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Adaptation of transport to climate change in Europe

Challenges and options across transport modes and stakeholders

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European Environment Agency

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Executive summary

Climate change threatens to compromise transport services that are indispensable for Europe's economy and society

Transport remains a critical support system for the smooth functioning of our societies and economies. It facilitates accessibility of services that are vital for business and for the quality of life of citizens. It also enables economic growth and job creation. Gradual climate change such as increases in temperature, sea level and rainfall regimes and the projected increase in frequency and intensity of some extreme weather events will seriously challenge the transport sector. Rising temperatures and extended heatwave periods increase the problems of rail buckling, pavement deterioration and thermal comfort for passengers in vehicles. Weather extremes generating floods or landslides can lead to short-term delays and interruptions but also long-term interruptions and detouring needs in the event of destroyed infrastructure. Sea-level rise can threaten harbours and other transport infrastructure and services in coastal areas. Air transport can be challenged by changing wind patterns, flooding of airport infrastructure, and other weather events. In addition, climate impacts that trigger changes in the organisation of society and economy, like different tourist destinations or agricultural productions, can impact upon transport demand.

The effects of malfunction, disturbance and broken links may stretch far beyond the originally affected area

The transport system is of trans-boundary character and highly interconnected inside its modes and across modes; hence, disturbances in one part of the network might have a domino effect in other parts too. As such, effects usually extend beyond the transport system by hindering the ability to deliver reliable services, and jeopardising the free movement of people and goods. Depending on the specific case, these indirect damage costs can be many times higher than direct costs to the transport sector itself. Transport disruptions caused by recent extreme weather events serve to illustrate what could happen in the future: it is important to anticipate the impacts of climate change on the transport system and prepare for this in time.

Despite the key role of transport and the huge challenges posed by climate change, attention to adaptation is as yet relatively low

While measures to reduce greenhouse gas (GHG) emissions from transport are being implemented and are relatively high on the policy agenda, adaptation to the unavoidable impacts registers relatively low awareness and is only at an early stage. It focuses on early, planning stages and less, so far, on implementation. Measures mostly follow a piecemeal and spontaneous approach, and are often organised autonomously by the different stakeholders.

Adapting the transport system could require substantial infrastructure investments; mainstreaming of adaptation in infrastructure planning is needed now

The smooth and effective operation of the transport system relies heavily on hard and extensive infrastructures, like roads, rail tracks, bridges and ports. These are intended to last long-term, in some cases beyond 100 years. Investments are usually costly and with long return rates. An anticipatory approach starting now is necessary for planning new infrastructure or improvements and for niche development. Considering future climate trends now helps in keeping the costs for adaptation bearable and avoiding lock-ins into an unsustainable development path of the transport system. Components of infrastructure have different life cycles, and adaptation at the time of renewal of a component can be realised at marginal costs.

Low-cost options also exist, but as yet are less in focus

Mainstreaming adaptation into regular transport planning, and into other policies and plans, is not yet

widespread across Europe. For example, measures planned in the context of low-carbon transport, such as improved inter-modality, also offer options for adapting transport to climate change, but currently do not include it. Many tools developed for natural disaster risk management or contingency plans can easily be made relevant for climate change adaptation too. Meanwhile, the adaptation focus is mostly on transport infrastructure, with little attention given so far to adapting operations for future climate impacts. Improving cooperation among different stakeholders and encouraging more out-of-the-box thinking would enable better benefiting from such synergies and low-cost options.

Cooperation between the many diverse stakeholders within and outside the transport sector can help achieve more efficient and effective adaptation

Transport is a complex sector with many different stakeholders, both in the private and public sector, such as infrastructure and services providers across different modes, producers of vehicles, regulators and, finally, users. Their actions are interconnected, but many stakeholders have only a partial perspective of the system they play a part in managing. A fragmented approach is unlikely to be efficient or to guarantee the necessary consistency to address long-term challenges. Moving from isolated and spontaneous adaptation to integrated, complementary and mutually supportive action of the many different stakeholders involved in the different transport modes and outside the sector can enable more effective and efficient adaptation.

The EU and national governments can create the enabling framework and invest in the knowledge base

While many adaptation measures need to be implemented directly by transport infrastructure and services providers (both private and public), the EU and national governments have a prominent role in enabling this integrated approach and cooperation by organising exchanges of experience, facilitating the generation of tailored knowledge and tools, and stimulating solution-finding across the board. Knowledge can be generated through, for example, the EU Framework Programme for Research and Innovation (Horizon 2020), national programmes, and information shared by Climate-ADAPT and national portals.

The EU Strategy on adaptation to climate change and national adaptation strategies are a starting point, but need to ensure that transport is included as an important and integral element. Furthermore, they need to create the enabling framework for integrated and innovative transport adaptation action, comprising standards, targeted funding, governance culture and collaboration.

The magnitude of climate change and related socio-economic change suggests potential benefits from exploring innovative options

Incremental improvements of transport infrastructure, operations and services based on past experience deliver valuable solutions that also work under the new conditions being created by climate change. This is still the prevailing approach among most stakeholders in the transport sector. However, given the magnitude of expected change, these approaches alone are unlikely to be sufficient. The anticipated impacts suggest long-term visions as well as thinking about solutions outside traditional paths in areas like spatial planning, relocations of infrastructure or regional flood risk management, and the exploration of transitional changes by organising future accessibility differently. Prevalent transport paradigms such as efficiency need to be reconsidered together with alternative paradigms such as flexibility using, for example, multi-modal concepts instead of uni-modal solutions, technology and redundancy.

Adaptation to climate change is a new policy area; the effectiveness of current steps should be evaluated in the future

Strategies, plans, guidance and innovative actions have been initiated by the EU and national governments. Funding streams like the TEN-T budget, the EU Structural Funds and national funds, among others, have integrated climate change considerations within their eligibility criteria, but the integration of adaptation within planning and assessment practices is at the very early stage and will need to be monitored and evaluated in the next years.

This report

The European Environment Agency (EEA) and others have long identified transport as an important sector in environmental terms. Over the last 15 years, the EEA has published annually the Transport and Environmental Reporting Mechanism (TERM) report looking into specific topics of sustainable transport, such as air quality, noise or urban transport, and tracked progress towards the

achievement of environmental targets in this sector. In recent years, climate change adaptation started to emerge as a new issue on the policy agenda. As an initial step towards the necessary widespread mainstreaming of climate change adaptation into transport planning and decision-making, this report aims to shed light on initial adaptation practices in the transport sector across Europe while providing a perspective on the emerging challenges and opportunities.

This report

This report explores current climate change adaptation practices concerning transport across European countries and provides:

- a summary of the challenges (Chapter 1);
- an overview on the state of adaptation action concerning the transport sector and system (Chapter 2);
- a review of a number of inspiring initiatives in different countries (Chapter 3);
- conclusions on a potential way forward (Chapter 4).

While not being an exhaustive description or assessment of adaptation policies or practices in transport throughout Europe, the purpose of the report is to stimulate discussions among the many different stakeholders concerned with transport adaptation. Opening the perspective on the transport system and sector as a whole should inspire and encourage learning from practices across modes and areas of responsibility and support efforts to mainstream adaptation within transport-related policy and practices.

The factual information collected is based on data available in the Climate-ADAPT ([1]) information platform, a literature review, case studies provided by many stakeholders, and a questionnaire on transport and adaptation addressed to EEA member countries in 2013. A total of 23 country representatives answered this questionnaire and provided information on the variety of national approaches to adaptation in transport. It must be stressed, however, that the results obtained reflect the perceptions of a limited number of respondents. Nevertheless, this information from countries provides interesting insights and encourages further analysis and discussions. Elements of this information are presented in the ETC Technical report *Adaptation to Climate Change in the Transport Sector* (ETC/CCA, 2013).

There is a wide variety of perspectives to describe the transport sector. From a practitioner's perspective, the transport sector is chiefly defined by the interactions of stakeholders such as infrastructure developers and managers, service providers — within a mode or integrating various transport modes — and manufacturers of vehicles, trains, aeroplanes, ships and equipment. From a user's perspective, the distinction is mainly made based on the purpose of travel, such as: daily recurrent trips in urban areas, business and leisure trips, freight distribution, and delivery within production and logistics chains. From a policymaking perspective, attention is focused on the actors involved in decision-taking processes at the global, European, national, regional and local levels.

This report aims to provide information of relevance to most of these stakeholders:

- From the perspective of European institutions, the report provides an overview of how adaptation is making progress throughout Europe, and how it is being integrated within transport policy and practices.
- For national and sub-national governments, the report collects and presents information on actions taken in some countries, which could be replicated by others.
- Practitioners and researchers may find it useful to address how adaptation needs are being identified and assessed in different contexts, and how actions are prioritised, as guidance for revising or expanding their professional or research activities in this field.

([1]) See http://climate-adapt.eea.europa.eu.

- Finally, the report aims to provide all stakeholders with an appreciation of the transport system as a whole, its interconnectedness, and the challenge of adapting to climate change across modes and governmental levels. This perspective is expected to stimulate the exchange of experience and to facilitate a Europe-wide debate on the future of transport in the context of climate change.

Use of some key terms in this report

This report uses different terms that are sometimes defined in different ways in various publications and by different authors. In this report, we do not prescribe any particular definition but rather apply context-specific definitions. This is relevant for the following terms:

Adaptation

Adaptation consists of actions responding to current and future climate change impacts and vulnerabilities (as well as to the climate variability that occurs in the absence of climate change) within the context of ongoing and expected societal change. It means not only protecting against negative impacts of climate change, but also building resilience and taking advantage of any benefits it may bring (EEA, 2013).

Resilience

Simply put, resilience refers to a system's capacity to remain operational under different external pressures. In IPPC, 2014, resilience is defined as 'the capacity of social, economic and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure, while also maintaining the capacity for adaptation, learning and transformation.'

In the context of this report, resilience is used in reference to the transport system. However, as transport is an important pillar to maintain services and quality of life in society, this refers indirectly to a resilient society. Although the resilience concept refers to all type of possible pressures — economic, social and environmental — this report focusses on a resilient transport system adapting to the impacts of climate change.

Transport system versus transport sector

This report uses both terms. The distinction between them is not totally fixed. The transport system is a set of interacting components include all the transport modes, the physical elements, and the movements that contribute to the services provided by transport to the socio-economic activity (Frybourg, 1991). With transport sector the report instead refers to transport as a part of the economy, including its governance structure and regulating authorities.

Accessibility

This refers to the ability to reach desired goods, services, activities and destinations (collectively called opportunities). Access is the ultimate goal of most transport options, except a small portion of travel in which driving itself is the purpose (Litman, 2003).

Policy stages of adaptation

This report understands here the following stages: agenda-setting, policy formulation, decision to adopt policies, implementing measures foreseen in the policies and monitoring of the policy/action (EEA, 2014).

Further definitions of terms related to adaptation can be found in the glossary of the EEA Report *National adaptation policy processes in European countries — 2014* (EEA, 2014b).

1 The transport sector and adaptation challenges

Key messages

- Observed and projected climate change — such as increases in temperature, sea level, changes in rainfall, and the increase in frequency and intensity of some extreme weather events — will seriously challenge the transport system, which is an important pillar of the economy and society.
- Reducing GHG emissions (mitigation) and adaptation to unavoidable impacts are complementary actions both needed to cope with climate change.
- Transport requires many costly and long-lasting investments in infrastructure, aeroplanes, trains, ships and other transport equipment. This calls for anticipatory planning approaches that consider future climate change but also other socio-economic changes.
- Transport, as many other sectors, is a very complex system with responsibilities distributed across many different stakeholders. This situation makes integrated adaptation approaches challenging to achieve and requires appropriate governance approaches.

1.1 Coping with climate change

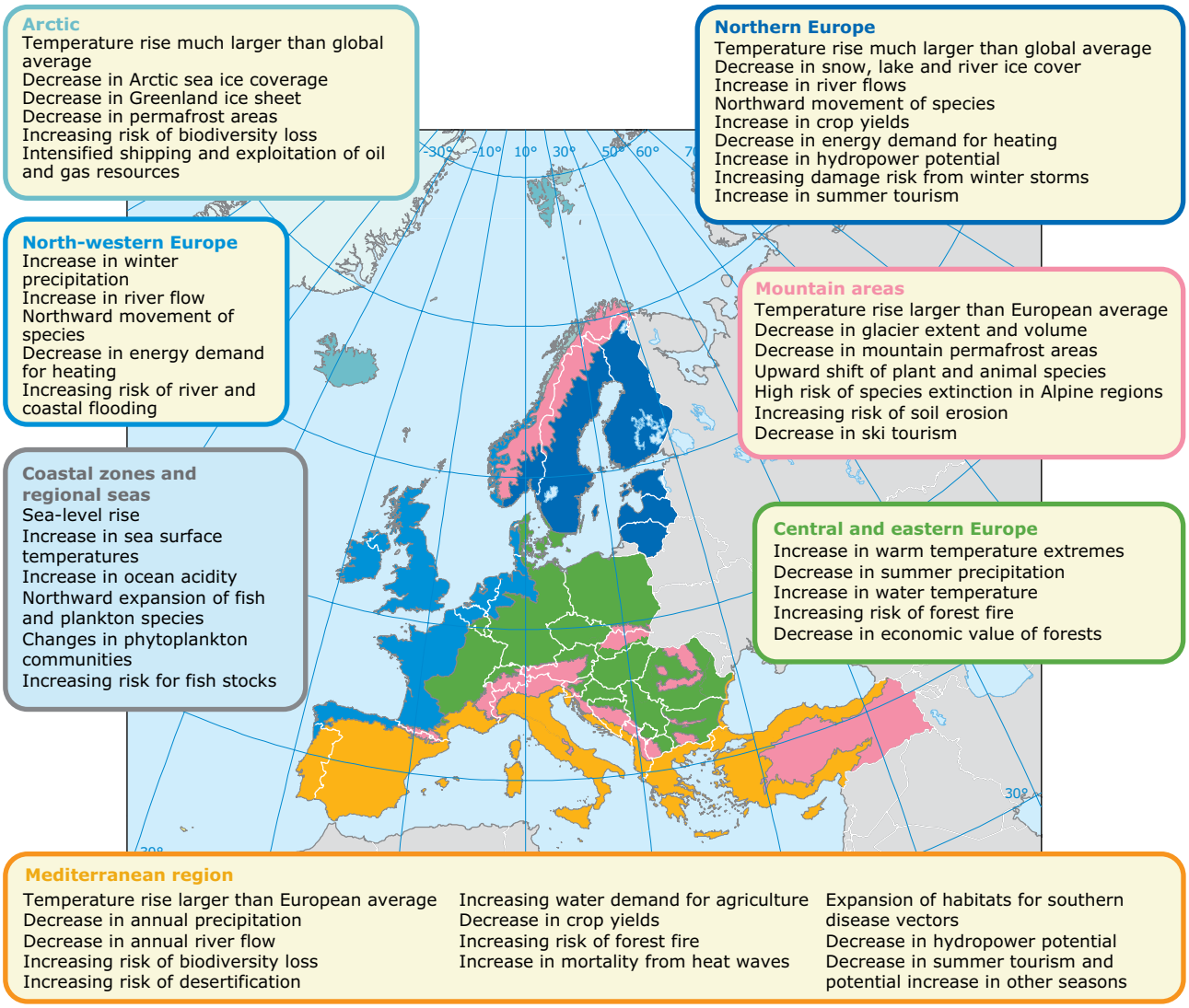
Climate change is occurring in Europe and some of the observed changes have established records in recent years. The last decade was the warmest decade since global temperature records became available. Human influence, primarily emissions of GHGs, but also changes in land use, has been the dominant cause of the observed warming since the mid-20th century. Human influence on the climate system has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, in global mean sea-level rise, and in changes in some climate extremes (IPCC, 2013).

Annual mean temperature and the frequency and duration of heatwaves have increased across Europe since the mid-20th century. Climate change impacts vary across Europe depending on climate and geographic and socio-economic conditions. Precipitation has generally increased in northern and north-western Europe whereas it has generally decreased in southern Europe. Snow cover has been decreasing, and most permafrost soils have been warming. The frequency and intensity of extreme temperature and precipitation events are projected to increase (EEA, 2012; IPCC, 2013) (Map 1.1).

Changes in the climate system, such as rising temperatures and sea levels as well as an increasing frequency and intensity of extreme weather events (e.g. storms, heat waves, flooding), are already having an impact on transport infrastructure and services in Europe (EC, 2013c). The consequences for transport can sometimes be negative and sometimes positive. On the one hand, rising temperatures and extended heatwave periods increase the problems of rail buckling, pavement deterioration and thermal comfort for passengers in vehicles or destabilise infrastructures due to melting permafrost soil, but could, on the other hand, decrease problems related to ice and snow. Weather extremes generating floods or landslides can lead to short-term delays and interruptions but also long-term interruptions and detouring needs in the event of destroyed infrastructure. Sea-level rise, in particular in combination with storm surges, can threaten harbours and other transport infrastructure and services in coastal areas. The effects of disturbance and broken links may stretch far beyond the original area due to the high connectedness of the transport system in itself and with other sectors of the society (Box 1.1).

Furthermore, transport demand is expected to change as a short-term reaction to delays and interruptions, but in addition long-term changes are also expected. This includes, for example, changes in tourism destinations and seasonal tourism caused by increasing temperature. Changes in agricultural production due to increased temperatures or

Map 1.1 Key observed and projected changes in climate in Europe



Source: EEA, 2012.

changed precipitation patterns can also alter the transport demand over time. A detailed list of climate risks and impacts on transport infrastructure is provided in the Annex.

Coping with climate change — mitigation and adaptation

The magnitude and rate of climate change depends partly on future global GHG emissions. Consequently, global mitigation action to reduce the GHG emissions has been and continues to be a paramount strategy addressed through the United Nations Framework Convention on Climate Change (UNFCCC) and a range of related EU GHG mitigation policies. As transport is one of the main contributors to GHG emissions, mitigation action was so far the main focus of the sector in dealing with climate change.

However, even if global GHG emissions were to stop today, climate change would continue for many decades as a result of past emissions and the inertia of the climate system. Adaptation to already experienced changes in climate as well as to plausible future climate scenarios is therefore a necessity.

In this report, 'adaptation' refers to actions responding to current and future climate change impacts and vulnerabilities (as well as to the climate

Box 1.1 Regional extreme events can trigger impacts far beyond the damaged area — recent examples from Austria, Germany and the United Kingdom

During spring 2013, severe flooding affected several central European countries such as Austria, the Czech Republic and Germany. Transport and supply chains were severely disrupted in many areas, sometimes for a long time:

- The main railway bridge across the River Elbe in Germany, servicing all trains to and from Berlin via Hannover, including the important high-speed services Berlin–Frankfurt and Berlin–Cologne/Dusseldorf, was affected and remained closed until early November 2013. This led to disturbances in the whole network.
- In Austria, rail service was heavily impacted on the Brenner crossing, which had to be closed for more than a week. This closure led to disruption for long-distance trains from Germany to Italy via Austria.
- Due to high water, several waterways including sections of the Rhine, Neckar, Main and Danube and the Rhine-Main–Danube Canal had to be closed for merchant ships, leading to disruption in some supply chains.

The winter of 2013/2014 saw exceptional weather affect the United Kingdom, with a run of winter storms culminating in serious coastal damage and widespread, persistent flooding (Met Office and CEH, 2014). During this period of exceptional weather, the transport system was among the most severely affected elements of infrastructure, with flooding and other damage to rail and road infrastructure, closures of railway lines and suspension of services for commuters, cancellation of flights and ferries, and other consequences. Perhaps the most iconic event was the severe damage to a coastal section of the south–west main line railway at Dawlish, Devon during the storms in February 2014. This event saw the railway in the south-west of the United Kingdom cut off from the rest of the railway network for two months (see also Box 3.16).

In general, it is not yet possible to attribute to climate change the occurrence of particular high-impact weather events, though progress is being made in this area (IPCC, 2013). However, it is clear that the projected increase in the frequency and intensity of some extreme events increases the need to properly prepare for such situations.

Photo 1.1 Damage to the railway at Dawlish in Devon, the United Kingdom

© Network Rail

variability that occurs in the absence of climate change) within ongoing and expected societal change. It means protecting against negative impacts of climate change, but also building resilience and taking advantage of any benefits it may bring (EEA, 2014b).

Although usually seen as different strategies — mitigation dealing with the source of the problem and adaptation with unavoidable impacts — mitigation and adaptation are complementary actions. The EU addresses both mitigation and adaptation, and at least 20 % of the entire European Union (EU) budget for 2014–2020 will be spent on climate-related projects and policies, including both mitigation and adaptation.

Furthermore, the European Commission proposes a *Roadmap for moving to a competitive low-carbon economy in 2050* that foresees a reduction of at least 80 % of GHGs by 2050 compared to 1990. This is in the context of the flagship initiative on a resource-efficient Europe of the Europe 2020 programme (EC, 2011a). In the transport sector, the European Commission's *White Paper: Roadmap to a Single European Transport Area — Towards a competitive and resource efficient transport system* sets out how the transport sector can contribute by reducing its carbon emissions by 60 % (EC, 2011b) from 1990 levels. Complementary to policies aimed at reducing GHG emissions, the EU Strategy on adaptation to climate change (EC, 2013d) aims at contributing to a more climate-resilient Europe by enhancing the preparedness and capacity to respond to the impacts of climate change at local, regional, national and EU levels. It also refers explicitly to transport as a sector that needs to adapt (see Section 2.1).

The envisaged long-term GHG reductions in the roadmaps towards a competitive low-carbon economy and resource-efficient transport require not

only gradual improvements of current strategies but structural changes leading to a transition of society and as such of the transport sector. These structural long-term changes in the organisation of transport and mobility might also offer potentials for reducing vulnerabilities to climate change. Conversely, the magnitude of climate change might require major structural modifications to adapt and these efforts can support the transition towards a competitive low-carbon economy too. For example, transforming transport behaviour and transport demand could achieve not only lower emissions but, at the same time, offer opportunities either to build a more resilient transport system and services under climate change or to develop more flexible social and economic practices that could better accommodate eventual disruptions in the transport system.

1.2 Resilient transport is necessary for society

Transport is today a critical support system for the smooth operation of our societies and economies. At the European level, the political relevance of transport is high as a necessary instrument for the facilitation of trans-boundary relationships and the physical and economic integration within the EU.

Changes in climate could compromise the smooth operation of our societies and the economy. The complexity of the current transport system has an amplifying effect on these impacts: if disruptions affect critical sections of the network, transport flows may be delayed or stopped many kilometres away from the area originally affected. Multi-modal, complex transport chains and their associated production and logistics activities could be halted, and the daily routines of millions of citizens could be altered; and if vulnerable infrastructures are serving regions with already limited accessibility alternatives, they could compromise their development prospects.

Even though not caused by climate change, the eruption of Iceland's Eyjafjallajökull volcano highlights dramatically some drastic consequences of a natural disaster. It illustrates well the high vulnerability of the European transport system and the wide-spread impacts even a regional event can generate (Box 1.2).

Transport has already in the past dealt with extreme events causing interruptions, whether stemming from natural hazards or human impacts like accidents and power cuts, and developed strategies to maintain resilience. Resilience refers to a system's capacity to remain operational under different external pressures. Society, as well as transport providers, has an interest in smooth transport operations. Current transport systems need to be reassessed to check if they remain operational under both extreme events and gradual changes of temperature, rainfall regimes or sea level.

Box 1.2 The eruption of the Eyjafjallajökull volcano — a local extreme event with worldwide impacts

In April 2010, Iceland's Eyjafjallajökull volcano erupted. Although this event was local, the ash cloud grounded 95 000 flights across Europe, accounting for 48 % of total air traffic and roughly 10 million passengers stranded in Europe and worldwide. This event caused massive secondary and tertiary costs for businesses and people depending on the flight connections (Jeunemaitre and Johnson, 2010; O'Regan, 2011).

While not related to climate change but a natural disaster, the extreme event provides an indication of the vulnerability of our transport system, with effects going far beyond local impacts, as an important pillar of our society. Climate change-induced extreme weather events could lead to similar situations in which a local event can have major impacts on regions or even countries far beyond. Although so far no indications are available pointing to the same magnitude of a single event, climate change adaptation stakeholders can learn from the disaster risk management and the measures triggered following this episode.

Photo 1.2 Flights disrupted at Charles de Gaulle airport due to Eyjafjallajökull volcano

© Joi Ito, Wikimedia Commons

The transport system is interconnected and it is an indispensable service making other economic and social activities possible. Therefore, adaptation of transport systems to climate change requires a wide perspective. This suggests strongly integrating climate change adaptation of the transport system with efforts in other sectors and policy areas. In addition, there will be a need to embed adaptation into broader transition strategies of our society, rather than leaving it to be implemented by single stakeholders like infrastructure managers, operators or regulating authorities in the transport sector.

1.3 Specific challenges for adaptation in the transport sector

Transport has numerous actors

Transport activity is the result of bringing together resources of quite a different nature: appropriate infrastructure, equipment, vehicles, trains, aeroplanes and ships need to be provided. Service providers put together these resources to make transport services available for different needs, thereby using different transport modes: rail, road, aviation, inland water or maritime shipping. Regulators at the various administrative levels provide the basic rules to facilitate operations to run smoothly, efficiently and with minimum impacts. Finally, the numerous users make their choices and thereby shape transport demand.

Most stakeholders may only have a partial perspective of the system they manage or use. They might also have different interests in transport (Table 1.1). It is expected that, without overall strategies, the main stakeholders will react autonomously to the challenges of climate change. Given the broad challenges of climate change and the strong interconnectivity inside the transport sector and with other sectors and areas of society, such a fragmented approach seems unlikely to be efficient. It challenges the necessary consistency and coherence across the sector and system to address long-term challenges.

Responsibility for adaptation

The responsibility for adaptation action in the transport sector is often not clear. Some adaptation happens spontaneously by single transport stakeholders as current events make action necessary. Systemic approaches fall in some countries into the responsibility of public authorities dealing with climate change, in other countries dealing with transport and again others dealing with disaster risk management (ETC/CCA, 2013). Some stakeholders may prefer to wait for other players to act first and take leadership: users will generally rely on transport providers; transport providers will expect the vehicle industry and infrastructure managers to provide 'adapted' or 'climate-proof' solutions. The providers of equipment and infrastructure will expect new standards and guidelines from regulators. Policymakers and regulators will look at researchers for collecting evidence and providing options.

Table 1.1 indicates that in the event that adaptation related to transport would happen only spontaneously, conflicting and ineffective strategies could follow. For instance, users might switch to another mode and not wait until the original mode is adapted or meanwhile some transport providers might find it more economical to accept interruptions under certain circumstances. This might not be an appropriate approach for businesses that may lose a lot of their income.

Some countries have therefore adopted a top-down approach to transport adaptation in addition to bottom-up approaches by single stakeholders as a means to create the necessary conditions to facilitate the action of all these stakeholders in the future. The national adaptation strategies and action plans of, among others, France and Germany (Box 1.3) illustrate this approach: at this stage, action is mainly in the hands of the national government and its associated public sector, by means of expanding the knowledge base and undertaking systematic assessment of current vulnerabilities in the system. Specific actions include the development of new research programmes or a systematic revision of standards and guidelines in different transport modes. In the United Kingdom, climate change legislation includes a mandate to organisations classed as critical infrastructure (including many transport infrastructure managers) to carry out risk assessments and to develop climate adaptation strategies (DEFRA, 2012). It can be expected that such governmental efforts serve to provide a sound basis for private and public stakeholders to identify their own risks and opportunities for action in a complementary bottom-up approach.

Long-term and costly investments

An important backbone of transport services are vehicles and infrastructure, which usually require investments with high costs. Furthermore, transport infrastructure but also vehicles and in particular

Table 1.1 Different adaptation interests of transport stakeholders

Actors	Likely primary interest in transport	Existing and potential adaptation approaches
Governments (acting for society as a whole)	• Ensure a well-functioning transport system as the backbone for economic activities and movement of people.	• Mange or support to ensure a stable transport system also under climate change and extreme weather events; • strategies, action plans, mainstreaming into other policies like Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA), spatial planning, emergency plans, urban renewal etc.; • ensure security through access to emergency aid in crisis situations.
Private and public users	• Need reliable, affordable transport for the exchange of goods; • commuting to work, study, daily life issues; • leisure and business trips.	• Switch to another provider; • switch to another mode; • access services without transport by ICT, telecommunication, etc.; • change their travel plans.
Private and public providers — service operation	• Business continuity by providing transport services; • provide transport services as a basic service for society.	• Adapt operation procedures; • request climate-proof infrastructures and vehicles/equipment; • change to other infrastructure and equipment providers if that is an option; • accept interruptions if the related costs are lower for the company than adapting (cost–benefit analysis for the company).
Private and public providers — infrastructure	• Business continuity by providing transport infrastructures to operators; • provide transport infrastructures to operators to ensure a well-functioning transport system.	• Proper maintenance of the infrastructure; • making infrastructure climate-resilient; • provide alternative routes (redundancies), if the related costs are lower for the company than adapting (cost-benefit analysis for the company); • otherwise accept interruptions and repair the affected infrastructure after a disaster; • insure against potential damages.
Providers — vehicles, aeroplanes, ships, trains, equipment	• Business continuity by providing vehicles and equipment to operators.	• Proper maintenance of the equipment, trains, etc.; • making equipment, trains, etc. climate-resilient (based on cost–benefit analyses for the company); • develop/provide climate-proof equipment according to the request of their clients (operators).

trains, aeroplanes, ships and other equipment are usually designed with a long-term perspective. If this infrastructure and equipment is not fit for future climate conditions, this would require additional climate-proofing measures at a later stage, in many instances with substantial additional costs. Considering the likely future climate conditions while planning and building new infrastructure, during upgrading or at maintenance work could not only limit the impacts of climate change but also reduce the costs substantially.

Dealing with uncertainty

Although there is a consensus that climate change is happening, the impacts of climate change on transport in the future face several uncertainties, such as the adequacy of the level of detail or scale of current climate models to transport planning purposes, or the uncertainties in climate models themselves and their basic assumptions (IPCC, 2013; EEA, 2012). Furthermore, the impacts of climate change are intertwined with socio-economic trends

Box 1.3 A comprehensive top-down approach to transport adaptation in Germany and France

Transport is one of the 14 sectors analysed within the German Adaptation Strategy (DAS). 'Sectorial adaptation research' is one of the measures considered to expand the knowledge. The KLIWAS project, dealing with adaptation of inland water shipping, is probably one of the best examples of this sectorial research (see also Box 3.5). Another initiative, closely related to transport infrastructure, is research in the area of spatial planning, regional development and urban development, identifying measures to be subsequently tested since 2009 in model regions (also related to KLIMZUG, a programme to integrate extreme weather in regional planning, running from 2008 to 2013).

In France, the National Adaptation Strategy, adopted in 2006, presents the French state's perspective on the climate change issue. Concrete measures are given by the National Plan for Climate Change Adaptation (PNACC), adopted in 2011. The PNACC has an item 'transport infrastructures and systems' that identifies several actions concerning the transport sector: revision of technical references; research on the impacts of climate change on transport demand and supply; development of a methodology for assessing vulnerability; completion of an evaluation of the vulnerability of transport networks and identification of response strategies needed. Within these actions, a total of 11 particular measures on the transport sector are included in the national adaptation plan — e.g. the revision and adaptation of standards and guidelines for transport infrastructure construction, maintenance and exploitation; the impact of climate change on transport demand; and the assessment of the vulnerability of the various modal networks.

Sources: BMU, 2012; ONERC, 2013.

like demographic change, changes in production patterns and lifestyles leading to altered transport demand.

Dealing with uncertainty requires, on the one side, an expansion of the knowledge base and to improve the information available. Increased collaboration among transport experts and climate change experts can inform the development of climate models and improve use of their outputs in connection with transport infrastructure design and transport operations. A better knowledge of local conditions, and learning from extreme events in the past can also reduce some uncertainties (Sections 3.1 and 3.2).

On the other side, despite better knowledge over time, uncertainty about future climate change will remain. Therefore, transport stakeholders need to ensure that their actions are taken according to the most appropriate use of the available knowledge. Several approaches have been developed and are also being implemented for dealing with uncertainty (EEA, 2013). A key approach is to develop and implement robust solutions that would be effective and efficient under a range of climate change scenarios. Flexible measures allow adjusting the solution over time and at the pace of new knowledge becoming available. Low-regret measures are measures that would yield benefits even in the absence of climate change impacts. They would be justifiable under all plausible future scenarios of climate change, as they usually show benefits for other areas and sectors too (Section 3.2).

Past experience is valuable but might not be sufficient

Weather conditions and specifically extreme weather events resulting in disasters are already a primary cause of disruption, and transport stakeholders have consistently dedicated resources to anticipate their impacts, to adapt infrastructure and operations, and to revise guidance and standards. Exchange of experience among European countries may serve as a support — e.g. the south-to-north transfer of know-how about infrastructure operation under warmer conditions. However, due to the projected magnitude of climate change and the associated impacts, and taking into account socio-economic change and uncertainties, an incremental approach based on traditional practice is expected not to be effective in the future. Therefore, innovative and broader approaches to adaptation are needed, leading to structural changes in transport services and strengthened cooperation with other sectors (Section 3.2).

2 State of transport adaptation

Key messages

- Initial action to adapt the transport system is taking place at all governance levels. The EU Strategy on adaptation to climate change and national adaptation strategies provide a framework.
- Transport adaptation is not yet a high-priority area in most national adaptation strategies and plans. In most countries, adaptation policies remain within the responsibility of environmental authorities, with transport administrations playing an implementing role.
- Transport adaptation action in countries mostly focuses on early policy stages (e.g. awareness raising, research, vulnerability assessments) and less on implementation through measures. Implemented measures are often spontaneous and relatively isolated, often as a reaction to a weather-related disaster.
- The large potential to mainstream adaptation into regular transport planning and actions and to mainstream transport adaptation into other policies, such as Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA), and plans is only partially used — e.g. only a few countries report on the preparation of risk management plans that are explicitly including the transport sector.
- Together with a relatively low awareness of the adaptation needs for the transport system, the lack of tailored knowledge, like adequate climate reference thresholds for the assessment of the vulnerability of transport infrastructure and services, capacities and resources, poses barriers to adapting the transport system.

2.1 European level

Key EU initiatives, particularly *Europe 2020 — Europe's growth strategy*, its flagship initiative for resource efficiency, and the European Commission's proposal for a *7th Environment Action Programme to 2020* (7EAP) (EC, 2012a) consider adaptation to climate change. For example, the 7EAP requests that projected expansion of transport infrastructure in Europe is compatible with the needs of climate adaptation ([2]). These documents provide stakeholders with a long-term plan for how Europe will make the transition to a sustainable, low-carbon, resource-efficient, green and climate-resilient economy, where ecological resilience has been achieved.

Various funds of the EU provide opportunities for transport investments, taking into account climate change. For the period 2014–2020, 20 % of the EU budget is foreseen for climate change action (both mitigation and adaptation). The European Structural and Investment Funds (ESI Funds) as well as Horizon 2020 and the LIFE programme will provide significant support to Member States, regions and cities to invest in programmes and projects on adaptation, especially in the framework of the dedicated investment priorities on adaptation in the European Regional Development Fund (ERDF) and Cohesion Fund ([3]). The five ESI Funds account for one third of the EU budget ([4]). These Funds provide a range of opportunities to enhance climate change adaptation while building new transport infrastructure and systems.

The main EU policy document specifically targeting adaptation to climate change is, however, the EU Strategy on adaptation to climate change (EC, 2013d). Its objective is to contribute to a more resilient Europe at national, regional and local levels, thereby focusing on enabling Member States and local governments to take action and to mainstream

([2]) See paragraph 87, within policy objective 7 of the programme 'To improve environmental integration and policy coherence'.
([3]) See http://climate-adapt.eea.europa.eu/eu-adaptation-policy/funding.
([4]) See http://climate-adapt.eea.europa.eu/web/guest/eu-adaptation-policy/funding/esi.

adaptation into different policy areas. The strategy considers that 'by prioritising coherent, flexible and participatory approaches, it is cheaper to take early, planned adaptation action than to pay the price of not adapting' (Box 2.1).

Action 7 of the strategy considers directly adaptation in the transport sector. The strategy mentions that adaptation has already been mainstreamed in legislation in sectors such as transport, but further efforts to ensure effective and efficient mainstreaming will be needed. It also cites the legislative proposal on the EU guidelines for the development of the Trans-European Transport Network (TEN-T), which were later approved (EU, 2013) (Box 2.2). The strategy further stresses the importance of analysing the extent to which the European standards and technical specifications for physical infrastructure should be strengthened. This is being addressed through a standardisation request addressed to the European standardisation organisations to map industry-relevant standards in the areas of energy infrastructure, transport infrastructure and construction/buildings, and to identify standards to be revised for better inclusion of adaptation considerations (EC, 2013a). The first outcome of this exercise could be available by the end of 2016.

The accompanying European Commission *Staff working paper: Adapting infrastructure to climate change* (EC, 2013c) provides valuable information on adaptation challenges for transport and how to deal with them. It also points out that EIA and SEA can be appropriate instruments to mainstream adaptation, helping to improve the climate resilience of infrastructure. Guidance to include climate change adaptation into EIAs and SEAs has been developed by the European Commission to support its Member States (EC, 2013f and 2013g). A further accompanying document, *Non-paper guidelines for project managers: Making vulnerable investments climate resilient*, provides helpful guidance for transport investments (EC, 2012b).

Several other actions in the strategy are also relevant for transport. Action 3 supports adaptation in cities through the Mayors Adapt initiative ([5]). Many climate change impacts in cities affect transport systems directly or indirectly. This initiative is therefore expected to enhance the development and implementation of urban transport adaptation actions across Europe.

Action 4 includes filling knowledge gaps through the EU Framework Programme for Research

Box 2.1 Objectives and actions of the EU Strategy on adaptation to climate change

Objectives

The overall aim of the EU Strategy on adaptation to climate change is to contribute to a more climate-resilient Europe. This means enhancing the preparedness and capacity to respond to the impacts of climate change at local, regional, national and EU levels, developing a coherent approach and improving coordination.

Actions

Promoting action by Member States:

- Action 1: Encourage all Member States to adopt comprehensive adaptation strategies.
- Action 2: Provide LIFE funding to support capacity building and step up adaptation action in Europe (2013–2020).
- Action 3: Introduce adaptation in the Covenant of Mayors framework (2013/2014).

Better informed decision-making:

- Action 4: Bridge the knowledge gap.
- Action 5: Further develop Climate-ADAPT as the 'one-stop shop' for adaptation information in Europe.

Climate-proofing EU action: promoting adaptation in key vulnerable sectors:

- Action 6: Facilitate the climate-proofing of the Common Agricultural Policy (CAP), the Cohesion Policy and the Common Fisheries Policy (CFP).
- Action 7: Ensuring more resilient infrastructure.
- Action 8: Promote insurance and other financial products for resilient investment and business decisions.

Source: EC, 2013d.

([5]) See http://mayors-adapt.eu.

and Innovation 2014–2020 — Horizon 2020. Around 35 % of the Horizon 2020 budget will be climate-related expenditure. Adaptation to climate change is most represented in two societal challenges: 'Climate action, environment, resource efficiency and raw materials' and 'Secure societies — protecting freedom and security of Europe and its citizens'. However, climate change will also be addressed in other areas, including 'Smart governance, network resilience and streamlined delivery of infrastructure innovation' ([6]).

Action 8 aims to improve the market penetration of natural disaster insurance and use of insurance for risk awareness, prevention and mitigation, and for long-term resilience in investment and business decisions, also taking into account climate change. A Green Paper on the insurance of natural and man-made disaster was published with the EU Strategy on adaptation to climate change in 2013 (EC, 2013e).

The EU White Paper on transport refers to adaptation in the context of selection of transport infrastructure projects to be co-financed with EU funds (EC, 2011b). Co-funded projects should equally reflect the need for 'green' infrastructure that is resilient to the possible impact of climate change. This is covered by initiative 34 within the list of actions included in Annex I of the White Paper that will ensure that EU-funded transport infrastructure takes into account energy efficiency needs and climate change challenges.

For the Trans-European Transport Network (TEN-T), the TEN-T Regulation (EU, 2013) covers this action, as it includes several references to adaptation to climate and resilience to extreme weather events during the planning process of TEN-T projects. The implementation of these criteria within the TEN-T assessment and funding processes is currently under development within the European Commission, in close contact with the Innovation and Networks European Agency (INEA) (Box 2.2).

Box 2.2 Adaptation to climate change in the new TEN-T guidelines

The revised guidelines of the TEN-T were approved in December 2013. The Network developments should take into account the contribution to climate change and the impact of climate change and of potential natural and man-made disasters on infrastructure (§33, Preamble), and they shall be planned, developed and operated in a resource-efficient way through, among others, adequate consideration of the vulnerability of transport infrastructure (Article 5.1.g).

The guidelines list the following provisions:

- Projects of common interest searching for EU funding will be subject to a socio-economic cost–benefit analysis taking into account also the relevant climate-related benefits and costs (§22, Preamble).
- During infrastructure planning, Member States and other project promoters should give due consideration to the risk assessments and adaptation measures adequately improving resilience to climate change and environmental disasters (§34, Preamble; Article 35).
- 'General priority shall be given to measures that are necessary for: … (e) improving or maintaining the quality of infrastructure in terms of safety, security, efficiency, climate and, where appropriate, disaster resilience, environmental performance, …' (Article 10.1.e).
- The work plans for the development of the corridors, that shall be submitted by the end of 2014 to the Member States, shall include an analysis of '… the possible impacts of climate change on the infrastructure and, where appropriate, proposed measures to enhance resilience to climate change' (Article 47.1).

The guidelines also include more specific provisions for mainstreaming adaptation within the key components of this European policy:

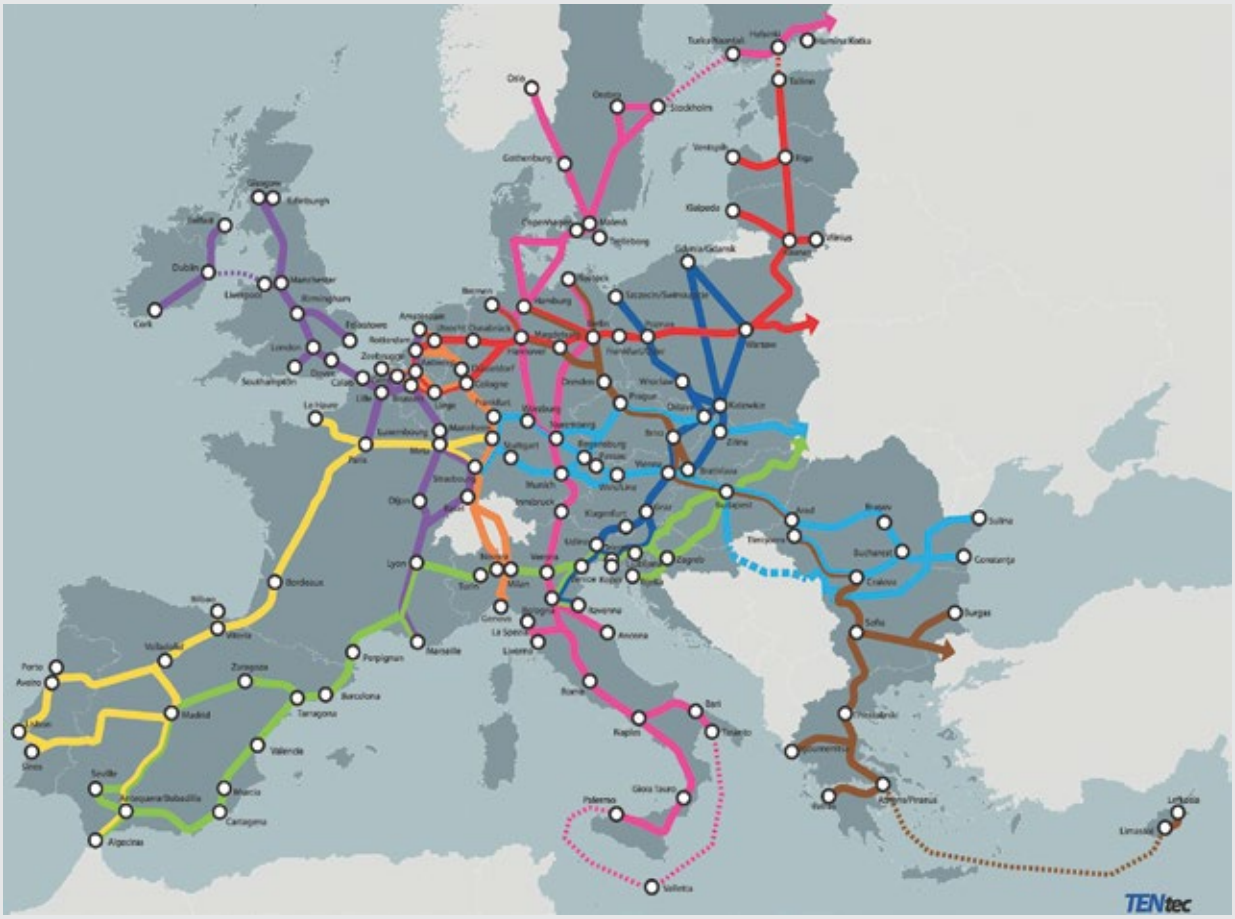
- Funding of projects of common interest, through the inclusion of climate impacts within compulsory socio-economic cost–benefit analysis.
- Development of the comprehensive network. Climate and resilience is considered as a development priority; technological development and innovation should also address the improvement of climate resilience.
- Core network corridors. The work plan for each corridor must include provisions on adaptation, with 'proposed measures to enhance resilience to climate change'.

Source: EU, 2013.

([6]) See http://climate-adapt.eea.europa.eu/web/guest/eu-adaptation-policy/funding/h2020.

Box 2.2 Adaptation to climate change in the new TEN-T guidelines (cont.)

Map 2.1 A map of the core Trans-European Transport Network



Source: © EC

2.2 EEA member countries

Climate-ADAPT ([7]), the European adaptation platform, provides an overview of adaptation strategies of EEA member countries. Some further information, based on a self-assessment survey, is available in the EEA Report on national adaptation policies (EEA, 2014b). This chapter uses information from both sources, together with the results of a specific questionnaire, *Adaptation of transport to climate change in EEA member countries*, which was sent to the Eionet national reference centres of EEA member countries in 2013 and answered by 23 countries (ETC/CCA, 2013). The results of the latter are to be read as a call to encourage further analysis and discussion rather than as a complete picture of the prevailing situation, as they reflect the perception of a limited number of respondents.

Transport in adaptation strategies and plans

At least 21 EEA member countries have developed national adaptation strategies or plans and such strategies are under development in at least five additional countries (Bulgaria, Czech Republic,

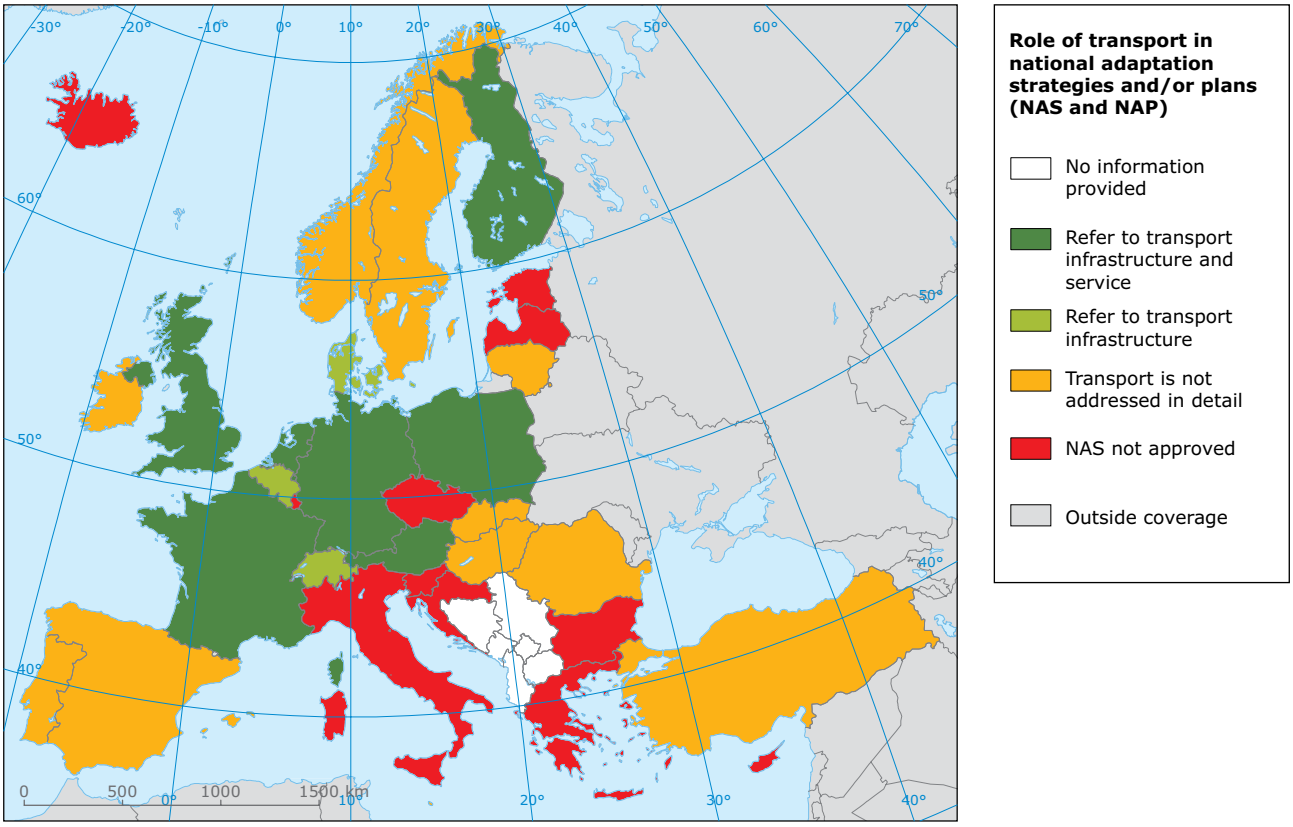
([7]) See http://climate-adapt.eea.europa.eu/en/adaptation-strategies and http://climate-adapt.eea.europa.eu/web/guest/countries.

Estonia, Italy and Liechtenstein). The transport sector is specifically addressed in most of those strategies and plans with some detail (including countries such as Austria, Belgium, Denmark, Finland, France, Germany, the Netherlands, Poland, Slovakia, Spain, Switzerland and the United Kingdom) (Map 2.2).

The contents and degree of detail of these strategies and plans for the transport sector are quite disparate: in general, the first strategies and plans approved (the first ones were adapted in 2005) are rather shallow and general, whereas the most recent ones tend to describe with some detail the key adaptation actions that will be developed for the transport sector. Most of the national adaptation strategies and plans focus on transport infrastructure issues, although those from at least eight countries (Austria, Finland, France, Germany, the Netherlands, Poland, Switzerland and the United Kingdom) also refer to some aspects of transport services, such as development of alternative routes and means of transport, traffic management, review of technical conditions for vehicles and their operations, or support to operators in the development of their adaptation assessment and actions.

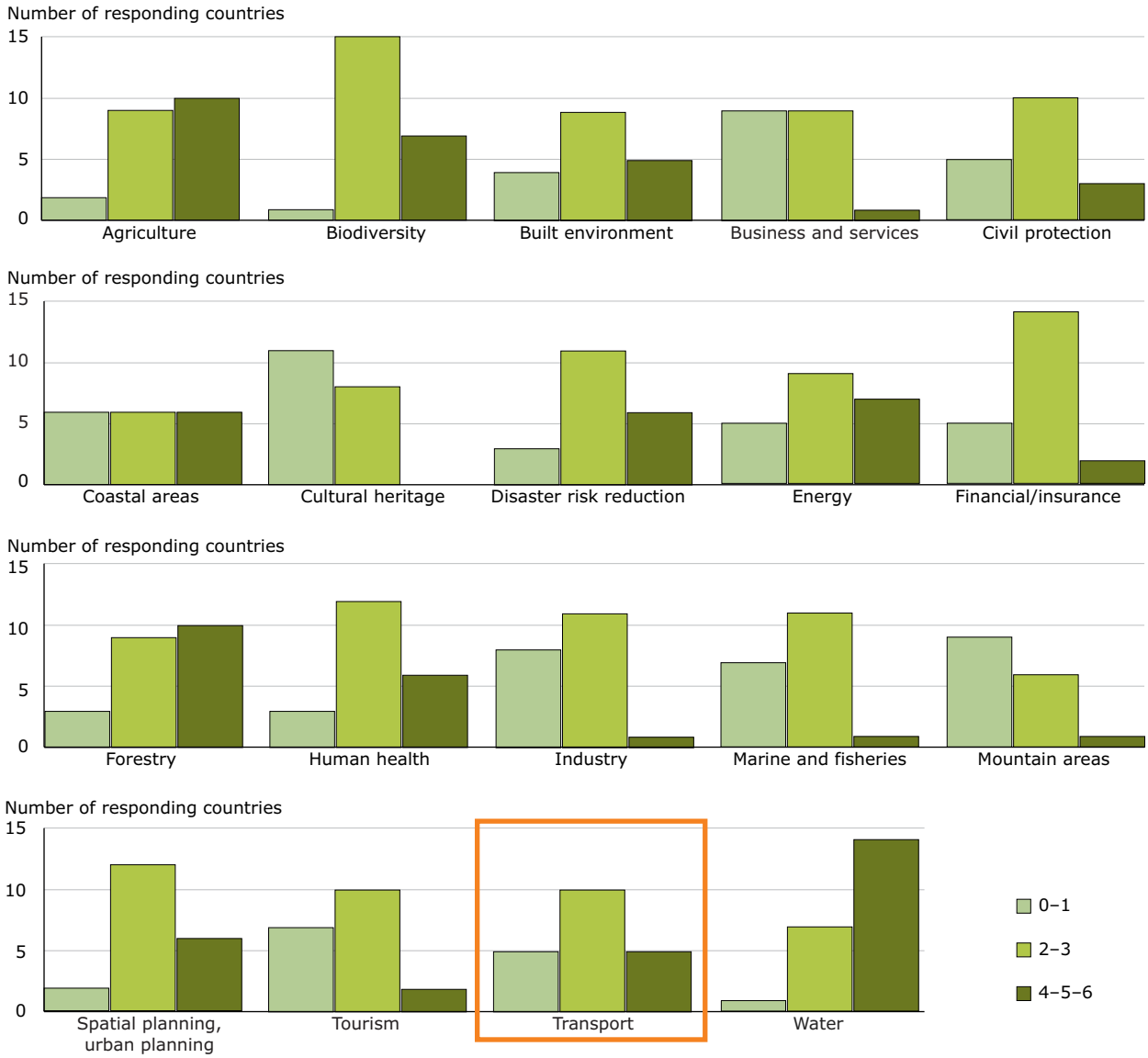
The EEA Report, *National adaptation policy processes in European countries — 2014* (EEA, 2014b), shows a similar picture, since both Climate-ADAPT and this 2014 report are building on the same nationally provided information. The 2014 report is based on a self-assessment survey addressed to EEA member countries. In terms of the knowledge base, transport is indicated as one of the seven sectors that have attracted more attention from policymakers in EEA countries (the others are agriculture, forestry, biodiversity, human health and water, and energy), and that has been the object of risk and vulnerability studies. From a planning perspective, the self-assessment also shows that transport is still at the initial stages within the planning process: out of the 19 countries providing answers on this question, 15 had recognised the need for action in this area, 10 of them had started coordination activities or identified measures, and only 5 had moved forward to implementation (Figure 2.1) (EEA, 2014b).

Map 2.2 Role of transport in national adaptation strategies and/or plans (NAS and NAP)



Sources: ETC/CCA, 2013; EC and EEA, 2014; EEA, 2014b.

Figure 2.1 Adaptation planning progress at national level



Note: 0: adaptation is not relevant for my country

1: need for adaptation not recognised and no measures implemented yet

2: coordination activities for adaptation started

3: some adaptation measures identified for the sector but not yet implemented

4: portfolio of adaptation measures identified and implementation (of some) launched

5: portfolio of adaptation measures implemented

6: portfolio of adaptation measures in place and monitored/evaluated.

Source: EEA, 2014b.

The transport sector is not yet a central issue in many adaptation strategies

Responses to the 2013 questionnaire on transport adaptation (ETC/CCA, 2013) showed that, although present in most of the national adaptation strategies and plans, the transport sector is not generally seen as a high priority in most of them. Only a few countries, most notably the United Kingdom and, to a lesser extent, Austria, France, Germany or Switzerland, gave significant attention to transport within their adaptation strategies. This is consistent

with the results of the self-assessment of national adaptation action: only 4 out of 19 countries answering this question identify transport as a priority area for action in adaptation (EEA, 2014b).

Nevertheless, the transport sector seems to be very receptive on this topic, and research and vulnerability assessments on transport systems develop rather quickly once the transport sector itself becomes active, usually going well beyond the initial mandate in national adaptation strategies and plans. This is, for example, the case in Germany, where an ambitious research programme on adaptation for water transport (KLIWAS) was launched by the Ministry of Transport in 2009. Although no action in this sense was initially envisaged within the German national adaptation plan, KLIWAS, developed between 2009 and 2013, became an important stepping stone within the German national adaptation strategy. A similar situation occurred in Spain, where a review of vulnerabilities and risks in the transport system was undertaken in 2012–2013, bringing all modes on board to think together on the main issues at stake, although this was not originally envisaged in the Spanish national adaptation strategy or plan. For the first time, the different modes could also share their databases on existing episodes where a disruption or failure in the infrastructure due to weather events had occurred. This was very helpful to monitor general figures and identify vulnerabilities.

The responses received also reflected that respondents were mainly aware about progress in adaptation at the national level (ETC/CCA, 2013). Only a few countries included information on actions at the sub-national level. Box 2.3 and Box 1.3 illustrate the different approaches to transport in national adaptation strategies with some examples.

Transport infrastructure and services are not equally considered

The transport sector is considered in a variable level of detail from country to country. Whereas transport infrastructure is included in the national adaptation strategies or plans of at least 12 EEA countries, only half of those consider also transport services (Map 2.2). The degree of detail is also variable: some of them describe actions on transport infrastructure and services with a good level of detail (e.g. Austria and Germany, whereas others make only reference to some specific questions of transport services (France, the United Kingdom); although not specific to transport services as such, road traffic management is also mentioned in some national strategies and plans (e.g. Denmark).

Different approaches across different transport modes

Transport modes are considered differently, depending on the specific conditions of each country. No country reports about an integrated, trans-modal approach to adaptation. All transport modes are

Box 2.3 Transport in national adaptation strategies — experience in Spain and the United Kingdom

Countries are addressing the transport sector in a variety of ways within their national adaptation policies, strategies and plans. For example:

- In Spain, the national climate change adaptation plan is conceived as a framework tool for reference and guidance for the national, regional and local governments; it is thus conceived as a point of departure, to be freely developed by the relevant government agencies based on their expertise and priorities, with no explicit mandates or goals. Explicit lines of action for the transport sector were approved much later, in December 2013, as an open working programme for the transport sector to develop in 2014–2020 (OECC, 2014).
- In the United Kingdom, the National Adaptation Programme (HM Government, 2013) is the latest output from a statutory process launched in 2008 when the Climate Change Act was passed. It is based on previous assessment of vulnerabilities and risks, and it includes specific objectives and actions, some of which focus on the local level. Many of the previous vulnerability and risk assessments used the UK Climate Projections 2009 (UKCP09), the fifth generation of climate change information for the United Kingdom, whose projections are based on a novel methodology designed by the Met Office Hadley Centre. Transport is represented principally as part of the infrastructure policy area.

These two examples show the variety of approaches found throughout EEA countries. In various countries, adaptation policies and strategies are encouraging transport ministries and agencies (and eventually other stakeholders) to include adaptation within their policies and current practices; in others, adaptation is taken as a new priority, requiring new and innovative approaches.

addressed, although rail, road and urban transport are those mentioned in a majority of responses. Aviation is also considered in many countries. Inland waterborne transport receives keen interest in those countries for which this mode is relevant. Maritime transport is explicitly mentioned only in the answers from five countries (Denmark, Finland, France, Germany and the United Kingdom).

There is a growing number of climate change adaptation initiatives for specific transport modes. In Finland, specific plans cover road infrastructure (2007), rail infrastructure and services (2008), and maritime transport (2009); the Flemish government in Belgium has produced a master plan for inland waterways, and the British government required the relevant infrastructure managers to develop their adaptation plans, including also local governments: London has developed various documents on urban transport infrastructure.

Not surprisingly, the main climate change challenges considered are also those linked to the specific conditions and geographical location of each country: most of them include in their analysis storms, flooding, droughts, ice, snow and changes in temperature; sea-level rise is mentioned by those countries with significant maritime activity or with major transport infrastructure in coastal areas.

Mainstreaming adaptation into transport planning and decisions

Climate change adaptation is not yet broadly mainstreamed within transport planning and decision-making practices. The involvement of national transport authorities is taking place in different ways. In some cases, the ministries of transport have been explicitly requested to produce sectorial adaptation strategies or programmes (Denmark in 2010, Finland in 2009, and the United Kingdom in 2012). In other countries (such as Hungary and, more recently, Germany and Sweden) national transport plans are including some general considerations or objectives on adaptation. In some countries (France, Germany, Spain), the ministry of transport is developing specific actions, as required by the national adaptation plan or other implementation documents. National adaptation plans and strategies in some cases (Denmark, France, Germany) include specific mandates for the transport sector, such as the revision of technical standards in the rail sector, network vulnerability studies, the revision of guidelines on the hazards of forest fires on infrastructure, or the development of scenarios in order to consider adaptation within the EIA process according to the newly amended EIA Directive (2014/52/EU). In general, it can be concluded that adaptation policies remain within the responsibility of environmental authorities, with transport administrations playing an implementing role.

Although disaster risk management plans covering extreme weather events can be helpful tools for also coping with climate change, only a few countries report on the preparation of risk management plans that are explicitly including the transport sector. This is the case for Austria, mainly under the responsibility of the Ministry of Environment or the meteorological services. It is also the case for Spain, under the responsibility of the Civil Protection Services, and for Switzerland, under the responsibility of the federal road administration. In Switzerland, a comprehensive study for all transport modes, covering risks and opportunities linked to climate change, is currently under development. In France, risk management plans for coastal disasters, including rail and road infrastructure and services, are operational since 1995; flash flood management plans have been prepared in 2011, but they do not include the transport sector. It is worth noticing that there were no transport-specific emergency protocols in any country reported, and that the sector is integrated within the general emergency protocols.

Revising guidelines and standards

In a few countries, preparatory initiatives have begun in order to revise design and operational guidelines and standards for transport infrastructure at the national level. For example, the French national adaptation action plan includes a mandate to the technical services of the French government for assessing the existing standards for design and maintenance in order to check the current vulnerability of the transport system, and their recommendations are expected to be issued in 2014 (ONERC, 2013). The United Kingdom conducted some studies for roads, including the document *Maintaining pavements in a changing climate*, published in 2008 by the Department for Transport (Willway et al., 2008). In Switzerland, the project to deepen the Rhine waterway between Basel and Birsfelden, in order to enhance reliability of inland navigation during low-water conditions, could also be seen as an implicit revision of traditional operational guidelines (OFEV, 2014). The example of Norway is given in Box 2.4.

Those countries undertaking a revision of standards (such as France, Germany or the United Kingdom)

Box 2.4 Revision of guidelines and manuals for road transport in Norway

The Norwegian Public Roads Administration (NPRA) led a thorough revision of existing manuals and guidelines for road transport to consider also climate change impacts, such as flooding, landslides (especially more frequent wet landslides), drifting snow, intense rain events, erosion and sea-level rise. This included all NPRA guidelines for planning, design and construction of new roads and bridges, operations and maintenance of existing roads and bridges as well as preparedness and emergency planning.

For instance, for operations and maintenance, a requirement was added that drainage infrastructure and waterways must be checked for obstructions ahead of major storms to ensure proper functioning of drainage infrastructure. Another example of a revision is the requirement for a plan to manage run-off in all new road plans.

The project also proposed four new manuals: 'Rockslide protection of roads', 'Debris flows and slush avalanches', 'Roads and snow avalanches', and 'Roads and drifting snow'. The new manual on 'Debris flows and slush avalanches' was developed in the face of the new phenomenon of wet landslides and their likely increase in the future. Most of these new manuals are currently in the final stages of approval by the road administration.

Source: NPRA, 2013.

Photo 2.2 Landslide in the Veiklidalen valley in June 2011

© Andrea Taurisano, Norwegian Water Resources and Energy Directorate (NVE)

have faced a more challenging situation than initially expected. The number of standards potentially influenced by climate parameters is large, and a systematic revision requires substantial resources. Furthermore, an important pre-condition for the revision of standards and guidelines is the selection of adequate climate reference thresholds for the assessment of the vulnerability of transport infrastructure and services across the modes; these thresholds are difficult to calculate and are not yet available in most countries.

Using natural hazards as a starting point

Few countries report on the actions of transport infrastructure managers and service providers related to climate change adaptation or extreme events within their respective areas of practice. Railway operators in Austria and Switzerland are addressing changing natural hazard situations. They monitor natural hazards and are aware of changes in intensity and frequency. Further details of the Austrian experience are provided in Box 3.2. An assessment of the vulnerability of airports to climate change is under development in France, covering infrastructure and operations (Box 3.8). In Germany, the impacts of extreme events on inland waterways and coastal areas have been studied in the context of the KLIWAS project (Box 3.5). These detailed observations and registrations of natural events seem to be a promising way to detect changing trends as early as possible.

Barriers to adaptation in transport

Adaptation in the transport sector still faces significant barriers both at political and technical levels. The 2013 questionnaire on transport adaptation included a question on the perceived importance of different barriers to improving adaptation to climate change in the transport sector, and the supporting activities that could be undertaken at the European level. The adaptation of transport systems to climate change was generally associated by respondents with a need for an additional dedication of resources, and particularly of financial ones; actual access to these financial resources was rated as very significant barrier. Lack of awareness, training and capacities are perceived as barriers with slightly lower importance and less consensus across countries. Out of their experiences, some respondents pointed out a number of additional barriers, such as uncertainty and the lack of political action. This lack of action can be due to the fact that adaptation is seen as a long-term issue, not requiring urgent short-term action, because there is no political priority or because adaptation is perceived as a

mainly local issue, not requiring much attention at the national level. Another barrier would be the lack of reference data on climate change, which might hinder technicians and infrastructure managers to include adaptation within their practices and investments, particularly in the private sector (ETC/CCA, 2013).

2.3 Transport organisations and providers

The transport sector embraces numerous stakeholders at the private level, in organisations and associations. Also here, some action is visible. For example, in the United Kingdom, more than 30 reports have been published by different transport infrastructure organisations related to their areas of competence (ETC/CCA, 2013). A comprehensive overview of these is not possible here, but the examples provide an indication of their activities. It seems that, in particular, bigger stakeholders, like rail companies, are aware of climate change impacts and the need to adapt, and have started to take action. The prospects of high reconstruction costs, lengthy recovery processes and severe disruptions in the transport system have encouraged infrastructure managers to undertake a comprehensive assessment of the vulnerability of some networks. This is, for example, the case of the French and German railway undertakings, following their respective national transport adaptation strategies and action plans (Boxes 2.5 and 2.6).

As an internally operating logistics company, DHL has developed scenarios and visions of a possible future looking decades ahead in its publication *Delivering tomorrow: Logistics 2050 — A scenario study*. These scenarios consider possible

Box 2.5 Assessing and gaining resilience: SNCF's adaptation strategy, France

The SNCF, the French rail company, has decided to consider the rail system as a whole rather than conducting a specific study for each component. The activities are developed under the SNCF project Climat D'Rail. It created a working group that brings together specialists from different areas of the company with external professionals and experts.

The study phase of the project included three main actions: (1) identification of the impacts of climate change, their timeframe and vulnerability of zones; (2) identification of priority adaptation measures, based on the identified impacts; and (3) assessment of the priority measures and selection, consistently with the overall strategy. The project has now entered its operational stage.

The SNCF has built its adaptation strategy by taking into account examples from other countries with harsher weather conditions. The heart of this strategy is based on low-regret measures, whose cost–benefit balance remains positive independently from the pace of climate change. The whole set of measures is divided into three parts:

- Creation of a knowledge base to refine the measurement of risks and associated losses to better assess the feasibility and cost of technical solutions.
- Development of tools for support to the different relevant timeframes: crisis management in emergency situations, prevention plans and medium-term investments.
- Mobilisation of internal and external stakeholders without which the SNCF cannot take action: staff organising authorities, public authorities, customers.

Three solutions/actions are in progress:

- To develop and update a regionalised map of climate vulnerabilities based on 30-year forecasts from Météo-France models (Arpège) and IPSL/Jussieu.
- To update construction and maintenance standards of the infrastructure in cooperation with RFF, and European and international specifications for the resilience of rolling stock, etc.
- Reflection on the management of a long-term climate crisis involving many players.

The SNCF adaptation plan looks beyond the impact of climate change-related natural risks on rail infrastructure and services. It also explores long-term indirect impacts, such as changes in leisure travel due to changes in tourist destinations and the availability of and access to electricity in case of hydrological shortages (ONERC, 2014). Furthermore, the prioritisation of investments is under revision, due to the uncertainty linked to the long-term estimates (20–50 years) required for impacts and measures (ONERC, 2014, p. 23).

Source: Kaddouri, 2014.

Box 2.6 Adaptation action of Deutsche Bahn, Germany

Deutsche Bahn (DB), the main German railway company, focuses its adaptation efforts on four main areas:

- Participation in a working group for the revision of standards with the German Standardisation Institute (DIN). The aim of this group is to determinate standardisation for the technological development due to necessary climate change adaptation.
- Revision of protocols and operational plans for extreme weather events by DB-Netz, which is responsible for the rail infrastructure.
- Research on climate change adaptation strategies: DB is working — together with the German Federal Railway Authority — on initiating research projects on climate change and adaptation strategies. The first research projects were launched in 2014.
- DB is part of the stakeholder process guided by the Federal Environmental Agency to develop the second Adaptation Action Plan of the German Strategy for Adaptation to Climate Change (APA2), which will be concluded, according to estimations, in 2016.

Photo 2.3 Flooding of the Hannover-Berlin railway line

© Deutsche Bahn AG, Frank Barby

Source: Hölzinger, 2014a and 2014b.

impacts of climate change on the transport sector but also on the economy and society. They also generate different transport demand patterns and request different services (DHL, 2012). A similar approach is taken by EUROCONTROL, the international aviation organisation composed of Member States from the European region and the EU, in its *Challenges of Growth 2013* Report (EUROCONTROL, 2013).

Numerous other stakeholders start adaptation action on their own or as part of broader initiatives together with public authorities or the research community, as examples in Chapter 3 illustrate.

3 Options and opportunities — examples that can inspire

Key messages

- Most practical examples of adaptation action in the transport sector and system that can be found across Europe focus on early steps like collecting the knowledge, and tailoring climate change impact information and assessments.
- Tools and measures developed to manage risks and disaster from natural hazards, including early warning systems and contingency plans, can be useful for climate change adaptation too; however, there are only few examples of implementation in the transport sector/system.
- Most adaptation action focuses on climate-proofing transport infrastructures; relatively little attention is given so far to transport operations.
- Only a few examples are found that search for innovative solutions across different transport modes, transport as part of broader adaptation plans, or outside traditional paths — e.g. by considering relocation, building redundancies, or changing services to accommodate current and future accessibility demands.
- Effective cooperation between stakeholders inside and outside the transport sector can help to make use of the knowledge gained in other sectors and to find tailored, innovative and effective solutions to adapt transport.
- Integrating adaptation requirements into the design of new and upgraded infrastructure comes at lower cost than adding them at a later stage.

The development of adaptation strategies typically follows a cycle moving from initial awareness raising among stakeholders and decision-makers to exploration of risks and vulnerability, identification of adaptation options, development of adaptation strategies or action plans, and monitoring of implementation and results. This cycle is described in detail in the European Commission guidelines for adaptation strategies (EC, 2013b) and the associated Adaptation Support Tool of Climate-ADAPT ([8]). The result of the search for examples of transport adaptation seems to indicate that most transport adaptation action, as presented also in Chapter 2, is in the early stages of the adaptation cycle.

3.1 Preparing the ground and assessing risks and vulnerabilities

Making available information accessible and filling gaps

Adaptation is still an emerging policy and research area, and there is a lack of comparable data across Europe, accepted methodologies for the assessment of risks and vulnerabilities, and agreed methods for the selection of actions and policy packages. Climate-ADAPT at the European level and national adaptation platforms are making first efforts in collecting relevant information for all stages of the policy process and making it more easily accessible (Box 3.1). However, overall, the information provided is still of a general nature and specific information on transport is scarce.

Transport information on these national platforms could be expanded by adding systematic data collection on transport disruption events at the national level (see Box 3.2). In addition, the transport section of the French action plan on adaptation to climate change included an action on how transport forecasting methodologies could take into account changes in climate. At this stage, significant problems remain regarding availability of data on impacts of hazards on transport systems. This is because the collection criteria and reporting practices are different between stakeholders and because some stakeholders consider this information

([8]) See http://climate-adapt.eea.europa.eu/adaptation-support-tool.

Box 3.1 Examples of national information platforms and their support of adaptation efforts

Many countries have set up a climate change adaptation platform providing information — mainly on their national adaptation plans — to all agents interested in the subject, covering the transport sector, for example:

France: WIKLIMAT

WIKLIMAT is a platform for sharing knowledge between actors involved in climate change. It was created in July 2013 within the framework of the National Climate Change Adaptation Plan, and allows stakeholders to contribute on French adaptation initiatives and achievements. WIKLIMAT covers three main objectives:

- To create a platform for gathering and sharing knowledge on adaptation and facilitating widespread dissemination of new ideas and innovative concepts.
- To make updated experiences available to training actors.
- To involve different contributors: public administrations at national and regional levels, municipalities and their technical services, consulting firms and companies, and non-governmental organisations.

WIKLIMAT includes one category on transport infrastructure. Documents and case studies are available for six sub-categories: ship design and boats, transport economics and logistics, management of navigation-related infrastructures, infrastructure and environment, and safety and e-navigation.

http://wiklimat.developpement-durable.gouv.fr/index.php/Cat%C3%A9gorie:Infrastructures_et_transport

Spain: The AdapteCCa Platform

The AdapteCCa Platform exchanges information on impacts, vulnerability and adaptation to climate change, and facilitates the coordination and transfer of adaptation information, knowledge and experiences among the different Spanish administrations and the scientific community, planners and managers, and other public and private agents, allowing multi-directional communication between them. The Platform includes transport among its main areas, and different transport-related reports and results are already available.

http://www.adaptecca.es/contenido/transporte

Poland: The KLIMADA adaptation platform

The project 'Development and implementation of a strategic adaptation plan for the sectors and areas vulnerable to climate change', with the acronym KLIMADA, provides a website, which has become the main information platform of adaptation in Poland. Aside from information related to the Polish adaptation policy and local adaptation initiatives, it considers adaptation in different sectors, including transport.

http://klimada.mos.gov.pl/en/2013/04/15/transport

as confidential, as it could be used to derive legal responsibilities for service disruptions.

Information collected on past weather events and their impacts can be a valuable starting point for assessing vulnerabilities and developing strategies to adapt to climate change. However, obtaining data on impacts, specifically on transport, available in the formats required to cross-check with weather information and with data from other stakeholders is difficult. Better, up-to-date tools for managing weather on an operational level serve to improve resilience on a day-to-day basis and provide the practitioners with a better understanding of their baseline vulnerability and they can then extend this to consider the climate change timescale. The Austrian railways developed an integrated system for information provided by automatic detection systems of different hazards that may cause traffic disruption (Box 3.2).

Within the EU, several initiatives are underway to improve national databases on economic losses from hazards, including those which are weather- and climate-related ([9]), which supports EU actions in the context of the global Hyogo Framework for Action (HFA) on disaster risk reduction ([10]).

Climate models cannot fully eliminate uncertainty about possible changes in climate and their impacts on transport systems; at best, they can reduce the boundaries to uncertainty, and highlight different degrees of uncertainty for different climate variables and/or different locations. The collaboration with climate experts can make transport stakeholders aware of the fact that climate-related topics cannot

([9]) See http://drr.jrc.ec.europa.eu/Loss-Data.
([10]) See http://www.unisdr.org/we/coordinate/hfa.

Box 3.2 Systematic data collections of disruption events under extreme weather by Austrian railways

The Austrian Federal Railways (ÖBB) as railway operator is directly responsible for the operation and management of the rail network and natural hazard and risk management for this type of infrastructure. The maintenance and management of the railway line falls under the responsibility of the ÖBB, where an in-company branch is responsible for natural hazard and disaster management (Romang et al., 2009).

The project KLIWA — Adaptation of the ÖBB infrastructure to climate change — assessed existing data of disruption events since 1990.

The data was not collected systematically, but was structured within this project. Since the project, the data of events of natural risks are systematically and correctly documented and assessed, and the internal damage database of the ÖBB was extended. The previously developed natural risk maps are extended and/or linked with climate projections (Prutsch, 2014, and Rachoy, 2012).

The project DESME — Detection of rockfalls and mudslides on railway lines.

In Austria, there is about 1 500 km of track that is threatened by natural hazards. Fully effective safety and prevention measures, for technical and economic reasons, cannot always be implemented. Therefore, the early recognition of the threat is all the more important. Warning of rockfalls and mudslides is particularly critical: DESME should develop a prototype system that alarms, in a timely fashion, the track network controller responsible for the particular stretch of track (Alten et al., 2012).

Further ongoing projects are RISKCAST, developing a flexible early warning system for the detection of the effects of hazardous natural processes on infrastructure installations, and IDSF, developing an integrated detection system for rockfalls and rock-face dislodgement processes (Scheikl, 2012).

Photo 3.1 Fog in Austrian Railways

© Maria Dewis

be addressed through traditional, unrealistically deterministic concepts, and that alternative approaches to risk principles would have to be explored (Wall and Meyer, 2013).

A number of experiences throughout Europe show that progress is being made not only at the research level, but also at the practical level: research efforts are supported by working and advisory groups comprising meteorological and transport experts, as well as transport professionals from different fields.

In some cases, transport infrastructure managers have approached meteorological experts for support in developing adequate assessment tools. This is the case of the TRaCCA project in the United Kingdom, where Network Rail approached the Met Office for support following the mandate in the UK climate change legislation and benefit from this cooperation (Box 3.3).

Cooperative projects may include other areas of expertise, such as hydrology. The xGeo tool developed in Norway (Box 3.4) is a good example of a collaborative framework that serves to pool together a variety of data sources initially isolated in different fields of expertise. The result is a platform providing a better basis for action to prevent transport disruptions in the case of natural events, and empowering researchers to identify patterns that could serve to anticipate responses to future possible changes in climate.

Collaborative efforts can be based on a broader initiative, mobilising public agencies and experts from a variety of fields in order to work together

Box 3.3 TRaCCA — Cooperation between Network Rail and Met Office on impacts of climate change, Great Britain

The mainline railway network of Great Britain is among the oldest in the world and in its current form is owned and operated by a variety of different stakeholders. The largest of these is Network Rail, which owns and operates the rail infrastructure (rail tracks, signalling, bridges, tunnels, level crossings, viaducts and 17 key stations).

Photo 3.2 Buckled rail

© Network Rail

In 2010–2011, Network Rail and RSSB commissioned the Met Office to undertake an assessment of possible climate change impacts on the railway network of Great Britain, as part of the project 'Tomorrow's Railway and Climate Change Adaptation' (TRaCCA) (RSSB, 2014a). The Met Office worked closely with rail industry experts to determine a list of climate change-related issues that were potential areas of concern for the industry, and then to undertake a further high-level study into a selection of the highest-priority areas. These included track buckling, excessive overhead line sag, and flooding of assets by river or surface water. During this work, the Met Office supported Network Rail in preparing its response under the Adaptation Reporting Power, a reporting process required by the Climate Change Act 2008 in which many infrastructure providers were required to report on their progress towards climate change adaptation.

One priority area identified was temperature-related track buckling. Using Met Office regional climate model simulations from the UKCP09, the present-day and future occurrence of summertime conditions requiring track buckling management actions was modelled. Assuming no changes to future track buckling management actions, a projected increase in occurrence of conditions conducive to such actions was found for all track conditions except those with the highest critical rail temperatures (Palin et al., 2013)

A major outcome of this work was to acknowledge, and set in motion, work to address the gap between scientific capability and the requirements of decision-makers. To this end, close collaboration with industry partners meant that novel ways could be found to link the knowledge of rail sector experts with the results of state-of-the-art climate projections, in order to supply decision-makers with information that is both scientifically robust and appropriately communicated.

Since the completion of this work, a further programme of research is now in progress deepening the knowledge base and cooperation. It aims to deliver step changes in climate science, knowledge of climate change vulnerabilities, and the development of support tools, to increase the weather and climate resilience of Great Britain's railway (RSSB, 2014b).

beyond concrete actions, and to establish a medium-term programme and organisational framework. This is the case of the German KLIWAS research programme, which provided a framework for cooperation of experts on climate, hydrological and maritime models with waterborne transport researchers and practitioners (Box 3.5). This interdisciplinary collaboration is one of the most interesting lessons of the project, as it has proved to be effective in getting transport stakeholders to look at the system as a whole and to explore concepts outside their traditional paradigms.

Through closer interaction, transport experts should be able to define their needs for climate forecasts in more scientific terms, and meteorological experts could better understand transport experts' needs and highlight innovative developments in their modelling and presentation/communication practices that could provide useful answers. Through cooperation with experts in other fields, transport stakeholders can increase their flexibility in management and decision-making, thus potentially finding innovative solutions. Another lesson from the above projects is that cooperation among experts with different backgrounds and expertise could be a useful way to further mainstream interdisciplinary approaches in transport.

Uncertainty is not only found in climate projections but also in socio-economic change, including changes in transport patterns. The air transport community has been particularly interested in exploring how changes in climate could impact future transport demand patterns. EUROCONTROL's periodic Challenges of Growth series intends to provide decision-makers with the best-achievable set of

Box 3.4 xGeo — Cooperation between transport stakeholders, hydrological and meteorological experts in Norway

Photo 3.3 Flood and landslide forecasting centre at NVE

© Hilde Harket, NVE

The xGeo tool is an online tool for risk assessment and preparedness, and for monitoring and forecasting of floods, landslides and avalanches. It was developed by the National Public Roads Administration (NPRA) and the Norwegian Water Resources and Energy Directorate (NVE) in collaboration with the National Rail Administration (JBV) and meteorological services. The tool was developed under the auspices of the Climate and Transport project (2007–2010) led by the NPRA.

The idea for combining different data sources such as hydro-meteorological data and maps of the road network in a single tool was developed after a major storm near the city of Trondheim in 2006 resulted in significant disruptions to transport infrastructure and operations.

The mapping tool combines historical, present and forecast weather data with ground and road data, threshold values for natural hazards and data on road network events such as floods, landslides and avalanches. Use of historical time series data on weather conditions and events such as floods and landslides affecting the road and rail networks supports better use of forecast data through improved identification of conditions that increase the risk of damages and operational disruptions.

The tool is primarily used for forecasting avalanche and landslide risks in the national alert system for landslides and avalanches. Alerts are issued by the NVE forecasting centre and communicated to road and railway authorities as well as a range of other authorities and media outlets. Originally, operations and maintenance contractors were also identified as possible users of the tool. While contractors are currently not obliged to use it, information about the tool is included in training for new contractors. The situation may change in the future as uncertainties related to formulated threshold levels are likely to decrease and contractors have time to learn using the tool. Overall, cooperation of the involved actors was and will be key for the successful development of the tool and its adoption for practical use in the national alert system for landslides and avalanches.

Source: Barfod et al., 2013; Devoli et al., 2013; xGeo, 2014.

information to support long-term planning decisions for aviation in Europe, with a particular focus on the capacity of the air transport network. One case study of the Mediterranean region concluded that a shift in aviation demand could be induced by changes in climate and their impact on tourism flows (EUROCONTROL, 2013). Another forward-looking study is the publication *Delivering tomorrow: Logistics 2050 — A scenario study*, presented in Box 3.18 (DHL, 2012).

The French government launched in 2014 a transport demand forecasting project, including passenger and freight. Considering the time horizon (2070), it is likely that transport patterns affected by impacts of climate change will be included, probably after 2030 or 2050 ([11]).

In the United Kingdom, the Met Office is providing transport stakeholders with probabilistic projections (Murphy et al., 2009); the German KLIWAS programme developed 'scenario corridors' with the same purpose of presenting the range of variability in projections, based on the use of different models, and the experts' advice on their likelihood of occurrence. The Scottish experience shown in Box 3.6 illustrates a stepwise approach, where progress in climate science has provided new climate information, which can then be used to update initial scenarios and to revise strategies and priorities. As more reliable, better focused information is made available, decision-makers gain more solid ground for taking decisions and stakeholders can get a more precise picture of future challenges and adapt more confidently to them.

([11]) Interview with French ministry of transport officials, May 2014.

Box 3.5 KLIWAS — cooperation on inland and coastal water ways in Germany enables better understanding and innovative thinking

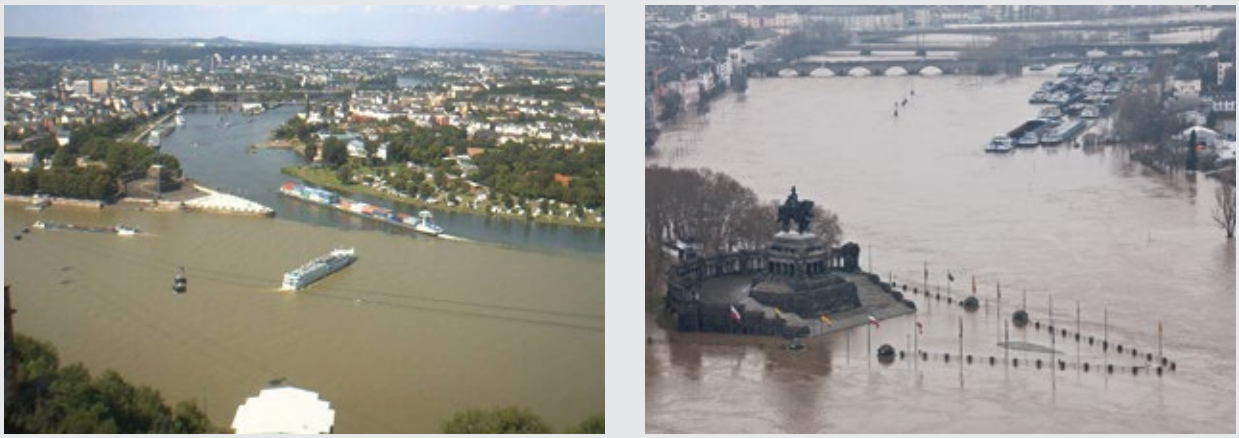


Photo 3.4 Rivers Rhine and Moselle at Koblenz: Common traffic situation (left) and interruption due to blocked waterways during the flood event in January 2011 (right). Vessels are waiting for passage

© BfG, M. Hils

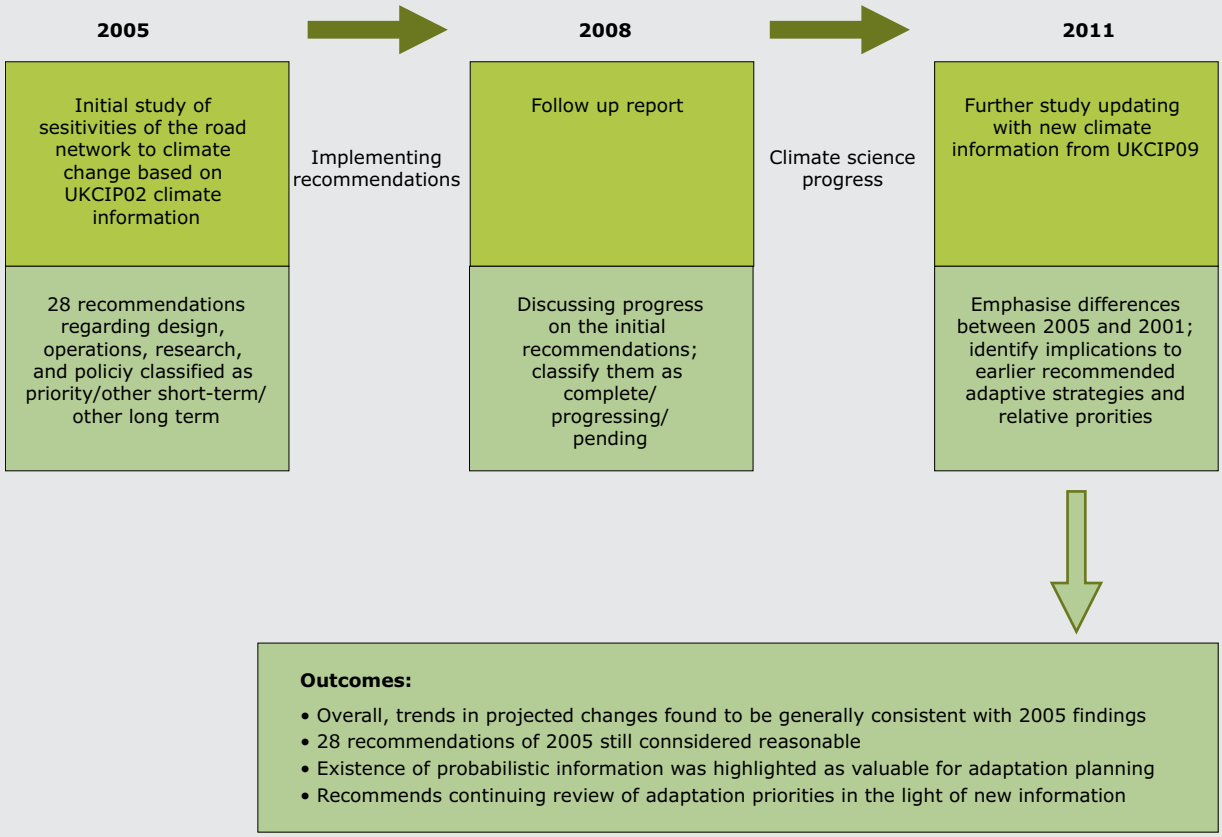
KLIWAS (2009–2013) was a joint effort of four federal agencies and their scientific network in order to provide scientific evidence on the future navigation conditions on key inland waterways and coastal routes in Germany. The outcome suggests no distinctive challenges or restrictions for shipping or waterway infrastructure in the near future. However, since stronger impacts are to be expected in the far future, a sound continuity in and a constant improvement of reliable information is a must-have.

The interaction between research and stakeholders is considered to be the most interesting lesson from this project. It included in particular the development of prognostic instruments ('model chain') and a procedure of knowledge communication between researchers and stakeholders that could be used in other transport modes or countries. For the involvement of stakeholders, KLIWAS benefited from its direct involvement in international river commissions and from regular meetings with politicians, water managers and waterway users. These meetings gradually provided better understanding among experts from both climate and transport viewpoints. KLIWAS first approached key maintenance authorities at the ministry of transport and then opened up to other stakeholders (water management and waterway transport). Although the research programme formally concluded in 2013, the agencies involved continued in 2014 communicating to a broader range of stakeholders (such as transport operators and logistics companies), once they finalised the programme's results.

The main lesson learned is that transport agency stakeholders are now aware of what climate models really mean and provide. And they are more interested in looking at the system as a whole. For example, instead of just focusing on incremental improvements of existing infrastructure they now consider other solutions such as increasing the storage capacity (for logistics operators) or changing the size distribution of the fleet (for vessels). Transport operators had initially been reluctant to consider these issues, until they realised that they may be taking additional economic risks if they do not become more flexible in their operations.

Source: Moser et al., 2012; BMVI, 2013; KLIWAS (www.kliwas.de).

Box 3.6 The stepwise approach of the Scottish Road Network Climate Change Study



Sources: Scottish Executive, 2005; Transport Scotland, 2008; Jacobs Engineering U.K. Ltd, 2011.

Assessing risks and vulnerabilities

The assessment of risks and vulnerability to the impacts of climate change on the sector is frequently the initial action for transport in national adaptation policies, strategies and plans. This assessment requires the availability of sound methodologies.

Vulnerability studies can, but do not always, rely on sophisticated technical tools. Simple methodologies, based on existing knowledge in other sectors such as hydrology or coastal management, can be transferred to the transport sector at minimum cost. This is, for example, the concept behind the identification of flood-sensitive sections (blue spots) in Sweden (Box 3.7).

Vulnerability studies concerning extreme weather events are also undertaken for civil protection and disaster management purposes. Transport is crucial within any plan on civil protection and disaster management and this experience can also be used to include future climate change impacts. The need for inter-sectorial cooperation in this field has been recognised by many stakeholders, particularly among transport managers and river basin authorities in mountainous and flood-prone areas. Contingency plans, disaster prevention and civil protection agencies should become more relevant areas of attention for transport stakeholders. Partners from those agencies can provide useful tools for the development of vulnerability assessment methodologies in the transport system and help to identify approaches to cope with them.

The air transport sector has been particularly active in the development of assessment methodologies and in the application of these methodologies to pilot case studies, particularly to airports. In the example of Nice in France, a lesson learned is the relevance of adequate local knowledge on airport infrastructure and on weather conditions (Box 3.8).

Box 3.7 Identification of flood-sensitive sections (blue spots) in the Swedish road network

Effects of climate change have become one of the focus areas for national road authorities. However, the uncertainties inherent in predictions of future climate make it difficult to precisely quantify the changes in terms of, for example, the magnitude and frequency of rainfall. But floods have always occurred in the past and will also in the future. Hence, identifying and improving road sections vulnerable to flooding are of great value in terms of assessing the sensitivity to extreme weather events and climate change impacts.

In 2005, the Swedish Road Administration developed instructions to create a homogeneous method for the inventory and analysis of serious physical dangers along a chosen road stretch. The instructions contain a methodology for a comprehensive risk analysis of the road transport system with emphasis on serious physical hazards. A variety of risks are considered within this methodology, including roads and bridges as well as risks associated with buildings and constructions in the surrounding area. A focus is placed on landslide and collapse risk, risk for damage on roads and bridges with high water flow, risks due to accidents with dangerous goods and risks of flooding.

In particular, flooding risks have been the subject of an in-depth study using different assessment methodologies. The Swedish Transport Administration (STA) uses several different methods. One of them compiled and analysed statistics for recorded nature-related stops (or road closures) and mapped them in a geographic information system. Another one is based on using accidents. But the best method is the blue spot method, in which topography is used. The results show that the number of floods increased during these years and they indicate several clusters where the road has been flooded on several occasions.

The model was applied to a Swedish study area with the aim of creating an assessment of TEN-T road sections vulnerable to extreme daily precipitation in southern Sweden.

Based on topographic identification, the results showed a total of 1 254 blue spots near the TEN-T roads, varying in volume between 10 (minimum) and 2 800 870 m^3 (median 687 m^3).

Photo 3.5 Flooded road in southern Sweden

© Eva Liljegren, Trafikverket

Sources: Löfling, 2005; Hansson et al., 2010; Lindeberg et al., 2014; Trafikverket, 2014a and 2014b.

Regarding other modes, this local knowledge is probably more complicated to obtain for linear infrastructure like rail and road, as it covers considerably large parts of the territory.

Regarding the vulnerability of the transport system, stakeholders need to consider its high complexity and interconnectedness. Many components of the transport system have increasingly specialised in covering particular functions, and what used to be independent sub-systems (e.g. different transport modes or urban versus interurban transport) are increasingly interlinked with the ambition to provide seamless accessibility of services in the future. This integration requires climate change vulnerability assessments that go beyond the single components or sub-systems, and consider them within the broader picture.

Box 3.8 Local knowledge in the vulnerability study of Nice Airport in France

The French national adaptation plan included provisions for the development of methodologies for assessing the vulnerability of transport infrastructure. The air transport sector prepared such a methodology in 2013 and applied it to Nice Airport as a pilot.

The risk mapping methodology applied to Nice provides a matrix showing each possible combination of probability of occurrence of a climate event with its potential impact on the airport. The risk is defined as the product of both variables, thus providing a vulnerability index with four levels (no impact, low impact, medium impact and strong impact), each of them requiring specific approaches.

The risk mapping methodology requires substantial local knowledge from several sides, airport infrastructure, operations and weather conditions. Gaining local knowledge from the airport community (managers, employees at the different units, providers of associated services, etc.) and users can support identifying the causal relationships in past disruption events, and identifying potential changes in climate that could be particularly disruptive for airport operations in the future.

From the transport perspective, local knowledge was needed at three levels: the structure of the airport (identifying the key components and how they interact); the vulnerabilities shown in the past (based on the collective memory about past disruption events, which are usually recorded only in a partial way and need to be complemented by the personal experience of the specialists who were involved); and the identification of those airport elements that are crucial for keeping operations at an acceptable level (based on the knowledge of those responsible for operations and on the expectations of the various airport users).

The application of the risk mapping methodology showed in particular that rising sea levels could increase already existing problems in the case of storm surges, such as: pebbles and stones on the runways, flooding of airside areas, disturbance of drainage systems. The assessment concluded that the general level of vulnerability was 'low' for most of the components of the airport. Signalling and air traffic management are those systems with vulnerability rated as 'medium', and the vulnerability of runways was rated as 'high'. As a consequence of this assessment, some improvements in the dyke protecting the runways were implemented in 2011–2013.

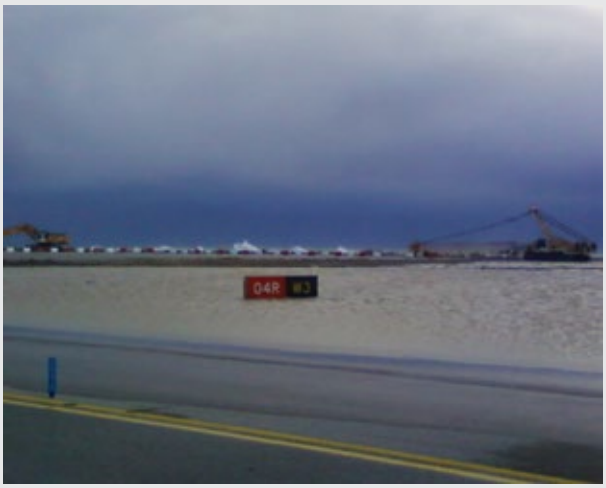


Photo 3.6 Runway 04R closed for repairs following high storm surge on 23 January 2013, Nice Airport

© Nice Aeroport

Source: DGAC/STAC, 2013.

3.2 Identifying adaptation options and implementation action

There are a variety of adaptation options available, for example in Climate-ADAPT ([12]) or the report *Adaptation in Europe — Addressing risks and opportunities from climate change in the context of socio-economic developments* (EEA, 2013): grey adaptation options that focus on technical infrastructure; green options focusing on working with nature and natural processes; and soft measures such as awareness raising and management. Several approaches to adaptation allow the management of uncertainties: robust solutions would act under any scenario, but could be quite expensive; flexible measures would allow adjusting the solution when new or more specific knowledge about climate change impacts becomes available; and low-regret measures would be justifiable under all plausible future scenarios of climate change as they, for example, show benefits for other areas and sectors as well. The last option is often preferred in practice as it usually also involves low costs.

In the transport sector, low-regret measures are typically measures that increase the resilience of transport systems, while providing additional,

([12]) See http://climate-adapt.eea.europa.eu/adaptation-measures.

short-term advantages in terms of, amongst others, smooth operations, quality of services and efficiency. This applies for example to sound maintenance practices for transport infrastructure, integration of transport systems (providing more alternatives to users), or the revision of already obsolete design standards or development of such standards if they do not exist. The experience gained through the implementation of low-regret measures can serve as a basis to start designing and assessing more costly adaptation actions that could be implemented in the future.

Operational tools

Transport has traditionally developed approaches to cope with the impacts of extreme weather events. These solutions might also be valuable options for adapting to climate change. Early warning systems, for example, allow transport managers to prepare for extreme weather events, whether they are induced by climate change or current climate variability. They therefore present a typical low-regret option. For example, EUROCONTROL Network Manager has developed a natural hazards and weather resilience tool (Box 3.9). The tool provides information about the potential vulnerability to such events of airports and en route sectors in Europe. It also allows the assessment of the likely impacts on the aviation network as a whole.

Actually preparing for a risk situation on the local site can be done with contingency plans for extreme weather events that present another low-regret option (Boxes 3.10 and 3.11). In addition, these plans can also be an opportunity to establish or to strengthen interdisciplinary knowledge networks and integrated local knowledge such as in the case of Copenhagen Airport (Box 3.10). This can provide support to comprehensive adaptation plans at a later stage.

Warning systems and contingency plans can get valuable support through the application of information and communications technology (ICT) to transport management. This is the case of sensors and devices, which provide real time information on traffic conditions on the network, including the distribution of vehicle speeds, weights and dimensions. Other sensors can provide information including the presence of obstacles, temperature, deformations and other surface characteristics. With the support of ICT, this information can be accessed in real time by transport infrastructure managers, service operators or users.

Furthermore, vehicles and users could increasingly serve as data collectors in their own right. This would allow infrastructure managers and transport operators to gain unprecedented real-time knowledge about the parts of the transport system they are interested in. Handling these enormous

Box 3.9 A tool for coping with natural hazards and extreme weather in aviation

Meteorological or other natural hazards, such as volcanic ash, earthquakes, fires and flooding, may cause air traffic management disruptions. As part of its role as European Network Manager, EUROCONTROL has developed a natural hazards and weather resilience tool. The tool defines the risk of such events for both en route sectors and airports according to the hazard probability and the impact severity. The inputs to the model are:

- a 6-hour updated, 48-hours look-ahead, numerical ensemble weather forecast for the European Civil Aviation Conference (ECAC);
- information on the presence and the characteristics of natural hazards;
- impact models, which translate the forecast meteorological variables and thresholds into capacity risks.

The tool has a map displaying all en route sectors and airports, and highlights the ones at risk of reduced capacity in the event of extreme weather and/or other natural hazards. It provides EUROCONTROL and other stakeholders with an overall perspective on how extreme weather and other hazards might not only impact single sectors or airports but also overall network operations.

This tool is a way of meeting the obligations of EUROCONTROL as Network Manager in two ways. In crisis management, it provides a single network picture and helps anticipate network-wide impact. In performance planning and monitoring, it calibrates the historical daily delays with actual impact risk.

The tool is in the operational validation phase. In the longer-term, the model's outputs will be integrated into the Network Operations Portal (NOP) and used to develop informed mitigation strategies for identified risks.

Source: EUROCONTROL, 2014.

Box 3.10 Contingency plan for Copenhagen Airport, Denmark

With a new climate change adaptation plan and a contingency plan for torrential rain, Copenhagen Airport is now in the process of adapting to future climate conditions. Copenhagen Airport is one of northern Europe's largest and most important transportation hubs. All parts of the airport infrastructure are potentially vulnerable to climate change.

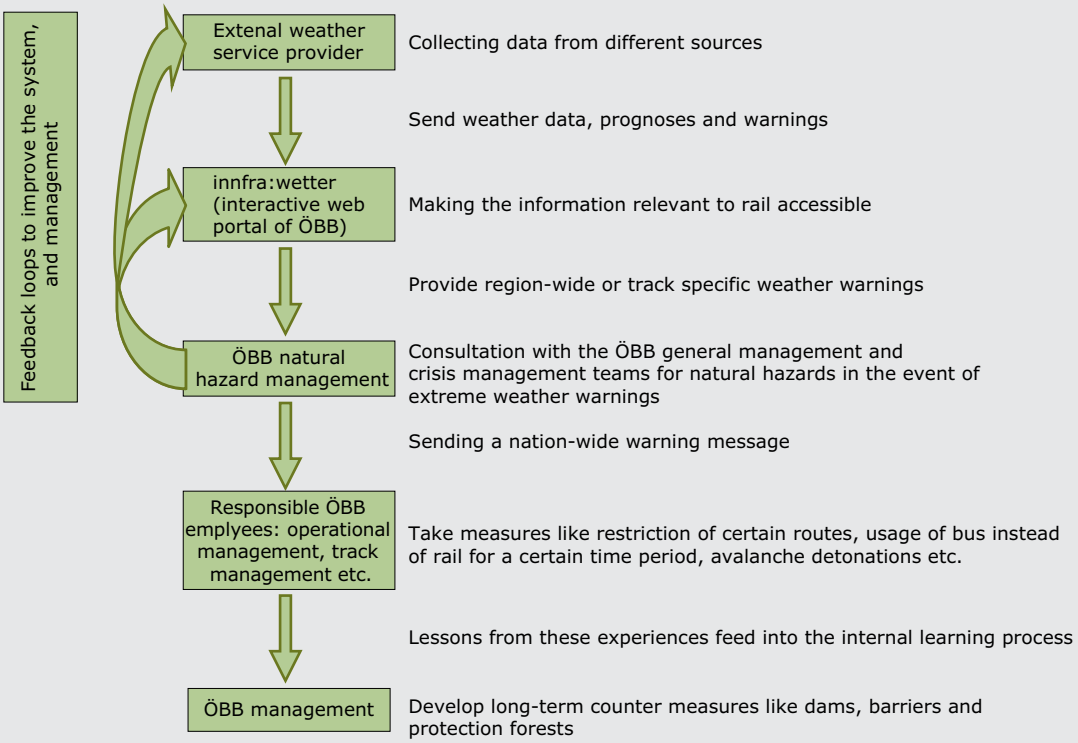
Copenhagen Airport examined the climate impacts that could hit the airport, such as temperature increases and changes in precipitation or wind conditions. Different to the Copenhagen areas as such, increased rainfall and rising sea levels are not the prevailing problems for the airport itself. Under the cloudburst that hit Copenhagen on 2 July 2011, it was not the airport's own drainage pipes that collapsed. The problem was in the highway towards the airport that was under water, so passengers could not reach the airport. Thus, the airport needs to cooperate with its neighbouring municipalities to make sure that all their climate adaptation plans are coherent.

The airport's main adaptation need was to establish a contingency plan that could take effect if there is warning of extreme rain. The contingency plan — currently under development — identifies the key areas of the airport that must be adequately protected, so that operations are not disrupted for a long time. The contingency plan will also designate the stands and taxiways that will quickly be able to work when a cloudburst has peaked and those that need help in getting rid of the water. Therefore, it provides precise instructions for the responsible staff, to manage effectively sandbags, pumps and other protective response measures. The plan also includes a proposal for the purchase of flood barriers that can act as a temporary reservoir. The next step for the airport is to decide which of the recommended solutions are to be implemented and in which order.

Source: Klimatilpasning, 2014a.

Box 3.11 Dealing with disruption of rail services and other emergency situations in Austria

The Austrian Federal Railways (ÖBB) faces risks related to natural disasters and has implemented natural risks management since 2008. The focus is on prevention instead of immediate responses. The work on Natural Hazard Management in the Federal Railways follows the classical risk cycle: prevention actions include natural hazard maps, protection forest management systems and technical facility management. A weather information system (infra:wetter), technical warning systems and emergency trainings are in place. infra:wetter is the interactive web portal of the ÖBB Infrastructure AG, which is continuously being updated. Also, avalanche and flood warning services are in place.



Box 3.11 Dealing with disruption of rail services and other emergency situations in Austria (cont.)

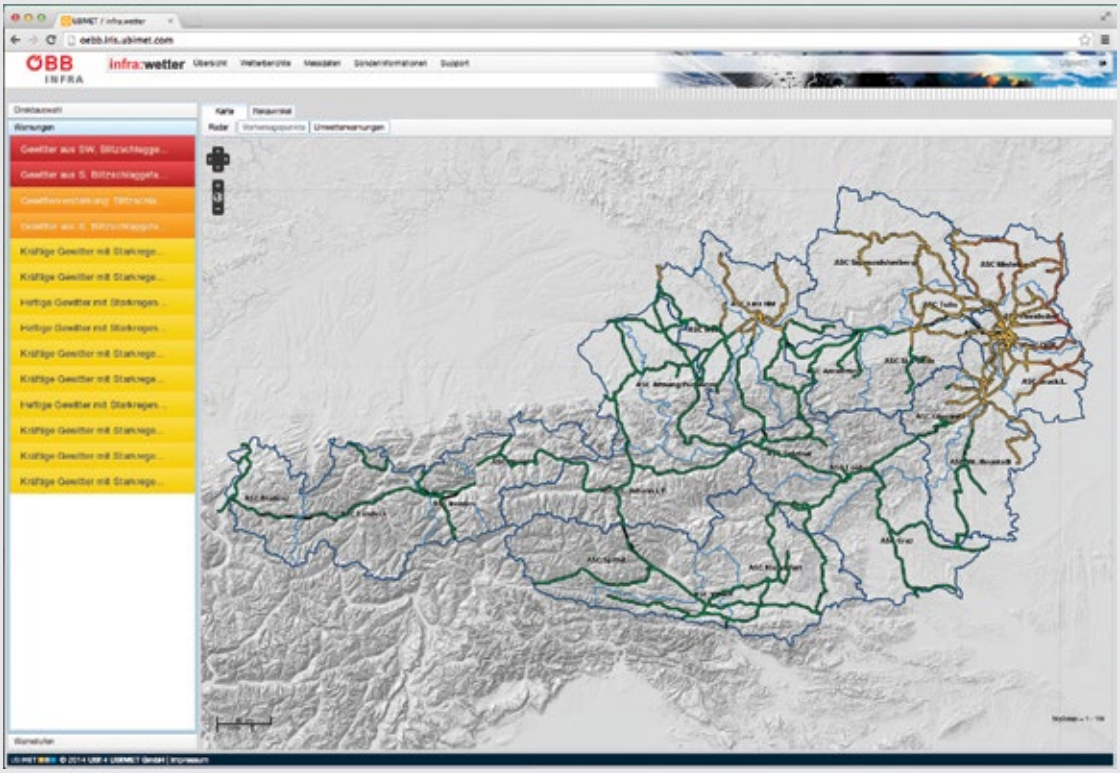


Photo 3.7 Infra:wetter system

© UBIMET

Natural risk maps have been created for the 5 700-km route network to assess natural risk potential, set priorities and use this information for long-term planning, considering climate change. A separate natural risk team is maintaining 165 km of rockfall and avalanche terrain, 2 700 ha of rock and stone, and 2 800 ha of protection forest.

Source: Kundela, 2013.

flows of information requires the deployment of communication technologies linking vehicles to other vehicles and to the infrastructure. Whilst by their vehicles, transport operators and users can receive the information they need on infrastructure conditions and on the behaviour of other vehicles, infrastructure managers can get a more detailed description of the traffic situation from their users, and communicate to them accordingly. Such exchange of data therefore greatly facilitates traffic management.

These technologies could also collect additional information for early warning systems and facilitate the implementation of contingency plans, avoiding severe disruptions, or at least keeping them at a manageable level (Grant-Muller and Usher, 2014).

Infrastructure design, construction and management

Infrastructure managers and service providers have traditionally learnt from past experience how to increase resilience and to reduce the effects of extreme weather events. In the aftermath of extreme rainfall or unusually severe storms, reconstruction has been undertaken with a view to avoiding recurrence of similar damage. This includes the improvement of maintenance practices and operations as well as revising long-established practices. However, climate change will challenge the validity of this empirical knowledge for the future and put the operations of transport systems at risk. Also, gradual climate change such as temperature and sea-level increases need to be considered (Box 3.12).

Box 3.12 Urban transport: new design standards for Copenhagen Metro

To reduce as far as possible the risk of flooding from sea or extreme rain, Copenhagen Metro has taken this factor into account in the metro's design and construction since the design of the first line in 1993–1995, In fact, the metro has been able to continue operating under the various floods that have hit the city, including the 2011 cloudburst, which stopped rail services, but not the metro. The basis for calculation has been revised, as climate change forecasts have changed over time. For example, the upper limits of all the stairways, emergency exists and ventilation openings on the Copenhagen Metro are now 2.2 m or more above normal sea level around the city for the new lines currently under construction.

Photo 3.8 Flooding gates at different stations with direct connections to shopping malls (left) and an extra step at the entrance at Kongens Nytorv station (right)

© Metroselskabet

The 17 new metro stations in the Copenhagen area will also be secured against flooding. The construction company has identified how to keep water out of the tunnels in the exposed stations by projecting worst-case scenarios of water levels in the streets around the 17 new metro stations during extreme rainfall. Specific design, like augmenting the entrance above street level by small access ramps or stairs, can prevent great quantities of rain water from running down into the metro. A study on the effects of sea-level rise in Copenhagen and on options for securing the metro against the combined effects of rising sea level and flood waters due to rainfall has been prepared. All new metro stations include access slopes and stairwells 2.42 m above current sea level.

Source: COWI, 2009; Klimatilpasning, 2014b.

Furthermore, building new transport infrastructure, which usually lasts for decades, if not centuries, to an already climate-resilient standard will in most cases save costs due to avoided damages and necessary upgrading at a later stage. Slapton Line road in South Devon, the United Kingdom, for example, runs along the coastline and is vulnerable to flooding and storm damage. Among other measures, Devon County Council has therefore also sought planning permission to realign the road further inland, to be prepared in the event funds can be made available, in order to reduce the risk of subsequent damage (Climate UK, 2013).

A revision of standards is currently in progress at the European level (see Section 2.1) and in some European countries, although with a different scope. In Germany and the United Kingdom, rail standards are receiving particular attention, and in the latter, some design parameters have been changed and are being applied now (Box 3.13); Norway is conducting a review of road design guidelines and manuals; and France is involved in an ambitious systematic review of those transport infrastructure standards that include climate parameters that could be affected by changes in climate (see Section 2.2). Finland is currently considering undertaking similar reviews of design standards and operational guidelines as part of wider activities aimed at expanding the available knowledge base.

On the one hand, changing standards may provide some basis for changes in design and operational practices in the short term. On the other hand, they show the enormous challenge ahead: a systematic review of transport design and operational practices from a climate change perspective could affect an enormous number of standards (around 100 technical documents, in accordance with the French experience (ONERC, 2013)) although it will

pay off in the long run to move across the traditional modal boundaries and to provide more consistency within the transport system as a whole.

Technological innovation is another option to address the emerging requirements linked to changes in climate. This is happening not only in the field of construction materials, aiming at providing a wider climate range of application, but also in the design of innovative structures for the operation of transport infrastructure, as illustrated for the Albert Canal in Belgium (Box 3.15).

A further alternative measure is to think about establishing alternative infrastructure or relocating it. This option comes particularly in focus when infrastructure needs to be replaced because it exceeds its lifetime or is substantially damaged by a disaster. In this situation and also considering future climate change impacts, the question is

Box 3.13 Great Britain: revision and application of railway drainage standards

The effective control of water is essential to the safe and economic management of railway infrastructure. Drainage problems can result in temporary speed restrictions or temporary closures of the line, as well as increasing maintenance costs. To be effective, railway drainage systems have to be designed and built to appropriate standards, maintained regularly and, when required, improved.

Network Rail is the national railway infrastructure operator for Great Britain, and in 2010 it published its first Railway Drainage Systems Manual (Network Rail, 2010) that considered, as the first in the United Kingdom's railway system, future climate change impacts in the design of railway drainage standards. For new and remediated railway drainage, the design life is specified as 60 years. The climate change allowance will increase the estimated present-day design flow for the design event return period by 20 %.

The drainage standards have been applied within Network Rail (Network Rail, 2014c):

- The new Borders rail link (Borders Railway, 2014) in Scotland will connect the city of Edinburgh with the Scottish Borders and Midlothian. The drainage for this new link has been designed according to the new standard, with appropriate scrutiny of business plan items pertaining to drainage or drainage enhancement, in order to ensure that the standard is being adopted correctly.
- All major flood sites on existing railways in Scotland have recently undergone Flood Risk Assessments to identify risk in the complete catchment area. As a result, attenuation ponds have been built in Drem and Dalmarnock and the siphon chamber capacity has been increased and an attenuation pond designed in Penmanshiel.

Network Rail is currently reviewing the drainage standard as a part of a wider review of asset management processes.

Photo 3.9 Drainage alongside the rail line to prevent flooding

© Borders Railway

Box 3.14 Climate-proof expansion of the Port of Rotterdam

The Port of Rotterdam (PoR) is located on the North Sea — the busiest sea route in the world — and serves a European hinterland with about 400 million consumers. It is of vital economic importance for Rotterdam and the Netherlands as a whole. The PoR is stretched out over 40 km and encompasses one third of the total land area in Rotterdam. It is situated in the outer-dike area and is directly linked to the river and the sea. For this reason, most of the 12 000 ha of port area has been developed on elevated land at an average height of about 3–4 m above mean sea level. Besides, large parts of the port area are protected by the Maeslant Storm Surge Barrier. This barrier, however, was designed for a maximum sea-level rise of 50 cm. This makes it vulnerable to high river levels and especially to storm tides. The older harbour areas are particularly vulnerable.

The Port is continuing to develop and modernise. New areas such as the Tweede Maasvlakte are being planned and constructed. In the new harbour areas such as the first and second Maasvlaktes, higher water levels have already been taken into account (this area is being developed at 5 m above mean sea level) and the main access roads are built at the same elevation as the dikes.

Source: Rotterdam Climate Initiative, 2009; Vellinga and Jong, 2012.

Box 3.15 Technological innovation: new locks in the Albert Canal in Flanders, Belgium

Photo 3.10 Installation of new locks in the Albert Canal

© De Scheepvaart

The Albert Canal in the eastern part of Flanders connects the industrial zones around Liege with the harbour of Antwerp. Ships can continue their way at both ends of the Canal: via the River Scheldt to the Netherlands, and via the River Meuse to France. In the future, the Meuse basin, from which the Albert Canal receives its water, is projected to experience more and longer periods of lower river discharge and so less water available for sluicing ships. This limits inland navigation.

The solution to use less Meuse water for navigation is large (fish-friendly) Archimedes screws that were constructed at the locks. In the low discharges on the Meuse, the screws can pump back the water lost due to the passage of a ship through the lock back to the upper canal reach. In the case of more than enough discharge at the Meuse, the screws are used as a bypass and to create hydroelectricity.

Source: De Scheepvaart, 2014.

whether the infrastructure should be repaired, upgraded, relocated or if services should be rearranged via redundant infrastructure or other modes. There is a balance to find between reliability, costs and service provision. The recent reconstruction of the coastal railway line in Dawlish (the United Kingdom) illustrates this problem (Box 3.16).

Box 3.16 Reconstruction of the Dawlish railway line in the United Kingdom

During a storm in early February 2014, the coastal railway line at Dawlish, Devon, the United Kingdom was severely damaged (see Box 1.1). A stretch of the sea wall, and the foundations beneath the railway track, were destroyed by huge waves during the storm, leaving the track unsupported. The railway station at Dawlish was also damaged. The initial breach was 80 m long, and this increased to 100 m in a subsequent storm.

In the short term: repairing the railway

The break in the line meant that towns and cities beyond Dawlish were cut off from the rail network, so it was imperative to repair this historic and strategically important stretch of railway as quickly as possible. Engineers were mobilised within two days of the event to begin clearing debris and install an inventive temporary breakwater made of concrete-filled shipping containers. The line was reopened in April 2014.

In the long term: a view on resilience

Although picturesque, the sensitivity of this stretch of railway to the weather has long been known. Following this severe incident, a task force was set up to review the long-term strategy for the coastal route. The task force is led by Network Rail, and includes other organisations such as the Department for Transport, the Environment Agency, local passenger train and freight train operators, and local government organisations.

Three long-term options will be considered by the task force:

- retaining the coastal route;
- building a second line;
- re-routing the main line.

Projected sea-level rises, passenger demand, the impact on communities, environmental, social and economic factors will be considered as part of the process, as well as examining engineering options to strengthen the sea wall. The task force will also be informed by findings from a study examining five potential relief routes outside the coastal route.

Sources: Network Rail, 2014a and 2014b.

Operations and service

Besides infrastructure, service and operations can also be adapted. Cooling or heating can be adjusted or transport operators can provide advanced information to their users, anticipating changes in their service performance. This enables passengers as well as freight operators to adapt their plans or find alternative transport options. Such measures can also improve the quality of services and have positive co-benefits for the company in general. The example of the Spanish railway RENFE provides possible actions (Box 3.17). Furthermore, tools developed for other purposes, like journey planners or the European Commission's initiative on the provision of EU-wide real time traffic information services under the Intelligent Transport Systems (ITS) Directive (2010/40/EU) ([13]) would also help passengers to find alternatives in the event of disruptions due to weather impacts.

Redundancies within and between modes

Changing operations can also mean using redundant infrastructure, like alternative rail links or roads. Usually, such a strategy involves extra cost to establish and maintain this redundant infrastructure, which, under normal conditions, might not be necessary. It has therefore probably been a less preferred option but could gain importance in the face of more extreme weather events due to climate change in the future.

Multi-modality offers redundancy potential at different levels. If different modes are available,

Box 3.17 Adjusting rail operations: RENFE, Spain

RENFE, the Spanish rail service operator, has introduced a tool for prediction of adverse weather events adapted exclusively to the rail system to enable the development of strategies pre- and post-crisis situations in real time. It warns RENFE in advance of the expected evolution of weather conditions in the coming hours that may affect the movements of its trains.

The operator receives information from the weather alert tool through its Travel Management Centres twice a day. Apart from implementing measures that directly affect infrastructure, additional procedures are possible:

- procedures for conducting alternative transportation services — i.e. buses — in the event of interruption;
- fleet changes, slowdowns, salt application, preheating units, covered parking at station, or working with extra trains to clean catenaries when there are ice accumulations, etc. in the event of heavy snowfall and temperatures below freezing;
- slow down the food and beverage catering service on board according to the expected increase in travel time, and increase stop times at intermediate stops in accordance with the needs of the food and beverage supplying companies;
- in the case of heatwave alerts with temperatures exceeding 38 °C, the Travel Management Centre provides recommendations for the revision of deficiencies in air conditioning systems, and preventive measures on closing doors are followed.

The procedure followed by RENFE freight is different, as it activates a message to the Freight Management Centres. Thus, staff members are aware and properly prepared, and diesel locomotives are refuelled if they are expected to be used in any freight alert.

The tool has been operational since 2011 and is used for RENFE's passenger and freight operations, resulting in cost savings and improved customer service.

Photo 3.11 RENFE train operating in winter conditions

© Patier, RENFE

Sources: RENFE, 2012; CEDEX, 2013.

([13]) See http://ec.europa.eu/transport/themes/its/consultations/doc/2014-03-14-rtti/consultation-document.pdf.

the user can choose which one best serves his/her transport needs, and might switch from one mode to another. Smart and flexible ticketing, which allow passengers to switch operators and modes in the event of disruption, would facilitate this process. Currently multi-modality is receiving keen attention from a mitigation perspective, as a way to make low-emission alternatives available as compared to high-emission door-to-door road services. This offers synergy potentials for adaptation measures.

Today, many technical barriers and limitations to this concept remain. For example, 'spare' transport infrastructure capacity available in some areas cannot offer an alternative to major disruptions in other transport modes. This was evident in the event of the eruption of Eyjafjallajökull volcano in Iceland where millions of air passengers were stranded in Europe (Box 1.2): there was not enough capacity in rail, road and ferry services to act as alternatives in the short term. However, the event provided many lessons about the flexibility and adaptive capacity of society and the economy, with many agents individually and spontaneously finding different ways to arrange their business (Jeunemaitre and Johnson, 2010; O'Regan, 2011).

On the one side, multi-modality offers transport alternatives for passengers and freight, thus resulting in a resilience gain for the system as a whole. On the other side, multi-modality could result in less resilient transport operations compared to long-established uni-modal practices, due to the dependency on an increased number of different infrastructures and services. This indicates a need for proper multi-modal governance to keep complex systems running smoothly and offer alternatives when needed.

Furthermore, changes in climate may have considerable impact on the organisation of the economy and on the relative importance of robustness vis-à-vis efficiency. A recent study (DHL, 2012), described in Box 3.18, illustrates this point for freight logistics: today, multi-modal chains are aiming at efficiency in order to compete with road services in terms of costs, time or reliability. Under this paradigm, the availability of infrastructure is

Box 3.18 Long-term visions of multi-modal freight logistics under changes in climate

The publication *Delivering tomorrow: Logistics 2050 — A scenario study* examines different scenarios (DHL, 2012). The one on 'Global Resilience — Local Adaptation' describes a world with a changed economic paradigm as a reaction to accelerated climate change, frequent disruption of supply chains by catastrophes and lean production structures, resulting in repeated supply failures for all kinds of goods. The new economic paradigm is distinguished by a shift away from efficiency maximisation to reducing vulnerability and increasing resilience. This radical move towards redundant systems of production and a change from global to regionalised supply chains allows the global economy to better cope with disruptions. The resilient world in 2050, with regionalised trade, has the following characteristics:

- It relies on a logistics sector that ensures the delivery of products in spite of unforeseen events. While timeliness no longer plays the key role it once did, supply security is a top priority.
- With the regionalisation of economic activity, the hub-and-spokes architecture changes. Global hubs no longer enjoy their former flagship position. They are replaced by a number of regional hubs located in safe regions.
- There are shorter transport distances with lower volumes, due to multiple suppliers, and logistics companies with regional or local roots will be in favour. However, big international providers continue to play a major role. The capital capacity of large players is needed to provide a fragile supply chain with enough backup infrastructure and machinery and guarantee reliable transport in unstable and hazardous times.
- To ensure maximum resilience of the supply chain, logistics firms maintain largely dormant or redundant capacities enabling them to quickly shift goods from one transport mode to another in case of an emergency.
- Such extensive backup systems are asset-heavy and conflict with the aim of carbon reduction. To counter this effect and balance energy efficiency and supply chain resilience, sophisticated logistics planning is used to achieve high capacity utilisation.
- Owing to risk reduction efforts, complex just-in-time delivery processes no longer exist. Instead, huge warehouse structures located close to the manufacturer are seen as indispensable buffers.

The discussion of the opposing concepts of resilience due to redundancies on one side and maximising economic growth/efficiency on the other side provides valuable input in developing long-term visions and strategies that go beyond the scope of one particular mode.

Source: DHL, 2012.

mostly taken for granted. However, the impact of changes in climate can provide a good reason to highlight the ability of multi-modal operators to provide a wider array of alternative options in case of disruptions in the system: redundancy could thus become another option.

From a piecemeal sector approach to broader concepts

So far, stakeholders tend to address transport challenges through a piecemeal approach. The prevailing approach is that of practitioners revising traditional practices and aiming at incremental improvements in design, construction, maintenance and operations. While this has its merits, its opportunities are limited and it can make it difficult to coordinate and integrate at a system level (Aparicio and Munro, 2014). In the case of the Port of Rotterdam, the authority explores opportunities that offer a joint approach with the city and other stakeholders. The collaborative approach allows finding efficient solutions outside the port area, but for its benefits (Box 3.19).

A much broader and more forward-looking view is provided by the scenario of DHL in Box 3.18 as well as the analysis undertaken by Rossello (2011), exploring the potential climate change impact on air transport patterns. They demonstrate the need to consider not only changes in climate but also in society and the economy, as they generate different transport patterns and demand. Transport is a derived demand, and it could therefore be worth exploring more generally whether resilience can be attained in a more efficient way by revising some economic and social practices, which are at the origin of that demand, rather than acting exclusively on the transport system as such. This requires a broader perspective and out-of-the-box thinking well beyond single modes or even beyond the transport system.

Assessing adaptation options may also require the subsequent revision of standard project assessment practices, such as cost–benefit or financial analyses, in order to integrate the new risks identified in the evaluation of future investment alternatives by planners and decision-makers (Cochran, 2009). An area of common interest for planning and management/regulatory experts, on the one side, and operations and maintenance experts, on the other side, emerges here, as vulnerability assessments would require input from both sides.

Developing effective transport governance for adaptation

Due to its high fragmentation and interconnectedness, the transport sector decisions on adaptation are likely to have different impacts across regions, economic sectors and agents or social

Box 3.19 A joint approach — the Port of Rotterdam in the Rotterdam Climate Initiative

Photo 3.12 Aerial photo of the Port of Rotterdam

Sources: Rotterdam Climate Initiative, 2009; Vellinga and Jong, 2012

The Port of Rotterdam is integrating climate change in the design of the new port areas (Box 3.14). Complementary to that single-actor approach, the port authority expands its perspective and moves beyond the harbour areas by cooperating with the city of Rotterdam in the Rotterdam Climate Initiative (RCI). This Initiative aims at joining forces and creating collaboration between government entities, companies, knowledge institutes and citizens to become climate proof by 2050. The expected climate change impacts will be mitigated by means of adaptive measures that may go beyond the scope of the single actors and include spatial planning measures and water management for the area as a whole. This approach across the board of different stakeholders will allow for non-traditional, non-incremental solutions that might even be more (cost-)effective. Measures adapted by other partners and in connected spaces could bring benefits for the adaptation of the Port too.

groups, at both the national and local levels. This interrelationship calls for broad collaboration among the many stakeholders and considering the transport system as a whole and as part of the society. As Section 1.3 indicates, adaptation actions that are spontaneous or isolated could result in conflicting and ineffective strategies.

As the EU Strategy on adaptation to climate change (EC, 2013c) and the Report *Adaptation in Europe — Addressing risks and opportunities from climate change in the context of socio-economic developments* (EEA, 2013) indicate, the role of governments at EU and national levels is mostly enabling adaptation action at local and regional levels by creating an appropriate framework. This includes effective institutions, knowledge, supportive policy and legal framework, and funding. As such, transport should also be a part of broader adaptation strategies and action plans. Hence, national adaptation strategies and plans (including Austria, Denmark, Finland, France, Germany and the United Kingdom) often request ministries of transport and, eventually, the different governments' agencies for each transport mode to produce sectorial plans or to implement specific actions (ETC/CCA, 2013). Further action is described in Section 2.2 and Boxes 1.3 and 2.3. Stakeholders acting at the local, regional or company level are rather the ones implementing measures like climate-proofing infrastructure or operations.

Metropolitan areas might have an important position in the transport system. Urban transport is frequently critical for the operation of inter-urban transport systems. Furthermore, urban areas with their rail and road intersections and airports and ports are often the critical nodes of the system and its inter-modal functioning. Urban areas are recognised as a critical field of attention in most national adaptation plans and strategies (EEA, 2014b). From this perspective, municipalities also become key stakeholders in transport adaptation processes. This is also recognised in various EU-wide activities on urban adaptation, including, for example, the EU-funded Mayors Adapt initiative ([14]).

Cooperation in the area of transport across countries and transnational regions is another important field. This is illustrated by an example of inland waterways across two countries (Belgium and the Netherlands) (Box 3.20).

As another example, the natural hazards and weather resilience tool of EUROCONTROL described in Box 3.9 provides air traffic managers with an overview on actual risks across the whole system and indicates possible impacts on the rest of the network. It enables them to take precautionary and adaptive action in regions and countries far away from the origin of the problem.

Box 3.20 Trans-boundary cooperation for the operation of the Albert Canal under extreme drought situation

The River Meuse has a total length of almost 875 km from its source in France, passing through Belgium to the Hollands Diep in the Netherlands. The Meuse is a rain-fed river and it often goes through periods with little discharge. The river feeds channels such as the Juliana Canal (the Netherlands) and the Albert Canal (Belgium) (see Box 3.15) that are important for navigation as well as for water supply in Flanders and the southern Netherlands. Therefore, the upstream water management in France and Wallonia as well as on major tributaries like the River Ruhr (Germany) is crucial in determining both peak and low river discharges.

These challenges have been addressed through a trans-boundary agreement for the Meuse catchment and more specifically between Belgium and the Netherlands for the distribution of Meuse water during periods of low discharge. In the agreement, rules apply as soon as the discharge on the Meuse (before water is diverted to the canals) goes below 100 m^3/s. A minimum of 10 m^3/s is reserved for the Grensmaas (Meuse at the border of Belgium and the Netherlands), where no navigation is possible, in order to maintain the ecosystem. Water management of the canals in Midden-Limburg and Noord-Brabant (the Netherlands) is laid down in a water agreement that aims to ensure that the supply and discharge of water is distributed equally among the areas managed by the regional water boards. This international coordination is important to continuing operation of inland waterway transport, mainly on the Albert Canal and Juliana Canal but also on the Campine Canals and the Zuid-Willemsvaart.

Sources: Rijkswaterstaat, 2011; Warmerdam, 2011.

([14]) See http://mayors-adapt.eu.

Mainstreaming of adaptation in planning and implementation

Another approach for implementation is mainstreaming adaptation — in policies, guidelines, regulations, standards, operational procedures and the design of infrastructure.

Important policy areas that require further mainstreaming and linking with transport adaptation are disaster prevention and management and water management. Transport is crucial within civil protection actions and disaster risk management.

As an example of guidelines, SEAs and EIAs have been instrumental for integrating sustainability objectives with transport plans and projects. The European Commission has provided guidance on how to include climate change adaptation in both types of procedures (EC, 2013f and 2013g) (see also Section 2.1). At the national level, the Netherlands Commission for Environmental Assessment (NCEA) recommended including a specific section on climate change within the EIA report. Climate change adaptation needs to be integrated into the plan depending on the climatic effects and the risk associated, the nature of the area, and the ratio between the cost on the short term and perceived long-term costs of the plan. Depending on the project or plan, this might also require considering much longer time horizons in the assessment (PBL, 2013; Willekens et al., 2011). The procedure can also foster the expansion of networks among professionals and among institutions, crossing over various expert communities and administrative boundaries. In particular, SEAs can be seen as a powerful instrument to support collaborative planning practices and governance structures (Van Buuren and Nooteboom, 2010).

At the EU level, the new TEN-T Regulations (EU, 2013) are a recent effort to integrate adaptation within the objectives of the European transport infrastructure policy. Climate change adaptation is included as a criterion to be considered at all the relevant levels, from network planning to project assessment, although without providing concrete methodological guidance on how this integration can be effectively implemented (Box 2.2). The consideration of adaptation needs in transport projects as a requisite for receiving EU funding, as established in the new TEN-T Regulations, is a promising way to incentivise countries to mainstream adaptation within their project assessment practices.

These examples are so-called 'soft measures' and require relatively low investments. However, further mainstreaming of adaptation into transport infrastructure investments can have substantial implications for the resilience of infrastructure and the costs of adaptation in a long-term perspective. In general, it can be expected that adaptation integrated into the design of new and upgraded infrastructure comes at lower cost than adding it at a later stage. This is shown by the examples of integration of adaptation needs into the design of metro stations in Copenhagen (Box 3.12) and application of new, climate-proof drainage standards in the new Borders rail link in Scotland connecting Edinburgh with the Scottish Borders and Midlothian (Box 3.13).

4 Ways forward to a resilient transport system

Key messages

- Transport systems are complex. They play a fundamental role in the economy and society, and are characterised by the long lifespan and high costs of their infrastructure. These characteristics all suggest the need for an adaptation approach with a long-term and systemic perspective, thus also preventing possible lock-ins into unsustainable development paths.
- Up until now, the dominant approach for reducing the vulnerability of transport systems has been to make incremental changes. While this approach works well for many cases, it can be insufficient to deal with disruptive or very fundamental changes in climate, the society or the economy. When changes of this sort happen, transport systems will need to adopt a more fundamental and comprehensive change, involving both the use of new technology and the implementation of alternative approaches for managing transport demand and supply.
- A flexible transport structure — the ability to easily find another transport option in the event that one option becomes unusable — plays an important role in creating a resilient transport system. One way to ensure this flexibility is through providing functionally redundant option. Redundancy offers a higher capacity and more options than needed under normal operational conditions, but enables flexibility in the event of a disaster or other interruption.
- An approach, where incremental and fundamental changes are employed complementary depending on the specific situation to solve, will result in a more resilient transport system. In deciding when to act, it is better to anticipate this need for change and to act early rather than wait for events to force change. Anticipatory action of this kind will require a shift away from piecemeal action to more planned and integrated approaches, including early action whenever possible.
- Good adaptation action requires information and knowledge. This information can be made available by the Climate-ADAPT website. Innovation and fundamental change often need research, which can be provided by the EU Framework Programme for Research and Innovation (Horizon 2020), and similar national activities.
- The EU and its Member States have started to put into place a variety of measures to promote the implementation of adaptation measures in the transport sector. These measures include funding support, the provision of information, capacity building, and review of technical standards. The engagement of all the main stakeholders in the transport sector is of key importance from the perspective of both equity and efficiency, and policymakers and researchers should make an extra effort to engage stakeholders in their research and information-dissemination activities.
- Currently, greater attention is given to adapting transport infrastructure (rail tracks, ports, roads, etc.) than to adapting transport services (operation of infrastructure and equipment, use of staff, timetables and routing, contingency plans, communication of service options, etc.). More use could be made of this underused potential of transport service operators.
- It is important that adaptation measures taken in the transport sector are monitored and analysed. This will enable stakeholders to improve the effectiveness and efficiency of future policy, and will help to stimulate a transparent public debate on what additional actions are needed.

The current and projected impacts of climate change pose serious challenges to transport. A resilient transport system that can continue to function under climate change is therefore of crucial importance for society.

Adapting the transport system is not an easy task. Individual investments in transport infrastructure projects fit into a broader transport system and have the potential to prevent or hinder future changes in the system and its operations. They can cause so-called 'lock ins'. For example, if a rail link is built in an area vulnerable to future climate change impacts, and businesses have located close to that rail link, it will be very difficult to relocate the rail link and its nearby businesses in the future.

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This systemic nature of the problem means that adaptation must go beyond individual actions (such as climate-proofing a road section) and also assess the advantages and disadvantages of introducing fundamental changes in the way passengers and goods are transported (such as reassessing the function of this road section in the overall road network or considering alternative modes of transport such as rail connections). Fundamental changes are difficult to make, but may prove more efficient in the long-term and be better aligned with other policies (such as spatial planning policy or energy policy). When considering transport projects, decision-makers must make sure they avoid any lock-ins in structures that limit the transition towards a more resilient and efficient transport system (EEA, 2014a).

The following four sections discuss ways to encourage a fundamental transition in the transport system towards greater resilience.

4.1 Increase awareness and knowledge

Despite the crucial role of transport in society, transport does not yet seem to be a key priority in national and regional adaptation plans. In fact, other sectors, such as water management, energy, or health receive more attention in these plans than transport. The fact that transport is not a priority in adaptation plans does not mean that no adaptation is happening in the transport sector. Adaptation is happening, but mostly in a bottom-up fashion (often led by individual transport stakeholders) and without a comprehensive strategy. If Member States and the EU placed transport adaptation higher on the political agenda (as high as they place the issue of climate change mitigation), it would generate more awareness and foster more action.

This low level of policy awareness of the need for transport adaptation also poses barriers for the development of strategies and measures. As a result of these barriers, current transport adaptation action is mostly focused on early-stage measures such as gaining more knowledge and identifying options. Implementation of specific measures is not yet taking place in many countries or regions.

In this situation, national governments and the EU can play an important role in supporting the development and dissemination of knowledge tailored to the needs of transport. This knowledge could come from research that builds on the results of climate-related projects in the EU Seventh Framework Programme (FP7) ([15]). Another avenue for improving and disseminating knowledge is to make use of the resources and opportunities available in the current Horizon 2020 research programme.

In concrete terms, the knowledge base would benefit greatly from more systematic data collection; improved monitoring and reporting on impacts of extreme weather and climate-related events; and the expansion of website platforms for information sharing, such as Climate-ADAPT and national platforms. Policymaking would also benefit from research on how best to make use of existing tools like Strategic Environmental Assessment, Environmental Impact Assessment and cost-benefit analysis, or how best to approach the challenge of acting under uncertainty (there is uncertainty both in climate projections and in projected socio-economic changes). Further research on scenario-building and collaborative planning can deliver a better understanding of the long term challenges from climate change. This research should consider transport within the larger framework of changes in the economy, society and demography, and the influence these changes will have on transport demand.

Furthermore, it is imperative for scientists working with climate change to better understand the transport sector's information needs and to provide the sector with information that is useful and easily accessible. Climate-change services being developed at national and EU levels (such as the Copernicus climate-change service, to be initiated soon ([16])) are expected to address these

([15]) Various finalised EU FP7 projects like MEDIATION and CIRCLE-2 provided approaches and guidance on dealing with uncertainty. The results of such projects should be better disseminated, and uptake with practitioners in the transport sector should be enhanced.
([16]) See http://www.copernicus.eu/pages-principales/services/climate-change.

issues in the coming years. Transport companies and transport authorities (whether publicly or privately owned) also have a role to play in filling some of the knowledge gaps. They should engage with researchers in climate science, hydrology, and meteorology to improve information exchange. The German research programme KLIWAS offers a good example of how this interdisciplinary dialogue can be promoted.

4.2 Innovation, transition and long-term visions

Future transport systems (in 2050 and beyond) could be quite different from those of today. There are a variety of ways in which they could differ. One way is that societal or climate changes might alter current transport needs and transport-generation patterns. Another possibility is that technological and operational innovations may phase out currently dominant forms of transport. In such a dynamic environment, efforts that focus merely on making incremental changes to today's transport systems could result in lock-ins. These lock-ins could leave Europe fixed in a transport structure that is inefficient, expensive, or vulnerable to outside shocks. In the worst case scenario, our transport structure could be outdated — designed to work in the context of conditions that no longer apply. For this reason, policy decisions should create a resilient transport system able to anticipate changes in climate and in the economy and society and to cope with them.

A number of EU processes will encourage the emergence of this more resilient and sustainable transport system. These processes include the Europe 2020 programme and the Commission's White Paper *Roadmap to a Single European Transport Area — Towards a competitive and resource efficient transport system* (EC, 2011b). Adaptation in the transport sector could benefit from synergies with the efforts currently being made in the area of climate-change mitigation. Focusing on a low-carbon, competitive, and resource-efficient transport system could also help to promote the transport system's resilience to climate change.

Although adaptation actions are already occurring in the transport sector, more attention should be paid to the type of adaptation approach being employed. Current approaches often focus on making incremental improvements to certain pieces of infrastructure. This approach might face limits in the event of expected climate-change impacts. These impacts include higher sea-levels under storm surges or conventional drainage systems being overloaded by water from rain cloudbursts. Where such situations are anticipated, incremental improvements to certain parts of the system could be insufficient or less effective; instead, the entire system will need to be rethought and redesigned. This redesign could include fundamental changes such as relocating or reorganising transport services (for example, re-routing a rail track or road), or ensuring accessibility by other transport modes (for example, shifting from road transport to rail or water transport or vice versa). In some cases it might mean using communications and production technology to avoid the use of transport altogether (better video-conferencing to remove the need for business travel, or relocation of production systems closer to consumer markets to reduce the need for transporting goods long distances).

The currently prevalent paradigm of incremental efficiency in transport systems is certainly insufficient. Facing vulnerability and uncertainty, it is worth also exploring other concepts like flexibility — the ability to easily find another option of transport in the event that one option becomes unusable. A society or economy that has a flexible transport structure is more resilient because a weather- or climate-related disaster or social change will not interrupt the flow of goods, people and services, or will only do so to a small extent.

Redundancy is another factor that assists resilience in transport systems. Redundancy in a transport system means having more capacity and options than is needed under normal operational conditions. One example of redundancy is maintaining a dense network of roads and rail tracks so that, if there is a problem with one section, the other route can be used. Another example is maintaining back-up supplies of fuel or spare parts in case the flow of either is interrupted.

There is a need for open debate on issues of redundancy, flexibility, resilience and efficiency in our transport systems. This is because the different options concern social preferences. For example, although redundancy and flexibility increase resilience they come with lower day-to-day efficiency (and thus higher day-to-day costs) because redundant systems leave resources unused. At a more detailed level of debate, the transport community could find it useful to discuss the cases in which it would be preferable to gain resilience through upgraded standards and infrastructure, and the cases in which resilience could be better gained through flexibility and redundancy.

Such discussions go far beyond the scope of transport and therefore require stimulation, facilitation, and guidance by regional and national governments and by the EU. These discussions should involve a broad array of stakeholders from within — and outside — the transport sector.

4.3 Moving from isolated and spontaneous to an integrated approach

Countries, cities, infrastructure managers, service operators, and transport users are all seeking ways to adapt. However they often do not interact with each other, and thus miss potential synergies. A balance must be found between the convenience of an approach that focuses only on the transport sector (or even on a single transport mode) and the overall greater effectiveness that comes from considering adaptation as a comprehensive challenge that concerns the economy, society and the environment. This more comprehensive understanding of adaptation requires a spatial perspective, focused on particular territories such as cities or regions.

Considering transport under a broader spatial perspective provides several benefits. Firstly, transport stakeholders may find it easier to develop and implement their adaptation actions if they can link to integrated adaptation strategies at the appropriate spatial level. Secondly, integrating transport within regional or city adaptation strategies also facilitates a discussion about how changes in climate can impact population flows and transport behaviour. This broader framework may offer a better basis for a revision of current transport plans based on particular regional or local characteristics (including their socio-economic developments).

There are many stakeholders in the transport sector and these stakeholders operate under different technical and governance cultures. This makes it difficult to formulate a strategy for mobilising the sector as a whole and integrating adaptation into stakeholders' current practices. Another difficulty in adaptation planning is that greater attention is given to adapting transport infrastructure (rail tracks, ports, roads, etc.) than to adapting transport services (operation of infrastructure and equipment, use of staff, time tables and routing, contingency plans, communication of service options, etc.). Operators are important since they provide the services for the transport of passengers and goods. This underused potential of transport service operators should therefore play a more central role in adapting the transport system to climate change.

There are other underused opportunities that also deserve attention. For example, stakeholders in one transport mode can learn from other modes about innovative solutions. They can also revise transport standards and management across transport modes to create more harmonised and consistent technical approaches. Useful knowledge can also be found in related policy areas, such as disaster-risk prevention or river-basin and flood-risk management.

Mobilising the cooperation of different stakeholders could help to overcome the fragmentation that exists in what is — ironically — a highly connected sector. An ambitious approach by the public authorities seems necessary to overcome these barriers. This approach has already been adopted in some countries, where the transport sector has been invited to participate in the formulation of national and regional adaptation initiatives.

4.4 Transitional thinking at European level

The EU has no legal competence to plan transport networks. However, it can indirectly influence the development of transport networks by means of the financial assistance it provides to infrastructure projects. Many EU funding streams for infrastructure projects, for example the Structural Funds and TEN-T funding, now require that these projects be made resilient to climate change. The EU also influences the development of transport networks through the revision of design guidelines and standards, a process that is currently ongoing. The revision will lead to a more consistent technical approach to creating an infrastructure better adapted to climate change across Europe. However, the revision process is currently proving to be difficult and resource-consuming.

It is critically important to climate-proof transport infrastructure and transport operations, and it is a positive step that the EU is now considering this. However, current approaches to climate-proofing typically follow a rather traditional and incremental method, and do not consider the need for fundamental transformational changes discussed earlier in this chapter. In this respect, EU transport adaptation policy is less advanced than EU transport policy for climate-change

mitigation and resource efficiency. The EU White Paper on transport (EC, 2011b) aims at building a competitive and resource-efficient transport system for the future. It includes a roadmap for a transition of the system. Concepts like multi-modality and clean transport are proposed as climate change-mitigation actions. These concepts could also offer options for adaptation, but this potential is not currently being explored. In relation to adaptation the White Paper only considers making infrastructure resilient to climate change. It does not integrate more comprehensive structural changes (or other transition concepts) that would be needed from the perspective of transport adaptation.

The next generation of transport policy will need to mainstream these transitional approaches to climate change adaptation and mitigation as two complementary strategies to cope with climate change, thereby facilitating the emergence of a resilient transport system.

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Annex Climate risk and impacts on transport infrastructure

	Type	Climatic pressures	Risks	Time frame of expected impact	Regions mainly affected
Rail infrastructure	Rail	Summer heat	• Rail buckling; • material fatigue; • increased instability of embankments; • overheating of equipment (e.g. engine ventilation, acclimatisation); • increase in wildfires can damage infrastructure	Medium negative (2025; 2080) to high negative (2080)	Southern Europe medium negative until 2025 and high negative until 2080; west, east and central EU medium negative until 2080
		Winter cold/ice	• Ice on trains and catenary	Medium negative (2025; 2080)	Northern Europe, central Europe
		Extreme precipitation	• Damage on infrastructure due to flooding and/or landslides; • scour to structures; • destabilisation of embankment	Medium negative (2025) to high negative (2080)	European-wide
		Extreme storms	• Damage on infrastructure such as signals, power cables, etc. (e.g. due to falling trees, etc.)	No information	No information
		In general:	• Reduced safety; • increased cost for reparation and maintenance; • disruption of 'just in time' delivery of goods and passengers		
Road infrastructure	Roads (including bridges, tunnels, etc.)	Summer heat	• Pavement deterioration and subsidence; • melting tarmac; • reduced life of asphalt road surfaces (e.g. surface cracks); • increase in wildfires can damage infrastructure; • expansion/buckling of bridges	Medium negative (2025; 2080) to high negative (2080)	Southern Europe (2025), west, east and central EU (2080)
		Extreme precipitation/ floods	• Damage on infrastructure (e.g. pavements, road washout); • road submersion; • scour to structures; • underpass flooding; • overstrained drainage systems; • risk of landslides; • instability of embankments	Medium negative (2025) to high negative (2080)	European-wide
		Extreme storm events	• Damage on infrastructure; • roadside trees/vegetation can block roads	No information	No information
		In general:	• Speed reduction; • road closure or road safety hazards; • disruption of 'just in time' delivery of goods; • welfare losses; • higher reparation and maintenance costs		
	Coastal roads	Sea-level rise	• Damaged infrastructure due to flooding; • coastal erosion; • road closure	Medium negative (2080)	European-wide
		Extreme storm events		No information	No information
		Heavy precipitation events		Medium negative (2025) to high negative (2080)	European-wide

	Type	Climatic pressures	Risks	Time frame of expected impact	Regions mainly affected
	Mountain road	Permafrost degradation	• Decrease of stability; • rockfalls; • landslides; • road closure	No information	No information
	Sewerage system	Heavy precipitation events	• Overloaded sewerage system can cause road flooding and water pollution	Medium negative (2025) to high negative (2080)	European-wide
Aviation infrastructure	Airports (including runways)	Summer heat	• Greater need for ground cooling; • degradation of runways and runway foundations; • higher-density altitudes causing reduced engine combustion efficiency; • decreased airport lift and increased runway lengths	Medium negative (2025; 2080) to high negative (2080)	Southern Europe (2025), west, east and central EU (2080)
		Heavy precipitation events	• Flood damage to runways and other infrastructure; • water run-off exceeds capacity of drainage system	Medium negative (2025) to high negative (2080)	European-wide
		Sea-level rise	• Flooding of runways, outbuildings and access roads	Medium negative (2080)	European-wide
		In general:	• Interruption and disruption to services supplied and to ground access; • periodic airport closures; • higher maintenance costs		
Shipping infrastructure	Inland shipping	High river flow (e.g. extreme precipitation, snow melt)	• Problems for the passage of bridges; • speed limitations because of dike instability; • some restrictions on the height of vessels	Medium negative (2080)	European-wide
		Low river flow (e.g. drought)	• Strong restrictions on the loading capacity; • navigation problems, speed reduction	Medium negative (2025) to high negative (2080)	South, east and central Europe; in 2080 also western Europe
		Change in ice cover	In general, shorter periods of ice cover can be expected. Nevertheless, warm and early winters, followed by a rapid decrease in air temperature, may result in thicker or rougher ice cover formation and, thus, lead to ice jams, and damage to navigation signs and infrastructure (e.g. locks)	No information	No information
		In general:	• Disruption of 'just in time' delivery of goods; • stopping of inland shipping; • welfare losses		
	Maritime transport	Sea-level rise	• Navigability could be affected by changes in sedimentation rates and location of shoals; • more frequent closure	Medium negative (2080)	European-wide
		Change in sea conditions	• More severe storms and extreme waves might affect ships	No information	No information
		Less days below freezing	• Reduce problems with ice accumulation on vessels, decks, riggings and docks; • Occurrence of dangerous ice fog	Medium positive (2080)	European-wide
		Reduced sea ice	• Improved access; • longer shipping seasons; • new shipping routes	Summer sea ice could completely disappear in the Arctic Ocean sometime in the period 2013–2040	No information

	Type	Climatic pressures	Risks	Time frame of expected impact	Regions mainly affected
	Ports	Extreme storm events	• Devastation of infrastructure; • interruptions and bottlenecks in the flow of products through ports	No information	No information
		Sea-level rise		Medium negative (2080)	European-wide
		Floods/landslide		Medium negative (2025) to high negative (2080)	European-wide
		In general:	• Disruption of 'just in time' delivery of goods; • welfare losses; • increased cost for reparation and maintenance		
Urban transport	Urban transport (road infra-structure, bike lanes, walkways, rail infra-structure, water-ways, public and private transport)	Temperature increase and heat waves	• Increase of the heat island effect (e.g. melting asphalt, increased asphalt rutting due to material constraints, thermal expansion on bridge expansion joints and paved surfaces, and damage to bridge structure material)	Medium negative to extreme negative	2025: Southern, eastern EU 2080: Northern, southern, eastern, central EU
		Heavy precipitation events (extreme flash floods)	• Damage to infrastructure due to flooding, property at risk due to location, heavy water run-off	Medium negative (2025;2080) to high negative (2080)	2025: Southern, western EU 2080: Eastern, southern, northern, western, central EU
		Sea-level rise and storm surge flooding	• Risk of inundation of road infrastructure and flooding of underground tunnels; • degradation of the road surface and base layers from salt penetration	Medium	2025: Southern, western, northern EU 2080: Southern, western, northern EU
		Extreme storms, strong winds	• Damages, increase of maintenance cost	Small to medium impacts	European-wide
Transmission and distribution infrastructure	Primarily electrical trans-mission and distri-bution networks	Extreme high temperatures	• Decreased network capacity	Medium negative (2025) to extreme negative (2080)	European-wide
		Snow, icing, storms	• Increased chances of damages to energy networks/blackout	Medium negative to low positive (2050)	North-west Europe
		Heavy precipitation	• Mass movements (landslides, mud and debris flows) causing damages	Medium negative to low positive (2050)	North-west Europe
	Primarily trans-mission networks (oil and gas)	Melting permafrost	• Ties of gas pipelines in permafrozen ground cause technical problems (this is touching only Arctic supply pipelines and not the east-west gas pipelines, since the latter ones are not grounded in permafrost)	Low for 2025 and gradually increasing	Arctic Eurasia
		Higher temperatures	• Reduced throughput capacity in gas pipelines	Low for 2025 and gradually increasing	European-wide
Primarily storage and distribution	Storms in connection with high tides and SLR	Storms in connection with high tides and SLR	• Threats to refineries and coastal pipelines due to SLR/high tide/storms		

Source: EC, 2013c.

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