Assessing Adaptation Knowledge in Europe: Infrastructure Resilience in the Transport, Energy and Construction Sectors

Final Report
European Commission
DG CLIMA

Assessing Adaptation Knowledge in Europe: Infrastructure Resilience in the Transport, Energy and Construction Sectors
Final Report

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Contributions from Roger Street, UKCIP

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<td>CENELEC</td>
<td>European Committee for Electrotechnical Standardization</td>
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<tr>
<td>DIVA</td>
<td>Dynamic Interactive Vulnerability Assessment</td>
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<td>DKK</td>
<td>Danish kroner</td>
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<td>DOT</td>
<td>Department of Transportation</td>
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<td>DSO</td>
<td>Distribution system operator</td>
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<td>EAD</td>
<td>Expected annual damage</td>
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<td>EbA</td>
<td>Ecosystem-based adaptation</td>
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<td>EC</td>
<td>European Commission</td>
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<td>EEA</td>
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<td>EUFIWACC</td>
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<td>GCM</td>
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<td>HDD</td>
<td>Heating Degree Days</td>
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<td>ICT</td>
<td>Information and communications technologies</td>
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<td>Intergovernmental Panel on Climate Change</td>
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<td>Information Technology</td>
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<td>JASPERS</td>
<td>Joint Assistance to Support Projects in European Regions</td>
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<td>LCM</td>
<td>Loosely couple models</td>
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<td>Land Use and Land Use Change</td>
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<td>MCA</td>
<td>Multi-criteria analysis</td>
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<td>MS</td>
<td>(EU) Member State</td>
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<td>Multi sector partnerships</td>
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<td>O&amp;M</td>
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<td>RES</td>
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<td>SEA</td>
<td>Strategic Environmental Assessment</td>
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<td>SRES</td>
<td>Special Report on Emissions Scenarios</td>
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<td>SUDS</td>
<td>Sustainable urban drainage systems</td>
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<td>TSO</td>
<td>Transmission system operator</td>
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<td>UIAF</td>
<td>Urban Integrated Assessment Facility</td>
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<td>WSUD</td>
<td>Water sensitive urban drainage</td>
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Executive Summary

Aim and scope

For the purposes of this project, the infrastructure sector comprises of the Transport, Energy and Construction sectors. The exact scope within these three sectors was developed together with DG CLIMA, is summarised below:

Energy sector: the focus is on electricity and renewable energy systems (solar, hydro, off-shore and on-shore wind); comprising generation, transmission and distribution. Whilst it was agreed that energy services and demand would not be included in the assessment, we have identified where sources highlight the particular importance of changing energy demand in light of climate change.

Construction sector: includes construction, deconstruction and renovation of the physical infrastructure of the buildings sector. The emphasis is placed on the building’s surfaces (e.g. roofs and facades), structural and integrated building design. The scope excludes behavioural and societal aspects of climate change adaptation.

Transport sector: the focus is on transport infrastructure covering ports, airports, rail, and roads, with an emphasis on railroad tracks, airport terminals, runways, and taxiways as well as roads (including bridges and tunnels) in particular. Whilst is was agreed that the scope excludes inland and marine shipping, we have identified where sources highlight the particular importance of the impacts of climate change on inland waterways, for example, where this constitutes a hotspot. The scope excludes vehicles and vessels, air traffic control and weather monitoring.

For each sector the following questions were the subject of the project study:

1. What (climate) data is available and needed for the assessment of climate impacts?
2. What information is available in terms of vulnerability and risk assessments?
3. What adaptation options are used in the infrastructure sector?
4. What decision-making tools, methodologies and mechanisms are used to address these climate impacts and vulnerabilities?
The analysis in this report is a result of having assessed over 185 sources (online: both within Climate-ADAPT and beyond, including some sources unpublished at the time of writing: December 2016); resources focused on European coverage mainly, but also include some national publications within Europe and publications with a global, US or Australian focus. Expert consultation was undertaken throughout the project1; assessment of the sources was broad in nature, plotting information where possible against various descriptive criteria selected by the project team. In some cases the project team made an estimation2 of the type of approaches taken, or climate scenarios used, for example.

**Findings related to the infrastructure sector as a whole:**

**Available climate data compared to infrastructure data needs:**

- Tools such as the Climate-ADAPT Map Viewer are potentially useful resources for practitioners wishing to access climate data from multiple projects: it combines into one map the climate projections from a number of different research projects. This type of tool goes a long way to overcoming accessibility requirements of individual data sources. 43% of the data sources assessed appear to offer the ability to address tailored requests by the user to varying degrees, such as in the form of interactive maps, which is the most common feature.
- 37% of the data sources assessed enable users to access both observed impacts as well as projections; observed climate data can help the infrastructure sector understand the nature of past and current vulnerabilities.
- Where information is available regarding the resolution levels for observed and projected data sources, the majority of observed climate data is available at 1-9km resolution; regarding data sources containing climate projections, the spatial resolution level information is not always available, however some maps which use climate projections data appear to be also at high resolution (1-9km), and an equal number of climate projections data is available at 50-99km resolution. This reflects one of the biggest challenges: users of projected climate data need high resolution projections data, sometimes below 1km which can be beyond the current boundaries of climate modelling.
- Climate datasets and data sources cover precipitation and temperature most frequently, which reflects users’ needs for these climate variables in particular, over other climate variables.
- Climate data requirements needs to be considered alongside other types of non-climate data3 which are equally relevant to undertaking vulnerability and risk assessments.

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1 Discussion with sector experts at events including Adaptation Futures Conference, Rotterdam May 2016; International Transport Forum 2016 Summit, Leipzig, May 2016; Mayors Adapt Information Event on urban adaptation, September 2016; in-depth interviews were undertaken with Dr Athanasios Sfetsos, National Centre for Scientific Research “Demokritos” EU-CIRCLE; Professor Alan McKinnon, Kühne Logistics University Hamburg; Craig Davies, Senior Environmental Advisor, EBRD.

2 Assessments of each source have not been validated by source authors and in some cases, descriptive inaccuracies may occur. When evaluating the sources, there is always the risk of misinterpretation as in some cases the assessment is subjective, or assessment information required is not described in the source assessed. To undertake the assessment, common guidance was developed for the team and then applied by two assessors and triple checked where necessary.

3 Non-climate data requirements include: age of relevant infrastructure; materials used for current infrastructure / building stock; information on land-use and land-use change; increase interconnectedness and dependencies therein of infrastructure systems; elevation models; urbanisation trends and GDP projections, amongst others.
**Information regarding of vulnerability and risk assessments:** There are different interpretations of these terms that exists across the infrastructure sector, which can be a source of confusion. The EC Guidelines for Project Managers: Making vulnerable investments climate resilient (DG Climate Action, 2011) helpfully provides guidance for project managers on how to make vulnerable investments resilient to climate change.

**Projected costs of impacts of climate change on infrastructure sector:** caution should be applied when comparing any numbers relating to all projected damage costs, due to the 'variations in practices among studies...whether results are reported for the impact of climate change and socio-economic change together, the effects of climate change alone above future socio-economic change, or the effects of future climate change on current socio-economic conditions. There are...major issues with reporting and adjustment of economic values in different time periods, whether future values are presented as discounted or present values". A recent study by the JRC suggests that 'damages from climate extremes to critical infrastructures...will be highest for the industry, transport and energy sectors, which are projected to face a 15-fold increase in economic damages with greater losses in Southern and South Eastern European countries. Implementing adaptation strategies within these critical infrastructure sectors 'can offer impressive prospects for increasing...resilience'.

**Adaptation options and innovation:** In terms of adaptation options discussed, grey measures of dam, coastal and river defence are common to all sectors, whilst other grey measures vary according to sectors. The role of cross-sector collaborative working and the cogeneration of tools to help the sector adapt comes up repeatedly in order to fill knowledge gaps. This type of working can be facilitated by EU and nationally funded research projects. A variety of visualisation and collaborative decision making tools are being designed and implemented in the US as well as the EU to aid collective decision making processes and facilitate collaborative working on adaptation.

**Recommendations relating to knowledge gaps:** the main focus of this report is on assessing currently available knowledge, however key recommendations and areas for further research have been developed to address the knowledge gaps on understanding and implementing adaptation within the infrastructure sector that emerged from this study. Where knowledge gaps and subsequent recommendations relating to each question apply to the infrastructure sector as a whole, these are dealt with in Chapter 6, otherwise they are listed in the relevant sector chapter.

**Findings related to the energy sector:**

**Available climate data compared to infrastructure data needs:** Information on projected impacts of climate change on electricity generation is very fragmented. Whilst effects of extreme events can be easier to detect, the effect of long-term climate change can be difficult to determine due to changes in technical, social, behavioural and economic aspects. There is a particular need for climate information relating to all extreme weather events to inform energy infrastructure resilience. Regarding renewable energy generation, depending on the energy type, climate change can have both positive and negative impacts on energy output.

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*Climate change, impacts and vulnerability in Europe, European Environment Agency, 2012*
Vulnerability and risk assessments: roughly half of the sources covering the energy sector focus on vulnerability assessments (52%), while 35% of sources focus on risk assessments, and the remaining 13% discuss both risk and vulnerability assessments. In addition to negative impacts of climate change on the energy sector, positive impacts are also described with regards to renewable energy generation and reduced winter maintenance regimes, such as snow and ice removal from energy infrastructure.

Hotspots for the energy sector include:

- Southern and Western Europe: flooding along the coastline and floodplains, as well as risk of damage to turbines due to sea-level rise and storm surges; droughts, lower river flows in summer and higher river water temperatures will impact hydropower and water cooling resources.
- Mountainous areas throughout Europe: Infrastructures will be threatened by geological instability owing to increased precipitation; for hydropower production and the cooling of power plants, maximum accumulated snow water equivalent may decrease by up to 78% (Germany, Austrian, Swiss and Italian border regions).
- Urban areas: are cited throughout the sources assessed, given the dense electricity networks and dependent assets in larger urban areas. One study identified hotspots are typically located around the periphery of urban areas rather than the centres where several critical infrastructures are concentrated in one location.

Adaptation options: In terms of structural measures, grey measures such as flood defences to manage coastal, fluvial and pluvial flooding are most frequently identified and of the EbA measures, those measures that mainly provide a water management function are also frequently discussed, which reflects the hotspots identified. Other grey measures discussed include increasing the network capacity through the installation of additional storage facilities, so that the system can manage more frequent extreme weather events with higher base load volatility. Infrastructure strengthening is mentioned particularly in the context of increasing the robustness of transmission grids.

Mechanisms prompting the energy sector to adapt: legislation is the mechanism discussed the most frequently as prompting the energy sector to adapt; in response to EU legislation or national reporting requirements on climate resilience, new related industry-wide standards have also been developed.

Findings related to the transport sector:

Available climate data compared to infrastructure data needs: Transport sector climate data needs vary the most in terms of the range of timeframes required for observed and projected data. The need to recognise the changing nature of climate hazards and how they behave is identified as a key challenge in this sector, especially with regards to flash flooding in mountainous regions for example. Such events can result in substantial damages which were not expected, even after having taken account of climate projections.

Vulnerability and risk assessments: the majority of sources assessed discuss vulnerability assessments (56%), followed by risk assessments (21%), and a minority of discuss both risk and vulnerability assessments (23%). In some cases where there are multiple actors and organisations working together to undertake assessments at one location, the decision to undertake a vulnerability assessment over a risk assessment is prioritised.
**Hotspots for the transport sector:**

› Areas of highly centralised traffic patterns: concentrating traffic through a smaller number of hubs can exacerbate vulnerability; the market for just-in-time services drives increasing centralisation, making these systems particularly vulnerable.

› Inland waterways: that are already drought sensitive, where reduced water levels will not offer sufficient draught protection; projections suggest that this may become more important beyond 2050.

› Road, rail: the angle of repose of slopes either side of road/railway networks in the case of avalanches, landslides; in mountainous regions transport networks are expected to be most vulnerable to intense rain and snow. Roads are vulnerable to flooding particularly in Central and northern Europe.

› Ports on the Atlantic coast are a hotspot due to sea-level rise and together with extreme wave events more than those on the Mediterranean coast.

› Air: vulnerability of aviation to extreme events will further increase as free capacity will increasingly be occupied by additional flights. Sea level rise and flooding could affect airports located in coastal areas across Europe.

**Adaptation Options:** With regards to structural measures, grey solutions are more often discussed across the sources, in terms of infrastructure strengthening, construction of sea-walls, coastal and river defences and increasing network capacity. EbA measures that are discussed the most in relation to the transport sector are those measures that provide a water management function. The role of transport operators anticipating and facilitating intermodal shifts of transport and use patterns in times of disruption, working together across modes in the same location is frequently discussed but not systematically implemented. Examples of the transport sector working with ICT sector in the US highlight options for rapid recovery after an extreme event.

**Mechanisms prompting the sector to adapt:** Legislation is the most frequently discussed mechanism, followed by spatial development/ land use planning and industry-wide standards. Often the development of such standards follows a requirement from a national government to review vulnerabilities in light of climate change; in the case of France, this resulted in over 800 standards for roads alone being revised.

**Findings related to the construction sector:**

**Available climate data compared to infrastructure data needs:** Regarding future climate data projections, the construction sector requires climate projections data up to 2050 to understand cooling and heating trends and up to 2080 to reflect the lifetime of infrastructure development and its resilience to climate impacts. The construction sector require data at very high resolution (below 1km, at building level), particularly in the urban context relating to interactions with the Urban Heat Island effect.

**Vulnerability and risk assessments:** Vulnerability within the construction sector is described and categorised in many different ways depending on the source assessed: some discuss socio-economic vulnerability as a function of the population age, health and well-being; vulnerability of the structure related to its built form (density, height, age, use orientation and proximity to greenspace), and a combination of these two types of vulnerability can present the temperature-related risk, for example. With regard to urban heat risk in particular, this can be described as a triple risk of location, building characteristics and characteristics of the buildings’ occupiers.
Hotspots for the construction sector:

› Keeping buildings and external spaces cooler or warmer;
› Maintaining structural stability below and above ground, in light of water scarcity and subsistence and fluvial, pluvial and coastal flooding;
› Identifying and classifying critical infrastructure within the construction sector itself, such as buildings whose continuing use is essential to the maintenance of services to the population for their security and safety and that need to remain operational.

Geographic locations discussed frequently include:

› Urban areas: the challenge of dealing with the urban heat island effect exacerbated by climate change stretching from northern Europe down to southern, eastern and central parts of Europe; furthermore the risk of forest fires has increased for cities in Portugal, Greece, southern France and Italy.
› Coastal areas due to the multiple threats of storms, fluvial, pluvial and coastal flooding, and coastal erosion, particularly in the north and north-west regions of Europe;
› Along the floodplains in central and western Europe.

Adaptation options: The top three types of adaptation options discussed are grey (structural) measures, which comprise buildings materials, site selection, structural design, and infrastructure strengthening; followed by awareness raising (non-structural) measures in terms of the variety of guidance and checklists that have been developed for planners, developers, owners and users of buildings and training within the profession; EbA (structural) measures which perform a water management action.

Mechanisms prompting the sector to adapt: Legislation is the mechanism the most frequently discussed across the sources, covering the construction sector, followed by spatial development/ land use planning. In terms of the development of industry-wide standards, some nationally developed standards are increasingly being adopted internationally.
1 Introduction

In order to strengthen Europe’s resilience to climate change, the EU Adaptation Strategy provides the foundation from which enabling conditions for adaptation have developed. The need to integrate consideration of climate change and develop resilience to climate impacts through adaptation of the infrastructure sector for both climate influenced projects (where infrastructure is impacted by climate change over its lifetime), and climate adaptation projects (where the main aim is to reduce vulnerability to climate change) is reflected in the EC publication ‘Non-paper: Guidelines for Project Managers: Making vulnerable investments climate resilient’. The importance of integrating climate change into infrastructure sector project development is also reflected in the European Financing Institutions Working Group’s work on Adaptation to Climate Change (EUFIWACC) which has recently produced guidance on integrating climate change information and adaptation into Project Development.

For this project, the infrastructure sector comprises of the Transport, Energy and Construction sectors. The exact scope within these three sectors was developed together with DG CLIMA, and is summarised below.

Energy sector: the focus is on electricity and renewable energy systems (solar, hydro, off-shore and on-shore wind), comprising generation, transmission and distribution. Whilst it was agreed that energy services and demand would not be included in the assessment, we have identified where sources highlight the particular importance of changing energy demand in light of climate change. The following subsectors or infrastructural elements are included: substations, pylons, power plants, transmission lines, solar panels, wind turbines.

Construction sector: includes construction, deconstruction and renovation of the physical infrastructure of the buildings sector. The emphasis is placed on the building’s surfaces (e.g. roofs and facades), structural and integrated building design (e.g. passive solar constructions). The scope excludes behavioural and societal aspects of climate change adaptation.

Transport sector: the focus is on transport infrastructure covering ports, airports, rail, and roads, with an emphasis on railroad tracks, airport terminals, runways, and taxiways as well as roads (including bridges and tunnels) in particular. Whilst it was agreed that the scope excludes inland and marine shipping, we have identified where sources highlight the particular importance of the impacts of climate change on inland waterways, for example, if this constitutes a hotspot. The scope excludes vehicles and vessels, air traffic control and weather monitoring for the operators of airports and ports.

5 Integrating Climate Change Information and Adaptation in Project Development: Emerging Experience from Practitioners, AFD, EC, CEB, EIB, KFW, EBRD, 2016
Key recommendations and areas for further research to address knowledge gaps emerge naturally from the study, and are addressed in Chapter 6; it was agreed that the main focus of the infrastructure assessment is on currently available knowledge rather than investigating areas for further research. The focus of the assessment is on primary impacts (rather than secondary impacts, e.g. those of behaviour change driven by climate change). Note that the analyses undertaken in this project is based on available information at the time of the assessment and has not been validated by the authors or owners of data sources as this was outside the scope of the project. Equally, gaps and recommendations have not been tested and validated within the research community, so there may be projects addressing these knowledge gaps underway at the time of writing.

The key audience for the outcomes of this study are policy makers at national, regional and local levels working in the infrastructure sectors. However, there are additional secondary audiences private and public bodies in charge of infrastructure security and expansion, such as TSOs in the energy field or port authorities for the transport sector, for example.

**Links to other Thematic Reports:**

There are three thematic reports produced under the same project CLIMA.C.3/SER/2015/0007 ‘EU strategy on adaptation to climate change: knowledge assessments to support informed decision making’: Thematic report on Ecosystem Based Adaptation, Thematic report on Infrastructure and Thematic report on National Vulnerability Assessments. The categorisation of ecosystem-based adaptation (EbA) measures relevant to the infrastructure sector as identified in the thematic report on the assessment of EbA measures has been included in this thematic report on infrastructure. Information on cost effectiveness of relevant EbA measures relevant to infrastructure has also been included in this report.

The assessment for EbA and infrastructure focuses on aspects that have relevance across the sectors, while the assessment on National Vulnerability Assessments has a focus on national, transnational and European assessments and cross-sector assessments, spatial/national assessments and/or aggregated across sectors.

For each infrastructure sector the following questions were the subject of the project study:

5. What (climate) data is available and needed for the assessment of climate impacts?
6. What information is available in terms of vulnerability and risk assessments?
7. What adaptation options are used in the infrastructure sector?
8. What decision-making tools, methodologies, and mechanisms are used to address these climate impacts and vulnerabilities?

The following chapters discuss the findings related to the questions; Chapter 2 presents a general overview of the common findings across the three sectors with a focus on the infrastructure sector as a whole; Chapter 3 focuses on the energy sector; Chapter 4 focuses on the transport sector and Chapter 5 focuses on the construction sector. Where knowledge gaps relating understanding and implementing adaptation within the infrastructure sector as a whole have been identified, these are dealt with in Chapter 6, otherwise they are listed in the relevant sector chapter.
2 General overview across the four questions

The following findings relate to all four project questions and apply to the infrastructure sector as a whole:

**Climate data available and needed:**
- Tools such as the Climate-ADAPT Map Viewer¹ are a potentially useful resource for practitioners wishing to access climate data from multiple projects: it combines into one map the climate projections from a number of different research projects. This type of tool goes a long way to overcoming accessibility requirements of individual data sources. 43% of the data sources assessed appear to offer the ability to address tailored requests, such as in the form of interactive maps, which is the most common feature.
- 37% of the data sources assessed enable users to access both observed impacts as well as projections; observed climate data can help inform the infrastructure sector understand the nature of past and current vulnerabilities.
- Observed climate data sources assessed are available at high (under 10km) resolution, with the exception of two sources. Where stated, some climate projections data is available at 50-99km resolution, which is a common resolution level for projections data. This reflects one of the biggest challenges, as users of projected climate data need high resolution (<1km), which can be beyond the current boundaries of climate modelling.
- Climate data sources cover precipitation and temperature most frequently, which reflects users’ needs for these climate variables in particular.
- Climate data requirements need to be considered alongside other types of non-climate data which are equally relevant to undertaking vulnerability and risk assessments and represent a challenge to the sector.

**Information regarding of vulnerability and risk assessments:** There are different interpretations that exist across the infrastructure sector which can be a source of confusion. The EC Guidelines for Project Managers: Making vulnerable investments climate resilient (DG Climate Action, 2011) helpfully provides guidance for project managers on how to make vulnerable investments resilient to climate change. It outlines a systematic methodology for undertaking a Vulnerability and Risk Assessment, broken down into the relevant stages familiar to the project lifecycle appraisal practiced by project developers.

**Projected costs of impacts of climate change on infrastructure sector:** Caution should be applied when comparing numbers relating to projected damage costs due to variations of approaches across all studies. A study by the JRC suggests that ‘damages from climate extremes to critical infrastructures...will be highest for the industry, transport and energy sectors, which are projected to face a 15-fold increase in economic damages’ with greater losses in Southern and South Eastern European countries. Implementing adaptation strategies within these critical infrastructure sectors ‘can offer impressive prospects for increasing...resilience’.

**Adaptation options and innovation:** In terms of adaptation options discussed, grey measures of dam, coastal and river defence are discussed the most across all sectors. The role of cross-sector collaborative working and the cogeneration of tools to help the sector adapt arises repeatedly in order to fill knowledge gaps. This type of project can be facilitated by EU and nationally funded research projects. A variety of visualisation and collaborative decision making tools are being designed and implemented in the US as well as the EU, to aid collective decision making processes and facilitate collaborative working on adaptation.

2.1 Key Messages
2.2 Introduction

This chapter describes the results of the online assessment and expert consultation undertaken throughout the project where the findings from all four project questions apply to the infrastructure sector as a whole. Where information relates to a specific sector, it is discussed in subsequent sector chapters on energy, transport and construction respectively.

The analysis in this report is a result of having assessed over 185 sources (online: both within Climate-ADAPT and beyond, including some sources unpublished at the time of writing: December 2016); resources focused on European coverage mainly, but also include some national publications within Europe and publications with a global, US or Australian focus. Expert consultation was undertaken throughout the project; assessment of the sources was broad in nature, plotting information where possible against various descriptive criteria selected by the project team. In some cases the project team made an estimation of the type of approaches taken, or climate scenarios used, for example.

2.3 Question 1: What (climate) data is available and needed for the assessment of climate impacts?

2.3.1 General overview

For this question, individual climate datasets and data sources that are freely available (without registration, or licence requirements) to users of climate data in the infrastructure sector were assessed; a total of 35 data sources or climate maps depicting climate variables were included. However, for each element analysed, the numbers will not always add up to 35, as in some cases information was lacking in order to accurately plot each characteristic of the data sources.

Most data sources assessed are situated within Climate-ADAPT directly or indirectly. However, there is a wide range of climate data sources covering observed and projected climate data available to users in the infrastructure sector beyond Climate-ADAPT. The project team looked at other sources beyond Climate-ADAPT, specifically those which are referred to in forthcoming guidance to city adaptation practitioners, resulting in an additional four sources of climate data which were reviewed.

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6 Discussion with sector experts at events including Adaptation Futures Conference, Rotterdam May 2016; International Transport Forum 2016 Summit, Leipzig, May 2016; Mayors Adapt Information Event on urban adaptation, September 2016; in-depth interviews were undertaken with Dr Athanasios Sfetsos, National Centre for Scientific Research “Demokritos” EU-CIRCLE; Professor Alan McKinnon, Kühne Logistics University Hamburg; Craig Davies, Senior Environmental Advisor, EBRD.

7 Assessments of each source have not been validated by source authors and in some cases, descriptive inaccuracies may occur. When evaluating the sources, there is always the risk of misinterpretation as in some cases the assessment is subjective, or assessment information required is not described in the source assessed. To undertake the assessment, common guidance was developed for the team and then applied by two assessors and triple checked where necessary.

8 Urban Adaptation e-learning module (Unpublished, to be made available in 2017) refers to the IPCC Data Distribution Centre and JPI Climate.

9 Additional data sources outside Climate-ADAPT assessed: LISCoAST - Large Scale Integrated Sea-level and Coastal Assessment Tool; Temperature-driven global sea-level variability in the Common Era; Future sea level rise constrained by observations and long-term commitment; European Climate Assessment & Dataset (ECAD)
Beyond individual data sources, the Climate-ADAPT Map Viewer\textsuperscript{10} is a potentially useful resource for practitioners wishing to access climate data from multiple projects: it provides projections of climate change impacts, vulnerability and risks from a number of different research projects and organisations, including ClimWatAdapt, ESPON Climate, JRC-IES and ENSEMBLES.

**Geographic coverage of climate data sources assessed**

Of the 35 data sources assessed, 40\% have a global coverage; 34\% of data sources assessed covered Europe and 26\% have a sub-European (transnational) scope. Data sources with a local (sub-national) or national scope were outside the scope of this assessment.

**Timeframe of data sources**

The climate data sources include a mixture of those focussing on the historic (observed) climate data, projections or a combination of both observed and projected climate data. Over one third of the data sources (37\%) enable users to access both observed climate information as well as projections. In addition, 51\% of data sources focus on observations, which can help inform the infrastructure sector understand the nature of past and current vulnerabilities.

Figure 1 below illustrates both different geographic scope of the data sources assessed as well as whether data sources cover projected, observed or both types of climate data.

\textsuperscript{10} http://climate-adapt.eea.europa.eu/knowledge/tools/map-viewer
Figure 2: Breakdown of projected data sources by timeframe

Note: A total of 17 data sources are considered in the graph above but the data points in the graph exceed 17 (42) as some projected data sources extend to multiple timeframes and could have been counted up to four times.

Scenarios and climate models

From the data sources assessed covering climate projections, the majority (59%) appear to be based on the Representative Concentration Pathways scenarios (RCP), compared to Special Report of Emissions Scenarios (SRES); however, it is worth noting that where the climate scenarios used are not explicitly stated in the source, an assumption was made, based on the publication date in light of the change to Representative Concentration Pathways (RCPs) used by the IPCC since 2014.
Resolution

With regard to the spatial resolution\(^\text{11}\) of the data sources, the observed climate data sources span from 1km upwards. With the exception of two sources, all observed climate data sources assessed are available at high (under 10km) resolution. Regarding data sources containing climate projections, the spatial resolution level information is not always available, however some maps which use climate projections data appear to be also at high resolution (1-9km), however it is not clear from the maps whether the corresponding levels of uncertainty are explained when applying climate projections data at such high resolutions. An equal number of climate projections data is available at 50-99km resolution, which is more common resolution level for projections data. This reflects one of the biggest challenges: users of projected climate data need high resolution projections data, sometimes below 1km which can be beyond the current boundaries of climate modelling.

\(^{11}\) Note that where a data source contains both observed and projected climate data, the highest resolution level was plotted which may only apply to one type of climate data.
Figure 4: Resolution of observed and projected data sources

Note: A total of 28 data sources were considered as a spatial resolution could not be identified for all 35 data sources.

Climate variables

Regarding climate variables, both precipitation and temperature (both mean / minimum /maximum; annual / seasonal / monthly and daily) categories are the most often addressed\textsuperscript{12} by the assessed data sources. This was followed by sea-level rise and water scarcity/drought equally.

\textsuperscript{12} Temperature and precipitation are larger in this graphic due to quadruple counting: if all references for those variables were combined it would be 9 and 11 respectively whereas SLR and water scarcity are each 10.
Note: A total of 35 data sources were considered but as one data source can address more than one climate variable and temperature/precipitation have been broken down into different temporal resolutions, the total number of sources or references does not add up to 35.

**Tailored functionality**

The ability to interrogate the climate data is an important option for many users of climate data; 43% of the data sources (15) seem to offer the ability to do tailored requests by the user to varying degrees, such as in the form of interactive maps, with the ability to zoom into location-specific data.

**Completeness, accessibility, user-friendliness**

The data sources or climate data maps were selected because, besides offering relevant climate data for users, they appear to be directly accessible (i.e. the link on Climate-ADAPT leads directly to the data set) and the data seem readily available (i.e. no license, registration is required to assess the data source). In terms of data accessibility, most data sources do not require users to possess or download specific software to visualise or process the data, however six sources do require specific software in order to access the data. In some cases the tool itself was not working, maps not loading, therefore plotting is based on a description of the data source or map from the source website, without seeing the data source itself. Some data sources are no longer being updated once the funding period of a project is over and in these cases, the maintenance of the online sources can decline over time.

**Common data needs across the whole infrastructure sector**

The infrastructure sector has a range of climate data needs regarding specific climate variables, time-slices, time series, resolution in order to interrogate observed data sources and future projections. Data needs were identified through the literature and expert consultation which can be characterised as common to all three sub-sectors (transport, energy and construction) of the infrastructure sector.
**Timeframe**

All sectors have a need for observed climate data, however the baseline of data required by users changes within sectors, ranging from needing paleoclimatic data to identify historic drought spells, to the recent past with baselines range from 1961-1990, or 1991 to present. There is a general need across the infrastructure sector for observed data on all ‘extreme’ weather events (definitions of ‘extreme’ differ not just between sectors but from one location to another); this type of observed data is particularly patchy at high resolution.

With regards to timeframes for climate projections, the infrastructure sector needs span the range of immediate term (related more to weather forecasting needs) to the far future (up to 2100), however pre-mid-century climate projections are the most frequently cited in the literature reviewed for this question.

**Climate variables**

With regards to climate variables, similar data needs regarding both temperature and precipitation are cited: the mean, minimum and maximum for daily, monthly and seasonal figures are cited across the sector which capture longer term changes, but also crucially the changes in extreme temperature, increased incidence of heatwaves and precipitation events. In terms of time periods, the infrastructure sector requires both longer term mean annual/ seasonal and monthly temperature and precipitation data as well as detailed daily, 3 hourly and hourly climate data.

Information on storm surges and crucially storm surges combined with or preceded / followed by other climatic events, such as drought / heavy precipitation are frequently cited, together with long term sea-level rise (both absolute and relative). This reflects a wider data need for information of the likelihood of joint probability of weather events occurring sequentially or concurrently expressed across the infrastructure sector. The ability to interrogate the climate data (using threshold detectors, for example) is particularly useful when critical thresholds have been identified within sectors at specific locations.

**Resolution of data sources**

High resolution climate data is needed across the infrastructure sector ranging from 1km - 12km, especially for precipitation, water equivalent of snow cover and river discharge data.

**Other data needs (non-climate)**

It is important to note that when discussing user needs for climate data with the infrastructure sector, there is a clear recognition by users across the transport, energy and construction sectors, that climate data (both observed and projected) must be considered and applied in conjunction with a host of other data needs. The combination of climate and non-climate data is used as inputs by users in order to create their own models, which use climate variable information in projections data together with hydrological modelling and other non-climate information, for example. The most frequent type of other non-climate data required, include the following:

- Age of relevant infrastructure;
- Materials used for current infrastructure / building stock;
- Information on land-use and land-use change;
- Increase interconnectedness -and dependencies therein- of infrastructure systems;
- Elevation models that also take into account how different adaptation strategies affect elevation and vice versa;
- Urbanisation trends;
- GDP projections;
Demographic projections and related impacts on demands from infrastructure.

Beyond these general user needs for data across the infrastructure sector as a whole, there are some specific data needs within the transport, energy and construction sectors listed in Chapters 3, 4 and 5.

There are a number of gaps and limitations with regards to climate data needs in the infrastructure sector; these are listed with accompanying recommendations in Chapter 6.

2.4 Question 2: What information is available in terms of vulnerability and risk assessments?

2.4.1 General overview of sources studied

A variety of reports, presentations and case studies were assessed for Question 2 totalling 75; this chart below illustrates the different sector coverage; note that some publications have been counted more than once, where a publication addresses the infrastructure sector as a whole or covers two or three of the different sectors.

![Sources by sectors covered](image)

**Figure 6: Breakdown of sources according to sectors covered**

Note: A total of 75 sources were considered for Question 2; however, the reports were counted as many as three times depending on the sectors covered in the report. For the energy sector 40 sources were studied, for the transport sector 48 and for the construction sector 28.

**Definitions and approaches to vulnerability and risk assessments within the infrastructure sector**

Reviewing the sources discussing vulnerability and / or risk assessments, it became clear that there are different approaches to and interpretations of vulnerability and risk assessments. Where the source states which has been undertaken, the project team have plotted it as such. Otherwise the team have tried to make a judgement based on the sources themselves.
Interestingly the glossary of the IPCC’s AR5 report\textsuperscript{13} contains for the first time an explicit definition of risk, which ‘results from the interaction of vulnerability, exposure and hazard’ and it is recognised that defining risk is partially subjective process.

With regard to the approach to be taken in the infrastructure sector, the guidance for project managers\textsuperscript{14} on how to make vulnerable investments resilient to climate change very helpfully defines a systematic methodology for undertaking a Vulnerability and Risk Assessment, broken down into the relevant stages familiar to the project lifecycle appraisal practiced by project developers. These steps are further reflected in both guidance from Joint Assistance to Support Projects in European Regions guidance (JASPERS)\textsuperscript{15} and IPCC definitions:

1. Identify climate sensitivity of the project
2. Evaluate exposure of the project
3. Assess vulnerability (sensitivity x exposure)
4. Assess risk (likelihood x impact)
5. Identify adaptation options
6. Appraise adaptation options
7. Integrate adaptation plan

The EEA report on urban adaptation (12/2016) defines a risk assessment, however regarding the concept of vulnerability, it recognises the variety of concepts and elements that exist, and does not use a specific definition or concept stringently.

This came up as an issue frequently debated within the infrastructure sectors and in interviews undertaken for this project\textsuperscript{16}, as there is often debate on how to define such assessments so that there is a common understanding across the sector (see Chapter 6 Gaps and recommendations).

The figure below outlines where sources have a particular focus on vulnerability and/or risk assessments within the infrastructure sector.

\textsuperscript{13} Fifth Assessment Report, IPCC, 2014
\textsuperscript{14} Non-paper Guidelines for Project Managers: Making vulnerable investments climate resilient, DG Climate Action, 2011
\textsuperscript{15} http://www.jaspers-europa-info.org/home
\textsuperscript{16} In addition to expert discussions held at various conferences, interviews were also undertaken during the project with Dr Athanasios Sfetsos, National Centre for Scientific Research “Demokritos” EU-CIRCLE; Professor Alan McKinnon, Kühne Logistics University Hamburg; Craig Davies, Senior Environmental Advisor, EBRD.
Figure 7: Breakdown of sources discussing vulnerability and/or risk assessments

Note: A total of 75 sources were assessed. Vulnerability assessments are the focus in 43 sources, risk assessments in 20 and both vulnerability and risk assessments are discussed equally in 12 sources.

Different approaches taken across the infrastructure sector

The project team assessed how the sources describe vulnerability and / or risk assessments and identified three different types of approach undertaken, which can be broadly described as

1. Multi-stakeholder based assessments: sometimes undertaken at smaller spatial scales, less emphasis on working with climate science communities, more qualitative;
2. Science-based assessments: Involving climate science communities, application of specialised skills, downscaling, GIS mapping, expert judgment involved;
3. Multi-stakeholder and science based assessments: a combination of the two approaches, involving sharing results with multiple stakeholders and possibly also across sectors, to discuss proxy values and indicators, for example.

Cost benefits assessments (CBA) tend to fall within the multi-stakeholder and science based approach described above, but for the purposes of this study we have identified where sources focus on CBA in particular.

These different approaches to undertaking vulnerability and risk assessments broadly reflect the different methodological approaches to undertaking vulnerability assessments, identified by the RESIN\textsuperscript{17} report which describes approaches as being:

\begin{itemize}
  \item \textsuperscript{17} State of the Art Report (4) Vulnerability Assessment, RESIN, 2015
\end{itemize}
1. Qualitative (Participatory) Assessments;
2. Quantitative assessments;

An approach characterised by ‘multi-stakeholder and science-based’ assessments was by far the most prevalent in the energy, transport, and construction sectors making up 75%, 75%, and 61% of all approaches respectively. Those sources which discuss a multi-stakeholder and science-based approach with an emphasis on CBA, cover 15%, 10%, and 25% of the sources assessed in each of the sectors.

Target audiences of the infrastructure sources assessed

In assessing the sources for Question 2, the project team tried to identify the governance level of the target audiences for each source; sometime this was clearly stated, otherwise an assessment was made by the project team, with a focus on the primary audience for the sources.

Target audience types are broken down into six different types:

1. **International**: aimed at a global audience, the sector as a whole, regardless of location;
2. **European**: aimed at European actors and decision makers, from the EU institutions and funders, to EU sector-wide associations;
3. **National**: aimed at national sector associations or reports for national governments;
4. **Regional**: Sub-national level focusing on infrastructure sector within a specific geographic or climatic region;
5. **Local**: Aimed at local actors, local authorities citing local examples sub regional level;
6. **Private / project**: Aimed at individual project level, or private sector at project level.

The chart below illustrates the different target audience levels for the publications, presentations, case studies assessed for Question 2; note that given the scope of this project, sources were prioritised where they had a European, transnational or sector-wide focus, therefore sources at regional (sub-national) level were not prioritised unless to illustrate specific elements, such as the costs and benefits of adaptation measures and their application (Question 3), or case studies (Question 4) for example.
Figure 8: Target audience of sources broken down by sector

Note: A total of 75 sources were considered; however, the reports were counted as many as three times depending on the sectors covered in the report. For the energy sector 40 sources were studied, for the transport sector 48 and for the construction sector 28.

Timeframes used to carry out vulnerability and risk assessments

The figure below illustrates the different timeframes which represent the upper limits of studies discussing risk and vulnerabilities of climate change. In some cases, where the timeframes were not stated, in those case the sources have not been included in the representation below. While sources often covered a time period that extended over several decades, every resource considered in this section was allocated to one of the eight decades based on the upper end of the assessment’s timeframe, meaning that sources were only counted once. For example, if a study covers the period from 2020s-2080s, it is counted as 2080.
Figure 9: Timeframes of sources

Note: The years listed above represent the preceding decades up to the stated year. A total of 49, as opposed to 75 sources, were reviewed as a timeframe could not be identified for 26 of the sources.

Different infrastructural elements discussed:

The focus of this study is to understand how sources discuss climate impacts on the physical infrastructure within the three different sectors, the chart below shows the different types of infrastructural elements that are covered when discussing risk and vulnerability assessments and the impacts of climate hazards on particular physical elements.
2.5 Question 3: What adaptation options are used in the infrastructure sector?

With regard to the different adaptation options used in the infrastructure sector, the types of adaptation measure are classified as ‘structural’ and ‘non-structural’ measures.

**Structural measures** include grey measures (engineering solutions); EbA measures are categorised according to their primary adaptation action and are listed in the table below. These measures are consistent with the classification of EbA measures described in the Thematic report on EbA, to ensure consistency.

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*Note: A total of 75 sources were reviewed.*
Table 1: EbA measures according to their primary adaptation action

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<thead>
<tr>
<th>Primary adaptation action</th>
<th>Measures</th>
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<td>Water management with green elements</td>
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<td>- WSUD/SUDS</td>
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<td>Water management without green elements</td>
<td>- Permeable surfaces</td>
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<td>- soakaways</td>
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<td>- Infiltration trenches</td>
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<td>- Infiltration basins</td>
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<tr>
<td>Temperature regulation</td>
<td>- green walls</td>
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<tr>
<td>Multiple actions</td>
<td>- urban trees and forests</td>
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<td>- urban greenspace</td>
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Non-structural measures include

- Knowledge transfer actions:
  - Awareness raising (internal or external stakeholders incl. general public);
  - Surveys;
  - Training
- Operational actions:
  - Integrating into existing maintenance regimes & other plans;
  - Integrating into programmes and standards.

Information impacts, costs and benefits of adaptation options:

Climate resilience can be considered as a parameter in obligatory cost-benefit analyses during the project development phase\(^\text{18}\): the ‘Non-paper Guidelines for Project Managers: Making vulnerable investments climate resilient’\(^\text{14}\) refers to the EC Guide to Cost Benefit Analysis of Investment Projects and provide a process for integrating climate change risks and uncertainty. Whilst integrating climate adaptation can increase costs for infrastructure projects, a World Bank study\(^\text{19}\) found that ‘the net cost of adapting infrastructure to climate change is no more than 1-2% of the total cost of providing that infrastructure and adaptation action can decrease costs over a longer period through damage prevention and reduced interruptions’. According to the study, the cost of adaptation overall appears small in relation to other factors that may influence the future costs of infrastructure.

However, it is often at the project and local level that costs of adaptation are considered; building a compelling economic case for investment in adaptation and justifying such measures in terms of avoided damages is challenging in times of austerity\(^\text{20}\) and given that the cost of climate impacts can vary widely at the local level.

\(^\text{18}\) Adapting Infrastructure to Climate Change, European Commission, 2013
\(^\text{19}\) The Costs of Adapting to Climate Change for Infrastructure, The World Bank, 2010
\(^\text{20}\) Use of Climate Projections in Local Adaptation Planning: Lessons from England and Germany, University of Leeds, 2016
The EEA\(^4\) highlights that caution should be applied when comparing numbers relating to all projected damage costs as, ‘a large number of caveats are needed, reflecting variations in practice among studies…whether results are reported for the impact of climate change and socio-economic change together, the effects of climate change alone above future socio-economic change, or the effects of future climate change on current socio-economic conditions. There are…major issues with reporting and adjustment of economic values in different time periods, whether future values are presented as discounted or present values’. Furthermore, the potential costs of the impacts of climate change due to river flooding for example, at EU level, were found to ‘vary by a factor of two (higher or lower) across the range of models sampled (12 regional climate models): at the country level the differences were even more significant, with different models even reporting differences in the sign of change.’

A study by the JRC\(^2\) suggests that ‘damages from climate extremes to critical infrastructures and key investments in the energy, transport, industrial and social sector, which at present total to €3.4 billion/year, could triple by the 2020s, multiply six-fold by mid-century, and amount to more than 10 times the present damages by the end of the century… losses will be highest for the industry, transport and energy sectors, which are projected to face a 15-fold increase in economic damages’. Furthermore the losses will be greater in Southern and South Eastern European countries. However, the study also concludes that implementing adaptation strategies within these critical infrastructure sectors ‘can offer impressive prospects for increasing…resilience’:

The study quantifies the benefits of adaptation: ‘indicative estimates based on average benefit to cost ratios from literature show that, for the EU+, the total accumulated benefits…of adapting…up to 2040 amount to €100 billion, with an accumulated cost of adaptation of €39 billion. Costs incurred now to put adaptation measures in place (i.e., capital costs) could amount to €12 billion, or 0.1% of EU+ 2010 GDP, plus a yearly operational and maintenance (O&M) cost of nearly 1 billion €. Expected annual benefits of these investments would amount to €3.3 billion’.

Examples of information on the projected impacts, costs and benefits of different types of adaptation measures is captured where relevant to specific measures within each sector chapter.

\(^2\) Resilience of large investments and critical infrastructures in Europe to climate change, Joint Research Centre, 2015  (Note: all damages reported are undiscounted and expressed in 2010 €. Only the effects of climate change are accounted for, assuming no socioeconomic changes in future scenarios. EU+ is the focus of this study, comprising EU28, Switzerland, Norway and Iceland).
2.6 Question 4: What decision-making methodologies, tools and mechanisms are used to address these climate impacts and vulnerabilities?

This question focuses on the different methods, tools and mechanisms which can be, or are being used for decision-making within the infrastructure sector. There is some overlap with the previous questions: a knowledge transfer option can be considered an adaptation option (Question 3) whilst also be referred to in Question 4, in terms of what tools, processes were used in resilience decision-making; a vulnerability/risk assessment can be regarded as both an input in a decision-making process (Question 2), or as part of the decision-making process itself (Question 4). This question aims to identify methods, tools and mechanisms which are prompting the infrastructure sector to adapt.

**Methodologies:** A wide range of different methodologies exist to assess and address climate impacts on the infrastructure sector, as well as approaches to them (and interpretations of such methodologies) which can be both qualitative, such as participatory vulnerability and / or adaptive capacity assessments or quantitative, such as statistical and / or modelling methodologies, including cost benefit analyses. Methodologies comprise of a series of sequential steps to be undertaken; there are a variety of methodologies and methodological approaches that sit within different stages of the adaptation decision-making process\(^\text{22}\) as well as those developed within the infrastructure sectors or by funders of infrastructure projects\(^\text{23}\).

**Tools:** are instruments created in order to facilitate a user in undertaking different methodological stages; in undertaking a methodology, several different types of tools can be used. Tools can be checklists\(^\text{24}\) or guidance factsheets used to integrate climate resiliency into wider procurement and permitting processes for specific sectors, for example.

Within the step by step methodologies, there are a range of methodological tools being used within the infrastructure sector which be classified as:

- Screening tools\(^\text{25}\);
- Risk analysis tools\(^\text{26}\), including integrated assessment modelling tools\(^\text{27}\);
- Cost benefit assessment tools\(^\text{28}\), quantitative damage estimation tools\(^\text{29}\);

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\(^{23}\) Methodologies developed or promoted by funders include: EBRD decision tree methodology to allow for climate risks (Ports); World Bank ‘stress testing’ approach based on [http://www.deepuncertainty.org/](http://www.deepuncertainty.org/); Green City methodology developed by EBRD, OECD

\(^{24}\) UK: Guidance for construction design to take account of specific climate variables, within the relevant timeframes, highlighting primary and secondary issues: Design for future climate Opportunities for adaptation in the built environment, Innovate UK, 2010

\(^{25}\) Denmark: the Blue Spot Project uses a risk screening tool to assess flooding on the road network.

\(^{26}\) Germany, Czech Republic: The RIVA Risk analysis tool, used in Germany to assess landslides impacting the road network, an excel based planning tool (it not include landslides) using temperature extremes and moisture levels

\(^{27}\) UK: Case IA Modelling for London: the Tyndall Centre UIAF (Urban Integrated Assessment Facility) combines sectoral economic analysis with transport demand analysis and environmental assessment for emissions and flood risk

\(^{28}\) EU: In the ClimateCost study calculating costs of impacts and adaptation, a Dynamic Interactive Vulnerability Assessment (DIVA) Model is used, considering future climate and socioeconomic change. Results are presented as expected annual damage (EAD) costs, based on probabilistic climate hazards.

\(^{29}\) Assessment of the vulnerability of critical infrastructure buildings to floods, Warren, 2012: assessed 5 such tools (ANUFLOOD methodology; USACE velocity-damage curves; HAZUS-MH Flood Model, Stochastic methodology using Monte Carlo simulation, Damage and
Visualisation tools: simulation environments including advanced modelling, extreme event visualisations using Google Maps\textsuperscript{30};

- Decision making tools, including multi-criteria analysis software tools. Adaptation options are scored based on evaluation criteria which are ranked; the rankings determine the weight assigned to each criterion in the MCA\textsuperscript{31, 32}.

From assessing the range of sources it is not possible to identify which tools and methodologies are employed in each case, however this was discussed across the three sectors in consultation activities. From discussions, the current interest and innovation is towards those tools which are designed to aid decision making processes, specifically to facilitate collaborative working beyond one organisation or sector, which is increasingly recognised as essential to undertaking vulnerability and risks assessments and assessing and prioritising adaptation options.

Visualisation and collaborative decision making tools are being employed to help assess and prioritise approaches amongst a wide range of stakeholders within the infrastructure sector; innovative examples include ‘serious gaming’ tools which combine gaming with computer simulation to address the climate adaptation in the urban infrastructure sector\textsuperscript{33}.

The importance of co-creation of methodologies and tools to integrate climate adaptation

Studies and interviews reveal that the development of technical adaptation tools and measures to use as part of undertaking step-by-step methodologies need to include stakeholders as part of this process. The role of cross-sector collaborative working comes up repeatedly in order to fill relevant knowledge gaps regarding all four guiding questions for the infrastructure sector. The potential and contribution to the knowledge base arising from cross sectoral working has yet to be fully explored or realised in the infrastructure sector. Two examples below serve indicate how the infrastructure sector is moving to address climate risks and adaptation collaboratively:

1. **Multi sector partnerships** (MSPs), such as Enhance\textsuperscript{34} partnership for risk reduction to natural hazards aims to
   - create indicators for successful (and unsuccessful) partnerships in improving resilience, and identify processes for fostering novel MSPs;
   - provide methods and guidelines for a harmonised scheme for risk assessment and scenarios through an inventory of existing risk information;
   - develop new methods and scenarios for (low-) probability risk assessment in collaboration with MSPs;
   - describe and test through case studies which concepts of economic instruments, including insurance and risk management policies, work for MSPs;

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\textsuperscript{30} US: used in the Port of Providence

\textsuperscript{31} NL: Use of DEFINITE software, Adaptation in the Dutch Electricity Sector IVM

\textsuperscript{32} US: [www.wecisien.com](http://www.wecisien.com) used in the Port of Providence

\textsuperscript{33} US: [www.sim4act.com](http://www.sim4act.com) recently developed in the US.

\textsuperscript{34} EU wide: multi-sector [www.enhanceproject.eu](http://www.enhanceproject.eu/)
- provide guidelines and policy recommendations for example can be used to reduce and manage risk, they are voluntary and can be temporary or permanent in nature.

2. **Critical infrastructure joint projects** involving the co-creation of methodological processes, tools and results applicable across the infrastructure sector. An example of this approach is embodied in EU-CIRCLE project which will create a framework for supporting the interconnected European Infrastructure’s resilience to climate pressures. This project includes an ‘end-to-end modelling environment where new analyses can be added anywhere along the analysis workflow and multiple scientific disciplines can work together to understand interdependencies, validate results, and present findings in a unified manner’, will be accessible to all and complemented by a web-based portal.

**Mechanisms**

There are a variety of different types of mechanisms prompting the infrastructure sector to adapt, taking the form of legislative, or industry-wide actions. These include:

- Industry-wide standards;
- Investment and procurement;
- Grants, subsidies;
- Insurance;
- Operational programmes and maintenance regimes;
- Spatial/ land-use planning;
- Legislation (EU or national).

The different actors that have been identified are involved in creating and applying such mechanisms in order to integrate adaptation to climate change is summarised in the table below, which apply to all three sectors. The table below covers both mechanisms in which climate change is already integrated and those mechanisms where the effects of climate change could have the potential to be integrated. Examples of sector specific measures in existence in different countries, and relevant articles and sections within specific Directives listed can be found in the footnotes.

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35 EU Wide, all critical infrastructure sectors: [http://www.eu-circle.eu/](http://www.eu-circle.eu/)
### Table 2: Infrastructure actors and mechanisms for integrating climate change into decision-making

<table>
<thead>
<tr>
<th>Level of actor</th>
<th>Mechanism used to integrate adaptation</th>
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</thead>
<tbody>
<tr>
<td>Energy Utilities and regulators</td>
<td>› Industry-wide standards(^{36})</td>
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<td></td>
<td>› Resilience standards, guidelines(^{37})</td>
</tr>
<tr>
<td>Transport networks and regulators</td>
<td>› Strengthening of infrastructure equipment (Investment and implementation)</td>
</tr>
<tr>
<td>Construction industry and associations (incl. manufacturers, installers, surveyors, engineers)</td>
<td>› Operational and maintenance regimes</td>
</tr>
<tr>
<td></td>
<td>› Demand-side management (all sectors)</td>
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<td></td>
<td>› Increase capacity (energy transmission, transport)</td>
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<tr>
<td></td>
<td>› Decentralised generation with RE &amp; microgrids (all sectors)</td>
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<tr>
<td></td>
<td>› Response plans (energy and transport sectors)</td>
</tr>
<tr>
<td></td>
<td>› Insurance</td>
</tr>
<tr>
<td>Local government</td>
<td>› Small scale spatial planning (elevation requirements)</td>
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<tr>
<td></td>
<td>› Small scale land-use planning (zoning provisions)</td>
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<tr>
<td></td>
<td>› Building regulations at local level, facilitating smart grids, decentralised generation</td>
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<tr>
<td></td>
<td>› Grants and subsidies</td>
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<tr>
<td>Regional and national governments</td>
<td>› Building regulations and laws to mainstream resiliency of equipment</td>
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<tr>
<td></td>
<td>› National regulations to undertake risk based asset management plans, adaptation reporting powers(^{38})</td>
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<tr>
<td></td>
<td>› Coastal flooding protection</td>
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<tr>
<td></td>
<td>› Ecosystem based approaches</td>
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<td></td>
<td>› Large scale spatial planning for high-voltage transmission infrastructure</td>
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<td></td>
<td>› Cross-sector collaborative R&amp;D and knowledge transfer projects</td>
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<tr>
<td></td>
<td>› Grants and subsidies</td>
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<td></td>
<td>› National risk assessment plans (see below)</td>
</tr>
<tr>
<td>EU level (EU institutions, investment banks)</td>
<td>› The EU Climate Adaptation Strategy (SWD (2013) 299)(^{39})</td>
</tr>
<tr>
<td></td>
<td>› Climate mainstreaming into EU policies(^{40})</td>
</tr>
<tr>
<td></td>
<td>› Adaptation incorporated into EU funding streams(^{41})</td>
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</tbody>
</table>


\(^{37}\) Infrastructure guidelines, such as Swedish Guidelines for Design Flood Determination for Dams, Svenska Kraftnät, 2007, as well as integration of resiliency standards in wider permitting and procurement processes.

\(^{38}\) US; UK Climate Change Act Reporting power, Civil Contingencies Act

\(^{39}\) The EU Adaptation strategy acknowledges that climate related hazards will have a defining impact on the status and operational capacity of European critical infrastructures, and society as a whole, including asset deterioration and reduced life expectancy; increases in Operational Expenditure (OPEX) and the need for additional Capital Expenditure (CAPEX); loss of income; increased risks of environmental damage and litigation; reputation damage; changes in market demand for goods and services and increased insurance costs or lack of insurance availability. [http://www.eu-circle.eu/about/what-is-eu-circle/](http://www.eu-circle.eu/about/what-is-eu-circle/)

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<tr>
<th>Level of actor</th>
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<tbody>
<tr>
<td></td>
<td>‣ Cross collaborative R&amp;D grants and knowledge transfer projects[^42]</td>
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<tr>
<td></td>
<td>‣ EU Guidance for infrastructure projects[^5,14,43]</td>
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<td></td>
<td>‣ European Standardization[^44]</td>
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<td></td>
<td>‣ The European Climate Adaptation Platform Climate-ADAPT[^45]</td>
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<td></td>
<td>‣ EU Directives:</td>
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<td>‣ EIA Directive 2011/92/EU &amp; the amended EIA Directive 2014/52/EU, the EIA shall identify exposure, vulnerability and resilience to natural and man-made disaster risks Environmental Impacts Assessment (EIA);</td>
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<tr>
<td></td>
<td>‣ National risk assessment plans:</td>
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<td></td>
<td>‣ COMMISSION STAFF WORKING DOCUMENT, Overview of natural and man-made disaster risks in the EU, SWD(2014) 134.</td>
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Relevant EU directives with the potential to integrate the effects of climate change:

- Strategic Environmental Assessment procedures (SEA) Directive 2001/42/EC[^46]  
- EU SEVESO II Directive 96/82/EC companies using large amounts of hazardous substances have to now consider risk of flooding in safety reports from 2016 onwards[^47].  
- COMMISSION STAFF WORKING DOCUMENT, on the review of the European Programme for Critical Infrastructure Protection (EPCIP), SWD (2012) 190[^48].

[^41]: The legal basis for integrating climate change considerations for ERDF, Social, Cohesion Funds is laid out in various regulations is listed in Climate Change and Major Projects, European Commission, 2016 [http://ec.europa.eu/clima/publications/docs/major_projects_en.pdf](http://ec.europa.eu/clima/publications/docs/major_projects_en.pdf). For example, the European Regional Development Fund and Cohesion Fund requires major projects delivering technical infrastructure (e.g. transport, power grids, water supply, sewage, buildings, and dykes) need to be assessed for resilience to current risks and future climate changes, and upgraded. Other relevant funds include the European Social Fund, the Cohesion Fund and the EIB’s Natural Capital Financing Facility.

[^42]: For example FP7, Horizon 2020 projects


[^44]: CEN and CENELEC recently published CEN-CENELEC Guide 32: the Guide for addressing climate change adaptation in standards Edition 1, 2016-04, providing guidance on addressing aspects of climate change adaptation in European standardization documents, being applicable to product (including design), service, infrastructure and testing standards [http://www.cencenelec.eu/standards/Guides/Pages/default.aspx](http://www.cencenelec.eu/standards/Guides/Pages/default.aspx)

[^45]: [http://climate-adapt.eea.europa.eu/](http://climate-adapt.eea.europa.eu/) Contains information organised according to the following entry points: Adaptation information (Observations and scenarios, Vulnerabilities and risks, Adaptation measures, National adaptation strategies, Research projects); EU sector policies (Agriculture and forestry, Biodiversity, Coastal areas, Disaster risk reduction, Financial, Health, Infrastructure, Marine and fisheries, Water management); Transnational regions, Countries and Urban areas; Tools (Adaptation Support Tool, Case Study Search Tool, Map Viewer).

[^46]: Guidance on integrating Climate Change and Biodiversity into Strategic Environmental Assessment, European Commission, 2013

[^47]: Discussed in Adaptation Futures 2016 Conference: Climate risk management and adaptation in ports, presentation by Marc Eisma Port of Rotterdam.

[^48]: This is a review of the EPCIP and focuses on the Directive 2008/114/EC. In this context, it mentions that “the underlying rationale is that disruption to infrastructures providing key services could harm the security and economy of the EU as well as the well-being of its citizens” (p. 2). Section 3.3.1, touches on evaluation: “The Directive then suggests evaluating the impact of any disruption to the identified CIs on other Member States. This can be done by applying either the cross-cutting criteria (CCC), which specify thresholds to assess the general effects of CI disruption, such as the number of casualties, economic effects or public effects, or the national equivalent of such criteria. This impact evaluation should factor in alternatives and disruption/recovery time.” In section 3.3.2, the transnational nature of disruption is touched upon:
It is worth noting that this is not an exhaustive list of the different mechanisms which can be used to integrate adaptation into the infrastructure sector, but it reflects the mechanisms that the infrastructure sectors themselves are discussing and citing which are prompting the sectors to adapt, or have the potential to do so.

However, research reveals that the potential of such mechanisms is not being realised, even in those Member States which are considered to be European leaders in adaptation, such as Germany and the UK. The use of climate projections and adaptation planning appears not to have been integrated into local planning processes in either country, due to austerity (UK), the localism agenda (UK), lack of clear overarching legal frameworks (DE), strongly regulated planning system which favours use of past and present (not future) climate data (DE).

Some Member States (e.g. Italy) have pointed out that the nature of the infrastructure under discussion often involves several Member States, and that bilateral negotiation does not reflect the nature of these infrastructures. This is especially true for energy and transport infrastructure, where disruption may impact more than the two Member States involved in the negotiations. Lastly, section 2.2 makes reference to Article 6(f) TFEU: “It calls on the EU to ‘encourage cooperation between Member States in order to improve the effectiveness of systems for preventing and protecting against natural or man-made disasters’.”

The European Programme identified Critical infrastructures which, if disrupted or destroyed, would have a serious impact on health, safety, security or economic well-being of citizens and/or effective functioning of government in Member States. The Directive requests an all-hazards risk framework treating natural hazards, setting the principles upon which the Member States must ensure that an operator security plan (OSP) or an equivalent measure for each designated CI is devised. Relevant sections include §3: “Under this approach, man-made, technological threats and natural disasters should be taken into account in the critical infrastructure protection process, but the threat of terrorism should be given priority”. §8: “Given the very significant private sector involvement in overseeing and managing risks, business continuity planning and post-disaster recovery, a Community approach needs to encourage full private sector involvement”, §11: Operator security plans (‘OSPs’) or equivalent measures comprising an identification of important assets, a risk assessment and the identification, selection and prioritisation of counter measures and procedures should be in place in all designated ECIs”. §14: The efficient identification of risks, threats and vulnerabilities in the particular sectors requires communication both between owners/operators of ECIs and the Member States, and between the Member States and the Commission”. §15: “In order to facilitate improvements in the protection of ECIs, common methodologies may be developed for the identification and classification of risks, threats and vulnerabilities to infrastructure assets”. Art.6: “Each Member State shall implement an appropriate communication mechanism between the relevant Member State authority and the Security Liaison Officer or equivalent with the objective of exchanging relevant information concerning identified risks and threats in relation to the ECI concerned”.

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The 5th Objective to Increase Europe’s resilience to crises and disasters calls for an all-hazards approach to threat and risk assessment: guidelines for disaster management will be drawn up. National approaches will be developed, cross-sectoral overviews of possible risks will be established together with overviews of current threats…and a risk management policy will be established. Use of Climate Projections in Adaptation Planning: Lessons from England and Germany, University of Leeds, 2016

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50 Directive on the identification and designation of European critical infrastructures and the assessment of the need to improve their protection (Directive 2008/114/EC)§50
51 The EU Internal Security Strategy COM (2010) 673 final§51

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<table>
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<tr>
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<tr>
<td></td>
<td>› COMMISSION STAFF WORKING DOCUMENT on a new approach to the European Programme for Critical Infrastructure Protection Making European Critical Infrastructures more secure, SWD (2013) 318§49</td>
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<td></td>
<td>› Directive on the identification and designation of European critical infrastructures and the assessment of the need to improve their protection (Directive 2008/114/EC)§50</td>
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<td></td>
<td>› The EU Internal Security Strategy COM (2010) 673 final§51</td>
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This has actually led to a loss of adaptation capacity and expertise in local authorities (UK), with no priority for adaptation whilst the use of climate projections data is discouraged by the current regulatory framework (DE).

The range of mechanisms covered in the sources assessed is represented in the figures 11 and 12 below; legislation is the primary mechanism discussed which is prompting the infrastructure sector to adapt in the energy and constructions sectors, whilst industry-wide standards are discussed as the main mechanism within the transport sector.

Figure 11: Mechanisms for adaptation discussed per sector

Note: A total of 87 sources were considered for Question 4; however, mechanisms could not be identified in all sources for each of the sectors. Ultimately, 39 sources were considered for the energy sector, 52 for the transport sector, and 35 for the construction sector. The size of the bubble above corresponds with the number of sources that referenced these mechanisms. For example, the smallest bubble (grants/subsidies in the construction sector) corresponds to 5, while the largest bubble (legislation in the transport sector) corresponds with 23. Each measure type was counted once if it appeared in a source, regardless of how many times the measure is mentioned in the same source.
Figure 12: Mechanisms for adaptation discussed per sector

Note: The spider diagram above is another way of presenting the information in the bubble diagram above. It reflects the frequency of each measure compared to the total number of sources considered in regards to that sector. A total of 87 sources were considered for Question 4; however, mechanisms could not be identified in all sources for each of the sectors. Ultimately, 39 sources were considered for the energy sector, 52 for the transport sector, and 35 for the construction sector. Each measure type was counted once if it appeared in a source but each source could contain references to more than one mechanism.

One of the directives which is discussed the most within the sectors interviews for this project is the revised EU Directive 2014/52/EU on Environmental Impact Assessment (EIA) (Amendment of the Directive 2011/92/EU based on the EIA Directive 1985/337/EEC). The Directive calls for assessing the impacts of projects on climate (for example greenhouse gas emissions) and their vulnerability to climate change. “The characteristics of projects must be considered, with particular regards to: ...(f) the risk of major accidents and/or disasters which are relevant to the project concerned, including those caused by climate change, in accordance with scientific knowledge;…” (Annex III selected criteria referred to in Article 4 (3). The changes in the EIA directive will require changes in EIA practices in Member States and several publications, studies and guidelines (e.g. Jiricka et al. 2015, McCallum et al. 2013 and Walker et al, 2013) show that EIA has the ability to address climate change issues and could provide a good entry point to incorporate considerations of climate change impacts and adaptation within existing modalities of the project design, approval and implementation.
The Commission Staff working Document, Adapting infrastructure to climate change (SWD (2013)), is recognised in discussions with the infrastructure sector as an important guiding and support document for energy, transport and construction sectors respectively.

**Further potential to integrate adaptation: mechanisms in development**

Further to the mechanisms outlined in the table above, there are additional important developments which will prompt the energy, transport and construction sectors to adapt. In 2014 the Commission requested the European standardisation organisations to initiate standardisation activities in order to support the implementation of the EU Strategy for Adaptation to Climate Change (Mandate M/526 – details at [http://www.cencenelec.eu/standards/sectors/climatechange/pages/default.aspx](http://www.cencenelec.eu/standards/sectors/climatechange/pages/default.aspx)). Additionally, the Mandate (M/515) for amending existing Eurocodes and extending the scope of structural Eurocodes requests the assessment of the climate change implications for Eurocodes.

The European Committee for Standardization (CEN) and the European Committee for Electrotechnical Standardization (CENELEC) will prepare a priority list of standards that will contain a maximum of 20 standards for each priority sector that should be developed or revised in order to improve resilience in the construction, energy and transport sectors. This preliminary work programme should be finalised in early 2017, and will then be followed by specific activities to develop new standards and/or revise existing ones.
3 Energy

**Climate data and needs:** Information on projected impacts of climate change on electricity generation is very fragmented. Whilst effects of extreme events can be easier to detect, the effect of long-term climate change can be difficult to determine due to changes in technical, social, behavioural and economic aspects. There is a particular need for climate information relating to all extreme weather events to inform energy infrastructure resilience. Regarding renewable energy generation, depending on the energy type, climate change can have both positive and negative impacts on energy output.

**Vulnerability and risk assessments:** roughly half of the sources covering the energy sector focus on vulnerability assessments (52%), while 35% of sources focus on risk assessments, and the remaining 13% discuss both risk and vulnerability assessments. In addition to negative impacts of climate change on the energy sector, positive impacts are also described with regards to renewable energy generation and reduced winter maintenance regimes such as snow and ice removal from energy infrastructure.

**Hotspots for the energy sector include:**

- **Southern and Western Europe:** flooding along the coastline and floodplains, as well as risk of damage to turbines due to sea-level rise and storm surges; droughts, lower river flows in summer and higher river water temperatures will impact hydropower and water cooling resources.

- **Mountainous areas throughout Europe:** Infrastructures will be threatened by geological instability owing to increased precipitation; for hydropower production and the cooling of power plants, maximum accumulated snow water equivalent may decrease by up to 78% (Germany, Austrian, Swiss and Italian border regions).

- **Northern Europe:** dams will be at risk during spring time due to increase in ice masses flowing down the river.

- **Urban areas:** are cited throughout the sources assessed, given the dense electricity networks and dependent assets in larger urban areas. One study identified hotspots are typically located around the periphery of urban areas rather than the centres where several critical infrastructures are concentrated in one location.

**Adaptation options:** In terms of structural measures, grey measures such as flood defences to manage coastal, fluvial and pluvial flooding are most frequently identified and of the EbA measures, those that mainly provide a water management action are also frequently discussed which reflects the hotspots identified. Other grey measures discussed include increasing the network capacity through the installation of additional storage facilities, so that the system can manage more frequent extreme weather events with higher base load volatility. Infrastructure strengthening is mentioned particularly in the context of increasing the robustness of transmission grids.

**Mechanisms prompting the energy sector to adapt:** Legislation is the mechanism discussed the most frequently as prompting the energy sector to adapt; in response to EU legislation or national reporting requirements on climate resilience, new related industry-wide standards have also been developed.

### 3.1 Key messages
3.2 Question 1: What (climate) data is needed for the assessment of climate impacts in the energy sector

**Timeframe**
For the energy sector, there is a general need for average standard climatic parameters up to the 2080s, the 2050-2080 period in particular, as energy infrastructure often has long lifetimes.

**Climate variables**
There is a particular need for climate information relating to all extreme weather events to inform energy infrastructure resilience in terms of transmission and distribution networks. For example information on sea-level rise and flooding (leading to damage to substations, erosion and instability of pylons, reduced functioning of power plants); extreme heat (leading to sagging and efficiency loss of transmission lines, risk of forest fires). Beyond these needs for climate variables which are common to the whole infrastructure sector described above, particular variables mentioned which impact the resilience of grid infrastructure include:

- Wind storms of 110km/h + (which result in damage to transmission lines, solar panels, wind turbines);
- Changing trends of storm patterns, including thunder and lightning;
- Freezing and melting cycles, including thawing of permafrost, impacts on river flows (impacts hydro energy, infrastructure stability, accumulation of snow on power lines);
- Cloudbursts of 100mm over ‘short’ periods (definition of short varies across locations, organisations);
- Water scarcity, drought severity indexes (related to low flows for hydropower plants, difficulties for cooling power plants).

Regarding renewable energy generation, there are particular climate variables relevant depending on the energy type which have direct impacts (positive and negative) on energy output:

- **Solar energy:**
  - Mean solar radiation, cloud cover.
- **Wind energy:**
  - Wind patterns (direction, speed) and wind gusts;
  - Wave height for offshore wind.
- **Hydro energy:**
  - Snow melt/depth/pack (seasonal, especially winter);
  - River flows (monthly, multi-annual).

The EEA’s latest Impacts and Vulnerabilities report\(^5\) concludes that ‘Information on past and projected impacts of climate change on electricity demand and electricity generation is very fragmented. The effect of long-term climate change can be difficult to determine owing to concurrent changes in technical, social, behavioural and economic aspects, while the effects of extreme events are usually easier to detect.’

\(^5\) ‘Climate Change, Impacts and Vulnerability in Europe 2016’, European Environment Agency, 2017
Resolution of data sources

The hydro sector needs climate data at resolution levels beyond those available in many climate projection data sources, such as the mean and changes in river discharge at very high resolution, as well as a range of climate parameters for each grid point of the river basin. To address such needs, models are created using climate variable information in projections data together with hydrological modelling and other non-climate information (see below). In terms of water availability for electricity generation in some regions (i.e. Veneto, Italy), gridded data sets of (monthly) temperature and precipitation are needed in order to integrate this information with data on the seasonal evolution of snow cover and river discharge. In the generation of solar energy, high (1 km) resolution geo-referenced grids of solar radiation are required as well as climate scenarios that have been downscaled to a high resolution matching that of the observational data sets. In addition to solar radiation, high resolution gridded historical (observed) data is required for temperature and heating and cooling degree-days.

Grid operators need high resolution data sources relating to flood maps in order to assess the flood risks for specific infrastructure. For temperature related vulnerabilities (leading to sagging and efficiency losses) as well as storm related vulnerabilities (causing damages to overhead lines), somewhat lower resolutions might already be sufficient as grid infrastructure is often so extensive that impacts need to be accounted for at a larger scale.

Other data needs (non-climate)

In addition to those cited above common to the infrastructure sector as a whole, the hydro energy sector requires information on soil moisture, local hydrological modelling and dam classification maps.

3.3 Q2: What information is available in terms of vulnerability and risk assessments for the energy sector?

3.3.1 General characteristics of assessments within the sector

Approach to assessing climate impacts

Roughly half of the sources covering the energy sector focus on vulnerability assessments (52%), while 35% of sources focus on risk assessments, and the remaining 13% discuss both risk and vulnerability assessments equally.
Figure 13: Energy sector sources discussing vulnerability and/or risk assessments

Note: A total of 40 sources were assessed for the energy sector. 21 sources discussed vulnerability assessments, 14 risks assessments, and 5 both vulnerability and risk assessments.

Different approaches taken across the infrastructure sector

Of the different approaches to undertaking vulnerability and risk assessments identified, 'Multi-stakeholder & science-based' was identified in 75% of the 40 energy sector sources. This was followed by 18% of the sources discussing 'Multi-stakeholder & science-based; CBA' approach.

Timeframe:

The timeframe of assessments of the energy sector often cover up to the 2050s, but some studies span up to 2100s. The reason for this is that certain network infrastructure can have very long operational lifetimes (between 30-80 years).
Figure 14: Breakdown of energy sector sources by timeframe of assessment

Note: The years listed above represent the preceding decades up to the stated year. A total of 28 sources were considered as a timeframe could not always be identified for all 40 of the energy sector sources.

Target governance level

The sources assessed are aimed at national audiences and European audiences equally, followed by regional audiences. A few reports address audiences at local, private or international levels:
Figure 15: Target audience of energy sector sources

Note: A total of 40 sources were considered for the energy sector. It is possible, however, that each source has more than one target audience. 14 sources targeted an EU audience, 15 the national level, 10 regional level, 7 local, and 6 the project/private level.

Infrastructure elements

The infrastructural elements most frequently discussed in the sources are power lines and power plants, followed by substations and pylons more frequently than renewable energy infrastructure.
3.3.2 Climate information used to perform assessments

Approximately two-thirds of the reports use the SRES as scenario type, compared to an estimated one third using the RCP. Of the sources that state explicitly whether the information used is from GCMs or RCMs, a small majority applies climate information derived from GCMs. Most reports cite the IPCC as the data source for obtaining climate information, and a limited number of reports mention other sources such as national probabilistic models (e.g. UKCP09), or national programmes (e.g. the National Atmospheric and Oceanic Administration (NOAA) or the U.S. Global Change Research Program).

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54 Where sources did not specify which climate scenarios (SRES or RCP) were used, the project team made an estimation based on the publication date of the study, as it was not possible to contact study authors for detailed information requests or validation within the resources for this project. Representative Concentration Pathways (RCPs) are four greenhouse gas concentration trajectories adopted by the IPCC for its fifth Assessment Report (AR5) in 2014, superseding Special Report on Emissions Scenarios (SRES) projections published in 2000.
3.3.3 Findings

Key climate hazards
The key climate hazards within the energy sector are outlined in the table below:

Table 3: Climate hazards addressed by energy sources

<table>
<thead>
<tr>
<th>Climate hazards</th>
<th>Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation</td>
<td>37</td>
</tr>
<tr>
<td>Temperature change</td>
<td>36</td>
</tr>
<tr>
<td>Sea level rise</td>
<td>33</td>
</tr>
<tr>
<td>Wind</td>
<td>33</td>
</tr>
<tr>
<td>Storm surge</td>
<td>32</td>
</tr>
<tr>
<td>Water scarcity/drought</td>
<td>29</td>
</tr>
<tr>
<td>Sea temperature</td>
<td>11</td>
</tr>
</tbody>
</table>

The most frequently discussed climate hazards in the energy sector are precipitation (changing precipitation patterns, more extreme precipitation events) closely followed by temperature change. Climate hazards associated with sea level rise, stronger winds (e.g. storms and hurricanes), storm surges and water scarcity are also often mentioned in the sources reviewed. Other climate hazards mentioned include forest fires (impacting distribution and transmission of energy in southern Europe), river level rise, increasing wave heights and lightning.

The above results reflect the findings regarding key vulnerabilities below, as energy infrastructure is impacted by both extreme events (storms, downpours) as well as gradual events (sea level rise along coastlines).

Key vulnerabilities

› Interdependent nature of the infrastructure sector: multiple sources discuss how the impacts on energy infrastructure are inherently complex, with knock-on, cross sectoral impacts. Poor spatial planning and design can exacerbate vulnerabilities across different infrastructure sectors, for example exposing certain roads to floods which provide access to electrical substations. In addition, ‘the increasing interconnection between national energy networks in the EU, particularly electricity transmission lines, enhances the interdependency across countries and, therefore, the risk of the vulnerability of energy infrastructures spreading’53.

› Renewable energy will be vulnerable to climate impacts in different ways:
  o Hydropower is vulnerable both to floods (fluvial, pluvial, coastal) in western and central Europe, as well as diminishing water flows in the Mediterranean due to a decrease in precipitation and increased evaporation.
  o Wind energy, in particular offshore and coastal turbines, are vulnerable to sea level rise and increased exposure to violent storms and storm surges.
  o Bioenergy crops will be impacted by the change in optimal growing zones due to temperature increase and changes in precipitation. For example, the optimal growing zone of Mediterranean oil and solid biofuel crops55 might move northward.

53 Impacts of Climate Change on Regional Energy Systems, ESPON, 2009
Solar power will be impacted by higher temperatures as well as potentially increasing cloud cover.

Energy transmission system and grid infrastructure is mainly vulnerable due to storms and more intense rainfall. Transmission infrastructure is also vulnerable to extreme temperatures which cause efficiency losses and sagging lines.

Thermo-electric facilities will be impacted by flooding (due to locations near water bodies) and also restricted cooling water supply in times of drought and heatwaves.

Impacts of climate hazards without adaptation

In terms of climate impacts, the sources focus specifically on damage to physical assets, rather than the economic and social impacts. Projected increases in cooling demand in southern and central Europe may further exacerbate peaks in electricity demand in the summer unless appropriate adaptation measures are taken.\(^{53}\)

Damage to physical assets is discussed above in the key vulnerabilities, and in further detail in the section ‘Hotspots’ below.

Human losses/ injury

One report discusses how adverse weather conditions due to climate change may lead to an increase in health and safety risks along with workplace security concerns, such as accessibility to sites.

Indirect social impacts are mentioned, such as the knock-on effect on vulnerable groups in times of black and brown outs.

Direct economic impacts:

Observed costs:

- EU-wide information on observed costs of climate impacts in the energy sector was not found in the scope of this study. Qualitative information is available on where climate change-related costs are likely to be incurred in the energy sector but no overall, quantitative estimate has been found. Most of the information about costs in the energy sector refers to projected costs (see below).

- One study\(^{56}\) outlines the general impact of climate hazards on different types of costs. For example, for hydropower generation and investment costs are not likely be impacted but storms could trigger power plant shutdown. For onshore and offshore wind, average wind speed may be reduced, resulting in a minor decrease in electricity generation; for solar PV the cost implications are negligible, however for Concentrated Solar Power on the other hand, cooling water could be scarce, impacting costs.

Projected costs:

- Projected damages arising from climate extremes from seven climate hazards (heat and cold waves, river and coastal flooding, streamflow droughts, wildfires and windstorms) suggest the ‘strongest increase in multi-hazard damages is projected for the energy sector, for which the baseline EAD of €0.5 billion/year could rise to €2, €4.4, and €8.2 billion/year (or 4, 9 and 16-fold increases in EAD) by the 2020s, 2050s and 2080s, respectively.\(^{21}\)

\(^{56}\) Investment needs for future adaptation measures in EU nuclear power plants and other electricity generation technologies due to effects of climate change, DG Energy, 2011
On the energy supply: in particular on hydro-electric generation, and ‘potentially on thermal power (nuclear and fossil) plants and on some renewables. The combined effects of these supply effects could be significant (at up to a few per cent of European generation) and have potentially large economic costs, potentially similar to the demand effects’ described directly below.

Costs of additional cooling demand: ‘costs from climate change alone estimated at around EUR 30 billion/year in the EU-27 by 2050, rising to EUR 109 billion/year by 2100 (current values, undiscounted). A much higher increase will occur in southern Europe. However similar levels of economic benefit are projected from the reduction in winter heating demand from warmer temperatures under the A1B scenario, estimated also at just over EUR 100 billion/year by 2100, though the benefits generally arise in different countries due to the costs of increased cooling’. Whilst there is a projected ‘decrease in Heating Degree Days (HDDs) as a result of future climate change is larger than the projected increase in Cooling Degree Days (CDDs) in absolute terms, in economic terms, the effects are almost equal in Europe, because cooling is generally more expensive than heating’.

Environmental impacts: A few studies mentioned environmental impacts in terms of additional strain on water resources given increased need for water sources for cooling.

Positive impacts were also mentioned in the following areas:

- Increased precipitation and warmer temperatures could positively impact hydropower capacity in Nordic and Baltic regions due to increased water flow. However, this also creates a risk of increased damage to dams in springtime due to floating ice masses.
- Possible positive impact of increased wind potential for energy production in northern regions. However, this again also creates risk of shutting down turbines in case of storms.
- Possibly faster bioenergy crop growth rates and higher temperature mean that the effects of climate change on crop production are expected to be positive in northern regions, however southern Europe (parts of France, Portugal, Greece and Spain) will see their potential for bioenergy crop production severely impaired.
- Reduction of winter maintenance regimes, such as snow and ice removal. The accumulation of snow and ice is an issue for multiple parts of the energy infrastructure, such as transmission lines and wind turbines.

Hotspots

- Southern and Western Europe: energy infrastructure is at risk of flooding along the coastline and floodplains, as well as risk of damage to turbines due to sea-level rise and storm surges.
- Southern and Western Europe: droughts, lower river flows in summer and higher river water temperatures will impact hydropower and water cooling resources, as well as water resources for biocrop production.
- Mountainous areas: Infrastructures will be threatened by geological instability owing to increased precipitation; in mountain watersheds for hydropower production and the cooling of power plants, annual low-flows will continually decrease and maximum accumulated snow water equivalent may decrease by up to 78% and decrease water resources releasing high and regular spring river flows downstream, in Germany, Austrian, Swiss and Italian border regions.

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57 Climate Change and Territorial Effects on Regions and Local Economies in EU, ESPON, 2011
> Northern Europe: dams will be at risk during spring time due to increase in ice masses flowing down the river.

> Urban areas: are cited throughout the sources, given the dense electricity networks and dependent assets in larger urban areas. One study identified more explicitly that the hotspots are typically located around the periphery of urban areas rather than the centres: a larger number of critical hotspots exist just outside urban areas, where there are large facilities upon which many customers depend or where several critical infrastructures are concentrated in one location.

> Rural areas: are particularly vulnerable to extreme events as distribution networks in these regions often comprise of overhead lines without redundancy in case of failure

> Low-lying unprotected areas: substations are vulnerable to flooding.

> Underground cables might not be able to divert enough heat in case of drought or flood (The Netherlands has many underground cables, for example).

### 3.4 Question 3: What adaptation options are used in the energy sector?

The latest EEA report on Impacts and Vulnerabilities highlights the fact that there are ‘158 major terminals in the European coastal zone and 71 operating nuclear reactors on the coast, with more currently planned’. With regard to adaptation options, it emphasises a mixture of structural non-structural measures are needed as ‘Planned adaptation and a high level of awareness of sea level rise threats could mitigate, to some extent, the risks to coastal energy infrastructure in north-western Europe’. This is reflected in the types of options most frequently discussed across the assessed sources; the ten most frequently discussed measures in the energy sector are shown in the table below:

#### Table 4: Measures discussed most frequently in regards to the energy sector

<table>
<thead>
<tr>
<th>Energy sector measures</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Awareness raising</td>
<td></td>
</tr>
<tr>
<td>2 Dam, coastal, river defence</td>
<td></td>
</tr>
<tr>
<td>3 Integrating into existing maintenance regimes &amp; other plans</td>
<td></td>
</tr>
<tr>
<td>4 Increase network capacity; Infrastructure strengthening; Programmes &amp; standards</td>
<td></td>
</tr>
<tr>
<td>5 Training</td>
<td></td>
</tr>
<tr>
<td>6 Underground grid; Cross-sector working</td>
<td></td>
</tr>
<tr>
<td>7 Water management with green elements; Surveys</td>
<td></td>
</tr>
<tr>
<td>8 Water management without green elements</td>
<td></td>
</tr>
<tr>
<td>9 Multiple actions (green measures)</td>
<td></td>
</tr>
</tbody>
</table>

Note: Each measure was counted once if it was mentioned in a source. Measures listed in the same row are discussed in an equal number of sources.

An overview of the different categories and types of adaptation measures mentioned for the energy sector is in the figure below. Please note that EbA measures with primarily temperature regulation action, as well as Urban trees, forests and greenspaces which perform multiple actions are in green; EbA measures which have primarily a water management action are in blue; grey measures are in grey; knowledge transfer actions in red, and operational actions in orange.
Note: A total of 87 sources were considered for Question 3; however, energy sector measures were not identified in 48 sources, meaning 39 sources were ultimately considered. The percentages above stem from the prevalence of these measures in these 39 sources. A measure was counted once if discussed in a source; each source could contain references to more than one measure.

3.4.1 Structural measures

Half of the sources focus on structural measures, and within structural measures, 41% focus on ‘grey’ measures, in particular, i.e. ‘hardening’ through creation of new or reinforcing existing infrastructure:

- The main focus of infrastructure measures covered is **flood defences** to manage coastal, fluvial and pluvial flooding, which reflects the hotspots identified above.\(^{58}\)

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\(^{58}\) In the Netherlands, the Delta Programme was established to structurally work on flood defences, taking into account climate change
Other grey measures which are discussed include increasing the network capacity through the installation of additional storage facilities, so that the system can manage more frequent extreme weather events with higher base load volatility.

Infrastructure strengthening is mentioned particularly in the context of increasing the robustness of transmission grids, pylon and transmission lines to cope with more violent storms, as well as elevation of substations and electrical infrastructure components and using saltwater-resistant equipment to prevent flooding damages. Another example of strengthening infrastructure is the installation of microgrids which would prevent local blackouts, which otherwise would be the case if electricity supply is dependent on centralised generation where the failure of one part might cause the whole system to collapse. In this case, if large transmission lines have failed, the microgrid could be disconnected from the larger grid and run on other sources. In particular, microgrids combined with distributed generation and storage could create a more resilient electricity system as they have the ability to separate from the larger electric grid during extreme weather events and run on renewable energy generated locally.

Another example of strengthening infrastructure is the installation of microgrids which would prevent local blackouts, which otherwise would be the case if electricity supply is dependent on centralised generation where the failure of one part might cause the whole system to collapse. In this case, if large transmission lines have failed, the microgrid could be disconnected from the larger grid and run on other sources. In particular, microgrids combined with distributed generation and storage could create a more resilient electricity system as they have the ability to separate from the larger electric grid during extreme weather events and run on renewable energy generated locally.

Underground grids are discussed widely in the sources, however undergrounding of grid might not be suitable to areas prone to coastal inundations. In these areas overhead bundled cable might be more applicable.

With regard to other types of structural measures discussed, EbA measures that mainly provide a water management function are most frequently cited, for example in order to provide natural areas as a buffer zone to inundation through afforestation or extension of sandbanks, for example.

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59 In New York, the utility ConEdison is implementing different storm hardening measures in response to damage caused by Superstorm Sandy
Such measures include the following:

Table 5: Table of EbA measures applicable to energy infrastructure

<table>
<thead>
<tr>
<th>Primary adaptation action</th>
<th>Measures</th>
</tr>
</thead>
</table>
| Water management with green elements           | ☐ green roofs  
|                                                | ☐ swales                                       |
|                                                | ☐ filter strips                                |
|                                                | ☐ rain gardens                                 |
|                                                | ☐ Channels and rills                           |
|                                                | ☐ WSUD/SUDS                                    |
| Water management without green elements        | ☐ Permeable surfaces                           |
|                                                | ☐ soakaways                                    |
|                                                | ☐ Infiltration trenches                        |
|                                                | ☐ Detention basins                             |
|                                                | ☐ Retention ponds                              |
|                                                | ☐ Infiltration basins                          |
| Multiple actions                               | ☐ urban trees and forests                      |
|                                                | ☐ urban greenspace                             |

3.4.2 Non-structural measures

Non-structural measures are discussed equally to structural measures in the sources assessed, with an equal focus on knowledge transfer actions compared to operational adaptation measures. Examples of actions include learning together through forums, mutual assistance groups and cross sector working. The need for increased cross sector planning scenarios is also highlighted to ensure that sectors with interdependencies use similar assumptions when reporting.

With regard to operational adaptation measures, such as integrating into existing maintenance regimes & other plans, programmes and standards in the industry, sources discuss examples such as:

> **Increased vegetation management regimes** in light of climate change, increased storms, etc.
> **Review and integrate climate change into new design standards regularly.**
  > For example, in the US, it is suggested that design standards should be used when hardening the system in order to protect infrastructure located in flood zones, with a review of standards should be done every five years. Standards include use of most currently available flood plain maps, with the addition of three feet protective construction in anticipation of future floods[^60].
  > In some Member States the energy sector is working closely with national and international standards committees to ensure that standards developed for the new networks will take account of the thresholds for climate change impacts on an international scale between 2015-17[^61].

[^60]: ConEdison Vulnerability Assessment, New York State Public Service Commission, 2014
Consider resilience of electrical infrastructure in new building design e.g. raise electrical equipment when possible, from cellar to first floor.

3.4.3 Costs & benefits of adaptation measures in the energy sector

The measured outcomes are variable, and will be context dependent (i.e. scale, location, specific measure or combination of measures) therefore the information included in the table below is a commentary on cost-effectiveness rather than a comparison of applications.

The proposal for ‘guidelines for trans-European energy infrastructure’ COM(2011) 658 Annex V, states that the ‘system resilience, including disaster and climate resilience, and system security, notably for European critical infrastructure as defined in Directive 2008/114/EC’ is an aspect to be considered for cost-benefit analyses for electricity transmission and storage.
### Table 6: Costs & benefits of adaptation measures in the energy sector

<table>
<thead>
<tr>
<th>Measure</th>
<th>How does it reduce vulnerability</th>
<th>Economic values</th>
<th>Observed/ projected</th>
</tr>
</thead>
</table>
| **Grey: Undergrounding of electricity grid** | • Prevents failures during extreme weather events such as storms or impacts from trees on electricity grids, ensuring the security of electricity supply.                                                                                      | Finland:  
  • Investments costs of bare conductor line is 20 k€/km, underground cable 46 k€/km.  
  • Overall costs of underground cable are 28 k€/a in Finland in all regions.  
  • Service costs for a service interval of six years have been calculated with a unit price of 400 €/km for overhead line and 250 €/km for underground cable.  
  • The clearing cost in forest is 150 €/km and the trimming cost 1200 €/km. The clearing of the ground below the line costs 150 €/km and the trimming is half of the costs in the forest, 600 €/km.  
  • The unit price for rot inspection is 115 €/km and the inspection interval is 12 years. The corresponding values for the maintenance inspection and data collection are 110 €/km with six year interval and for the cable inspection 100 €/km with six year interval as well  
  • The fault repairing cost is in the overhead line network 1600 €/fault and for the underground cables 3200 €/fault.  
  • Cables mounted in rural areas cost double the amount of the bare overhead line.  
  • Repair time increases for infrastructure when roads are in poor condition.  
  • In rural areas consumers have to be prepared for power interruptions. If interruption is not acceptable, a reserve back-up power system is the most economically feasible solution.  
  62 Recognizing climate change in electricity network design and construction, VTT, 2007.                                                                 | Observed |
| **Grey: Reinforcing of pylons** | • Increases the ability of electricity infrastructure to deal with extreme winds                                                                                                                                                        | Germany  
  RWE Netz re-enforced 28,000 pylons of its transmission grid in the aftermath of icy winter storm in 2005. The overall cost amounted to €500 million.  
  France  
  • After severe damages from storms in 1999 the grid operator RTE improved the “mechanical security” of the grid by strengthening 45,000 km of overhead lines and the development of a strategy to restore power within five days if outages occur. By January 2009 the 2.4E billion programme showed some success: the storms reached 1999 levels but outages only occurred on half the number of overhead lines. | Observed |

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62 Recognizing climate change in electricity network design and construction, VTT, 2007
<table>
<thead>
<tr>
<th>Measure</th>
<th>How does it reduce vulnerability</th>
<th>Economic values</th>
<th>Observed/ projected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grey: Additional cooling towers for energy production</td>
<td>• Cooling water for energy production</td>
<td>EU</td>
<td>Observed</td>
</tr>
<tr>
<td></td>
<td>• Maximum design wind speed ranges from around 130 km/h for older lines to 180 km/h for critical lines in vulnerable areas (Peters et al, 2006). Damage cost estimates range from €1,600 per fault for a single line breakage (Martikainen et al, 2007) to €17,000 per pylon and attached lines in cases of widespread disruption (ADAM, 2009).</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grey: Additional air temperature cooling</td>
<td>• Reduces heat effect on power plant</td>
<td>EU</td>
<td>Observed</td>
</tr>
<tr>
<td></td>
<td>• To withstand an increase of air temperature to critical levels, a biomass power plant smaller than 30MW would need to invest in more cooling area, which would cost ca. €5 million for the whole plant.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Another waste-wood-fired facility estimates that every 1 °C increase in air temperature above 25 degrees can cause a loss of income of €40 for every operating hour.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grey: Additional dry cooling for Concentrated Solar Power</td>
<td>• Reduce effects of temperature increase</td>
<td>EU</td>
<td>Observed</td>
</tr>
<tr>
<td></td>
<td>• As CSP plants tend to be in arid regions, dry cooling systems are often necessary. Dry cooling has in principle three drawbacks: higher parasitic losses, lower steam-cycle efficiency and higher investment costs. The difference in cost between dry and wet cooling is approximately $200/kWe, increasing the construction costs by 3-6%, and operation and management costs by 1-3%. Plant performance can decline by 5-9%. However, costs varying widely with site specifications.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grey: Thermal inversion</td>
<td>• Reduce effects of temperature increase</td>
<td>EU</td>
<td>Observed</td>
</tr>
<tr>
<td></td>
<td>• To avoid &quot;thermal inversion&quot; (rare but possible at around 45° C) walls can be constructed around the chimney which would cost around 1 M€ (= 1 €/kW), which is a relatively low cost, but also</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Energy

<table>
<thead>
<tr>
<th>Measure</th>
<th>How does it reduce vulnerability</th>
<th>Economic values</th>
<th>Observed/ projected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grey: Seawalls</td>
<td>• Strengthen coastal protection against storm surges and rising sea level</td>
<td>Netherlands</td>
<td>Observed</td>
</tr>
<tr>
<td></td>
<td>• Construction costs vary according to shape of structures but usually they require low maintenance. In the Netherlands it has been estimated that a seawall would cost 300-500 € per m³.</td>
<td>United Kingdom</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• In the UK estimates varied from £200,000 to £500,000 (250,000 – 625,000€)/100m length for seawalls.⁶⁴</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For relevant EbA water management measures (i.e. basins and ponds, wetland restoration and management, and floodplain restoration and management), see Table 16 in the Construction section.

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⁶⁴ ‘Seawalls and Jetties’. Climate-ADAPT, 2015
3.5 Question 4: What decision-making tools, methodologies, and mechanisms are used to address these climate impacts and vulnerabilities in the energy sector?

3.5.1 Tools and methods discussed in the energy sector

For an overview of tools, methods and mechanisms which are used or have the potential to be used by the energy sector, please see Chapter 2.

The figure below illustrates the different types of mechanisms that are being discussed in sources covering the energy sector as opportunities for addressing the impacts of climate change.

![Mechanisms used in the energy sector](image)

**Figure 18: Mechanisms for adaptation used in the energy sector**

Note: A total of 87 sources were considered for Question 4; however, energy sector mechanisms were not identified in 48 sources, meaning 39 sources were ultimately considered. The percentages reflect the prevalence of these mechanisms in the 39 sources. Each measure type was counted once if it appeared in a source but each source could contain references to more than one mechanism and multiple references to the same mechanism.

3.5.2 Case study illustrating how the energy sector is adapting
**Case study: Adaptation within the energy sector, France, UK, Poland**

**Situation:** France: Following the extreme heatwave in 2003 across France, EDF drafted a climate risk plan for France to improve resilience to subsequent heat waves in 2006. More recently in 2015, the EDF Group drew up a climate change adaptation strategy covering current and future industrial facilities, customer offers, generation/consumption optimisation and R&D. The strategy is driven by lessons learned, from events such as the 2003 heat wave in France, storms Klaus in 2009 and Xynthia in 2010, and the Fukushima accident in Japan.

The strategy for adapting to climate change covers generation, network, distribution activities as well as meeting changing energy demand from customers. The strategy has four areas of action:

1. Assess the impacts of climate change on installations and activities especially in the water-energy nexus
2. Adapt the installations concerned to make them less sensitive to extreme weather
3. Take into account future climate conditions in the design of new installations
4. Improve the resilience to changes and extreme situations that are more difficult to predict.

In the UK and France, EDF developed a long-term adaptation plan in 2011 and is also learning from the Japanese Earthquake Response programme on extreme weather events. EDF is working with the Met Office, Météo France and European initiatives such as Copernicus to develop climate services for different energy activities, long-term weather studies and R&D on extreme precipitation episodes.

**Mechanisms used:** In both France and the UK, EDF’s strategies were developed in response to national government requests:

**France:** In response to the 2011-2015 national climate change adaptation plan in France, the EDF Group drew up its climate change adaptation strategy.

**UK:** The Climate Change Act 2008 introduced a new power to direct “reporting authorities” (companies with functions of a public nature such as energy utilities) to prepare reports on how they are assessing and acting on the risks and opportunities from a changing climate. EDF Energy’s long-term adaptation report was published in 2011; EDF works with the Electricity Producers Association on critical infrastructure resilience and long-term adaptation planning.

**Outcomes:**

- **France:** Increased distribution network resilience
  - burying HV networks in order to avoid the risk of falling trees, wind, snow and frost and it gives priority to the structures that are most exposed to climate risk and critical to the time needed to resupply customers.
  - Investment and appropriate design and operating measures for flooding and heatwaves.
  - 27,400 km of HV overhead lines, including 12,600 km with strong climate risk, replaced between 2007 and the end of 2013
  - FIRE rapid electricity response team can mobilize up to 2,000 people and large amounts of resources to respond in France and abroad.
- **UK:** The design of new nuclear generation sites takes account of the risk and impact of climate change; the existing power plants are already managing these risks as part of their regular activities and results of the adaptation assessment are being integrated.
- **Poland:** EDF Polska has included climate change risks in its assessment and management procedures and response planning, mainly at EDF Polska Krakow and Kogeneracja, aimed at minimising the impact of flooding and drought.
- **EDF R&D** work is used in different countries outside the EU to support the business plans for projects. (Source: EDF)
3.6 Gaps and recommendations specific to the energy sector

Where knowledge and implementation gaps have been identified regarding the energy sector which are common to the infrastructure sector as a whole, these are covered in Chapter 6 ‘Gaps and Recommendations’. Gaps inhibiting adaptation which are specific to the energy sector are listed in the table below, together with suggested recommendations.

<table>
<thead>
<tr>
<th>Gaps discussed in energy sector</th>
<th>Recommendation</th>
<th>Level to be addressed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Policy uncertainty: for example rapid changes in renewables subsidy schemes at the national level.</td>
<td>Provide clarity in policy direction, for instance with regard to duration of national renewables schemes.</td>
<td>Policymakers, in particular national governments</td>
</tr>
<tr>
<td>2. Lack of coherence in land-use policies (in particular concerning competing objectives such as between water resource management, flood risk management and RE production)</td>
<td>Assess competing land-use objectives and optimal land-use options (for example, in terms of water resources, flood management, RE production and wayleaves).</td>
<td>National, regional and municipal governments</td>
</tr>
<tr>
<td>3. Lack of consistency and comprehensiveness of the risk and nature of risks (i.e. sensitivity, timing, thresholds) for critical assets (e.g. substations). This includes the identification of ‘hot spots’ where disruption and failure can have significant impacts, including cascading failures.</td>
<td>Issue reporting requirements on risks and measures being taken (for example, for TSOs/DSOs on resiliency of substations).</td>
<td>National governments and/or energy sector regulators</td>
</tr>
<tr>
<td>4. Potential of decentralised energy supplies not fully realised.</td>
<td>Consider the potential and risks of specific distributed energy generation with small scale renewables, including in the context of climate change, and actions that can be taken to enhance resilience.</td>
<td>Subnational level: regional and municipal authorities with energy companies and DSOs</td>
</tr>
<tr>
<td>5. Lack of standardisation of threshold levels for infrastructure equipment (e.g. for overhead lines, the wind speeds that they need to cope with).</td>
<td>Create standardisations for infrastructure equipment where possible.</td>
<td>Product standard committees to address potential hazards from a system and installation practices perspective(^{65}).</td>
</tr>
</tbody>
</table>

\(^{65}\) Note that the European Committee for Standardization (CEN) and the European Committee for Electrotechnical Standardization (CENELEC) will prepare a priority list of standards for each priority sector ‘by the end of 2016’ at the time of writing.
4 Transport

4.1 Key messages

**Climate data and needs:** Transport sector climate data needs vary the most in terms of the range of timeframes required for observed and projected data. The need to recognise the changing nature of climate hazards and how they behave is identified as a key challenge in this sector, especially with regards to flash flooding in mountainous regions in smaller side catchments which are not linked to river levels. Such events can result in substantial damages which are not expected, after having taken account of the climate projections.

**Vulnerability and risk assessments:** The majority of sources assessed discuss vulnerability assessments (56%), while 21% discuss risk assessments and 23% both risk and vulnerability assessments. In some cases where there are multiple actors and organisations working together to undertake assessments at one location, the decision to undertake a vulnerability assessment over a risk assessment is prioritised.

**Hotspots:**
- **Areas of highly centralised traffic patterns:** concentrating traffic through a smaller number of hubs can exacerbate vulnerability; the market for just-in-time services drives increasing centralisation, making these systems particularly vulnerable.
- **Inland waterways:** that are already drought sensitive, where reduced water levels will not offer sufficient draught protection projections suggest that this may become more important beyond 2050.
- **Road, rail:** in mountainous regions transport networks are expected to be most vulnerable to intense rain and snow. Roads are vulnerable to flooding particularly in Central and northern Europe. The angle of repose either side of the road/railway is critical in relation to risks of avalanches and landslides.
- **Ports on the Atlantic coast** are a hotspot due to sea-level rise and together with related extreme wave events more than those on the Mediterranean coast.
- **Air:** vulnerability of aviation to extreme events will further increase as free capacity will increasingly be occupied by additional flights. Sea level rise and flooding could affect airports located in coastal areas across Europe.

**Adaptation Options:** With regards to structural measures, grey solutions are more often discussed across the sources in terms of infrastructure strengthening, construction of sea-walls, coastal and river defences and increasing network capacity; EbA measures that are discussed the most in relation to the transport sector are those measures that provide a water management function. The role of transport operators anticipating and facilitating intermodal shifts of transport and use patterns in times of disruption, working together across modes in the same location is frequently discussed but not implemented systematically. Examples of the transport sector working with ICT sector in the US highlight options for rapid recovery after an extreme event.

**Mechanisms prompting the sector to adapt:** Legislation is the most frequently discussed mechanism, followed by spatial development/ land use planning and industry-wide standards. Often the development of such standards follows a requirement from a national government to review vulnerabilities in light of climate change; in the case of France, this resulted in over 800 standards for roads alone being revised.
4.2 Question 1: What (climate) data is needed for the assessment of climate impacts in the transport sector?

Timeframe
The timeframes cited by the sector for observed climate data vary the most widely, spanning from paleoclimatic data required by the airports sector to the more recent past; 1960s to present as a typical historical time slice for the road and rail sectors.

In terms of climate projections, the transport sector has two different type of data needs:

1. The medium/long term climate impacts projections up to mid-century in particular, which serve for long term strategic planning for transport infrastructure (e.g. a port deciding to invest in strengthen its quays to cope with increased frequency and severity of heavy weather events).

2. Short term weather forecasting data (6-48 hours) which are used for operational purposes and influence immediate decisions. E.g. the ability for flights to land in certain conditions, downtime at ports.

Climate variables
The road and rail sectors are particularly concerned with future extremes of precipitation, total seasonal precipitation and temperature change, including the number of frost / freezing days.

This data is needed to understand the likelihood and frequency of exceeding critical thresholds which can lead to sections of road or rail closure, or increased operational efforts. (For example, the need to clear standing water on main trunk roads within a specific time limit, gritting roads in case of extreme heat and cold, increased risk of rail buckling in extreme heat).

Critical thresholds are highly location dependent; examples of illustrative thresholds cited include:

- the change of 7-day maximum (pavement) temperature (after which there is a risk of surface melt);
- exposure to >60% increase in 1/100 year river discharge rates (in relation to bridges);
- annual number of days with precipitation higher than X mm/day (20 and 50mm/day was cited in relation to understanding conditions for risk of landslides);
- maximum precipitation over a 7-day period.

With regard to bridges and culverts in particular, the road sector in Norway has identified a further need regarding climate projection data: the need to recognise the changing nature of climate hazards and how they behave. An example is unexpected flash flooding that can occur in rural, smaller side catchments which are not linked to river levels. The flash flooding of side catchments results in substantial damages which are were not expected, having taken account of the climate projections. Information on wind storm frequency and intensity is also a need with the sector where this creates debris and inhibits transport services and impedes intermodal transport shifts (e.g. people taking trains in the case of road closures and vice versa).

Ports are concerned with changes in seasonal rainfall, particularly if there are seasonal increases and intense precipitation patterns which cause surface water flooding, increasing the down time when terminals are not able to receive or dispatch goods. Ports are also particularly interested in data on storm surges, sea level rise and the joint probability of combined flooding events. Ports are also interested in climate data on wave action due to the likelihood of sedimentation and changing sea water temperature which contribute to algal blooms.

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66 Paleoclimate: a climate prevalent at a particular time in the geological past
67 Norway Directorate of Public Road session 10.05.16, Adaptation Futures Conference
Airports and ports are particularly concerned with climate data on:
- Temperature extremes (in relation to damages to access road and runway surfaces);
- Information on flooding;
- Wind storms: gusts over 100 knots, forecasting for cross and tail winds, trends including for thunder and lightning;
- Information on fog and relative humidity:
  - spatial variability and temporal fluctuations of surface visibility and low clouds;
  - intensity and type of reduced visibility.

Resolution data needs
In the rail road and airport sector, high resolution geo-referenced grids of solar radiation, or extreme heat, are required as well as climate projections that have been downscaled to a high resolution matching that of the observational data sets. Road operators need high resolution data sources relating to flood maps in order to assess the flood risks for specific infrastructure. For storm related vulnerabilities (causing damages to overhead lines for railways), somewhat lower resolutions might already be sufficient.

Other data needs (non-climate)
In addition to those cited above common to the infrastructure sector as a whole, to facilitate climate resilient infrastructure planning within the transport sector, non-climate data is also needed, including:
- Soil maps;
- Impervious surface maps;
- Current and future traffic / passenger patterns;
- Current and future international trade patterns.

4.3 Question 2: What information is available in terms of vulnerability and risk assessments in the transport sector?

4.3.1 General characterises of assessments within the sector:

Approach to assessing climate impacts

The majority of studies assessed focus on vulnerability assessments (56%), while 21% focus on risk assessments (21%), and 23% discussed both risk and vulnerability assessments equally (23%). In some cases where there are multiple actors and organisations coming together to commission such assessments, such as at a port location, the decision can be taken to undertake a vulnerability assessment over a risk assessment\[68\]. Where risk assessments are undertaken this can be followed by taking a value chain approach across affected assets\[69\].

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68 Port of Long Beach California Adaptation Futures Conference, 11.05.16

69 Considering impacts on goods storage, handling, equipment, building stock, e.g. in the case of Manzanillo Port, Mexico
Figure 19: Transport sector sources discussing vulnerability and/or risk assessments

Note: A total of 48 sources were assessed for the transport sector. 27 sources focus on vulnerability assessments, 10 on risk assessments, and 11 on both vulnerability and risk assessments.

Different approaches taken across the infrastructure sector

Of the different approaches to undertaking vulnerability and risk assessments identified, the ‘Multi-stakeholder & science-based’ approach was identified in 75% of the 48 transport sector sources and ‘Multi-stakeholder & science-based; CBA’ in 15%. Together ‘Multi-stakeholder’, ‘Science-based’, and ‘Science-based; CBA’ make up the remaining 10%.

Timeframes: As for the timeframe of assessments, studies covered different ranges, with a number of studies looking at long range impacts up to 2100. This is followed by the 2050s, with a few studies focused on the 2020s, in particular.
Figure 20: Breakdown of transport sector sources by timeframe of assessment

Note: The years listed above represent the preceding decades up to the stated year. A total of 37 sources were considered as a timeframe could not always be identified for all 48 of the transport sector sources.

**Target governance level**

Most sources covering transport are aimed primarily at national governance levels, followed by European levels, and then local and regional levels.

Figure 21: Target audience of transport sector sources

Note: A total of 48 sources were considered for the transport sector. It is possible, however, that each source has more than one target audience. 17 sources targeted an EU audience, 20 the national level, 8 regional, 9 local, and 4 the project/private level.
Infrastructural elements

The figure below illustrates the different infrastructure elements discussed in the transport sources. The majority of sources focused on roads (21%), closely followed by rail sector and bridges. Airport terminals and tunnels were also discussed equally, albeit less frequently (13%), followed by coverage on ports and airport taxiways and runways, which were tackled in a few publications.

![Infrastructural elements of the transport sector addressed in all sources](image)

**Figure 22: Infrastructural elements of the transport sector addressed in all sources**

Note: A total of 75 sources were reviewed. 44 sources discussed roads, 36 rail tracks, 33 bridges, 27 airport terminals and tunnels, 26 ports, and 19 airport taxi and runways.

4.3.2 Climate information used to perform assessment:

**Scenarios used:** Climate information used in the studies predominantly cite the Special Report on Emissions Scenarios (SRES) with approximately 20% of sources citing the Representative Concentration Pathways (RCPs), which the IPCC Fifth Assessment Report (2014) based its findings on. In many cases climate information was provided by the corresponding national meteorological service. Most studies refer to general circulation models (GCM), some refer specifically to the regional circulation models and a few studies refer to both.

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4.3.3 Findings

Key climate hazards
Key climate hazards and identified vulnerabilities within the transport sector are outlined in the table below:

<table>
<thead>
<tr>
<th>Climate hazards</th>
<th>Transport</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation</td>
<td>45</td>
</tr>
<tr>
<td>Temperature change</td>
<td>42</td>
</tr>
<tr>
<td>Sea level rise</td>
<td>39</td>
</tr>
<tr>
<td>Storm surge</td>
<td>37</td>
</tr>
<tr>
<td>Wind</td>
<td>34</td>
</tr>
<tr>
<td>Water scarcity/drought</td>
<td>28</td>
</tr>
<tr>
<td>Sea temperature</td>
<td>12</td>
</tr>
</tbody>
</table>

Climate hazards discussed most frequently in the transport sector are similar to the energy sector, in terms of a focus on precipitation and temperature change. However, these were followed closely by sea-level rise and storm surge, which are discussed slightly more than wind storms and water scarcity and significantly more than sea temperature. This reflects the findings regarding physical vulnerabilities and hotspots (see sections below) in that the main impacts to the transport sector in most of Europe are heavy precipitation and floods. Other key climate hazards cited include the increase in fog which is particularly relevant to the transport sector, as well as black ice, blizzards, increase in snow fall and increase forest fires. Heat waves are the main hazard for networks in southern and eastern Europe.\(^{53}\)

Key vulnerabilities

- Maritime navigation and ports are particularly vulnerable to storm surges, wave action, wind loading, sea temperature change;
- Inland waterways, lock and dam operations are most vulnerable to warmer temperatures, increase evaporation and water scarcity;
- Road, rail, airports are vulnerable to extreme high temperatures in terms of:
  - buckling and pavement sections experiencing heave;
  - runways not long enough to enable planes to take off as they experience less lift.\(^{71}\)
  - disruption of electrical power supply to supporting ancillary assets (for example electronic signing);
  - failure and malfunction of IT systems due to many of the assets being unprotected from extreme heat (overhead signs, surveillance cameras and many traffic signals).\(^{80}\)
- Road and rail networks:
  - along coastlines are vulnerable to marine erosion and storm overtopping, estuarine & river flooding, cliff instability and slope deformation;

\(^{71}\) US Phoenix: ‘flights were cancelled due to extreme temperatures and concern runway was not long enough for planes to take off’; Jacobs, J. and Lammerer, A., 2016 ‘Scenario 2: Minimising Disruption during extreme weather events’ in Turnbull, K. ‘Transportation Resilience: Adaptation to Climate Change and Extreme Weather Events. Summary of the Fourth EU-US Symposium on Transportation Research’ Conference Report 53, Transportation Research Board, National Academy of Sciences, Washington DC.
slopes will be vulnerable to potential changes and frequency of failures due to precipitation changes.

**Impacts of climate hazards without adaptation**

In terms of different types of impacts, without adaptation the sources focus specifically on damage to physical assets, rather than the economic and social impacts. Damage to physical assets is discussed above in relation to climate hazards, and in further detail in ‘Hotspots’ below.

- An example in Norway particularly highlights the fact that water from flooding does not behave as previously expected or stay in the water courses, due to unfavourable catchment conditions which require further hydrological modelling.
- Decrease of functionality of infrastructure due to rail rutting and buckling.

**Direct economic losses** are also expected in the form of increased spending for repairs and maintenance and loss of revenue due to limited functionality of the transport system. Furthermore, what can be perceived as relatively minor incidents such as small scale flooding, can result in severe economic impacts due to the interconnectivity of sectors. Assets, operations and user time costs and user safety across all transport sectors are discussed. As well as reduced network availability or functionality, increased costs to maintain a safe serviceable network.

**Observed costs** vary depending on definitions of extreme events, consideration of externalities and logistics:

- The WEATHER project estimates that between 1998 to 2010, the total costs borne by the transport sector (damages, repair and maintenance costs of infrastructures, vehicle damages, increased system operation costs) across all weather phenomena were estimated at EUR 2.5 billion per year. Indirect costs of transport disruptions on other sectors were estimated at EUR 1 billion per year. The EWENT project estimate is more than four times above the estimates of direct and indirect costs from the WEATHER project due to differences in definitions.

- UK, London: cost of floods in 2005 £29m; one incident disrupting the rail network in UK February 2014, due to a storm destroying a sea-wall together with a landslide, cost £40-50 million (includes the cost of repairs to the affected infrastructure and the compensation payable to passenger and freight train operators, and their customers).

**Projected costs:**

- Assessments of projected climate change impacts on transport, including the costs from extremes, ‘do not give a comprehensive overview of climate-related risks for transport across Europe owing to their widely different methodological approaches’

Globally, coastal assets at risk represent 9% of global GDP by 2070.

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72 For example, road tunnel flooding which occurred in a major industrial area in NL resulted in heavy congestion with traffic rerouted to a bridge, which in turn required stopping inland water transport as the bridge needs to be lowered for traffic flow; some commuters took trains led to further congestion on rail network. ‘Knowledge gaps for risk management in critical infrastructure’, Adaptation Futures Conference session 12.05.16

73 Case IA Modelling for London: the Tyndall Centre UIAF (Urban Integrated Assessment Facility), Tyndall Centre UIAF, 2011

74 West of Exeter Route Resilience Study, Network Rail, 2014

75 Climate Change: Implications for Transport, BSR, University of Cambridge, 2014
Projected damages arising from climate extremes from seven climate hazards (heat and cold waves, river and coastal flooding, streamflow droughts, wildfires and windstorms) within the transport sector suggest that the baseline estimated annual damages of €0.8 billion/year is expected to reach nearly €12 billion/year (a 15-fold increase) by the end of this century.

Rail: Projections for the period 2040–2050 (based on predictions of extremes taken from the EWENT project) suggest that rail will face the highest cost increase, with particular emphasis on the British Islands, central Europe and Scandinavia, mostly due to increases in hydrological extremes.

Roads: average precipitation-induced normal degradation of road transport infrastructures will only slightly increase in the future. However, more frequent extreme precipitations, fluvial and pluvial floods in different regions in Europe could result in an extra cost for road transport infrastructures (50-192 million €/yr for the A1B scenarios, period 2040–2100). Milder winter conditions are projected to result in reduced costs for road infrastructure (−170 to −508 million €/yr for the A1B scenarios), yet increasing average temperature all over Europe could require changes in maintenance operations and practices and represent extra costs.

Human losses /injuries: Extreme temperatures are often discussed, as this has implications for vulnerable groups, in terms of transport users and passenger comfort and safety; the increased safety risks posed to road and rail workers is also mentioned as they may need to work more often and also during extreme conditions.

Environmental impacts: environmental impacts are described in fairly general terms, such as the uncontrolled transport of pollution in water courses in the case of flooding and subsequent damage to ecosystems, faster plant growth, changes in road-side vegetation growth rates and impacts on maintenance regimes.

Positive impacts:
- One positive impact is that higher temperatures will increase road safety due to less snow, for example.

Hotspots
Hotspots for transport may be caused because the location itself is exposed to extreme weather (e.g. Atlantic coast of Europe), or because it is a key hub in a transport network. Such hotspots become significant where there is a combination of location vulnerability and transport corridor or hub which leads to ripple effects across the wider network and to other sectors.

- Areas where transport patterns are highly centralised, concentrating traffic through a smaller number of hubs: the relatively new market requirement for just in time services makes these systems very vulnerable to extreme weather events. Key transport hubs for Europe include Rotterdam, Hamburg, Le Havre, being major ports for Europe through which much traffic is channelled.
- Inland waterways: those waterways that are drought sensitive, where reduced water levels will not offer sufficient draught. Projected climate change until 2050 is unlikely to have a sufficient impact on reliability and cost effectiveness of some corridors; drier summers and wetter winters will gain in importance towards the end of the 21st century.
- Road, rail: in mountainous regions transport networks are expected to most vulnerable to intense rain and snow, and it is particularly difficult to predict which side rainfall will flow and how run-off will

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76 Impacts of climate change on transport: A focus on road and rail transport infrastructure, JRC, 2012
behave in this context. For example, flooding can completely reroute water courses by more than 500 feet in some locations. Projections also suggest that ‘rail transport will face particularly high risks from extreme weather events, mostly as a result of the projected increase in heavy rain events and limited route alternatives’. The angle of repose either side of the road/railway tracks is critical in relation to risks of avalanches and landslides.

- Roads vulnerable to flooding particularly in Central and northern Europe.
- Ports on the Atlantic coast are a hotspot due to sea-level rise and related extreme wave events much more so than those on the Mediterranean for example.
- Air: vulnerability of aviation to extreme events will further increase as free capacity (currently used to absorb the impact of weather events) ‘will increasingly be occupied by additional flights. Sea level rise and flooding could affect airports located in coastal areas across Europe, and increased extreme weather events (mainly increased wind and storms) would mainly affect northern, eastern, western and central Europe and would have operational impacts such as loss of capacity and increased delays’.

4.4 Question 3: What adaptation options are used in the transport sector?

The table below identifies the ten most frequently discussed measures in the sources covering adaptation in the transport sector:

| Table 9: Measures discussed most frequently in regards to the transport sector |
|-----------------------------|---------------------------------------------------------------|
| Transport sector measures   |                                                                 |
| 1 Dam, coastal, river defence |
| 2 Infrastructure strengthening |
| 3 Integrating into existing maintenance regimes & other plans; Programmes & standards |
| 4 Awareness raising          |
| 5 Increase network capacity  |
| 6 Training                   |
| 7 Water management with green elements |
| 8 Cross-sector working       |
| 9 Water management without green elements; Surveys |
| 10 Multiple actions (green measures) |

Note: Each measure was counted once if it was mentioned in a source. Measures listed in the same row are discussed in an equal number of sources.

An overview of the different categories and types of adaptation measures discussed in the transport sector is in the figure below. Please note that EbA measures with primarily temperature regulation action, as well as Urban trees, forests and greenspaces which perform multiple actions are in green; EbA measures which have primarily

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a water management action are in blue; grey measures are in grey; knowledge transfer actions in red, and operational actions in orange.

![Diagram: Breakdown of measures addressed in the transport sector](image)

**Figure 23: Breakdown of measures addressed in the transport sector**

Note: A total of 87 sources were considered for Question 3; however, transport sector measures were not identified in 33 sources, meaning 54 sources were ultimately considered. The percentages above stem from the prevalence of these measures in the 54 sources. A measure was counted once if discussed in a source, each source could contain references to more than one measure.

### 4.4.1 Structural measures

Within the structural options, grey solutions are more often discussed across the sources:

- **Infrastructure strengthening** is most frequently discussed in terms of
  - *Road, rail & airports:*
    - Strengthening bridges and tunnels, decrease bridge scour by supporting pillars from bridges.
    - Designing drainage systems\(^{57}\), such as culverts (size and location) need to take into account the watercourse as a continuous unit, as well as the issue of material
transport (e.g. stones, soil, larger objects such as dead sheep), as one blocked culvert causes significant unexpected impacts downstream. In some cases, the lessons from urban techniques of managing surface water run-off could be applied to non-urban contexts where necessary.

- Elevating runways, road & rail (elevating to a flood-safe height, horizontal alignment); construction of floating roads.²⁷
- Applying materials to withstand higher surface temperatures materials, heat-resistant paving materials, increase use in polymer-modified bitumen, polymeric grids to avoid rutting; for the rail sector this includes using materials that reflect radiation can decrease rail temperature by up to 3 degrees. This is particularly beneficial where the expansion of rails affects switches and crossings, changing the anchoring conditions (using stress-free temperature material).
- Relocating runways, rail and road network in some cases.

- **Ports, maritime**: Upgrading sediment traps is mentioned across port organisations, redevelopment of wharf fendering, increase quay levels, sea wall structures, use of different materials to withstand higher salt water erosion.
- **All transport types**: Transport infrastructure adjacent to coastlines is particularly vulnerable and beach nourishment is cited as an adaptation option to slow down rate of erosion but this does not prevent the erosion forces themselves.

  > **Construction of sea-walls, coastal and river defences** is discussed in relation to all transport types apart from airports.

  > **Increasing network capacity**:
    - For all transport types this requires climate resilient infrastructure to be implemented in all new transport projects, which aim to increase capacity.
    - Some measures in the transport sector can deliver adaption and increase the capacity, such supplementary road networks which can be used as storm water tunnels when required.²⁸
    - Increase (free transport) capacity to move vulnerable groups from transport facilities to shelters in times of extreme events, as experienced in the US.²⁹

With regard to other types of structural measures discussed, EbA measures that provide a mainly water management action (with and without green elements) are most frequently cited. Vegetation along transport corridors which deliver multiple adaptation actions such as trees will need to be more drought resistant. Such measures would include the following:

<table>
<thead>
<tr>
<th>Primary adaptation action</th>
<th>Measures</th>
</tr>
</thead>
</table>
| Water management with green elements | 🌿 green roofs  
  🌿 swales  
  🌿 filter strips  
  🌿 rain gardens  
  🌿 Channels and rills  
  🌿 WSUD/SUDS |
| Water management without green | 🌿 Permeable surfaces |

²⁷ ‘Floating or Elevated Roads’, Climate-ADAPT, 2015
²⁸ Stormwater Management and Road Tunnel (SMART), Kuala Lumpur
4.4.2 Non-structural measures

Regarding non-structural elements, the most frequently cited operational adaptation actions within the transport sector include:

- The creation and implementation of **programmes and standards** so that climate change also becomes part of the sector’s lexicon. The need to integrate climate change assessments and resilience measures into design criteria, traffic management and evacuation programmes, permitting and leasing processes. Examples were discussed at micro (individual locations) and macro (across transport modes, sectors, international standards) levels such as including climate change adaptation criteria into harbour development permit processes and plans as well as in terminal leases.

- **Integrating climate resilience into operational and maintenance regimes:**
  - Airports, road and rail: include increased maintenance of embankments, drainage sites, increased vegetation management to reduce risk in storms.
  - Rail: speed limits in the case of rail buckling in extreme heat.
  - Road, rail, maritime: increase in inspections intervals especially bridges.
  - Road: include new agreements with partners to provide portable pumps in flooding events, for example.
  - In the case of extreme events, monitor asset performance to identify when stress levels are approaching dangerous levels.
  - The increased use of early warning systems in terms of:
    - Sector infrastructure: through sensors and smart materials to provide advance warning of stresses caused by extreme environmental conditions;
    - Providing network capacity before, during and after extreme events.

With regards to **knowledge transfer actions**, awareness-raising measures, for example such as evacuation procedures, as part of a well-designed and communicated evacuation plan was mentioned in 12% of the sources as a relevant knowledge transfer action, followed by the provision of appropriate training.

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81 Discussion following Climate risk management and adaptation in Ports’ session, Adaptation Futures, 11.05.16

82 For example in the US, suggestion that all field staff to undertake training in river mechanics in the case of extreme rainfall ‘in order to lessen impacts to rivers and decrease potential for future damages’, develop public information materials to inform users of extreme event-related disruption; Jacobs, J. and Lammerer, A., 2016 ‘Scenario 2: Minimising Disruption during extreme weather events’ in Turnbull, K. ‘Transportation Resilience: Adaptation to Climate Change and Extreme Weather Events. Summary of the Fourth EU-US Symposium on Transportation Research’ Conference Report S3, Transportation Research Board, National Academy of Sciences, Washington DC.
Beyond adapting transport infrastructure: the roles of operators, transport users and ICT

Whilst this project focuses on the transport infrastructure itself, there is a clear role for transport operators to play with regard to facilitating intermodal shifts of transport and use patterns in times of disruption, for example, increasing network capacity in one transport mode, such as the rail network when another mode is impacted by a weather event, such as roads closed due to flooding. Another example is that the impact on road freight could be reduced to withstand ice and snow if the use of winter tyres were compulsory during certain conditions; this could prove more effective than increasing salting and gritting regimes, for example.

With regard to the transport sector in particular, the role of information and communications technologies (ICT) - and new collaborations beyond the transport sector - is highlighted as a way to minimise human and economic impacts during and after transport disruptions arising from extreme events. In one example in the US, following extreme rainfall event, ‘the Department of Transportation (DOT) system had been “brought to its knees.” With the system down, Google reached out to set up jointly a system for real-time mapping of closed roads, with public updates twice daily. By this time, the storm had passed and communities were stabilizing and assessing impacts. The mapping tool was widely used to (advise) travellers... Social media provided valuable updates throughout the event...the DOT also used a mobile phone microsite to allow for easy access to information and used social media to communicate conditions. Media outlets followed the DOT Facebook and Twitter accounts; at one point, five DOT administrators worked full-time maintaining the Facebook page.'

4.4.3 Costs and benefits of adaptation measures in the transport sector

The measured outcomes are variable, and will be context dependent (i.e. scale, location, specific measure or combination of measures) therefore the information included in the table below is a commentary on cost-effectiveness rather than a comparison of adaptation options. The table below focuses on measures applied in the transport sector.

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83 Using winter tyres is compulsory in some Member States.
Table 11: Costs & benefits of adaptation measures in the transport sector

<table>
<thead>
<tr>
<th>Measure</th>
<th>How does it reduce vulnerability</th>
<th>Economic values</th>
<th>Observed/ projected</th>
</tr>
</thead>
</table>
| Grey: Defending against sea level rise | • Prevents impacts from rising sea level                                                                                                                                                                                         | Denmark • Copenhagen: Net present values for rising sea levels (1 meter in 100 years) in million DKK. Damage cost without measures would amount to 20,098; the damage cost with measures would only be 189 DKK. The cost of the measure amounts to 3,997 DKK.  
[84](#) | Observed |
| Grey: Seawalls                | • Strengthen coastal protection against storm surges and rising sea level                                                                                                                                                          | Netherlands • Construction costs vary according to shape of structures but usually they require low maintenance. In the Netherlands it has been estimated that a seawall would cost 300-500 € per m³.  
[85](#)  
United Kingdom • In the UK estimates varied from £200,000 to £500,000 (250,000 – 625,000€)/100m length for seawalls.  
[85](#) | Observed |
| Grey: Jetties                 | • Strengthen coastal protection against storm surges                                                                                                                                                                               | Netherlands • In the Netherlands cost related to jetties are estimated at 10000 € to 20000 € per running meter. Costs mostly depend on availability of rock and water depth.  
[85](#) | Observed |
| Grey: Floating roads          | • Roads that float on the water                                                                                                                                                                                                   | Netherlands • "Floating roads are less expensive than bridges. Elevated roads on top of a bank are cheaper to construct than bridge-like roads, but both investments will only be returned once flooding occurs. After construction, both floating and elevated roads do not need more maintenance than any other road."  
[86](#) | Observed |
| Grey: Asphalt binder         | • Reduces impacts from extreme weather events such as flooding and heat on roads                                                                                                                                                   | Europe • Asphalt binder is the least costly measure and expected to cost 52-180 € million/year.  
• Current weather induced wear & tear and extreme weather costs 10,405 and 629 € million/year respectively.  
[87](#) | Projected |

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[84](#) Non-paper Guidelines for Project Managers: Making vulnerable investments climate resilient, DG Climate Action, 2011  
[85](#) ‘Seawalls and Jetties’, Climate-ADAPT, 2015  
[86](#) ‘Floating or Elevated Roads’, Climate-ADAPT, 2015
### Transport

<table>
<thead>
<tr>
<th>Measure</th>
<th>How does it reduce vulnerability</th>
<th>Economic values</th>
<th>Observed/projected</th>
</tr>
</thead>
</table>
| Grey: Self-healing concrete | • Potential to eliminate paving repairs after damage caused by de-icing | • The projected costs for asphalt binder in France amount to 6-15 € million/year.  
• Current weather induced wear & tear and extreme weather costs 535 and 133 € million/year respectively. | Projected |
| Grey: scour protection for river bridges | • Reduces risk to bridges associated with increasing river flood | • Overall cost in Europe for protection of bridges against bridge scour are projected 262-381 million/year.  
• Current weather induced wear & tear and extreme weather costs 10,405 and 629 € million/year respectively. | Projected |
| Operational: Speed limit restrictions | • Reduces impacts from heat-induced rail track buckling | • Speed limits result in delays assessed to represent roughly 0.01% of current travelling time. Adaptation costs in Europe amount to 25-48 € million annually. | Observed |

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87 Impacts of Climate Change on Transport: A focus on road and rail transport Infrastructures, JRC, 2012

88 Hendrik Marius Jonkers (The Netherlands): Finalist for the European Inventor Award 2015, European Patent Office
<table>
<thead>
<tr>
<th>Measure</th>
<th>How does it reduce vulnerability</th>
<th>Economic values</th>
<th>Observed/Projected</th>
</tr>
</thead>
</table>

For relevant EbA water management measures (i.e. basins and ponds, wetland restoration and management, and floodplain restoration and management), see **Table 16** in the Construction section.
4.5 Question 4: What decision-making tools, methodologies, and mechanisms are used to address these climate impacts and vulnerabilities in the transport sector?

4.5.1 Tools and methods discussed in the transport sector

For an overview of tools, methods and mechanisms which are used, or have the potential to be used by the transport sector, please see Chapter 2.

The figure below illustrates the different types of mechanisms that are being discussed in sources covering the transport sector as opportunities for addressing the impacts of climate change.

![Mechanisms used in the transport sector](image)

**Figure 24: Mechanisms for adaptation used in the transport sector**

Note: A total of 87 sources were considered for Question 4; however, transport sector mechanisms were not identified in 35 sources, meaning 52 sources were ultimately considered. The percentages above stem from the prevalence of these mechanisms in the 52 sources. Each measure type was counted once if it appeared in a source but each source could contain references to more than one mechanism and multiple references to the same mechanism.
4.5.2 Case study illustrating how the transport sector is adapting

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**Case study: Adaptation of transport sector, France**

**Situation:** Significant climate challenges were identified in climate vulnerability studies (in 2011 and 2012) in the framework of the French National Climate Change Adaptation Plan. Some of these climate challenges include an increase in average temperature (up to $+3.5\, ^\circ\mathrm{C}$); increased surface water flows in winter and severe low flows in summer; uncertainty regarding expected changes in wind; and increased frequency and intensity of extreme weather events. Such climatic shifts present challenges to transport infrastructure and make clear the need to update existing adaptation-related standards in the transport sector. To do so, the Ministry of Ecology, Sustainable Development and Energy (DGITM), requested that Cerema (Centre d’Études et d’Expérience sur les Risques, l’Environnement, la Mobilité et l’Aménagement) undertake a systematic review & screening of standards and guidelines on the design, maintenance and operation of transport infrastructures. The review was completed in 2015.

**Mechanisms used:** National review requested of transport standards and guidelines following vulnerability assessment by classifying climate-related standards into 3 groups: (1) those with no need for revision (e.g. road traffic noise, road drainage guidelines); (2) those in need of revision (e.g. road pavement design, general actions for aquatic structure), and (3) those needing more precise information of the climatic variables and indicators (e.g. design and construction of new roads, guidance on road embankments, maintenance of urban roads).

**Outcomes:**
- Hundreds of standards (over 800 for roads alone) with life spans of 25 to 100 years were revised;
- Comprehensive list of other revisions to be made including climate-related information like timing and extent of climate impacts;
- Long-term savings in operating and maintenance costs of transport infrastructure;
- Innovate approach to transport infrastructure adaptation employed, characterised by partnerships with climate experts, mobilisation of in-house knowledge, and transparency; and
- Resilient transport infrastructure.

Source: Climate-ADAPT

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4.6 Gaps and recommendations specific to the transport sector

Where gaps have been identified regarding the transport sector which are common to the infrastructure sector as a whole, these are covered in Chapter 6 ‘Gaps and Recommendations’. Gaps inhibiting adaptation specific to the transport sector are listed in the table below, together with suggested recommendations.
## Table 12: Gaps and recommendations for the transport sector

<table>
<thead>
<tr>
<th>Gaps discussed in transport sector</th>
<th>Recommendation</th>
<th>Level to be addressed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The potential to integrate climate change considerations more fully into existing training, operational and maintenance regimes is not fully realised.</td>
<td>Increase training and inspection regimes and monitor asset performance to identify when stress levels are approaching potential critical thresholds.</td>
<td>Transport Operators</td>
</tr>
<tr>
<td>2. Understanding the transport sector’s current and future vulnerabilities across modes, including inter-modal vulnerability assessments and the potential for integrated adaptive solutions across and beyond the transport sector.</td>
<td>Undertake inter-modal transport vulnerability assessments addressing current as well as future impacts, based on socio-economic, political and service implications; Identify and prioritise adaptation options through collaborative working across transport modes and to key stakeholders beyond transport sector.</td>
<td>Transport Operators</td>
</tr>
<tr>
<td>3. Lack of coordinated action plans to assess, prioritise and implement adaptation actions across different transport modes, agencies and different governance levels.</td>
<td>Increase coordinated planning among different transport agencies, including when transport agencies are responsible for similar assets (e.g. pavements and structures) at different levels of governance.</td>
<td>National and regional authorities together with transport operators</td>
</tr>
</tbody>
</table>

---

80 When some transport modes, such as inland waterways experience reduced resilience because of the long-term nature of the disruption (low water levels) other transport modes can adapt more quickly. Meyer, M. and O’Connor, A., 2016 ‘Scenario 3: Drought, Heat, and Extreme Temperatures’ in Turnbull, K. ‘Transportation Resilience: Adaptation to Climate Change and Extreme Weather Events. Summary of the Fourth EU-US Symposium on Transportation Research’ Conference Report 53, Transportation Research Board, National Academy of Sciences, Washington DC.
5 Construction

5.1 Key messages

**Climate and data needs:** Regarding future climate data projections, the construction sector requires climate projections data up to 2050 to understand cooling and heating trends and up to 2080 to reflect the lifetime of infrastructure development and its resilience to climate impacts. The construction sector requires data at very high resolution (below 1km, at building level), particularly in the urban context relating to interactions with the Urban Heat Island effect.

**Vulnerability and risk assessments:** Vulnerability within the construction sector is described and categorised in many different ways depending on the source assessed: some discuss socio-economic vulnerability as a function of the population age, health and well-being; vulnerability of the structure: related to its built form (density, height, age, use orientation and proximity to greenspace), and a combination of these two types of vulnerability can present the temperature-related risk, for example. With regard to urban heat risk in particular, this can be described as a triple risk of location, building characteristics and characteristics of the buildings’ occupiers.

**Hotspots:**
- Keeping buildings and external spaces cooler or warmer;
- Maintaining structural stability below and above ground, in light of water scarcity and subsistence and fluvial, pluvial and coastal flooding;
- Identifying and classifying critical infrastructure within the construction sector, which could be considered as buildings whose continuing use is essential to the maintenance of services to the population for their security and safety and that need to remain operational Geographical locations include:
  - Urban areas: the challenge of dealing with the urban heat island effect exacerbated by climate change stretching from northern Europe down to southern, eastern and central parts of Europe; furthermore the risk of forest fires has increased for cities in Portugal, Greece, southern France and Italy.
  - Coastal areas due to the multiple threats of storms, fluvial, pluvial and coastal flooding, and coastal erosion, particularly in the north and north-west regions of Europe;
  - Along the floodplains in central and western Europe.

**Adaptation options:** The top three types of adaptation options discussed are:
- Structural, grey measures that involve buildings materials, site selection, structural design, and infrastructure strengthening;
- Awareness raising (non-structural) in terms of the variety guidance and checklists that have been developed for planners, developers, owners and users of buildings in and training within the profession; and
- EbA (structural) measures which perform a water management action.

**Mechanisms prompting the sector to adapt:** Legislation is the mechanism the most frequently discussed across the sources, followed by spatial and land-use planning and industry-wide standards. In terms of the development of industry-wide standards, some nationally developed standards are being adopted internationally: BREEAM the UK green building rating system is used globally mostly in the commercial sector; new versions (2015 and beyond) have a new credit to require resiliency risk assessment for the project.
5.2 Question 1: What (climate) data is needed for the assessment of climate impacts in the construction sector?

**Timeframes**

Within the construction sector the need for observed climate data varies between 5 to 30 years (e.g. heating and cooling degree days can either be derived by a long-time climatic average or short-term, e.g. current weather). Due to the fact that, among others, ventilation, heating and cooling simulations as well as simulations of load curves operate with very short time intervals, data sets below one hour and up to 15 minutes are needed. Additionally, daily, monthly and seasonal figures are used for study and research in the construction sector. Regarding the timeframe for climate data projections, needs can be described in terms of:

1. Climate projections up to 2050 in particular, to understand cooling and heating trends;
2. Climate projections up to 2080, to reflect the lifetime of infrastructure development and its resilience to climate impacts.

**Climate variables**

Aspects such as site selection, construction technique and materials are all influenced by long-term, slower onset climate impacts such as coastal erosion, sea-level rise, temperature rise (related to projections for heatwaves and the contribution to the Urban Heat Island effect) and droughts (relating to subsidence), as well as short-term impacts such as flooding, freezing cycles and storms.

In terms of climate data needs relating to extreme weather events, the following were most frequently cited:

- Intense precipitation (cloudbursts), and changes in return periods for such events;
- Hail: changes in patterns, frequency and duration (due to the extensive damage to building structures that can occur);
- Wind storms;
- Freezing and melting cycles (due to extensive damage to buildings that can occur, e.g. frost bursting);
- Information on relative humidity (regarding cooling and heating aspects);
- 4th day heatwave data.

The construction sector is also particularly interested in information (observed and projected) regarding landslides.

**Resolution of data sources**

The construction sector need climate data at very high resolution – below 1km – as this information is vital in the urban context and how this interacts with the Urban Heat Island effect and the changing nature of the albedo of buildings.

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90 Heating and cooling degree days express the severity of the cold and the heat over a specific time period taking into consideration outdoor temperature and room temperature. External and internal building conditions may require additional energy for cooling and ventilation in order to meet a defined comfort level.
Other data needs (non-climate)
In addition to those cited above which are common to the infrastructure sector as a whole, specific needs around the cooling effect of greening at the local level (building level as well as city-scale) are cited, including the temperature mitigation potential of vegetation, the impacts of green roofs combined with climate scenarios up to the 2040s.

5.3 Question 2: What information is available in terms of vulnerability and risk assessments in the construction sector?

5.3.1 General characterises of assessments within the sector

Approach to assessing climate impacts
Slightly over half of the construction sector sources focus on vulnerability assessments specifically (54%), compared to 25% focussing on risk assessments and 21% focussing on both vulnerability and risk assessments (21%).

![Construction sector sources discussing vulnerability and/or risk assessments](image)

**Figure 25: Construction sector sources discussing vulnerability and/or risk assessments**
Note: A total of 28 sources were assessed for the construction sector. 15 sources focus on vulnerability assessments, 7 on risks assessments, and 6 on both vulnerability and risk assessments.

Different approaches taken across the infrastructure sector
Of the different approaches to undertaking vulnerability and risk assessments identified, the ‘Multi-stakeholder & science-based’ approach was identified in 61% of the 28 construction sector sources. This was followed by ‘Multi-stakeholder & science-based; CBA’, approach which was identified in 25% of the sources.
**Timeframe:**

An equal number of sources assessed cover up to 2050s and up to 2100s when discussing climate projections.

**Figure 26: Breakdown of construction sector sources by timeframe of assessment**

Note: The years listed above represent the preceding decades up to the stated year. A total of 17 sources were considered as a timeframe could not always be identified for all 28 of the construction sector sources.

**Target governance level**

Unlike the energy and transport sectors, the majority of sources addressing adaptation in the construction sector appear to be aimed primarily at European level audiences, followed by sources aimed at local and national levels. A few reports are focused on the regional (sub national) and international levels and as with all sectors, while a minority of reports are aimed mainly at the project or private sector levels.

**Figure 27: Target audience of construction sector sources**
Note: A total of 28 sources were considered for the construction sector. It is possible, however, that each source has more than one target audience. 14 sources targeted primarily an EU level audience, 7 the national level, 5 regional, 8 local, and 3 the project/private level.

**Infrastructural elements**

The figure below illustrates the different infrastructural elements discussed in the sources covering construction:

![Infrastructural elements of the construction sector addressed in all sources](image)

**Figure 28: Infrastructural elements of the construction sector addressed in all sources**

Note: A total of 75 sources were considered. 32 sources discussed design, 22 buildings surfaces, 19 construction materials, 17 insulation, 12 technical components, 11 roofs.

The majority of sources focus on integrating adaptation at the design stage, as it is at this stage that the most opportunities to embed climate resilience and adaptation options lie. This is followed by a focus of reports discussing building surfaces in particular, due to the increased incidence of higher temperatures contributing to the urban heat island effect as well as increased incidence of flooding; this is followed by construction materials in general, then insulation, technical components and roofs.

### 5.3.2 Climate information used to perform assessment\(^5\):

Nearly four times as many sources focused on using the SRES scenarios compared to the estimated use of RCPs. The majority of sources mention Global Circulation Models (GCMs) compared to Regional Circulation Models (RCMs); one report\(^9\) used loosely couple models (LCMs) which can represent the outputs of a GCM based earth system model.

\(^{91}\) Reducing urban heat risk, Arup, 2014
5.3.3 Findings

Key climate hazards

Key climate hazards and identified vulnerabilities within the construction sector are outlined in the table below:

Table 13: Climate hazards addressed by construction sources

<table>
<thead>
<tr>
<th>Climate hazards</th>
<th>Construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation</td>
<td>22</td>
</tr>
<tr>
<td>Temperature change</td>
<td>21</td>
</tr>
<tr>
<td>Storm surge</td>
<td>20</td>
</tr>
<tr>
<td>Sea level rise</td>
<td>19</td>
</tr>
<tr>
<td>Wind</td>
<td>15</td>
</tr>
<tr>
<td>Water scarcity/drought</td>
<td>13</td>
</tr>
<tr>
<td>Sea temperature</td>
<td>4</td>
</tr>
</tbody>
</table>

As is the case in the other sectors, sources discussing climate hazards relevant to the construction sector covered precipitation and temperature change the most, followed very closely by storm surges and sea-level rise, which were discussed more than wind, water scarcity, and sea temperature. Other climate hazards mentioned include fog, forest fires, snow and blizzards, fluvial flooding in particular, saturated water catchments and lightning.

Key vulnerabilities

- Vulnerabilities are discussed and classified in different ways in the sources; some discuss three broad categories:
  - those that affect comfort and energy performance (heating and cooling);
  - those that affect the construction itself (resistance to extreme conditions, detailing, and the behaviour of materials); and
  - managing water: in terms of flooding and also in the case of water scarcity, risks of subsidence, and pressure on drinking water resources.

- Other sources discuss vulnerability in relation to the construction sector in different ways:
  - socio-economic vulnerability: a function of the population age, health and well-being;
  - vulnerability of the structure: related to its built form (density, height, age, use orientation and proximity to greenspace).
  
  A combination of these two types of vulnerability can be then used to present the temperature-related risk, for example. With regard to urban heat risk in particular, this is described as a triple risk of location, building characteristics and characteristics of people.

- Many sources discuss vulnerable groups occupying the buildings and how temperature rise will impact an aging population, the young and infirm;

- Flood risk as a threat to buildings and construction is mentioned throughout most sources as a general risk arising from fluvial, pluvial and coastal flooding in terms of reduction of land suitable for building or possible relocation of communities (see the example of Eferdinger Becken, Austria below).

Impacts of climate hazards without adaptation

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92 UK: Reducing Urban Heat Risk, Arup, 2014
In terms of different types of impacts without adaptation, the sources focus specifically on damage to physical assets.

- **Damage to physical assets** is discussed above in relation to climate hazards, and in further detail in ‘Hotspots’ below. Impacts of climate hazards without adaptation are expected to mostly affect physical assets as a result of floods and heat waves, amplifying existing flaws in poor building design. With regard to flooding, 20% of the 411 European cities are ‘continuing to spread into areas potentially prone to river floods during the period 2006–2009, thus increasing their sensitivity to the impacts of flooding’\(^9\). Increase in wind damage is also mentioned throughout the sources. Forest fires are mentioned in southern European countries, especially with the increase in ‘urban sprawl with low-density housing (which) has led to a growing intermingling of wild land and urban areas’\(^9\). The physical damage also extends to damage of cultural assets.

- **Human losses /injuries** were discussed in general terms covering:
  - Human relocation;
  - Impact on human health due to extreme temperatures, floods and wild fires;
  - Reduced quality of life, discomfort and distress (physical and psychological) through relocation, temporary or permanent.

- **Economic losses**: economic impacts of climate change are discussed with regards to indirect economic impacts such as the loss of productivity due to thermal comfort in houses and workplace, for example. Many sources cite costs but do not separate the construction sector specifically.

**Observed costs of extreme events (Europe)**: the EEA\(^9\) attributes increased in observed damages due to population rise, economic wealth, human activities in hazard-prone areas and better reporting:
  - Hydro-meteorological events (storms, floods, and landslides) account for 64% of the reported damages due to natural disasters in Europe since 1980;
  - Climatological events (extreme temperatures, droughts and forest fires) account for another 20%;
  - Overall damages from extreme weather events have increased from EUR 9 billion in the 1980s to more than EUR 13 billion in the 2000s (inflation-corrected).

There are a variety of sources that calculate the cost of individual past events at sub-national level, which do not necessarily separate the construction sector, for example in the UK, the cost of floods in London in 2005 is estimated to be £29 m\(^9\).

**Projected costs of climate change**: The EEA states that for impacts of climate change at European level, the ‘cost estimates are not available or very incomplete for infrastructure, built environment, tourism, transport and forestry’. Another study reviewed existing tools to estimate damage costs and concluded that ‘state of the art of existing methods and tools for damage estimation was reviewed ... none of the existing methods is suitable for precise prediction of the damage of floods to individual buildings, taking into account all their individual characteristics’\(^9\).

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\(^9\) Climate change, impacts and vulnerability in Europe, EEA, 2012

\(^9\) Case IA Modelling for London: the Tyndall Centre UIAF (Urban Integrated Assessment Facility), Tyndall Centre, 2011

\(^9\) Assessment of the vulnerability of critical infrastructure buildings to floods, Nicholas Warren, 2012
The ClimateCost study\(^{96}\) details the annual costs in Europe due to sea-level rise alone could cost €11 billion (mid estimate) for the 2050s, rising to €25 billion by the 2080s (combined effects of climate and socio-economic change, based on current prices, with no discounting). Whilst the study does not separate costs to the construction sector specifically, the costs include direct impacts, salinisation, costs of moving and land loss.

- Most costly impacts vary by region and climate hazard:
  - Southern Europe: due to increase in energy demand and heat waves;
  - Western Europe due to coastal flooding and heat waves;
  - Northern Europe due to coastal and river floods;
  - Eastern Europe due to river floods;
  - North-west Europe due to sea level rise.

- **Environmental impacts**: environmental impacts are described in fairly general terms, such as the uncontrolled transport of pollution in water courses in the case of flooding and subsequent damage to ecosystems, faster plant growth.

- **Positive impacts**:
  - Reductions in fuel poverty due to reduced need for heating, due to rising wintertime temperature in northern, eastern and central Europe.

### Hotspots

Hotspots can be classified in terms of the building itself and the geographic location in Europe. Those hotspots relating the building itself that are frequently discussed in the sources include:

- Keeping buildings and external spaces cooler or warmer;
- Maintaining structural stability below and above ground, in light of water scarcity and subsistence and fluvial, pluvial and coastal flooding;
- Identifying and classifying critical infrastructure within the construction sector, which could be considered as buildings ‘whose continuing use is essential to the maintenance of services to the population for their security and safety and that need to remain operational (including)... the organisation networks of health, security and emergency services.’ \(^{97}\)

Hotspots relating to a geographic location include buildings situated in:

- Urban areas: the challenge of dealing with the urban heat island effect exacerbated by climate change stretching from northern Europe (from southern UK) down to southern, eastern and central parts of Europe; furthermore the risk of forest fires has increased for cities in Portugal, Greece, Southern France and Italy\(^{53}\);
- Coastal areas due to the multiple threats of storms, fluvial, pluvial and coastal flooding, and coastal erosion, particularly in the north and north-west regions of Europe;
- Along the floodplains in Central and Western Europe.

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\(^{96}\) Sea-Level Rise: The Impacts and Economic Costs of Sea-Level Rise on Coastal Zones in the EU and the Costs and Benefits of Adaptation, ClimateCost, 2011

\(^{97}\) FLOODPROBE: Assessment of the vulnerability of critical infrastructure buildings to floods, 2012
5.4 Question 3: What adaptation options are used in the construction sector?

The table below identifies the ten most frequently discussed measures in the sources covering adaptation in the construction sector:

Table 14: Measures discussed most frequently in regards to the construction sector

<table>
<thead>
<tr>
<th>Construction sector measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Water management with green elements</td>
</tr>
<tr>
<td>2. Building materials</td>
</tr>
<tr>
<td>3. Awareness raising; Integrating into existing maintenance regimes &amp; other plans</td>
</tr>
<tr>
<td>4. Structural design</td>
</tr>
<tr>
<td>5. Site selection</td>
</tr>
<tr>
<td>6. Water management without green elements</td>
</tr>
<tr>
<td>7. Training</td>
</tr>
<tr>
<td>8. Programmes &amp; standards</td>
</tr>
<tr>
<td>9. Multiple actions (green measures); Cross-sector working</td>
</tr>
<tr>
<td>10. Infrastructure strengthening</td>
</tr>
</tbody>
</table>

Note: Each measure was counted once if it was mentioned in a source. Measures listed in the same row are discussed in an equal number of sources.
An overview of the different categories and types of adaptation measures discussed in the construction sector is in the figure below.

Legend: Please note that EbA measures with primarily temperature regulation action, as well as Urban trees, forests and greenspaces which perform multiple actions are in green; EbA measures which have primarily a water management action are in blue; grey measures are in grey; knowledge transfer actions in red, and operational actions in orange.

Figure 29: Breakdown of measures addressed in the construction sector

Note: A total of 87 sources were considered for Question 3; however, construction sector measures could not be identified in 50 sources, meaning 37 sources were ultimately considered. The percentages above stem from the prevalence of these measures in the 37 sources. A measure was counted once if discussed in a source; each source could contain references to more than one measure.

5.4.1 Structural measures

Within the structural options, grey solutions are most widely discussed, in terms of
› **Building materials**: with a focus on materials to reduce the albedo effect of buildings and heat gain or to increase the flood resilience of the building and building envelope;

› **Structural design of buildings**: to maximise opportunities for passive heating and cooling, increased water efficiency and reduced flood ingress;

› **Site selection**: taking account of flooding, zoning and spatial planning to increase resilience to climate impacts as far as possible, whilst at individual location level, considering building orientation, shading.

In terms of EbA structural measures, all types measures that have been identified as part of this project (see table below for the full list of measures) are discussed in the sources with regard to the construction sector.

**Table 15: Table of EbA measures applicable to construction infrastructure**

<table>
<thead>
<tr>
<th>Primary adaptation action</th>
<th>Measures</th>
</tr>
</thead>
</table>
| Water management with green elements            | - green roofs  
- swales  
- filter strips  
- rain gardens  
- Channels and rills  
- WSUD/SUDS |
| Water management without green elements         | - Permeable surfaces  
- soakaways  
- Infiltration trenches  
- Detention basins  
- Retention ponds  
- Infiltration basins |
| Multiple actions                                 | - urban trees and forests  
- urban greenspace |

EbA solutions discussed in relation to the construction sector are:

› measures that perform a **water management function together with a green element**[^98], such as green roofs, swales, filter strips, rain gardens, channels and rills, WSUD/SUDS;

› measures which provide both a **water management and temperature regulation** at the same time, such as urban trees, forests and urban greenspace were discussed equally to **water management measures without green elements**, such as permeable surfaces, soakaways, infiltration trenches, detention basins, retention ponds and infiltration basins.

### 5.4.2 Non-structural measures

Regarding non-structural measures, knowledge transfer actions are discussed the most, in terms of

› **awareness raising** for example of
  - Planners, developers[^99],


o users of buildings in terms of flooding\textsuperscript{100}, increasing water efficiency\textsuperscript{101} through change in practice, and;

> providing training are the most relevant knowledge transfer actions.

The most frequently cited operational adaptation measures have to do with:

> integrating climate hazards into existing maintenance regimes and other plans: this occurs both at the building owner level, but also by local authorities and industry professionals in terms of surveying, product installation and maintenance stages for example. These types of actions are often promoted through knowledge transfer actions discussed above, followed by

> the creation and implementation of programmes and standards including for specific construction technologies, through an industry driven standard, which provides a benchmark for climate resilience technologies\textsuperscript{102}.

5.4.3 Cost & benefits of adaptation measures in the construction sector

The measured outcomes are variable, and will be context dependent (i.e. scale, location, specific measure or combination of measures) therefore the information included in the table below is a commentary on cost-effectiveness rather than a comparison of adaptation options. The table below focuses on measures applied in the construction sector.

\textsuperscript{99} UK: SMARTeST: Smart Resilience: Technologies, Tools and Systems Guidance for local authorities and professionals against flood protection

\textsuperscript{100} UK: SMARTeST: Smart Resilience: Technologies, Tools and Systems Guidance for property owners against flood protection

\textsuperscript{101} Case IA Modelling for London: the Tyndall Centre UIAF (Urban Integrated Assessment Facility), Tyndall Centre, 2011

\textsuperscript{102} For example the UK standard PAS 1188 (BSI 2009) is an industry driven standard, which provides a benchmark for flood resilience technologies
### Table 16: Costs & benefits of adaptation measures in the construction sector

<table>
<thead>
<tr>
<th>Measure</th>
<th>How does it reduce vulnerability</th>
<th>Economic values</th>
<th>Observed/Projected</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Grey: Seawalls</strong></td>
<td>• Strengthen coastal protection against storm surges and rising sea level</td>
<td>Netherlands</td>
<td>Projected</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Construction costs vary according to shape of structures but usually they require low maintenance. In the Netherlands it has been estimated that a seawall would cost 300-500 € per m³.¹⁰³</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>United Kingdom</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• In the UK estimates varied from £200,000 to £500,000/100m length for seawalls¹⁰³</td>
<td></td>
</tr>
<tr>
<td><strong>Grey: Jetties</strong></td>
<td>• Strengthen coastal protection against storm surges</td>
<td>Netherlands</td>
<td>Projected</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• In the Netherlands cost related to jetties are estimated at €10,000 to € 20,000 per running meter. Costs mostly depend on availability of rock and water depth¹⁰³</td>
<td></td>
</tr>
<tr>
<td><strong>Grey: Floating houses</strong></td>
<td>• Protection against flooding and water level rise</td>
<td>Netherlands</td>
<td>Observed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Ground price is a determining factor in development of new houses. The price of water surface area is lower compared to typical building ground.</td>
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<tr>
<td></td>
<td></td>
<td>• Floating houses have higher building costs. The investments ins usually returned in less than 10 years.</td>
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<tr>
<td></td>
<td></td>
<td>Flood residence capacity has a positive effect on their value.¹⁰⁴</td>
<td></td>
</tr>
<tr>
<td><strong>Grey: Relocation of houses</strong></td>
<td>• Houses are moved into protected areas</td>
<td>Austria</td>
<td>Observed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Erferdinger Becken in Austria has no protection against floods with a 1:100 year probability; the area covers 24 hectares including around 130 houses.</td>
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<tr>
<td></td>
<td></td>
<td>• It is cheaper to relocate these houses than designing and implementing flood protection. The governments compensate citizens for 80% of the value of the house if they move:¹⁰⁵</td>
<td></td>
</tr>
<tr>
<td><strong>Grey: Non-return</strong></td>
<td>• Reducing the impact from extreme rainfall in Denmark</td>
<td>Denmark</td>
<td>Observed</td>
</tr>
</tbody>
</table>


### Building

<table>
<thead>
<tr>
<th>Measure</th>
<th>How does it reduce vulnerability</th>
<th>Economic values</th>
<th>Observed/ projected</th>
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</thead>
<tbody>
<tr>
<td>valves c.f. increase sewer capacity</td>
<td>Copenhagen</td>
<td>Copenhagen: Net present value for extreme rainfall in DKK: Damage cost without measures would amount to 15,552. Damage cost with the cheapest measures (non-return valves) would amount to 4,316 whereas damage cost with the most expensive measure (increased sewer capacity network) would amount to 5,458. There is a gain in preventing flooding for the cheapest measure but not for the most expensive one.</td>
<td></td>
</tr>
</tbody>
</table>

**EbA: Green roofs**

- Green roofs can reduce rainwater runoff.
- Store/slow run off (literature indicates wide variation 5%-100% rainfall retention).
- Increased Evapotranspiration.
- Reduce peak temperature, Bass et al (2003), modelled the influence of 50% green roof coverage in the city of Toronto, and found temperature reductions of up to 2 °C.

- Germany
  - The city of Hamburg estimated that adapting the urban sewage system would cost tens of billions of EUR. With green roofs it expects to decrease the need for future investments into the drainage system. Green roofs reduce the outcome of strong rain and relieve the sewers by holding back 40 to 90% of rain water.106

- Helsinki, Finland
  - 50 €/m² (+VAT 24 %, = 62 €/m²). The additional costs include the sedum mats (around 53% of the additional costs), the additional installation costs (around 24% of the additional costs) and additional taxes (23%). Some studies suggest that a new industrial building could require up to 45% increase in building structural costs in order to accommodate a green roof with a design load of 125 kg/m².3
  - Energy savings - cooling €1.9 /m² –€8.5 /m², heating €3.3 /m² –€24 /m²
  - Air-quality benefits (average benefits in Helsinki) €4.8 /m² –€6.9 /m²
  - Storm-water management (average benefits in Helsinki) €1.9 /m² –3€.4 /m²
  - €25–€130 per m² extensive green roof area €130–€300 per m² area for intensive green roofs. Maintenance Up to €55 per m² area per visit107

- Denmark
  - Copenhagen: The Cloudburst project is concerned with the storage and transfer of water during heavy rain events to reduce the impact of pluvial flooding in Copenhagen. The costs of pluvial flooding are estimated at 16 bn DKK, the investment cost for an upgraded sewer drainage system is €2.68bn (20 bn DKK) suggesting a net loss of

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106 Non-paper Guidelines for Project Managers: Making vulnerable investments climate resilient, DG Climate Action, 2011

<table>
<thead>
<tr>
<th>Measure</th>
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<th>Economic values</th>
<th>Observed/ projected</th>
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<tbody>
<tr>
<td><strong>Building</strong></td>
<td></td>
<td>€537m (4 bn DKK). However a combined system including elements of both drainage (grey measures) combined with green infrastructure to slow and store storm water is estimated to cost €1.74bn (13 bn DKK) indicating a net benefit of €403m (3 bn DKK).</td>
<td></td>
</tr>
</tbody>
</table>
| EbA: Urban forest parks and trees | • Not quantified, but will including slowing and storing run-off, increasing evapotranspiration and infiltration, and providing temperature regulation. | Barcelona: trees tempering the Mediterranean city climate  
• Costs: €9.3M /yr for 20 yr (€186M).  
• Remove over 305 tons of air pollutants at a value of €1.12M/yr,  
• 13,000 tons of Carbon storage/yr | Observed  
| | | Projected | |
| EbA: Dune construction and strengthening | • Not stated | • Dune grass planting: €250-2000/100m  
• Dune thatching: €250-2500/100m  
• Dune fencing: €500-2500/100m | Observed | |
| EbA: Beach and shoreface nourishment | • Not stated | • Costs are variable and depend on the volume of dredged material required, the distance from dredging site to beach and the frequency of replenishment.  
• Estimated costs for Europe are €4-6 per cubic metre of sand, for the UK the costs are €3.5-35 per cubic metre and for the Netherlands these are lower at €2-6 per cubic metre.  
• The annual volume of sand used in the Netherlands is 12 million cubic metres giving an annual total cost of €24-72m  
• SNH (2000) provide a cost of €6300-251700 per 100m of beach frontage. | Observed | |
| EbA: Floodplain | • Store/slow run off | • Large scale project > 10 ha, Land acquisition costs dependant on land use but can | Projected | |

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108 [http://international.kk.dk/artikel/climate-adaptation](http://international.kk.dk/artikel/climate-adaptation)  
109 ‘Individual NWRM Urban Forest Parks’, European Commission  
110 ‘Barcelona Trees Tempering the Mediterranean City Climate’, Climate-ADAPT, 2016  
111 ‘Dune Construction and Strengthening’. Climate-ADAPT, 2015  
112 ‘Beach and Shoreface Nourishment’, Climate-ADAPT, 2015
### Building

<table>
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<th>Measure</th>
<th>How does it reduce vulnerability</th>
<th>Economic values</th>
<th>Observed/ projected</th>
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</thead>
<tbody>
<tr>
<td>restoration and management</td>
<td>• Store/slow river water</td>
<td>range from 700,000€/ha in residential areas to 10,000 €/ha in agricultural areas.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Groundwater recharge</td>
<td>• Dyke heightening Standard 300–2,000 €/m, Wall on top 800–2,500 €/m.</td>
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<tr>
<td></td>
<td>• Increase evapotranspiration</td>
<td>• Sheet pile wall 3500–5,000 €/m, Quay wall (Antwerp) 6,100 €/m.</td>
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<tr>
<td></td>
<td>• Increase soil water retention</td>
<td>• Flood control area Inner dike adaptation 770 €/m, Outer dike construction 840 €/m.</td>
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<td></td>
<td>• Reduce peak temperatures</td>
<td>• Outlet sluices 19,000 €/ha, Inlet sluices CRT 4,000 €/ha.</td>
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<tr>
<td></td>
<td></td>
<td>• Engineering cost: 10% of investment costs.</td>
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<td></td>
<td></td>
<td>• Maintenance Costs 0.5–1.5% investment costs.</td>
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<td></td>
<td></td>
<td>• Other costs 5% investment costs.</td>
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<td></td>
<td>Sigma Plan, Belgium (incl. restoration of coastal wetlands)</td>
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<td></td>
<td></td>
<td>• €1056m Sigma Plan</td>
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<td></td>
<td></td>
<td>• Safety benefits of the optimal scenario were estimated to be €736m</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>• ES benefits ranging from €143m– €984m113, 115</td>
<td></td>
</tr>
<tr>
<td>EbA: Swales</td>
<td>• Store and slow run off, CIRIA (2007) states that the capacity of a swale should be designed to attenuate and treat a rain event with a 10–30 year return period, although there is potential for runoff rate control up to a 1 in 100 year event (Blanc et al, 2012).</td>
<td>• Investigative costs: €0.5K–€2K. Capital costs €15–€80 /m2, maintenance costs €0.5–€4 per m² surface area116</td>
<td>Observed</td>
</tr>
<tr>
<td>EbA: Rain Gardens</td>
<td>• Example in Lambeth, London in the UK anticipates reduction in peak runoff rate of 70–96% for a 1 in 2 year event, 8–39% for a 1 in 30 year storm, and 4–16% for a 1 in 100 year event (URS, 2013).</td>
<td>• The construction cost of rain gardens will vary depending on the site preparation required and the type of planting selected. Scale of operation means costs will likely be comparatively low.117</td>
<td>Projected</td>
</tr>
<tr>
<td>EbA: Detention Basins</td>
<td>• Store/slow run off.</td>
<td>• Detention basins are high land-take measures used within the urban environment cost of land acquisition typically high but site dependant. €1k–€10k investigation, construction €10 to €110 per m³, maintenance €0.5–€5 / m²118</td>
<td>Projected</td>
</tr>
</tbody>
</table>

113 ‘Individual NWRM Floodplain Restoration and Management’, European Commission
115 ‘An Integrated Plan Incorporating Flood Protection: The Sigma Plan (Scheldt Estuary, Belgium)’, Climate-ADAPT, 2014
116 ‘Individual NWRM Swales’, European Commission
117 ‘Individual NWRM Rain Gardens’, European Commission
<table>
<thead>
<tr>
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<th>How does it reduce vulnerability</th>
<th>Economic values</th>
<th>Observed/Projected</th>
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<tbody>
<tr>
<td><strong>EbA: Infiltration basins</strong></td>
<td><em>Typically, infiltration basins are generally designed to capture and infiltrate runoff volumes for events up to 1.30 year storm for the drainage area, but sometimes even for events up to 1.100 year storm.</em>&lt;br&gt;<em>Barber et al (2003) indicated that infiltration basins can be effective in reducing peak runoff by up 65-87% (<em>small storms</em>), 50-60% (<em>medium storms</em>) and 40% (<em>large storms</em>).</em>&lt;br&gt;<em>Increase ground water recharge.</em>&lt;br&gt;</td>
<td>• Primary cost is land acquisition which will be dependent on location but as in urban areas likely to be comparatively high, investigation € 2 k-€10 k, Capital costs €15-€90 /m³ storage volume, maintenance costs €0.15-€5.5 per m² pond surface area&lt;sup&gt;119&lt;/sup&gt;</td>
<td>Projected</td>
</tr>
<tr>
<td><strong>EbA: Basins and ponds</strong></td>
<td><em>Store/slow run off&lt;br&gt;Peak flow reduction estimated to be between 15-30% for Northumberland project.&lt;br&gt;Groundwater recharge</em>&lt;br&gt;Retention ponds:&lt;br&gt;<em>Store/slow run off high (Typically, retention ponds will be designed to attenuate runoff for events up to at least the 1 in 30 year storm).</em>&lt;br&gt;</td>
<td>• Land acquisition variable depending on site&lt;br&gt;• Capital costs ~44 000€ /ha&lt;br&gt;• Maintenance costs ~60€/ha/year&lt;br&gt;• Total costs: €43080000&lt;br&gt;• Ancillary benefits: €500000 (reduced flood damage)&lt;br&gt;• Employment: €7700 seasonal jobs during implementation projects&lt;sup&gt;120&lt;/sup&gt;</td>
<td>Projected</td>
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</tbody>
</table>

<sup>118</sup> ‘Individual NWRM Detention Basins’, European Commission
<sup>119</sup> ‘Individual NWRM Infiltration Basins’, European Commission
<sup>120</sup> ‘Individual NWRM Basins and Ponds’, European Commission
<sup>121</sup> ‘Individual NWRM Retention Ponds’. European Commission
<sup>122</sup> ‘Landscape Revitalisation Program in Slovakia’. Natural Water Retention Measures, 2012
5.5 Question 4: What decision-making tools, methodologies, and mechanisms are used to address these climate impacts and vulnerabilities in the construction sector?

5.5.1 Tools and methods discussed in the construction sector

For an overview of tools, methods and mechanisms which are used, or have the potential to be used by the construction sector, please see Chapter 2.

The figure below illustrates the different types of mechanisms that are being discussed in sources covering the construction sector as opportunities for addressing the impacts of climate change.

![Mechanisms used in the construction sector](image)

**Figure 30: Mechanisms for adaptation used in the construction sector**

Note: A total of 87 sources were considered for Question 4; however, construction sector mechanisms could not be identified in 52 sources, meaning 35 sources were ultimately considered. The percentages above stem from the prevalence of these mechanisms in the 35 sources. Each measure type was counted once if it appeared in a source but each source could contain references to more than one mechanism.

5.5.2 Case study illustrating how the construction sector is adapting
Case study: Adaptation within the construction sector, Germany, Italy

**Situation:** EU-CIRCLE is a research project funded by H2020 aiming to assess and to strengthen the resilience of interconnected and interdependent critical infrastructures. One case study focus on the City of Dresden and neighbouring counties and towns. The densely populated region has borders to Czech Republic and Poland. The City of Dresden, with a population of > 500 thousand inhabitants is its cultural, scientific and industrial centre. The topography is hilly between 100 m and 1,200 metres and many bodies of water from the mountains are directed to the valley of the river Elbe, which is the main development area. The region has suffered many severe rapid flooding situations (1845, 1890, 2002, 2006, 2013). In the 2002 flood, the State of Saxony recorded over 25,000 buildings to be damaged, with 400 completely destroyed. Costs were assessed to the order of 8.6 bil EUR. In 2013, several German federal states even declared a state of emergency.

**Mechanisms used:** Before but especially after the disastrous flood in 2002, a number of mechanisms to mitigate and adapt to emerging risks were put in place, including:
- Development of emergency plans that analyse the needs for response forces and equipment and prepare the procedures and structures,
- Public warning systems to allow the population to react properly,
- Updated land-use planning in order to facilitate the implementation of structural adaptation measures such as flood barriers (including mobile ones), dykes, enlargement of retention spaces, and renaturation,
- Adaptation of electric grid and communication infrastructure, especially through relocation of transformers and base stations to higher altitude places and fitting of cables with higher water resistance.

**Outcomes:**
- Reduction of damage and reconstruction costs,
- Lowering of response costs, such as evacuation efforts,
- Lowering of mobility/transport limitations during the hazard and in the phase of recovery

**Source:** EU-CIRCLE, Dr. Ralf Hedel (Fraunhofer IVI) and Dr. Thanasis Sfetsos (Demokritos)

**Situation:** Bologna, Italy like many Italian cities, is increasingly prone to extreme weather events, particularly extreme heat in summer periods leading to thermal discomfort and poor air quality for the resident population.

**Mechanisms used:**
- In June 2014, the city adopted a Municipal Operative Plan (POC) in an effort to create a more resilient environment. The plan consists of 28 projects specifically aimed at increasing the amount green space in the city and promoting urban safety. Some of the measures include reducing soil consumption through green and blue measures focused on improving landscape maintenance and watershed management, and regenerating or transforming abandoned industrial and commercial buildings.
- Bologna is using a special index called RIE, taken from a tool used in the Italian city of Bolzano, to measure the microclimatic performance of its public spaces.
- The measures carried out in Bologna are the result of agreements between the municipality and private developers, who fund the plan's implementation. The city council approved the plan in 2015. Measures should be completed within five years, with many already under development or completed.

**Outcomes:**
- 17,000 m² of new public and private green areas created.
- The total area of sealed surfaces has also been reduced in favour of semi-permeable and permeable surfaces.
- 125,295 m² of new building space will have been created, of which 2,474 m² is intended for social housing.
- Reduction in the urban heat island effect, storm water flooding and runoff, and greater biodiversity as a result of habitat creation.
- The implementation of the Plan also led to job creation, an increase in property values and improved air quality.

**Source:** Municipality of Bologna, Adaptation e-learning module (to be published)
5.6 Gaps and recommendations specific to the construction sector

Where gaps have been identified regarding the construction sector which are common to the infrastructure sector as a whole, these are covered in Chapter 6 ‘Gaps and Recommendations’. Gaps inhibiting adaptation specific to the construction sector are listed in the table below, together with suggested recommendations.

Table 17: Gaps and recommendations for the construction sector

<table>
<thead>
<tr>
<th>Gaps discussed in construction sector</th>
<th>Recommendation</th>
<th>Level to be addressed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The way that urban areas/cities are defined has significant implications for understanding climate change risks and adaptation responses(^{123}): implementing actors not always used to abstract concepts of urban systems and prefer the territorial delimitation of a built-up area or administrative borders.</td>
<td>1.1 Develop guidelines and tools with city practitioners; 1.2 Integrate the required knowledge and skills into professional training and other learning programmes.</td>
<td>Cross-collaborative initiatives, such as EU, national research projects; city initiatives(^ {124})</td>
</tr>
<tr>
<td>2. Developing, selecting and applying adaptation indicators and the appropriate monitoring system at city level to assess progress in adaptation and the effectiveness of measures(^ {125}).</td>
<td>Collate, reviews and assess the range of indicators being used and developed for and by cities, bottom-up and top-down created indicators covering impacts, processes and outcomes.</td>
<td>EU, national research projects; relevant EU institutions such as JRC and EEA; city initiatives</td>
</tr>
<tr>
<td>3. Lack of awareness of which tools are most appropriate to guide cities according to which stage they are at in the adaptation cycle(^ {126}).</td>
<td>Promote the practical application of the Urban Adaptation Support Tool meta-guidance.</td>
<td>Covenant of Mayors for Climate and Energy</td>
</tr>
<tr>
<td>4. Lack of understanding of where to go, who can help and how to access available (credible) knowledge(^ {125}).</td>
<td>4.1 Promote use of freely available adaptation support available to cities from a credible source: online, in person, peer to peer, interaction with adaptation experts and telephone based support throughout the adaptation cycle; 4.2 Increase use of demonstration projects focussing on the application of climate services at the urban level and nature based solutions in cities.</td>
<td>Covenant of Mayors for Climate and Energy; EU and national funded projects</td>
</tr>
</tbody>
</table>


\(^{124}\) City initiatives focused on adaptation related topics could include, amongst others: 100 Resilient Cities, Covenant of Mayors for Climate and Energy, UNISDR Making Cities Resilient, for example.

\(^{125}\) Mayors Adapt Knowledge Base Strategy ‘Urban Adaptation Gaps in Europe’, Ecofys and Fresh Thoughts, 2016
6 Gaps and recommendations

6.1 Introduction

Gaps and recommendations are derived in part from the online sources assessed, but also through in depth discussions undertaken through expert consultation, interviews and reviewing additional sources cited in the References to this report.

Beyond the specific actors identified in the tables below, each recommendation considered should be developed in cooperation with the sector-specific professional bodies and organisations.

6.2 Question 1: What (climate) data is available and needed for the assessment of climate impacts? Gaps & Limitations of the data sources compared to user needs

After consulting different sources and discussing with users of climate data across the transport, energy and construction sectors, the gaps and limitations of data sources experienced by users are common across the sectors, therefore recommendations apply to all three sectors.

There is a clear role and potential that climate services have in terms of generating a meaningful dialogue directly with users to help them understand common challenges, such as understanding of uncertainty, how to deal with biases in models. This goes beyond making climate data available to users, towards working directly with users from all sectors to understand the questions that users need answering.

Table 18: Gaps and recommendations regarding data sources and user needs

<table>
<thead>
<tr>
<th>Gaps relevant to climate data sources</th>
<th>Recommendation</th>
<th>Level to be addressed</th>
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</thead>
<tbody>
<tr>
<td>1. Lack of availability of data on past events: Using observed climate data helps to inform the sector about past conditions which impact infrastructure resilience; however, the priority for users is to understand how and where climate hazards occurred in the past, to identify potential hotspots and their characteristics. Climate variables themselves often serve as a proxy for identifying such extreme weather events, where there are data gaps. Whilst observed climate data can be made available, data regarding where climate hazards, their nature, frequency and severity took place in the</td>
<td>1.1 Create a central repository, combining observational climate data (and impacts for operations and services where this exists) into one repository, accompanied by user-friendly tools enabling users to interrogate the data in different ways; 1.2 Expand existing interactive data maps which combine multiple sources of climate data, such as Climate-ADAPT Map Viewer.</td>
<td>Infrastructure operators; Copernicus Climate Change Services; national meteorological and hydrological services; European Climate institutions, such as the EEA, Climate-ADAPT</td>
</tr>
</tbody>
</table>

126 Adaptation Futures: 11.05.16 ‘User Orientated Climate Services’, discussions with Climate service providers in Sweden, UK; interview with Dr Anthonasis Sfetsos 27.06.16 National Centre for Scientific Research Demokritos EU-CIRCLE; discussion with various sector experts, including International Transport Forum, Leipzig May 2016
<table>
<thead>
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<th>Gaps relevant to climate data sources</th>
<th>Recommendation</th>
<th>Level to be addressed</th>
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<tbody>
<tr>
<td>past which impacted the infrastructure network can be hard to map, right up to the recent past such as the 1980s. This type of data, together with data on impacts for operations and services for past events – where it exists at all – is not available centrally, but where it exists, it is widely dispersed across and within a number of different organisations.</td>
<td>2.1 Increased focus on climate services to support capacity to use risk-based forecasts, to understand the changing nature and behaviour of climate hazards, (e.g. heavy precipitation under different conditions, including in mountainous regions, for example);</td>
<td>Climate Services sector\textsuperscript{127} working with different sectors, such as hydrological modellers and other data generators across different sectors</td>
</tr>
<tr>
<td>Lack of ability to predict how certain climate hazards behave: Climate hazards are not always behaving as predicted. For example water from flooding does not behave as previously expected or stay in the water courses, due to unfavourable catchment conditions which require further hydrological modelling.</td>
<td>2.2 Engage further in the co-generation and evaluation of climate (and weather) services that support decisions: Combining climate projections knowledge with local weather station data, hydrological modelling and socio-economic data leads to the development of decision-support tools, specialised models which can be used and applied within all sectors.</td>
<td></td>
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<tr>
<td>User needs and the capabilities of climate projections can be in conflict: information on some climate variables are more uncertain to predict than others. For example, users across the infrastructure sector seek information on storm intensity, wind direction, lightning. Local and micro-scale wind flows are not captured by climate models. Similarly, users of climate data in the infrastructure sector require information at high resolution, up to 1km; this adds an extra element of uncertainty and can be beyond climate model capabilities, or users’ computational power to access the data in a</td>
<td>3.1 Investigate the ability to produce higher resolution data: developing and pushing the boundaries of climate science to address users’ needs for high(er) resolution data.</td>
<td>Climate services and modelling communities</td>
</tr>
<tr>
<td></td>
<td>3.2 Working with users to better understand their needs and to interpret these needs into viable and robust information that could be extracted from the models and brought into the projections or other support services.</td>
<td>Copernicus Climate Services; National Meteorological Institutions</td>
</tr>
<tr>
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<td>3.3 Climate services to consider</td>
<td>Copernicus Climate</td>
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</table>

\textsuperscript{127} The European Roadmap for climate services identifies such gaps and details the timing and what were seen as the responsible agents, including the Copernicus Climate Change Service (C3S), but also H2020 and others.
<table>
<thead>
<tr>
<th>Gaps relevant to climate data sources</th>
<th>Recommendation</th>
<th>Level to be addressed</th>
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<tbody>
<tr>
<td>reliable manner.</td>
<td>communicating simply and boldly: Currently the range of communications cultures, styles, methods and messages developed for users of climate data by climate services vary across Europe. Some climate services organisations are hesitant to communicate any messages regarding climate projections at all at the local level as levels of associated uncertainty rise. However, others are creating ways of communicating uncertainty in simple ways, as they consider users inherently understand the concept of uncertainty. Equally where users think that they want more weather forecasting services than climate projections, climate services could challenge this need and demonstrate other ways users' data needs can be met.</td>
<td>Services, National Meteorological Institutions</td>
</tr>
<tr>
<td>4. Accessibility of data sources determines how much they are used: Many data sources are not completely accessible; they may require user registration, a licence, specific software, online training / e-learning. In discussions amongst the climate services community it was revealed that where users are simply required to register (no charge) before accessing climate data, this can lead as much as a 50% drop in users attempting to access such data. Furthermore, across Europe there are different rights for commercial companies, so some cannot use the data for commercial reasons.</td>
<td>4.1 Facilitate open access to climate data with registration, licence and software requirements kept to a minimum. 4.2 Ensure ongoing availability and accessibility of climate data in user-friendly formats, including after project funding has expired. 4.3 Reduce restrictions for use of climate data where currently for non-profit purposes only.</td>
<td>All EU and nationally funded projects National Meteorological institutions</td>
</tr>
<tr>
<td>5. How to combine climate and non-climate data? Across all the infrastructure sector, users of climate data are combining it with specialised modelling, such as hydrological modelling as well as with different types of non-climate data</td>
<td>5.1 Greater collaboration between climate services sector and socio-economic data providers: the linkages between climate and wider society in terms of how society behaves in light of</td>
<td>Copernicus Climate Services</td>
</tr>
</tbody>
</table>

128 Adaptation Futures: 11.05.16 ‘User Orientated Climate Services’
130 European Roadmap does not limit climate services to climate data and information only; this aspect is recognised as an element of the Roadmap with proposed activities and identified responsibilities.
<table>
<thead>
<tr>
<th>Gaps relevant to climate data sources</th>
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<th>Level to be addressed</th>
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</table>
| as inputs to create different models. However, the range of non-climate data that is used varies not just across the three sectors but within sectors, countries and organisations. There is a lack of widespread systematic collaboration between the climate services sector, the user communities and other key data generators of socio-economic data and social sciences expertise. | climate impacts and vice versa needs further investigation.  
5.2 Further joined up working at EU level to streamline and prioritise focus of climate service development: Whilst there is a range of different initiatives funded by the EU in order to develop the role and potential for climate services and users’ understanding and application of such climate data, there is a perception that these efforts can occur in a fragmented nature and need to be coordinated and streamlined with lessons learnt shared across such initiatives. | |

129 There is a history of co-generation of observed data between the insurance and climate services sectors for example, however within the infrastructure sectors this occurs in a varied, dispersed manner.
### 6.3 Question 2: Gaps and limitations relating to vulnerability and risks assessments

Table 19: Gaps and limitations regarding vulnerability and risk assessments

<table>
<thead>
<tr>
<th>Gaps relevant to Vulnerability and risk assessments</th>
<th>Recommendation</th>
<th>Level to be addressed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Uncertainties in land use change are a key constraint in the immediate and near terms, including consideration of impacts of climate change as an additional factor often exacerbating vulnerabilities.</td>
<td>1.1 Research the potential trade-offs and synergies between LULUC with regards to mitigation and adaptation measures at sub national level. 1.2 Further use of spatial and land-use planning at regional (sub-national) level to provide an understanding the current status and to inform the development of a future common plan regarding land-use changes.</td>
<td>European and National research institutions; National, regional and municipal authorities</td>
</tr>
<tr>
<td>2. Lack of data (pre-1960) on location, type and performance of infrastructure assets and services that could support assessments.</td>
<td>Location-specific cross collaborative data sharing regarding existing critical infrastructure.</td>
<td>Infrastructure organisations across the three sectors at critical hotspots / hubs</td>
</tr>
<tr>
<td>3. Lack of clear understanding of how climate impacts influence and link to the sector’s adaptive capacity</td>
<td>Increase institutional knowledge of lessons learnt after weather-related disruptions.</td>
<td>Infrastructure organisations across the three sectors</td>
</tr>
<tr>
<td>4. The development of agreed definitions and a common language on vulnerability, and associated concepts, within the infrastructure sector and in particular with regards to the critical infrastructure</td>
<td>Further integration of EC infrastructure guidance(^{14}) on undertaking vulnerability and risk assessments as a mandatory requirement to be undertaken in all publicly funded projects.</td>
<td>EU and national funding requirements and guidelines</td>
</tr>
<tr>
<td>5. Standardised indicators and measurements to allow comparability across sectors, timescales, and units of analysis;</td>
<td>Collate, revise and assess standards, measures and indicators across each infrastructure sector.</td>
<td>Research community, EEA, JRC, CEN-CENELEC</td>
</tr>
<tr>
<td>6. Lack of understanding to evaluate and address dependencies and interdependencies within and across infrastructure sectors (also includes water and ICT), how cascade effects impacts</td>
<td>Increase collaborative work to identify and explore the nature of these dependencies and interdependencies, but also the nature and scope of adaptation measures needed to address these; combine research into cascading effects of critical</td>
<td>Infrastructure operators, regulators, policymakers and the research community; EU &amp; nationally funded projects</td>
</tr>
</tbody>
</table>
6.4 Question 3: Gaps and limitations regarding adaptation measures

Table 20: Gaps and limitations regarding adaptation measures

<table>
<thead>
<tr>
<th>Gaps relevant to adaptation measures</th>
<th>Recommendation</th>
<th>Level to be addressed</th>
</tr>
</thead>
</table>
| 1. A dominant focus on technical systems and their operations – the need to engineer our way out of the challenge; | 1.1 Infrastructure systems should comprise more than the technical infrastructure: dependencies between infrastructure, blue and green infrastructure and built infrastructure to be further researched.  
1.2 Mandatory reporting (where relevant) to Climate-ADAPT in all service contracts and research projects should be envisaged to strengthen database of adaptation measures to cover the costs of implementation of the measure; a focus on the environmental and social impacts of adaptation. | Research Community, EEA, EU and nationally funded projects |
| 2. Inadequate consideration of environmental and social dependencies on (critical) infrastructure; | Mandatory reporting (where relevant) to Climate-ADAPT in all service contracts and research projects should be envisaged, with a focus on the environmental and social impacts of adaptation. | Research Community, EEA, EU and nationally funded projects |
| 3. Lack of comparability of information on project damage costs and the impacts of climate change. | Strengthen existing mechanisms between data providers and the EEA to support the knowledge transfer on this topic in particular: establish a process for ensuring all newest and relevant EU funded (and to extent | EU funding requirements; MS funding requirements, EEA, JRC |
### 6.5 Question 4: Gaps and limitations regarding methods and mechanisms to adapt

<table>
<thead>
<tr>
<th>Gaps relevant to methods and mechanisms for adaptation</th>
<th>Recommendation</th>
<th>Level to be addressed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Existing national policy, legal and regulatory frameworks(^{131}) can limit the use of climate projections in local adaptation planning; political and economic constraints can strongly affect the usefulness of climate information in adaptation decision making.</td>
<td>Strengthen the existing links between EC adaptation activities and national frameworks and increase the leverage of national activities &amp; tools to a wider audience.</td>
<td>European Commission and national adaptation policymakers</td>
</tr>
<tr>
<td>2. Lack of coordination between governance levels / different operators responsible for the same infrastructure.</td>
<td>Establish arrangements for systematic cross-sector working for operators responsible for the same infrastructure.</td>
<td>National governments, infrastructure operators</td>
</tr>
<tr>
<td>3. Lack of widespread methodology for undertaking vulnerability and risk assessments in an affordable, replicable manner across all infrastructure projects.</td>
<td>Critical assessment of standardised vulnerability assessment methodologies that can be applied at the least cost, in order for widespread, systematic implementation across all projects.</td>
<td>EU and nationally funded projects</td>
</tr>
</tbody>
</table>

\(^{131}\) Use of Climate Projections in Local Adaptation Planning: Lessons from England & Germany, University of Leeds, 2016
7 Annexes

7.1 References: Question 1


7.2 References: Questions 2, 3, 4


