European Environment Agency

Map book urban vulnerability to climate change – Factsheets

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European Topic Centre on Climate Change Impacts, Vulnerability and Adaptation

European Topic Centre on Spatial Information and Analysis

This working paper has been produced as a technical background document for the map book "Urban vulnerability to climate change in Europe" http://climate-adapt.eea.europa.eu/tools/urban-adaptation/introduction by a team of the European Environment Agency (EEA), the European Topic Centre on Climate Change Impacts, Vulnerability and Adaptation (ETC CCA) and the European Topic Centre on Spatial Information and Analysis (ETC SIA)

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Acronyms

CCLM	COSMO Climate Limited-area Modelling
CLC	Corine Land Cover
DIVA	Dynamic and interactive vulnerability assessment
EC	European Commission
ECA&D	European Climate Assessment and Dataset
EEA	European Environment Agency
EFFIS	European Forest Fire Information System
ET	Effective temperature
FWI	Fire Weather Index
GDP	Gross domestic product
GMES	Global Monitoring for Environment and Security (Copernicus programme)
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre
NDVI	Normalized Difference Vegetation Index
PET	Physiologically equivalent temperature
PMV	Predicted mean vote
RDA	Rapid damage assessment
TAR	Third Assessment Report
UHI	Urban Heat Island
UMZ	Urban morphological zone
UTCI	Universal thermal comfort index
WBGT	Wet bulb globe temperature
WEI	Water Exploitation Index
WHO	World Health Organization

1. Introduction

The objective of this map book is to provide a scientific and technical background to the EEA website's maps[1]. The explanatory texts accompanying the maps in the digital map book have been derived directly from the more elaborate fact sheets in this report. In 2012, the EEA published the report *Urban adaptation to climate change in Europe - Challenges and opportunities for cities together with supportive national and European policies* (EEA, 2012). As a follow-up to this report, a technical paper on urban vulnerability indicators (Swart et al., 2012) explored the availability of information on exposure, sensitivity and response to a variety of urban climate threats, and the feasibility of developing vulnerability indicators that could be mapped. The current map book is an update of the 2015 Map Book, and is based on the findings of these earlier reports and adds more detailed assessments on the various indicators.

Political background

The European Commission acknowledges that the average global temperature is rising and will continue to do so. This will affect natural phenomena like precipitation patterns, glacier mass changes and sea level rise.

Mitigation efforts are needed to limit global warming. However, even if these efforts are successful, the temperature rise and related changes will continue to manifest for several decades or even centuries. To avert the most serious effects on society as well as nature, adaptation efforts on all levels (from international to local) are needed. The EU strategy on adaptation (EC, 2013a) provides a general direction on how to adapt in Europe, while underlining the particular importance of adaptation action in European urban areas (EC, 2013c). Such action builds on, but does not replace, earlier EU policies. These include directives on a framework for Community action in the field of water policy (EC, 2000) and on the assessment and management of flood risks (EC, 2007b), the communication addressing the challenge of water scarcity and droughts in the European Union (EC, 2007a), and the recommendation concerning the implementation of Integrated Coastal Zone Management in Europe (EC, 2002).

Because cities are home to a major section of the European population and its economic activities, they are particularly vulnerable to climate change impacts: actions taken for their adaptation are important for Europe. The European Commission encourages city action via the Mayors Adapt initiative[2], now part of the Covenant of Mayors for Climate and Energy, through which cities can commit to adopt local adaptation strategies and awareness-raising activities.

In order to support actions at national level, the European Commission will develop indicators to support evaluation of adaptation efforts and vulnerabilities. The urban vulnerability indicators in this map book and the short guidance on how to use them can aid this joint effort between the European Commission and city governments.

Approach

The selections of the indicators follows a simple system. They are grouped according to exposure, sensitivity and response capacity in relation to certain climatic threats: heatwaves, water scarcity and droughts, flooding and forest fire (see Tables 2.1 to 2.4). In this way, indicators can serve different categories: green urban areas are relevant to our understanding of exposure to heatwaves and pluvial flooding, while themselves being sensitive to droughts; their increase over time can be

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[1] See *http://climate-adapt.eea.europa.eu/tools/urban-adaptation/introduction* online.

[2] See *http://mayors-adapt.eu/* online.

viewed as a positive response activity. This system builds on an EEA practice that is in turn based on Intergovernmental Panel on Climate Change (IPCC) definitions. It has been amended slightly, in two ways. Firstly, coping capacity and adaptive capacity are subsumed under the term response capacity, which is further categorised into awareness, ability and action. Secondly, it is acknowledged that exposure is not influenced by climatic factors alone, but also by morphological factors (e.g. topography influencing wind speed and direction, for heat), hydrological factors (river basin characteristics, for floods) and human factors (e.g. soil sealing for both heat and floods). For further information on the system, see the technical paper on urban vulnerability indicators (Swart et al., 2012).

The selection of indicators is further driven by data availability. Only a limited set of relevant urban data of sufficient quality are available Europe-wide.

The main data sources for city data are:

- the Urban Audit database including the Urban Audit perception surveys (Eurostat)[3];
- the Urban Atlas (EEA)[4];
- the EEA Fast Track Service Precursor on Land Monitoring - Degree of soil sealing (EEA)[5].

The indicators provide an initial indication of cities' vulnerability that needs to be further analysed, by using data and indicators on other factors not yet considered here (see Tables 2.1 to 2.4) as well as local data.

A total of 13 urban vulnerability indicators were developed, relating to 4 climatic threats that have been found to have particular urban relevance (heatwaves, water scarcity and droughts, floods and forest fires):

- green urban areas
- soil sealing
- heat
- water consumption
- river flooding
- coastal flooding
- forest fires
- vulnerable people
- socio-economic status
- education
- trust
- city commitment.
- cities engaged in initiatives

[3] See *http://ec.europa.eu/eurostat/web/cities/overview* online.

[4] See *http://www.eea.europa.eu/data-and-maps/data/urban-atlas* online.

[5] See *http://www.eea.europa.eu/data-and-maps/data/eea-fast-track-service-precursor-on-land-monitoring-degree-of-soil-sealing* online.

2. Exposure, sensitivity and response to climatic threats

Multiple factors influence exposure to heat, flooding, water scarcity and droughts, and forest fires, as well as sensitivity to these threats and the capacity to respond to them. The following tables 2.1-2.4 provide some indication of the situation. Dark green cells represent indicator maps presented in the digital map book and described in the following factsheets, while light green cells represent information included in background layers originally developed for other purposes (while it has been made available for the map book, it is not described further in this report). White cells indicate factors that are not available at European level and require local quantitative or qualitative information. The single factors interact with each other, and thus need to be considered from a comprehensive perspective.

Table 2.1. Heatwaves

Factors that tend to increase vulnerability to heatwaves...		Response capacity
Exposure	Sensitivity	
High **thermal discomfort** values and increasing	High share of vulnerable people	Increasing the share of **green urban areas**
Lack of green urban areas	High share of low-income households – socio-economic status	Decreasing soil sealing
High degree of **soil sealing**	High population number	Commitment to fight climate change — awareness of and trust in city governance;
Increased background heat and heatwaves	High share of very young population	**Trust** in other people
Population density	High share of lonely pensioner households	Education
Less ventilation	Abundance of many assets	Socio-economic status — financial resources
Little shadowing	Abundance of key services for the city and for other regions	Awareness of business and citizens
Insufficient building insulation	Low cooling water availability	Well-functioning institutional structures and processes
Heat generation by production, transport, etc.	…	Sufficient capacity in administrations to act
Specific geographical location and topography		Sufficient number of hospital beds
…		…

Table 2.2 Water scarcity and droughts

Factors that tend to increase the vulnerability to water scarcity and droughts…		Response capacity
Exposure	Sensitivity	
Low precipitation	High water consumption	Commitment to fight climate change — trust in city governance Education
Water stress in the region	High share of vulnerable people	**Trust** in other people
High population number		
Drought situations	High share of low-income households –**socio-economic status**	Education
High abstraction in relation to available resources	High share of green urban areas	Socio-economic status — financial resources
Low water availability (surface and underground)	High share of lonely pensioner households	Awareness of business and citizens
Saltwater intrusion	High share of very young population	Well-functioning institutional structures and processes
Water pollution	Inefficient water supply infrastructure and management	Sufficient capacity in administrations to act
Water-intense industry, tourism, agriculture in the region	…	Availability of technical measures like reservoirs, water recycling, rainwater harvesting, etc.
High degree of soil sealing in the region		Availability of organisational measures like water use restrictions
…		…

Table 2.3 Flooding

Factors that tend to increase the vulnerability to flooding by rivers, sea or heavy rain fall…		Response capacity
Exposure	Sensitivity	
High share of low-lying **urban areas**, potentially prone to flooding	High share of low-income households – socio-economic status	Decreasing soil sealing
High and increasing degree of **soil sealing**	High share of vulnerable people	Increasing the share of **green urban areas**
Lack of green urban areas	High share assets (**commercial, residential areas**) in potentially flood prone areas	Commitment to fight climate change — awareness of and trust in the city governance; Cities engaged in initiatives
Sea level rise in combination with storm surges	Key services like **transport** and energy infrastructure in potentially flood-prone areas	**Trust** in other people
Increase of frequency and levels of river floods	High population number in potentially flood prone areas	Education
Increase of frequency and intensity of heavy precipitation	High share of very young population	Socio-economic status — financial resources
Geographical location (at coasts or rivers) and topography (low-lying)	High share of lonely pensioner households	Awareness of business and citizens
Snowmelt	…	Well-functioning institutional structures and processes
High soil moisture levels		Sufficient capacity in administrations to act
…		Availability of flood defences and retention areas
		Effective sewage system and storage systems
		…

Table 2.4. Forest fires

Factors that tend to increase the vulnerability to forest fires		Response capacity
Exposure	Sensitivity	
High share of **urban areas** in forest fire risk zones	High share of vulnerable people	Commitment to fight climate change — trust in city governance; Cities engaged in initiatives
High share of **population** in forest fire risk zones	High share of low-income households — socio-economic status	**Trust** in other people
Forest fire probability	High share of residential areas in high-risk zones	Education
Drought situations	High share of commercial areas in high-risk zones	Socio-economic status — financial resources
Increasing temperature	High share of transport infrastructure in high-risk	Accessibility of urban areas for firefighting and evacuation
Increased wind speeds	Proximity to forests and high number of vegetated areas at the edge of cities	Awareness of business and citizens
Human behaviour increasing ignition probability	High share of very young population	Financial resources of the city
…	High share of lonely pensioner households	Well-functioning institutional structures and processes
	High share of other service infrastructure in high-risk	Sufficient capacity in administrations to act
	…	Availability of effective forest-fire risk management
		…

3. Factsheets of indicator maps

3.1 Green urban areas

Indicator definition

The green urban areas indicator comprises three sub-indicators, as explained below.

1. The share of green areas is defined
   a. in cities: as the share of green urban area within the city boundaries [%];
   b. around cities: as the share of green area in a 5 km buffer zone around the urban area of the city) [%].
2. The distribution of green urban areas expressed with the proxy of edge density per hectare of edges/boundaries [m/ha] between vegetated and built-up areas of the urban area of the city.
3. The change of the share of green urban areas [%]. From the Urban Atlas update for the year 2012, partially completed in 2016, the change in the share of green areas within the city boundaries between 2006 and 2012 could be computed for a subset of the city's urban areas. A similar change indicator for green area in the buffer zone could not yet be determined.

Justification of the indicator

The indicator relates to:

- heatwaves
- flooding
- water scarcity
- forest fires.

Heatwaves have been the most prominent hazard causing human fatalities over the past decades (EEA, 2012). The 2003 summer heatwave alone caused up to 70 000 excess deaths over 4 months in Central and Western Europe. Increased mortality is the most drastic impact of heatwaves; however, exposure to hot weather can have other effects on human health and well-being, including 'bad moods', feeling discomfort and getting sick.

The impact of heatwaves is felt particularly intensely in cities and towns. The term 'Urban Heat Island' (UHI) is used to describe the increased temperature of urban air compared to its rural surroundings. The temperature difference can be 10 °C or more (Oke, 1982). The difference is most pronounced during the night, when high temperatures are generally most problematic (Grize *et al.* 2005).

Green areas inside the warm urban microclimate of densely populated cities can improve the thermal comfort (Steeneveld et al., 2011) as well as the overall health and living conditions of inhabitants (Bowler et al., 2010a). The effect of green infrastructure on UHIs is primarily due to shading and evapotranspiration (Bowler et al., 2010b). The more green urban areas a city contains (including at the fringes), and the better distributed these green spaces are, the lesser the impact of the UHI effect. Apart from this effect at city scale on neighbourhoods, green may provide considerable relief from heat and improve thermal comfort locally by providing local shade to individual residents (Armson et al., 2013). In the Netherlands, a rule of thumb indicates that the 95 percentile of the UHI strength typically decreases with 0.6 degrees per 10% of green (Rovers et al., 2015). Reducing the numbers of trees decreases shading opportunities as well and can have a large consequences locally, such as a significant deterioration of indoor and outdoor thermal comfort (Rovers et al., 2015).

The status information of the share and the distribution of urban green in a city can be used as an overall exposure indicator for the potential UHI of a city, while information on the change of green urban area surface would be contained in the response capacity indicators.

Regarding a city's exposure to pluvial and other floods, unsealed[6] and green areas can help to maintain the infiltration capacity and provide water storage capacity. By contrast, sealed surfaces decrease natural drainage and hamper infiltration into soils, which leads to increased run-off and a faster passing on of rainwater into the sewage system. Due to the often weak rainwater management systems, urban drainage infrastructures are not capable of dealing with the events of extremely heavy precipitation expected to occur more frequently in future in several regions of Europe. Thus, green is to some extent also an indicator of a city's sensitivity to such events (EEA, 2012).

The amount and type of vegetation close to the urban fringe is also relevant to sensitivity to forest fires, as it can provide favourable conditions for the spread of fire into the city.

In prolonged drought and water-scarcity situations green areas may themselves suffer from water shortage, depending on the vegetation type. Then, they may no longer be able to provide some of the benefits described above. Furthermore, droughts and water scarcity are caused and aggravated partly by the prevailing land cover and its changes in a region, notably loss of vegetated areas in favour of extension of sealed artificial areas. Land use changes which lead to further urbanisation alter the existing run-off and underlying groundwater level; furthermore, areas important for groundwater generation might be occupied and hence be lost.

Methodology

The workflow of the productions of the share of green urban areas is illustrated in Figure 3.1. The selection of classes contained in the green urban areas is based on their relevance for the Urban Heat Island effect. In general, green areas are made up of Urban Atlas classes that contain substantial amounts of vegetation. These classes are the two least sealed discontinuous urban areas (sealing degree < 30%), urban green spaces (such as parks, allotment gardens, sport and leisure facilities), and agricultural areas as well as forest and semi-natural areas. All other Urban Atlas classes are considered as non-green areas and aggregated into one class to represent the sealed surfaces. By consequence, two strata are created: (i) "green" and (ii) "red". See Table 1 for a description of the Urban Atlas classes and their classification as "green".

The basic reference unit for the processing are the Urban Morphological Zones (UMZ) inside the city's urban area which function as a representation of the "real" city[7]. In addition, to account for land use and cover in the urban fringe a buffer of 5 km is computed around the city's urban area UMZ.

[6] Also see indicator 'soil sealing'.

[7] See more details in the "Data specification" section and in the Annex

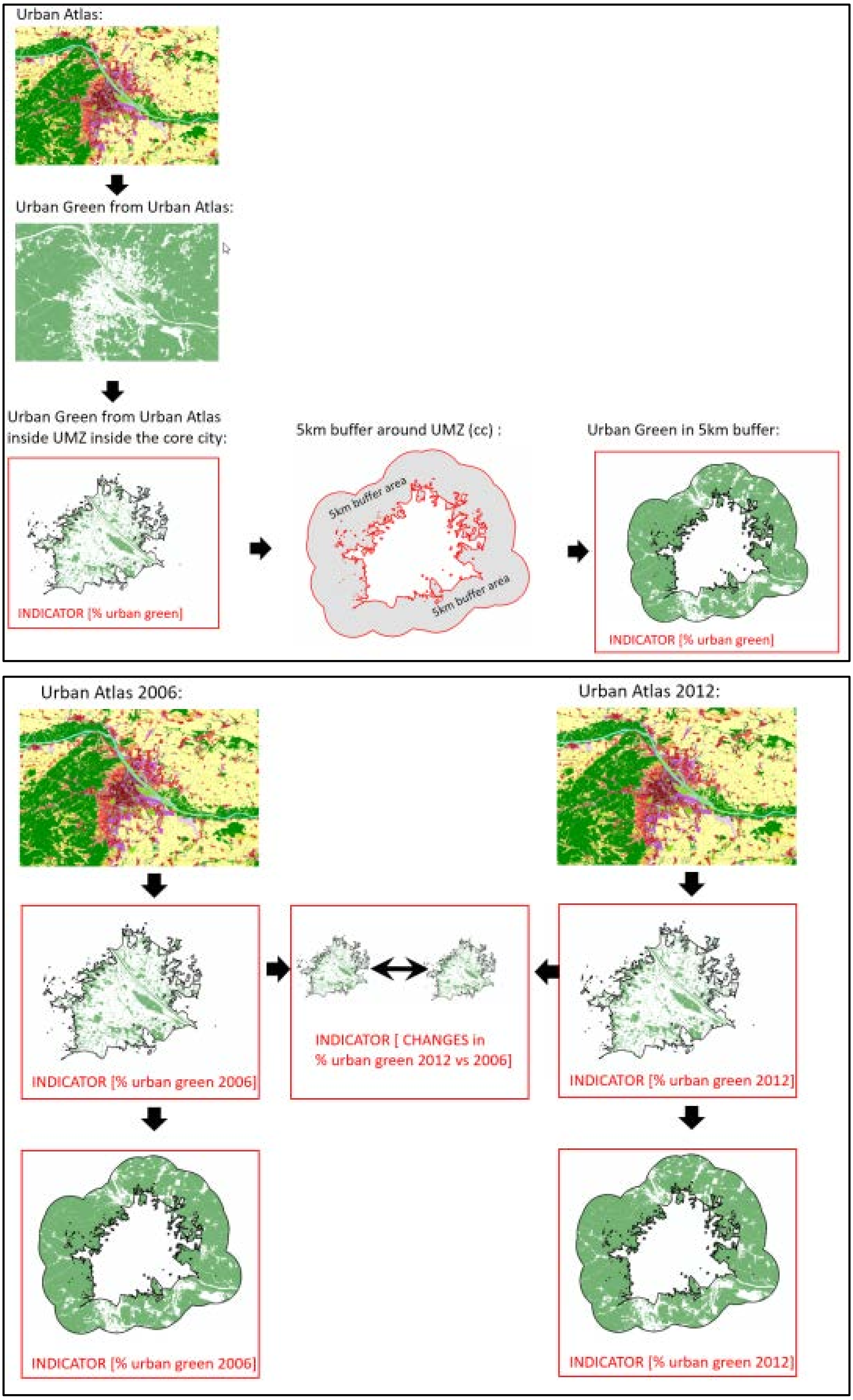


Figure 3.1: Workflow of the production of the share of green urban areas

1. Sub-indicator: Share of green urban areas

Green urban areas are extracted from the Urban Atlas product (reference years 2006 and 2012) for the city's urban area UMZ and the buffer around (Figure 3.1). For 2006 values for 300 city's urban areas are available and for 2012 for 563 cities. The change in the share of urban green could therefore be computed for 300 cities. It has to be noted that the nomenclature for the non-urban classes in the Urban Atlas has changed between the reference years 2006 and 2012. The differences are shown in Table 1, along with the selection of the classes used for the share of green urban areas (last column). The share of green urban areas in the buffer zone is at present only available for the year 2006, for 384 cities.

Table 3.1.1: Urban Atlas classes that were selected as green urban areas

ID	CODE2012	ITEM2012	CODE2006	ITEM2006	UA12_urban_green
1	11100	Continuous Urban Fabric (S.L. > 80%)	11100	Continuous Urban Fabric (S.L. > 80%)	
2	11210	Discontinuous Dense Urban Fabric (S.L. : 50% - 80%)	11210	Discontinuous Dense Urban Fabric (S.L. : 50% - 80%)	
3	11220	Discontinuous Medium Density Urban Fabric (S.L. : 30% - 50%)	11220	Discontinuous Medium Density Urban Fabric (S.L. : 30% - 50%)	
4	11230	Discontinuous Low Density Urban Fabric (S.L. : 10% - 30%)	11230	Discontinuous Low Density Urban Fabric (S.L. : 10% - 30%)	1
5	11240	Discontinuous Very Low Density Urban Fabric (S.L. < 10%)	11240	Discontinuous Very Low Density Urban Fabric (S.L. < 10%)	1

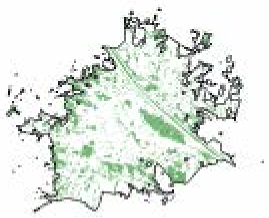
ID	CODE2012	ITEM2012	CODE2006	ITEM2006	UA12_urban_green
6	11300	Isolated Structures	11300	Isolated Structures	
7	12100	Industrial, commercial, public, military and private units	12100	Industrial, commercial, public, military and private units	
8	12210	Fast transit roads and associated land	12210	Fast transit roads and associated land	
9	12220	Other roads and associated land	12220	Other roads and associated land	
10	12230	Railways and associated land	12230	Railways and associated land	
11	12300	Port areas	12300	Port areas	
12	12400	Airports	12400	Airports	
13	13100	Mineral extraction and dump sites	13100	Mineral extraction and dump sites	
14	13300	Construction sites	13300	Construction sites	
15	13400	Land without current use	13400	Land without current use	
16	14100	Green urban areas	14100	Green urban areas	1
1	14200	Sports and	14200	Sports and	1

ID	CODE2012	ITEM2012	CODE2006	ITEM2006	UA12_urban_green
7		leisure facilities		leisure facilities	
18	21000	Arable land (annual crops)	20000	Agricultural areas, semi-natural areas and wetlands	1
19	22000	Permanent crops (vineyards, fruit trees, olive groves)	20000	Agricultural areas, semi-natural areas and wetlands	1
20	23000	Pastures	20000	Agricultural areas, semi-natural areas and wetlands	1
21	24000	Complex and mixed cultivation patterns	20000	Agricultural areas, semi-natural areas and wetlands	1
22	25000	Orchards	20000	Agricultural areas, semi-natural areas and wetlands	1
23	31000	Forests	30000	Forests	1
24	32000	Herbaceous vegetation associations (natural grassland, moors...)	30000	Forests	1

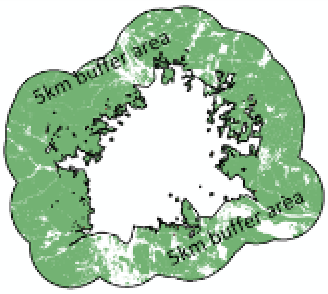
ID	CODE2012	ITEM2012	CODE2006	ITEM2006	UA12_urban_green
25	33000	Open spaces with little or no vegetation	30000	Forests	1
26	40000	wetland	20000	Agricultural areas, semi-natural areas and wetlands	1
27	50000	Water bodies	50000	Water bodies	

The extracted polygons are grouped to create a "green" class. Afterwards, the area of all "green" patches is summed and the share of this total calculated:

a) in relation to the total area of the city's urban area UMZ; and



b) in relation to the buffer of 5 km around the city's urban area UMZ (leaving out the city's urban area UMZ area).



2. Sub-indicator: Distribution of green urban areas

Intra-urban edges are the boundaries between the green areas as defined in the sub-indicator "Share of green urban areas" and all other areas that are not included in the green urban areas (henceforth called "red areas" for simplicity). The total length of the boundaries between the two classes (i.e., between the green and red areas) is computed within the UMZ inside the city's urban area. Afterwards, the total length is divided by the area of the UMZ inside the city's urban area to obtain the edge density, defined as the average total edge length per square kilometre.

The edge density provides an indication about the distribution of green urban areas. A high edge density in a city can be interpreted as an indication of 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 city's urban area UMZ (Figure 3.1) for the two reference years 2006 and 2012.

3. Sub-indicator: Change of share of green urban areas

The changes in the share of green urban areas are computed by calculating the difference between the share of green urban areas in 2006 and 2012 for each UMZ within the city's urban area. In the present stage of the development only positive and negative values will be distinguished in order to provide a first impression on the trends within the cities.

Data specifications

EEA data references

The GMES Urban Atlas data for 2006 and 2012 are used to extract the relevant classes and produce the maps of green urban areas from which the statistics can be computed. Data available for download from the Copernicus Land Monitoring Services web portal[8].

Urban Morphological Zones (UMZ) are the reference unit for the city morphology. They are regarded as the best approximation of the "real" city form, which often does not correspond to the administrative delineation. The UMZ is derived from the high-resolution Urban Atlas 2012 data set. In the current processing, all UMZ patches located within the city's urban area boundaries are used (see annex). The 2012 data set is a very recent development and not yet available as an EEA data service.

External data references

Eurostat Urban Audit city/greater city[9].

Uncertainties

Together with local temperature measurements, an overview of the coverage of the green areas, the distribution of these areas and the trends in coverage will help to assess whether smaller patches of green areas or larger parks are more effective in reducing the UHI effect, thus further clarifying the link between green space and heat, or thermal comfort. For this to be achieved, further research is needed in different cities. Policies can be developed using the outcomes of such research.

Whether water areas (the 'blue' class) are to be included or excluded from the analysis remains an issue to be resolved. The physical processes that lead to cooling by green structures are clearly different from the processes that link water temperature to air temperature. For example, water may enhance the UHI in particular on warm nights during the later summer. While literature from the Netherlands proposes excluding blue areas, some researchers prefer to include them. This may depend on the context, but it is certainly an issue to be further explored and agreed upon in the future.

Indicator assessment

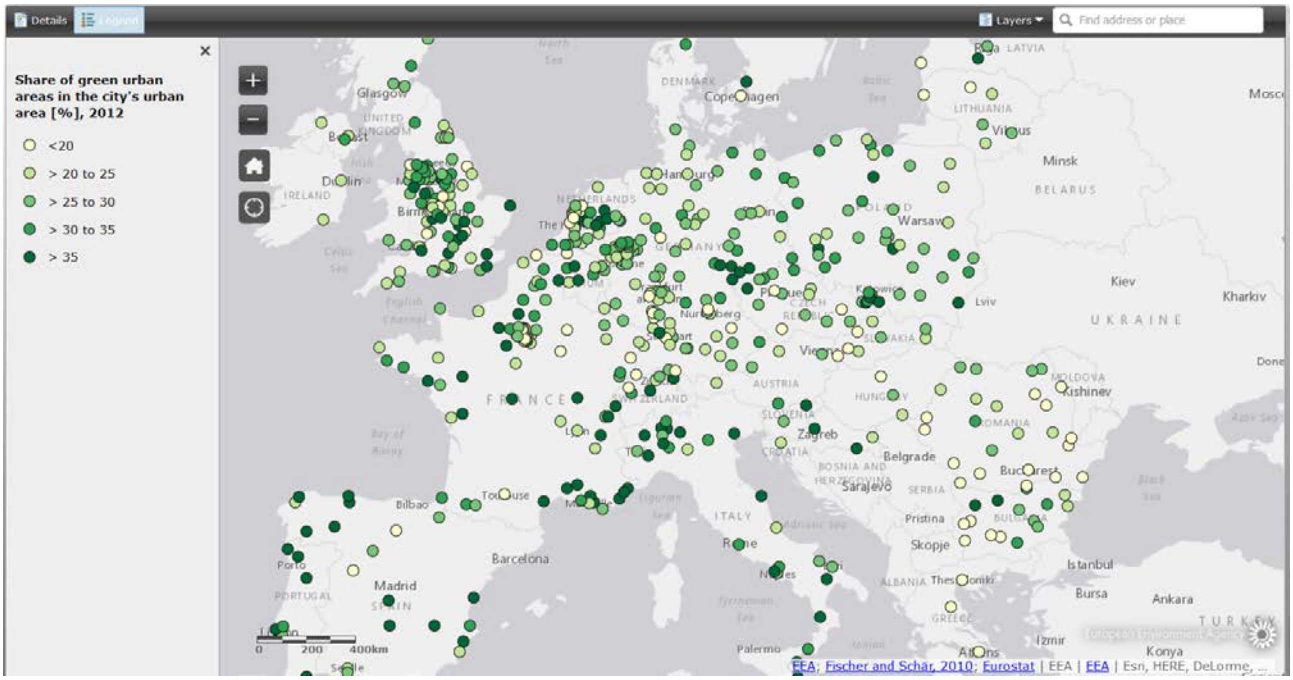
Key question: What is the share of green areas in European cities and their surrounding areas, and how are these areas distributed within the cities?

[8] See *http://land.copernicus.eu/local/urban-atlas/view* online

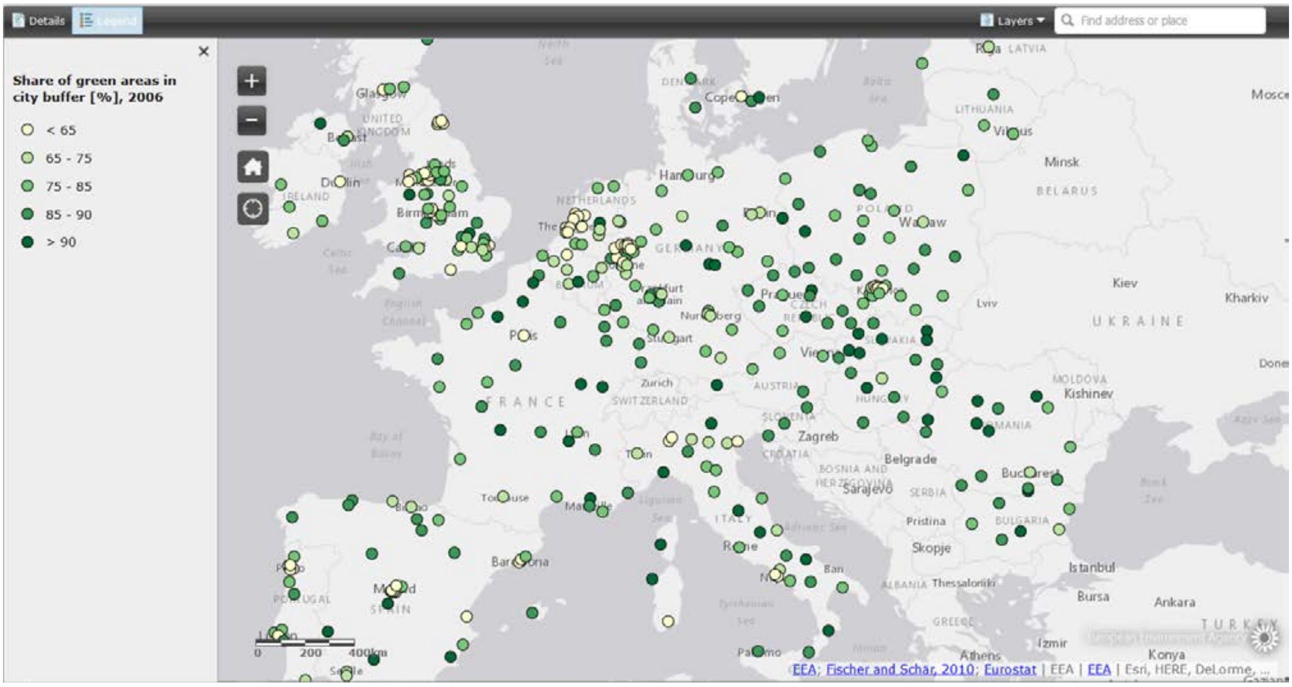
[9] See *http://ec.europa.eu/eurostat/web/cities/overview* online

Web link to maps

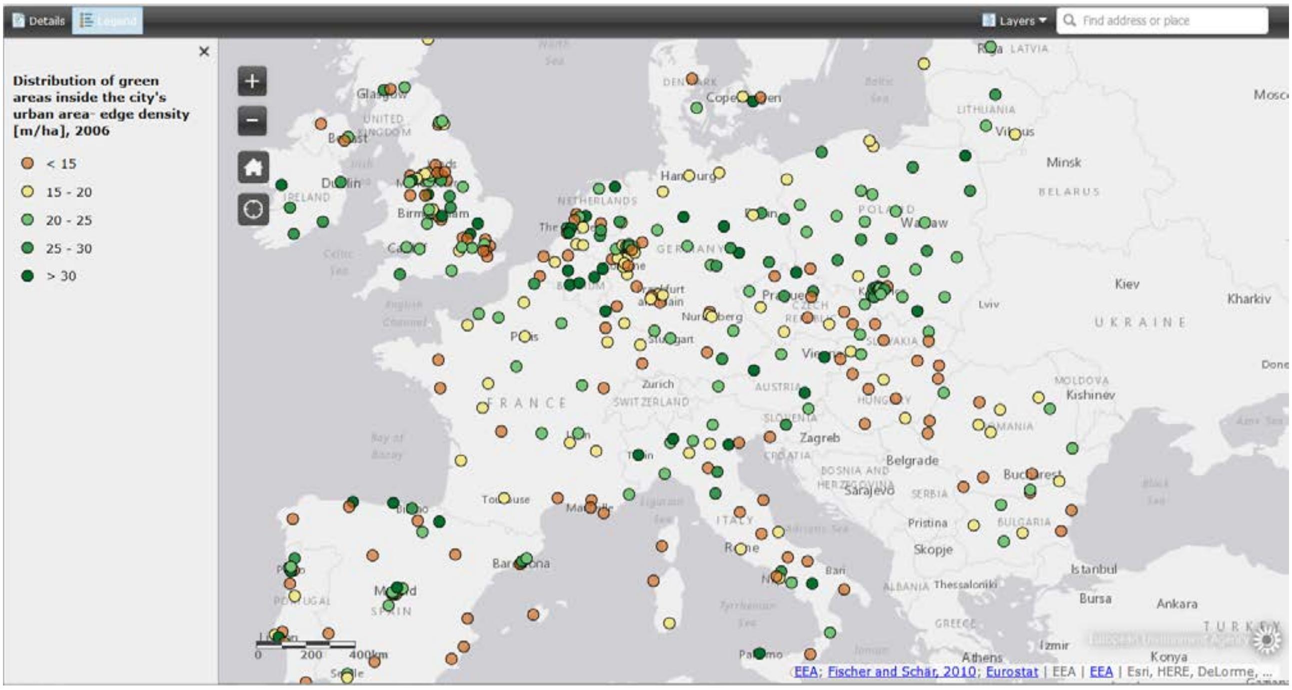
http://maps.eea.europa.eu/EEABasicviewer/v3/?appid=e6f0c5adad4d445684c48312dbce2331&webmap=18ba829030e5420d99b117f1d0d21ee5&embed=false



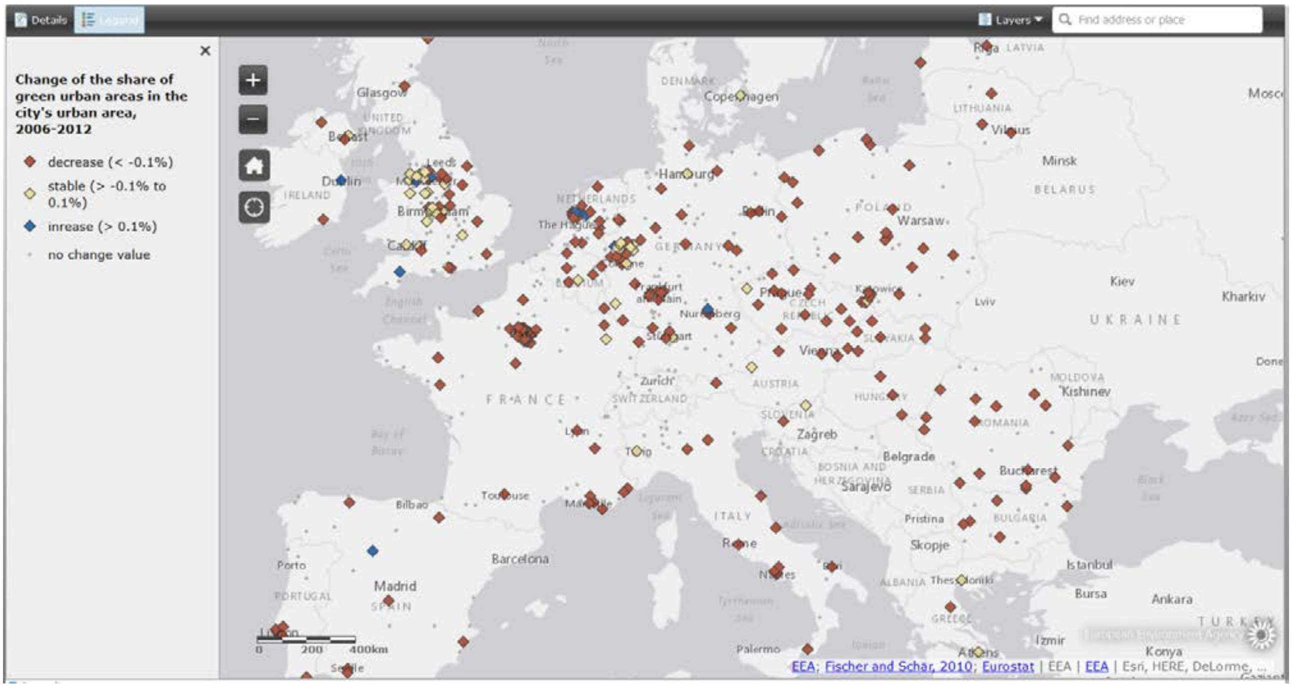
Map 3.1.1 Share of green areas in the city's urban area [%], 2012



Map 3.1.2 Share of green areas in the city buffer [%], 2006



Map 3.1.3 Distribution of green areas inside the city's urban area-edge density [m/ha], 2006



Map 3.1.4 Change in the share of green in the city's urban areas, 2006-2012

In 2012, green fractions differed considerably among cities in Europe. Considering that the share of green is an indicator related to thermal comfort it can be seen that cities in some densely populated areas in Central Europe, such as the German Ruhr area and cities around the Black Sea in Eastern Europe would benefit most from green infrastructure for improvement of thermal comfort. In the eastern part of Europe, lack of green in the cities is to some extent compensated by relatively large green fractions in the buffer areas. There is a clustering of cities with a low share of green in the densely populated areas of the Netherlands and the German Ruhr area as well as some areas in Central and Northern UK, where at the same time the share of green in their buffer area tends to be somewhat lower than that of cities in other parts of Europe. Although the present climate does not yet lead to frequent conditions of thermal discomfort in cities in the north-western part of Europe, their UHIs can be as large as in other regions (Steeneveld et al., 2011). Since climate change is expected to increase the frequency of thermal discomfort occasions in the near future (see Section 3.3) increasing the share of green might be beneficial in these areas as well.

Cities having a relatively small green share are found all over Europe, except in Scandinavia. Relatively large fractions of green are found in the cities in the north of Europe as well as in the mid and eastern Mediterranean areas. Cities with most green cover are found in the north, notably in Scandinavian countries. It is likely that the vegetation type used in these parts of Europe differ, because of the differences in climate, including the greater water availability in the North versus the South. Drought tolerant or drought resistant, less evaporating vegetation may be expected in the South, with smaller effect on the UHI via evapotranspiration than well evaporating species. However, trees showing low evapotranspiration may still provide heat relief by shading. In both parts of Europe, the cities tend to be surrounded by relatively large shares of green, further increasing the potential to mitigate heat in the city.

The trend in the green fraction inside the city's urban area between 2006 and 2012 could be determined for 300 cities in Europe from the difference between the share of green areas in those years (Map 3.1.4). In spite of the potentially beneficial effect of natural green elements in cities it can be seen that the trend in the green fraction was negative in by far most of the cities analysed here (268 out of 300, or 89.3%). The average decrease in these cities was 1.2%, the median 0.7%. In three cities the decline in green area according to this analysis was more than 10%: Oulu / Uleåborg (25%), CA de Sophia-Antipolis (17%) and Aubagne (12%). In the small number of cities with a positive trend the increase in the fraction of green ranged between 0.01 and 1.7%, with an average of 0.2% and a median of 0.1%. There is no indication that the decline is smaller in less green cities. The trend in green fraction is consistent with the increasing fraction of impervious areas between 2006 and 2009 (see Section 3.2), which may indicate that at least some of the green urban areas are converted into sealed areas like buildings and roads. This means that the potential for heat mitigation has been reduced in most cities of Europe.

In 2012, most of the cities (75% out of 563) in Europe analysed here had a share of green areas between 20% and 40%. The average share of green area was 29.0%, the median value was 27.7%. The share of green areas in the buffer zone was on average 77%, the median value being 82%. For 67% of the cities the share of green areas in the buffer zone is between 65% and 90%. Furthermore, for 52 cities (14%) the share of green in the buffer zone even exceeded 90%. So, in general the buffer zones may be expected to improve thermal comfort in the cities. Cities with a lower share of green in the buffer zones (less than 65% of green) are mainly clustered in industrial areas in north-western Europe, with some additional clusters of cities with less green surroundings, such as in Poland and Italy. These clusters contain industrial cities with less than 40% of their buffer zone classified as green, like Manchester in the UK (36%) and Schiedam in The Netherlands (26%). On the other hand, some cities may have a low green share because they are located near water, like Copenhagen in Denmark (31%). The cities' green areas are mostly concentrated in larger areas; the edge density is mostly between 4 m/ha and 24 m/ha, while some 20 % of the cities' edge densities range from 25 m/ha to 34 m/ha.

When further assessing the indicators, the extremes of two sub-indicators are of particular interest. First, the 'share of urban green' and 'edge density' inside the city's urban area are considered. Data combinations from 2006 are analysed because data for that year were available for both indicators. In total 384 data combinations were available. The indicators are first classified in three classes, using the 10 and 90 percentiles, respectively:

	class 1 (10% lowest)	class 2	class 3 (10% highest)
share of urban green [%]	<17.5	17.5-34.5	>34.5
edge density [m/ha]	<9.4	9.4-30.5	>30.5

Then the classifications were used to construct the following matrix, showing the number of cities in each pair of classes:

Count of city		**Share of urban green**			
		1	**2**	**3**	*Grand Total*
Edge Density	**1**	*6*	*26*	*7*	39
	2	*33*	*251*	*22*	306
	3	*1*	*28*	*10*	39
	Grand Total	40	305	39	384

Based on this analysis, the following cities showed extreme value combinations (i.e. located in the corner boxes of the matrix, highlighted using bold gridlines).

- Low share of green urban areas and low edge density (uneven distribution) (1/1): Valencia, Nyíregyháza, Pécs, Kecskemét, Reggio di Calabria and Haarlemmermeer (10). In such cities, exposure to heat at local and neighbourhood scale is expected to be relatively large, since the share of green is low. On average, citizens' access to green areas is limited as these areas are relatively far away from their homes. Furthermore, in these cities, there is little mitigation of the effects of extreme precipitation events thanks to green structures.
- Low share of green urban areas and high edge density (even distribution) (1/3): unsurprisingly, this is an unusual combination. If there is little green, the edge density is expected to be relatively low as well. Only one city is found in this class: the city of Porto. At larger scales, in this type of city one might expect a relatively high exposure to heat, and sensitivity to strong precipitation events. However, the large edge density suggests the green structures are quite well distributed: there will be more places inside these cities benefitting locally from city green.
- High share of green urban areas and low edge density (uneven distribution) (3/1): Badajoz, Sassari, Jönköping, Uppsala, Linköping, Örebro and Warwick. In these cities, exposure to heat at city to neighbourhood scale is expected to be reduced because of the large share of green. However, the green is distributed in relatively large patches, so a relatively small number of favourable local effects are expected, partly due to the fact that the green is probably relatively far away. The cities are expected to be less sensitive to strong precipitation events than cities with less green. However, water will be required to optimally sustain the favourable effect of green on thermal comfort, making these cities somewhat sensitive to drought.
- High share of green urban areas and high edge density (3/3): Graz, Namur, Alcobendas, Helsinki, Palermo, Monza, Gozo, Ruda, Slaska, Vila Nova de Gaia and Malmö. This is in principle the most favourable condition regarding prevention of thermal discomfort and

adverse effects of strong precipitation events. Thermal comfort is optimally improved from local to city-scale and green will generally be within relatively close distance from the residents' homes. However, like in the previous class water will be required to sustain the vegetation, making these cities somewhat sensitive to drought.

It must be stressed that the assessment is based on the present sub-indicator combination only, which is only related to green structures. Other conditions may be more or less favourable. For heat, for example, the lack of green may be balanced out by a favourable building style and other elements that provide shade locally; likewise, the lack of water storage capacity diagnosed from the low share of green may be offset by the presence of surface waterbodies.

The combination of green share in the city's urban area and green share in the buffer area are also of interest. Adverse effects of the lack of green in the city's urban area may be counterbalanced somewhat by green in the buffer zone. For example, air flowing over green areas in the buffer zone may provide cool air for densely built areas. For smaller cities in particular, the influence of the green buffer might reach quite far into the city. However, it is difficult to quantify such effects at present, and the type of green in the surroundings is also important. For example, while forested areas provide relatively little cooling in the first phase of a heatwave as compared to grassland, they may provide such cooling for a much longer time, thereby mitigating temperature in the later phase of a heatwave (Teuling et al., 2010). Again, both indicators are classified with the 10 and 90 percentiles.

	class 1 (10% lowest)	class 2	class 3 (10% highest)
share of urban green [%]	<17.5	17.5-34.5	>34.5
green in buffer zone [%]	<54.0	54.0-90.7	>90.7

Thus, for the vast majority of the cities the share of green in their buffer zones is well over 50%. This classification results in the following matrix, showing the number of cities in each pair of classes:

Count of city		**Share of urban green**			
		1	**2**	**3**	*Grand Total*
Green in buffer zone	**1**	*10*	*27*	*2*	39
	2	*29*	*249*	*27*	305
	3	*1*	*29*	*10*	40
	Grand Total	40	305	39	384

We identify cities in the extreme classes (i.e., located in the corner boxes of the matrix, highlighted by means of the bold gridlines), while noting that there is hardly any overlap with the previous classification:

- Low share of green urban areas and share of green in the buffer area (1/1): København, L'Hospitalet de Llobregat, Badalona, Paris, Milano, Napoli, Rotterdam, Schiedam, Portsmouth, Southend-on-Sea. In these cities lack of green inside the UMZ is apparently not compensated by a relatively large share of green in the buffer zone. It should be noted, however, that there may be other compensating factors, such as a relatively large share of water surfaces within the city or its surroundings (e.g., Rotterdam, København).

- Low share of green urban areas and green share in the buffer zone (1/3): again, this is an unusual combination. If there is little green inside the UMZ, there is apparently a tendency of having little green in the surroundings as well. The only city with a possibly relatively large compensating mechanism is Debrecen. However, for the vast majority of the cities the share of green in their buffer zones is well over 50%.
- High share of green urban areas and low green cover in the buffer zone (3/1): Leganés and Monza. This is apparently a relatively rare combination as well, indicating that cities with a high share of urban green tend not to be located in areas with relatively little green.
- High share of both green urban areas in the city and amount of green in the buffer zone (3/3): Namur, Weimar, Badajoz, Córdoba, Oulu, Perugia, Catanzaro, Sassari, Uppsala, Lund. This is in principle the most favourable condition for prevention of thermal discomfort and mitigation of the effects of extreme precipitation events.

Again, we caution that the assessment is based on the present sub-indicator combination only. Other conditions may be favourable or less favourable. For example, relatively deep water in the city or its surroundings may be present, allowing ventilation and cooling in particular during daytime.

3.2 Soil sealing

Indicator definition

This indicator comprises two sub-indicators, showing:

1. the average degree of sealed surfaces within the city's urban area [%];
2. the net change of the degree of sealed surfaces within the city's urban area [%] over time.

Justification of the indicator

Soil sealing is the covering of the soil surface with impervious materials as a result of urban development or infrastructure construction. It was identified as one of the main soil degradation processes in the Soil Thematic Strategy (COM (2006), 231) of the European Commission and in the latest EEA report on the status of the European environment (EEA, 2010). Depending on its density and extent, soil sealing reduces or completely disrupts natural soil functions and the related delivery of ecosystem services in the area concerned, e.g. water absorption, filtering and buffering (EC-DGENV, 2012; EEA, 2014; JRC, 2014; Prokop et al., 2011).

Soil sealing plays a major role in pluvial floods and the generation of heat. In the case of pluvial floods, soil sealing decreases the water infiltration potential of the soil, thus increasing the risk from flooding caused by increasing run-off. Conversely, the infiltration of storm water into soils would significantly increase the time needed for water to reach rivers, thus reducing the amount of peak flow and therefore the risk of flooding (EC-DGENV, 2012). In the event of heavy rainfalls in cities with high rates of soil sealing, the sewage system might no longer be able to cope with the high amount of run-off water, and thus cause pluvial flooding.

Soil sealing or imperviousness is known to enhance the UHI, while urban vegetation tends to reduce it (Heusinkveld et al., 2014). Generation of the UHI effect depends largely on the surface material, the degree and area of soil sealing and the share of green (vegetated) urban areas. Compared to vegetated areas, sealed surfaces absorb more solar radiation and emit less energy through radiation from the surface. Thus, the urban fabric becomes relatively warm and releases the heat more slowly, which is one of the causes of the UHI effect. Moreover, as more surfaces are sealed, evapotranspiration of the vegetation that is present is reduced, which further increases air and surface temperatures (EC-DGENV, 2012).

Since there is some correlation between the urban green share and the degree of soil sealing (note that not all unsealed area is vegetated and vice versa), increasing soil sealing at the cost of urban green will strongly enhance exposure to heat via the UHI. Thus, cities with extremely high rates of soil sealing are not only exposed to a higher risk of urban drainage flooding, but also to the UHI. Considering that the mean temperature in Europe is rising and the number of heatwaves is expected to increase, large areas with sealed surfaces combined with limited areas covered with vegetation will further exacerbate the heat island effect of cities (EEA, 2014).

The changes of the soil sealing degree over time shown here contain processes of new sealing as well as densification due to urbanisation processes. Both developments have a negative impact on the flood and temperature regulation potential of soils.

Methodology

The soil sealing values (sometimes also described as the degree of imperviousness) are derived from satellite images with a spatial resolution of 20 m. Proxy parameters quantify the cover of green vegetation considered as inversely correlated with the degree of soil sealing. More detailed information about the data set and its production workflow can be retrieved from the delivery report (Gangkofner et al., 2010; Kopecky and Kahabka, 2009).

The basic reference unit for the processing is the city's urban area (city/greater city as defined in the Urban Atlas/Urban Audit), which functions as a representation of the morphological city (see annex).

The extent of soil sealing is taken from the pan-European soil-sealing layers 2006 and 2012, which contain the fraction of sealed soil per 1 ha cell. To compute the mean soil-sealing degree of city's urban area by means of zonal statistics, the soil-sealing mosaic of Europe was overlaid with these reference unit objects. Subsequently, these continuous values were classified into five discrete classes and presented as coloured dots.

To obtain better estimates of changes of soil sealing over time, a wider delineation was chosen. The reference unit for this sub-indicator comprises the city boundaries. Note that this delineation is different from the delineation used to compute the second sub-indicator and the delineation for the green urban area indicators, which only use the urban area inside city. This inconsistency is acceptable, since the change indicator can be regarded as a policy indicator for which a wider urban delineation is appropriate.

In order to capture the change in soil sealing, the imperviousness density change layer was employed. These values were also classified into five classes (from very low to a very high increase), and were represented as coloured dots.

Note that the changes are net changes, since the increase of soil sealing integrates two different processes:

- sealing of areas that were previously unsealed;
- increase in the degree of sealing of areas that were already sealed (densification).

The city's urban area is defined by its morphological form (UMZ) inside the city boundaries derived from Urban Audit (Annex).

As for the background map showing the change in annual mean number of days with extreme precipitation (> 20 mm/day) between the COSMO Climate Limited-area Modelling (CCLM) scenarios for (2071–2100) and the reference (1961–1990) were run for the IPCC scenario A1B.

Data specifications

EEA data references

Degree of sealed surfaces: can be most easily calculated via the Normalized Difference Vegetation Index (NDVI) from satellite images. In the frame of GMES (Copernicus) precursor activities, the 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) were produced under the FP7 Geoland2 project, while the 'imperviousness 2012'12 data were produced under the first operational Copernicus contracts. Both status layers as well as the change layer are now distributed by the EEA and are available for download via the Copernicus Land Monitoring Services portal[10]. A licence agreement is required.

The UMZ as a reference unit for city morphology (as the best approximation of the 'real' city form, which often does not correspond to the administrative delineation) is available from the EEA data service[11]. NB: In the current processing, all UMZ patches located within the city's boundaries are used (see annex).

External data references

Eurostat Urban Audit city/greater city[12].

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[10] See *http://land.copernicus.eu/pan-european/high-resolution-layers/imperviousness* online.

[11] See *http://www.eea.europa.eu/data-and-maps/data/urban-morphological-zones-2006-umz2006-f3v0* online.

[12] See *http://ec.europa.eu/eurostat/web/cities/overview* online.

Uncertainties

Despite the attempt to achieve cloud-free coverage of Europe (e.g. by using multiple overlapping image information sets to substitute clouds), the underlying satellite images for both imperviousness status maps (2006 and 2012) still show some amount of cloud cover over certain regions. Those areas have been excluded by applying a cloud mask. Moreover, 'no data' areas of 2006 (clouds) that are cloud-free in 2012 are predominantly visually mapped and subsequently integrated during the post-editing step, to reduce the unclassifiable area of the 2006 coverage.

In general, the appearance of cloud cover on one of the images leads to an exclusion of this area from the computation of the average soil sealing degree, that is, the average was computed based on the cloud-free area of a city. For the computation of changes, this leads to an incomparability of the 2 years, as the total area for which the change is computed varies across years for the respective city.

Therefore, the sealing density change layer has been produced separately, applying correction measures to account for such issues and create a reliable change layer.

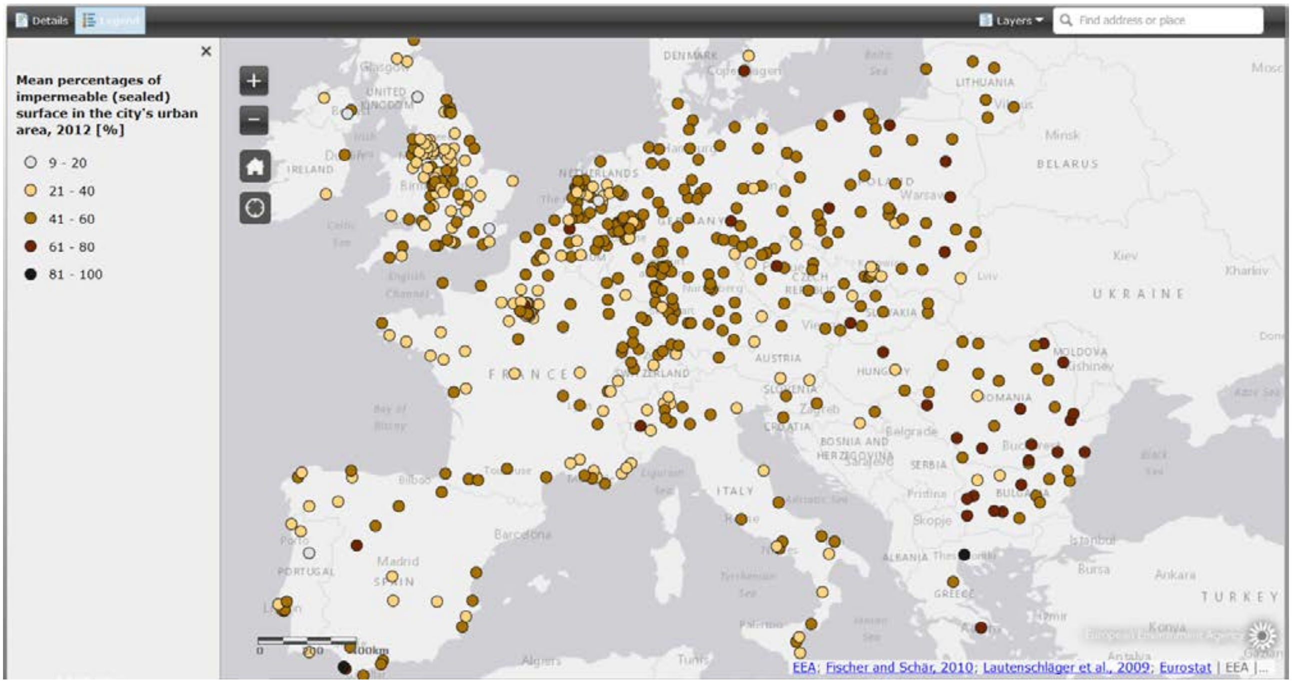
The NDVI distinguishes between vegetation and other surfaces. The index may not always correctly distinguish between vegetated and bare surfaces; generally, the type of soil sealing cannot be distinguished. And not all unsealed areas are vegetated, and vice versa; (dense) vegetation overhanging sealed soil cannot be distinguished from (dense) vegetation over other vegetation or bare soil.

Indicator assessment

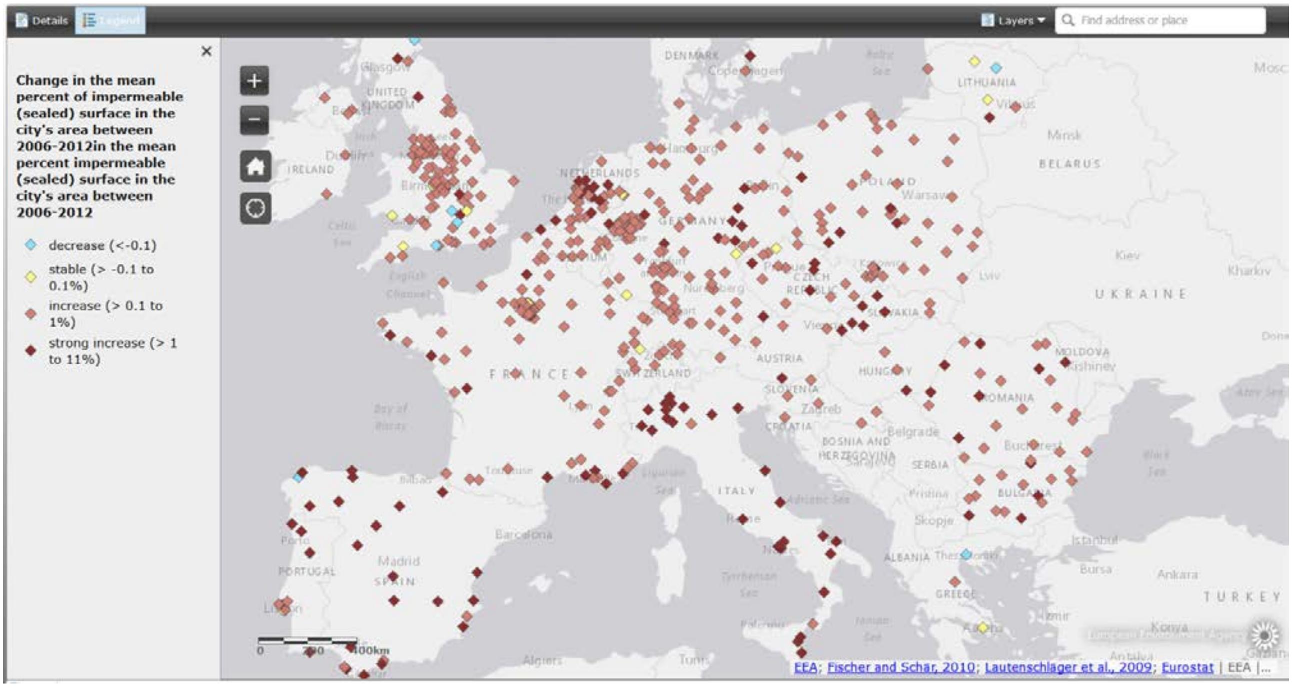
Key question: What is the current degree of soil sealing in cities and the trend indicating vulnerability to flood risks and heatwaves?

Web link to maps

http://maps.eea.europa.eu/EEABasicviewer/v3/?appid=e6f0c5adad4d445684c48312dbce2331&webmap=18ba829030e5420d99b117f1d0d21ee5&embed=false



Map 3.2.1 Mean percentages of impermeable (sealed) surface in the city's urban area, 2012 [%]



Map 3.2.2 Change in the mean percent of impermeable (sealed) surface in the city's area between 2006-2012

Note: Urban delineation corresponds to city/greater city boundaries[13].

Cities with high soil sealing and an increasing number of intensive rainfall events facing a higher risk of urban drainage flooding are found particularly in north-western and northern Europe. Cities in areas with a decreasing number of such events but with high soil sealing still face a flood risk, but will do so less often in the future. Cities of high and low soil sealing can be found in all regions, and do not cluster in a particular region. This finding is confirmed by Prokop et al. (2011) who report that 'individual regions with high sealing rates exist all over the EU'. The cities with low sealing levels in Finland and Sweden are exceptional. However, it should be stressed that a city's weakness does not depend on soil sealing alone, but also on rainwater management (EEA, 2012).

Cities with an extremely high degree of soil sealing and a low share of urban green are exposed to a relatively strong UHI (Heusinkveld et al., 2014) and therefore to heat, to which the UHI contributes. Examples are Thessaloniki in Greece and Cadiz in Spain. Here, the share of impervious surfaces in the city's urban area amounts to more than 80 %, while the share of urban green is only around 10 % (2012).At the other end of the spectrum, Kuopio in Finland that has only 9.3 % soil sealing (2012).

[13] See *http://ec.europa.eu/eurostat/web/cities/overview* online.

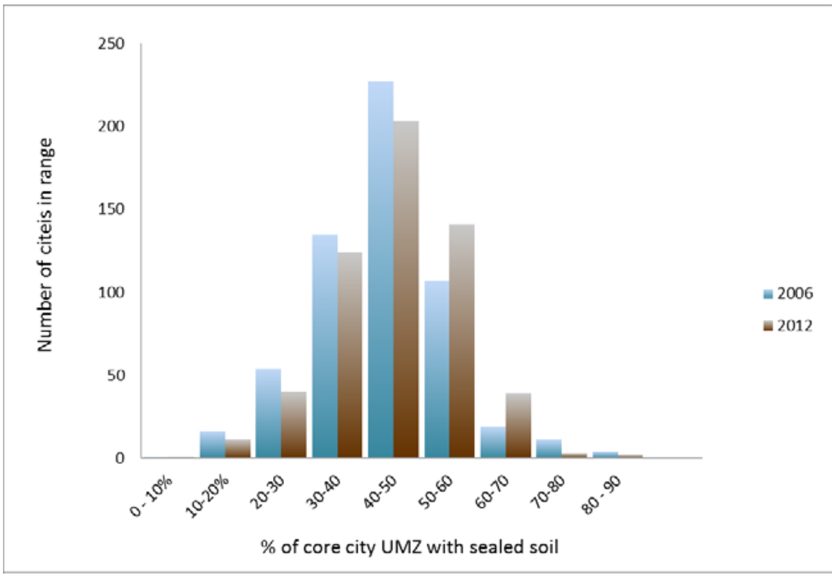


Figure 3.2.1 Distribution of cities over classes of degree of soil sealing (2006-2012)

Figure 3.2.1 shows the distribution of cities over various classes of the degree of soil sealing in the city's urban area in 2006 and 2012. Cities in the classes with between 40 % and 60 % of sealing are most common in both years. From 2006 to 2012 the number of cities in the classes with higher percentages (50-70%) is increasing, whereas cases with lower percentages of soil sealing have decreased in this period. However, in the short period of 6 years (2006-2012), a rapid increase in a large number of the cities is observed (Map 3.2 2): in 166 out of 564 cities, the increase was more than 5 % over 6 years. At the same time, the share of green urban areas in cities decreased (see Map 3.1.4). Most of the extremely strong increases of over 10 % per 6 years (65 cities) occurred in cities of Southern European countries where exposure to heat is already strong and where there is a tendency of a decreasing number of extreme precipitation events, which somewhat compensates the increased vulnerability to such events due to more sealed surface. Nevertheless, also cities from Germany and the UK are found in this group which the frequency of extreme events is expected to increase. An overall of 16 cities in the database, among these Thessaloniki (EL) Dundee and Reading (UK) showed instead a considerable decrease in soil sealing over the 6 years of observation, up to 6% in the case of Thessaloniki and 3-5% in the case of Dundee and Reading. Furthermore, hardly any change (< 1 %) was detected in 54 cities in the database. This category includes a consistent group of United Kingdom's cities (17) French (11) and German (10) cities, whereas cities from Southern Europe are almost absent in this group. Thus, with respect to heat the trend seems to be less favourable in regions where cooling would probably be most desired. With regard to extreme precipitation the less favourable trend tends to be found in regions were the number of extreme events is expected to decrease, and vice versa.

It is also of interest to note which cities with a high soil-sealing degree tend to have a slower rate of increase, and also the reverse. We therefore consider extremes of the two sub-indicators. Both indicators are classified using the 10 and 90 percentiles, respectively, as shown below.

	Class 1 (10 % lowest)	Class 2	Class 3 (10 % highest)
Soil sealing [%]	< 30.5	30.5 – 58.6	> 58.6
Change of soil sealing [%]	< 0.967	0.967– 11.716	> 11.716

The classifications were used to construct the following matrix, showing the number of cities in each pair of classes.

Count of		Degree of soil sealing			
		1	2	3	Gra
Trend of soil sealing	1	2	47	8	57
	2	46	36	40	450
	3	8	41	8	57
Grand total		56	45	56	564

The matrix reveals that, based on the 2006 and 2012 data, only two cities (Dacorum, UK and Göteborg, S) with a relatively low degree of soil sealing succeeded in maintaining growth rates low or even decreasing percentages of soil sealing. Inversely, among cities that already had a high degree of sealing, both those which succeeded in maintaining growth rates low and those with the highest growth rates are equally important, consisting of 8 cities each. 4 out of the 8 cities with low growth rates (Athens, Lisbon, La Coruña and Thessaloniki), and 6 out 8 cities in the group characterized by high levels of soil sealing and high growth rates are situated in Southern Europe , where increasing frequencies of heat waves will accentuate the risk from UHI[14]. Thus, from a climate adaptation point of view, there is a tendency for both unfavourable and favourable conditions to persist.

Additional policies may be needed to slow down or even reverse this development. Prokop et al. (2011) provide an overview of pressures and state (i.e. sealing degree), as well as responses and policy targets per EU Member State. This list reveals that a number of countries had already implemented response measures by the time of their survey (e.g. the Netherlands, Belgium, Germany, Luxembourg, Denmark and the United Kingdom), while others were either commencing to do so (e.g. Portugal, France, Italy and Poland) or have no measures in place (Malta, Cyprus, Hungary and Greece). Surprisingly, response measures are not always based on a specific policy target (the Netherlands, Belgium (Flanders), Germany, Luxembourg, the United Kingdom, France and Austria). Implemented response measures aim to improve quality of life in large urban centres by launching urban renewal programmes to revive declining urban centres (e.g. in Porto, Lisbon, Catalonia, Malmö and Vienna), programmes to redevelop brownfields (e.g. in the United Kingdom, France, the Czech Republic, and Belgium (Flanders)), and programmes for the protection of agricultural soils and landscapes (Spain, France, the Netherlands, the Czech Republic and Slovakia). The policy targets are mostly contained in the key spatial planning regulations (the principle of sustainable development), but indicative quantitative limits for annual land take (used here as a proxy for soil sealing) only exist in Austria, Belgium (Flanders), Germany, Luxembourg, the Netherlands and the United Kingdom (Prokop et al. 2011).

[14] Overall, 75 out of the 564 cities represented in the sample are situated in Southern Europe.

3.3 Heat

Indicator definition

This indicator comprises two sub-indicators:

1. As a proxy for the thermal comfort, the indicator shows the average number of days and nights with thermal discomfort occurring in the period from April to September. Here, thermal discomfort is defined as the maximum effective temperature (ET) being > = 23 °C at daytime (12:00) and > = 21 °C at night-time (0:00), taking into account the Urban Heat Island (UHI) effect on the night-time temperature.
2. Changes of the median minimum and maximum summer temperatures expected under future climate conditions (2051 – 2011) with respect to present-day climate (1951-2000).

Justification of the indicator

One of the main consequences of climate change is a rise of ambient temperature and an increasing occurrence of heatwaves, hot days (maximum air temperature over 35 °C) and tropical nights (minimum air temperature over 20 °C).

In contrast to rural areas, cities have a large stock of buildings and infrastructure materials that serve as heat accumulators. Urban structures hamper airflow to some extent. Furthermore, human energy use and the consequent release of heat is concentrated in cities. All of these factors create the city-specific UHI phenomenon: the temperature in urban areas tends to be higher than the temperature in their rural surrounding areas. The UHI typically is a nocturnal phenomenon (Oke, 1982). While the UHI can ease impacts of cold in urban areas in winter time, it elevates temperatures in cities during summer time. This may further decrease thermal comfort of residents and even increase mortality rates during heatwaves. High night-time temperatures hamper healthy sleep and recovery of humans during the night (Grize et al., 2005). In general, the beneficial effects of rising minimum temperatures in cold areas are thought to be outweighed by far by the health impacts of more frequent heat extremes (Smith et al., 2014).

Whether or not citizens feel comfortable within the urban microclimate depends not only on temperature, but also on a complex interaction between physical, physiological, behavioural, and psychological factors. This can be expressed by thermal comfort indices. The indicator described here expresses thermal comfort at the spatial scale of the city, being an index that approximates the effect of the various interactions and integral effects of all thermal parameters. This indicator should not only measure possible enhanced mortality, but should also represent human well- being in urban environments in a more general sense under heatwaves. It should also take into account the possible UHI contribution to thermal comfort. Thus, it may be interpreted as an indicator designed to describe cities' liveability under high temperature conditions. As such, the indicator presented here will complement the EEA Core Set Indicator CSI 012[15] (that describes the number of consecutive hot days and tropical nights), by a city-specific indicator. In addition, possible city-scale future changes of the maximum and minimum temperatures will be provided.

A consequence of using an indicator at neighbourhood to city scale is that threshold exceedance does not necessarily correspond to hot or extremely hot conditions for every individual citizen. A possible feeling of discomfort on a particular day depends on local conditions a citizen is exposed to, behaviour and activity pattern. For example, local shade may provide a considerable relief, while intensive physical activity may increase the level of discomfort. Furthermore, citizens in warmer regions may be accustomed to slight or moderate heat stress (Baccini et al., 2008).

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[15] See *http://www.eea.europa.eu/data-and-maps/indicators/global-and-european-temperature/global-and-european- temperature-assessment-5* online.

Minimum and maximum temperatures play a dominant role in the present estimates of the thermal comfort index. An assessment for the change in these quantities between periods 1951-2000 and 2051-2100 [ºC] is provided too[16].

Methodology

To assess the thermal exposure of the human body, the integral effects of all thermal parameters must be taken into account. To this end, rather sophisticated bio meteorological indices are available to assess thermal comfort. Examples include the predicted mean vote (PMV), the physiologically equivalent temperature (PET), and the recently developed Universal Thermal Climate Index (UTCI), which are based upon models for the human heat budget. Such models use all relevant meteorological parameters as well as physiological factors as input (Fanger, 1970; Fiala et al., 2012; Höppe, 1999; Matzarakis et al., 2010). They rely on many variables, some of which are difficult to obtain in practice for large regions, and are not routinely observed and reported at meteorological stations. Therefore, they are less suited to be applied as European-wide indicators for thermal comfort.

Empirically derived indices, like the discomfort index (Thom, 1959), wet bulb globe temperature (WBGT), apparent temperature (Steadman, 1979), and wind-chill index (Steadman, 1979) have been used to describe thermal comfort for several decades. However, these simple indices only consider a limited number of the relevant meteorological parameters. Furthermore, they generally do not take into account thermal physiology directly. But clearly, the advantage of most of the empirical indices is that they can be derived from meteorological information that is generally available. Moreover, in terms of ease of communication to the general public, they are sometimes more appealing than indices based on sophisticated models (Koppe et al., 2004).

Recently, Blazejczyk et al. (2012) compared several of the thermal comfort estimates from the simple empirical indices with UTCI. This latter index has been proposed as the standard model to assess human thermal comfort and is one of the indices based on a rather complete description of the human energy balance (Jendritzky et al., 2012; COST UTCI, 2004). It was found that notably the so-called Effective Temperature (ET) can be regarded as a reasonable proxy for the much more sophisticated UTCI. ET is computed from air temperature, relative humidity and wind speed, which are generally available from meteorological observations. The findings of Blazejczyk et al. (2012) were confirmed in an independent analysis based on data from the Dutch city of Rotterdam (Swart et al. 2012).

Based on the results from the aforementioned analyses, it is proposed to use ET as a thermal comfort index. ET is estimated as follows (Blazejczyk et al. 2012):

$$ET = 37 - \frac{37 - T_{air}}{0.68 - 0.0014RH + \frac{1}{1.76 + 1.4w_s^{0.75}}} - 0.29T_{air}(1 - 0.01RH) \quad (1)$$

where T_{air} is the air temperature (°C), RH the relative humidity of the air (%) and w_s the average wind speed (m/s).

ET is computed two times per day: at 12 UTC, representing a daytime estimate of the maximum ET, and at 00 UTC, representing an night-time estimate of the minimum ET. Often, RH decreases during the day as T_{air} increases. The maximum RH then coincides with the minimum T_{air}. During the night the minimum T_{air} and maximum RH often coincide. Therefore, the minimum ET is computed using the maximum RH and the minimum T_{air}, while the minimum RH and the maximum T_{air} are used to compute the maximum ET.

[16] European Community's Seventh Framework Programme under Grant Agreement No. 308497 (Project RAMSES)

Standard meteorological data usually represent rural areas. Neither observations and data reanalyses nor RCMs explicitly take the urban landscape into account. The largest difference between urban and rural temperatures is generally observed during night-time. Therefore, the minimum T_{air} is increased by adding an estimate of the daily nocturnal UHI intensity to represent the night-time temperature in urbanised areas. Although the physical background of the UHI has been known for a long time (Oke, 1982), there is still a rather vivid and ongoing scientific research effort to determine the relation between UHI, urban characteristics and meteorological conditions from the local to the city scale. For now, until a more general relationship becomes available, we use the relationship between UHI and population density assessed by Steeneveld et al. (2011):

$$UHI_{med} = 0.1822 P_d^{0.2996} \; (r^2 = 0.56) \quad (2)$$

where UHI_{med} is the median UHI in K and P_d is the population density in inhabitants per km^2. Although (2) was derived at the scale of neighbourhood, we take P_d to be the population density of the city, in inhabitants per square kilometer. We use the median value of the UHI because high percentiles (e.g. 95 percentile) or maximum values would exaggerate UHIs, on average. Note that (2) is only a diagnostic and statistical relationship used to enable us to include the UHI in the thermal comfort indicator. In future, other, more physically based relationships may be used. For example, Steeneveld et al. (2011) also found a strong quantitative relationship between UHIs and % green cover. Although such a relationship is physically more feasible than (2), it is not proposed here. Though many studies show the importance of urban green in mitigating heat in the urban environment, this statistical relationship between green cover and UHI intensity may depend strongly on the specific plant species found in a particular region, and therefore may be less representative of Europe as a whole.

For now, we assume that RH in the urban outdoor areas approximately equals RH in the rural surroundings. This assumption only has a relatively small impact on the value of ET.

Observational data of wind speed in the urban environment are scarce. Meteorological models compute a wind speed that generally represents rural areas. The available datasets indicate that the wind speeds in the urban environment are much lower than in rural surroundings. Particularly during hot days, wind speeds are usually low (< 2 ms^{-1}). Preliminary estimations (Swart et al., 2012) show that only a small error is made by filling in a fixed wind speed of 1 ms^{-1} for urban areas in Equation (1).

The ET threshold used to count occurrences of thermal discomfort is shown in Table 3.3.1. This table has been used to relate thermal comfort to ET in Central Europe (Blazejczyk et al., 2012). Above ET = 23 °C, conditions are generally perceived as 'warm', which corresponds to strong heat stress in other indices. Hence, we counted the number of days where the maximum ET exceeds 23 °C. The perception of heat has typically been derived for daytime conditions. No data similar to those in Table 3.3.1 are available for night-time conditions. However, night-time air temperatures of 20 °C or more hamper healthy sleep and recovery of humans during the night (Grize et al., 2005). Temperatures perceived as 'comfortable' during the day may therefore be perceived as 'too warm' during the night. Therefore, we chose a (slightly) lower ET threshold for night-time conditions. ET = 21 °C (corresponding to 'comfortable' during daytime (see Table 3.3.1)) was used as the night-time threshold.

Table 3.3.1 Thresholds for effective temperature (ET) (°C)

ET range (°C)	Thermal comfort class
>27	Hot
23..27	Warm
21..23	Comfortable
17..21	Fresh
9..17	Cool
1..9	Cold
<1	Very cold

(a) Note that the ET is different from air temperature.

Since the minimum and maximum temperature play a dominant role in the present estimates of thermal comfort, an assessment for the change in these quantities from future climate projections for 571 European cities are provided in Maps 3.3.2 and 3.3.3. The results (based on the temperature data provided by the EU-funded project RAMSES[17]), were derived from 54 RCP8.5 ensemble runs performed in the framework of CMIP5[18]. For each city, the ensemble median of the mean summer daily T_{max} or T_{min} (May-September) was computed for the present-day climate (1951-2000) and the future climate (2051-2100), respectively. The maps show the difference in the ensemble median temperatures. The projections and the resulting differences do not take into account urban effects such as the UHI. See Tapia et al. (2016) for more details on the RAMSES climate assessments for urban areas.

Data specifications

EEA data references

The UMZ as a reference unit for city morphology (as best approximation of the 'real' city form, which often does not correspond to the administrative delineation) is available from the EEA data service[19].

NB: In the current processing, all UMZ patches located within the city's boundaries are used (see annex).

External data references

- Population density was determined by dividing the total population by the city area.
- Population data were obtained from the regional statistics database at Eurostat Urban Audit cities/greater cities
- DE1001V Population on 1 January by age groups and sex - cities and greater cities[20]. The ET is calculated from the meteorological variables:
    - maximum and minimum of diurnal air temperatures;
    - maximum and minimum relative air humidity;

Data were obtained from:

- gridded meteorological observations (station data) (present-day) European Climate Assessment Data (ECA&D) project: E-OBS[21].

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[17] European Community's Seventh Framework Programme under Grant Agreement No. 308497 (Project RAMSES)

[18] http://cmip-pcmdi.llnl.gov/index.html

[19] See *http://www.eea.europa.eu/data-and-maps/data/urban-morphological-zones-2006-umz2006-f3v0* online.

[20] See *http://ec.europa.eu/eurostat/web/cities/overview* online.

- Mean summer daily minimum and maximum temperatures were provided by the EU-RAMSES project (European Community's Seventh Framework Programme under Grant Agreement No. 308497 (Project RAMSES)[22]) and were originally obtained from the CMIP5 archive of RCP8.5 ensemble runs[23].

Uncertainties

Although the relationship between the ET and the UTCI is quite strong and nearly linear, a considerable scatter around the regression line remains. For example, the analysis by Swart et al. (2012) shows that the ET ranges from about 22 °C to 26 °C at UTCI = 30 °C. This range crosses two ET threshold classes.

Clearly, the uncertainty in ET will become larger if a fixed wind speed is used.

The ET as applied here cannot describe micro-scale variations in thermal comfort. For example, trees or buildings may provide shade very locally, with a large impact on the UTCI of individuals via reduced radiation input, but not on the ET. Thus, the indicator used here must be considered to represent a city- scale average only.

The thresholds applied to assess the frequency of events (number of days with ET > 23 °C and number of nights with ET > 21 °C) are rather arbitrary. First, it is difficult to compare the thermal comfort classes for different thermal comfort indicators. Second, thresholds may have to differ across climatic zones, but often they have been evaluated for one particular region only. Third, most thermal comfort indices apply to daytime conditions only.

Although Equation (2) can be applied at neighbourhood scale, the UHI is currently evaluated at city scale, using data averaged over the UMZ. However, city design and meteorological conditions have a strong impact on UHI intensity, even within a neighbourhood. A combination of various factors may lead to strong variations in UHI intensity in time and in space. Thus, UHI intensity is known to reveal a strong spatial as well as temporal variation. The present estimation method for UHIs does not take into account such variations.

Data used in the present methodology represent the situation at classical meteorological stations, preferably located outside urban areas. The relation to their urban (micro) climatic equivalents depends on city design, local features and meteorological conditions. An attempt has been made to adjust night-time air temperature to urban conditions by adding an UHI effect for night-time conditions, this estimate of the UHI of the cities must be considered a rough first estimate only. For example, it always leads to a positive value of the UHI while in some conditions the UHI may actually be negative, notably when a city is located in a dry rural environment.

Indicator assessment

Key question: What is the thermal comfort in the cities across Europe?

Web link to map

http://maps.eea.europa.eu/EEABasicviewer/v3/?appid=e6f0c5adad4d445684c48312dbce2331&webmap=18ba829030e5420d99b117f1d0d21ee5&embed=false

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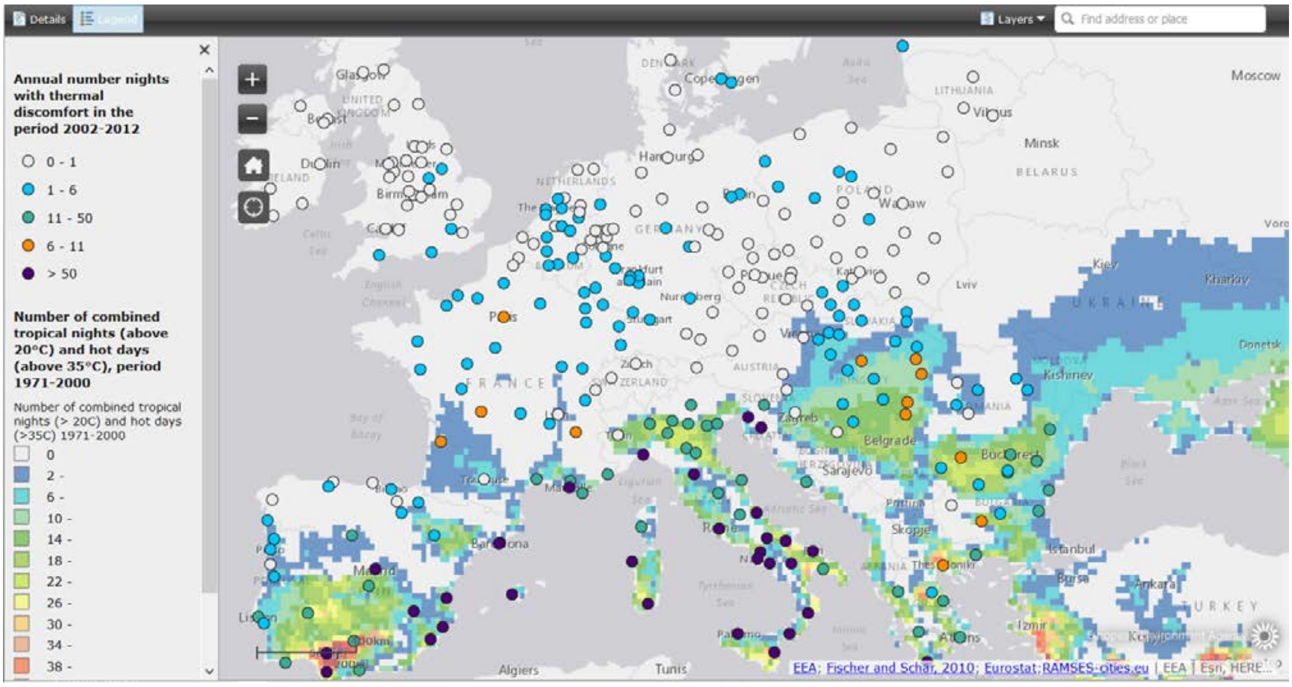
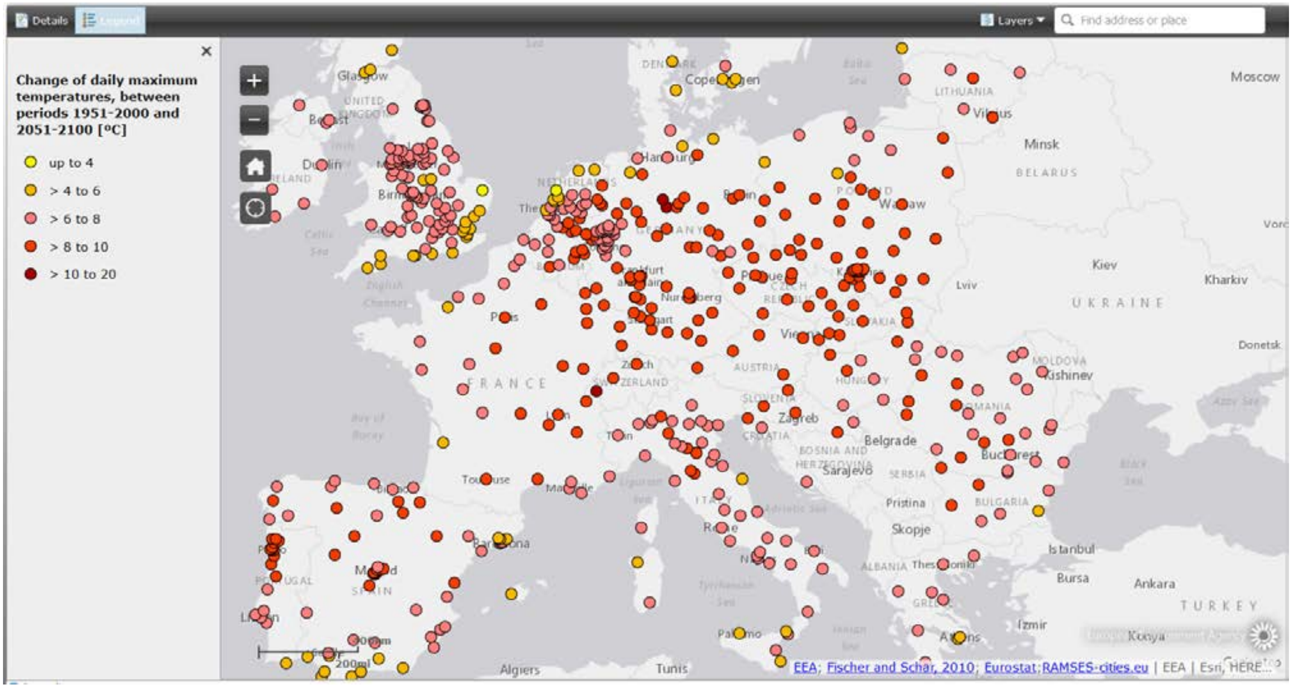
[21] See *http://eca.knmi.nl* online.

[22] See *http://www.ramses-cities.eu/* online.

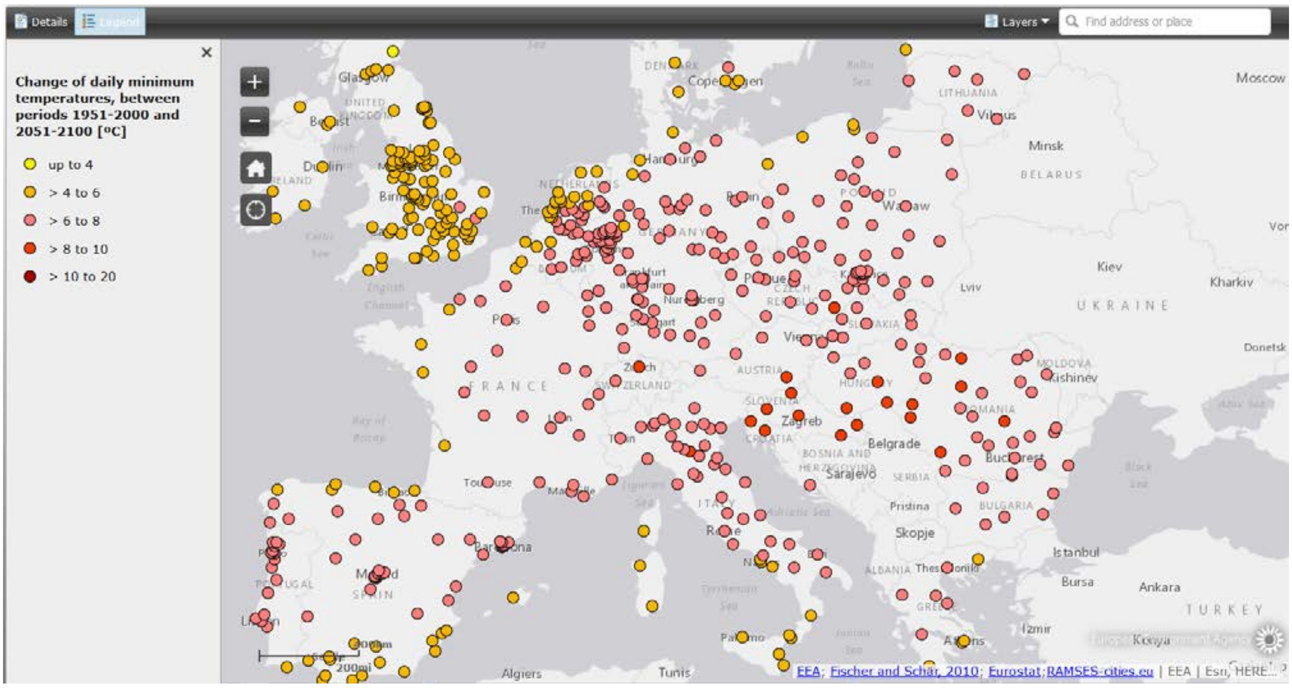
[23] See *http://cmip-pcmdi.llnl.gov/index.html* online.



Map 3.3.1 Average number of days (averaged over a period of 11 years from 2002-2012) with a night-time ET of > 21°C including UHI (ECA&D climatological data). The background map shows the number of combined tropical nights and hot days in the reference climate (1971-2000) (Fischer and Schär, 2010).



Map 3.3.2 Change of daily maximum temperatures, between periods 1951-2000 and 2051-2100 [ºC].



Map 3.3.3. Change of daily minimum temperatures, between periods 1951-2000 and 2051-2100 [°C].

The thermal comfort maps are based on present-day weather patterns. As may be expected, the mean number of days with a maximum ET > = 23 °C during daytime increases towards the south. In the southernmost cities, daytime conditions for whole summer season could represent at least slight-to-moderate heat stress. By contrast, in the reference climate similar conditions are rare or even absent in cities in the north of Europe and in coastal cities. However, climate change may lead to a strong increase of summertime daily maximum temperature. According to the RAMSES-study24 (Tapia et al., 2016) large changes of 3-10°C may be expected across Europe for the summertime daily maxima under the RCP8.5 scenario (see Map 3.3.2). Although RCP8.5 may arguably be considered a worst-case scenario, this difference illustrates that climate change may lead to a strong increase of the number of days in the warm to hot thermal comfort classes, in particular because even under present-day climate the daytime conditions are often near the lower threshold of the "warm" class.

Specific differences at relatively short distance are evident as well, particularly in Southern Europe. Coastal cities at the Atlantic borders of Europe tend to be cooler than inland cities or coastal ones at the Mediterranean Sea. This is a particularly noticeable feature on the Iberian Peninsula. While sea breezes and the related ventilation may be important for cooling during hot periods, the cooling effect of the sea is only captured in the present indicator insofar as it is observed in the standard meteorological data –temperature and humidity- since the wind speed is fixed.

In the present-day climate, the present assessment indicates that in about 40% of the cities included here warm night-time conditions with ET > 21°C on average occur less than one night per year. Mostly in southern cities, during several nights the minimum, night-time ET exceeds 21 °C. In about 16% of the cities (93 out of 572) the ET threshold of 21°C is surpassed during 30 days or more per year, which is equivalent to about one month per year. According to the RAMSES results, strong increases in the summer-season daily minimum temperature of 4-9 °C are expected across Europe (Map 3.3.3). Thus, the number of nights with warm conditions is also expected to increase in the future. Again, we caution that RCP8.5 may be considered as worst-case scenario. On the other hand, the UHI has not been included in the RAMSES estimates. Nevertheless, the RAMSES results illustrate the possible changes that might be anticipated under climate change. The rather qualitative

[24] See http://www.ramses-cities.eu/ online

assessment of such changes is corroborated by studies on individual cities, showing that also cities in the North may experience significant periods of time with warm nights in the future. For example, a regional analysis for cities in the Randstad area in the Netherlands (including the cities of Amsterdam, Rotterdam and The Hague)[25], hardly shows any warm nights at present, but a significant increase in the number of nights with thermal discomfort in the future. At present, the number of hot nights in the centres of these cities was found to add up to a total of, typically, about 5 days per year (~ 1 'week'), which is consistent with the results of the analysis at European scale. In the period around 2050, in some parts of the Randstad cities, the number of hot nights may add up to more than a month per year in the Dutch climate scenarios. Although that analysis has been based on air temperature instead of on thermal comfort indices, it does include the UHI effect, and clearly reveals the possible impact of climate change on urban night-time conditions. Urbanisation may further increase the number of uncomfortable warm nights.

The present night-time ET includes an estimate of the UHI. Although the outcome of this estimate (based on Equation 2) seems to be quite small, between 0.4 °C and 3.6 °C for the cities shown on the map, the UHI effect appears to cause a significant increase in the number of nights with thermal discomfort. Without UHI correction, when using the standard rural data, the threshold value of 21 °C is often just not exceeded. Including the UHI, as has been done in this indicator, will lead to exceedance of the threshold in such cases. Note that the UHI value included here represents a median value. Thus, the UHI may become much larger on individual days. For example, Steeneveld et al. (2011) found that in the Netherlands, the median value of the UHI (UHI_{50}) and the 95 percentile UHI (UHI_{95}, representing about nine summer season (April-September) days per year) are strongly related in a non-linear way:

$$UHI_{95} = 1.94\ UHI_{50}\ \exp(0.4233)\ (r^2=0.82) \qquad (3)$$

Applying this relationship to the European cities included in the present analysis would imply UHI_{95} values between 2.3 and 8.9 °C. To include realistic variations at city scale would require an estimation of the UHI strength based on weather conditions, along with city characteristics (see Brandsma and Wolters (2012), for an example). In addition, more spatially explicit estimates could be made using more physically based estimates of the UHI strength. Such estimates could also take into account possible effects of climate change on the UHI –decrease or increase, depending on the conditions in the rural surroundings of the cities - if such estimates are driven by climate change scenarios (Lauwaet et al., 2015; 2016).

An illustrative example of the impact of the UHI is seen in the city pair Lisbon and Setubal in Portugal. These cities are only some 30 km apart, and both are situated near the Atlantic coast. Their background weather is quite similar, but the estimated median UHI is 2.5 °C for Lisbon and 1.3 °C for Setubal. This small difference appears to be the main cause of the different classification of the cities. While Lisbon has 16 nights per year on average with an ET > 21 °C, Setubal has only 3 such nights on average in the period from 2002 to 2012. Thus, the choice of the threshold values and the UHI estimate can substantially influence classification in cases with temperatures near the threshold value. It should be stressed that since the UHI is a difference measure it is no direct indication of thermal comfort. Even when the UHI is declining, urban temperatures and the number of heatwave events may increase (see, e.g., Lauwaet et al., 2016).

The indicator presented here should be interpreted as a first assessment of the climate comfort condition in cities, mainly related to standard meteorological conditions and partly related to city structure, via the reduced wind speed and the estimate of the UHI during night-time. To fully assess the urban climate at neighbourhood and sub-neighbourhood level, much more detailed analyses of the urban climate are required. Examples of such maps are the Urban Climate Maps of Stuttgart

[25] See http://www.ruimtelijkeadaptatie.nl/en/climate-adaptation-atlas online.

(Germany) and Arnhem (the Netherlands) (EEA, 2012). In the framework of the EU-RAMSES project[26] more detailed assessments of urban temperature changes including effects of urban structure will be provided in the near future for many cities in Europe, allowing a more advanced assessment of thermal comfort as well. Assessments at yet smaller scales may require estimation of shading and wind patterns, along with temperature and humidity patterns (e.g., Ketterer and Matzarakis, 2016). In addition, it should be noted that threshold exceedance does not necessarily correspond to thermal discomfort for every individual citizen. For example, a feeling of discomfort on a particular day depends on behaviour and activity patterns. Staying in local shade provided by trees and other city structures may provide a considerable relief while intense physical activity may increase discomfort levels. Furthermore, citizens in warmer regions may be accustomed to slight or moderate heat stress (Baccini et al., 2008).

Under climate change, Fisher and Schär (2010) show general trends in the number of hot days (maximum air temperature > 35 °C) followed by tropical nights (minimum air temperature > 20 °C) (Figure. 3.3)). The frequency of such occasions is expected to increase in future and much larger parts of Europe will experience a significant number of hot days followed by tropical nights. The number of such events is expected to increase from the North-West to South-East.

The RAMSES RCP8.5 assessments of changes in maximum and minimum temperatures for individual cities, shown in Maps 3.3.2 and 3.3.3, respectively, suggest a strong increase of these temperatures across Europe. There seems to be a strong coastal influence, since cities located in coastal areas or on land mass surrounded by seas generally show smaller changes than more the inland cities of Central and Eastern Europe. An enhanced UHI due to urbanisation or climate change (EEA, 2012), neither included in CSI 012, nor in the RAMSES assessment, may further contribute to the increases. Such a combined climatic and urbanisation trend will not only affect Southern European cities; like already suggested above, it may be expected that cities in the north will also experience a significant number of days with unfavourable conditions in future. Conditions in the north are often quite close to the threshold of moderate heat stress in present-day conditions (Steeneveld et al., 2011), so only a small increase in air temperature may already cause a significant number of unfavourable events in the near future.

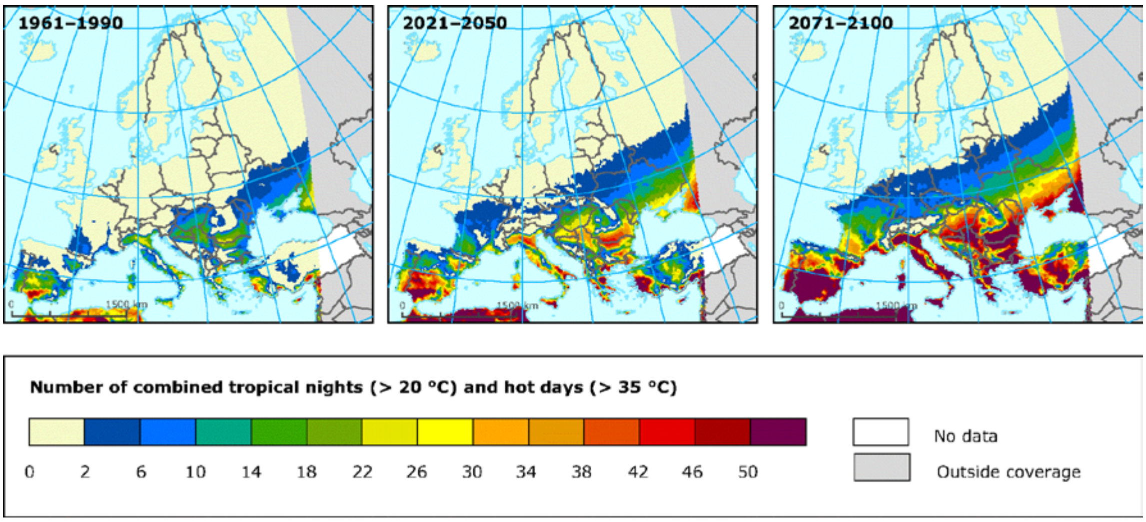


Figure 3.3.1 General trends in the number of hot days (maximum air temperature > 35°C) followed by tropical nights (minimum air temperature > 20°C) (Fisher and Schär, 2010)

[26] See http://www.ramses-cities.eu/ online

Cities that experience many days with high daytime ET followed by nights with high night-time ET may benefit from measures that decrease these numbers, complemented with measures to cope with such conditions. Such adaptations not only help to prevent increased mortality during heatwaves as much as possible, but also increase and maintain the liveability and attractiveness of a city and help maintaining economic productivity (Measures to decrease the ET include boosting green infrastructure such as green urban areas, trees, green walls and roofs, where possible (EEA, 2012). This will improve the daytime and the night-time situation. At present, while cities in the south would benefit most from green infrastructure, the cities with the greatest green cover are actually found in the north (see the indicator factsheet on 'Green urban areas'). Other structures or city design features that provide shade, prevent energy absorption or enhance ventilation may improve thermal comfort of citizens locally, but may reduce the UHI as well.

Examples of measures to cope with unfavourably hot days and warm nights are improvement in health infrastructure, heat action plans, awareness-raising and improved accessibility of green and blue areas (EEA, 2012). Some of the cities with high maximum ET in the southern countries also have a high share of elderly people who are more sensitive to heat, on average. In these cities, extra attention is needed to measures that mitigate the effects of heatwaves.

3.4 Water consumption

Indicator definition

This indicator shows the total consumption of water in a given city, divided by the total resident population [m^3/inh].

Justification of the indicator

Expected climate change impacts include higher ambient temperature, precipitation irregularities and more frequent extreme weather events leading to prolonged periods of water scarcity and drought, among others. This increases the pressure on cities' water supply, including the need for enhanced storage of water due to frequent droughts, the need for irrigation of urban green areas, and increased personal water use as a result of higher temperatures.

A direct indicator that describes water scarcity in terms of precipitation, water availability at the surface and underground, the quality of available water and water demand is not available at city level. Thus, water consumption per capita is selected as a proxy indicator for which data are available, and that partially reflects the fact that the level of water consumption may indicate the level of dependency on water sources and the potential vulnerability to the climate effects that may decrease water availability in future. The more water a city uses, the more vulnerable it will be should there be a reduction or disruption of its supply.

Methodology

The indicator itself is the quotient of two Urban Audit indicators for cities/greater cities: Indicator EN3003V 'Total consumption of water' (m^3) and DE1001V 'Total resident population'(inhabitants) resulting in consumption per capita (m^3/inh)

Data specifications

EEA data references

None

External data references

Eurostat Urban Audit database[27]:

- EN3003V Total use of water (m^3);
- DE1001V Population on 1 January by age group and sex — cities and greater cities.

Uncertainties

If urban areas have a high amount of industry, the indicator will show a higher consumption per capita. Chemical industries and the production of food, beverages, pulp or paper can significantly increase apparent consumption per capita, even if household consumption of water is decreasing. A full indicator assessment should therefore consider the industry present in the city.

The total population only includes residents in the city. Cities with a high number of commuters tend to have higher water consumption per capita. Touristic hubs increase the number of people in the city significantly during high seasons. Therefore, the apparent water consumption per capita in such a city also tends to be higher.

The total use of water (EN3003V) does not include water leakages, nor any unpaid water losses in general, and therefore does not provide a full picture of how much pressure is exerted on the water sources by consumption. When analysing this indicator, it is recommended that it be complemented with data on water supply losses.

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[27] See http://ec.europa.eu/eurostat/web/cities/overview online.

The indicator does not provide any information on water that is available for the given city. Cities with high water consumption due to industry tend to be located near reliable water sources. Assessments using this indicator should always examine the water availability for the given city as well. A suitable complementary indicator for this might be the Water Exploitation Index (WEI), for example, although this is not available at city level.

While big cities have almost always centralised their water supply, which allows for good data collection, smaller cities often have a certain share of self-supply (e.g. private wells and water bore-holes), which might be omitted from statistics. For analysis of this indicator, it is recommended that information be used from the Urban Audit indicator EN3004V 'Number of dwellings' connected to potable drinking water system.

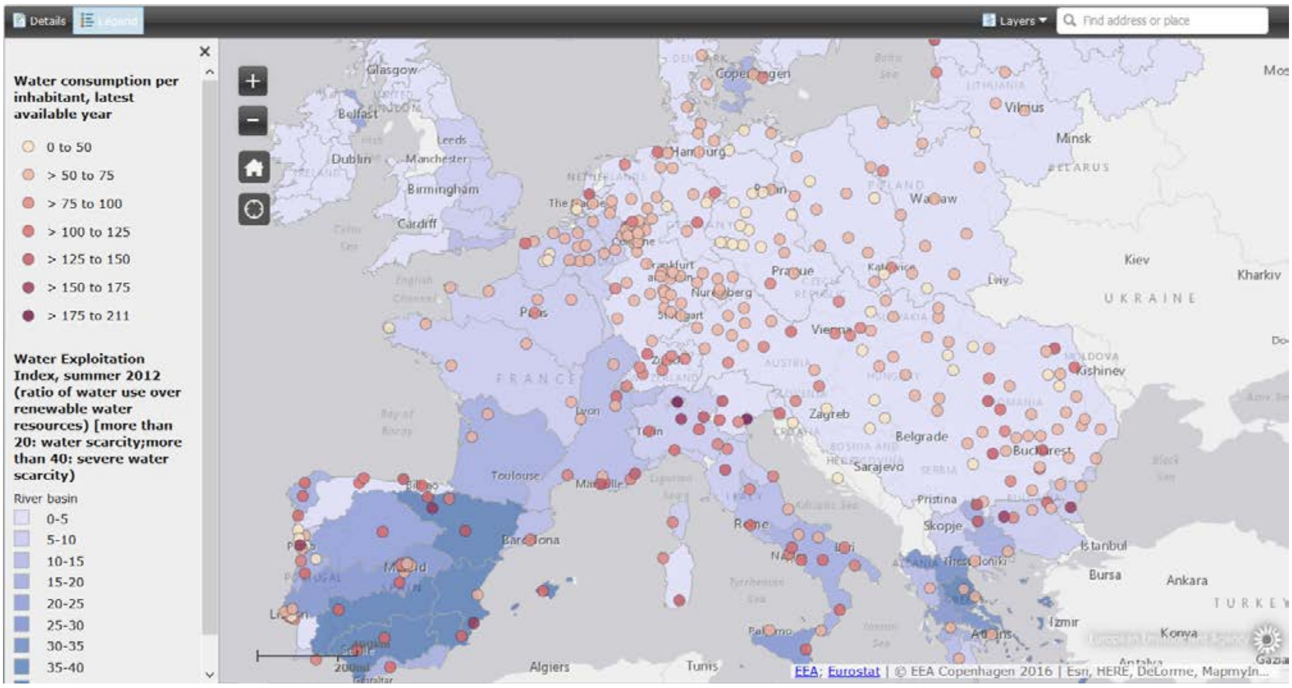
Not all cities have data available for all years. The Urban Audit database does not give exact dates for a particular year, but rather gives one value per 3-year period. This means that data for particular cities and countries sometimes refer to different years and might reflect different climatic conditions in those particular years. Therefore, a longer observation period is needed in order to draw reliable conclusions.

Indicator assessment

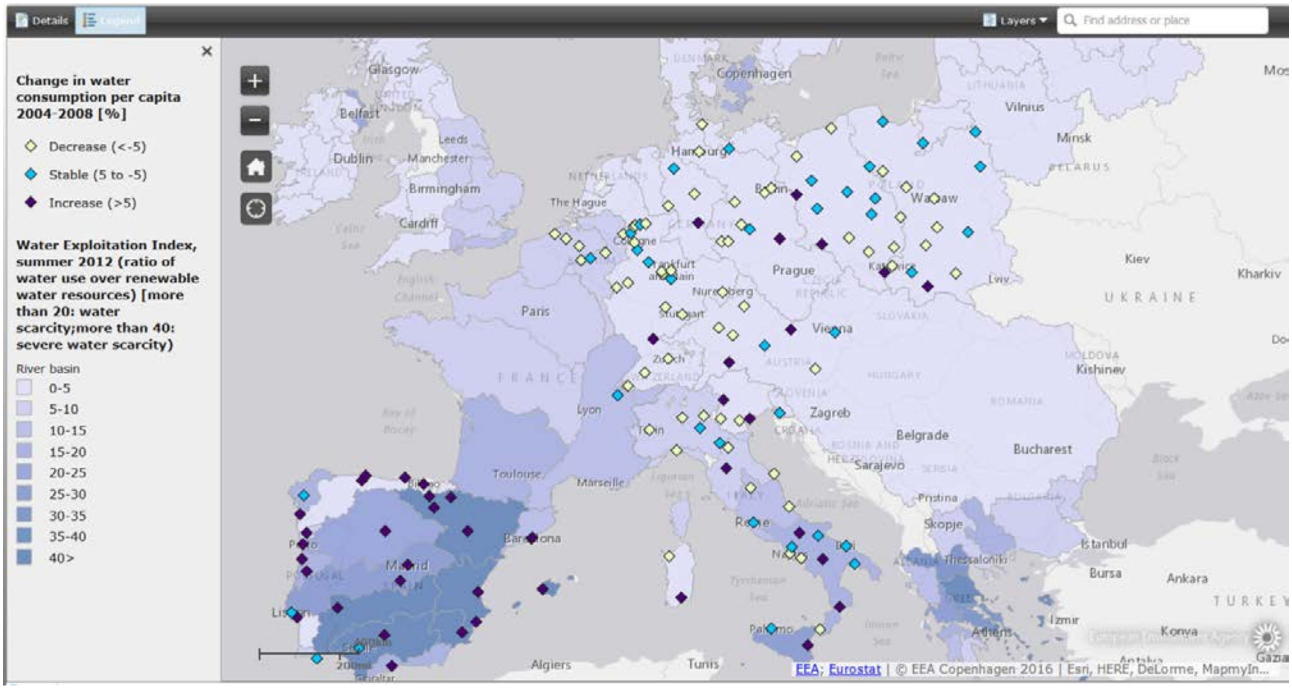
Key questions: How much water is used in the city in relative terms? Does the level of water consumption in cities increase their sensitivity to water scarcity and droughts?

Web link to maps

http://maps.eea.europa.eu/EEABasicviewer/v3/?appid=0f90e2a5925140feb3c8ac220f22227b&webmap=b7dbf7120856411f961f13d61c13928a&embed=false



Map 3.4.1 Water consumption per capita (latest available year)



Map 3. 4.2 Change in Water consumption per capita (trend 2004–2008)

The Water Exploitation Index (WEI) is an indicator of the level of pressure that human activity exerts on natural water resources; it gives an indication of how total water demand puts pressure on the water resource (CSI 018[28]). It is an indicator for water scarcity currently being applied at national level, computing the mean annual demand for freshwater, divided by long-term average freshwater resources. Therefore, it is not city specific, though it contextualises cities' water consumption and increases explanatory power for assessment. The warning threshold for the WEI which distinguishes a non-stressed from a stressed region is around 20 % (Raskin et al., 1997). In summer 2012, most European countries are in this range, with the exception of many regions in Spain, some in Portugal, Italy, Greece and Cyprus.

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 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). Regions in the south of Europe, but also Northern Ireland and Denmark are in this intermediate range, between 20 % and 40 % in summer 2012. Other experts consider that 40 % is too low a threshold, and that water resources could be used much more intensively, up to a 60 % threshold. In any case, this group exhibits the greatest vulnerability to water stress, but at European scale, only Cyprus reaches such values.

Irregular water use in urban environments, especially where scarcity problems could emerge, is an issue that crucially needs to be understood in Europe. Is climate one of the most explicative drivers of domestic water consumption? Is domestic water consumption supposed to vary depending on climate variables, especially temperature and rainfall?

The World Health Organization (WHO) calculates that people need between 40 l and 70 l of water per day to meet basic health and hygiene needs (Inman and Jeffrey, 2006). This is equivalent to between 15 m^3 and 25 m^3 per inhabitant per year. Urban water consumption in Europe differs considerably across countries; it is generally higher in south-western countries such as Italy or Spain, and lower in the central and western parts of the continent such as Germany.

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[28] See http://www.eea.europa.eu/data-and-maps/indicators/use-of-freshwater-resources-2/assessment-1 online.

There is a huge discrepancy in data, ranging from relatively low values that are slightly above the WHO-suggested minimum value (about 30 m^3/inh/year) to very high values that eventually include irrigation for agriculture (around 200m^3/inh/year in some Eastern European and Norwegian cities). Assessing trends between two or three data points is difficult, as it may be that none of those years can be considered a ‘typical’ year, hence providing false information that skews the real trend. Eastern Europe has at the same time many cities with low values and low WEI values as well, which makes the positive message conveyed by this indicator mode solid.

From other sources and reports, a general trend can be observed: cities are making efforts to reduce water consumption. However, since the available data are scarcely comparable across particular cities and years, this cannot be convincingly demonstrated here. The best results obtained in the period from 2004 to 2008 were presented by some German, Swiss and Italian cities that reduced water consumption by more than 25 m^3/inh. However, contrary to the indicated effort, the general trend between 2004 and 2008 was for an increase in consumption — by an average of 2.84 m^3/inh in the 147 cities assessed. Most of this increase is in Spain, where almost all cities had higher values in 2008 than in 2004, a similar trend could be observed also in parts of Italy, Germany and Poland. Spain is also a country with a high WEI.

To tackle increasing water scarcity, cities should make their water consumption and supply more efficient. Losses from transfer are generally high: values of about 30 % of loss are not uncommon. There is also a need for better data, so as to be able to evaluate the situation in European cities in a more robust way.

3.5 River flooding

Indicator definition

The river flooding indicator is based on one-indicator:

- The share of city's urban area potentially vulnerable to river floods [%].

Further sub-indicators are:

(1) share of residential area potentially sensitive to flooding [%];

(2) share of transport infrastructure potentially sensitive to flooding [% by type];

(3) share of industrial and commercial area potentially sensitive to flooding [%].

Justification of the indicator

Climate change brings changes in precipitation patterns all around Europe. Changes in periodicity and amount will increase the number of flood events. River floods are a common natural disaster in Europe, and — along with storms — they are the most important natural hazard in Europe in terms of economic damage. River floods can result in huge economic losses, due to damage to infrastructure, property and agricultural land, as well as indirect losses in or beyond the flooded areas, such as production losses caused by damaged transport or energy infrastructure. Urbanisation and associated increases of impermeable land surface coupled with housing and business development of river floodplains aggravate flood risk in urban areas.

Urban infrastructures provide citizens with various services such as provision of water, electricity, transport, housing, social services and places of work or leisure. Flooding of these infrastructures means a substantial disturbance of public life, and undermines the security of service supply (Lenz, 2009). Once, beyond a certain water level or threshold, floods can seriously affect an infrastructure system upon which other infrastructures, companies/industries or the urban population depend on. Then, another significant issue is the duration of outage of an infrastructure, which depends, among others, on the speed of onset, specific critical time frames, and the average time needed to restore its functionality.

In developing new infrastructure, urban planners should take the flood risk into account. The indicator on urban sprawl captures these developments through identifying if urban sprawl is occurring in areas vulnerable to river flooding. For the indicator, the imperviousness changes between 2006 and 2009 are taken as a proxy of urban sprawl.

Methodology

The intersections of three layers (area potentially vulnerable to flooding, UMZ and the land use layer of the Urban Atlas 2006) allow identification of which areas per land use category might be flooded. This indicator focuses the analysis on residential areas, transport infrastructure, and built-up areas of industrial and commercial categories.

Table 3.5.1 Residential, industrial and commercial, transport area and related classes in the Urban Atlas

Code	Nomenclature — Urban Atlas level 4 class legend	
11100	Continuous Urban Fabric (S.L. > 80 %)	Residential
11210	Discontinuous Dense Urban Fabric (S.L.: 50 %–80 %)	

Code	Nomenclature — Urban Atlas level 4 class legend	
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	Industrial and commercial
12210	Fast transit roads and associated land	Transport
12220	Other roads and associated land	
12230	Railways and associated land	
12300	Port areas	
12400	Airports	
13100	Mineral extraction and dump sites	Other areas of the city
13300	Construction sites	
13400	Land without current use	
14100	Green urban areas	
14200	Sports and leisure facilities	
20000	Agricultural + Semi-natural areas + Wetlands	
30000	Forests	
40000	Wetlands	
50000	Waterbodies	

The procedure follows these steps:

1. intersection of potential flooded areas (LISFLOOD) with Urban Atlas 2012 layer;
2. intersection with city's urban area;
3. statistical analysis in order to obtain the potentially flooded area (in %) for every Urban Atlas city and category:
    a. share of residential areas potentially flooded in % (11100, 11210, 11220, 11230, 11240, 11300);
    b. share of transport areas potentially flooded in % (12210, 12220, 12230, 12300, 12400);
    c. share of industrial, commercial areas potentially flooded in % (12100).

For each city, the potentially flooded area is divided by the total area (city's urban area; see annex) in order to obtain the percentage according to their use.

The intersections of three layers (area potentially vulnerable to flooding, UMZ 2006 and the Imperviousness changes 2006-2009 layer) allows for identification of which areas with increase of imperviousness density might be flooded.

Table 3.5.2 Imperviousness changes 2006-2009 raster dataset, filtered changes 20m - Jan. 2013

Classes	Description
0-99	Decreased imperviousness density
100	Unchanged areas with imperviousness degrees of 1-100
101-200	Increased imperviousness density
201	Unchanged areas with imperviousness degrees of 0 (unsealed in 2006 and 2009)
254	Unclassifiable (no satellite image available, or clouds, shadows, or snow
255	Outside area

For each city, the imperviousness changes potentially flooded area is divided by the imperviousness total changed area in order to obtain the percentage.

The potentially flood-prone area is calculated based on elevation and does not include flood protection measures like dams, dikes, etc., as data for these are not yet available. Areas shown here as potentially at risk of flood might in reality be protected by adaptation measures. However, since measures can fail in certain circumstances, the risk remains.

Data specifications

EEA data references

The Urban Atlas 2006[29] is providing Europe-wide comparable land use and land cover data for large urban zones with more than 100 000 inhabitants as defined by the Urban Audit. GIS data can be downloaded together with a map for each urban area covered, and a report containing metadata. A web map service is also published[30].

[29] See http://land.copernicus.eu/local/urban-atlasatlasonlineonline.

[30] See http://land.discomap.eea.europa.eu/arcgis/rest/services/UrbanAtlas/UrbanAtlasV2_WM/MapServer online.

The UMZ as a reference unit for city morphology (as the best approximation of the 'real' city form, which often does not correspond to the administrative delineation) is available from the EEA data service[31]. A new layer of UMZ has been produced from Urban Atlas 2012 (see also annex).

NB: In the current processing, all UMZ patches located within the city's boundaries are used (see annex).

External data references

Fluvial flooding: The discharge return levels were derived for every river pixel for return periods of 100 years. For time windows of 30 years (control represents 1961–1990, and future period represents 2071–2100, a Gumbel distribution was fitted to the annual maximum discharges simulated by LISFLOOD in every grid cell of the modelled domain based on 12 models and the A1B scenario (Rojas et al. (2012)[32] and Rojas et al. (2013)[33]).

Uncertainties

Uncertainties originate mainly from the climate projections used in the flood model. To assess climate change impacts on flood hazard, one needs high-resolution climate simulations. To build the database, simulations from 12 climate experiments have been used within the ENSEMBLES project. Further information on uncertainties is provided in Rojas et al. (2012).

The threatened areas of the city are based on flooding from 1961 to 1990. This period does not capture major flood events of the past 25 years (among others, the Eastern Europe flood in 1997, and the Central Europe flood in 2002) that may have been more typical for the future climate extremes. If these events had been included, the threatened area would probably have been larger.

Moreover, because the assessment period is in the past, some areas that were previously flooded are no longer flood-prone, due to implemented adaptation measures. The potentially flooded area will probably be smaller due to this fact.

We also used the city's urban area based on the urban characteristics of 2006. One may assume that this is (slightly) different from the period in which we have data about floods (1961–1990), and that it will be slightly different in future.

Indicator assessment

Key question: How potentially vulnerable are cities — their people, economic assets and infrastructure — to river flooding and does urban sprawl take account of flood risks?

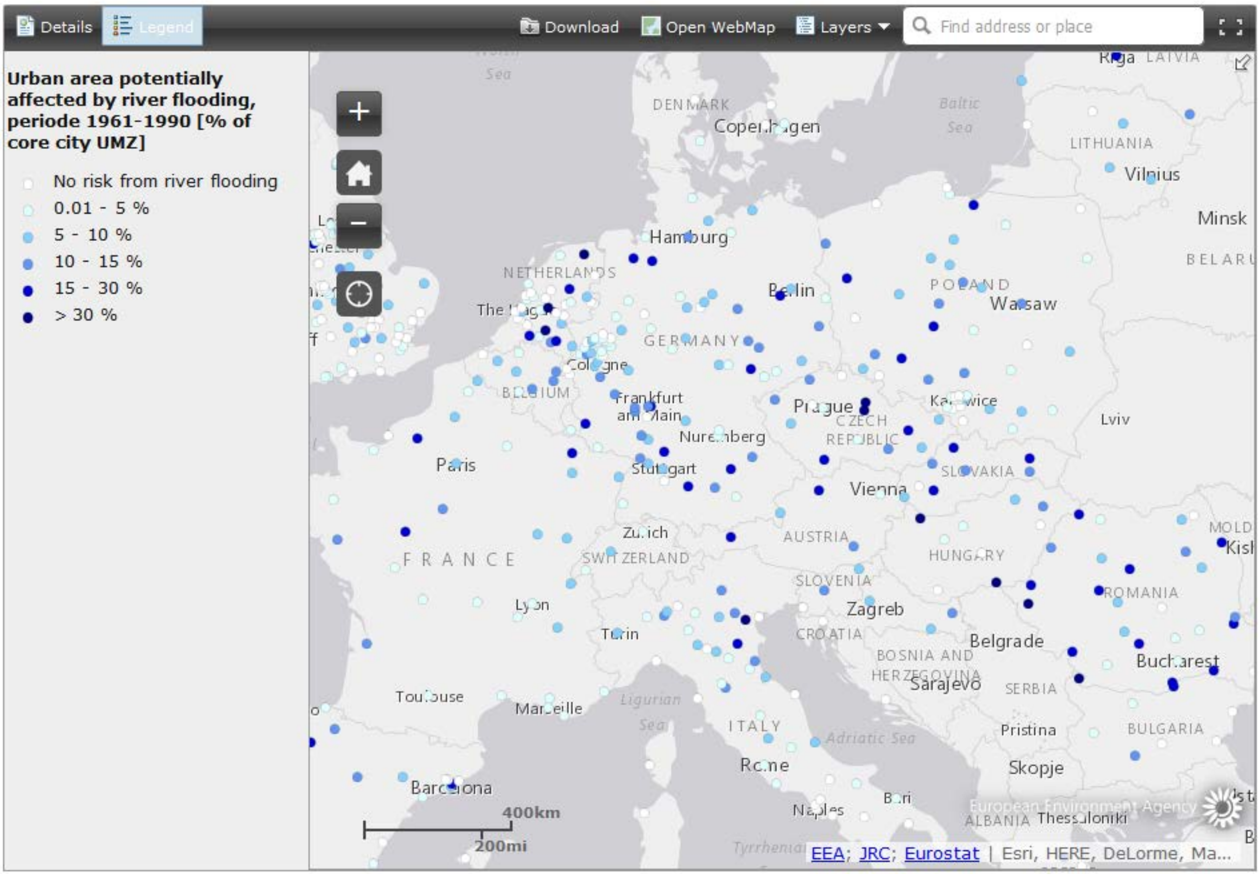
Web link to maps

http://maps.eea.europa.eu/EEABasicviewer/v4/?appid=6114f4c3e7494bf0a8a8f04996639120&webmap=ffd7c266c4844678bf4cad410100ba89&embed=false

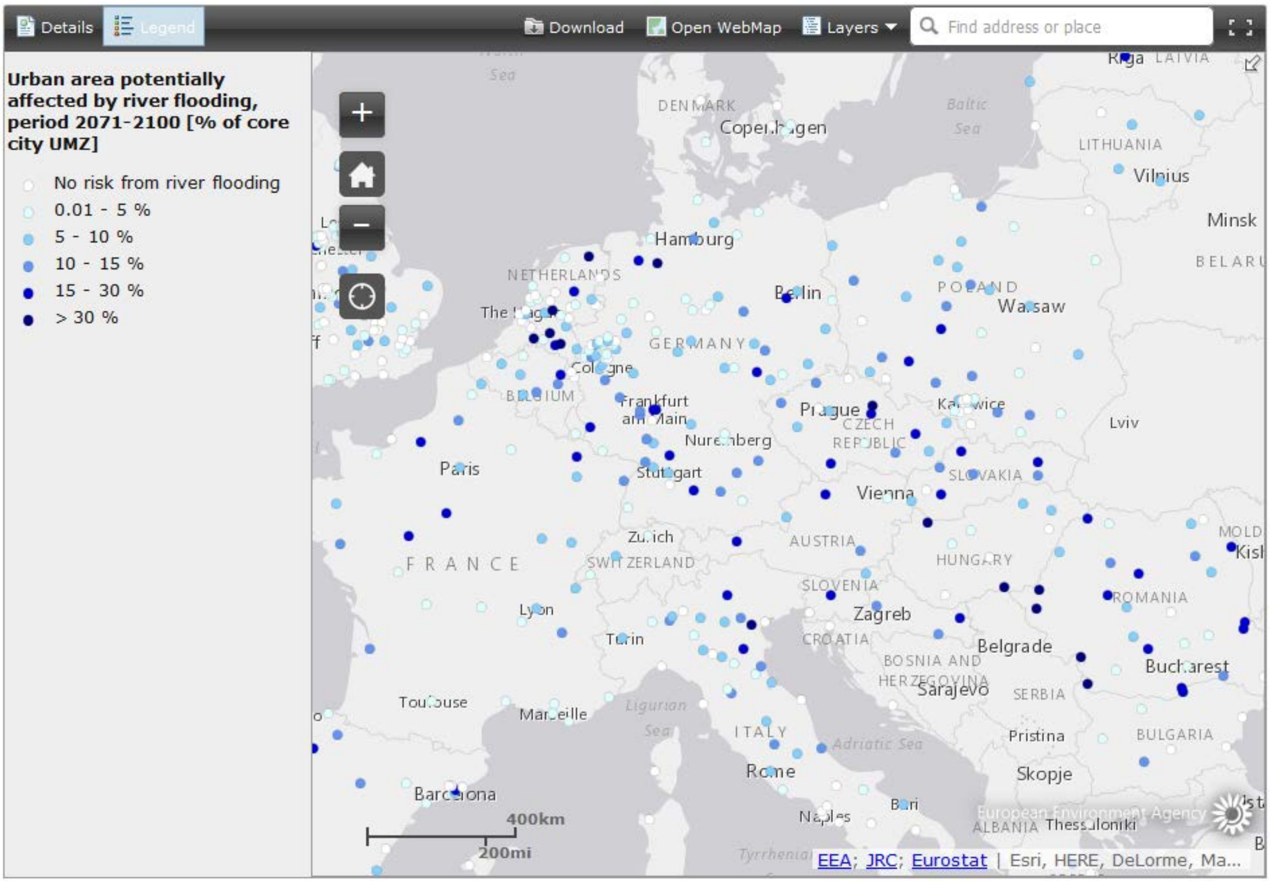
[31] See http://www.eea.europa.eu/data-and-maps/data/urban-morphological-zones-2006-1 online.

[32] See http://onlinelibrary.wiley.com/doi/10.1029/2012JD017461/full online.

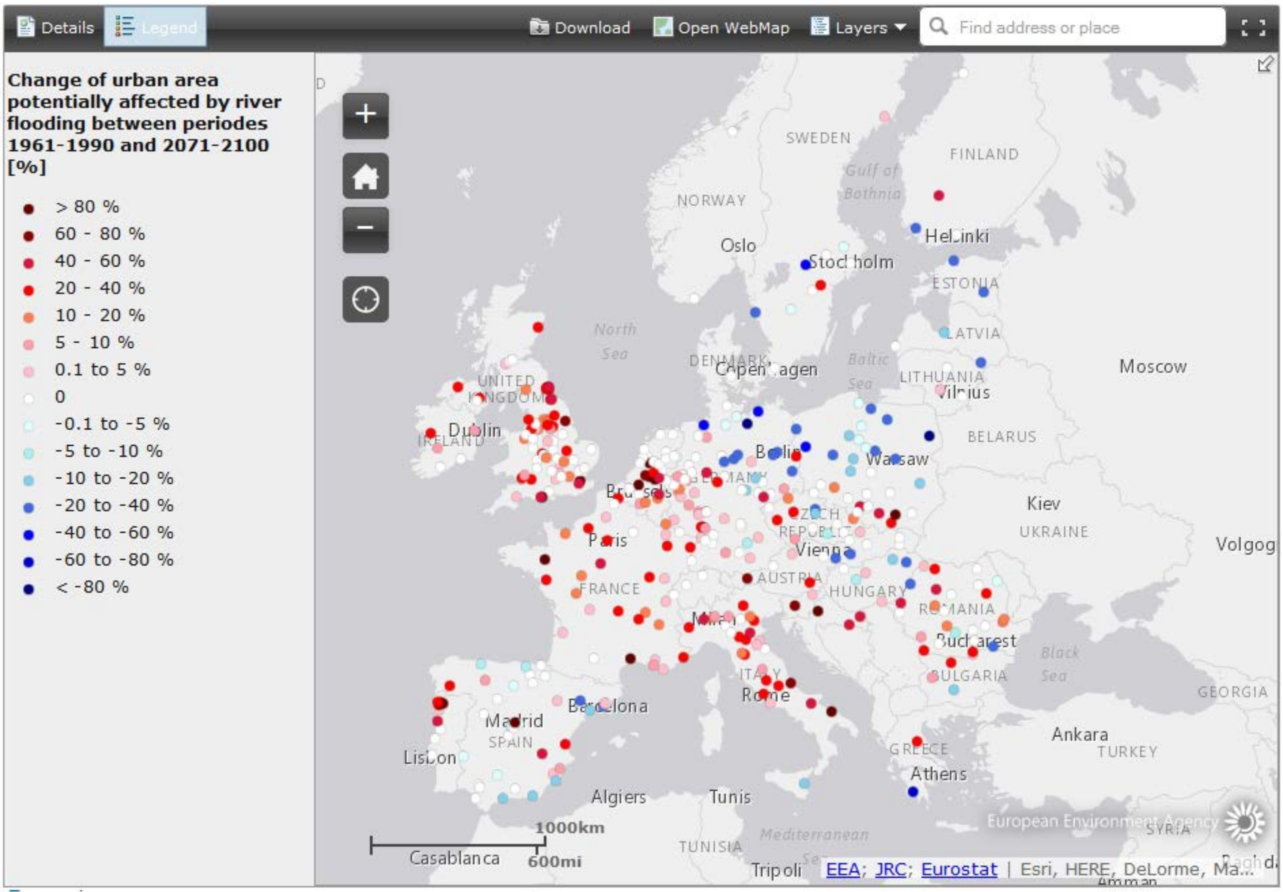
[33] See http://www.sciencedirect.com/science/article/pii/S0959378013001416 online.



Map 3.5.1 Percentage of cities' urban area potentially affected by river flooding (period 1961–1990)



Map 3.5.2 Percentage of cities' urban area potentially affected by river flooding (period 2071–2100 using the A1B scenario)



Map 3.5.3 Change in percentage of cities' urban area flooded (periods 2071–2100 and 1961–1990)

Floods are natural phenomena that have always been present in Europe. The changing climate and sprawling cities are likely to increase the flood risk in Europe, in terms of economic damage in urban areas.

Cities in Europe have often been built close to rivers which offered water, transport and a source of food. Within cities, most of the historical centres are located close to rivers banks. Cities with a high percentage of their areas at potential risk of river floods are found along the big European rivers — the Danube, Rhine, Rhone, Moldau-Elbe, Po and Vistula.

It is expected that in the period from 2070 to 2100, cities in central and western Europe will face more severe flooding. The highest relative increase is expected for cities in Portugal, the United Kingdom, France, western Germany and the Balkans. Eastern parts of Europe will see a reduced flood pressure. Northern Germany, Poland and other Baltic states and some cities in Czech Republic may see a slight to pronounced reduction of floods. However, change is expressed in relative terms; thus, a high relative change of the area at risk might actually be a rather small change in the absolute area, if the original urban area sensitive to flooding was already small.

Adaptation measures include flood-proof urban design, technical protection against floods, early warning systems and ecosystem measures to increase the capacity of green areas to retain water. This calls for a regional approach.

Proper integrated measures in land use, forestry and agriculture can reduce the frequency of floods, and proper urban planning and technical adaptations can limit their impacts on residential, industrial and commercial areas, and transport infrastructures.

Vulnerability increases not only because of climate change but also of socio-economic change. Up to 2050, urbanisation levels in Europe are expected to increase and urban population is projected to grow in particular in north-western Europe but also in parts of the southern Mediterranean. This will result in higher urban vulnerabilities due to more city residents being affected by urban climate change. Substantial growth is also expected in the Northern and Arctic region but starting at lower population levels, while for central and eastern Europe the projections foresee population declines. Urban sprawl and densification have happened in low-lying areas that are potentially flood-prone. Cities may take account of the increasing flood risk by preventing further developments of infrastructure in (potentially) flood prone areas.

Almost a fifth of 411 considered cities in Europe have increased their urban land use in areas already potentially prone to river floods by values between 10 and 70% between 2006 and 2009. With these increasing assets, the sensitivity to flood impacts has grown, even if the probability of actual flooding due to dikes and flood walls might be low. The highest share of cities in which a substantial part of the imperviousness change (> 15%) takes place in potentially flooded areas are found along the big European rivers — the Danube, Rhine, Rhone, Moldau-Elbe, Po and Vistula. It is expected that in the period 2070 to 2100, cities in central and western Europe will face more severe flooding, and Map 3.5.5 shows that the extent of imperviousness change in flood areas increases relative to the period 1961 to 1990.

3.6 Coastal flooding

Indicator definition

The share of city's urban area [%] that is low-lying and would potentially be inundated by a sea level rise of 1 m combined with a 100 year return-period storm-surge event, if no coastal defence systems are in place.

Justification of the indicator

One important impact of climate change is sea level rise. In Europe, significant economic, social and infrastructural assets are located at or near the coastline. Cities located at the coast face the possibility of being flooded by the sea. Sea floods can damage residential, commercial and industrial areas of the city as well as interrupt transport infrastructure, thus limiting the city's accessibility and reducing supplies. Coastal flooding occurs when the sea level exceeds normal levels due to storm surges and tidal waves; chances of these occurring increase by sea level rise. In deltas and river mouths, flooding may be caused by a combination of fluvial flooding with storm surges or otherwise exceptionally high sea levels. In Europe, coastal flooding has already caused much damage in low-lying areas around the North Sea (Hildén et al., 2010). Increasing exposure is expected in the future as climate change intensifies.

As a consequence of climate change, the flood return periods may change owing to sea level rise, and may cause more frequent flood events and/or higher water levels (EEA, 2012). However, vulnerability varies due to socio-economic or demographic differences in coastal areas, such as urban sprawl and presence of technical measures to prevent flooding.

Methodology

Assessing the exposure of urban areas to the risk of coastal flooding is based on information about:

- return periods of flooding;
- the rate of sea level rise, which is one of the factors causing increased flood damage in coastal areas (e.g. climate change);
- frequency of storms leading to more frequent sea surges.

The data on maximum storm surge heights (100-year event of actual climate) as generated by the 'Dynamic and interactive vulnerability assessment' (DIVA) project were used to determine actual medium inundation heights along coastal segments of each NUTS 3[34] region. To account for the effects of climate change, 1 m of potential sea level rise until 2100 was calculated on top of these values[35]. In order to determine potentially inundated areas, the Hydro1k digital elevation model was utilised. By identifying the cells below the respective regional inundation threshold, continuous areas have been delineated, which can be considered as potentially at risk of storm surge-related inundation. However, one should bear in mind that coastal defence systems have been neglected in this analysis, as the employed database lacks this information.

The inundation information has been combined with the urban area of all coastal cities. For each city, the proportion of the area affected by a 1-metre sea level rise is computed and represented by coloured dots in the map. As this indicator is simply based on elevation by identifying low-lying areas, and does not take into account existing adaptation measures like dikes, the actual risk is likely to be much lower than the indicator shows.

[34] NUTS: Nomenclature of Units for Territorial Statistics; a geocode standard for referencing the subdivisions of countries for statistical purposes. NUTS 3 is the most detailed level.

[35] For useful overviews of sea level rise projections, see Horton et al. (2014) and Vermeer and Rahmstorf (2009).

Data specifications

EEA data references

The UMZ as reference unit for city morphology (as the best approximation of the 'real' city form, which often does not correspond to the administrative delineation) is available from the EEA data service[36].

NB: In the current processing, all UMZ patches located within the city's boundaries are used (see annex)

External data references

- DINAS-COAST - Dynamic and Interactive Assessment of National, Regional and Global Vulnerability of Coastal Zones to Climate Change and Sea-Level Rise (2004): DIVA data set[37].
- Technische Universität Dortmund, Institute of Spatial Planning (IRPUD)[38].
- Urban Audit database (Eurostat)[39].

Uncertainties

The main uncertainties relate to the DIVA flood-modelling methodology. The spatial extent of a coastal flood largely depends on the methodology used and its definition (Visser et al., 2012). As a wave moves inland, its height will diminish. The decay rate depends largely on terrain and surface features, as well as on factors specific to the storm generating the wave.

Data uncertainties are mainly related to data accuracy for the 1-metre level rise used to run the model. The Hydro1k digital elevation model was utilised. Coastal defence systems have been omitted from this analysis since the database employed does not contain this information. Including defence infrastructures like dams or dikes in the analysis would most certainly improve the share of urban area vulnerable to floods, especially in the case of the Netherlands.

Indicator assessment

Key question: How potentially vulnerable are cities across Europe regarding flooding, due to projected sea-level rise in combination with storm surge events?

Web link to map

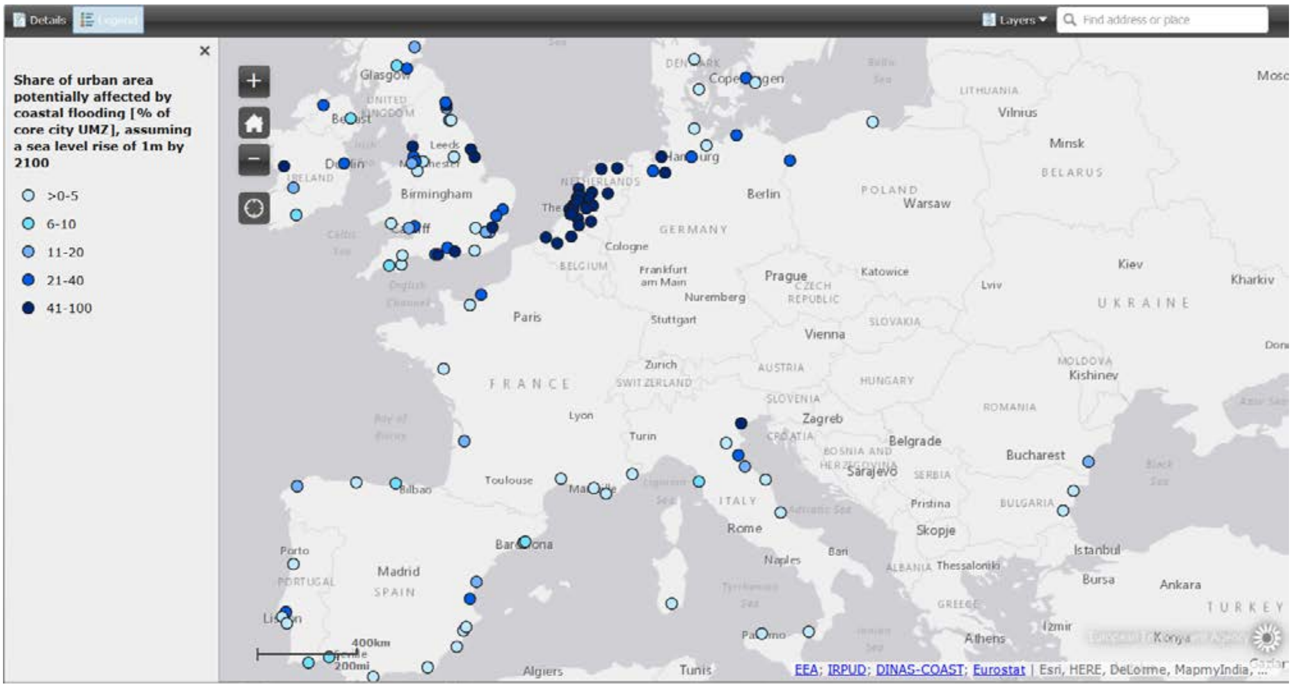
http://eea.maps.arcgis.com/home/webmap/viewer.html?webmap=ffd7c266c4844678bf4cad410100ba 89

[36] See http://www.eea.europa.eu/data-and-maps/data/urban-morphological-zones-2006-umz2006-f3v0 online.

[37] See http://www.diva-model.net/ online.

[38] See http://www.raumplanung.tu-dortmund.de/irpud/en/home/ online.

[39] See http://ec.europa.eu/eurostat/web/cities/overview online.



Map 3.6.1 Potential coastal inundation exposure as a result of a 1-metre sea level rise combined with a 100-year return period storm-surge event (2100)

The map shows how major cities might be affected by the change of inundation height, given a 100-year coastal storm surge event on top of a 1-metre sea level rise as it can be expected in a scenario of sea level rise for 2100. Primarily cities on the Dutch, German, Belgium and northern Italian coastlines can expect severe changes. Due to data constraints, coastal defence systems such as dikes could not be considered in these calculations, so the map only shows the potential effect on urban areas. The hotspots which emerge from this analysis, however, appear to be plausible, and can serve as a basis for checking local and regional preparedness for climate change– influenced coastal storm surges.

Map 3.6.2 Low-lying urban areas under potential inundation exposure due to projected sea-level rise in combination with storm surge events

While our map shows potential inundation risks without any defences, adding regional information shows that cities are actually less exposed to the threat. There are flood adaptation measures in many cities and regions. For example, the storm defence infrastructure in the Netherlands comprises 13 dams, including barriers, sluices, locks, dikes, and levees, to reduce the length of the

Dutch coastline and protect the areas within and around the Rhine-Meuse-Scheldt delta from the North Sea (Map 3.6.2, Figure 3.6.1). However, these cities will still be as sensitive or even more sensitive to flooding in the (rare) event of the defence measures failing. In fact, while exposure to coastal floods may be reduced by improved flood defence systems, the sensitivity might actually increase, due to more physical and economic assets as well as more people living in low-lying areas.

Figure 3.6.1 Flood protection measures in the Netherlands to protect land from flooding by the North Sea

3.7 Forest fires

Indicator definition

The share of areas and their population in and around cities at high risk of forest fires. Sub-indicators:

1. share of areas in cities, and related peri-urban areas, exposed to high risk of forest fire [%];
2. share of population in cities, and related peri-urban areas, exposed to high risk of forest fire [%];
3. share of residential areas in cities, and related peri-urban areas, exposed to high risk of forest fire [%];
4. share of transport infrastructure in cities, and related peri-urban areas in high risk area of forest fire [%];
5. share of commercial areas in cities, and related peri-urban areas in high risk area of forest fire [%].

Justification of the indicator

During recent decades, fire frequency and fire extent have changed, as have burning patterns, especially in terms of expansion of fire-prone areas (Arianoutsou et al., 2008; Fernandes et al., 2010; Koutsias et al., 2012). Fire seasons have lengthened as a result of recent changes in land use (e.g. abandonment of agricultural lands, inadequate forest management), long seasonal droughts, environmental disturbances and human activities (Martinez et al., 2009; Romero-Calcerrada et al., 2010).

The steady expansion of urban centres and the resultant construction of peripheral residential neighbourhoods characterised by low-density housing led to a growing intermingling between wild land and urban areas (wild land–urban interface or WUI), that has increased the risk of forest fires in many residential areas. It is estimated that around three-quarters of fire ignition points in Mediterranean countries are located in this mixed type of land characterised by a high aggregation of vegetation and a high density of houses (Vélez, 2009).

Residential areas in high fire-prone regions are most exposed to fire damage, with 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 structure (i.e. lower density increases sensitivity) and isolation. Other factors that increase the sensitivity of settlements are the characteristics of the surrounding vegetation, as well as topographic aspects (Marzano et al., 2008).

There is also a significant danger for the population beyond direct fire damage, related to smoke, ash and fire fumes for areas that are not in immediate contact with fire. However, this indicator does not include these effects.

The indicator also assesses possible exposure of transport infrastructures by considering them in urban areas that are prone to forest fires. As shown by the 2007 fire season in Greece, fire can significantly influence transport networks, and can affect the operability and functionality of the national and local road network.

Methodology

The indicator provides an overview of the extent of urban and peri-urban areas potentially directly affected by forest fires, by combining the following variables.

Area

1. Select the city's urban area as reference units.
2. Delineate peri-urban areas around the city's urban area:

- a buffer of 20 km outside the border of the city's urban area ;
- a buffer inward of the city's urban area, proportional to the degree of soil sealing (up to 50 % confirmed by sensitivity analysis). Inward of the city's urban area, we do not consider any distance, just 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.

3. Cross the areas selected in 2 with the Burnt areas perimeter from JRC data (2000–2012), resulting in a classification of peri-urban areas and low dense areas inwards the city's urban area, according to the Burnt areas perimeter from JRC data (2000–2012).

Population

1. Cross 3 with the population grid resulting in the total population in peri-urban areas exposed to different degrees of fire danger.
2. For each city's urban area , calculate the ratio between population in high risk areas (from 4) and total population (city's urban area +peri-urban area).

Residential areas

3. Cross 3 with selected residential areas in the Urban Atlas (classes 11100 to 11300).
4. For each city's urban area , calculate the ratio between residential areas in high risk zones (from

6) and total residential areas (city's urban area +peri-urban area).

Commercial areas

5. Cross 3 with selected industrial, commercial, public, military and private units areas in the Urban Atlas (class 12100).
6. For each city's urban area , calculate the ratio between commercial, public, military and private units areas in high risk zone (from 8) and total residential areas (city's urban area +peri-urban area).

Transport network areas

7. Cross 3 with selected transport network (12210 Fast transit roads and associated land, 12220 Other roads and associated land, 12230 Railways and associated land, 12300 Port areas, 12400 Airports).
8. Calculate percentage of transport network area at high risk of forest fire in the buffer of 20 km and low dense areas inwards.

Table 3.7.1 Residential, industrial and commercial, transport area and related classes in the Urban Atlas used for forest fire risk assessment

Level 4 class legend Urban Atlas (residential, commercial and	
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 %)	Residential

Level 4 class legend Urban Atlas (residential, commercial and	
11300 Isolated Structures	
12100 Industrial, commercial, public, military and private units	Industrial and commercial
12210 Fast transit roads and associated land	Transport
12220 Other roads and associated land	
12230 Railways and associated land	
12300 Port areas	
12400 Airports	

Figures 3.7.1 and 3.7.2 show how the methodology as described here is applied to the city of Genoa.

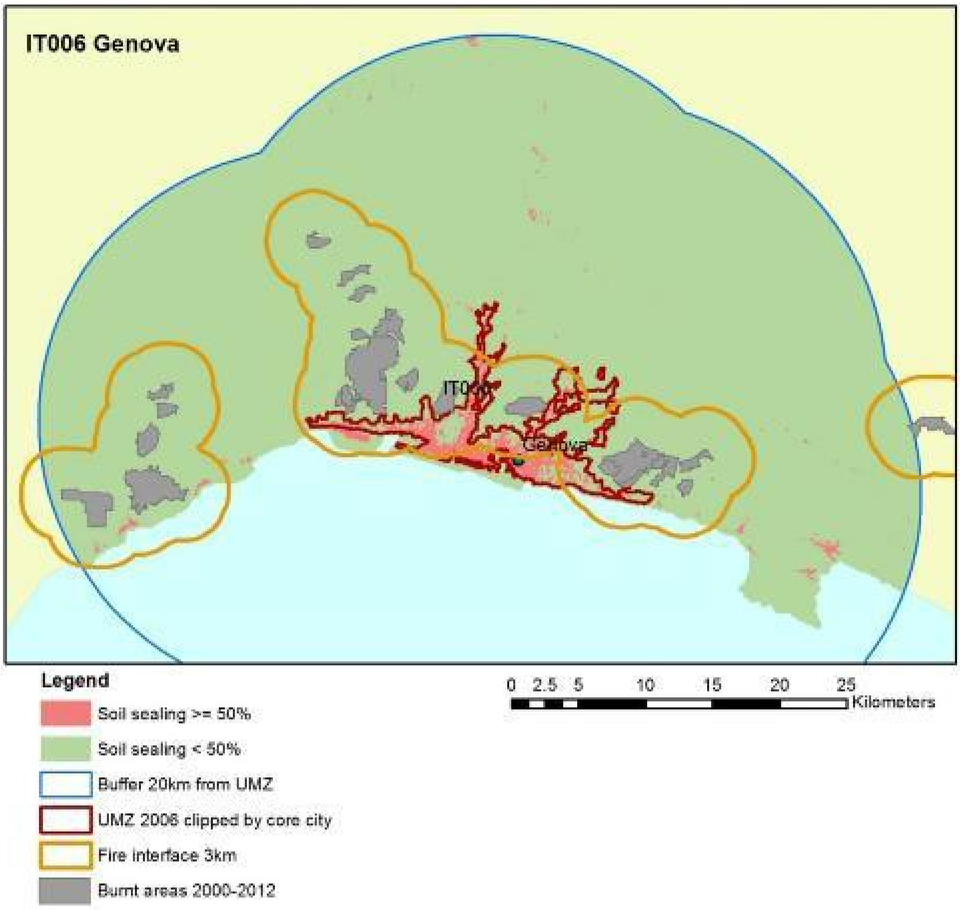


Figure 3.7.1 Example of the delineation of peri-urban areas around UMZs in the city of Genoa

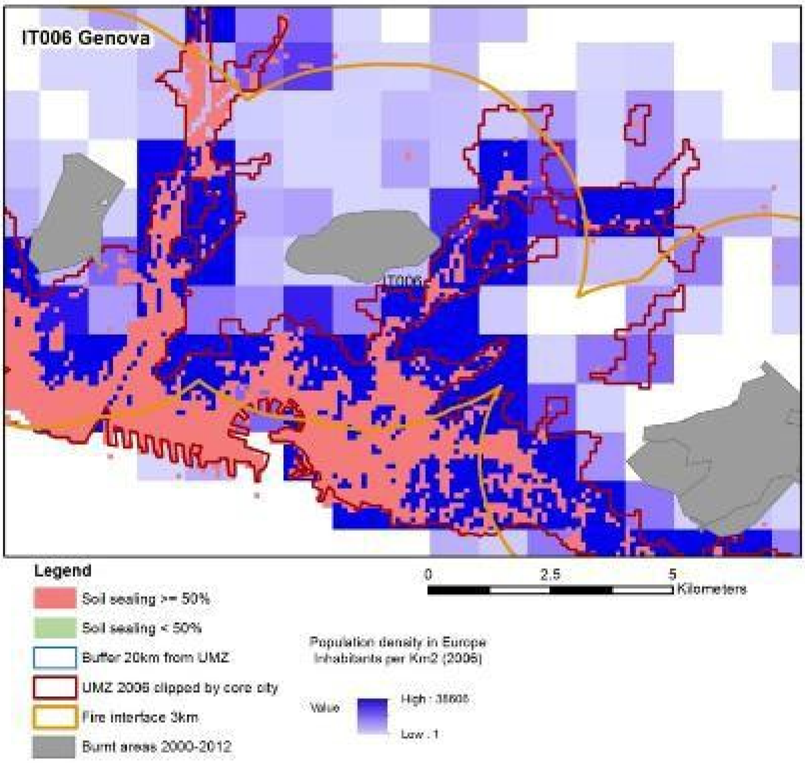


Figure 3.7.2 Example of population density in relation to the forest fire risk in the city of Genoa

Data specifications

EEA data references

The UMZ as a reference unit for city morphology (as the best approximation of the 'real' city form, which often does not correspond to the administrative delineation) is available from the EEA data service[40].

NB: In the current processing, all UMZ patches located within the city's boundaries are used.

Degree of sealed surfaces: can be most easily calculated via the NDVI from satellite images. In the frame of GMES (Copernicus) precursor activities, EEA produced a high-resolution soil-sealing layer for the whole of Europe for the year 2006, based on the same satellite pictures as were used for CORINE land cover data[41].

The 'imperviousness 2009' data were produced by the FP7 Geoland2 project[42].

High-resolution land cover data for built-up areas with degree of imperviousness 2009. A histogram smoothing procedure was applied to address minor inconsistencies.

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[40] See http://www.eea.europa.eu/data-and-maps/data/urban-morphological-zones-2006-umz2006-f3v0 online.

[41] See http://www.eea.europa.eu/data-and-maps/data/eea-fast-track-service-precursor-on-land-monitoring-degree-of-soil-sealing-100m-1 online.

[42] See http://www.geoland2.eu/portal/service/ShowServiceInfo.do?serviceId=CB80D480&categoryId=CA80C581 online.

Classes: 0: unsealed; 1-100: degrees of sealing/imperviousness; 254: clouds, no data; 255: outside area.

External data references

Map of meteorological fire danger (European Commission: Forest Fires in Europe, Middle East and North Africa 2011[43]). Fire danger indices, which are routinely used to rate the fire potential due to weather conditions. The Canadian Fire Weather Index (FWI) is used in the European Forest Fire Information System (EFFIS) to rate the daily fire danger conditions in Europe.

Rapid damage assessment. The rapid damage assessment (RDA) module of EFFIS has been implemented since 2003. It maps burned areas during the fire season by analysing Moderate Resolution Imaging Spectroradiometer (MODIS) daily images with a 250-metre spatial resolution[44].

GMES Urban Atlas database provides reliable, intercomparable, high-resolution land use maps for 305 Large Urban Zones and their surroundings for the reference year 2006. These data are used to identify residential areas (classes 1100 to 11300)[45].

Population density grid for 2006 based on GEOSTAT data (raster). This data set contains the number of inhabitants per square kilometre for the reference year 2006 that are located within the Grid_ETRS89- LAEA_1K. The data set should be referred to as GEOSTAT_Grid_POP_2006_1[46].

Uncertainties

The explanatory power of this indicator may be disputed in the area of transport networks, because these are of paramount importance in ascertaining the impact of forest fire on urban and peri-urban areas. For example, wide roads can interrupt fuel continuity; primary and secondary roads are important for accessibility in extinguishing the forest fire, as well as for evacuation routes. A high proportion of such kinds of infrastructure in fire-prone areas means increased vulnerability of an urban area. This applies not only to the region, but also to the larger urban area, as it might also depend on the services provided by the infrastructure at risk.

Indicator assessment

Key question: How sensitive is an urban area — its people and assets — to a direct impact (i.e. the sensitivity of being burnt) of forest fire under the current situation and future climate changes?

Web link to maps

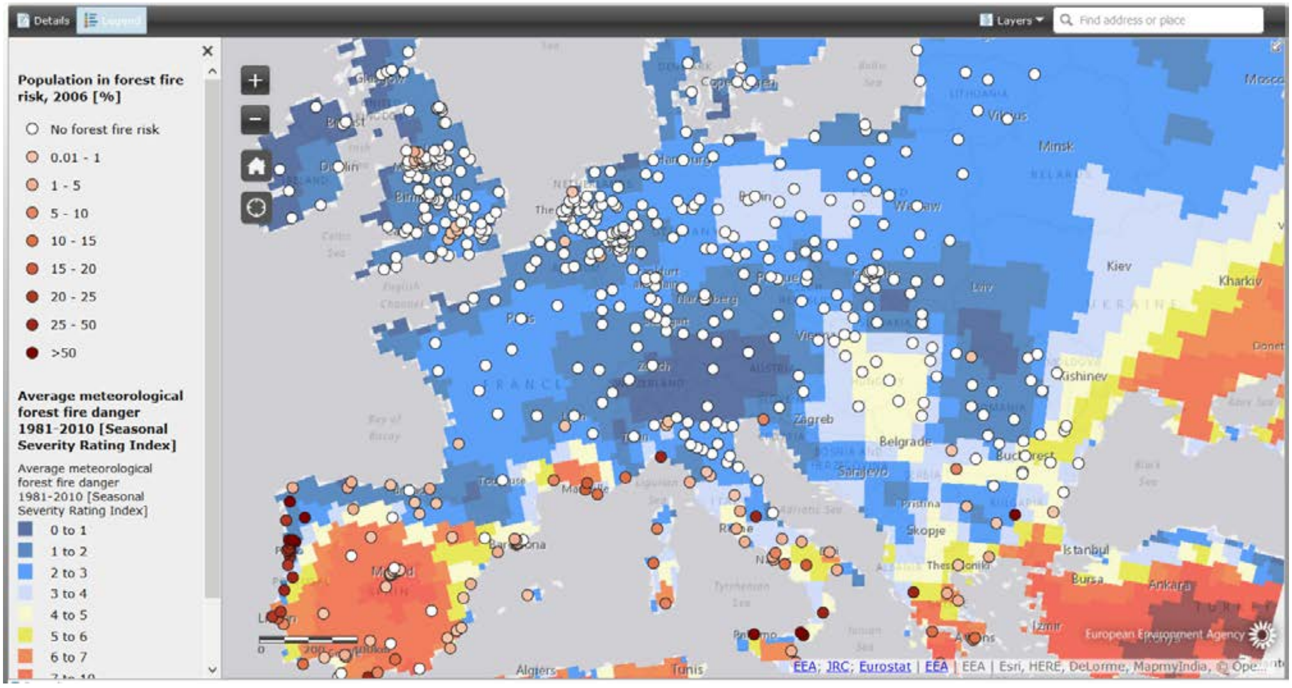
http://climate-adapt.eea.europa.eu/knowledge/tools/urban-adaptation/climatic-threats/forest-fires/exposure

[43] See http://www.eea.europa.eu/data-and-maps/indicators/forest-fire-danger-1/assessment online.

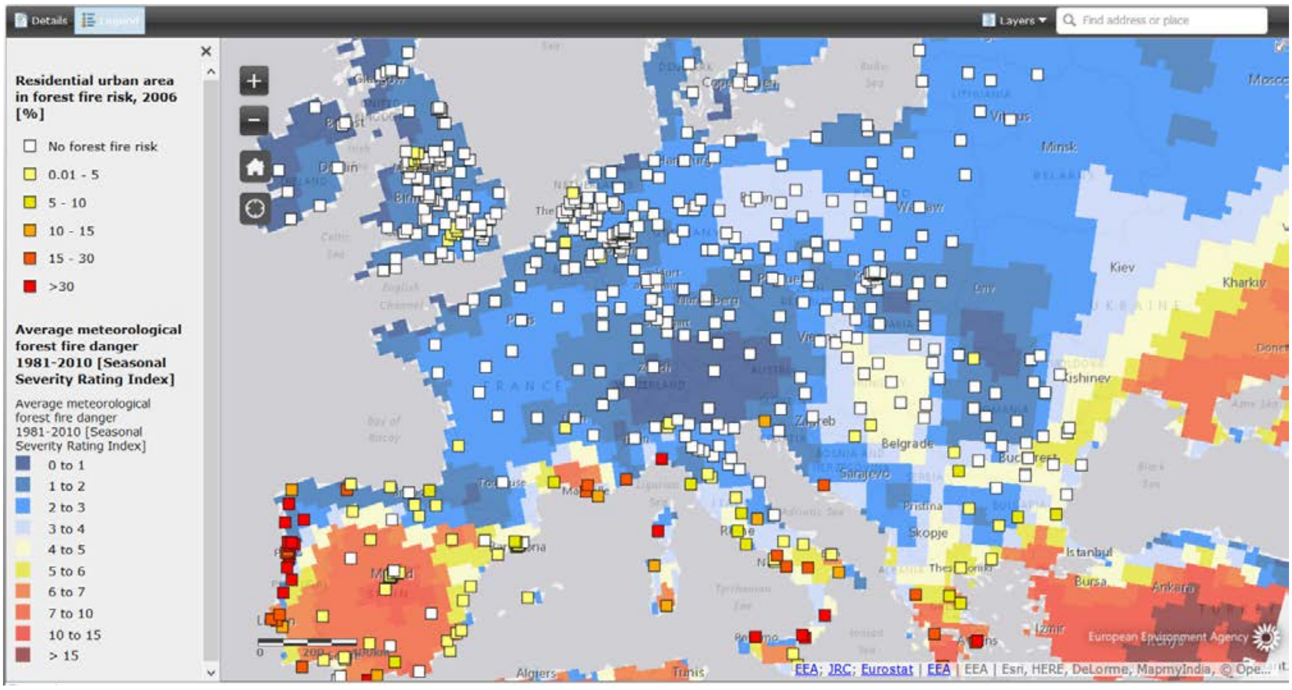
[44] See http://forest.jrc.ec.europa.eu/effis/about-effis/technical-background/rapid-damage-assessment/ online.

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

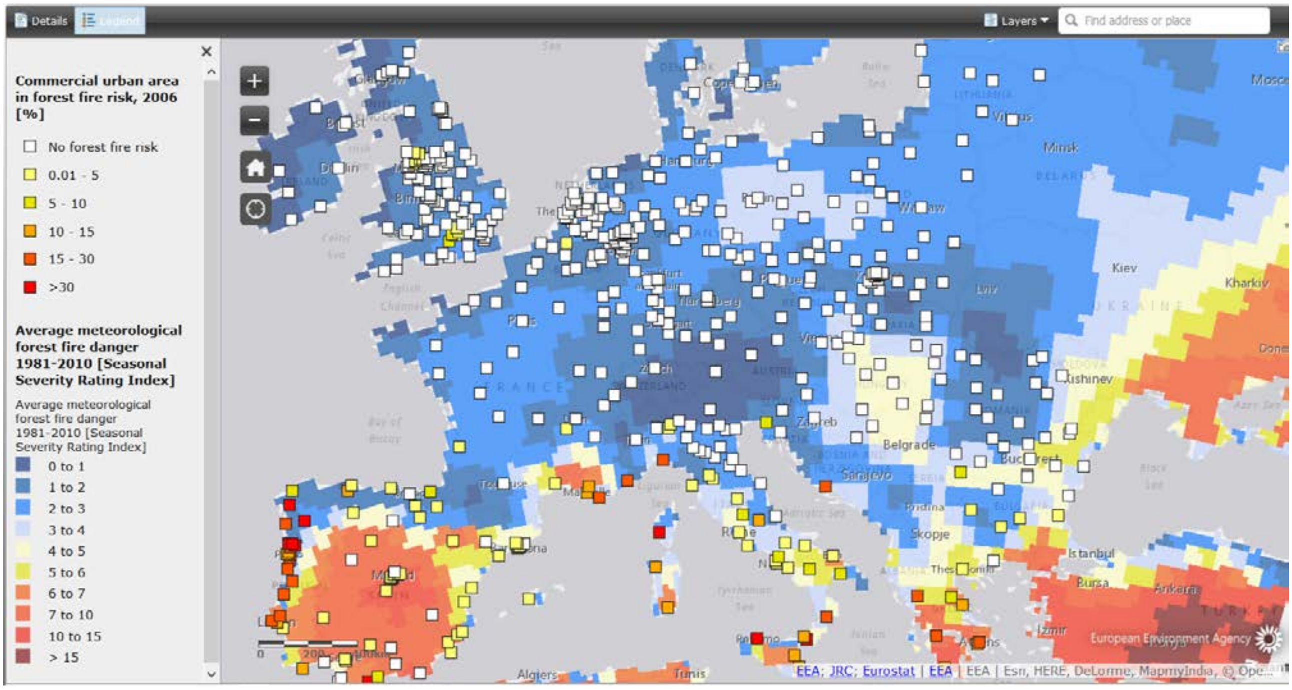
[46] See http://epp.eurostat.ec.europa.eu/cache/GISCO/geodatafiles/GEOSTAT_Grid_POP_2006_1K.zip online.



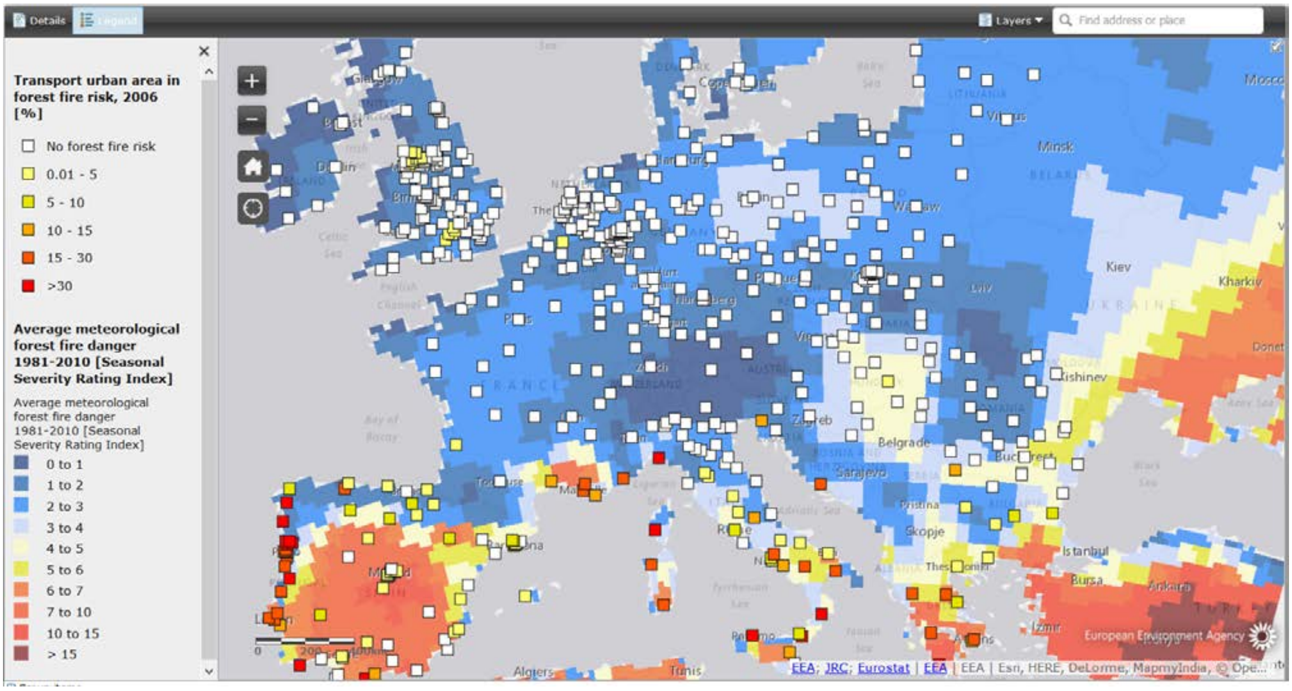
Map 3.7.1 Population currently at high direct risk areas of forest fires



Map 3.7.2 Share of residential areas at high direct risk of forest fires



Map 3.7.3 Share of commercial areas at high direct risk of forest fires



Map 3.7.4 Percentage of transport infrastructure in European cities and related peri-urban areas at high direct risk of forest fires

The maps show that the largest shares of people and residential areas vulnerable to fire are in southern countries. Results highlight that all Portuguese cities show a high percentage (> 16 %) of residential area at high direct risk of forest fires. Southern France and Greece present the same pattern, while in Southern Italy, the situation is more variable. Commercial areas appear less vulnerable than people and residential areas. Nevertheless, northern Portugal, southern France, southern Italy and Greece are the countries with the majority of commercial areas vulnerable to fires. Similarly, this pattern is shown, but is more marked, with transport infrastructures (Map 3.7.4)[47].

This is particularly important also in the context of projected changes on fire danger, as estimated by the JRC. Results highlighted a marked increase of fire danger, particularly in south-western Europe, and an enlargement of the fire-prone area going north (European Commission: Forest Fires in Europe, Middle East and North Africa 2011)[48].

[47] For the UK only, data on the population are available.

[48] See http://www.eea.europa.eu/data-and-maps/indicators/forest-fire-danger-1/assessment online.

3.8 Vulnerable people

Indicator definition

- The share of the urban population aged 65 or older and
- the share of lone pensioner households in European cities,

represented in [%] of the total population.

Justification of the indicator

Elderly people in general are more vulnerable because they are more sensitive to environmental stressors such as heatwaves, flooding, water scarcity or forest fires, due to various factors that accompany older age. A higher percentage of people aged 65 or older in a city indicates a higher social sensitivity of that city for exposure to these impacts. The proportion of single person households in pension age serves furthermore as a proxy for the share of highly vulnerable people, as elderly persons more frequently depend on assistance for dealing with impacts which potentially is less available or less continuously available for persons living alone. Further to this individual aspect of vulnerability, the proportion of vulnerable people also affects the age dependency ratio, which in turn affects response capacity in a city.

Health is a key determinant for climate change vulnerability (Brooks et al., 2005). Older people are, on average, more sensitive to health-related impacts of climate change than younger people. Generally speaking, they are also less mobile, and less able to avoid or cope with climate stressors and extreme events. Many studies consider the elderly more vulnerable to a variety of climate-related stressors: extreme weather events (Brooks et al., 2005; Fernandez et al., 2002); high temperatures and resulting mortality and morbidity (Huynen et al., 2001; Kovats and Hajat, 2008); respiratory problems related to forest fires, for instance (Johnston et al., 2012). The heatwave that affected Europe in the summer of 2003 caused more than 19 000 excess deaths, according to official estimates, making it one of the deadliest hot-weather disasters in a century. The highest maximum temperature in Europe was recorded in the metropolitan area of Milan, with a mean value of 39 °C in August. In this area, an increase of 23 % of deaths for all causes throughout the summer was observed, as compared with the mean number of deaths recorded in summer during the period from 1995 to 2002 (Russo and Bisanti, 2004). The social situation and the lack of social networks is furthermore considered as a factor influencing the individual capacity of responding to impacts, . In this sense studies consider elderly persons living alone as potentially more vulnerable (Ligon and Schechter, et al. 2003, Harlan, Declet and Stefanov,; Harlon et al. 2012,; Fouillet, et. al. 2006) .).

The share of population over 65 years of age in European cities serves as an indicator of social sensitivity, and it also serves as a proxy for health, in the absence of large-scale data on information about physiological (e.g. cardiovascular) health.

Methodology

The indicator regarding the share of people aged 65 or older is the quotient of two Urban Audit indicators for cities/greater cities: Indicator DE1028I 'Proportion of population aged 65-74 years' and DE1055I 'Proportion of population aged 75 years and over'. The share of lone pensioner households (DE3008I) is collected according to specific national pension ages.

In order to maximize the spatial coverage of the indicators and thus include as many cities as possible, data is provided in two individual layers:

1. showing the indicator value for the most recent available year and,
2. showing changes between the first and last available year normalized by the count of years.

Data specifications

EEA data references

None.

External data references

Eurostat Urban Audit database[49]:

- DE1028I Proportion of population aged 65-74 years;
- DE1055I Proportion of population aged 75 years and over.
- DE3008I Proportion of households that are lone-pensioner households

Uncertainties

For the share of people aged 65 or older, other possible age thresholds could be considered. Life expectancy and ageing of the population in Europe are increasing. 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. Therefore, it remains unclear at which age above 65 years the sensitivity really increases. To date, only a few studies have analysed this in greater detail. For instance, an analysis of the impact of the 2003 heatwave for Greater London shows a clear increase in daily mortality among elderly people above the age of 75 years, whereas no notable effect was observed for the group aged between 65 and 74 years (Kovats and Hajat, 2008).

The share of lone pensioner households comprises different age ranges, depending on the specific national pension age, and is thus a proxy for the share of households in European cities that might be less able to cope with heat of flood impacts because of age dependent increased sensitivity which go together with a potentially low level of available networks.

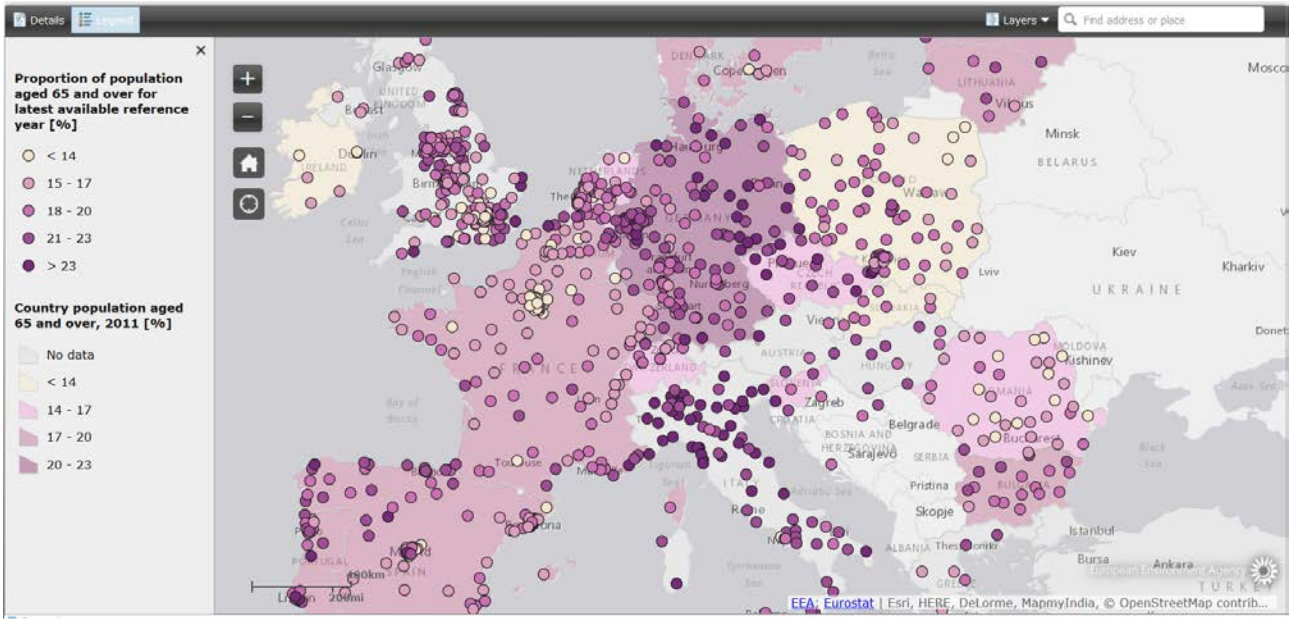
Indicator assessment

Key question: What is the share of vulnerable people in cities as an indication of current and future sensitivity and response capacity to climate change impacts?

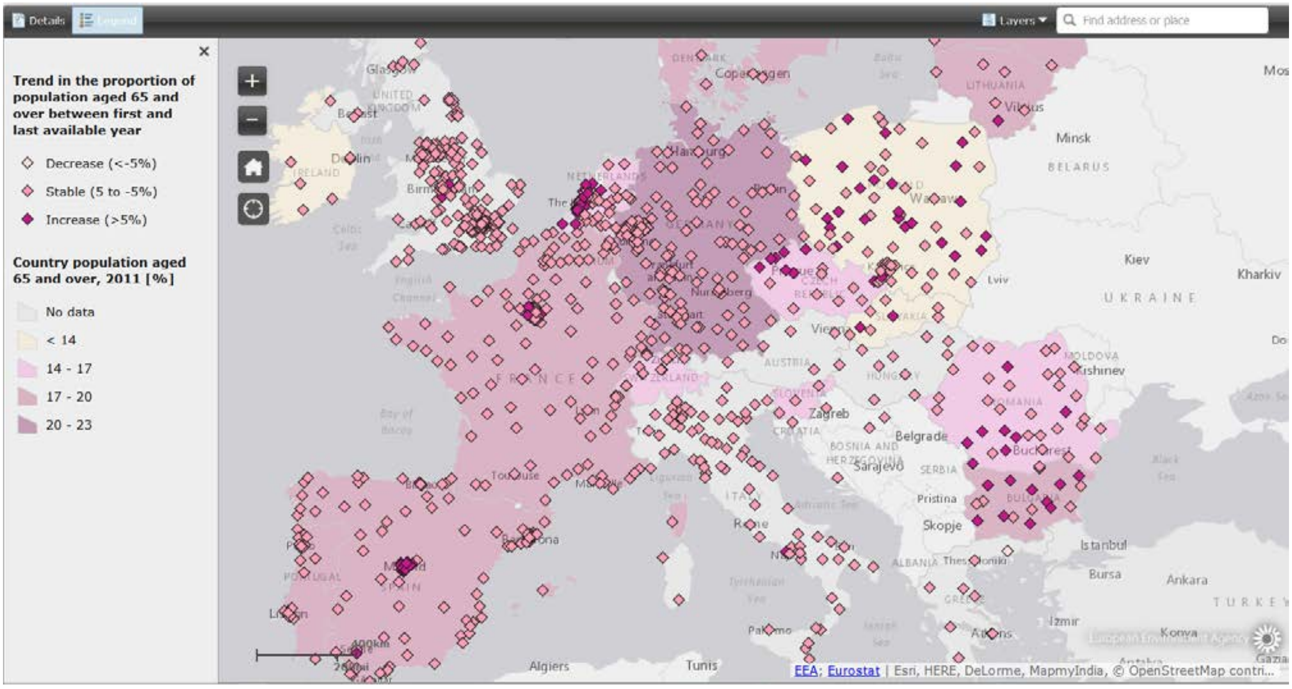
Web link to maps

http://maps.eea.europa.eu/EEABasicviewer/v3/?appid=5f060968d0b8430ab635c68bc7ccb1af&webmap=395b44bba1d643dfa7a72019d94afb77&embed=false

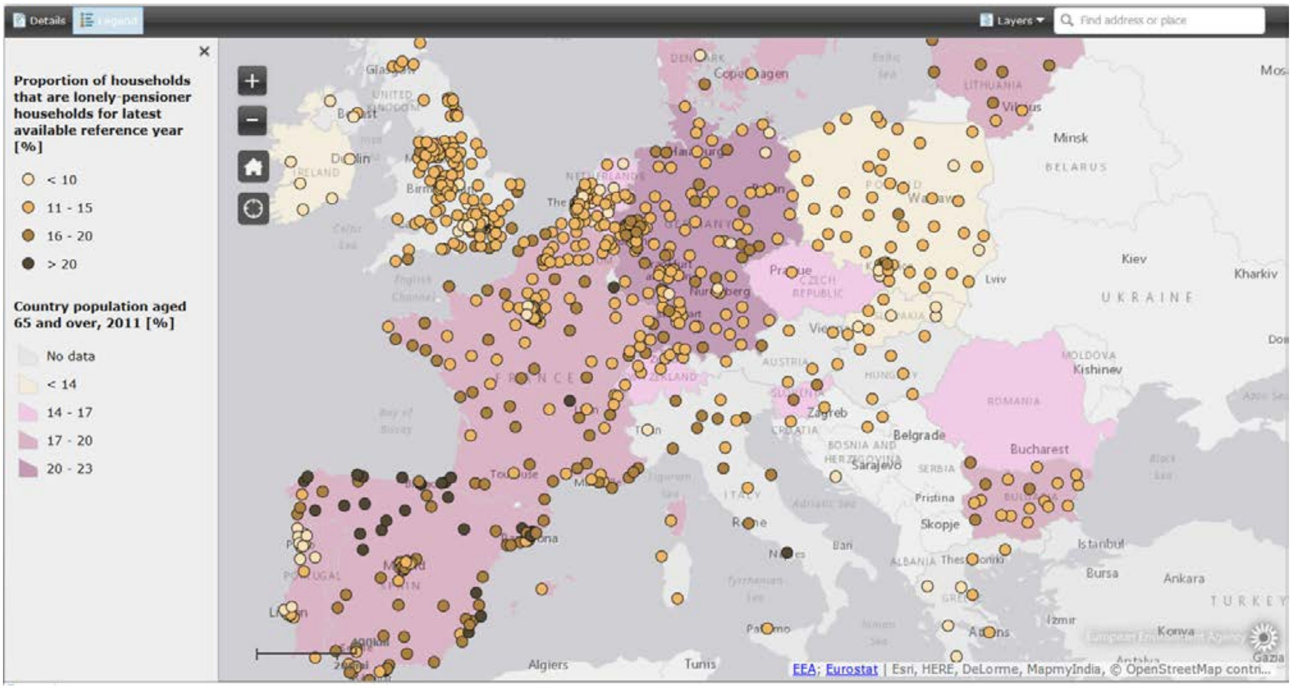
[49] See http://ec.europa.eu/eurostat/web/cities/overview online.



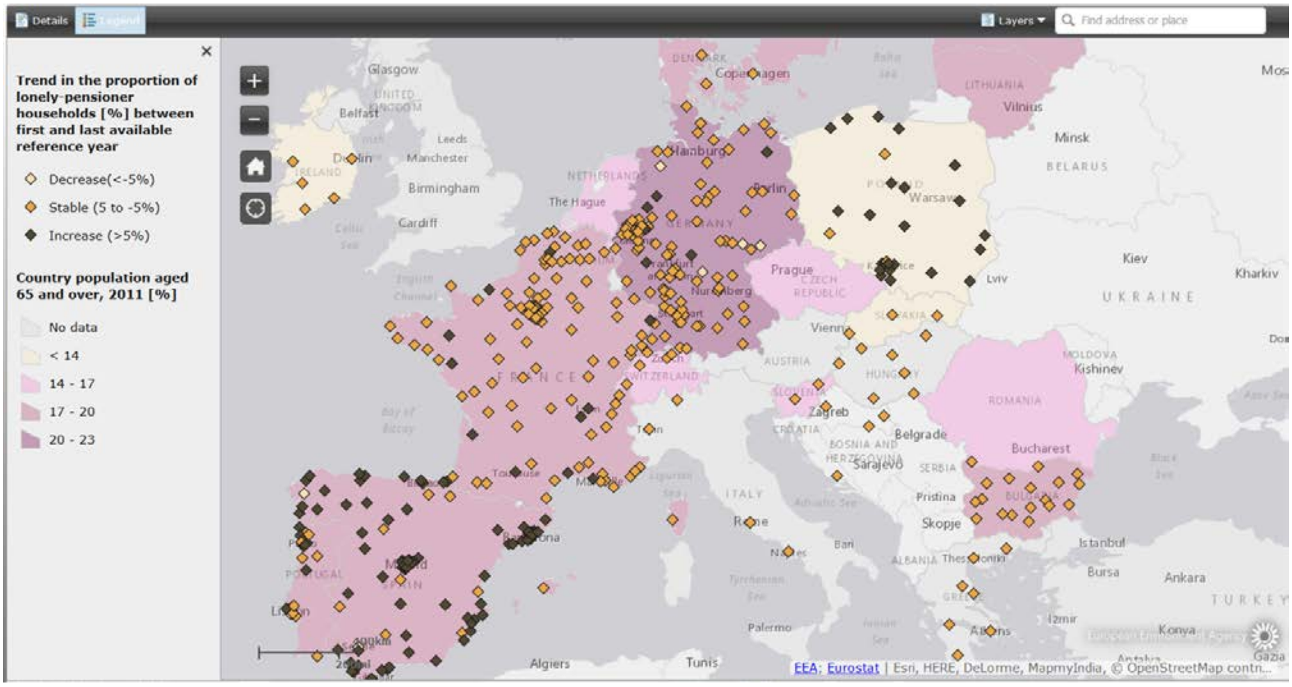
Map 3.8.1. Share of urban population with an age of 65 years or older for most recent available year.



Map 3.8.2 Normalized trend in the share of urban population with an age of 65 years or older based on first and last available year.



Map 3.8.3 Portion of households that are lonely pensioner households for the latest available year [%]



Map 3.8.4 Normalized trend in the portion of lonely pensioners' households

The group of people aged 65 or older currently constitutes about 17.5 % of the total population of Europe (2011), but this share is expected to rise to 29.5 % by the year 2060. The share of people aged 80 years or older (4.1 % in 2010) will nearly triple by 2060, to reach 11.5 % (Eurostat Population Projections 2010-based, Europop2010)(Figure 3.8.1). This demographic trend will lead to an increased sensitivity to climate impacts. This change also affects the age dependency ratio, i.e. the ratio between older and younger people, relevant for how elderly people are supported economically and tended in the event of extreme climatic events.

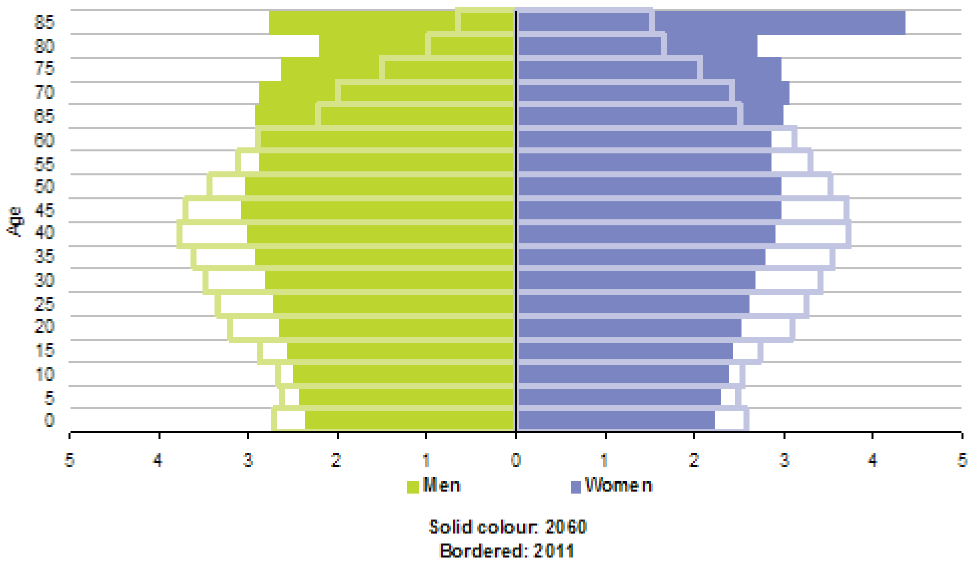
The proportion of people aged 65 or older in cities is higher in the area extending from Italy to Germany and into northern Spain. In Belgium and Germany, this proportion usually follows the country average. Cities in northern Italy, meanwhile, tend to have values above the country average.

For other countries, such as Bulgaria, France, Romania, southern Spain and the United Kingdom, the share of elderly people in most cities is lower than the country average (EEA, 2012).

The same pattern is reflected in the concentrations of elderly persons (or pensioners) living alone. Cities in Central and northern European countries see less evident concentrations of lone pensioners households, although also in these cases the portion easily reaches 15% of the overall number of households. Relatively low values are found in Portuguese, Greek and Irish cities. Those areas which see the highest concentration of potentially vulnerable households also share the highest increases in these values, especially in Spanish cities, but is also increasing, albeit starting from a lower level, in Poland and Finland (see Maps 3.8.3 and 3.8.4)

Population ageing is a long-term trend, which began several decades ago in the EU. This ageing is visible in the development of the age structure of the population, and is reflected in an increasing share of older persons and a declining share of young and working-age persons in the total population (Map 3.8.2; Figure 3.8.1). Overall, changes are limited (over 800 cities out of 941 fall within the -5% - +5% per year range (the trend is nevertheless positive for more than half of these cities)) but trends are higher (>+5%) in The Netherlands/Belgium, Romania/Bulgaria, and eastern Germany and Poland. The only downward trend (>-5%) is in the city of Kavala in Greece.

The share of the population aged less than 15 years in the EU-27 population decreased by 3.7 percentage points in the past 2 decades, while the share of the older population (65 years and above) increased by 3.6 percentage points. As a result, the top of the EU-27 age pyramid for 2011 has widened and will continue to do so until 2060 (see Figure 3.8.1). The growth in the relative share of older people may be explained by increased longevity as life expectancy has risen; this development is often referred to as 'ageing at the top' of the population pyramid.



(1) 2011, provisional; 2060 data are projections (EUROPOP2010 convergence scenario).
Source: Eurostat (online data codes: demo_pjangroup and proj_10c2150p)

Figure 3.8.1 Changes in share of age classes in EU-27 population (year 2011) Source: EUROSTAT

Table 3.8.1 Overview of trends in ages in several European cities

City code	Name	Population > 65 (%) (2004)	Population > 65 (%) (2011)	Trends (%) (2004–2011)
IT002	Milan	23.35	23.91	0.56
IT004	Turin	23.31	23.86	0.55
IT006	Genoa	26.61	26.87	0.26

DE001	Berlin	16.59	19.1	2.51
DE002	Hambu	17.92	18.82	0.9
DE003	Munic	17	17.72	0.72
FR001	Paris	14.08	-	-
RO001	Buchar	14.53	14.19	-0.34
FI001C	Helsink	13.78	14.96	1.18
UK001	London	11.97	-	-

Urban Audit data confirm the overall ageing trend. As an example of the data, cities in northern Italy (Turin, Milan, Genoa) have high values above 23 %, while other major European cities start at a lower value, but have higher growth rates for elderly populations. In Germany, the values of share of population aged 65 and over are around 17 % to 18 % (Berlin, Hamburg, Munich). Paris, Bucharest and Helsinki show values around 14 %. In the United Kingdom, the share of elderly people in most cities is lower than in rural areas (London: 11.97 %) (Table 3.8.1).

3.9 Socio-economic status

Indicator definition

- Unemployment rate [%]
- Gross domestic product at current market prices by NUTS3 regions [EUR per capita]

Justification of the indicators

Economic status is a widely recognised determinant for vulnerability and response capacity (IPCC, 2001 and 2007). It relates to both social sensitivity and response capacity.

In terms of social sensitivity, low income at household level may result in poor quality of housing as well as lack of access to resources and transportation. As a result, low-income households may be more sensitive to climatic risks such as heat-related mortality (Reid et al., 2009; Stafoggia et al., 2006; WHO, 2004). At the individual level, people with low income are also more likely to have a chronic disease or other medical risk factors, such as obesity or mental illness, which will increase their vulnerability (Kovats and Hajat, 2008).

In terms of response capacity, economic assets, capital resources, financial means and wealth play an important role in vulnerability and responses to climate change and related hazards (Smit and Pilifosova, 2001; Yohe and Tol, 2002). Wealthy nations, regions and communities are more likely to be in a better position to adapt to changes in the climate, by being able to bear the costs of adaptation, although wealth alone is not a sufficient indicator of the capacity to adapt (IPCC, 2001 and 2007).

Economic resources are also predictive of the availability of technological options for adaptation and risk-spreading processes such as insurance coverage (Yohe and Tol, 2002).

Economic resources can be distributed unequally, resulting in a lower response capacity. It is typically argued that response capacity will be greater if resources and power in governing resources for adaptation are equitably allocated within a community or nation or at global level (IPCC, 2001). At the community level, low income is often linked to patterns of social marginalisation such as class and ethnic divisions (Blaikie et al., 1994). Especially long term unemployment rate can be considered as a driver of social exclusion.

When considered together the unemployment rate and gross domestic product of the surrounding region serve to depict different perspectives on economic status and response capacity.

Methodology

In order to maximize the spatial coverage of the indicators and thus include as many cities as possible, data is provided for both indicators in two individual layers:

1. showing the indicator value for the most recent available year and,
2. showing changes between the first and last available year normalized by the count of years.

Note:

Unemployment rate as well as GDP were selected to represent socio-economic status following the discontinuation of the previous indicator “Share of households with less than half of the national average income” in 2014. The Urban Audit database offers a variety of alternative indicators for living conditions and thus, socio-economic status. However, indicator availability and reference years can vary considerably between cities and therefore do not allow for a comparative assessment. GDP and unemployment rates on the other hand, are readily available indicators both temporally and spatially. This was the main reason for selecting these two indicators.

Data specifications

EEA data references

None.

External data references

Eurostat Urban Audit database[50]:

- EC1020I - Unemployment rate

Eurostat database[51]:

- nama_10r_3gdp Gross domestic product at current market prices by NUTS3 regions.

Uncertainties

The unemployment rate and GDP is at present a selection of the various indicators to depict different perspectives on economic status and response capacity (e.g. per capita income, ratio of first to fourth quintile earnings etc.).

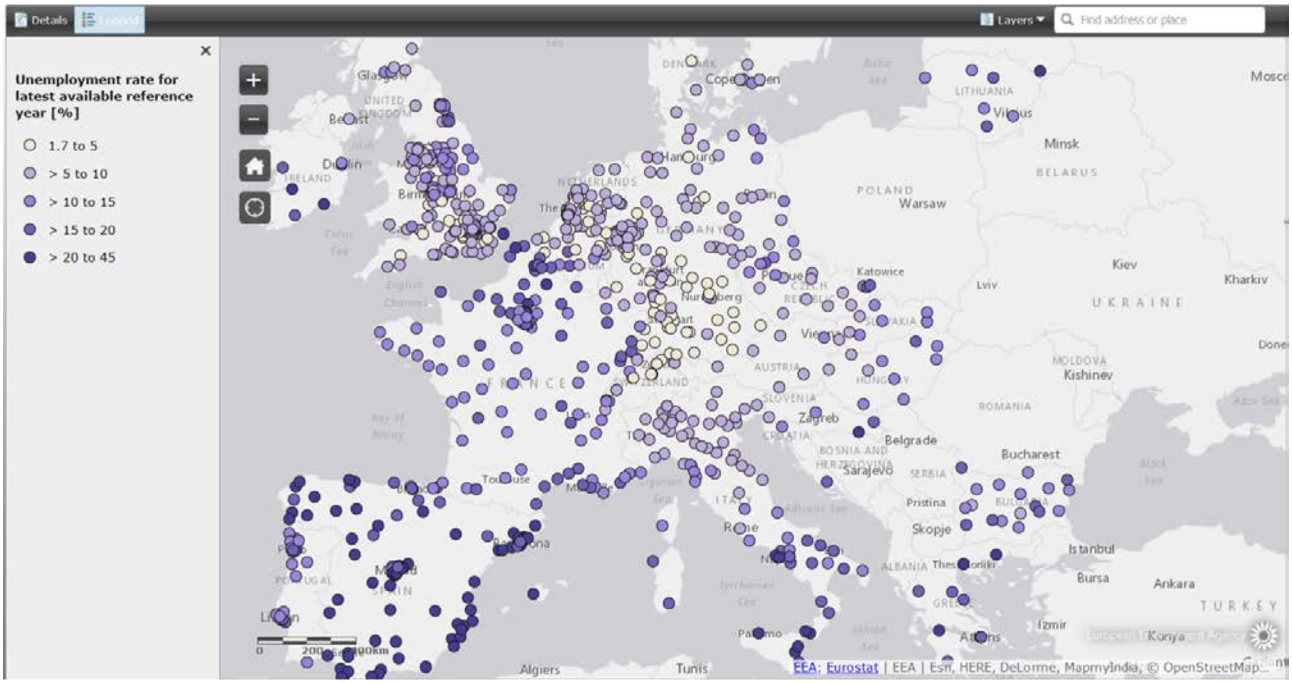
These need to be considered in interpreting and assessing the indicator results. Large inequalities within cities may blur the difference in income and associated sensitivity/response capacity between cities.

Indicator assessment

Key question: What is the rate of unemployment in European cities and how does it compare to the economic volume of the greater region?

Web link to map

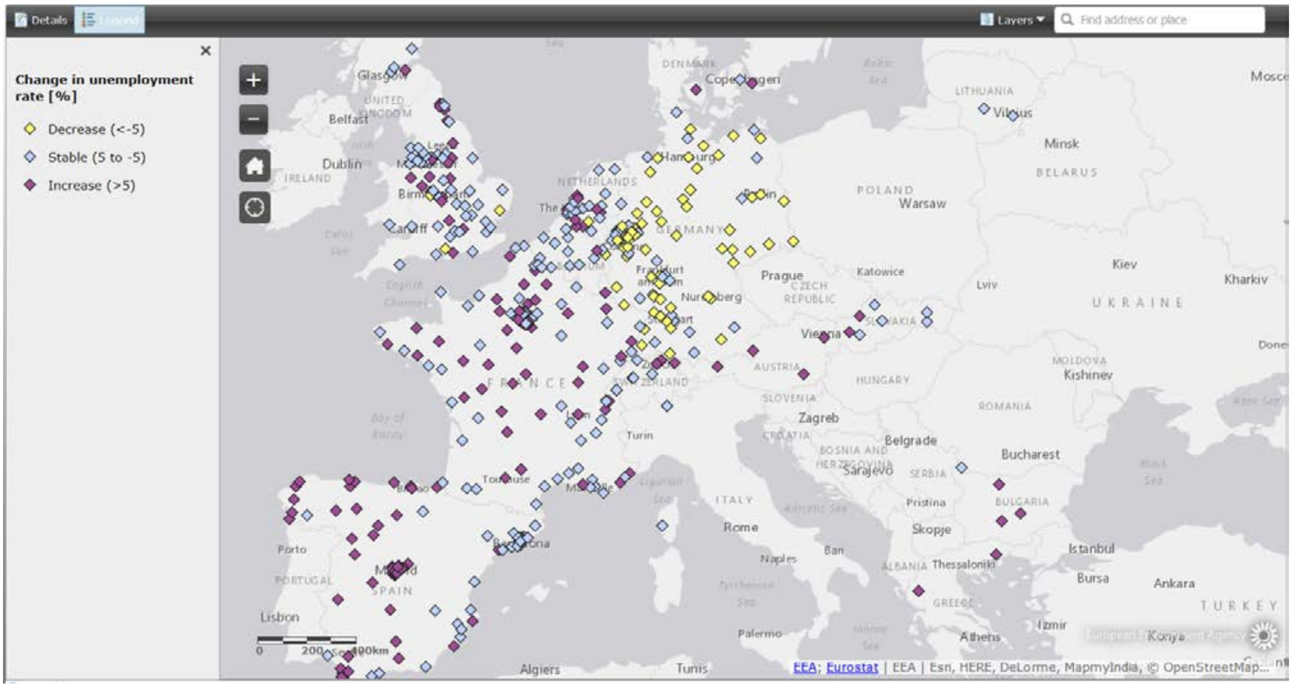
http://maps.eea.europa.eu/EEABasicviewer/v3/?appid=5f060968d0b8430ab635c68bc7ccb1af&webmap=395b44bba1d643dfa7a72019d94afb77&embed=false



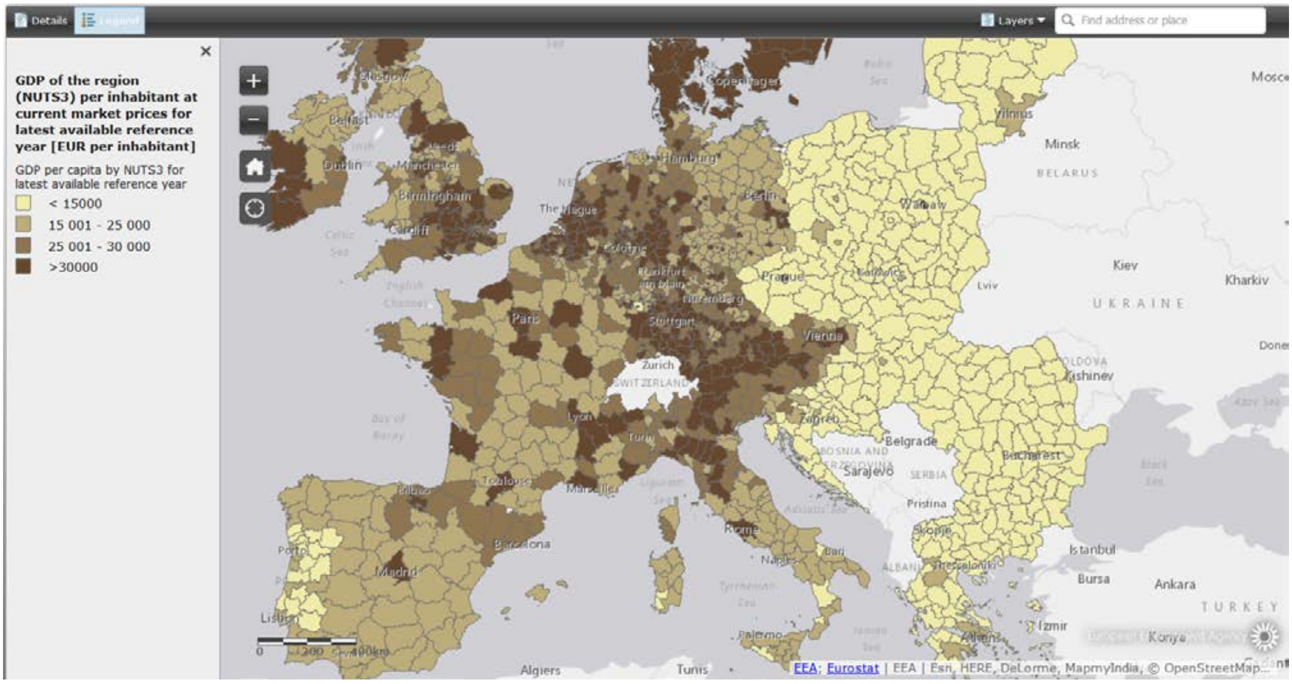
Map 3.9.1 Unemployment rate [%] for latest available reference year.

[50] See http://ec.europa.eu/eurostat/web/cities/overview online.

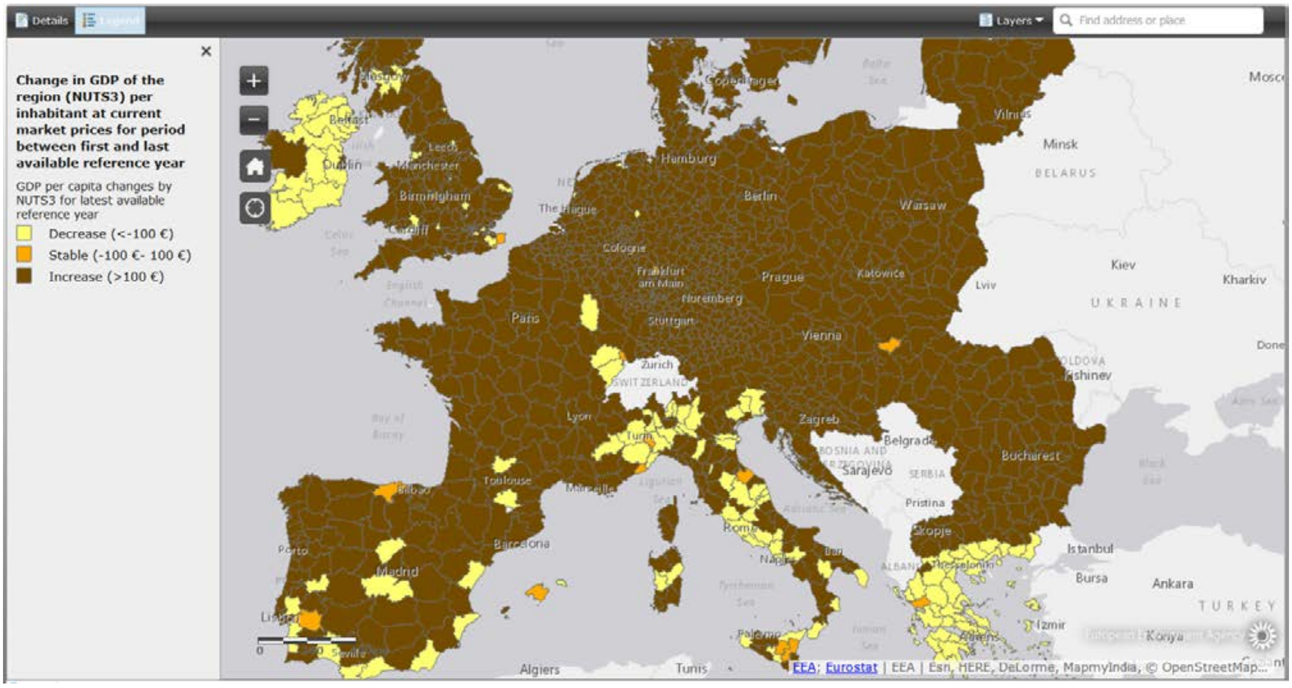
[51] See http://ec.europa.eu/eurostat online



Map 3.9.2 Changes in unemployment rate [%] f or period between first and last available reference year.



Map 3.9.3 Gross domestic product at current market prices per inhabitant by NUTS3 regions for latest available reference year [EUR/inh.]



Map 3.9.4 Change of gross domestic product at current market prices per inhabitant by NUTS3 regions for period between first and last available reference year [EUR]

The gross domestic product per inhabitant shows a clear divide with having the lowest in most Eastern European countries and Portugal, but capital regions often performing above, and the highest values in the Scandinavian countries. For the rest of Europe the pattern can be very mixed even inside a country. In terms of social equity, such varying GDP levels inside a country can show city regions with relative poverty. In most regions the GDP per inhabitant has increased, but in many Southern European regions and Ireland it has decreased over the last years.

Unemployment is generally also higher in cities of these regions. Changes in unemployment rate are only available for the countries more to the west. In Germany, most cities show a decrease in unemployment rate (<-5%), while in countries like France, Spain and the UK the unemployment rate is stable (>-5%, < +5%) or increasing (>+5%).

The indicator highlights the need for more detailed analysis on the causes of low socio-economic status in relation to vulnerability. Important questions relate to the persistence of low income status, and the role of immigration and ethnic divides. University towns (e.g. Tartu, Estonia) present an interesting case: here, large transitory student populations with low socio-economic status have high levels of education.

3.10 Education

Indicator definition

The share of population aged 15 to 64, qualified at tertiary level (ISCED 5-6), living in cities, represented in [%] of the total population.

Justification of the indicator

The indicator was selected based on the assumption that the education levels of urban populations contribute positively to the response capacity, through higher awareness and understanding of climate change impacts and adaptation options, thus increasing the response capacity of the society.

Awareness is needed to recognise the problem of adaptation. Awareness builds on the knowledge base and education levels of the local population, but also on values such as equality and perceptions of climate change as a problem. Knowledge, values and perceptions pose social limits to adaptation. These limits can severely increase vulnerability, but they are also mutable (Adger et al., 2009). Education is a key means of altering such social limits to adaptation. Education levels are also an significant predictor of civic and political participation in Europe (Gallego, 2008), something which supports collective action.

Research on disaster mortality suggests that education is a major factor in reducing human vulnerability. Adger et al. (2004) tested national-level vulnerability and response-capacity indicators against the outcome of disaster mortality. Their analysis pointed to human health status, governance and education as being key factors of human vulnerability. The level of scepticism over climate change may decline with an increasing level of education (Whitmarsh, 2011). However, it was also observed by this author that political views strongly affect scepticism and uncertainty over climate change. Weber (2010) believes that at least for some people, better (environmental) science and statistics education can familiarise people with the scientific presentation of climate change information, and thus increase their understanding of the issue.

The link between education via awareness to response capacity is indirect. Thus, the level of education serves as a proxy for awareness of the climate change problem and related response measures.

Tertiary education, the level of education following secondary schooling, was selected as indicator for education. Universities and other higher education institutions play an essential role in society, creating new knowledge, transferring knowledge to students and fostering innovation. Around 20 million students (undergraduate and postgraduate) studied in the 4 000 higher education institutions in the EU-27 in 2010.

Methodology

Data on education in Urban Audit cities/greater cities were collected. Proportion of population aged 15 to 65, qualified at tertiary level, living in Urban Audit cities [%] TE2031I - Proportion of working age population qualified at level 5 or 6 ISCED - TE2031V - DE1046V + DE1049V + DE1052V + DE1025V

In order to maximize the spatial coverage of the indicator and thus include as many cities as possible, data is provided in two individual layers:

1. showing the indicator value for the most recent available year and,
2. showing changes between the first and last available year normalized by the count of years.

Data specifications

EEA data references

None.

External data references

Eurostat Urban Audit database[52]:

- TE2031I Proportion of working-age population qualified at level 5 or 6 ISCED.

Uncertainties

Uncertainties are related to education being one proxy of awareness and related corollary phenomena such as civic engagement. Education should be seen as a factor in building awareness, but it is not necessarily decisive in all cases. Also, other measures of education might be possible in this context, ranging from illiteracy to higher education. The choice between secondary and tertiary education is somewhat arbitrary. In the European context, using lower level differences in education would not differentiate between cities, but using tertiary education may overemphasise the role of university cities.

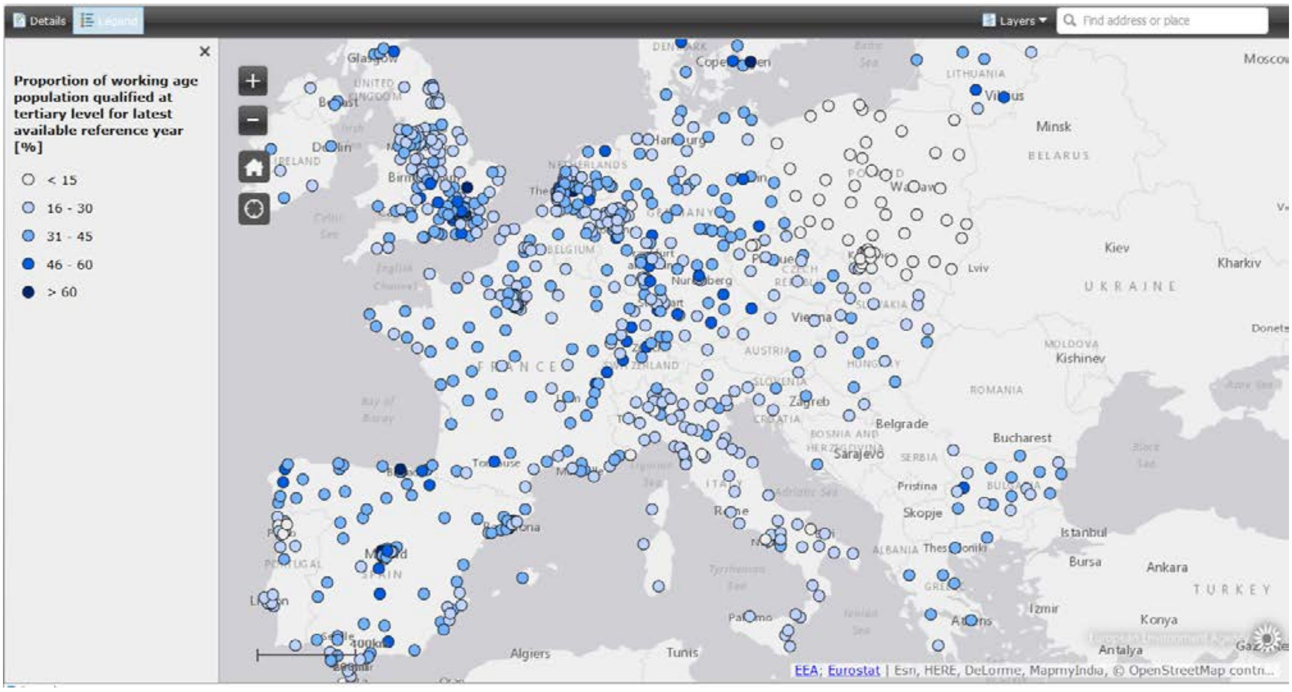
Data uncertainties could also be related to possible national differences in how students are registered as residents in cities. If students are not registered as residents, the indicator may show a substantially lower value.

Indicator assessment

Key question: What is the level of education of the city's population indicating the potential to create a higher awareness and coping capacity?

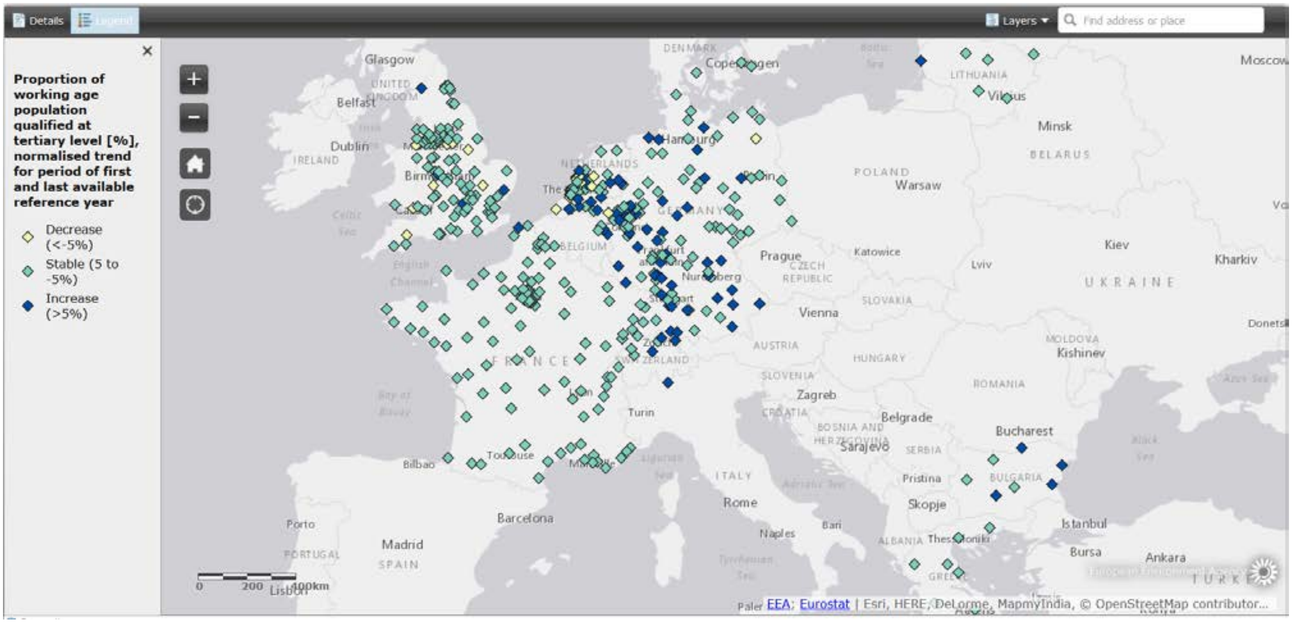
Web link to maps

http://maps.eea.europa.eu/EEABasicviewer/v3/?appid=3ebe4671be9a46fc86a2b16f3d254ac7&webmap=6cd82a9c247d4f8188d3c48daba290e1&embed=false



Map 3.10.1 Proportion of population aged 15 to 64, qualified at tertiary level (ISCED 5-6) for latest available reference year.

[52] See http://ec.europa.eu/eurostat/web/cities/overview online.



Map 3.10.2 Change in proportion of working age population qualified at level 5 or 6 ISCED [%], normalised trend for period of first and last available reference year.

There are cities with high levels of education following tertiary schooling all over Europe. They are somehow less present in South-Eastern Europe. However, data is not available for all countries. Higher education might balance lower income levels and ensure adaptive capacity despite lower economic resources. The disparity in income could potentially be bridged by further developing knowledge exchange programmes and strengthening equity and participatory processes. The EU 2020 Agenda[53] has taken a significant step forward, by setting the target for tertiary graduation rates at an ambitious 40 %.

Large differences can exist within one country: for instance, Hamm (13.1 %) and Erlangen (51.8 %) in Germany. The main industrial branches in Hamm are the coal-mining industry, steel industry, chemical industry and the car component supplier industry. Erlangen is dominated by the University of Erlangen- Nuremberg and the numerous branch offices of Siemens AG, as well as a large research Institute of the Fraunhofer Society and the Max Planck Institute for the Science of Light. These findings suggest that differences in education levels and awareness may arise between declining industrial areas and knowledge-intensive university cities, contributing to a higher response capacity for the latter.

Most cities show a stable (>-5%, < +5%) trend. Increasing trends (>+5%) can mostly be found in cities in Germany, Switzerland, the Netherlands and Bulgaria, while several cities in the UK and the Netherlands show a decreasing trend (<-5%) in education.

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[53] European Commission (2010a), Europe 2020 - A European strategy for smart, sustainable and inclusive growth, Communication from the Commission, European Commission, Brussels (http://ec.europa.eu/eu2020/pdf/COMPLET%20EN%20BARROSO%20%20%20007%20-%20Europe%202020%20-%20EN%20version.pdf)

3.11 Trust

Indicator definition

The share of respondents thinking, generally speaking, that most people in the city can be trusted (synthetic index 0–100), represented in [%] of the total respondents.

Justification of the indicator

The presence of competent and efficient institutions (defined as the formal and informal structures and practices that bind society) can enable adaptation to take place, and reduce the impacts of climate-related risks (IPCC, 2001). Countries that have well-developed and functioning institutions are considered to have a higher response capacity. Well-developed institutions and governance structures not only have the capacity to deal with present-day challenges, but also allow planning for the future.

Social capital has been seen as an elusive but important aspect of institutional adaptive capacity. It refers to the norms and networks that enable people to act collectively. One of the dimensions of social capital is trust, both in other people and in institutions. Thus, it can be seen as an underlying factor of institutional response capacity, relevant for predicting whether communities will act together in facing future challenges of climate change adaptation (Adger, 2003; Adger et al., 2009; Yohe and Tol, 2002).

Higher levels of trust are conducive to good governance, and they increase the probability that city residents will work together to enhance local response capacity.

Methodology

The perception surveys on the quality of life in European cities in 2009 (EC, 2010), 2012 (EC, 2013c) and 2015 (EC, 2016) aimed at measuring local perceptions in selected European cities. The data are based on surveys/interviews of randomly selected citizens. The Flash Eurobarometer survey (No 277) in 2009 included 75 cities, each with 500 randomly selected citizens (aged 15 and older) interviewed. This constituted a representative profile of the wider population; respondents were taken from all areas of the designated cities. In total, more than 37 500 interviews were conducted between 30 October and 10 November 2009. This perception survey included all capital cities of the countries concerned, together with between one and six more cities in the larger countries. Similarly, the Flash Eurobarometer survey (No 366) in 2012 was conducted in 79 cities and 4 areas surrounding big cities, with a total of more than 41 000 citizens interviewed between 15 November and 7 December of 2012 and the Flash Eurobarometer survey (419) was conducted between 21 May and 9 June 2015 in 79 cities and 4 Greater cities involving more than 40.700 interviewees.

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 was then added to the result. The resulting index covers values between 0 and 100. A value above 50 means positive answers predominate; values below 50 mean more negative answers.

Data specifications

EEA data references

None.

External data references

Urban Audit Perceptions Surveys 2009, 2012 and 2015 (EC, 2010, 2013c and 2016). Alongside the Urban Audit data collection, in December 2006, in November 2009, and again in May-June 2015, a perception survey was conducted in 75 cities in the EU-28, in 79 cities in 2012 and 79 cities plus 4 Greater cities in 2015[54].

Uncertainties

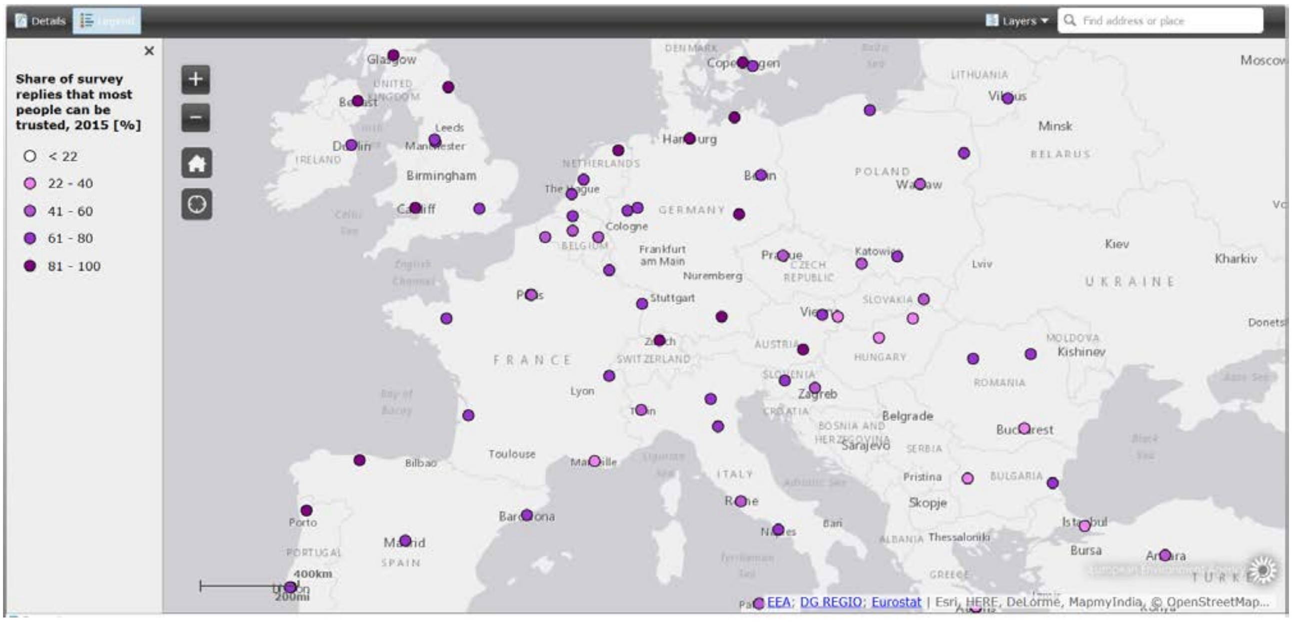
Perceptions of the interpersonal may be affected by multiple factors, and there is uncertainty as to how well perceptions on trust correspond to adaptive actions taken. The link between trust and response capacity is indirect. Similarly, changes in the levels of trust can be affected by many factors, and do not necessarily lead to proportional changes in response capacity.

Indicator assessment

Key question: What is the level of interpersonal trust in European cities with potential for a higher response capacity?

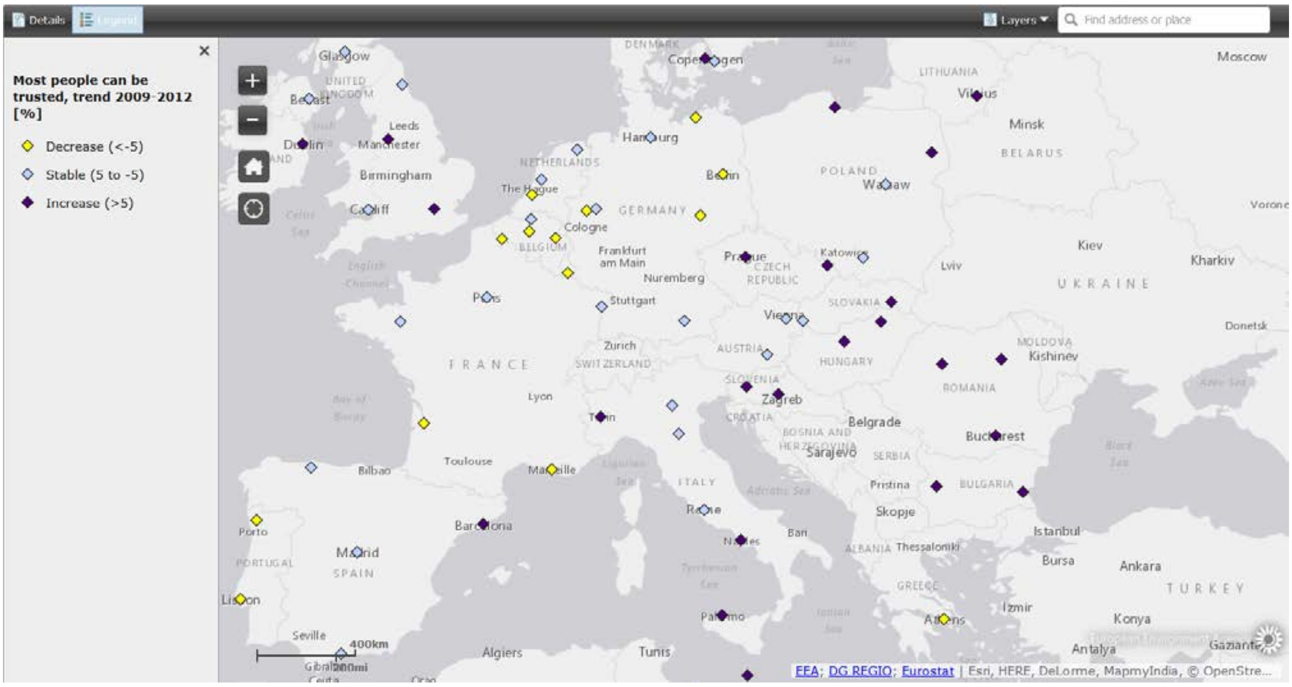
Web link to maps

http://maps.eea.europa.eu/EEABasicviewer/v3/?appid=3ebe4671be9a46fc86a2b16f3d254ac7&webmap=6cd82a9c247d4f8188d3c48daba290e1&embed=false

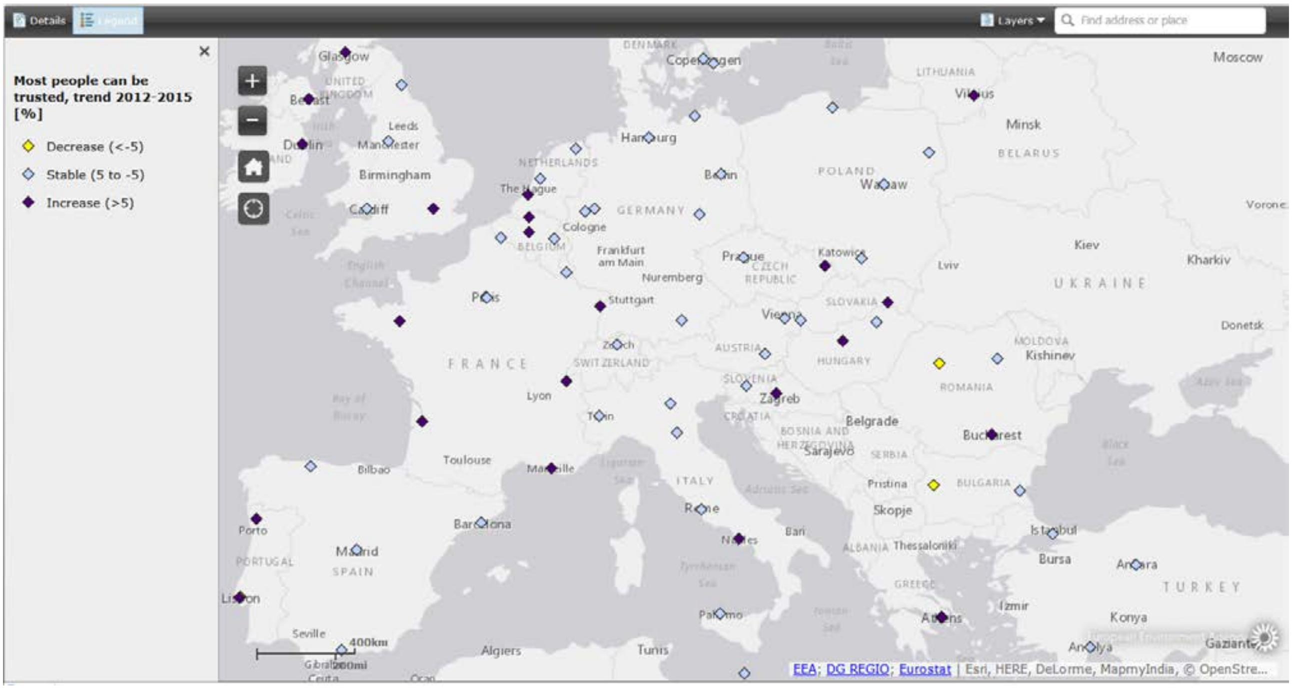


Map 3.11.1 Trust in other people (2015)

[54] See http://ec.europa.eu/eurostat/web/cities/overview online.



Map 3.11.2Trust in other people (trend in percentage, 2009–2012)



Map 3.11.3 Trust in other people (trend in percentage, 2012–2015)

In all perception reports v from 2009 to 2015, cities in Germany, Austria, the Benelux and Scandinavian countries score particularly high on indicators relating to the qualifications of the population and social trust. With respect to the latter criterion, especially Scandinavian countries score well, . In On the other side, The survey of 2015 showed that in a large majority of the cities (69 out of 89), at least 50 % of respondents agreed that people can be trusted in their city. In 16 cities, this number exceeded 80 %, notably in Aalborg (91 %), Oulu (92 %), Groningen and Oviedo (both 88 %). Of the 6 Nordic cities included in the scope of the survey, 5 recorded more than 80 %, the exception being Malmo (71 %). On the opposite side of the ranking, several capital cities of eastern European countries are found, including Athens, Sofia, Bucharest, and Budapest, but also Marseille only between 30 and 40 % of the interviewees agreed that and most people living in their city could be trusted. Cities like Prague (42%), Warszawa (45%), Rome (47% and Paris (49%) follow closely up to this group in 2015.

With respect to changes from 2012 to 2015, the majority of cities in Europe show low variations in social trust, suggesting that the patterns are relatively stable over time. However, some high-ranking cities have seen slightly negative trends: Aalborg (− 2 %), Oviedo (− 2 %), Helsinki, Groningen and Muenchen (– 3%) while some of the cities with negative trends between 2009 and 2012 have regained in trust, like Brussels (+23%) and Berlin (+6%) and some of the lowest ranking cities are among those which show the highest increases in trust as Athens (+ 69%), Budapest and Bucharest (+20%) and Marseille (+ 19%).

3.12 City commitment

Indicator definition

The share of respondents agreeing somewhat or strongly that their city was committed to fight climate change, represented as synthetic index [0-100].

Justification of the indicator

The indicator is based on the assumption that awareness of the issues of climate change leads to a greater chance of action not only 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. Also, the climate change agenda in cities has expanded from mitigation to adaptation, and the two are increasingly addressed in parallel. A global survey among cities in the ICLEI network 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 (Carmin et al., 2012).

Similar percentages have been reported in an EU survey on cities, with 70 % reporting adaptation measures, even if most of these are in the 'early stages of adaptation' (AEA, 2012).

Methodology

The perception survey on the quality of life in European cities for the years 2009, 2012 and 2015 (EC, 2010, 2013c, 2016) aimed at measuring local perceptions in 79 cities in the EU. The data are based on surveys/interviews of randomly selected citizens.

The information is provided as a '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 was 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.

Data specifications

EEA data references

None.

External data references

Urban Audit Perceptions Surveys 2009, 2012 and 2015 (EC, 2010, 2013c, 2016) Parallel to the Urban Audit data collection, perception surveys were conducted in 79 cities in the EU-28[55].

Uncertainties

Perceptions of local government may be affected by multiple factors, and there is uncertainty as to how well perceptions on local climate action correspond to actions taken. The indicator does not differentiate between adaptation and mitigation of climate impacts. The data rely on perception surveys, where uncertainties may exist with respect to evaluating climate change commitments of local actors as opposed to perceptions derived from other local government actions.

Indicator assessment

Key question: To what extent are the local authorities committed to fight climate change?

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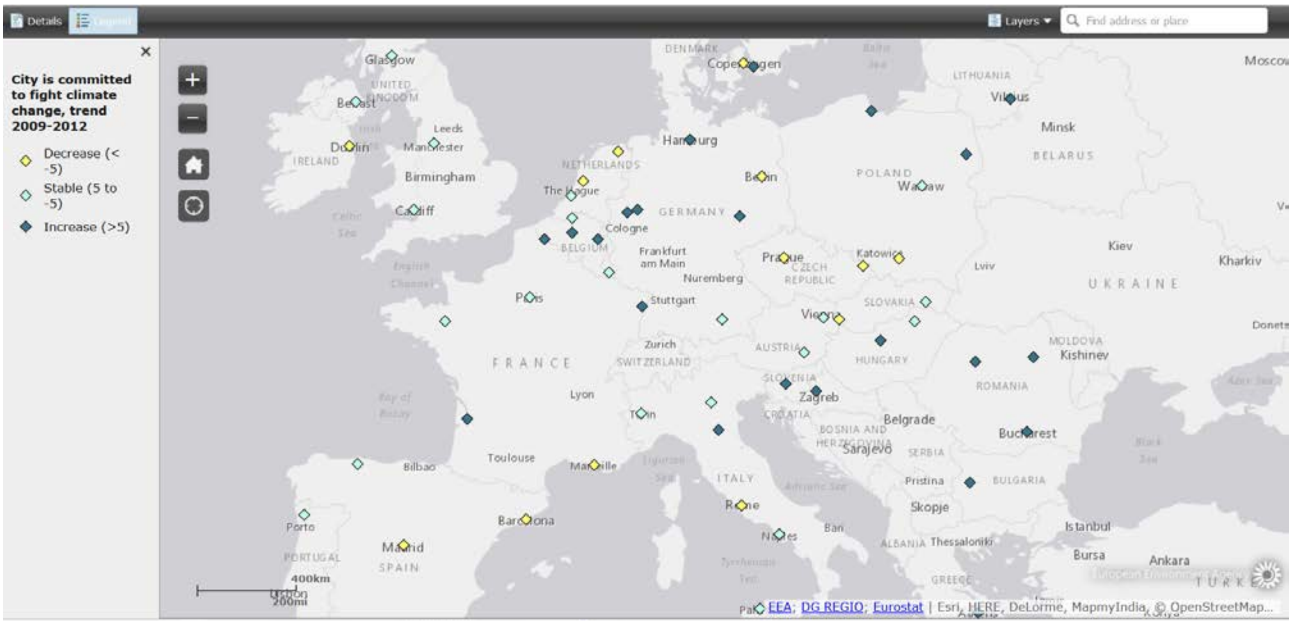
[55] See http://ec.europa.eu/eurostat/web/cities/overview online.

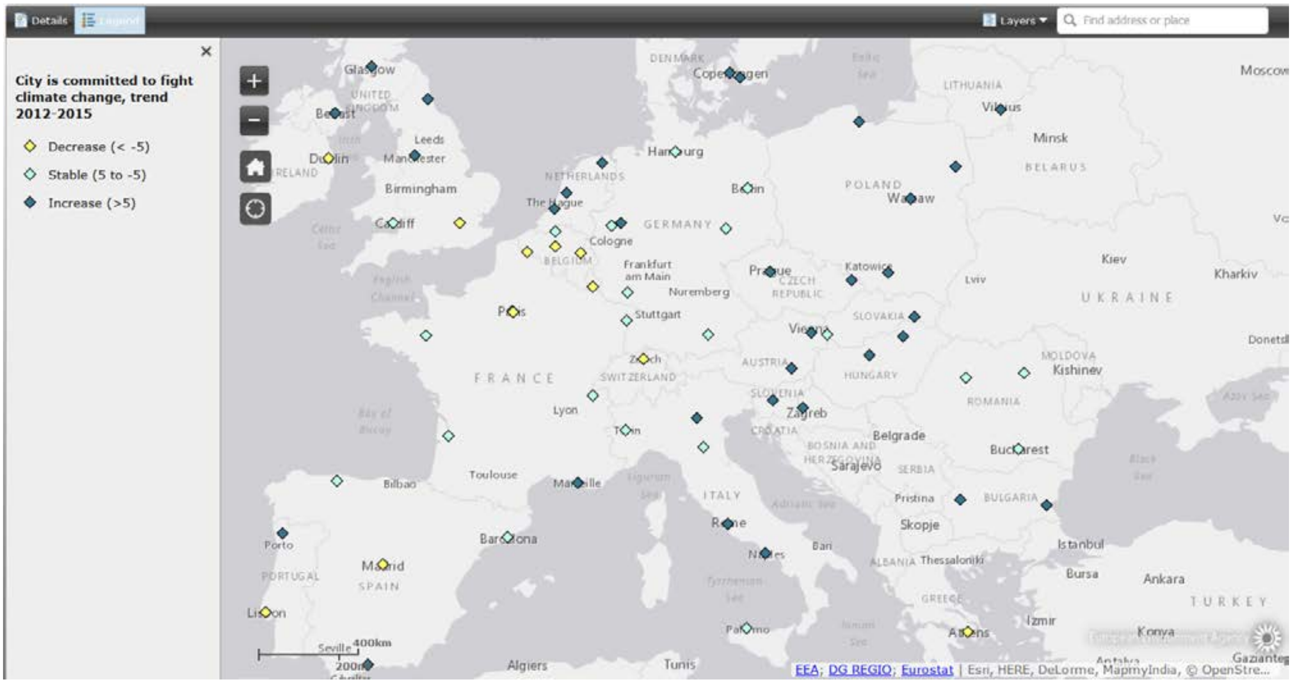
Web link to maps

http://maps.eea.europa.eu/EEABasicviewer/v3/?appid=3ebe4671be9a46fc86a2b16f3d254ac7&webmap=6cd82a9c247d4f8188d3c48daba290e1&embed=false

Map 3.12.1 Synthetic Index based on survey replies: City is committed to fight climate change (2015).



Map 3.12.3 Perception of the city population that authorities are committed to fight climate change (trend change in percentage 2009–2012).



Map 3.12.4 Perception of the city population that authorities are committed to fight climate change (trend change in percentage 2012–2015).

The cities where most citizens feel that their administration is committed to fighting climate change are predominantly located in western and northern Europe. Even if trends are negative in some western countries, overall, awareness-raising activities are expected to have more effect when they target eastern and southern countries.

In 2009 the proportion of respondents who somewhat or strongly agreed that their city was committed to fight climate change (e.g. by promoting eco-friendly means of transport) ranged from 19.2 in Sofia to 82.7 in Bordeaux. Munich, Rennes, Newcastle and Luxembourg joined Bordeaux at the higher end of the ranking (between 78.7 and 80.7), while Burgas and Palermo joined Sofia at the lower end (31 and 31.8 respectively). Considerably less variation was observed in the proportion of respondents who strongly agreed that their city was committed to fighting climate change — in the majority of cities in this study, between one-tenth and one-fifth of respondents expressed strong agreement.

In 2012, when asked about their city's commitment to the fight against climate change, a majority of respondents in almost two-thirds of the cities surveyed (54 of 83) agree with this statement (index >50.0). In 9 cities, the level of agreement is at least 75.0. The highest agreement rates are in Bordeaux, Zurich (both 83.0), Strasbourg (82.0) and Luxembourg (79.5). In 7 cities, the level of agreement is below 40.0. The lowest agreement rates are in Rome (33.0), Palermo (35.0) and Prague (37.5).

In the 2015 survey (field data of 2014), over 80% of the cities surveyed (67 out of 80) agree about their city's commitment to the fight against climate change (index >50.0). In 18 cities, the level of agreement is at least 75.0. The highest agreement rates are in Malmö (87.5), Bordeaux (83.7), Strasbourg (83.5) and Rostock (81.9). In 6 cities, the level of agreement is below 40.0. The lowest agreement rates are in Madrid (32.3), Palermo (34.4) and Riga (35.6).

The 2009-to-2012 trend of people's perception of the fight against climate change shows some interesting cases, representative of the different groups of trends and geographical areas in Europe. Comparing this survey with the indicator 'Most people can be trusted', reveals that some cities are in the same group of trends. Sofia is in the positive trend (+ 54.1), Munich is in the equal group (+ 0.1), and Marseille is in the negative trend (− 26.9).

The 2012-to-2015 trend in many cities shows opposite trends compared to the 2009-to-2012 trend. For instance, Prague changed from - 32.7 in the2009-to-2012 trend to + 30.1 in the 2012-to-2015 trend. On the other hand, Istanbul changed from + 35.3 in the2009-to-2012 trend to - 28.4 in the 2012-to-2015 trend.

Trends in the perception that local authorities are fighting against climate change show some improvement for cities at the lower level, like Sofia (that more or less doubled its score between 2009 and 2015). This warrants further research, but may suggest a phenomenon of 'take-off' in countries where climate change has not been on the agenda to date. On the other hand, where Madrid changed from 52.8 in 2009 to 32.3 in 2015, Burgos changed from 37.8 in 2009 to 77.3 in 2015, which suggests an important influence from individual cities in raising climate change awareness.

3.13 Cities engaged in initiatives

Indicator definition

A range of initiatives exist to address the environmental challenges that cities face through networking and competition between cities. This indicator shows the number of initiatives aiming at improving climate- (both adaptation and mitigation, including e.g. energy neutrality) and environment-related measures that a city is engaged in. Initiatives included in the indicator are: Mayors Adapt - Covenant of Mayors for Climate and Energy[56], Compact of Mayors[57], C40 with adaptation action[58], Making Cities Resilient (United Nations Office for Disaster Risk Reduction, UNISDR)[59], European Green Capital Award (EGCA)[60], European Green Leaf (EGL)[61], Metropolis no regret[62], and Rockefeller 100 resilient cities[63].

Justification of the indicator

The indicator is based on the assumption that cities that are involved in one or more initiatives are more aware of the issues of climate change, which leads to a greater chance of action not only on climate mitigation but also on adaptation. Moreover, being involved in an initiative entails being involved in events and platforms that further the exchange of knowledge, lessons learned and good examples that will support cities in developing their own climate strategies.

Methodology

For a number of European cities and municipalities, the database contains binary values on the engagement in the eight above-mentioned climate-, energy- and environment-related initiatives ("1" if they are engaged, "0" if they aren't) by the end of 2015. However, the European Green Capital Award on the one hand and the European Green Leaf on the other are mutually exclusive as the former applies to cities above 100.000 inhabitants whereas the latter addresses cities and towns with between 20.000 and 100.000 inhabitants. Moreover, the database only contains cities that are engaged in at least one initiative. By consequence, on the map (i.e. Map 3.13.1) the values (i.e., the sum of the single binary values) range from 1 to 7 as the maximum possible.

Map 3. 13.2 below presents a subset of the cities and municipalities that are engaged in the EU Mayors Adapt initiative. Map 3.13.3 is again another subset of cities and municipalities that are engaged in the UNSIDR initiative "Making Cities Resilient".

Data specifications

EEA data references

None.

External data references

Data of Mayors Adapt and Making Cities Resilient (UNISDR) are received from the secretariats directly. Data for the other initiatives are derived from the respective websites.

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[56] See http://mayors-adapt.eu/ online.

[57] See www.compactofmayors.org online.

[58] See http://www.c40.org/networks/climate_change_risk_assessment online.

[59] See http://www.unisdr.org/campaign/resilientcities online.

[60] See http://ec.europa.eu/environment/europeangreencapital/ online.

[61] See http://ec.europa.eu/environment/europeangreencapital/europeangreenleaf/ online.

[62] See http://www.circlesofclimate.org online.

[63] See http://www.100resilientcities.org online.

Uncertainties

The level of adaptation activity in the cities engaged in these initiatives can vary substantially, but they all have to comply with the minimum standards of the respective initiative. Further, cities may be very active in adaptation efforts without being involved in one of the European or international initiatives included in this indicator.

Some initiatives are closer related to adaptation (e.g., Mayors Adapt) and others only in a wider and less comprehensive way (e.g., Making Cities Resilient).

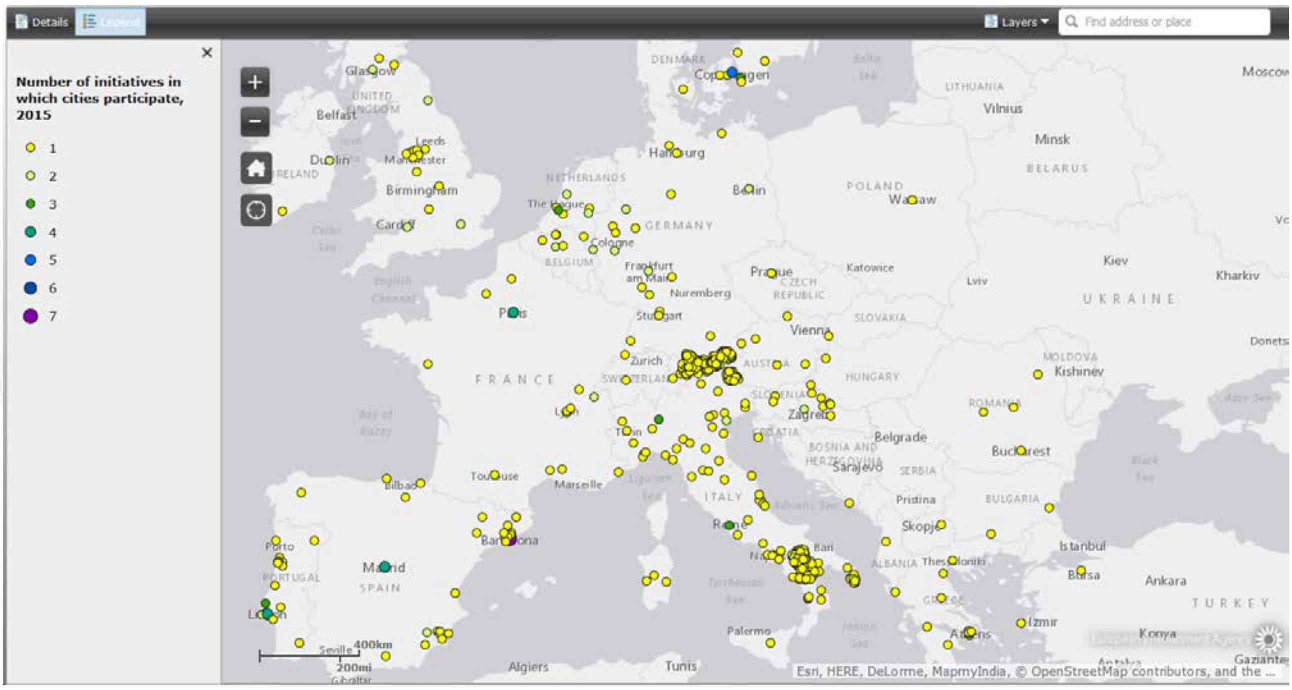
Several of the smaller municipalities could not be geographically located by any of the spatial databases available and did also not have metadata with coordinates attached to them. It was therefore necessary to extract Lat/Lon information from Wikipedia. Despite of this internet based coordinates search, two municipalities could not be located: Povera (IT) and Platten (AT). Consequently, those municipalities are not displayed on the map.

Indicator assessment

Key question: To what extent are the local authorities committed to be engaged in climate change adaptation and mitigation initiatives?

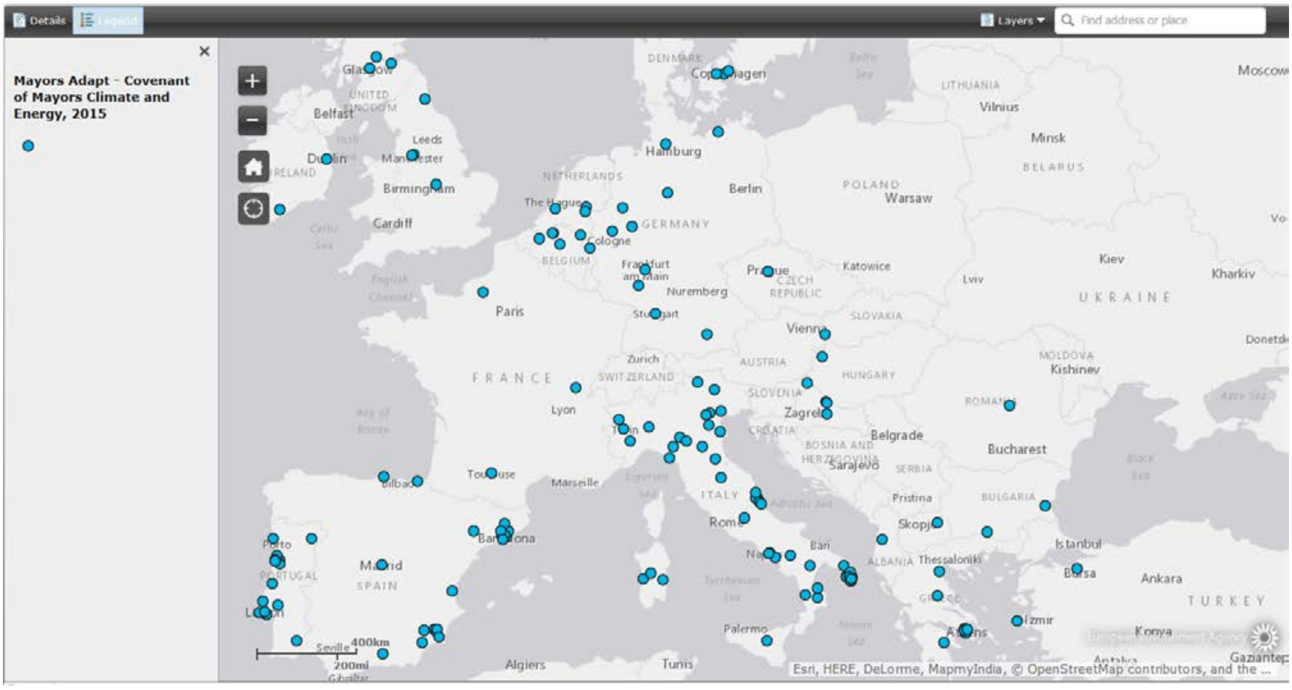
Web link to maps

http://maps.eea.europa.eu/EEABasicviewer/v3/?appid=3ebe4671be9a46fc86a2b16f3d254ac7&webmap=6cd82a9c247d4f8188d3c48daba290e1&embed=false



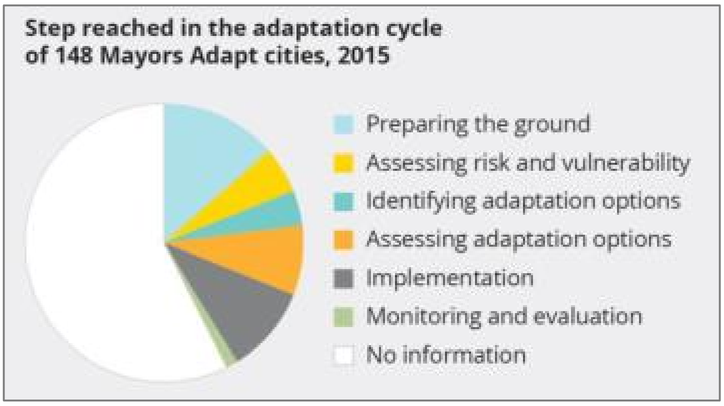
Map 3.13.1 Participation of European cities in European and global city initiatives related to adaptation (2015)

Most of the European cities included in the Map 3.13.1 are committed to one initiative, mostly the Mayors Adapt - Covenant of Mayors for Climate and Energy (many in, a.o., Belgium, Greece, Italy and Spain)(Map 3.13.2) or Making Cities Resilient (many in, a.o., Austria and Italy)(Map 3.13.3). A substantial number of cities is committed to two initiatives in differing combinations; only few are committed to three or more initiatives. Only Barcelona is committed to all seven initiatives.

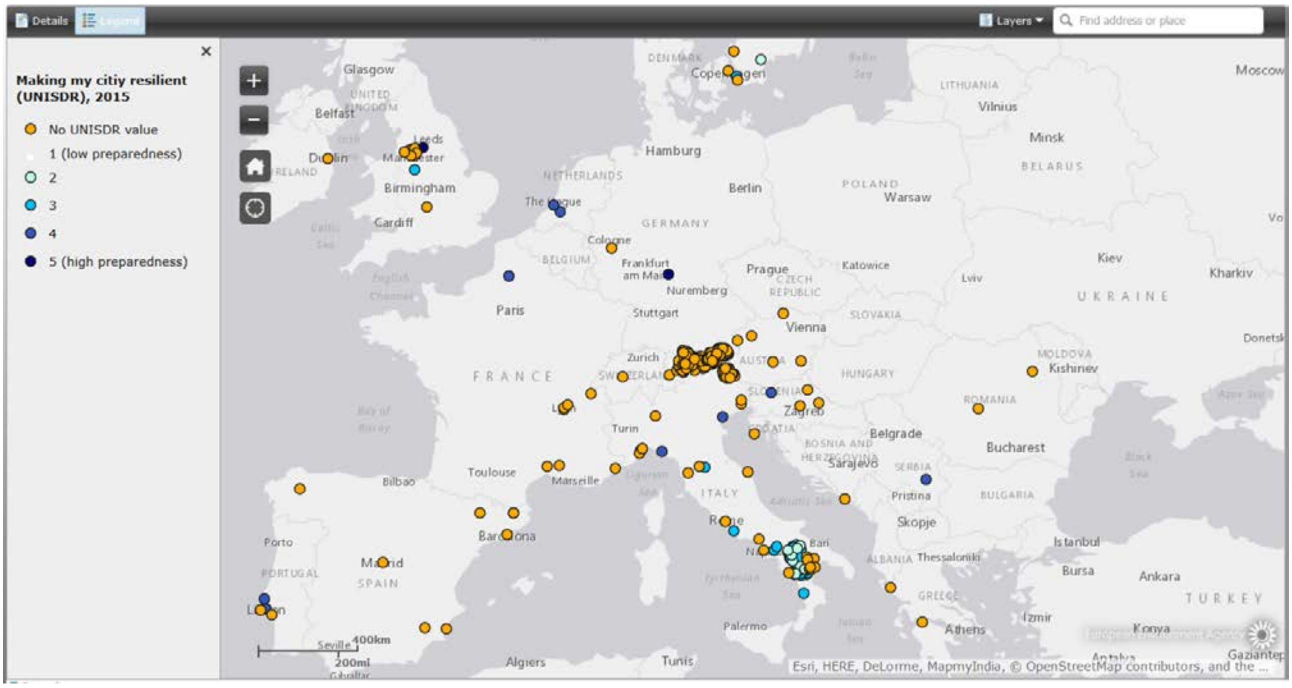


Map 3.13.2 Examples of urban adaptation activities: cities committed to adaptation action in Mayors Adapt / the Covenant of Mayors Climate and Energy (2015)

Since 2014, around 150 cities have committed themselves to taking adaptation action by signing up to the EU Mayors Adapt initiative by the end of 2015. The signatory cities either develop a comprehensive adaptation strategy or integrate climate change adaptation into relevant existing plans. Mayors Adapt follows the model of the Covenant of Mayors, which has become the key European initiative on urban mitigation action, with more than 6 700 signatories. In October 2015, the initiatives merged as a new Covenant of Mayors for Climate and Energy. The new covenant is open to non-European cities too and builds upon the success of the two original initiatives.

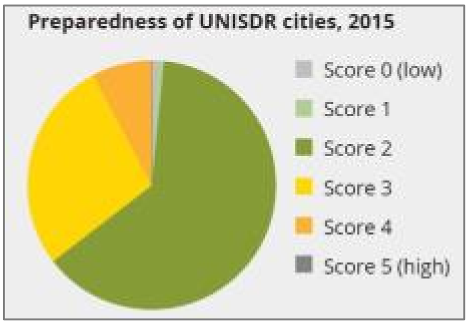


A high proportion of Mayors Adapt signatories have not yet developed an adaptation strategy or have not yet provided any information (www.mayors-adapt.eu/).



Map 3.13.3 Cities participating in the UNISDR initiative Making Cities Resilient that have reported on the 10 Essentials (2015)

The global "Making Cities Resilient" campaign addresses issues of local governance and urban risk. Local governments are the closest level to the citizens and to their communities and local government officials are faced with the threat of disasters on a daily basis and need better access to policies and tools to effectively deal with them. The campaign is seeking to convince city leaders and local governments to commit to a checklist of Ten Essentials for Making Cities Resilient and to work alongside local activists, grassroots networks and national authorities. In 2015, 2551 cities globally are committed to the Campaign. The second phase that started in 2016 is dedicated to implementation. The Campaign now aims to ensure that the commitments made by governments are integrated into the local context.



Of the 470 European cities (EEA member countries) participating in UNISDR's Making Cities Resilient campaign, only 118 have provided a 10 Essentials report[64] by the end of 2015. The majority of those score 2 out of 5 on their average level of disaster risk preparedness. If the availability of a report indicates how seriously cities are taking the process, then few regions seem to be particularly active (Map 3.13.3). Cities in a few regions in Italy and Austria are in particular active.

[64] See www.unisdr.org/files/26462_13.tenessentialschecklist.pdf online

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Annex: Definition of the city and the city's urban area

1. INTRODUCTION

This annex describes the methodology with which the spatial reference unit for the production of many of the urban vulnerability indicators presented in the report have been computed.

There are two ways to delineate a city boundary: (i) with the administrative 'city' or 'greater city' (where available) used as an approximation of the city in the Urban Audit[65], and (ii) with the urban morphological zones (UMZ) produced for the EEA[66]. While the Urban Audit city/greater city is the administrative reference unit for many socio-economic indicators (with all the known weaknesses that administrative boundaries have when it comes to European comparisons, e.g. different scales), the UMZs better reflect the physical outlines of the cities.

To take advantage of both reference units (accepted and coded reference for European socio-economic indicators on the one hand, and the better representation of the real city boundary on the other hand), both data sets have been combined by applying GIS geoprocessing techniques. Input data, workflow and results are presented in the paragraphs below.

2. INPUT DATA SETS

As mentioned in the introduction, the two input data sets are:

- The city/greater city layer from the Urban Audit;
- the UMZs.

For most cities the boundary used in the Urban Audit corresponds to the general perception of that city. In most countries, the city/greater city corresponds to the level LAU2.

An UMZ is defined as 'a set of urban areas laying less than 200 m apart'. Those urban areas are defined with land cover classes contributing to the urban tissue and function. For the reference year 2006, UMZ are derived from CORINE Land Cover (CLC) by using urban core classes (residential, industrial and commercial, green urban areas) and adding enlarged core classes if they fulfil certain neighbourhood conditions of the core classes. A new version of UMZ has been produced recently by the ETC-ULS which is based on Urban Atlas data from 2012, this to make the UMZ boundaries more precise due to the better resolution of the Urban Atlas data. However, at the time of producing the maps only around two third of the Urban atlas 2012 cities were produced. Therefore, the UMZ coverage is incomplete and has not been used for all applicable indicators in the context of this study. The production is, in principle, identical to the one for the CLC-based UMZ.

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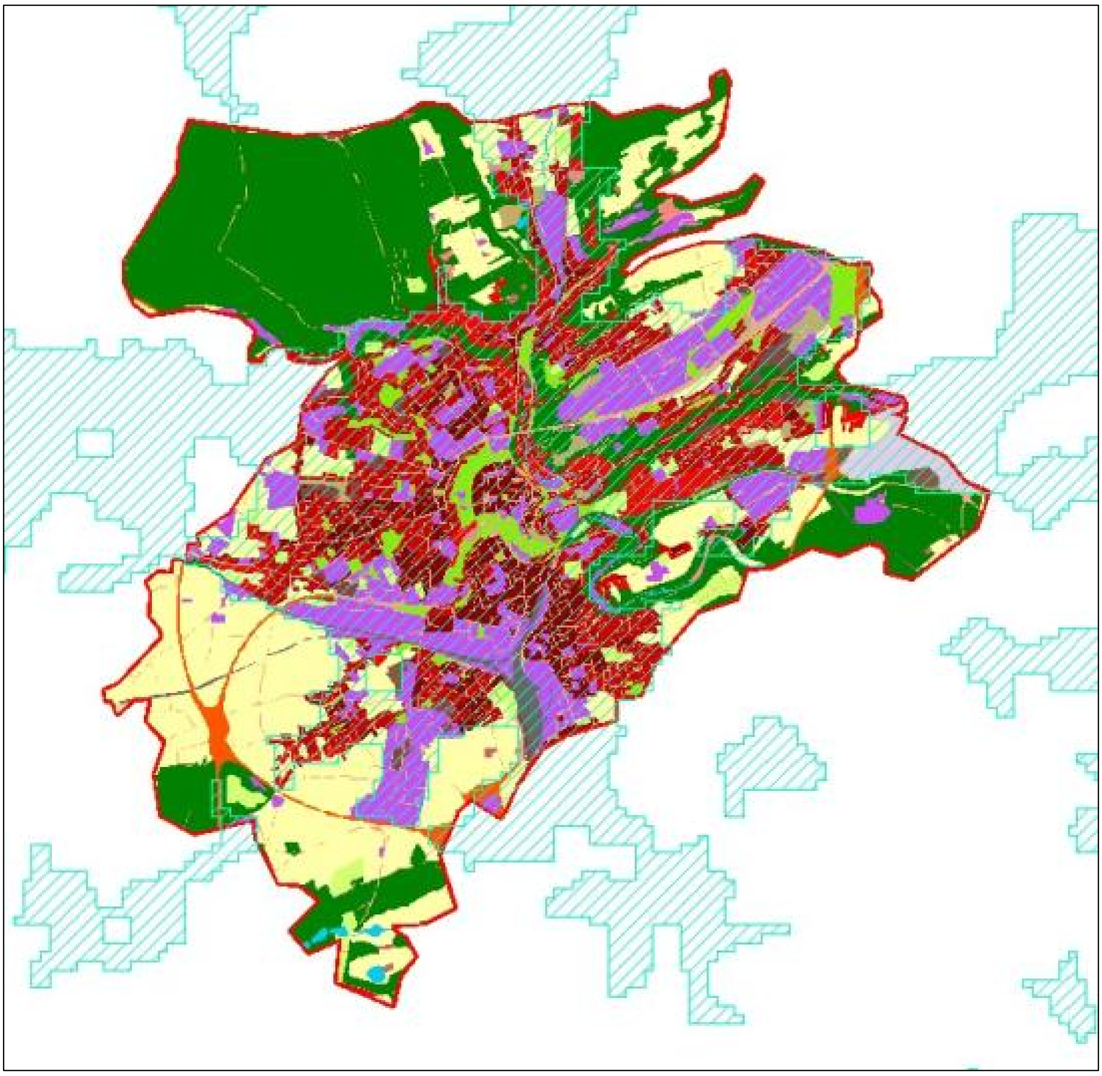
[65] See *http://ec.europa.eu/eurostat/web/cities/spatial-units* online.

[66] See *http://www.eea.europa.eu/data-and-maps/data/urban-morphological-zones-2006-1* online

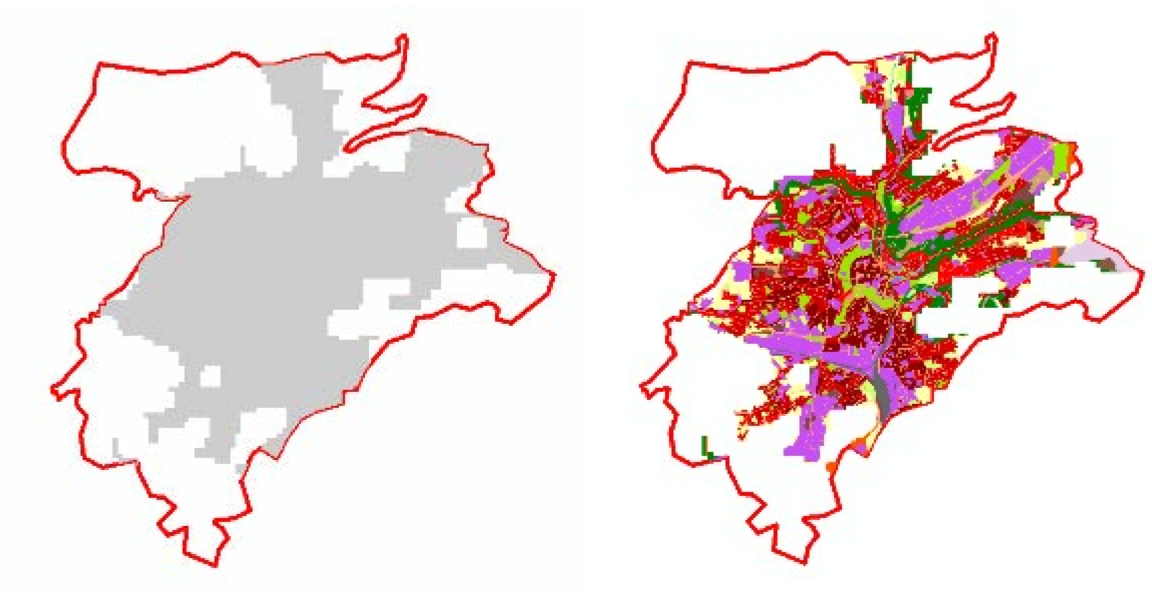


Map A1.1 Urban Atlas map of the city of Luxembourg, UMZ objects on top in cyan-coloured hatching

3. PROCESSING

Both data sets are available as shape files. First, both data sets are overlaid, and subsequently, the UMZs, which contain many more objects than the city/greater city layers, are clipped by the outlines of the cities or greater city defined in the Urban Audit database. The result is an UMZ layer that only contains those UMZ objects that are located within the cities/greater city. UMZ objects that cross the city/greater city boundaries are cut off along the borders. The last processing step is the creation of one UMZ per city/greater city, so that all UMZ objects located within the city/greater city become one object (they are logically rather than physically connected, i.e. they possess only one object ID).

These objects build the basic spatial reference unit for the computation of further indicators, in particular for extraction of the Urban Atlas information. This spatial unit is called the '*city's urban area'* here.



Map A1.2 Workflow illustration; city of Luxembourg in red (left), containing UMZs located inside the city in grey; the resulting Urban Atlas map of the city's urban area (right)

Data sources:

UMZ_v15_2006 Urban Morphological Zones 2006 (EEA) - http://www.eea.europa.eu/data-and-maps/data/urban-morphological-zones-2006-1

Urban Audit database (Eurostat) - http://ec.europa.eu/eurostat/web/cities/overview

Urban Atlas (EEA) - http://www.eea.europa.eu/data-and-maps/data/urban-atlas