exposure indicator) in order to obtain the percentage of exposed industrial/commercial area in comparison to the entire exposed area.
Example (if	

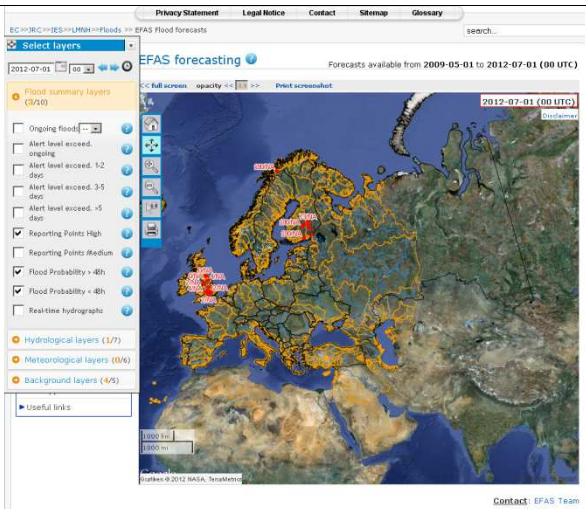
available)	
Feasibility	Easy
Scientific evidence	(Scientific) justification provided in the field “rationale and context”.

Indicator	**Sensitivity of (critical) infrastructure**
Key question	How resilient is a city regarding flooding? How sensitive is the infrastructure in an urban area to the risk of flooding? What kind of infrastructure is exposed to the risk of flooding?
Climatic threat	Floods
Dimensions	Sensitivity
Rationale and context	Infrastructures are an important basis of urban life which is densely networked and defined by a highly differentiated society. Infrastructures provide services (such as provision of water, electricity or social services) that ensure a high standard of living and economic productivity. How dependent modern (urban) societies are on these kinds of lifelines becomes particularly obvious when such services are no longer provided. The criticality of infrastructure services becomes most evident and visible in case of failure, when services and resources are suddenly not available anymore“ (Fekete 2011, 15). In this sense the failures of critical infrastructure means a substantial disturbance of public life and undermine the security of service supply (Lenz 2009, 19). More the sensitivity of critical infrastructure depends on two overarching elements (based on Fekete 2011): (1) The quantity of elements or nodes of infrastructure as well as critical number of services provided by that infrastructure. If a flood reaches a certain water level or a certain threshold this will seriously affect an infrastructure system upon which other infrastructures, companies/industries or the urban populations depends; (2) the duration of outage of an infrastructure which depends, among others, on the speed of onset, specific critical times frames, but also average time to restore its functionality. There are many different kinds of infrastructure and there are many different way of characterising them. Quite often it is distinguished in technical basic structures as well as social infrastructures. While the first three types of infrastructure are based on some kind of technical elements, the last two are rather based on social aspects (although they also contain technical components. a. Transport and traffic related infrastructure (% by type in LUZ) b. Water related infrastructure (e.g. sewage) c. Electricity related infrastructure (e.g. grids, power plants etc.) d. Social infrastructure (e.g. schools, kindergarten, nursery homes, hospitals,) e. Emergency related infrastructure (e.g. fire departments, police stations, other relevant public institutions etc.) Assessing the sensitivity of infrastructure to the risk of flooding is a challenging task as data is quite often not public available since many infrastructures are operated privately. Furthermore, their sensitivity depends critically on the exact spatial location and parameters of the floods (e.g. depth, velocity, speed, duration) but also on the physical condition of the very structures. Therefore it is proposed to assess the sensitivity of infrastructure on a European scale by considering the existence of infrastructures in urban areas prone to the risk of flooding. A high proportion of such kind of infrastructure in flood prone areas means an increased

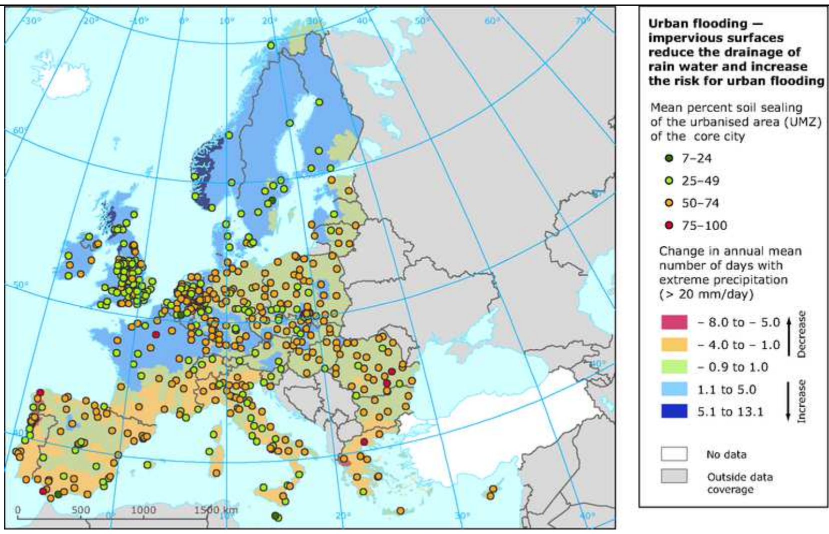
	vulnerability of an urban and this not only for the very region but also for the larger urban area, as it might depended on the services provided by the at risk infrastructure.
Data requirements and sources	Currently, data in the Urban Atlas seems to be only available on traffic related infrastructure: http://www.eea.europa.eu/data-and-maps/data/urban-atlas Additionally, there seems to be information available on flooded treatment plans as well as on power plants exposed on ECRINS (however, not quite sure about the quality of the information) http://projects.eionet.europa.eu/ecrins
Processing	1) Output layer from exposure indicator (fluvial and sea-level rise) should be crossed with the layer on infrastructure (if available) in order to determine the extent to which infrastructure is sensitive to the risk of flooding.
Example (if available)	
Feasibility	Depends on the availability of water
Scientific evidence	(Scientific) justification provided in the field “rationale and context”.

Indicator	**Early warning related activities (monitoring system or emergency plans)**
Key question	If there is yet any monitoring system or emergency plan available, who could/should be responsible to develop and establish it? How can the maintenance and the update of the activities be guaranteed?
Climatic threat	Floods
Dimensions	Coping/adaptive capacity
Rationale and context	In the case of flooding as a response to intensive rainfalls the existence of (web-based) early warning system can predict expected water levels based on detailed data and models, and thereby serve as a general proxy for copying with the occurrence of flood. Of outmost importance in this context is the continuous update of the input data in order to guarantee an effective forecast with adequate warning times, a stable, user-friendly operation of models and a reliable forecast to allow for an adequate copying of the population with the occurrence of the hazard. Emergency plans can help in order to help evacuation activities and thereby enhance the overall coping capacities as there is guided information provided of how to protect from losses.
Data requirements and sources	For establishing a monitoring system detailed data and models on precipitation and water levels is necessary. For establishing emergency plans detailed information is needed on risk prone areas and transport infrastructure. The European Floods Portal brings together information on river floods and flood risk in Europe, resulting from ongoing research within the “Floods” Action at the Joint Research Centre (JRC) of the European Commission, as well as from public available information from EU countries: http://floods.jrc.ec.europa.eu/ The European Floods Awareness System (EFAS) is an early flood warning system complimentary to national and regional systems. It provides the national institutes and the European Commission with information on possible river flooding to occur within the next 3 or more days.
Processing	Use existing dynamic GIS-based Web applications in order to combine different input data.
Example (if available)	 http://floods.jrc.ec.europa.eu/efas-flood-forecasts
Feasibility	It is difficult to agree on responsibilities of maintenance and updating data but if existing European portals will be used and further developed with lower higher resolution the problem could be solved.

Scientific evidence	(Scientific) justification provided in the field “rationale and context”.

Example (if available)	 **http://floods.jrc.ec.europa.eu/efas-flood-forecasts**
Feasibility	It is difficult to agree on responsibilities of maintenance and updating data but if existing European portals will be used and further developed with lower higher resolution the problem could be solved.
Scientific evidence	Bowler, D.E.; Lisette M Buyung-Ali, Teri M Knight and Andrew S Pullin (2010): A systematic review of evidence for the added benefits to health of exposure to natural environments. BMC Public Health 2010, 10:456 Chen, X.L., Zhao, H.M., LI, P.X., Yin, Z.Y. (2006): Remote sensing image based analysis of the relationship between urban heat island and land use/cover changes – Remote Sensing of Environment 104: 133-146. EEA (2012a). Urban adaptation to climate change in Europe - Challenges and opportunities for cities together with supportive national and European policies. European Environment Agency Report No 2/2012, Copenhagen, Denmark. Gabor and Jombach (2009). The relation between the biological activity and the land surface temperature in Budapest. App. Ecology and Environm. Research 7:241-251. Jusuf, S.K.l., Wong, N.H., Hagen, E., Anggoro, R., Hong, Y. (2007). The influence of land use on the urban heat island in Singapore. Habitat International 31: 232-242. Klok, L., Zwart, S., Verhagen, H., & Mauri, E. (2012). The surface heat island of Rotterdam and its relationship with urban surface. Resources, Conservation and Recycling. doi: 10.1016/j.resconrec.2012.01.009. Oke, T. R. (1982): "The energetic basis of the urban heat island". Quarterly Journal of the Royal Meteorological Society 108 (455): 1–24. Steeneveld, G.J., Koopmans S., , Heusinkveld, B.G., van Hove, L.W.A. and Holtslag, A.A.M. (2011). Quantifyingeffects and outdoor human comfort in relation to urban morphology by exploring observations from hobby-meteorologists in the Netherlands. J. Geophys. Res.116, D20129, 14pp.

Indicator	**Soil sealing**
Key question	How to decrease the amount of soil sealing in order to reduce pluvial flood and heat?
Climatic threat	Floods (mainly pluvial) / heat
Dimensions	Exposure (state) Response capacity (change)
Rationale and context	Soil sealing plays a major role for pluvial floods and the generation of heat. In the case of pluvial flood, soil sealing increases the run-off by decreasing the retention and infiltration degree of the soil. It therefore is responsible for flood hazard generation. As the generation of heat, especially the urban heat island (UHI) largely depends on the surface material, soil sealing is a dominant factor. In comparison to vegetated areas, it increases solar reflectance and thermal emissivity, which is the relative ability of a surface to emit energy by radiation.As more surfaces are sealed, there is a reduced evapotranspiration which contributes to elevated surface and air temperatures. In order to identify urban areas potentially affected by flooding/inundation or heat the overall sealed surface area gives an additional link to the overall area exposed
Data requirements and sources	Degree of sealed surfaces. Can be most easily calculated via the NDVI from satellite imageries. EEA produced a high resolution soil sealing layer for the whole of Europe for the year 2006 based on the same satellite pictures as used for CORINE land cover data. http://www.eea.europa.eu/data-and-maps/figures/urban-flooding-2014-impervious-surfaces
Processing	http://www.eea.europa.eu/data-and-maps/figures/urban-flooding-2014-impervious-surfaces : The degree of soil sealing is taken from the Pan-European soil sealing layer that contains the degree of soil sealing. To approximate the morphological area of the city, the reference unit is composed of the Urban Morphological Zones (derived from CLC 2006) inside the core city boundaries (core city defined in Urban Atlas / Urban Audit) and above a threshold of 10ha. Those reference unit objects have been overlaid onto the soil sealing mosaic of Europe to compute the mean soil sealing degree of each core city-UMZ by means of zonal statistics. Those values have again been classified into four classes and presented as coloured dots. The modelled map has been computed in the framework of the ESPON Climate project and shows the change in annual mean number of days with extreme precipitation (>20mm/day) between the CCLM scenarios run (2071-2100) and the reference run (1961-1990) for IPCC scenario A1B. Those data are calculated based on the CCLM parameter ‘rainfall’ (yearly). This indicator will illustrate regional exposure to changes in heavy rainfall events and thus indicate hydrologic extremes. This variable has strong relevance for local heavy rainfall event, especially when occurring over highly sealed surface area

<table>
<tr><td>Example (if available)</td><td>
</td></tr>
<tr><td>Feasibility</td><td>Easy</td></tr>
<tr><td>Scientific evidence</td><td>Hildén et al., 2012
Storch & Dones, 2011</td></tr>
</table>

Indicator	**Likelihood of meteorological drought event**
Key question	What is the likelihood that drought event would be triggered based on long term meteorological conditions?
Climatic hazard	Droughts and water scarcity
Dimensions	Exposure
Definition	The occurrence of below average precipitation in a given area and time.
Rationale and context	While meteorological drought/precipitation deficit does not threaten urban systems directly, it usually precedes the other types of drought that do have direct impact on urban systems. Therefore it is a good proxy exposure indicator for water scarcity and droughts. There are many ways how precipitation deficit can be measured (see e.g. Heim 2002). One of the commonly used metrics to monitor precipitation irregularities is SPI (Standardized Precipitation Index). The Standardized Precipitation Index measures the difference of precipitation from the mean for a specified time divided by the standard deviation, where the mean and standard deviation are determined from the climate record (McKee, Doesken, and Kleist 1993). SPI is commonly monitored by meteorological services in EU member states as well as by the European Drought Observatory at JRC. The Standardized Precipitation Index (SPI-n) is a statistical indicator comparing the total precipitation received at a particular location during a period of n months with the long-term rainfall distribution for the same period of time at that location. SPI is calculated on a monthly basis for a moving window of n months, where n indicates the rainfall accumulation period, which is typically 1, 3, 6, 9, 12, 24 or 48 months. The corresponding SPIs are denoted as SPI-1, SPI-3, SPI-6, etc. SPI takes values between +2 and -2 and values below -1.5 are indicating severe dryness.
Data requirements and sources	SPI is regularly quantified by meteorological surveys around the Europe. In 2010, WMO selected the SPI as a key meteorological drought indicator to be produced operationally by meteorological services. Standardized source of information for this indicator can be EDO - European Drought Observatory at JRC which provides timely data in tabular and graphical form. Data for particular cities in Europe are available online on the EDO website since 1971. Likelihood of occurrence is the number of events in the predefined period, which are fulfilling certain criteria. The data is SPI-12 obtained from precipitation datasets and a criterion is when SPI12 is below -1.5. Number of events is in this case calculated for each grid cell and then aggregated as needed. See NUTS3 example below.
Processing	The Standardized Precipitation Index (SPI-n) is a statistical indicator comparing the total precipitation received at a particular location during a period of n months with the long-term rainfall distribution for the same period of time at that location. SPI is calculated on a monthly basis for a moving window of n months, where n indicates the rainfall accumulation period, which is typically 1, 3, 6, 9, 12, 24 or 48 months. The corresponding SPIs are denoted as SPI-1, SPI-3, SPI-6, etc. The data for SPI-12 obtained from ECA&D (E-OBS) precipitation datasets and a criterion is when SPI12 is below -1.5. Number of events in given time horizon is calculated for each grid cell and aggregated. Suppose we are studying dryness in last 30 year (1982-2012) and we would like to see if there is high or low likelihood for extreme dry event across Europe. We calculate SPI-12 at specific location or grid point for each month between 1982 and 2012

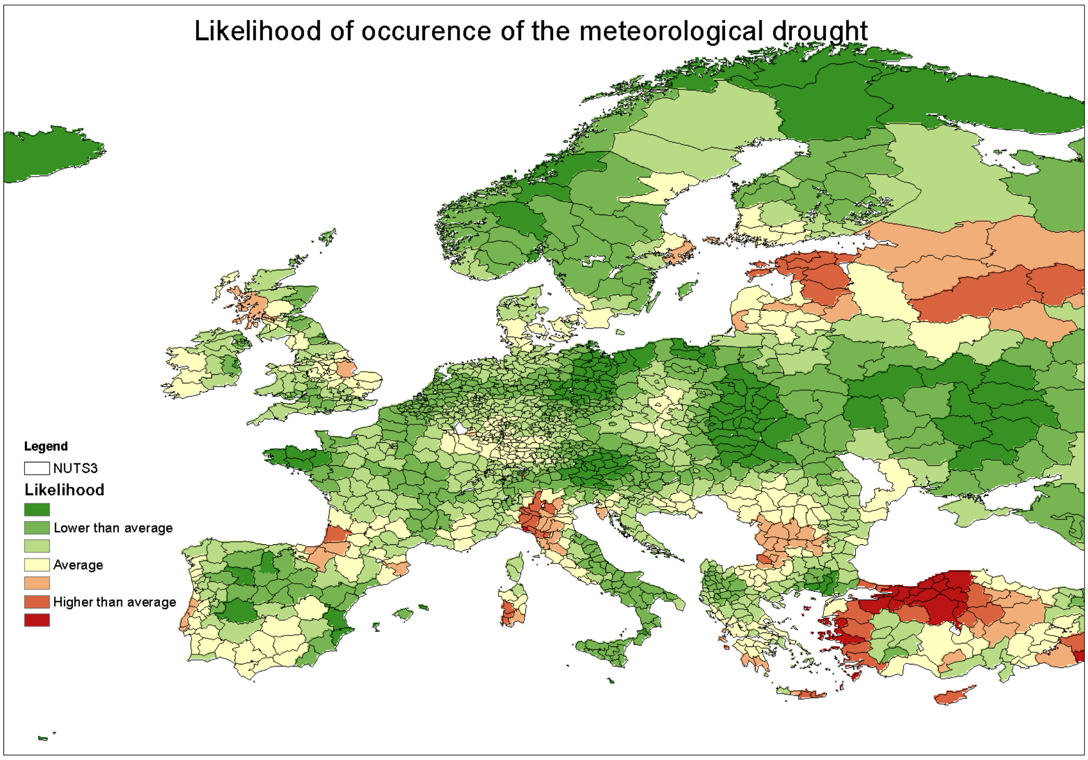
(based on the ECA&D (E-OBS) precipitation datasets) and count how many times SPI-12 was lower than -1.5. This will range between 0 and 360 (30 years * 12 months) and the likelihood (the number of dry events divided by the total number of possible events [360]) will be between 0 and 100 %.

The scale for this indicator is to be set in the process of further development of this indicator. In this example (see map below) scale is arbitrary with same size intervals between minimum and maximum values. In the selected example minimum is zero and maximum is 20 %. Meaning that having 20 % or more cases of the all possible cases is described in map scale as likelihood higher than average. In case of 30 years data (360 months) 20 % is around 70 months with SPI12 lower than -1.5 in.

The table shows the SPI classification that is used by EDO in tabular and map forms.

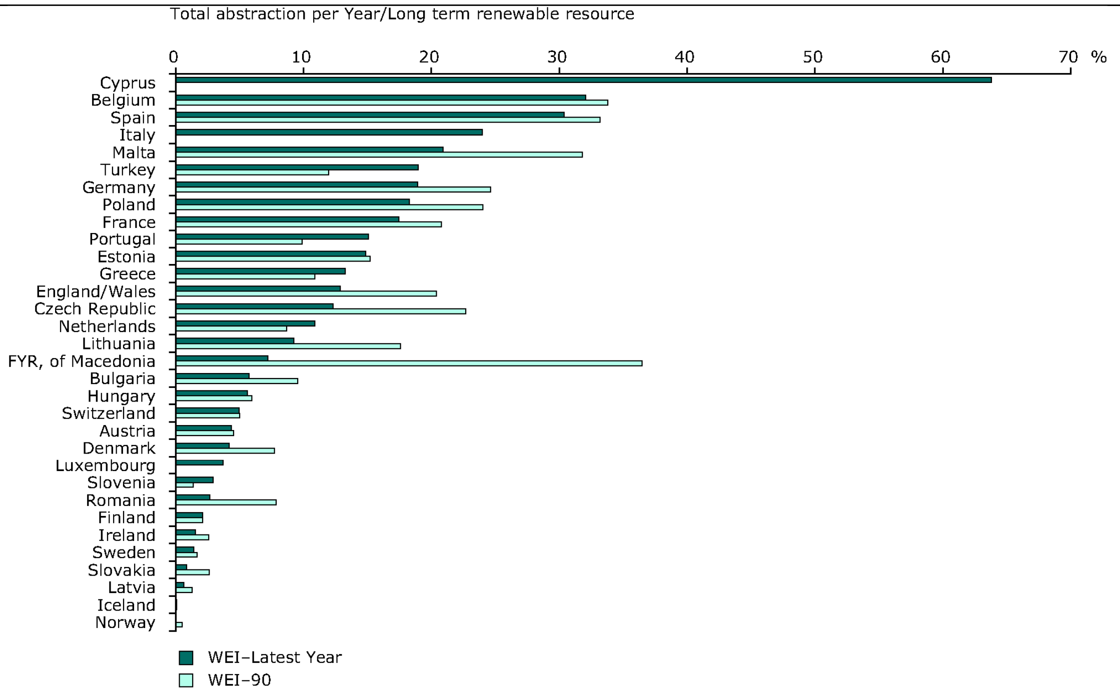
SPI Value	Class	Cumulative Probability	Probability of Event [%]	Colour
SPI ≥ 2.00	Extreme wet	0.977 – 1.000	2.3%	Blue
1.50 < SPI ≤ 2.00	Severe wet	0.933 – 0.977	4.4%	Purple
1.00 < SPI ≤ 1.50	Moderate wet	0.841 – 0.933	9.2%	Lilac
-1.00 < SPI ≤ 1.00	Near normal	0.159 – 0.841	68.2%	White
-1.50 < SPI ≤ -1.00	Moderate dry	0.067 – 0.159	9.2%	Yellow
-2.00 < SPI ≤ -1.50	Severe dry	0.023 – 0.067	4.4%	Orange
SPI < -2.00	Extreme dry	0.000 – 0.023	2.3%	Red

***Table 1** – SPI Classification following McKee et al. (1993)*

Example (if available)	 Likelihood of occurrence of the meteorological drought for the period 1989-2008 (Source: Blaz Kurnik, EEA, personal communication)
Feasibility	Indicator is ready to use with minimum additional effort. Data are freely available and aggregation algorithm is already used by EEA in other projects.
Scientific evidence	The description of SPI method is based on EDO factsheets and is well described by Barbosa et al (2011). A reduction in precipitation with respect to the normal precipitation amount is the primary driver of drought, resulting in a successive shortage of water for different natural and human needs. Since SPI values are given in units of standard deviation from the standardised mean, negative values correspond to drier periods than normal and positive values correspond to wetter periods than normal. The magnitude of the departure from the mean is a probabilistic measure of the severity of a wet or dry event. Since the SPI can be calculated over different rainfall accumulation periods, different SPIs allow for estimating different potential impacts of a meteorological drought: - SPIs for short accumulation periods (e.g., SPI-1 to SPI-3) are indicators for immediate impacts such as reduced soil moisture, snowpack, and flow in smaller creeks; - SPIs for medium accumulation periods (e.g., SPI-3 to SPI-12) are indicators for reduced stream flow and reservoir storage; and - SPIs for long accumulation periods (SPI-12 to SPI-48) are indicators for reduced reservoir and groundwater recharge, for example. The exact relationship between accumulation period and impact depends on the natural environment (e.g., geology, soils) and the human interference (e.g., existence of irrigation schemes) and this indicator, mainly if presented in probabilistic way of likelihood is good early

	warning signal. Barbosa P., Horion S., Kurnik B., Vogt J.V. (2011): Drought hazard mapping in Africa: preliminary results , Geophysical Research Abstracts, 13, 5, European Geosciences Union http://publications.jrc.ec.europa.eu/repository/bitstream/111111111/23582/1/lbna25235enn.pdf

Indicator	**Water exploitation index (WEI)**
Key question	How much water is used in the city in relative terms? How much is it compared with available water resources? Is abstraction of water sustainable?
Climatic hazard	Droughts and water scarcity
Dimensions	Exposure
Rationale and context	The majority of European cities draw their water supply either from surface or from ground water reservoirs. Water availability in physical terms can be simply described as the amount of water in a given time and given place. For urban localities, however, this can be misleading. Big cities often drain water from distant aquifers or they can supply water from different river basins at one time. However to capture such complex reality there is no data available. The Water Exploitation Index (WEI) is metrics that can be used to describe exposure of cities to droughts and water scarcity in terms of freshwater sources. The WEI is a standard EEA indicator (CS 018). It is defined as the mean annual total abstraction of fresh water divided by the long-term average freshwater resources. It describes how the total water abstraction puts pressure on water resources.
Data requirements and sources	Primary data for WEI are Eurostat data on total water abstraction (totABS) and long term annual average renewable resource (LTAA). Data are already processed by EEA and WEI for indicator CS 018. City scale WEI needs more detailed data from the Urban Audit (water abstraction) and data about local availability of freshwater. At the moment WEI is available for catchment areas but not for local (city level). Temporal coverage: 1990-1992, 1994-1995, 1997-2007 Geographical coverage: EU25, EU27, EU12, EU15, EFTA4, EEA32
Processing	WEI is calculated, by country and year, as the ratio of total water annual abstraction to the long-term annual average available volume (Ltaa) of freshwater resources, expressed in percentage terms. WEI = totABS / LTAA x 100 Where: totABS = total annual freshwater abstraction for all uses; LTAA = long term annual average of freshwater resources, where data are averaged over a period of at least 20 consecutive years. Unit are percentages

<table>
<tr><td>Example (if available)</td><td>

Source: EEA, CS 018</td></tr>
<tr><td>Feasibility</td><td>Indicator is ready to use. Should it be disaggregated to local level additional work is needed.</td></tr>
<tr><td>Scientific evidence</td><td>The water exploitation index (WEI), or withdrawal ratio, in a country is defined as the mean annual total abstraction of fresh water divided by the long-term average freshwater resources. It describes how the total water abstraction puts pressure on available freshwater water resources. Thus it identifies those countries having high abstraction in relation to their resources and therefore are prone to suffer problems of water stress. The long-term average freshwater resource is derived from the long-term average precipitation minus the long-term average evapotranspiration plus the long-term average inflow from neighboring countries.

The warning threshold for the water exploitation index which distinguishes a non-stressed from a stressed region is around 20 % (Raskin et al. 1997). Severe water stress can occur where the WEI exceeds 40 %, indicating strong competition for water but not necessarily enough extraction to trigger frequent water crises. Some experts argue that 40 % is too low a threshold, and that water resources could be used much more intensively, up to a 60 % threshold. Others argue that freshwater ecosystems cannot remain healthy if the waters in a river basin are abstracted as intensely as indicated by a WEI in excess of 40 % (Alcamo et al., 2000).

Raskin, P., Gleick, P.H., Kirshen, P., Pontius, R. G. Jr and Strzepek, K., 1997. Comprehensive assessment of the freshwater resources of the world. Stockholm Environmental Institute, Sweden. Document prepared for UN Commission for Sustainable Development 5th Session 1997 - Water stress categories are described on page 27-29.

Alcamo, J., Henrich, T., Rosch, T., 2000. World Water in 2025 - Global modelling and scenario analysis for the World Commission on Water for the 21st Century. Report A0002, Centre for Environmental System Research, University of Kassel, Germany</td></tr>
</table>

<table>
<tr><td>Indicator</td><td>Water use per capita</td></tr>
<tr><td>Key question</td><td>How much water is required by particular cities? Is there a way how to decrease this consumption?</td></tr>
<tr><td>Climatic hazard</td><td>Droughts and water scarcity</td></tr>
<tr><td>Dimensions</td><td>Sensitivity</td></tr>
<tr><td>Definition</td><td>The total consumption of water in a given city divided by the total resident population.</td></tr>
<tr><td>Rationale and context</td><td>The more water a city uses the more it is sensitive to disruption of its supply. Large urban formations in Europe are generally entirely dependent on centralized water supply that can ensure appropriate water quantity and quality for the city population. Smaller urban forms, towns and villages, often still have a certain share of self-supply (private wells and water bore holes). Supply of water per capita seems to be an appropriate indicator for water use that can ensure comparability amongst European cities with similar conditions.</td></tr>
<tr><td>Data requirements and sources</td><td>Data on European cities are collected in the Urban Audit and in the Large City Audit project. Water use per capita in a country is a standard indicator that can be derived from Eurostat Regional statistics. To indicate water use in urban areas, the indicator EN3003I Consumption of water (cubic metres per annum) per inhabitant should give a relatively accurate picture of consumption of water in the city. Indicator is collected at the core city level for time periods: 1989 – 1993; 1994 – 1998; 1999 – 2002; 2003 – 2006; 2007-2009; 2010-2012. However not all cities have data available for all years.

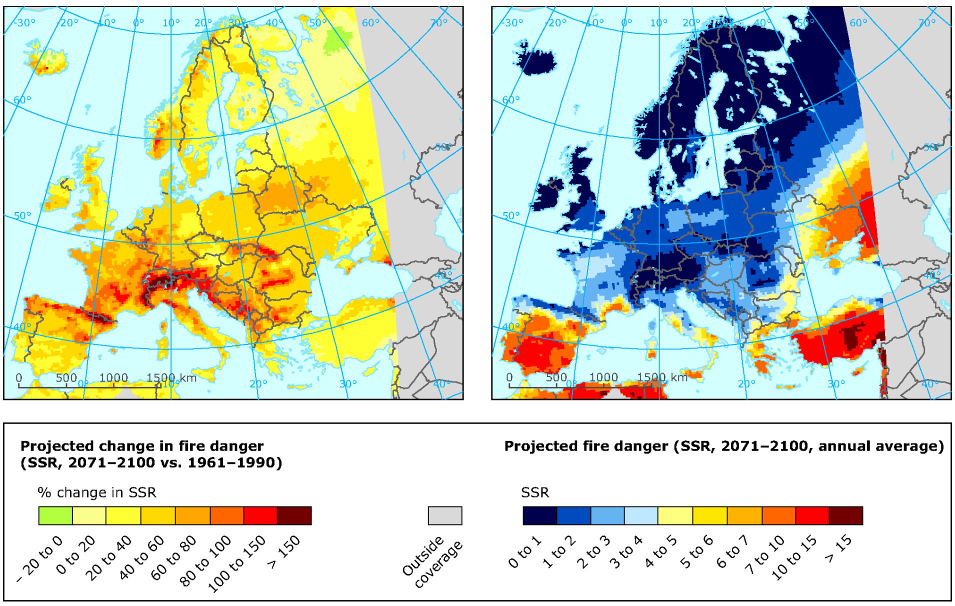
Total consumption of municipal water (cubic meters per annum) by all users (EN3003V) excludes leakages; consumption by industries with own water and sea water for cooling.

Total resident population is defined as the count of all persons recorded as resident in households in an area even if they were present elsewhere on Census night, plus residents in communal establishments who were present in the establishment on Census night. This will include all persons, national or foreign, who are permanently settled (i.e. resident one year or more) in the (urban) area. Eurostat stresses that this population number is the reference for measuring the general size of the urban entity within the specified boundaries of the administrative city, the Larger Urban Zone and the SubCity District.</td></tr>
<tr><td>Processing</td><td>Indicator itself is composed as fraction of two other Urban Audit indicators: Indicator EN3003V Total consumption of water in cu. meters (numerator) and DE1001V Total resident population.</td></tr>
<tr><td>Example (if available)</td><td>INDIC_UR: Consumption of water (cubic metres per annum) per inhabitant
INFO: Value
<table>
<tr><th>TIME / CITIES</th><th>1989_1993</th><th>1994_1998</th><th>1999_2002</th><th>2003_2006</th><th>2007_2009</th><th>2010_2012</th></tr>
<tr><td>København</td><td>:</td><td>:</td><td>66.1</td><td>63.6</td><td>:</td><td>:</td></tr>
<tr><td>Bonn</td><td>77.3</td><td>76.3</td><td>51.6</td><td>62.0</td><td>60.6</td><td>:</td></tr>
<tr><td>Roma</td><td>:</td><td>124.9</td><td>146.6</td><td>120.4</td><td>120.6</td><td>:</td></tr>
<tr><td>Wien</td><td>91.3</td><td>85.1</td><td>83.6</td><td>78.6</td><td>79.9</td><td>:</td></tr>
<tr><td>Helsinki</td><td>:</td><td>:</td><td>95.4</td><td>76.4</td><td>:</td><td>:</td></tr>
<tr><td>Stockholm</td><td>:</td><td>157.6</td><td>:</td><td>:</td><td>131.8</td><td>:</td></tr>
</table>
Source: Eurostat</td></tr>
</table>

Feasibility	Indicator is relatively easy to use, however there are gaps in timeline for some cities which might require additional work.
Scientific evidence	Not applicable

Indicator	**Water rationing and water cuts**
Key question	How much cities limit water distribution among their citizens to cope with water scarcity?
Climatic hazard	Droughts and water scarcity
Dimensions	Sensitivity Response capacity
Definition	The number of water rationing cases in days per year.
Rationale and context	One of the immediate responses how to deal with pressure exerted on water supply systems in the cities is to diminish or interrupt water supply. Water rationing is one of the adaptations on increasing water scarcity. Cutting water supplies (for rationing reasons or for technical reasons) and can cause socioeconomic drought and can be used as proxy indicator for this phenomena. However it is only benchmark indicator shoving to what extend cities have to cope with water supply problems. This indicator has limited forward looking component, however should it be observed in long period, some patters might emerge. Number of water rationing cases, days per year includes scheduled water cuts due to shortage, e.g. hosepipe bans; excluding cuts due to maintenance or repair which are highly infrequent and seldom impact on quality of life. Number of water cuts, days per year should include water cuts due to repair and maintenance. Both of the indicators should be reported only if above mentioned events affects more than 10% of city population.
Data requirements and sources	Data should be taken from Eurostat's Urban Audit EN3008V - Number of water rationing cases, days per year and EN3009V - Number of scheduled water cuts, days per year.
Processing	No processing required if data are available. Indicators should be however presented and interpreted separately.

<table>
<tr><td>Example (if available)</td><td>
<table>
<tr><th>TIME / CITIES</th><th>1989_1993</th><th>1994_1998</th><th>1999_2002</th><th>2003_2006</th><th>2007_2009</th><th>2010_2012</th></tr>
<tr><td>Lens - Liévin</td><td>:</td><td>:</td><td>:</td><td>:</td><td>:</td><td>:</td></tr>
<tr><td>Italy</td><td>:</td><td>:</td><td>:</td><td>:</td><td>:</td><td>:</td></tr>
<tr><td>Roma</td><td>:</td><td>:</td><td>0</td><td>0</td><td>0</td><td>:</td></tr>
<tr><td>Milano</td><td>:</td><td>:</td><td>0</td><td>0</td><td>0</td><td>:</td></tr>
<tr><td>Napoli</td><td>:</td><td>:</td><td>0</td><td>0</td><td>0</td><td>:</td></tr>
<tr><td>Torino</td><td>:</td><td>:</td><td>0</td><td>0</td><td>0</td><td>:</td></tr>
<tr><td>Palermo</td><td>:</td><td>:</td><td>180</td><td>0</td><td>:</td><td>0</td></tr>
<tr><td>Genova</td><td>:</td><td>:</td><td>0</td><td>0</td><td>0</td><td>:</td></tr>
<tr><td>Firenze</td><td>:</td><td>:</td><td>0</td><td>0</td><td>0</td><td>:</td></tr>
<tr><td>Bari</td><td>:</td><td>:</td><td>365</td><td>365</td><td>:</td><td>0</td></tr>
<tr><td>Bologna</td><td>:</td><td>:</td><td>0</td><td>0</td><td>0</td><td>:</td></tr>
<tr><td>Catania</td><td>:</td><td>:</td><td>0</td><td>120</td><td>:</td><td>0</td></tr>
<tr><td>Venezia</td><td>:</td><td>:</td><td>0</td><td>0</td><td>0</td><td>:</td></tr>
<tr><td>Verona</td><td>:</td><td>:</td><td>0</td><td>0</td><td>0</td><td>:</td></tr>
<tr><td>Cremona</td><td>:</td><td>:</td><td>0</td><td>0</td><td>0</td><td>:</td></tr>
<tr><td>Trento</td><td>:</td><td>:</td><td>0</td><td>0</td><td>0</td><td>:</td></tr>
<tr><td>Trieste</td><td>:</td><td>:</td><td>0</td><td>0</td><td>0</td><td>:</td></tr>
<tr><td>Perugia</td><td>:</td><td>:</td><td>0</td><td>0</td><td>0</td><td>:</td></tr>
<tr><td>Ancona</td><td>:</td><td>:</td><td>0</td><td>:</td><td>0</td><td>:</td></tr>
<tr><td>L'Aquila</td><td>:</td><td>:</td><td>0</td><td>0</td><td>0</td><td>:</td></tr>
<tr><td>Pescara</td><td>:</td><td>:</td><td>0</td><td>0</td><td>0</td><td>:</td></tr>
<tr><td>Campobasso</td><td>:</td><td>:</td><td>0</td><td>0</td><td>0</td><td>:</td></tr>
<tr><td>Caserta</td><td>:</td><td>:</td><td>0</td><td>0</td><td>0</td><td>:</td></tr>
<tr><td>Taranto</td><td>:</td><td>:</td><td>365</td><td>365</td><td>:</td><td>0</td></tr>
<tr><td>Potenza</td><td>:</td><td>:</td><td>120</td><td>0</td><td>0</td><td>:</td></tr>
<tr><td>Catanzaro</td><td>:</td><td>:</td><td>365</td><td>365</td><td>:</td><td>0</td></tr>
<tr><td>Reggio di Calabria</td><td>:</td><td>:</td><td>365</td><td>:</td><td>0</td><td>:</td></tr>
<tr><td>Sassari</td><td>:</td><td>:</td><td>365</td><td>120</td><td>0</td><td>:</td></tr>
<tr><td>Cagliari</td><td>:</td><td>:</td><td>365</td><td>0</td><td>0</td><td>:</td></tr>
<tr><td>Padova</td><td>:</td><td>:</td><td>0</td><td>0</td><td>0</td><td>:</td></tr>
<tr><td>Brescia</td><td>:</td><td>:</td><td>0</td><td>0</td><td>0</td><td>:</td></tr>
<tr><td>Modena</td><td>:</td><td>:</td><td>0</td><td>0</td><td>0</td><td>:</td></tr>
<tr><td>Foggia</td><td>:</td><td>:</td><td>365</td><td>0</td><td>:</td><td>0</td></tr>
<tr><td>Salerno</td><td>:</td><td>:</td><td>0</td><td>12</td><td>0</td><td>:</td></tr>
<tr><td>Cyprus</td><td>:</td><td>:</td><td>:</td><td>:</td><td>:</td><td>:</td></tr>
</table>
</td></tr>
<tr><td>Feasibility</td><td>Indicator has problem with data availability. It is regularly collected by Eurostat, however large amount of cities are not reporting it. There are gaps in time series. Additional work is required to make it functional indicator.</td></tr>
<tr><td>Scientific evidence</td><td>See rationale and context</td></tr>
</table>

Indicator	**Fire probability index**
Key question	Is the risk of forest fires increasing because of climate change? How large is the area potentially exposed to the risk of forest fires?
Climatic threat	Forest fires
Dimensions	Exposure
Defintion	Overall fire risk of a given year due to meteorological conditions
Rationale and context	Although it is generally recognized that the occurrence of forest fires in Europe is mainly caused by anthropogenic factors, the total burned area varies significantly from year to year largely due to weather conditions. Climate factors that determine fire risk are well known and relate to the occurrence and length of dry and hot summers (Bassi et al., 2008). These climate conditions decrease the water content in plants, leading to the increased inflammability of vegetation. Climate change projections in the Mediterranean areas indicate an increase in air temperature, heat waves and dry spells, and a decrease in summer rainfall, suggesting a future increment in water deficit. This in turn may lead to an increase in ignition probability and fire propagation during the summer period. Fire danger is also expected to increase in the boreal and central European regions (Lindner et al., 2008). The **fire probability index**is designed to rate the component of fire risk that depends on weather conditions, and can be employed to analyse fire trends in a consistent way over longer periods. These indices, normally applied on a daily basis, can be summarised on a seasonal basis to rate the overall fire potential of a given year (seasonal fire severity) due to meteorological conditions.
Data requirements and sources	Fire probability index http://forest.jrc.ec.europa.eu/effis/applications/data-and-services/
Processing	Data source already provides the index, so there is no need for further processing.
Example (if available)	

Feasibility	Feasible (already developed and published)
Scientific evidence	The Fire Weather Index (FWI, Van Wagner 1987) is the fire danger assessment method most widely applied all over the world (San Miguel- Ayanz et al. 2003). It is also used by the European Forest Fire Information System (EFFIS) in order to provide a harmonized European-wide assessment of daily fire danger. One application of the FWI is the Seasonal Severity Rating which aggregates the daily rating over a period of time. Bassi, S., Kettunen, M., Kampa, E., Cavalieri, S., 2008, F*orest fires: causes and contributing factors in Europe*, European Parliament, Policy Department Economic and Scientific Policy. Lindner, M., Garcia-Gonzalo, J., Kolström, M., Green, T., Reguera, R., Maroschek, M., Seidl, R., Lexer, M. J., Netherer, S., Schopf, A., Kremer, A., Delzon, S., Barbati, A., Marchetti, M., Corona, P., 2008, *Impacts of Climate Change on European Forests and Options for Adaptation. Report to the European Commission Directorate-General for Agriculture and Rural Development*, European Forest Institute, Joensuu, Finland. San Miguel-Ayanz, J., Carlson, J.D., Alexander, M., Tolhurst, K., Morgan, G., Sneeuwjagt, R.and Dudley, M. 2003, Current Methods to Assess Fire Danger Potential. In: *Wildland Fire Danger Estimation and Mapping. The Role of Remote Sensing Data* (E. Chuvieco, Ed.). World Scientific Publishing, Singapore, pp. 21-61. Van Wagner, C.E. 1987. Development and structure of the Canadian Forest Fire Weather IndexSystem. Canadian Forestry Service, Ottawa, Ontario. Forestry Technical Report 35. 37 p.

Indicator	**Population potentially affected by the risk of forest fires**
Key question	How many people are exposed to the risk of forest fires in an urban area? Where are hotspots that need particular attention in case of emergency?
Climatic threat	Forest fires
Dimensions	Sensitivity (population)
Definition	Share of population in European cities (and peri-urban areas) leaving in areas of high risk of forest fires.
Rationale and context	The land development in the last decades, in particular urban sprawl, mean that the built-up areas are encroaching into semi-natural and natural areas, including those prone to wildfires. Whilst part of this process is related to the trend of having second homes in the countryside, the number of permanent residents in these peri-urban areas has been steadily increasing. People living in the peri-urban areas are those most exposed to direct impacts of forest fire. Frequently, a distinction is made between permanent and floating population, i.e. temporary residents staying in second homes and tourist establishments. However, as the summer season is the season with the higher fire risk and higher occupancy rates in the peri-urban areas, both types of peri-urban residents should be considered in order to estimate the resource needed in the case of evacuation (transport and temporary shelter) and the number of people affected by e.g. psychological trauma. Therefore the indicator on population potentially affected is intended to provide an overview on the quantity and spatial distribution of population in and around urban area. Currently the indicator only focuses on resident population since there is not a European wide data source on floating population.
Data requirements and sources	Fire probability index http://forest.jrc.ec.europa.eu/effis/applications/data-and-services/ Urban Morphological Zones as reference unit for the city morphology (as best approximation of the "real" city form, which is often not corresponding to the administrative delineation), available from the EEA data service: http://www.eea.europa.eu/data-and-maps/data/urban-morphological-zones-2000-umz2000-f1v0. NB: In the current processing we use all UMZ patches which are located within the core city boundaries. Eurostat. Population data (2006) at 1 km grid. Data has been derived by two different procedures depending on the country: bottom-up (aggregation from census statistics), which is highly reliable; and top-down (disaggregation from national statistics), which has more errors (see Barredo, 2005). http://epp.eurostat.ec.europa.eu/portal/page/portal/gisco_Geographical_information_maps/popups/references/population_distribution_demography GMES Urban Atlas data base provides reliable, inter-comparable, high-resolution land use maps for 305 Large Urban Zones and their surroundings for the reference

	year 2006. http://www.eea.europa.eu/data-and-maps/data/urban-atlas EEA Fast Track Service Precursor on Land Monitoring - Degree of soil sealing. This information is required to identify the low urban density areas within the UMZ. http://www.eea.europa.eu/data-and-maps/data/eea-fast-track-service-precursor-on-land-monitoring-degree-of-soil-sealing-100m-1
Processing	1. Select UMZs as reference units. 2. Delineate peri-urban areas around UMZs A buffer of 20 km outside the border of the UMZ. A buffer inward the UMZ, proportional to the degree of soil sealing (up to 50% -confirmed by sensitivity analysis). It is generally accepted that vulnerability to fires is higher in low density settlements due to a higher proportion of flammable vegetation in the area. 3. Cross the areas selected in 2 with the fire risk index resulting in a classification of peri-urban areas according to fire risk index. 4. Cross 3 with the grid of population resulting in the total population in peri-urban areas exposed to different degree of fire risk. 5. For each UMZ calculate the ratio between population in high risk area (from 4) and total population (UMZ+peri-urban area).
Example (if available)	
Feasibility	Easy
Scientific evidence	Bassi, S., Kettunen, M., Kampa, E., Cavalieri, S., 2008, FOREST FIRES: causes and contributing factors in Europe, European Parliament, Policy Department Economic and Scientific Policy Marzano, R., Camia, A., Bovio, G., 2008,'Wildland-Urban Interface Analyses for Fire Management Planning', In: *Proceedings of the Second International Symposium on Fire Economics, Planning, and Policy: A Global View*, Gen. Tech. Rep., U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA. Mell, W. E., Manzello, S. L., Maranghides, A., Butry, D., Rehm, R. G., 2010, 'The wildland–urban interface fire problem – current approaches and research needs', *International Journal of Wildland Fire*, 19(2):238-251. Rábade, J. M., Aragoneses, C., 2008,'Social Impact of Large-Scale Forest Fires', In: *Proceedings of the second international symposium on fire economics, planning, and policy: a global view*, Forest Service, U.S. Department of Agriculture, Albany, California.

	Weinhold, B., 2012, 'Landscape Fire Smoke as a Cause of Death: Burning Vegetation Estimated to Kill Hundreds of Thousands Worldwide', *Environmental Health Perspectives*, 120(5):204-214. Williamson, T. B., Northern Forestry Centre (Canada), 2007, A framework for assessing vulnerability of forest-based communities to climate change, Canadian Forest Service, Northern Forestry Centre, Edmonton, Canada.

Indicator	**Residential area affected by the risk of forest fire**
Key question	How sensitive is an urban area to an impact of forest fire? Which areas are particularly affected?
Climatic threat	Forest fires
Dimensions	Sensitivity (economic assets)
Definition	The indicator presents the share of residential areas in European cities, and related peri-urban areas, exposed to high risk of forest fire.
Rationale and context	The steadily growing interface between wildland and urban areas in the last decades, has increased the risk of forest fires in many residential areas. Moreover, it is estimated that around three quarters of fire ignition points in the Mediterranean countries are located in interface type characterised by high aggregation of vegetation and high density of houses (Vélez, 2009). Residential areas in high risk zones are most exposed to fire damage, which have serious consequences. For example, forest fires in Greece in 2007 caused thousands of people to lose their homes (Bassi et al., 2008). The sensitivity of settlements is usually related to its structure (lower density increases the sensitivity) and isolation. Other factors increasing sensitivity of the settlements are the characteristics of the surrounding vegetation, as well as topographic aspects (Marzano et al, 2008). The indicator would provide an overview of the extent of residential areas potentially affected. It is also relevant in terms of resources that would be needto protect o prevent these areas from the expected future risk.
Data requirements and sources	Fire probability index http://forest.jrc.ec.europa.eu/effis/applications/data-and-services/ Urban Morphological Zones as reference unit for the city morphology (as best approximation of the "real" city form, which is often not corresponding to the administrative delineation), available from the EEA data service: http://www.eea.europa.eu/data-and-maps/data/urban-morphological-zones-2000-umz2000-f1v0. NB: In the current processing we use all UMZ patches which are located within the core city boundaries. GMES Urban Atlas data base provides reliable, inter-comparable, high-resolution land use maps for 305 Large Urban Zones and their surroundings for the reference year 2006. This data is used to identify the residential areas (classes 1100 to 11300). http://www.eea.europa.eu/data-and-maps/data/urban-atlas
Processing	
Example (if available)	1. Select UMZs as reference units. 2. Delineate peri-urban areas around UMZs

	A buffer of 20 km outside the border of the UMZ. A buffer inward the UMZ, proportional to the degree of soil sealing (up to 50% -confirmed by sensitivity analysis). It is generally accepted that vulnerability to fires is higher in low density settlements due to a higher proportion of flammable vegetation in the area. 3. Cross the areas selected in 2 with the fire risk index resulting in a classification of peri-urban areas according to fire risk per UMZ. 4. Cross 3 with selected residential areas in Urban Atlas (classes 11100 to 11300). 5. For each UMZ calculate the ratio between residential areas in high risk zone (from 4) and total residential areas (UMZ+peri-urban area).
Feasibility	Easy
Scientific evidence	Bassi, S., Kettunen, M., Kampa, E., Cavalieri, S., 2008, FOREST FIRES: causes and contributing factors in Europe, European Parliament, Policy Department Economic and Scientific Policy Marzano, R., Camia, A., Bovio, G., 2008,'Wildland-Urban Interface Analyses for Fire Management Planning', In: Proceedings of the Second International Symposium on Fire Economics, Planning, and Policy: A Global View, Gen. Tech. Rep., U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA. Mell, W. E., Manzello, S. L., Maranghides, A., Butry, D., Rehm, R. G., 2010, 'The wildland–urban interface fire problem – current approaches and research needs', *International Journal of Wildland Fire*, 19(2):238-251. Rábade, J. M., Aragoneses, C., 2008,'Social Impact of Large-Scale Forest Fires', en: Proceedings of the second international symposium on fire economics, planning, and policy: a global view, Forest Service, U.S. Department of Agriculture, Albany, California. Robert G. Haight, David T. Cleland, Roger B. Hammer, Volker C. Radeloff, T. Scott Rupp, 2004, 'Assessing Fire Risk in the Wildland-Urban Interface', *Journal of Forestry*, 102(7), p.41-48. Vélez, R., 2009, Causing Factors of Wildfires: A Focus on Economic and Social Driving Forces, In: *Living with Wildfires: What Science can Tell Us* (Y. Birot, ed.), EFI Ciscussion Paper 15, European Forest Institute. Williamson, T. B., Northern Forestry Centre (Canada), 2007, A framework for assessing vulnerability of forest-based communities to climate change, Canadian Forest Service, Northern Forestry Centre, Edmonton, Canada.

Indicator	**Industrial/commercial areas affected by the risk of forest fire**
Key question	How sensitive are industrial7commercial areas to an impact of forest fire? Which areas are particularly affected?
Climatic threat	Forest fires
Dimensions	Sensitivity (economic assets)
Definitions	The indicator presents the share of industrial/commercial areas in European cities, and related peri-urban areas, exposed to high risk of forest fire.
Rationale and context	Industrial and commercial areas have been one of the drivers of the increase of built-up area in Europe (EEA, 2012). Very often this expansion has gone in parallel with city development. In terms of economic damage, forest fires have a stronger impact on residential areas than on industrial and commercial areas (Marzano et al, 2008). The reason is that the development of industrial and commercial areas has more strict regulations (especially in terms of fire protection) and is characterised by better planning than housing (in particular second homes). In addition, industrial and commercial facilities tend to aggregate in areas with easy access to infrastructure and are less isolated, therefore are more accessible by the emergency services.However, economic losses are still relevant. The indicator would provide an indication of the extent of industrial/commercial areas potentially affected. It is also relevant in terms of resources that would be needto protect o prevent theses areas from increased risk.
Data requirements and sources	Fire probability index http://forest.jrc.ec.europa.eu/effis/applications/data-and-services/ Urban Morphological Zones as reference unit for the city morphology (as best approximation of the "real" city form, which is often not corresponding to the administrative delineation), available from the EEA data service: http://www.eea.europa.eu/data-and-maps/data/urban-morphological-zones-2000-umz2000-f1v0. NB: In the current processing we use all UMZ patches which are located within the core city boundaries. GMES Urban Atlas data base provides reliable, inter-comparable, high-resolution land use maps for 305 Large Urban Zones and their surroundings for the reference year 2006. This data is used to identify the industrial/commercial areas (class 12100). http://www.eea.europa.eu/data-and-maps/data/urban-atlas
Processing	1. Select UMZs as reference units. 2. Delineate peri-urban areas around UMZs A buffer of 20 km outside the border of the UMZ. A buffer inward the UMZ, proportional to the degree of soil sealing (up to

	50% -confirmed by sensitivity analysis). It is generally accepted that vulnerability to fires is higher in low density settlements due to a higher proportion of flammable vegetation in the area. 3. Cross the areas selected in 2 with the fire risk index resulting in a classification of peri-urban areas according to fire risk per UMZ. 4. Cross 3 with selected industrial/commercial areas in Urban Atlas (classes 12100). 5. For each UMZ calculate the ratio between industrial/commercial areas in high risk zone (from 4) and total industrial/commercial areas (UMZ+peri-urban area).
Example (if available)	
Feasibility	Easy
Scientific evidence	Bassi, S., Kettunen, M., Kampa, E., Cavalieri, S., 2008, FOREST FIRES: causes and contributing factors in Europe, European Parliament, Policy Department Economic and Scientific Policy EEA, 2010, *Land use –SOER 2010 themaatic assessment*, Office for Official Publications of the European Communities, Luxembourg. Marzano, R., Camia, A., Bovio, G., 2008,'Wildland-Urban Interface Analyses for Fire Management Planning', In: Proceedings of the Second International Symposium on Fire Economics, Planning, and Policy: A Global View, Gen. Tech. Rep., U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA. Mell, W. E., Manzello, S. L., Maranghides, A., Butry, D., Rehm, R. G., 2010, 'The wildland–urban interface fire problem – current approaches and research needs', *International Journal of Wildland Fire*, 19(2):238-251. Rábade, J. M., Aragoneses, C., 2008,'Social Impact of Large-Scale Forest Fires', en: Proceedings of the second international symposium on fire economics, planning, and policy: a global view, Forest Service, U.S. Department of Agriculture, Albany, California. Robert G. Haight, David T. Cleland, Roger B. Hammer, Volker C. Radeloff, T. Scott Rupp, 2004, 'Assessing Fire Risk in the Wildland-Urban Interface', *Journal of Forestry*, 102(7), p.41-48. Williamson, T. B., Northern Forestry Centre (Canada), 2007, A framework for assessing vulnerability of forest-based communities to climate change, Canadian Forest Service, Northern Forestry Centre, Edmonton, Canada.

Indicator	**Sensitivity of transport infrastructure**
Key question	How resilient is a city regarding forest fire? How sensitive is the infrastructure in an urban area to the risk of forest fire? What kind of infrastructure is exposed to the risk of forest fire?
Climatic threat	Forest fires
Dimensions	Sensitivity (economic assets)
Definition	Percentage of transport infrastructure in high risk area of forest fire
Rationale and context	Transport infrastructures are substantial part of the economic development of cities, but also relates to citizens and flows of different type of networks (jobs, food, services, community, personal links,…). Its relevance becomes evident when a disruption occurs resulting in both direct and indirect impacts. A part of the isolation of urban areas one important element to consider is that increased sensitivity will difficult the accessibility to hot spots to extinguish the forest fire. The impact of the forest fire is strongly dependent on the quality and quantity of the transport network. In that case quality refers to the type of structure that is built (e.g. number or nodes). Therefore all these elements are relevant when considering the sensitivity to forest fires. It is proposed to assess the sensitivity of infrastructure by considering the existence of infrastructures in urban areas prone to the risk of forest fires. A high proportion of such kind of infrastructure in fire risk prone areas means an increased vulnerability of an urban area and this not only for the very region but also for the larger urban area, as it might depended on the services provided by the at risk infrastructure.
Data requirements and sources	Fire probability index http://forest.jrc.ec.europa.eu/effis/applications/data-and-services/ Urban Morphological Zones as reference unit for the city morphology (as best approximation of the "real" city form, which is often not corresponding to the administrative delineation), available from the EEA data service: http://www.eea.europa.eu/data-and-maps/data/urban-morphological-zones-2000-umz2000-f1v0. NB: In the current processing we use all UMZ patches which are located within the core city boundaries. GISCO. This is the reference data for transport infrastructure in Europe provided by Eurostat.(http://epp.eurostat.ec.europa.eu/portal/page/portal/gisco_Geographical_information_maps/geodata/reference)
Processing	1. Select UMZs as reference units. 2. Delineate a buffer of 20 km outside the border of the UMZ in order to integrate transport network accessing the city. 3. Cross the areas selected in 2 with the fire risk index resulting in a classification

	of peri-urban areas according to fire risk per UMZ. 4. Cross 3 with transport network. Calculate percentage of transport network in high risk of forest fire in the buffer of 20 km.
Example (if available)	
Feasibility	Easy
Scientific evidence	Bassi, S., Kettunen, M., Kampa, E., Cavalieri, S., 2008, FOREST FIRES: causes and contributing factors in Europe, European Parliament, Policy Department Economic and Scientific Policy EEA, 2010, *Land use –SOER 2010 themaatic assessment*, Office for Official Publications of the European Communities, Luxembourg. Marzano, R., Camia, A., Bovio, G., 2008,'Wildland-Urban Interface Analyses for Fire Management Planning', In: Proceedings of the Second International Symposium on Fire Economics, Planning, and Policy: A Global View, Gen. Tech. Rep., U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA. Mell, W. E., Manzello, S. L., Maranghides, A., Butry, D., Rehm, R. G., 2010, 'The wildland–urban interface fire problem – current approaches and research needs', *International Journal of Wildland Fire*, 19(2):238-251. Rábade, J. M., Aragoneses, C., 2008,'Social Impact of Large-Scale Forest Fires', en: Proceedings of the second international symposium on fire economics, planning, and policy: a global view, Forest Service, U.S. Department of Agriculture, Albany, California. Robert G. Haight, David T. Cleland, Roger B. Hammer, Volker C. Radeloff, T. Scott Rupp, 2004, 'Assessing Fire Risk in the Wildland-Urban Interface', *Journal of Forestry*, 102(7), p.41-48. Williamson, T. B., Northern Forestry Centre (Canada), 2007, A framework for assessing vulnerability of forest-based communities to climate change, Canadian Forest Service, Northern Forestry Centre, Edmonton, Canada.

Indicator	**Accessibility in peri-urban areas**
Climatic threat	Forest fires
Data requirements and sources	Fire probability index http://forest.jrc.ec.europa.eu/effis/applications/data-and-services/ Urban Morphological Zones as reference unit for the city morphology (as best approximation of the "real" city form, which is often not corresponding to the administrative delineation), available from the EEA data service: http://www.eea.europa.eu/data-and-maps/data/urban-morphological-zones-2000-umz2000-f1v0. NB: In the current processing we use all UMZ patches which are located within the core city boundaries. GISCO. This is the reference data for transport infrastructure in Europe provided by Eurostat.(http://epp.eurostat.ec.europa.eu/portal/page/portal/gisco_Geographical_information_maps/geodata/reference) GMES Urban Atlas data base provides reliable, inter-comparable, high-resolution land use maps for 305 Large Urban Zones and their surroundings for the reference year 2006. This data is used to identify the industrial/commercial areas (class 12100). http://www.eea.europa.eu/data-and-maps/data/urban-atlas
Definition	Percentage of built-up areas where more than 75% of infrastructure connecting them to other areas is located in a high risk area of forest fire.
Dimensions	Response (ability)
Example (if available)	
Feasibility	Feasible also it requires high computing resources given the complexity of some calculations.
Policy question	What is the capacity to evacuate residents in fie prone areas?
Processing	1. Select UMZs as reference units. 2. Delineate peri-urban areas around UMZs A buffer of 20 km outside the border of the UMZ. A buffer inward the UMZ, proportional to the degree of soil sealing (up to 50% -confirmed by sensitivity analysis). It is generally accepted that vulnerability to fires is higher in low density settlements due to a higher proportion of flammable vegetation in the area. 3. Cross the areas selected in 2 with the fire risk index resulting in a classification of peri-urban areas according to fire risk per UMZ. 4. Cross 3 with selected residential areas in Urban Atlas (classes 11100 to 11300) resulting in residential areas in high risk o forest fire.

	5. Cluster polygons in step 4 laying less than 50 m apart. 6. For each cluster in step 5 select those roads connecting to the UMZ and estimate which proportion is in high risk area. Rank clusters by percentage of roads in high risk area. It is suggested 75% threshold for high isolation (or low accessibility) –it could be confirmed by sensitivity analysis. 7. For each UMZ calculate number of clusters, and corresponding area, classified as low accessible (step 7). Calculate percentage in relation to total residential area in the peri-urban area of the UMZ.
Rationale and context	When a wildfire threatens a community,residents generally evacuate in a condensed time either voluntarilyor by order. Then, road infrastructure is a critical component of accessibility in order to provide ways of evacuation, but also for fire suppression forces. There are two components of accessibility: capacity, which relates to the width of the infrastructure, and connectivity, represented by alternative ways to connect two points. The indicator will calculate the percentage of built-up areas where more than 75% of infrastructure connecting them to other areas is located in a high risk area. This indicator does not take into account either the topographic components that would modulate the fire risk, or vegetation types, since these would require a more complex modelling.
Scientific evidence	Camia, A., Varela, V., Marzano, R., Eftichidis, G., 2003,Spatialanalysis in European Wildland-Urban Interface environments using GIS. In:Proceedings of the International Workshop “Forest Fire in the Wildland-Urban Interfaceand Rural Areas in Europe”. 15–16 May 2003, Athens (Greece). Cova, T., J.Johnson, J. P., 2002, 'Microsimulation of neighborhood evacuations in the urban - wildland interface', *Environment and Planning A*, 34(12), p.2211-2229. de Silva, F., Eglese, R., 2000, Integrating simulation modeling and GIS: spatial decision supportsystems for evacuation planning, *Journal of the Operational Research Society* 51:423-430. Marzano, R., Camia, A., Bovio, G., 2008,'Wildland-Urban Interface Analyses for Fire Management Planning', In: Proceedings of the Second International Symposium on Fire Economics, Planning, and Policy: A Global View, Gen. Tech. Rep., U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA. Mell, W. E., Manzello, S. L., Maranghides, A., Butry, D., Rehm, R. G., 2010, 'The wildland–urban interface fire problem – current approaches and research needs', *International Journal of Wildland Fire*, 19(2):238-251. Rábade, J. M., Aragoneses, C., 2008,'Social Impact of Large-Scale Forest Fires', en: Proceedings of the second international symposium on fire economics, planning, and policy: a global view, Forest Service, U.S. Department of Agriculture, Albany, California. Robert G. Haight, David T. Cleland, Roger B. Hammer, Volker C. Radeloff, T. Scott Rupp, 2004, 'Assessing Fire Risk in the Wildland-Urban Interface', *Journal of Forestry*, 102(7), p.41-48. Williamson, T. B., Northern Forestry Centre (Canada), 2007, A framework for assessing vulnerability of forest-based communities to climate change, Canadian Forest Service, Northern Forestry Centre, Edmonton, Canada