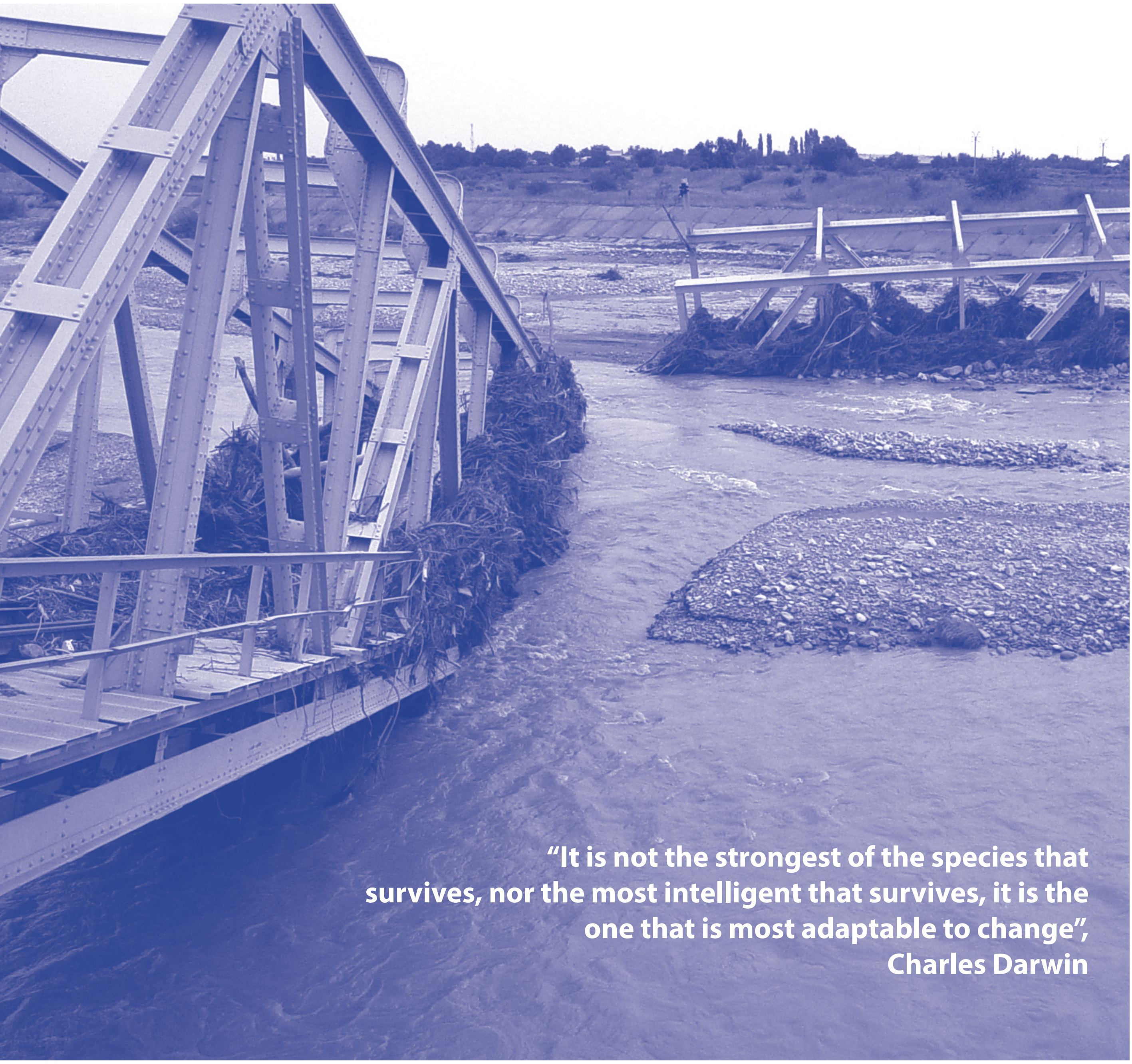
UNITED NATIONS ECONOMIC COMMISSION FOR EUROPE

Climate Change Impacts and Adaptation for International Transport Networks



“It is not the strongest of the species that survives, nor the most intelligent that survives, it is the one that is most adaptable to change”,
Charles Darwin

UNITED NATIONS

Climate Change Impacts and Adaptation for International Transport Networks

Expert Group Report

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Note

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Acknowledgements: The report was prepared by Prof. A.F. Velegrakis, University of the Aegean, Greece, who would like to express his thanks to all members of the UNECE Group of Experts on Climate Change Impacts and Adaptation for International Transport Networks for their invaluable inputs in the cause of drafting this report, and to all those who participated in the Questionnaire Survey that formed a part of this research.

ECE/TRANS/238

United Nations Economic Commission for Europe

The United Nations Economic Commission for Europe (UNECE) is one of the five United Nations regional commissions, administered by the Economic and Social Council (ECOSOC). It was established in 1947 with the mandate to help rebuild post-war Europe, develop economic activity and strengthen economic relations among European countries, and between Europe and the rest of the world. During the Cold War, UNECE served as a unique forum for economic dialogue and cooperation between East and West. Despite the complexity of this period, significant achievements were made, with consensus reached on numerous harmonization and standardization agreements.

In the post-Cold War era, UNECE acquired not only many new Member States, but also new functions. Since the early 1990s the organization has focused on analyses of the transition process, using its harmonization experience to facilitate the integration of Central and Eastern European countries into the global markets.

UNECE is the forum where the countries of Western, Central and Eastern Europe, Central Asia and North America – 56 countries in all – come together to forge the tools of their economic cooperation. That cooperation concerns economics, statistics, environment, transport, trade, sustainable energy, timber and habitat. The Commission offers a regional framework for the elaboration and harmonization of conventions, norms and standards. The Commission's experts provide technical assistance to the countries of South-East Europe and the Commonwealth of Independent States. This assistance takes the form of advisory services, training seminars and workshops where countries can share their experiences and best practices.

Transport in UNECE

The UNECE Inland Transport Committee (ITC) facilitates the international movement of persons and goods by inland transport modes. It aims to improve competitiveness, safety, energy efficiency and security in the transport sector. At the same time it focuses on reducing the adverse effects of transport activities on the environment and contributing effectively to sustainable development. The ITC is a:

- Centre for multilateral transport standards and agreements in Europe and beyond, e.g. regulations for dangerous goods transport and road vehicle construction at the global level
- Gateway for technical assistance and exchange of best practices
- Promoter of multi-country investment planning
- Substantive partner for transport and trade facilitation initiatives
- Historic center for transport statistics.

For more than six decades, ITC has provided a platform for intergovernmental cooperation to facilitate and develop international transport while improving its safety and environmental performance. The main results of this persevering and important work are reflected in more than 50 international agreements and conventions which provide an international legal framework and technical regulations for the development of international road, rail, inland water and intermodal transport, as well as dangerous goods transport and vehicle construction. Considering the needs of the transport sector and its regulators, UNECE offers a balanced approach to and treatment of facilitation and security issues alike.

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Putna Seaca Rail Bridge, Romania. Damaged by Floods in 2005 © Club Feroviar

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Executive Summary

Even though the last years the impacts of climate change on various human activities have been considered by both Governments and International Organizations, relatively little consideration has been given to impacts associated with the infrastructure and operations of international transport networks and related adaptation measures. Recognizing the need for concerted action, experts from various countries, international organizations and academia, under the auspices of the United Nations Economic Commission for Europe (UNECE) established a Group of Experts on Climate Change Impacts and Adaptation for International Transport Networks. The Group met six times and organized an international conference in June 2012 on this subject. Relevant information for the ECE region and beyond was analyzed and the potential implications of climate variability and change on transport infrastructure and services were identified. Information was collected (through a questionnaire survey) on (a) the current level of awareness and preparedness, (b) the availability of relevant information and tools, (c) the existing and planned transport adaptation policies, (d) measures and initiatives and (e) the research needs and financing requirements as well as the collaboration mechanisms at national, regional and international levels. Relevant national initiatives, case studies and research projects were reviewed, and experiences on mode-specific adaptation measures were shared together with existing best practices in national policies for risk management and the resilience enhancement. Finally, the experts recognized the need for an increased awareness about the assessment of the climate change impacts on the transport sector and of pertinent adaptation measures.

Climate Variability and Change Trends and Projections

Concerning the current climate trends, a long-term increasing trend in the mean air temperature is clear. Precipitation has been also changing, but in a more complex manner. These trends are predicted to hold or even pick up pace in the future. A most damaging side-effect of the temperature increases concerns the significant rise in the mean sea level. Since the 1860s, sea levels have increased by about 0.2 m, with satellite information showing a progressive increase in the rates since the 1990s. Concerning temperature projections for the end of the 21st century, the recent report (AR5) of the Intergovernmental Panel for Climate Change (IPCC, 2013) projects temperature increases between 1.0 and 3.7 °C (depending on the scenario). Such temperature increases could also drive substantial mean sea level rises, which for the same period, are projected to be in the range of 0.26 - 0.82 m, with other recent studies projecting even higher rises.

Changes in the average climate conditions can also lead to fluctuations in the frequency, intensity, spatial coverage, duration, and timing of weather and climate extremes, which can, in turn, modify the future climatic conditions. Extreme events (e.g. storms, storm surges, floods and droughts and heat waves), as well as changes in the patterns of particular climatic systems such as the monsoons can have, at smaller spatio-temporal scales, more severe impacts on transport networks than changes in the mean variables. One of the clearest trends appears to be the increasing frequency and intensity of heavy downpours. Climate models project the continuation of this trend, with heavy downpours that occur presently about once every 20 years being projected to occur every 4-15 years by 2100, depending on location. Concerning river floods, these also appear to present a significant hazard, particularly for central and eastern Europe and for central Asia. There is also evidence to suggest increases in the frequency and intensity of heat waves and droughts.

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One of the major causes of the observed temperature increases is considered to be the increasing atmospheric concentrations of Greenhouse Gases (GHGs), which absorb heat reflected back from the Earth's surface and, thus, increase the heat storage in the Earth system. Since the industrial revolution, atmospheric concentrations of the GHGs have been steadily increasing, being now higher than they have been for some million years. Global warming can be amplified by reinforcing feedbacks, i.e. climate change-driven processes that can induce further warming, such as the activation of currently inert carbon reservoirs (e.g. the tropical peatlands and the vast CH_4 stores of the Arctic permafrost) and the rapid reduction in the spatial coverage of Arctic Ocean ice.

Implications for transport networks

Demand for transport services grows in line with the global economy, trade and world population. As transport is a demand-driven industry, climate change-induced changes in e.g. population distribution, commodity production and its spatial distribution, tourism patterns and the trade and consumption patterns can also have significant implications.

Climate variability and change (e.g. mean sea level rise, warmer water temperatures, higher intensity of storms and storm surges and potential changes in the wave regime) may severely impact coastal transport infrastructure and services, such as ports and other coastal transport hubs/networks. Ports, which form key-nodes in international transport networks and link international supply-chains, will be particularly impacted, due mostly to the long life-time of their key infrastructure, their exposed location, and their dependence on trade, shipping and inland transport that are also vulnerable to climate variability and change. Daily port operations can be directly influenced by storm surges; coastal inundation will render ports unusable for the flood duration and damage terminals, intermodal facilities, freight villages, storage areas and cargo and, thus, disrupt intermodal supply chains and transport connectivity.

Precipitation changes can result in stream flow changes that are likely to affect roadways, railways, rail and coach terminals, port facilities, and airports. There can be direct damages during the events, necessitating emergency responses. There can also be effects on the structural integrity and maintenance of roads, rail lines, bridges, tunnels, drainage systems, telecommunication and traffic management systems, necessitating more frequent maintenance and repairs. Increases in heavy precipitation events and floods will cause more weather-related accidents, delays, and traffic disruptions in the already congested networks. Inland waterways can suffer navigation suspensions, silting, changes in river morphology and damages of banks and flood protection schemes, whereas airports may suffer infrastructure damages and increased delays and cancellations of operations.

Extreme winds can damage port facilities (e.g. cranes and loading terminals), damage airport facilities and interrupt air services and stress road and rail operations; they can also destroy agricultural crops and, thus, indirectly affect the transport industry. Changes in the directional patterns of winds and wind-waves can affect seaport operations and safety. Heat waves may also affect transport services and infrastructure by inducing wildfires and crop failures, stressing water supplies, food storage and energy systems and increasing refrigeration requirements. They can also deform/deteriorate road pavements and disrupt road traffic, deform rail tracks and desiccate track earthworks causing lengthy delays through speed restrictions. Airport facilities, runways and operations will be also affected as will inland waterway transport. The decline in the Arctic Ocean ice extent may allow the opening of new shipping routes, but also alter demand and supply of regional transport services and significantly increase the costs for linking Arctic ports to major national and international inland transport networks. Arctic warming may also affect the freezing and thawing cycles, damaging building foundations, causing frost heaving at roadways and rail lines, and affecting the integrity of bridges and other transport structures.

Recommendations

To avoid significant future expenditures it appears that transport policy makers and stakeholders should address the climate change issue as a matter of urgency. A clear understanding of the potential impacts, risks and vulnerabilities appears to be both a first step and a prerequisite for the design and construction of resilient transport infrastructure and their management systems. It must be noted that the transport sector of the developing and poorly-diversified economies will be particularly vulnerable not only to catastrophic, large-scale extreme events but also to 'slow- burning' stresses due to the projected higher average temperatures and mean sea levels and more frequent flooding and/or droughts.

Adaptation action aims to reduce vulnerabilities and increase the resilience of systems to climatic impacts. In the transport sector, resilience refers not only to the physical strength and durability of the infrastructure that allows it to withstand adverse impacts without losing its basic functions, but also to its ability to recover quickly and at minimal cost. It follows that potential climate change impacts should be factored in the planning, design, construction and operations, as well as in the broader economic and development policies involving the sector. Developing effective adaptation strategies requires policy action, investment and collaborative research. Well targeted vulnerability studies, empirical studies and assessments of projected risks and related costs are deemed as a necessary first step towards bridging the current knowledge gap and defining priority areas.

The following general recommendations are based on experiences gained so far and on scientifically confirmed potential manifestations of climate change impacts. With regard to Government action, a necessary prerequisite for the development and formulation of effective climate change adaptation strategies should be a clear understanding and systematic mapping of the transport sector vulnerabilities to climate variability and change on the basis of the nature/extent of change, the transport system sensitivity and the required adaptive capacity. It is recommended that:

(i) Governments, in collaboration with transport infrastructure owners/operators and International Organizations should establish inventories of critical and sensitive transport nodes.

(ii) Climate variability and change should be incorporated into the long-term capital improvement plans, facility designs, investment works, maintenance practices, operations, engineering practices and emergency response plans.

(iii) Transport infrastructure and services are subject to regulation; therefore, institutional and regulatory adaptation may also be necessary.

(iv) Transport infrastructure planners and designers together with transport infrastructure managers, vehicle and rolling stock manufacturers should take into account from the planning stage, climate change projections and their potential impacts.

Regarding adaptation strategies:

(i) Adaptation actions should take place within integrated natural hazard management frameworks; such frameworks should be able not only to pro-actively address the present weather- related challenges and disruptions, but also to design and build mid- to long-term climate change adaptation measures. Building upon current management systems that already deal with the present weather related impacts is likely to create a working adaptation framework.

(ii) Well-structured nationally as well as internationally integrated databases of digitized network data, disruption hotspots and incidents, management and maintenance plans and asset management practices could form the core of an efficient natural hazard management system for the transport sector. Such databases should be maintained and updated and supplied with necessary and innovative (software) tools that can project future risks in order to form an integrated tool to assist climate change adaptation in the transport sector.

(iii) Possible climate change impacts should be considered at the early stages of planning and included in risk and vulnerability assessments; future projects should integrate climate change considerations into their asset design and maintenance planning.

Although the present report deals with the adaptation of the transport sector to climate change, issues relevant to Climate Change mitigation should always be kept in mind.

(i) Adaptation is not an alternative to reducing GHG emissions. Global emission monitoring is considered necessary to constrain climate change.

(ii) Many fundamental decisions regarding both climate change adaptation and mitigation will be influenced by cost-benefit assessments. Presently, such assessments are constrained by uncertainties; therefore, reducing such uncertainties, where possible, should become an urgent integrated research priority.

(iii) The possibility of developing synergies with GHG emission mitigation and other environmental objectives should be investigated further.

The present study has shown that there are significant information and knowledge gaps that must be filled by appropriate research. Concerning this issue, the following recommendations are presented:

(i) The study of Climate Change impacts and adaptation requires integration of a range of disciplines, such as law, natural and social science, engineering and economics.

(ii) Focused research should be undertaken for different climate change impacts. These studies could be complemented by case studies on the potential economic, social and environmental consequences and the costs and benefits of adaptation options. For instance, the river flood risk on road and rail networks could be assessed by detailed studies that will model the potential extreme flood hazard in the ECE region under different scenarios of climate change in order to identify flood 'hot spots'.

(iii) Initial assessments of the transport sector vulnerabilities are possible without a detailed knowledge of future climatic changes; these assessments can be based upon the analysis of the sensitivity to past climatic variability and the current capacity of the systems to absorb disruption and adapt to changing conditions.

(iv) In view of the interconnectedness and interdependence of economies in a globalized trading system, the special needs of developing counties, and particularly Small Island Developing States, should also be taken into consideration.

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(v) It is important to foster cooperation between the UNECE and other relevant International Organizations and Agencies, in particular with United Nations Framework Convention on Climate Change (UNFCCC), and the Global Framework for Climate Services (GFCS) of the World Meteorological Organization, in order to institute a process for better communication among transport professionals, climate scientists, and other relevant scientific experts, and establish, if possible, a clearing house for transport-climate change relevant information. Bearing in mind the global nature and implications of the climate change on transport sector as well as the importance to take into account climate change challenges when international transport norms and standards are discussed in the ITC and in its subsidiary bodies, UNECE is to take the initiative and contact the Partners Advisory Committee of the GFCS. Sharing of best practices for addressing potential impacts of climate variability and change in the transportation sector is also warranted.

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Report Scope and Structure

Records of the earth's temperature levels over the past decades indicate a rising temperature (global warming), which is considered to be due to the Greenhouse Effect. Although there has been a global effort to reduce Greenhouse Gas (GHG) emissions, scientific evidence suggests that the global warming cannot be reversed, but only be slowed down. Global warming has significant effects on climate and these effects are expected to become more severe in the coming decades, regardless of what could be achieved in reduction of GHG emission. A warmer world will affect all aspects of our environment, including resulting in extreme events (temperatures, rainfalls and floods as well as rising sea levels). These climatic changes are likely to affect the way we live, travel, transport goods and do business. Consequently, it is obvious that there is not only an urgent need to address climate change causes, but to also learn how to address the impacts.

This report has been prepared to assist the work of the UNECE Group of Experts on Climate Change Impacts and Adaptation for International Transport Networks, in accordance with its agreed work programme and its main objectives, (ECE/TRANS/WP.5/GE.3/2011/1).

The report consists of 5 substantive chapters. Chapter 1 provides a short review of the scientific background of climate change and its effects on both a global scale and in the ECE region. Chapter 2 presents some of the potential impacts of the different manifestations of climate change on transport networks. This section pays particular emphasis identifying issues pertinent to transport infrastructure in the ECE region and taking into account the different modes of transportation. Chapter 3 presents a brief analysis of the results of the questionnaire circulated to UNECE member countries and international organizations in 2012. Chapter 4 provides a summary of available adaptation responses. Chapter 5 summarizes the conclusions and recommendations of the Group of Experts.

There are also 4 Annexes. Annex I presents a brief overview of some of particularly pertinent studies relating to different modes of transportation. Annex II provides a summary of the work presented in the UNECE International Conference on Adaptation of Transport Networks to Climate Change (25-26/06/2012 Alexandroupolis, Greece) and inputs provided by experts . Annex III presents the questionnaire sent to Governments and organizations and Annex IV presents a quantified summary of the answers provided by the respondents to the Questionnaire.

It should be noted that the report is not comprehensive in its scope, nor should it be seen as a full inventory of issues arising. Rather, it represents a first step to take stock of some of the available information (data and analysis) on the impacts climate change has on international transportation infrastructure in the ECE region and beyond, including their type, range and distribution across varied areas and transport modes. In addition, it analyses answers provided by 27 member States and 7 organizations to the questionnaire designed by the Expert Group, in order to record, for the first time, perceptions and opinions about the implications of Climate Change and variability on transport[1] .

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[1] This report contains information available up to July 2013. It also includes comments to earlier drafts submitted to the UNECE by international experts.

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Chapter 1. Climate Change: The Physical Basis

1.1. Climate Changes: Phenomenology

1.1.1 Temperature, precipitation and sea level rise

Climate is controlled by the heat inflows and outflows and its storage dynamics in the various constituents of the Earth System, i.e. the ocean, land and atmosphere (Intergovernmental Panel on Climate Change (IPCC), 2007a). Most of the heat storage occurs in the ocean and, thus, changes in ocean temperature are important indicators of climatic changes. In recent years, there has been ample evidence of ocean warming (e.g. Domingues et al., 2008), with the rate being estimated as 0.64 W m^{-2} for the period 1993-2008 (Lyman et al., 2010). This is notwithstanding the temporal variability due to e.g. the large climatic modulations and the sun spot cycles (e.g. Richardson et al., 2009).

With regard to the atmospheric air temperature, in accordance with previous forecasts (e.g. IPCC, 2001; 2007) a long-term increasing trend is clear (Fig. 1); in the ocean, warming has been found to be highest in the surficial waters, with the upper 75 m of the ocean having warmed by 0.11 °C per decade over the period 1971–2010 (IPCC, 2013). Concerning temperature projections for the end of the 21st century, it is expected that the atmospheric temperature will increase between 1.0 and 3.7 °C (mean estimates, see Table 1), depending on the scenario. Forced by a range of possible Greenhouse Gas (GHG) concentration scenarios (IPCC, 2013), the central (mean) estimate for the warming has been predicted to be 1.0 - 2.0 °C for the period 2046–2065 compared to the mean of the period 1986–2005, whereas by the late 21st century (2081–2100) increases of 1.0 - 3.7 °C are projected. However, the range of the projections broadens to 0.3 - 4.8 °C when model uncertainty is included.

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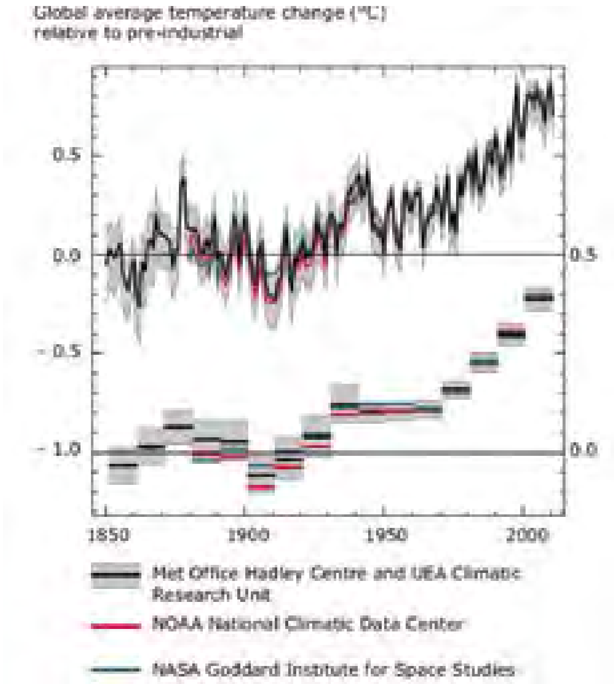

Figure 1 **Changes in the global average air temperature (in °C): (a) annual anomalies; and (b) decadal average anomalies. Key: black line, results from HadCRUT3 from the UK Met Office Hadley Centre and the University of the East Anglia (UEA); grey envelope, 95 per cent confidence range; red line, MLOST from the United States of America National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Centre (baseline period 1880–1899); blue line, GISSTemp from the National Aeronautics and Space Administration (NASA) Goddard Institute (baseline 1880–1899). (From EEA, 2012).**

Table 1 **Forecasts of global mean surface temperature and global mean sea level changes for the period 2081-2100 (means and likely ranges) with respect to the period 1986–2005, according to different scenarios (after IPCC, 2013). Predictions are made according to 4 radiative forcing scenarios (Representative Concentration Pathways-RCP)[2]: RCP 8.5, 6184 Gt CO_2 (2012-2100 cumulative CO_2 emissions); RCP 6.0 3890 Gt C02; RCP 4.5, 2863 Gt CO_2; and RCP 2.6, 991 Gt CO_2. Global mean surface temperature changes are based on the CMIP5 ensemble (5–95% model ranges). Sea level rise estimates are based on 21 CMIP5 models (5–95% model ranges). The contributions from ice sheet rapid dynamical change and anthropogenic land water storage are treated as having uniform probability distributions, and as largely independent of scenario, as the current knowledge state does not permit quantitative assessments of the dependence[3].**

Scenario	Temperature		Sea level rise	
	Mean (°C)	Likely Range (°C)	Mean (m)	Likely Range (m)
RCP 2.6	1.0	0.3 - 1.7	0.40	0.26-0.55
RCP 4.5	1.8	1.1- 2.6	0.47	0.32-0.63
RCP 6.0	2.2	1.4-3.1	0.48	0.33-0.63
RCP 8.5	3.7	2.6-4.8	0.63	0.45-0.82

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[2] The recent IPCC Assessment Report AR5 (2013) forecasts are made on the basis of the Representative Concentration Pathways-RCP scenarios and not the IPCC SRES scenarios. The CO_2 equivalent concentrations have been set to (e.g. Moss et al., 2010): RCP 8.5, 1370 CO_2-equivalent in 2100; RCP 6.0 850 CO_2-equivalent in 2100; RCP 4.5, 650 CO_2-equivalent in 2100; and RCP 2.6, peak at 490 CO_2-equivalent before 2100.

[3] According to the scenarios the sea level will not stop rising in 2100, but will continue rising during the following centuries; median sea level rises of 1.84 for the lowest and 5.49 m for the highest forcing scenario (RCP 8.5) have been projected for 2500 (Jevrejeva et al., 2012).

Climate does not change uniformly, with temperatures close to the poles rising faster than at the equator. Precipitation is changing in a much more complex manner, with some regions becoming wetter and others dryer (Fig. 2). Such trends are expected to pick up pace in the future, as e.g. in the E. Mediterranean where mean rainfall has been predicted to decrease by up to 25 per cent in the decade 2020-2029 compared to that of the decade 1990-1999 (IPCC, 2007a). Snow cover in the northern hemisphere also shows a decreasing trend, which between 1970-2010 has been estimated to be about 0.8 million km2/per decade (for the months March and April); these decreases amount to 7 and 11 per cent decreases in March and April, respectively, from the pre-1970 values (Brown and Robinson, 2011). However, these trends are not uniform with some regions, such as the Alps and Scandinavia, showing consistent decreases in the snow cover depth at low elevations but increases at high elevations, whereas in other mountainous regions (e.g. the Carpathians, Pyrenees, and Caucasus) there are no consistent trends (EEA, 2012).

Finally, concerning droughts, recent studies (e.g. SREX, 2012) project (with a medium confidence) decreases in their duration/intensity in the S. Europe and the Mediterranean, the central Europe and parts of the North America.

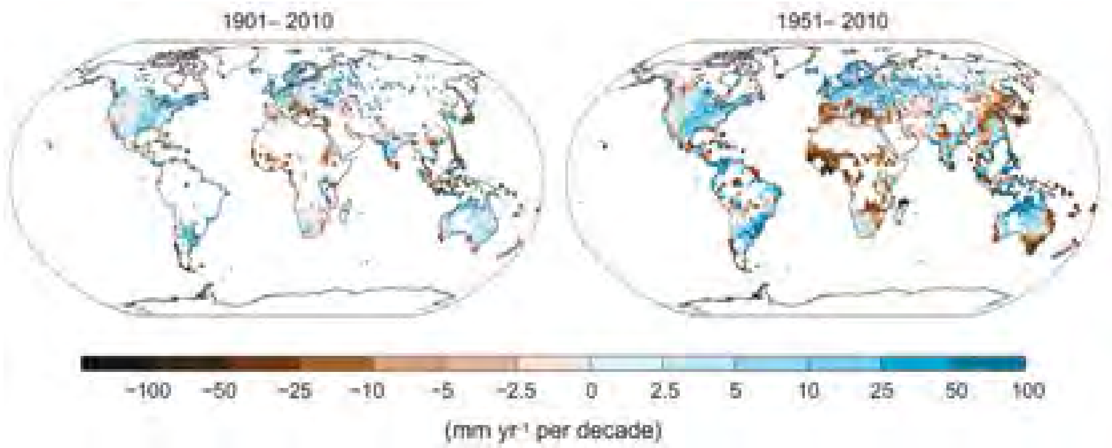

Figure 2 Changes in observed precipitation over land in the period 1951-2010 (IPCC, 2013).

Temperature increases are also associated with a substantial rise of the mean sea level. Global mean sea level rise is due to (a) ocean thermal expansion (OTE), i.e. ocean volume changes due to steric effects; (b) glacio-eustasy i.e. ocean mass increases from the melting of the Greenland and Antarctic ice sheets (GIS and AIS) and the glaciers and ice caps (GIC)[4]; (c) glacio-isostatic adjustment (GIA); and (d) changes in terrestrial water storage (e.g. Hanna et al., 2013). Since 1860, sea level has increased by about 0.20 m, with the rate of increase becoming progressively greater, particularly since the 1990s; satellite information (Church and White, 2011) shows that sea levels rise at a rate close to the upper range of previous IPCC projections (about 3.1 mm yr^{-1}, see also Fig. 3).

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[4] Continental ice loss of 360 Gt of ice (360 x 109 tons or 360 km^3 water) translates to a mean sea level rise of about 1 mm; current ice loss is about 500 Gt yr-1 (Cronin, 2012).

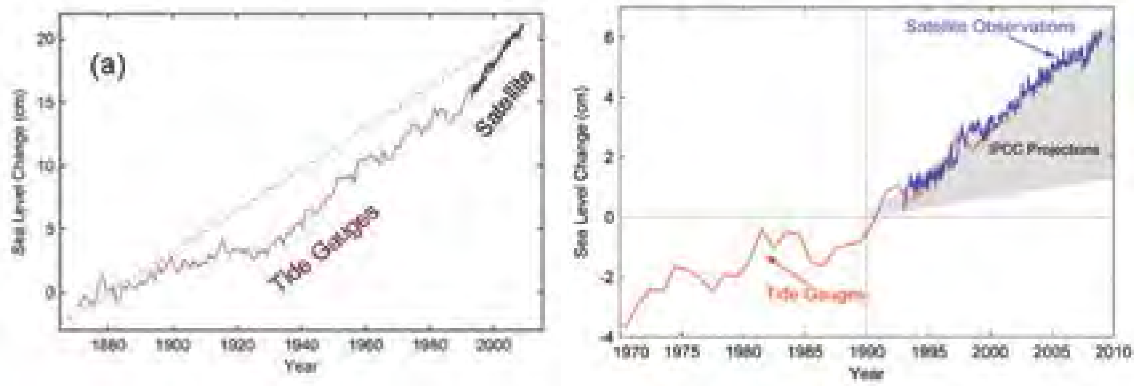

Figure 3 **(a) Global sea level changes 1860-2010 (Rahmstorf, 2011), showing accelerating rates of increase. (b) Change in sea level in 1970-2008 relative to the 1990 level. Red solid line from tide gauge observations, smoothed to remove interannual variability and blue line from satellite observations. The envelope of early IPCC projections is also shown (Richardson et al., 2009).**

It is thought that the steepening of the curve of the sea level rise during the last decades is mostly due to the increasing contribution of ice loss from the Greenland and Antarctica ice sheets, which appears to be accelerating (e.g. Velicogna, 2009; Rignot et al., 2011; but see Hanna et al., 2013). However, our understanding of the ice sheet processes appears to still be inadequate to describe accurately the ice sheet behavior. Therefore, sea level rise projections to the end of 21st century are still uncertain on the basis of process models (Richardson et al., 2009). Alternative approaches could be, for example, to use the observed relationship between the global average temperature rise and the sea-level rise over the past 120 years, assuming that this relationship will hold well into the future (Rahmstorf, 2007; Rahmstorf et al., 2007). Recent sea level rise estimates based on alternative approaches project a mean sea level rise much larger (3-5 times) than that predicted by the IPCC in 2007 (see e.g. Fig. 4)[5]. Sea-level rise will not cease in 2100 (see Jevrejeva et al., 2012), as the changes in ocean heat content could affect thermal expansion for several centuries at least, whereas melting and dynamic ice loss in Antarctica and Greenland will also continue well into the future.

The mean sea level trends and variations in regional climate have led to worldwide changes in the trends of extreme high water levels in the late 20th century (IPCC, 2007a). However, there is considerable spatial variability in the sea level rise trends, particularly along the coast. Menendez and Woodworth (2010), using data from 258 tide gauges across the globe, have confirmed earlier studies that there has been an increasing trend in the extreme sea levels since the 1970's that is consistent with the trends in the mean sea level (e.g. Woodworth and Blackman, 2004; Lowe and Gregory, 2006; Marcos et al., 2009; and Haigh et al., 2010). Other recent studies have shown that there is high regional variability. In Europe, for example, sea levels have increased along most of the coast in the last 40 odd years, with the exception of the N. Baltic coast (Fig. 5).

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[5] Recently, the IPCC has updated its projections for the 2100 sea level rise to 0.26-0.82 m (Table 1 and Fig 4).

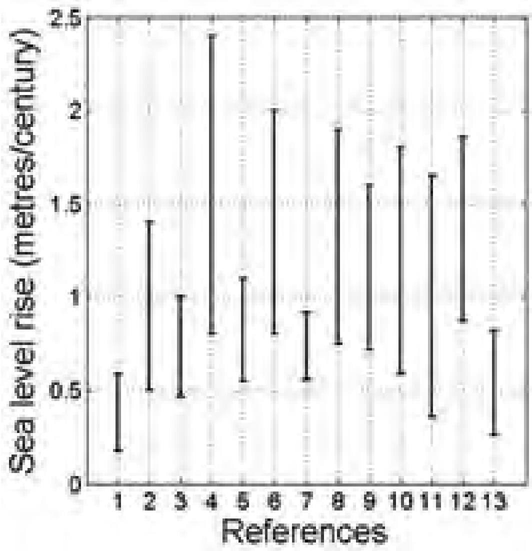

Figure 4 **Recent sea level rise projections for 2100 compared to that of IPCC (2007a). Key: 1, IPCC (2007a), 0.18-0.59 m; 2, Rahmstorf et al. (2007); 3, Horton et al. (2008); 4, Rohling et al. (2008); 5, Vellinga et al. (2008); 6, Pfeffer et al. (2008); 7, Kopp et al. (2009); 8, Vermeer and Rahmstorf (2009); 9, Grinsted et al. (2010); 10, Jevrejeva et al. (2010); 11, Jevrejeva et al. (2012); 12, Mori et al. (2013); and 13, IPCC (2013). The variability of the projections reflects differences in assumptions and approaches.**

It should be noted that due to the large spatial variability observed in the sea level rise, regional trends in sea level should be considered when assessing potential impacts along any particular coast. In addition to the global processes (see above), regional factors may also contribute to observed coastal sea level changes, such as changes in ocean circulation (e.g. Meridional Overturning Circulation (MOC)) and differential rates in regional glacial melting, glacio-isostatic adjustment (GIA) and sediment deposit subsidence. Palaoclimate, instrumental and modeling studies have shown that combinations of global and regional factors can cause relatively rapid rates of sea level rise along particular coasts that can exceed the current global rate of about 3 mm yr^{-1}significantly (e.g. Cronin, 2012).

For the United Kingdom of Great Britain and Northern Ireland, sea level rise (excluding land level changes) for the 21st century has been projected to be 0.12 - 0.76 m depending on the emission scenario, with larger rises predicted in the case of additional ice sheet melting (Lowe et al., 2009). For the North Sea coast of the Netherlands, Katsman et al. (2011) have estimated sea level rises of 0.40 - 1.05 m for a plausible high end emission scenario. However, Marcos and Tsimplis (2008) have predicted a temperature-driven sea level rise of 0.03 - 0.61 m in the Mediterranean for the 21st century on the basis of 12 global climate models and for three emission scenarios; this rise should be combined with salinity-driven changes of - 0.22 - 0.31 m (see also EEA, 2012).

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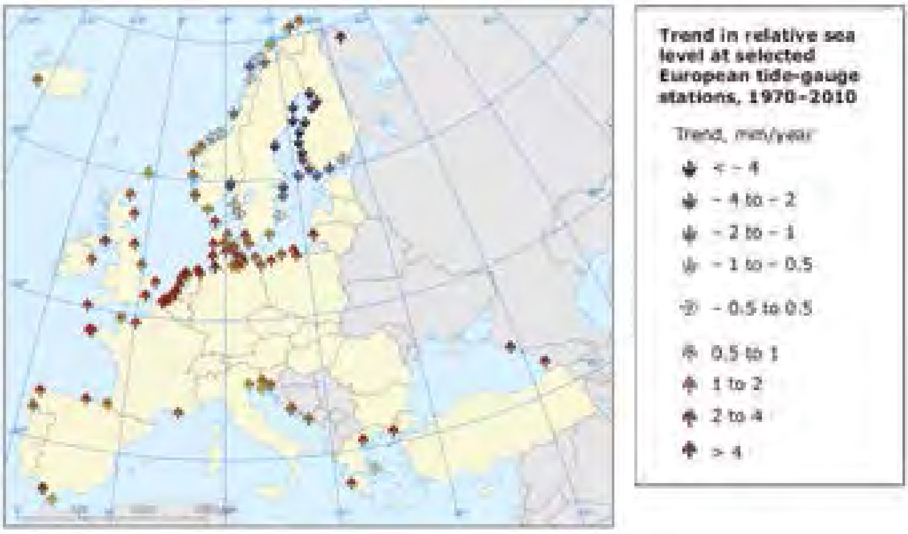

Figure 5 Trends (1970-2010) in relative sea level at selected European tide gauge stations (not corrected for local land movement) (from EEA (2012), see also [HTTP://WWW.PSMSL.ORG/PRODUCTS/TRENDS](http://www.psmsl.org/products/trends)).

1.1.2 Extreme events

Changes in the mean climate can also lead to changes in the frequency, intensity, spatial coverage, duration, and timing of weather and climate extremes, potentially resulting in unprecedented extremes. These extremes can, in turn, modify the distributions of the future climatic conditions; thus, future mean conditions for some climatic variables are projected to lie within the 'tails' of the present-day conditions (SREX, 2012).

Extreme events - such as storms, floods, droughts and heat waves - as well as changes in the patterns of particular climatic systems - such as the monsoons - (Richardson et al., 2009) can be, at smaller spatio-temporal scales, the most impacting climatic phenomena (IPCC, 2007a) as they may induce more severe effects/natural disasters (Fig. 6) than changes in the mean variables. Moreover, societies are rarely prepared to face efficiently extreme weather events, having become dependent on predictable, long-term climatic patterns.

Extreme events have consequences that are difficult to predict. Their variability covers a large spectrum, such as sudden and transient temperature changes, rapid retreats of sea and lake ice, bouts of abnormally high precipitation, intensive storms, storm surges, extended droughts, heat waves and wildfires and sudden water release from melting glaciers and permafrost[6] slumping that may have substantial impacts (e.g. Post et al., 2009). There is some evidence to suggest that extreme events, such as tropical and temperate storms, may respond to a warming climate by becoming even more extreme (Webster et al., 2005; Emanuel, 2005; Allan and Soden, 2008; Ruggiero et al., 2010). For example, even a modest increase (of 5 m/s) in the surface wind speed of the tropical cyclones driven by a 1 °C rise in the ocean temperature may result in a substantial increase of the incidence of the most intense and destructive (Category 5) cyclones (e.g. Steffen, 2009). The implications of these extreme events for e.g. the coastal communities and infrastructure could be severe,

[6] Permafrost is permanently frozen ground, consisting sediment/soil that has remained at or below 0 °C continuously for > 2 years. It is a widespread phenomenon in the Arctic and in the high alpine environments (Dobinski, 2011; Boeckli, et al., 2012).

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as they may increase the likelihood of extreme sea levels-storm surges[7] and wave run ups (e.g. Stockdon et al., 2012) and consequent coastal floods, especially if combined with the projected increases in the mean sea level (McKee Smith et al, 2010).

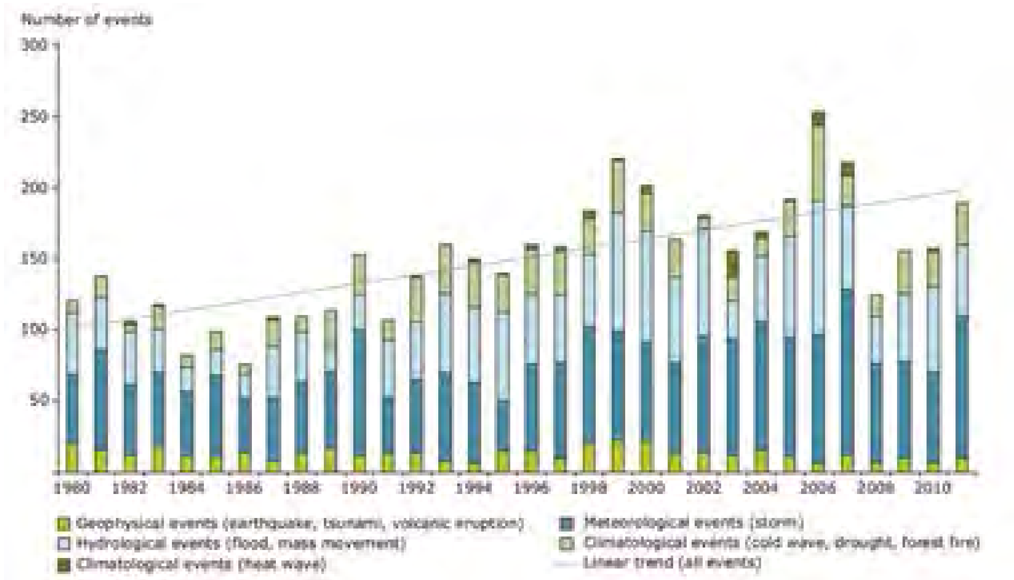

Figure 6 **Natural disasters in the EEA member States (1980-2011). An increasing trend might be discerned that appears to be controlled by extreme storms, floods, mass movements/ landslides, heat waves, droughts and forest fires, as the number of natural disasters induced by geophysical events has remained more or less stable during this period. These events have resulted in €455bn losses, of which €126bn were insured losses (EEA, 2012).**

In addition, increases in the intensity and frequency, and/or changes in the patterns, of extreme waves (e.g. Callaghan et al., 2008; Ruggiero, 2013; Bertin et al., 2013) will also induce, at least temporarily, coastal erosion orinundation, particularly when combined with increasing mean sea levels (e.g. Tsimplis and Shaw, 2010; Xu and Huang, 2013; Losada et al., 2013). In Europe, 200 million people live in the coastal zone and insurable losses due to coastal floods are likely to rise during the century, at least for the North Sea coast (Gaslikova et al., 2011).

Storm surges pose a particular threat to highly developed coastal areas, particularly the low lying deltas such as the Rhine, Danube and the Mississippi river deltas which are considered hotspots of coastal erosion/vulnerability (IPCC, 2007b) due to their commonly high relative mean sea level rises. A study involving 40 major deltas, representing all major climatic zones, has found relative mean sea level rises ranging between 0.5 to 12.5 mm/ yr (Erickson et al., 2006). In these areas, diminishing fluvial sediment supply can also be an important factor forcing coastal erosion (Velegrakis et al., 2008; Ranasinghe et al., 2013). Studies of trends in extreme coastal sea level/storm surges from tide gauge records (e.g. Woodworth and Blackman, 2004; Menendez and Woodworth, 2010; Haigh et al., 2010; and Marcos et al., 2011) have shown that changes in extreme water levels tend to be dominated by the mean sea level rise. Coastal areas currently experiencing erosion and/or inundation are projected with high confidence that will continue to do so in the future, due to increasing sea levels, all other contributing factors being equal (SREX, 2012).

[7] Storm surges are temporary deviations in sea water levels from that of the astronomical tides, caused by changes in atmospheric pressure and winds; storm surges are controlled by the regional/local topography, add to the tidal levels and increase the risk of coastal flooding by extreme water levels (Horsburgh and Wilson, 2007).

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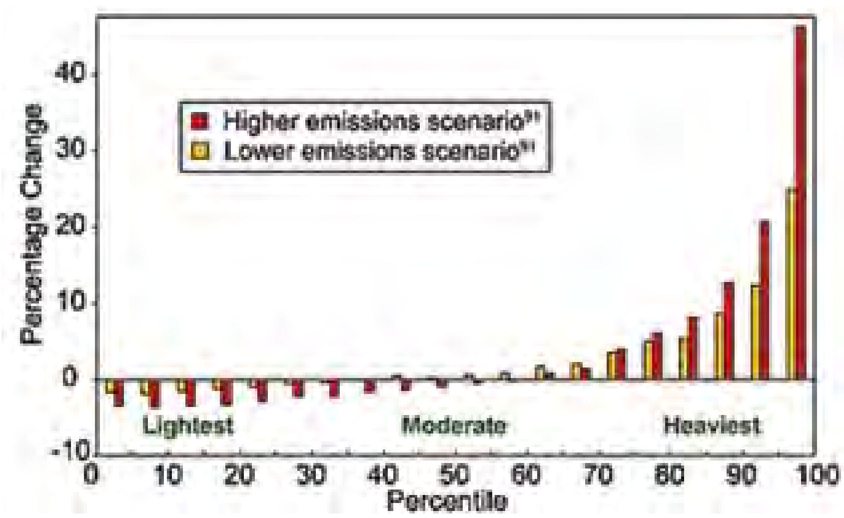

Figure 7 Projected changes in the 2090s average (compared to 1990s average) in North America precipitation, for light, moderate and heavy events see also IPCC, 2007a). Light precipitation is projected to decrease, whereas heavy precipitation to increase. Note that the higher emission scenario yields greater changes (Karl et al., 2009).

One of the clearest trends appears to be the increasing frequency andintensity of heavy downpours. This increase has been responsible for most of the observed increases in overall precipitation during the last 50 years. Climate models project this trend to continue during this century. For example, Karl et al. (2009) have projected that the heavy downpours that occur about once every 20 years are going to occur, depending on location, every 4-15 years by 2100, whereas there will also be decreases in the lightest precipitation events (Fig. 7). It is likely that the frequency of such events will increase over many regions in the 21st century, especially in the high and tropical latitudes and the northern mid-latitudes in winter. Heavy precipitation events are also predicted with medium confidence to increase even in regions with projected decreases in the total precipitation (SREX, 2012).

Riverine floods are phenomena of extreme water discharge that involve both physical and socio- economic factors. The former are strongly connected to the hydrological cycle, which is currently influenced by changes in temperature, precipitation as well as the melting of glacier and snow cover (IPCC, 2007a). The latter are controlled by land use changes, river management schemes, and construction in the flood plains that reduces their capacity to absorb flood waters. Human development has changed the natural water flows considerably, making it difficult to ascertain climate change-induced trends in hydrological variables (EEA, 2010). In the ECE region, floods are an ever present threat (see Fig. 8).

The current trends in the Eurasian countries show a significant flood hazard (for the 1 in a 100-year events), particularly for central and eastern Europe, the central Asia and along the large S-N drainage basins of Siberia (Fig. 9). However, changes in extreme hydrological events and their impacts are better studied at a regional/local scale, with most existing studies focusing on the generation and impacts of floods due to e.g. increases in torrential precipitation. In Europe, annual water discharges have generally been observed to increase in the north and decrease in the south (EEA, 2010; 2012), a trend that is projected to hold in the future, as is associated with projected changes in precipitation regimes that control the intensity and frequency of rain-fed floods and possibly of flash floods (Feyen et al., 2006, 2010).

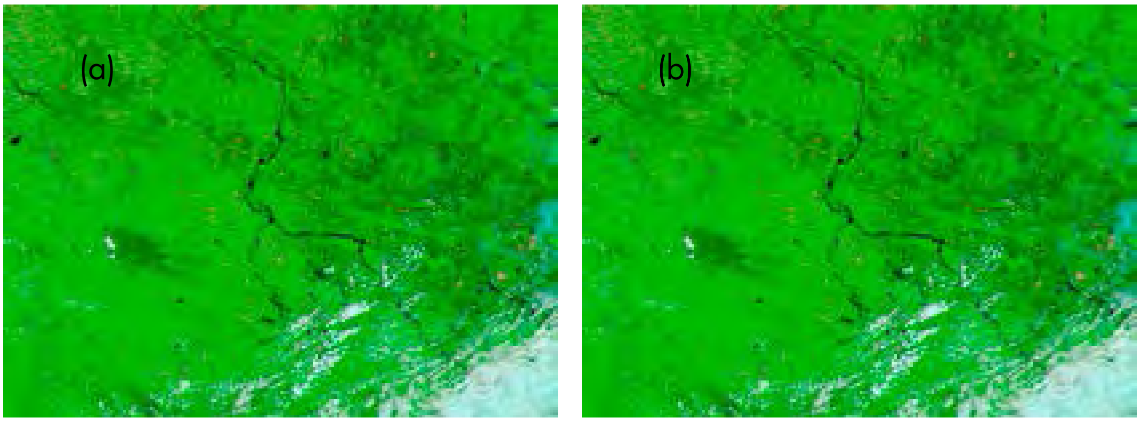

Figure 8 **Satellite images (MODIS on NASA's Terra satellite) of the German region flooded in early June 2013. (a) image acquired in 05/05/2013 (before the flood) and (b) image acquired on 06/06/2013 (during the flood). In late May/early June 2013, uncommon heavy rains brought serious flooding to Germany, Austria, and the Czech Republic. The Elbe River reached 8.76 meters that day in the area, with the norm being 2 m. River water appears as navy blue to black and vegetation as bright green. Clouds are pale blue-green and cast shadows. (http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=81287)**

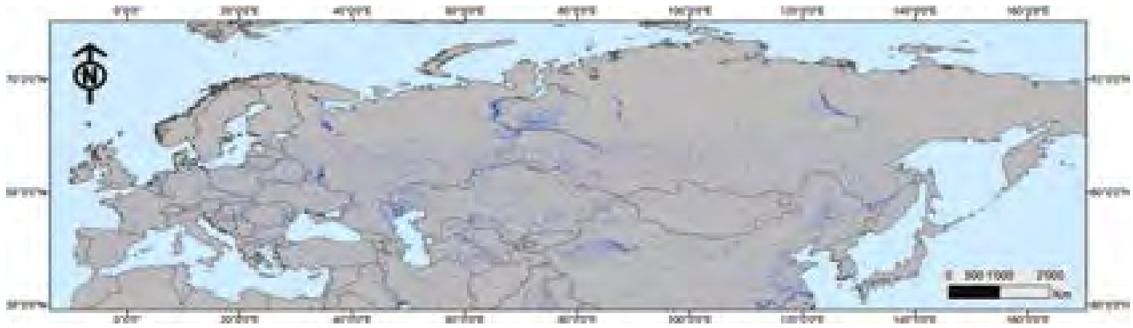

Figure 9 **Current flood hazard (95 per cent probability) in the Eurasian region of the UNECE for the 1 in a 100-years flood from a global GIS model based on river discharge time-series. Resolution of Digital Elevation Model (DEM), 90 m. Areas over 60º N are not fully covered, due to DEM limitations. (From UNEP-GRID and UNISDR, 2008).**

Slope failures/landslides (Kawagoe and Kazama, 2009) are also expected to increase at mountainous areas (Beniston, 2003), as are also linked to heavy downpours the frequency and intensity of which is projected to increase (Fig. 7). Consequently, flood damages in e.g. Europe (Fig. 10) are expected to rise considerably by the end of the century, being generally higher in the north than in the south.

There is also evidence to suggest increases in the frequency and intensity of heat waves, i.e. of extended periods ranging from several days to weeks, of abnormally hot weather. The European 2003 heat wave (e.g. Stott et al., 2004), which has been shown to resemble simulations by regional climate models of summer temperatures in the latter part of the 21st century under the A2 IPCC scenario (Beniston and Diaz, 2004), produced record-breaking temperatures, with absolute maximum temperatures exceeding the previous record temperatures observed in the 1940s-early 1950s in many European locations and average summer temperatures being up to 5 standard deviations above the long-term summer temperature mean. This 2003 record was, nevertheless, broken in 2010 (Fig. 11). Generally, there has been a three-fold increase since 1920s in the ratio of the observed monthly heat extremes to that expected in a non-changing climate (Coumou and Rahmstorf, 2012).

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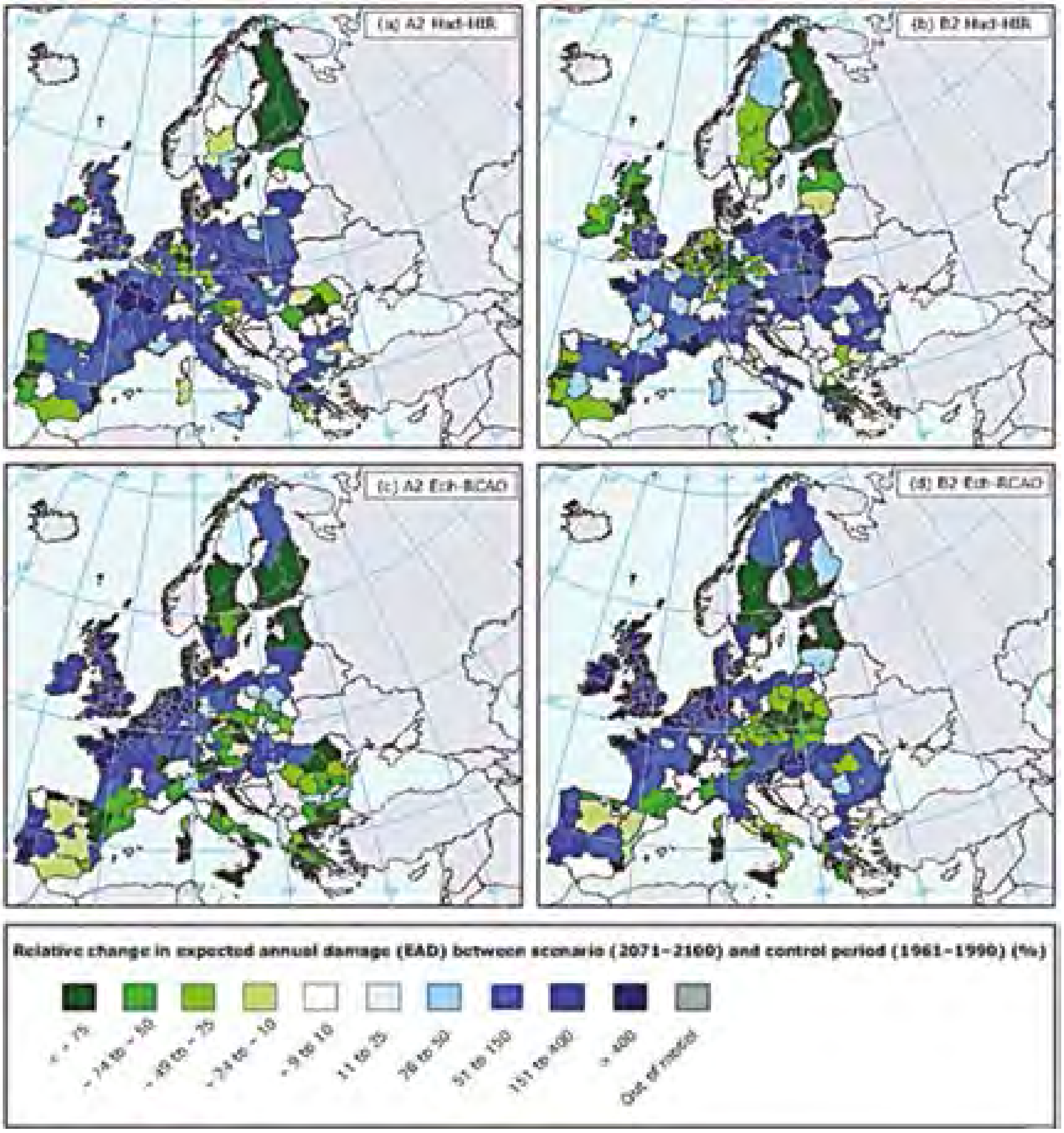

Figure 10 Relative change in Expected Annual Damage (EAD) in Europe from river floods, between scenario (2071–2100) and control (1961–1990) periods (http://ies.jrc.ec.europa.eu/).

Since 1950s, it is very likely that there has been an overall decrease in the number of unusually cold days and nights and an overall increase in the number of unusually warm days and nights at the global scale (for land areas with sufficient data). For example, most of North America appears to have experienced more unusually hot days and nights, fewer unusually cold days and nights and fewer frost days.

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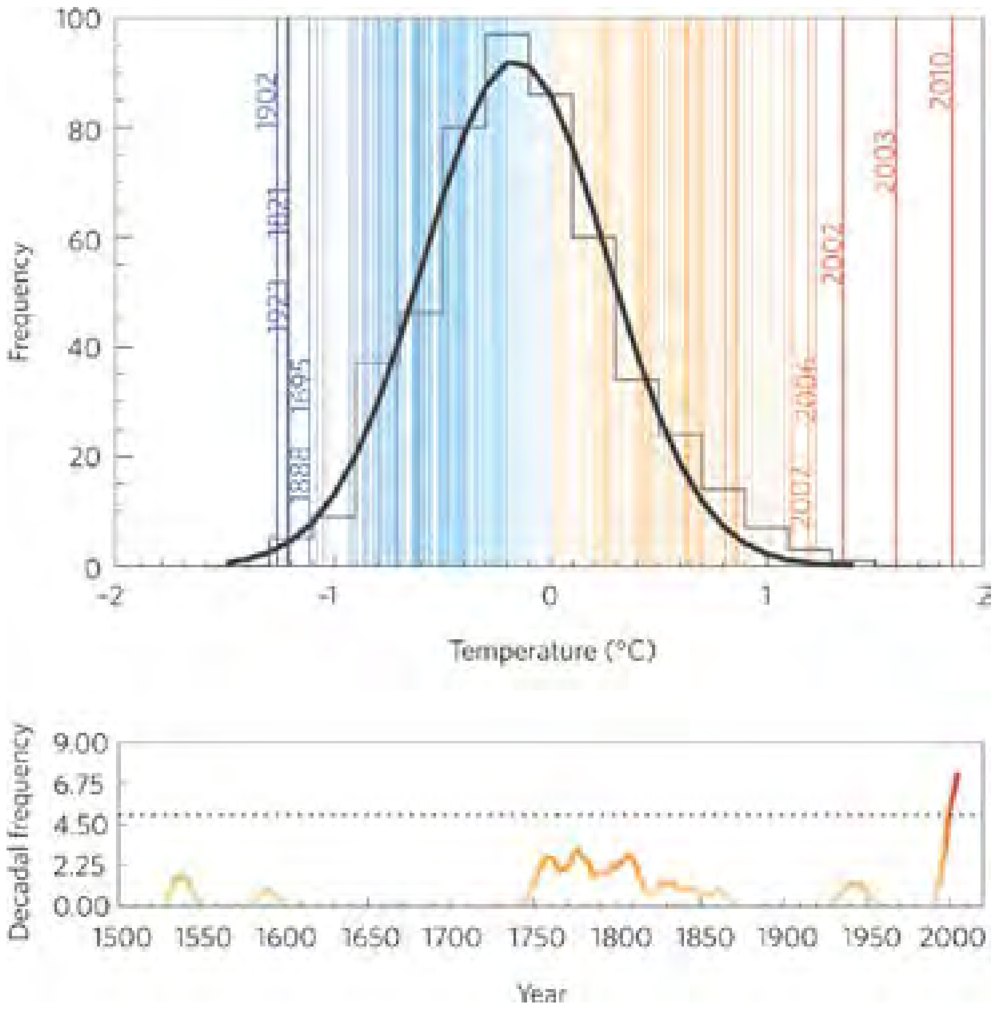

Figure 11 Frequency distribution of the European summer land temperature anomalies relative to 1970-1999. (Coumou and Rahmstorf, 2012)

There has also been an increasing trend in heat waves, characterized by the persistence of extremely high night temperatures (Kunkel et al., 2008) this trend is projected to accelerate in the 21st century (Fig. 12). At a global scale, with mean temperatures continuing to rise, models project that increases in the frequency/magnitude of hot days and nights and decreases in the cold days and nights are virtually certain (SREX, 2012; IPCC, 2013).

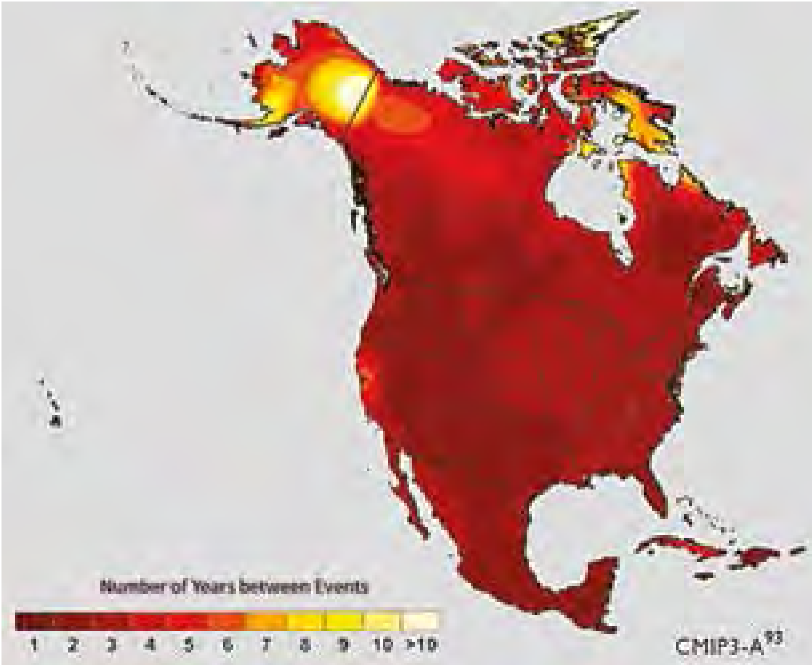

Figure 12 Projected frequency of extreme heat waves (2080-2099 average). Simulations for 2080-2099 show that rare extremes (1-in-20-year events) will become more frequent in North America. A heat wave with a 20 year- return-period might occur every other year or even every year by the end of the century in many parts of North America, under the higher emissions scenario (Karl et al., 2009).

Heat waves are often associated with severe droughts (as e.g. in 2003). Generally, droughts are becoming more severe in some regions (SREX, 2012), a trend that is projected to hold (and possibly increase) in the 21st century (Fig. 13).

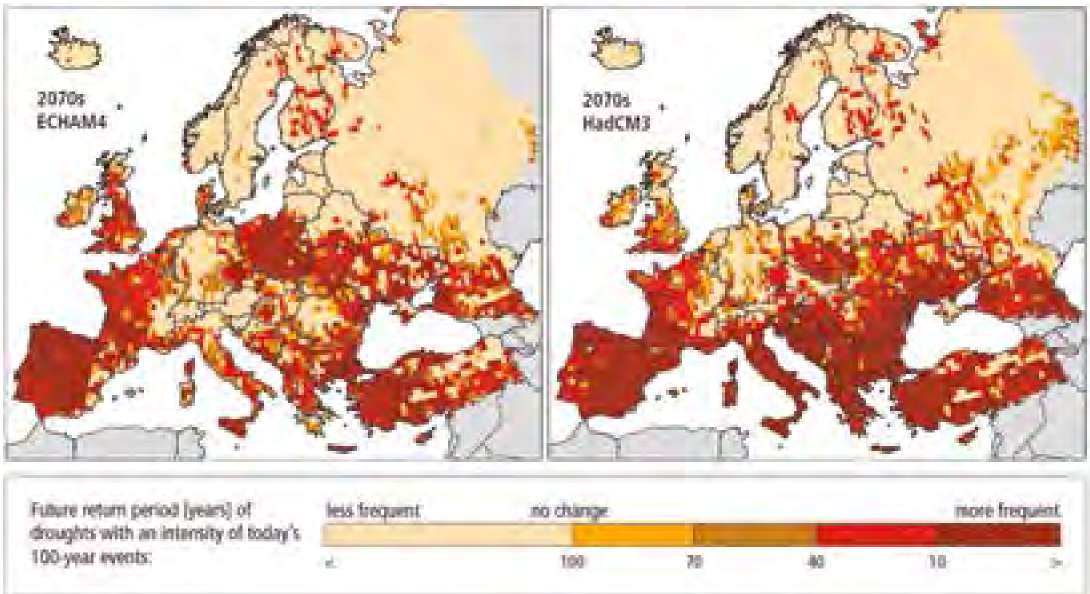

Figure 13 Projected changes by the 2070s in the return period of the (1961–1990) 100-year drought for two climate models, ECHAM4 and HadCM3 (SREX, 2012).

1.2 Mechanism

One of the major causes of the observed increase of the heat content of the planet's surface is considered to be the increasing concentrations of greenhouse gases (GHGs) in the atmosphere (Fig. 14). These gases enhance the "greenhouse effect", which is a well-documented and understood physical process of the Earth System, known since the 19th century (e.g. Canadell et al., 2007). GHGs in the atmosphere, such as water vapor, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) absorb heat reflected back from the Earth's surface and, thus, store more heat in the ocean, land and atmosphere. Without the greenhouse effect, average temperatures on Earth would be about -19ºC (i.e. about 34ºC colder than it is at present). All planets with heat absorbing gases in their atmosphere, experience a greenhouse effect. For example, the extreme surface temperature (about 440ºC) of Venus can be explained by the high concentration of GHGs in its atmosphere.

Changes in the atmospheric GHG concentration affect the magnitude of the greenhouse effect. Water vapor is an abundant GHG and makes the greatest contribution to the 'natural' greenhouse effect. Human activities have not yet shown to have had a significant direct effect on net global flows of water vapor to/from the atmosphere (e.g. Richardson et al., 2009), although locally they may have influenced such flows through e.g. deforestation and large irrigation schemes.

Nevertheless, as the ability of the atmosphere to retain water vapor is strongly dependent on temperature, atmospheric water vapor is regulated by the Earth's temperature itself, increasing with global warming. Thus, water vapor not only follows, but also exacerbates changes in global temperature that are induced by other causes, such as the increasing concentrations of the other GHGs (e.g. Richardson et al., 2009). It appears that the atmospheric concentrations of CO_2, CH_4 and the other GHGs have increased very substantially over recent decades (Fig. 14), probably as a result of human activities. Ice core and sediment records show that the atmospheric concentration of GHGs is now higher than it has been for some million years (e.g. Solomon et al., 2009; Caldeira, 2009). At the same time, there is mounting evidence for a link between GHGs concentration and climate. For example, the covariation of CO_2 concentration and temperature in Antarctic ice-core records suggests a close link between CO_2 and climate during the Pleistocene ice ages. However, the exact role and relative importance of CO_2 concentrations in producing such climatic changes at global level remains unclear (e.g. Shakun et al., 2012).

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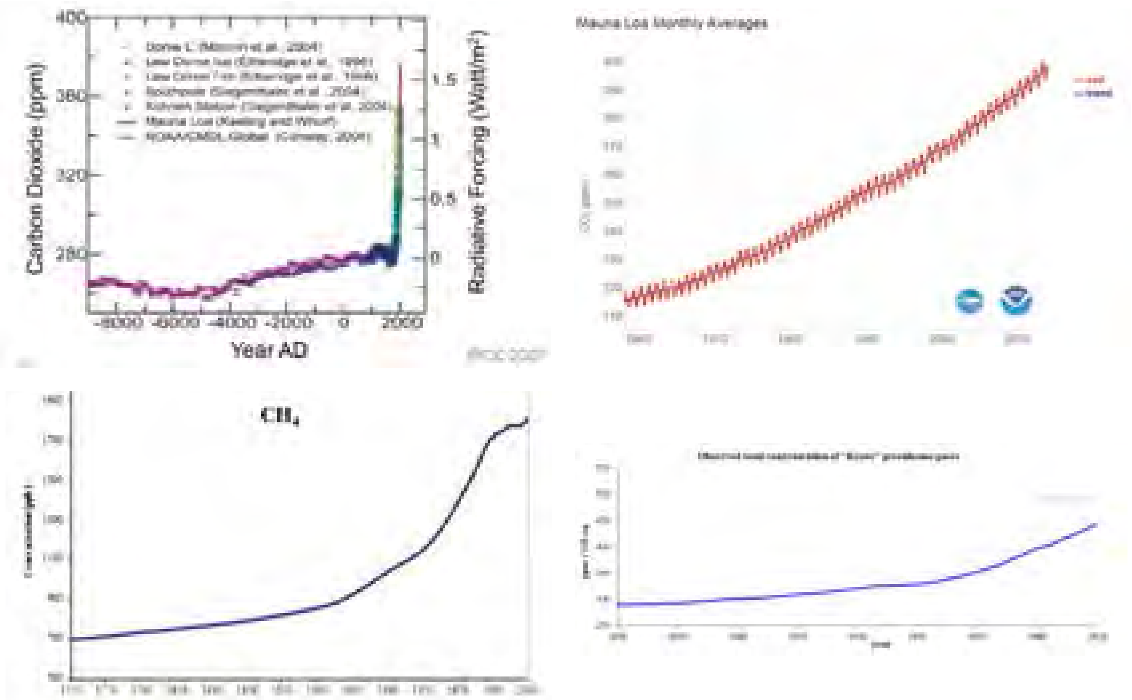

Figure 14 **CO_2 concentration (in parts per million-ppm) in the atmosphere during the last 11000 years (Rahmstorf, 2011) and during the last 50 years (Mauna Loa data, P. Tans (www.esrl.noaa.gov/gmd/ccgg/trends/) and R. Keeling (scrippsco$_2$.ucsd.edu/), 2013). Preliminary analysis of the most recent data suggests that CO_2 concentrations have increased further, passing the 400 ppm milestone for the first time in the last 800000 years in 9th May 2013 (http://www.esrl.noaa.gov/gmd/ccgg/trends). Also shown are the concentrations of the CH_4 (in ppb- parts per billion) (http://www.eea.europa.eu/data-and-maps/figures/atmospheric-concentration-of-ch4-ppb-1) and the total concentration of the 6 GHGs included in the Kyoto Protocol (in ppm CO_2 Equivalent), which has increased by about 60 per cent compared to pre-industrial levels (http://www.eea.europa.eu/data-and-maps/figures/observed-trends-in-the-kyoto-gases-1).**

1.3 Feedbacks and tipping points

The global warming from increased GHG concentrations can be amplified by reinforcing feedbacks, i.e. climate change-driven processes that can induce further warming. In addition to the water vapor feedback described above, another important feedback is associated with the various "carbon sinks", i.e. with processes that can remove CO_2 from the atmosphere. Over half of the CO_2 emitted to the atmosphere through human activities is removed through land and ocean sinks. Without these sinks that remove and store CO_2 from the atmosphere, the total human emissions since 1800 would have caused the concentration of atmospheric CO_2 to increase from its pre-industrial level of 280 ppm to close to 500 ppm, which is much higher than its present level (Richardson et al., 2009).

However, the fraction of human CO_2 emissions removed by these sinks appears to have decreased over the last 50 years due to several effects (e.g. ocean acidification, ocean circulation changes and water, temperature and nutrient constraints on land CO_2 uptake), with some evidence suggesting that there will be further decreases over the coming decades (e.g. Canadell et al., 2007). If this weakening of the CO_2 sinks continues, a greater fraction of emissions will remain in the atmosphere, requiring greater emission reductions to achieve specific targets for the CO_2 atmospheric concentration. In addition, previously inert carbon reservoirs can be mobilized by increasing temperatures and release CO_2 and/

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or CH_4 (a much more potent GHG) to the atmosphere. Reservoirs of concern include the tropical peat lands that are vulnerable to land clearing/drainage and the vast CH_4 stores of the Arctic permafrost (e.g. Dobinkski, 2011) that are vulnerable to global warming (e.g. Zimov et al., 2006).

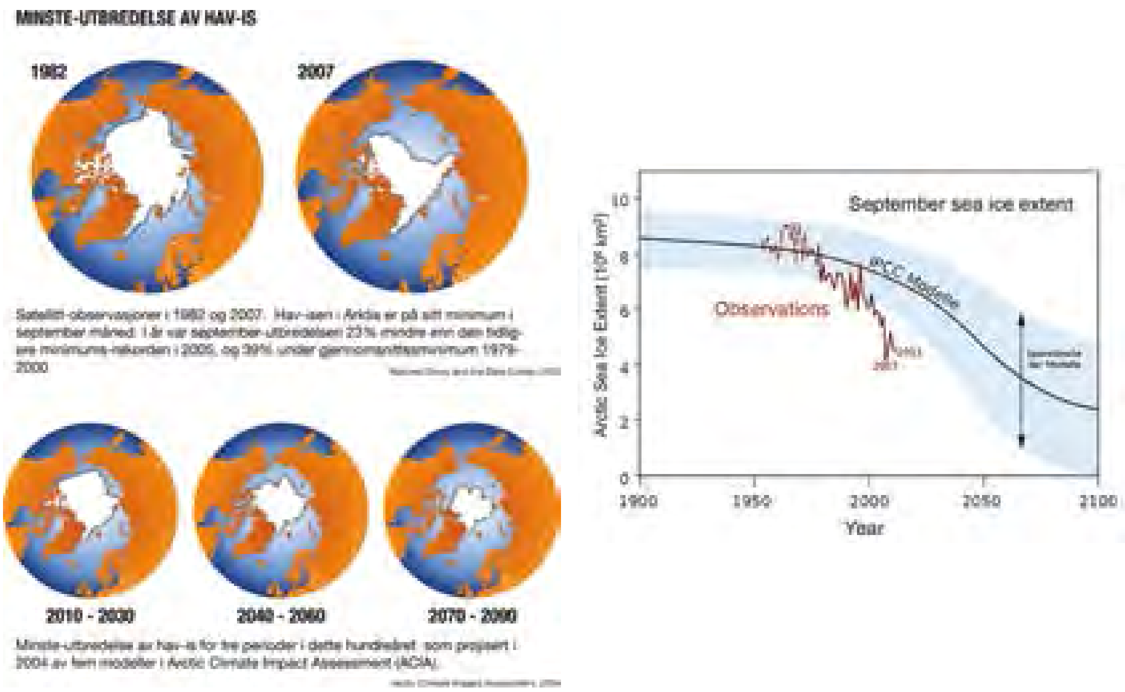

Figure 15 (a) The decrease of Arctic sea ice: minimum extent in September 1982 and September 2007 and projections for the future late summers (2010-2030, 2040-2060 and 2070-2090) (http://maps.grida.no/go/graphic/the-decrease-of-arctic-sea-ice-minimum-extent-in-1982-and-2007-and-climate-projections-norwegian). (b) Model results/observations of sea ice loss (Rahmstorf, 2011).

A significant development is the rapid reduction in the extent of Arctic sea ice, particularly during summer (e.g. Richardson et al., 2009). The ice extent has decreased at a rate of 3-4 per cent per decade over the last 3 decades, with the September ice extent having decreased at an even faster rate (> 11 per cent per decade). It appears that the loss of the Arctic ice in recent years is much greater than that predicted by most climate models (Fig. 15), due possibly to the inability of the current climate models to represent accurately the Arctic Ice thickness (e.g. Wang et al., 2012). Arctic summer sea ice is projected to continue to shrink, and even disappear, at the end of the summer melt season, although there could still be substantial ice coverage in winter (EEA, 2012).

Table 2 Tipping elements, concerns, thresholds and implications for the next 50 years (see also Lawrence and Slater, 2005; Zimov et al., 2006; Vecchi et al., 2006; Challinor et al., 2006; Scholze et al., 2006; Rahmstorf, 2007; Barnett et al., 2008; Kurz et al., 2008; Lenton, 2013; Lenton et al., 2008, 2009; and Shanahan et al., 2009).

Tipping element(s)	Key concerns	Thresholds -impacts- (next 50 years)
Melting of Arctic sea- ice	Amplified regional/global warming, ice albedo feedbacks; opening of new (shorter) shipping routes	0.5 – 2°C above the 1980–1999 mean-Yes-
Partial melting of Greenland, W. Antarctica ice sheets	Global sea level rise of about 0.5 m by 2050 is possible	1 – 5°C above 1980–1999 mean-Yes-
Melting of continental glaciers (e.g. Alpine glaciers)	Initial increased flooding/inundation, followed by river flow reduction (up to 30 per cent over the next 50 years for India) with impacts on (amongst others) inland waterway navigation	1–3 °C above the 1980–1999 mean-Yes-
Permafrost and its carbon stores	Amplified global warming; however, 'runaway' feedback effects might be exaggerated	9 °C for E. Siberia above the 1980–1999 mean-Some-
Boreal forest	Increased forest fires, destruction of associated transport networks, problems with flights	3–5 °C above the 1980–1999 mean-Some-
Atlantic thermohaline circulation (THC)	Weakening leading to regional dynamic sea level changes (especially in the N. Atlantic) and effects on hydrological elements	3–5 °C above the 1980–1999 mean-possible-
b. El Nino southern oscillation -ENSO	Impacts on other climate variables/tipping elements– stronger El Niño events will affect many regions	3–6 °C above the 1980–1999 mean-possible-
West African Monsoon (WAM)	Potential greening of the Sahel and parts of the Sahara. In the best-case scenario, the tipping of the WAM might provide a net benefit	3–5 °C above the 1980–1999 mean-Possible net benefits-
Indian Summer Monsoon (ISM)	Interference with monsoon cycle/drought frequency, possible monsoon weakening; warming could trigger stronger monsoons with higher interannual variability	Related mostly to aerosol forcing-Yes-
Amazon rainforest	Droughts, wildfires, effects on hydroelectric power generation, agricultural production and related service industries and river navigation, effects on a major carbon sink	More frequent droughts at 1°C, die-backs at 2 °C above the 1980–1999 mean-Yes-
SW North America (SWNA)	Droughts, more wildfires, impacts on water resources	Underway-Yes-

In addition to direct impacts on coastal arctic areas, such as increasing coastal erosion (see e.g. Lantuit and Pollard, 2008), the decreasing sea ice coverage can affect climate on a much larger scale, as sea ice reflects most of the impinging radiation from the sun back into the atmosphere in contrast to the sea water (e.g. ACIA, 2005). Therefore, a climate warming induced ice-free ocean, which absorbs more heat than an ice-covered ocean, creates a climatic "feedback" that increases warming. Sea ice reduction can also affect ocean currents, cloudiness, humidity and heat exchanges at the sea surface (IPCC, 2007a).

Another important consideration is associated with the levels of climate change at which 'tipping points' might be crossed i.e. changes that are no longer linear and reversible, but abrupt and large (and potentially irreversible in human temporal scales), with large impacts to communities/infrastructure (Lenton et al., 2008; Lenton, 2013). At present, the focus of climate change mitigation policy (UNFCCC) has been mostly on "preventing dangerous anthropogenic interference with Earth's climate system". Although there has been no scientific consensus for delineating dangerous from acceptable climate change, limiting global average temperature rise to 2°C above pre-industrial levels may be considered as a starting point/focus for policymakers (see also the 2007 Bali Conference and the July 2009 G8 summit) (Lenton et al., 2009). However, if these goals are not achieved, significant tipping elements or impacts could be triggered if the temperature increase crosses certain thresholds (Table 2).

Gara de Nord, Bucuresti, Heavy Snow and Blizzard in january 2008 © Club Feroviar

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Chapter 2. Climate Change Implications for Transport

2.1 Introduction

Different climatic change effects/extreme events may have a range of diverse impacts on transport infrastructure and services. These will vary significantly by mode, climate change factor, and depend on the local or regional circumstances and vulnerabilities, including those associated with the natural environment, as well as a broad range of socio-economic factors which are not addressed specifically in this report.

The transport sector is instrumental to many economic and social functions. At the same time, transport infrastructure and services depend on weather conditions and, thus, it is important to improve our understanding on how these would be affected by the present and future climate and its dynamics. Although it is claimed that the transport sector is particularly vulnerable to climate change (e.g. Eddowes et al., 2003; IPCC, 2007b; Karl et al., 2009; USDOT, 2012a), there is comparatively little detailed research into specific implications/impacts, adaptation strategies and costs and benefits, compared with other sectors such as energy and agriculture (EEA, 2010).

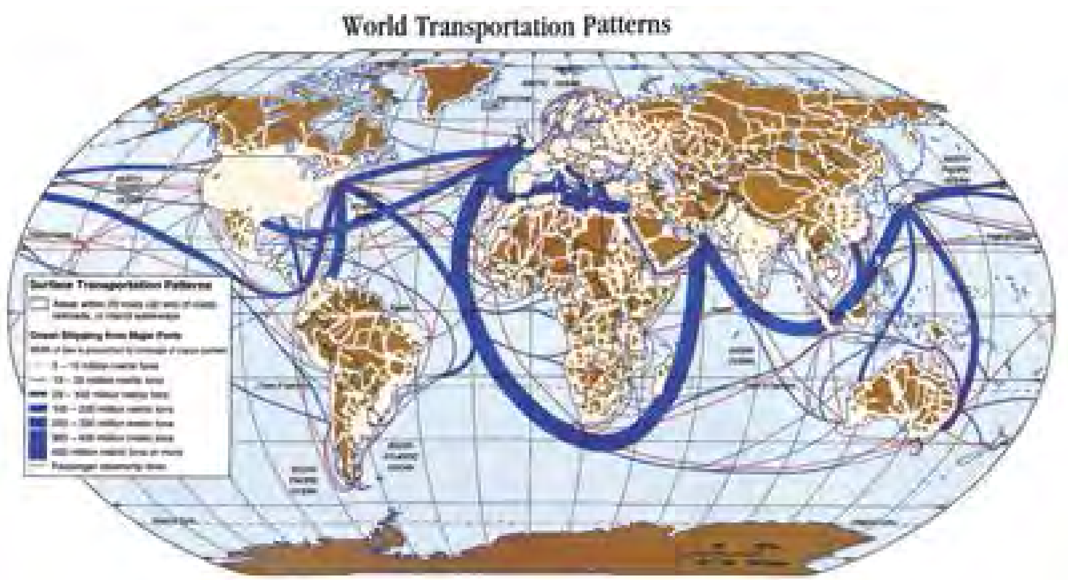

Figure 16 Global transportation patterns. https://qed.princeton.edu/index.php/User:Student/World_Transportation_Patterns

Transportation has become a most important global industry (Fig. 16) that requires operational and efficient transport networks. At the same time, climate change is likely to have significant implications for these networks. Thus, well-targeted adaptation measures are required (e.g. Lochman, 2012), which should be based on detailed relevant research. Attribution of operational or infrastructure damages to climate change is not a straightforward exercise, particularly as information on past climate-related impacts on transport are mostly restricted to individual extreme events (EEA, 2012). Nevertheless, information on the current and future risks of climate change for transport has recently improved, as a result of several research projects (see Annexes I, II and III).

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Most of the climate change impacts outlined below are particularly relevant to the ECE region (Fig. 17), due to its large spatial extent and diverse climatic regimes. Sea level rise, storm surges and waves are likely to induce major coastal impacts, including transient and permanent flooding of airports, roads, rail lines and tunnels. Flooding from intensifying extreme rainfalls/downpours, as well as other associated extreme events (e.g. landslides, see Kawagoe and Kazama (2009)), will increase the risks of disruptions or delays in air, rail and road transportation (see e.g. Fig. 18).

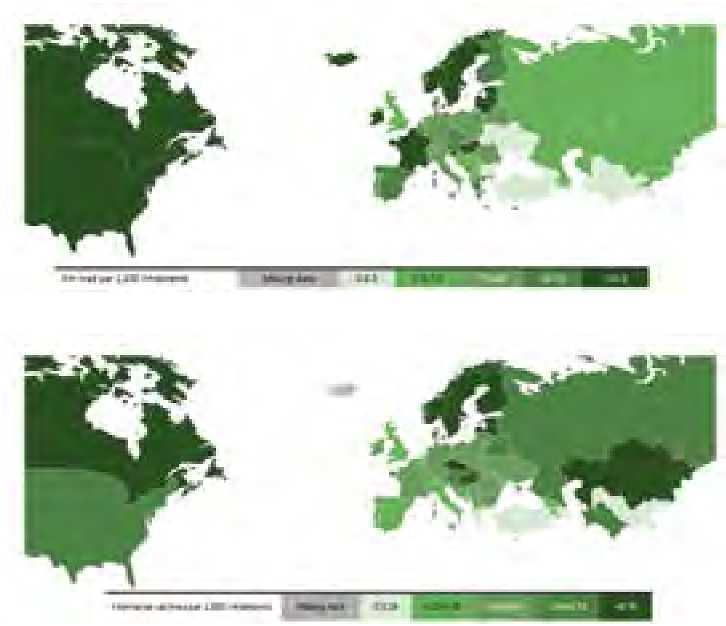

Figure 17 Density of (a) road and (b) rail networks per 1000 inhabitants in the ECE region (UNECE, 2011).

Heat waves will limit operations and cause pavement and track damages (PIARC, 2012), whereas increased intensities of tropical storms or hurricanes could lead in more evacuations, infrastructure damages or failures and transportation interruptions. Arctic warming will continue to reduce sea ice, lengthening the arctic shipping season, but also resulting in greater erosion due to increased wave activity at the northern ECE Member State shorelines (e.g. Lantuit and Pollard, 2008). Permafrost thaws in e.g. Alaska, Canada and northern Russia Federation will also damage infrastructure, and ice road seasons will become shorter.

The significance of transport networks in the ECE region is highlighted by the increased density of the road and rail networks in its area (Fig. 17), as well as the presence of many major seaports and airports. As globalization and trade has led to very significant increases in global trade and transport within as well as to and from the ECE region (Figs. 16 and 19), efficient, integrated and resilient international transport networks are of paramount importance for further economic development, particularly for the Euro-Asian land-locked countries (Fig. 20).

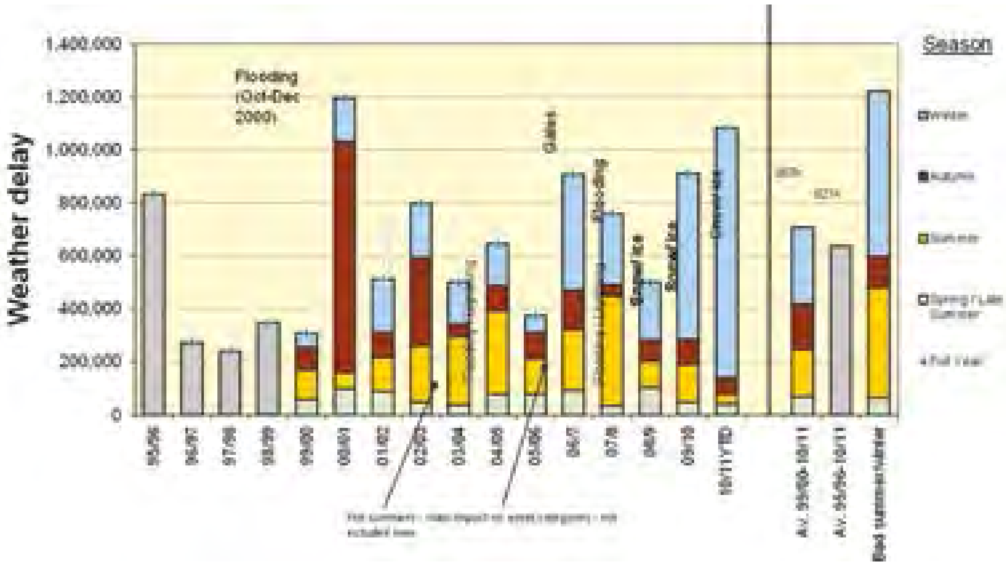

Figure 18 Delays (in minutes) of the British rail services caused by extreme weather-related impacts (Rona, 2011). Key: summer delays, blue; autumn delays, red; summer delays, yellow; and spring delays, green.

With regard to the sensitivity of transport networks to climate variability and change forcing, a recent study (USDOT, 2012a) has shown that: (a) transportation assets tend to be more sensitive to extreme events, such as storm surges, heavy precipitation events, heat waves and high wind events than to incremental changes in the mean of the climate variables (b) services (e.g. maintenance, traffic conveyance and safety) are more sensitive to climate stressors than physical assets, as thresholds for e.g. delaying or cancelling services are lower than thresholds for damage to infrastructure and (c) assets are sensitive to stressors whose occurrence is relatively unlikely in comparison to typical weather variability. For example, during the 2005 Katrina hurricane, the superstructure of the United States of America Gulf Coast bridges proved to be susceptible to excessive loading from direct wave impacts due to the unprecedented storm surge-induced coastalsea levels.

Figure 19 Foreign trade of goods (import and goods) in the ECE region, as a share of GDP (UNECE, 2011).

With regard to transport sector vulnerability, recent studies suggest that the effects will vary according to the region. Rail transport appears to be particularly sensitive, with e.g. the European railway sector facing the highest (percentage-wise) increases in costs from extreme events; the United Kingdom of Great Britain and Northern Ireland, the C. Europe and France, the Eastern Europe and Scandinavia are projected to be most adversely impacted (EEA, 2012).

Figure 20 Important international railway and combined transport networks in the Eurasian region of the UNECE (UNECE, 2009).

Two recent EU FP7 projects have studied the impacts of climate change and extreme events on the European transport systems: the WEATHER (http://www.weather-project.eu) and the EWENT (http://www.weather-project.eu/weather/inhalte/research-network/ewent.php) projects. The WEATHER Project aimed at identifying risks, economic impacts and adaptation strategies for all modes of transport. The EWENT Project considered long term climate scenarios in more detail. Both projects identified a dearth of reliable statistical data relevant to vulnerability assessments of the transport modes. In the WEATHER Project, the total costs borne by the transport sector (e.g. damages, infrastructure repair/maintenance, vehicle damages, increased operation costs) have been estimated for the period 1998-2010 as € 2.5 billion annually, with indirect costs through transport disruptions as €1 billion annually. Rail has been the most affected transport mode with 'hot spots' in Eastern Europe and Scandinavia, whereas the effects on roads have been found to be more evenly distributed. The EWENT project assessed average annual costs due to weather extremes for the current and future (2041–2070) periods. Costs from extreme climate events in the baseline period (1998-2010) have been estimated as greater than €15 billion, dominated by road accident costs. According to the EWENT results, different regions in Europe will respond differently. In N. Europe and E. Europe, cold spells will become less frequent by 2050, whereas in the Mediterranean region heat waves will become more prolonged. Road transport is projected to experience both beneficial and negative impacts, whereas rail transport will experience mostly negative impacts. Aviation is also projected to experience negative impacts throughout Europe.

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2.2 Coastal areas

Climate variability and change induces several impacts that are pertinent to transport in coastal areas, including mean sea level rise, warmer water temperatures, higher intensity of cyclones and storm surges and potential changes in the wave regime; such changes can severely affect ports (Becker et al., 2013) as well as other coastal transport hubs and networks. Superimposed upon the intrinsic relative sea level trends of coastal systems (due to e.g. tectonic movements, see Vott, 2007), are impacts from mean sea level rise (MSLR), storm surges and waves and precipitation/run-off extremes of potentially increasing frequency and intensity (e.g. Wang et al., 2008; Allan and Soden, 2008; Ruggiero et al., 2010). In addition, recent increases in coastal development test the ability of coastal systems to respond effectively to climatic changes (Nicholls et al., 2007; Lenton et al., 2009).

Figure 21 (a) New York Underground (http://www.bbc.co.uk/news/world-us-canada-20135420) and (b) street (http://eandt.theiet.org/news/2012/nov/sandy-storm-warning.cfm) flooding due to the Hurricane Sandy (30th October 2012). Estimated insured losses of $10–20 billion and total economic damages of $30–50 billion (EQECAT, 2012).

However, although predictions of exposure to adverse climatic changes are required at decadal scales (e.g. Viles and Goudie, 2003), most of the available information/models are based on long- term (century-to millennium) (e.g. Nott et al, 2009), annual (e.g. Greenwood and Orford, 2008) and even storm event (e.g. Callaghan et al., 2008) scales. There have been several attempts to develop global coastal hazards data bases (e.g. Vafeidis et al., 2008), as well as methodologies or tools to assess coastal vulnerability to sea level rise and extreme events (e.g. Hinkel and Klein, 2009; Ramieri et al., 2011; Peduzzi et al., 2013; Ranasinghe et al., 2013), but the work is still far from concluded (Nicholls et al., 2007; McLeod et al., 2010).

Although coastal inundation due to long-term sea level rise (see Figs. 3 and 4) will certainly be a significant problem for coastal populations, activities and infrastructure/assets in low elevation coastal zones (McGranahan et al., 2007), the most severe implications will be related to extreme sea levels from tropical/extra-tropical storms (e.g. Ebersole et al., 2010; Stockdon et al., 2012), particularly in the case of deltas, small islands and large coastal urban centers (e.g. Dasgupta et al., 2009) (see also Figs. 21 and 22)[8].

[8] The 2012 Hurricane Sandy was an extreme disaster for public transit systems (e.g., bus, subway, commuter rail). On October 30, 2012, the morning after the storm made landfall, more than half of the daily transit riders were without service, with the New York City subway system already shut down. During that time, the NYC experienced traffic gridlock. Seawater also breached many critical infrastructure systems, e.g. flowing into the Hugh L. Carey (Brooklyn-Battery) Tunnel, flooding eight of the NYC Subway tunnels, and damaging a variety of other regional transportation systems (HSRTF, 2013).

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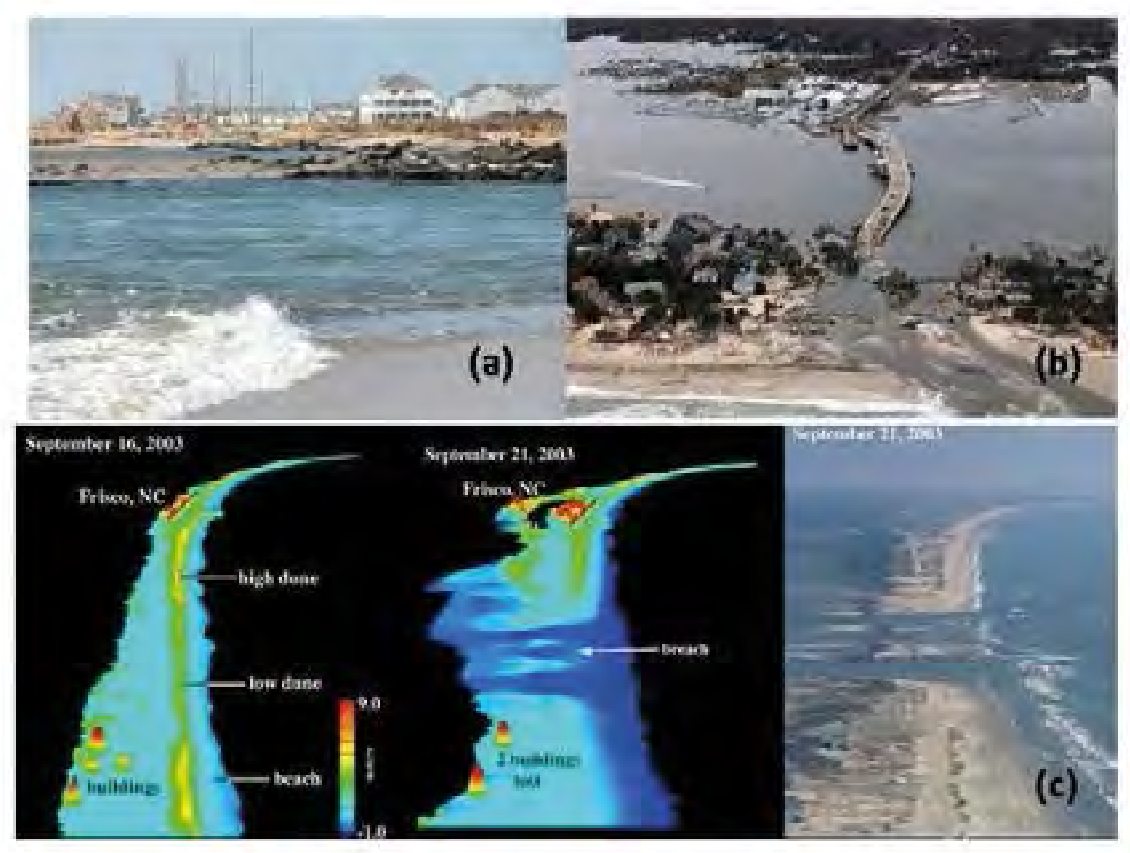

Figure 22 (a) Storm surge, waves and currents driven by Hurricane Isabel (August 2003) cut a breach across Highway 12 on Hatteras Island, N. Carolina US, the Atlantic Ocean is to the left of the image and asphalt debris from the destroyed highway to the right (Stockdon et al., 2012). (b) Storm surge, waves and currents from Hurricane Sandy (October 2012) destroyed a road/bridge in Mantoloking, New Jersey USA (AP Photo/Doug Mills) (Doran et al., 2012). (c) Lidar-based elevations of Hatteras Island, North Carolina, before (left panel) and after (middle panel) the Hurricane Isabel landfall showing erosion/breaching of sand barrier (see also the aerial photograph of the right panel) (Stockdon et al., 2012).

For example, statistical analysis of the coastal sea levels of the period 1900-2010 has shown that the tropical cyclone-generated storm surge levels for the U.S. Gulf Coast range from 2.7 m for the 2-year to 8.2 m for the 100-year return period (Needham et al., 2012). Daily port operations can be also directly influenced by adverse wave conditions, which may lead to port closures. Harbour conditions may become unbearable for large vessels, due to e.g. penetration of long period waves, generated by swell waves propagating in groups (e.g. Rossouw and Theron, 2012). The extent/distribution of exposure in each particular area/ urban center will be influenced by both its natural characteristics (e.g. the occurrence of coastal wetlands that may attenuate surges, see Wamsley et al., 2010) and human-induced changes such as water management and land reclamation schemes (e.g. Le et al., 2007). It must also be noted that, as ports and other transport infrastructure links are not associated exclusively with open coasts, but also with estuaries, climate change impacts on these environments are particularly pertinent.

Figure 23 Roads at risk in the event of a sea level rise of about 1.2 m (4 feet), which is within the range of projections for this part of the United States of America Gulf Coast in this century under medium- and high-emissions scenarios. In this case, 2,400 miles of major roads are predicted to be inundated (CCSP, 2008; Karl et al., 2009).

In estuaries, sea-level rise generally translates into landward transgression (Pethic, 2001), leading to different (higher) relative water levels and dynamics (e.g. Shennan et al., 2003). Sea level rise can, therefore, increase the flooding hazard of estuarine ports, particularly in the case of combined high river flows and storm surges (e.g. Karim and Mimura, 2008). Sea level rise is also likely to affect regional tidal regimes. A recent study (Pickering et al., 2012) which used the validated operational Dutch Continental Shelf Model (DCSM98a, see Verlaan et al. (2005)) to assess the effects of mean sea level rise on the tides of the NW European continental shelf has shown that under a 2 m rise scenario, the amplitude of the predominant M2 tidal constituent as well as spring tidal ranges will change significantly (by many tens of cm), decreasing in the resonant areas of the Bristol Channel and Gulf of St. Malo and increasing in the SE German Bight and the Dutch Wadden Sea; such tidal changes may have important implications on future adaptation measures for open coast and estuarine ports, such as the effective design of flood defenses and dredging strategies. With regard to human-induced changes, it has been shown that their effects on estuarine morphology and dynamics can, in some cases, exceed those of the sea level rise itself (e.g. Chust et al., 2009; Reeve and Karunarathna, 2009).

Tropical cyclones and related storm surges and wave inundation can cause very considerable damage, in the order of tens of billion dollars, to the built coastal environment (e.g. Figs 21 and 22) and reveal vulnerabilities in infrastructure design and construction (Arumala, 2012). With regard to the economic impacts of climate change on coastal areas, a study by Nicholls et al. (2008) has assessed the population/asset exposure of 136 port cities with more than one million inhabitants (in 2005). They estimated that, by the 2070s, more than 120 million people will be exposed to extreme events in these port cities, if effective coastal protection schemes will not be put in place. Lenton et al. (2009), who included tipping point scenarios (see Section 1.3), estimated that, by 2050, the asset exposure in the same 136 port megacities will be close to 28,000 billion US dollars.

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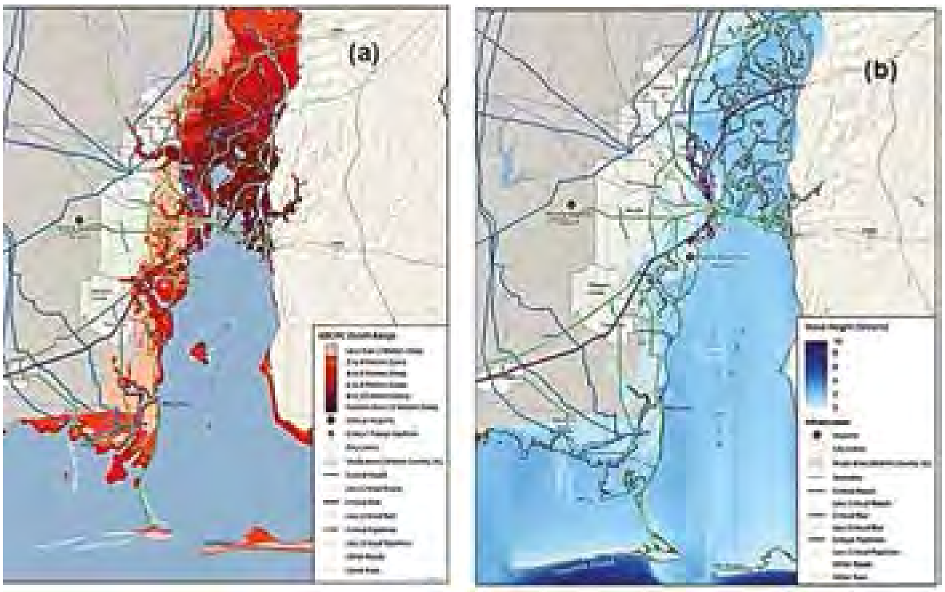

Figure 24 Inundation/damage risk of critical road, rail, airport and pipeline infrastructure elements at Mobile (United States of America Gulf coast) under a storm surge according to a Hurricane Katrina shifted path Scenario and 0.75 m mean sea level rise: (a) storm surge depths (depth in m, relative to the current dry ground); (b) wave heights. Mobile's critical transportation assets, have been found to be minimally exposed to mean sea level rises of 0.3 and 0.75 m, as only 0 - 2 per cent of critical assets of each transportation mode will be exposed; under a higher-range scenario (2 m rise), exposure of critical assets of each transportation mode will range from 2.6 to 50 per cent. (USDOT, 2012a).

Transport will be affected by extremes in temperature and precipitation, storm surges and rising sea levels. Coastal inundation through storm surges (e.g. Figs 21, 22, 23 and 24) can have very significant impacts on transportation systems by (a) rendering them unusable for the duration of the surge (for several hours/days) and (b) damaging significantly terminals, intermodal facilities, freight villages as well as storage areas and cargo and, thus, disrupting intermodal supply chains and transport connectivity for longer periods. The extent of inundation of critical transportation assets from storm surges is much greater than that from long-term mean sea level rise (USDOT, 2012a).

Ports, which form key-nodes in international transport networks and link international supply- chains, will be particularly impacted (see Table 3) due mostly to (a) the long life-time of their key assets, which means that many existing ports have been designed for a much milder energetic regime, (b) their exposed location (e.g. Fig. 25), and (c) their dependence on trade, shipping and inland transport that are also climatically-vulnerable (including also changes in demand for transport) (see UNCTAD 2011). Port development depends on various conditions such as the availability of deep water and/or protected harbors and the possibility of multi-modal connections.

Some port locations are highly vulnerable to extreme events such as tropical storm-generated surges and high winds (Fig. 25) as well as the MSLR (CCSP, 2008), which can cause economic losses on the billions of US dollars (Haveman and Shatz 2006).

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Table 3 Climate change impacts on seaports (Crist, 2011).

Vulnerable location	Exposure to climate change impacts
Navigation and Berthing	a. Sea level rise – decreased dredging, quay upgrading, bridge headways, b. Storm surge and winds – inability to dock, congestion c. Increased precipitation – sitting, increased dredging d. Decreased precipitation – inland navigation limitations e. Sea ice – change in port access
Goods handling	a. Increased storm frequency and strength – damage, restriction of crane operations or loading of bulk / liquid cargoes due to winds and lighting
Storage	a. Storm surges and increased precipitation – coastal or fluvial flooding of storage platforms and facilities, damages, material losses of infrastructure, spoiling of goods c. Increased temperature – material damage to structures, increased energy costs
Vehicle movements inside port	a. Storm surges and increased precipitation and inadequate drainage – flooding of port facilities prevents essential vehicle movements b. Chronic / permanent flooding can render parts of port inoperable
Infrastructure, building and equipment damage	a. Flooding and wind damage – threat to buildings and equipment b. Sea level rise and storm surges can damage essential protective infrastructure c. Storm surges and flood-related scouring can weaken bridges, quay and pier foundations d. Increased temperatures can lead to metal failure for equipment and infrastructure
Inland transport networks	a. Inland transport networks essential for port operations; failure of critical inland links can render the port inoperable

Port physical infrastructure and activities appear to be particularly vulnerable to climatic changes. In order to assess climate change-induced risks for a given port, all potential climate change impacts, vulnerabilities and critical thresholds should be analyzed, together with the factors affecting the port's success. A detailed case study of the port Muselles el Bosque Cartagena (Colombia) (Stenek et al. (2011), see also Annex I) has found that climate change could result in: (i) changes in the level/patterns of shipping (ii) increased flooding that could affect port operations and cause damages to stored goods (iii) reduced navigability of access channels and (d) material business implications. However, there could also be commercial benefits for ports that can demonstrate resilience to disruption from adverse weather/climatic events. The Muselles el Bosque study has found that the materiality of climate change impacts will vary significantly, depending on the location, type and functionality.

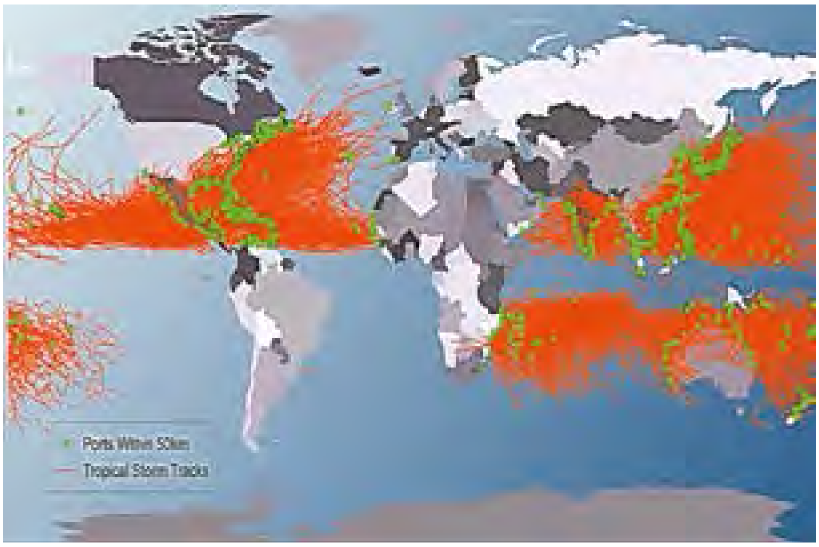

Figure 25 Ports within 50 km of tropical storm tracks (1960–2010). Port and storm data from National Geospatial-Intelligence Agency (2011) and Knapp et al. (2010). (Becker et al., 2013)

A questionnaire survey to IAPH/AAPA members (see IAPH/AAPA, 2010; and Becker, 2012 Annex II) has revealed that, although the climate change impacts on ports are generally understood, specific consequences are not. The respondents have divided impacts of extreme events (storms) into 6 groups: (i) direct damages (ii) debris in the port area (iii) business consequences (iv) local/regional consequences external to port (v) damages to intermodal systems and supply chains and (vi) environmental degradation. In this study, 125 unique strategies have been mentioned that might increase port-resilience.

Other coastal transportation infrastructure is also very vulnerable to inundation. For example, a recent study by Robertson et al. (2011) has revealed that most of the United States of America United States of America Gulf Coast concrete bridges were severely damaged by the storm surge/waves of the 2005 Katrina Hurricane. There had not been structural restraints to prevent uplift of the bridge decks or efficient restraints against lateral movement relative to the supporting piers under the Katrina's very considerable hydrodynamic forcing. It appears that there is an urgent need to review structural designs in order to improve future new constructions or retrofit the existing transportation infrastructure threatened by coastal inundation.

One of the most detailed studies on the potential impacts of climate change on transportation systems was carried out in the United States of America Gulf Coast (see also Annex I). According to this study, relative sea level rise of approximately 1.2 m -4 feet (Fig. 23) could permanently inundate more than 2,400 miles of roads, over 70 per cent of the existing port facilities, 9 per cent of the railway lines and three airports; in the case of a 5.5 m storm surge (less than that of Katrina), more than 50 per cent of interstate and arterial roads, 98 per cent of port facilities, 33 per cent of railways and 22 airports in the United States of America Gulf coast could be affected (CCSP, 2008). These results should be viewed in relation to another finding of the study, i.e. that the connectivity of intermodal systems – including goods movement to and from ports – can be severely disrupted even if short segments of roadways are flooded (Savonis et al., 2008). A more recent study on the exposure of the United States of America Gulf critical infrastructure assets (Choate et al, 2012; USDOT, 2012a) has suggested that: (a) critical port facilities are the most vulnerable to extreme weather and storm surge, together with critical coastal rail lines (b) the extent of inundation of critical transportation assets from storm surge will be much greater than that due to long-term sea level rise which will, however, exacerbate the severity of storm surge (Fig. 24) and (c) pipelines have the lowest fractional extent of exposure (3 -16 per cent of pipeline-miles exposed), whilst exposure varies (16 - 62 per cent of the road length) for the critical roads depending on the scenario.

French studies (e.g. ONERC, 2009; Pecherin et al., 2010) have also projected substantial impacts of climate change on coastal transport infrastructure. It has been estimated that a 1 m increase in sea level above the inundation level of the current 1-in 100 year-storm event (and assuming an average linear property cost at €10 million/km of road surface and costs of repair at ~ €250 thousands/km), would amount to asset costs (i.e. excluding operational and connectivity costs) for mainland French A-roads (not motorways) of up to €2 billion. It has also been found that this sea level rise could inundate 2.9 per cent of motorways, 1.7 per cent of national roads, and 6.3 per cent of the railway network. Another recent study (EC, 2012a) has provided an initial estimate of the future risk of the European coastal transport infrastructure due to mean sea level rise (MSLR) and storm surges on the basis of a comparison between the coastal infrastructure elevation and the combined level of 1 m MSLR and the 100-year storm surge height. The study has found that coastal transport infrastructure (e.g. coastal roads) at risk represents the 4.1 per cent of the total, with an asset value of about €18.5 billion.

In response to concerns that climate change will pose increasing challenges to the operation of Australia's seaports, a recent study (McEnvoy et al., 2013) has analysed climate change impacts in Australia and its potential implications for port infrastructure, using an integrated assessment methodology comprising quantitative, qualitative and participatory approaches. It was recognized that the expert input and knowledge of the port authorities and other stakeholders can provide an important contribution to the assessment process. Six main components were used for the risk assessment: (i) analysis of ports as systems (ii) consideration of observed climate/weather data (iii) future climate projections (iv) comparison of climate information with research needs (risk assessment and adaptation planning for infrastructure and functions) (v) compilation of climate information for case study ports and (vi) putting non-climate drivers into context. The study has found that dealing with the uncertainty of the climate data proved to be a most significant challenge.

Generally, significant impacts are expected on the coastal infrastructure (e.g. ports, coastal transportation hubs etc) and services, due to climate-change induced changes (SREX, 2012). This may have far reaching implications for international trade, as more than 80 per cent of global trade in goods (by volume) is carried by sea (UNCTAD, 2011). All coastal modes of transportation are considered vulnerable, but exposure and impacts will vary, for example, by region, mode of transportation, location, elevation, and condition of transport infrastructure (SREX, 2012).

2.3 Riverine floods, heavy precipitation, snow fall and strong winds

Changes in precipitation may result in stream flow changes. These are likely to have significant effects on roadways (Fig. 26), but also on railway lines, port operations, airports, bus stations and train terminal facilities. There can be direct damages during and immediately after the precipitation event, necessitating emergency response. This can also generate problems to the structural integrity and maintenance of roads, bridges, drainage systems, and tunnels, necessitating more frequent repairs and reconstruction (USDOT, 2012a).

Climate-induced changes together with development practices - more than 10 million people and assets valued at € 165 billion live in areas prone to extreme floods along the Rhine River alone (EEA, 2010) - have increased substantially the risks[9] of riverine floods/flash floods (see Figs. 8, 9 and 10 and Section 1.1.2). For example, in the period 1998-2002, there have been more than 100 major floods in Europe (including the 2002 catastrophic floods along the Danube and Elbe rivers) that caused several hundred fatalities, the displacement of about 500,000 people and over € 25 billion in insured economic losses (EEA, 2004). Additional catastrophic floods in the following years prompted the European Union to adopt the Flood Risk Directive (2007/60/EC) (EC, 2007). Figure 27 shows projections of potential flood damages due to climate change, assuming that no adaptation or disaster risk reduction measures are adopted (Feyen et al., 2010; EEA, 2010).

Results from the PESETA study (Ciscar et al., 2009) suggest that flood damages are likely to rise across much of western and central Europe. For the EU 27 Member States, current expected annual damages (EAD) of € 6.4 billion are projected to increase to € 14–21.5 billion (in 2006 constant prices) by the end of the 21st century depending on the scenario, whereas the number of people affected by flooding is also projected to rise by about 250,000 - 400,000.

[9] Flood risk is defined as a product of flood probability/hazard, exposure of assets/infrastructure and population and vulnerability to flooding based upon land-use information and an assessment of flood inundation.

Most notable increases in flood losses are projected for Western Europe (Belgium, Denmark, France, Germany, Ireland, Luxembourg, the Netherlands and the United Kingdom of Great Britain and Northern Ireland), as well as for Hungary and Slovakia (Feyen et al., 2010). At the same time, riverine flows/floods are expected to decrease in the northeast of central Europe (see Fig. 10).

Figure 26 Flood damages on roads (a) Highway 8 (Munich to Salzburg) in Grabenstaett near Traunstein, S. Germany (early June 2013, Matthias Schrader, AP); (b) heavily damaged road between Lofer and Waidring in Tyrol (Austria) (3rd June, 2013, Kerstin Joensson, AP); (c) flooded highways in Deggenfdorf; and (d) collapsed bridge in Cumbria (United Kingdom of Great Britain and Northern Ireland) in November 2009, (http://news.bbc.co.uk/2/hi/uk_news/8369934.stm).

Alcamo et al. (2007) assessed the situation in Russia Federation on the basis of inter-annual climatic variability and suggested that although Russia Federation will experience an overall increase in water discharges, the South West Russia Federation will be associated with more frequent low runoff events. It must be noted here, that floods are likely to be particularly catastrophic for transport networks as major roadways and railways are located within and/or crossing flood plains (e.g. Fig. 28).

With regard to precipitation, more frequent as well as intense and heavy precipitation events can cause immediate damages, undermine road structural integrity, affect the maintenance of roads, bridges, drainage systems and tunnels and induce delays in air travel (USDOT, 2012a). In the USA, Milly et al, (2008) have suggested that, by 2050, precipitation runoffs will increase at the northeast and decrease at the southwest (Fig. 29). Heavy downpours have already increased substantially, with the heaviest 1 per cent of precipitation events having increased by 20 per cent, whereas total precipitation increased by only 7 per cent over the past century (Kunkel et al., 2008). Such intensive precipitation, which is also projected to increase in the future (see Fig. 7), is likely to increase the frequency and intensity of catastrophic flooding along the major river flood plains.

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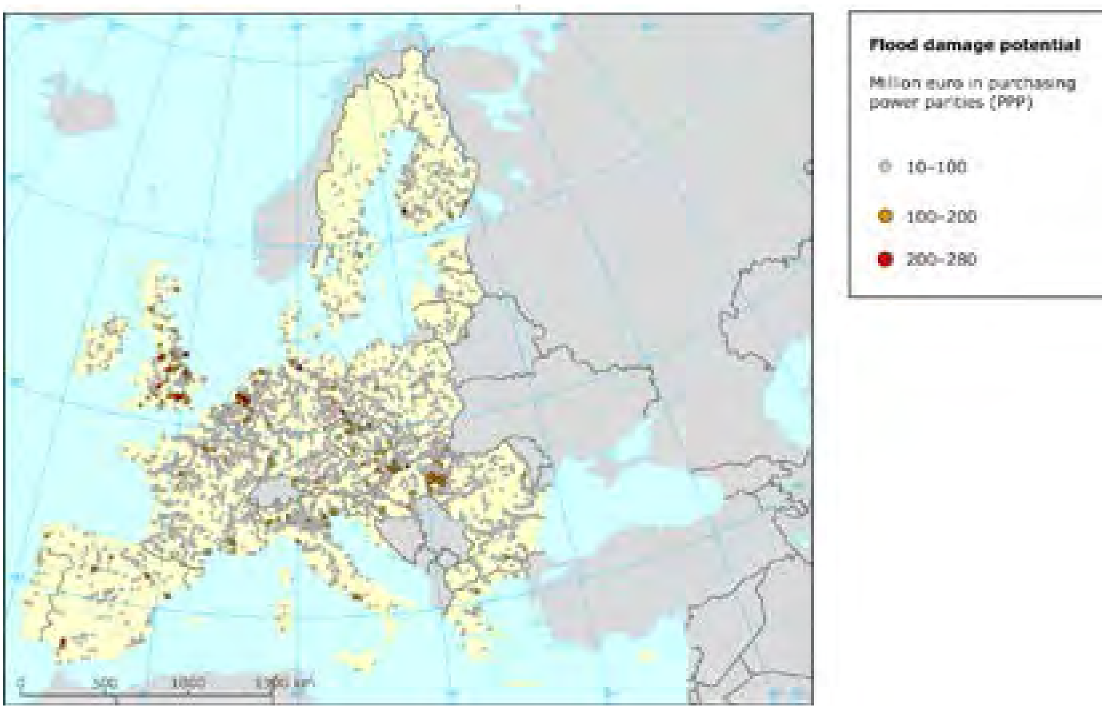

Figure 27 Flood damage potential in Europe (EEA, 2010). The estimations have been based on the assumption of an event with a 100-year return period (i.e. the record flood in 100 years), present climate and no defenses. Catchments of less than 500 km² are not included.

In the southern Eurasian ECE Member states, floods are already a hazard for transport networks (see Figs. 9 and 28 for effects in the Eurasian ECE region). The projected changes in catastrophic flooding are likely to affect all modes of transport, as is shown by our current experience. For example, the 2008 the United States of America Midwest flood resulted in breaching/overtopping of levees along several States and in flooding of huge areas, rendering numerous road and rail bridges unusable together with long stretches of highways, rail lines and normally navigable waterways (Karl et al., 2009).

One area of particular concern that has been identified (e.g. Galbraith et al., 2005) is the potential increase in winter rainfall, which may result in drainage systems failing to perform in the desired manner. It has been recommended that: (i) the design storm parameters used in surface water drainage designs should be revised to allow for predicted increases (ii) the design storm parameters used in culvert and river bridge designs should be also revised (iii) locations of historical road flooding should be identified and potential solutions evaluated on a cost/benefit basis, with priority for areas with frequent flooding (iv) pre-emptive clearance of debris from drainage channels and watercourses should be routinely undertaken in areas of increased flood risk and (v) further research should be undertaken to improve estimations of catchment runoffs to enable guidance on risk-based design approaches. A recent report study by the United Kingdom of Great Britain and Northern Ireland Government (DEFRA, 2012) has also suggested that the United Kingdom of Great Britain and Northern Ireland transportation infrastructure will be affected by both extreme weather events and long-term gradual change in the climate. Road and railway networks are projected to face significant risks of flooding as well as bridge scouring.

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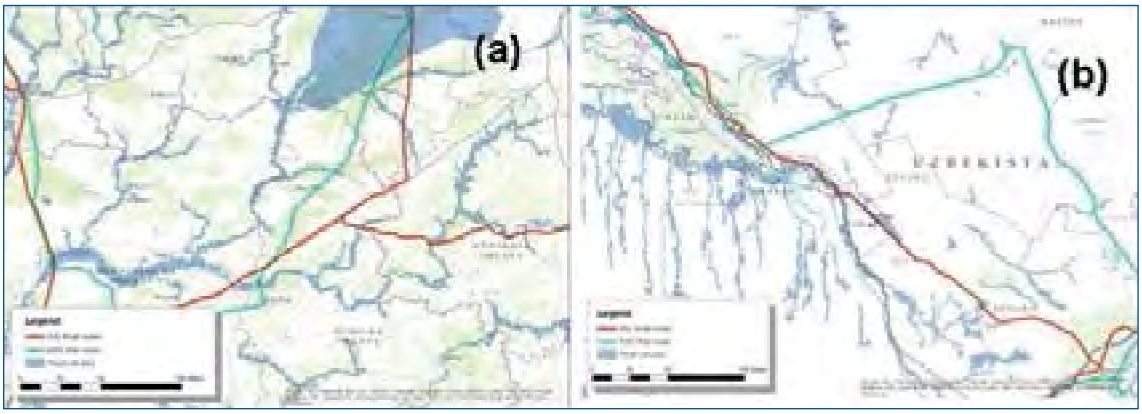

Figure 28 Current flood hazard (95 per cent probability) for transport networks in Ukraine and Central Asian ECE member States for the 1 in a 100-year floods from a global GIS model based on river discharge time-series (Flood projections from UNEP-GRID and UNISDR (2008)).

Increases in heavy precipitation events/floods will also cause more weather-related accidents due to vehicle and road damages and poor visibility, delays, and traffic disruptions in the already congested networks (e.g. Potter et al., 2008). A recent study relating climate change with road safety (Hambly et al., 2012) has suggested that the projected change in precipitation will translate into higher collision counts in Greater Vancouver, Canada by the mid-2050s.

Regions where flooding is already common will face more frequent and severe problems. Standing flood waters could impact severely on the roadway system. For example, damages due to long-term road submersion in Louisiana have been estimated as $50 million for 200 miles of the state highways. Port facilities will be also vulnerable to short-term rain-induced flooding, whereas extreme precipitation-induced silting could reduce navigation channel depths, increasing considerably dredging costs (e.g. Karl et al., 2009). Inland waterways can be affected by suspension of navigation, silting and changes in the river morphology and damage of banks and flood protection (Siedl, 2012). Increased delays and cancellations of flight operations due to airport flooding are also likely, together with effects on the structural integrity of runways and other airport infrastructure (National Research Council, 2008).

A recent study (Wright et al., 2012) assessed the potential impacts of climate change-induced river flooding on the continental USA bridges, a critical component of the national transportation system. A uniform assumption was applied to peak flow increases that would make bridges vulnerable. Daily precipitation statistics from 4 GCM (climate models) and 3 GHG emission scenarios (A2, A1B, and B1) were used to define a range of potential changes in precipitation and freshwater flooding, which was then combined with information from the United States of America National Bridge Inventory to assess bridge scour vulnerability. Projected increases in flow at the 100-year recurrence intervals were used to identify bridges that would make for significant risks (Fig. 30). The results indicate that about 129,000 bridges are currently deficient, 48,000 - 96,000 bridges will be at risk by 2055 from increases in the 100-year return flow and 66,000 - 117,000 by 2090. Adaptation costs of vulnerable bridges have been estimated as $140 - $ 250 billion through the 21st century. The A2 scenario resulted in about 40 per cent more costs than the B1 scenario and about 15 per cent more costs than the A1B scenario. Estimations for the EU 27 (EC, 2012a) appear to be lower, as the future cost for bridge protection against scour has been estimated as €0.38 - 0.54 billion per year, 80 per cent of which is for road and 20 per cent for rail bridges, respectively. Such differences in the estimates may be due to differences in the bridge inventory between EU and the United States of America and/or the different premises/methodology used.

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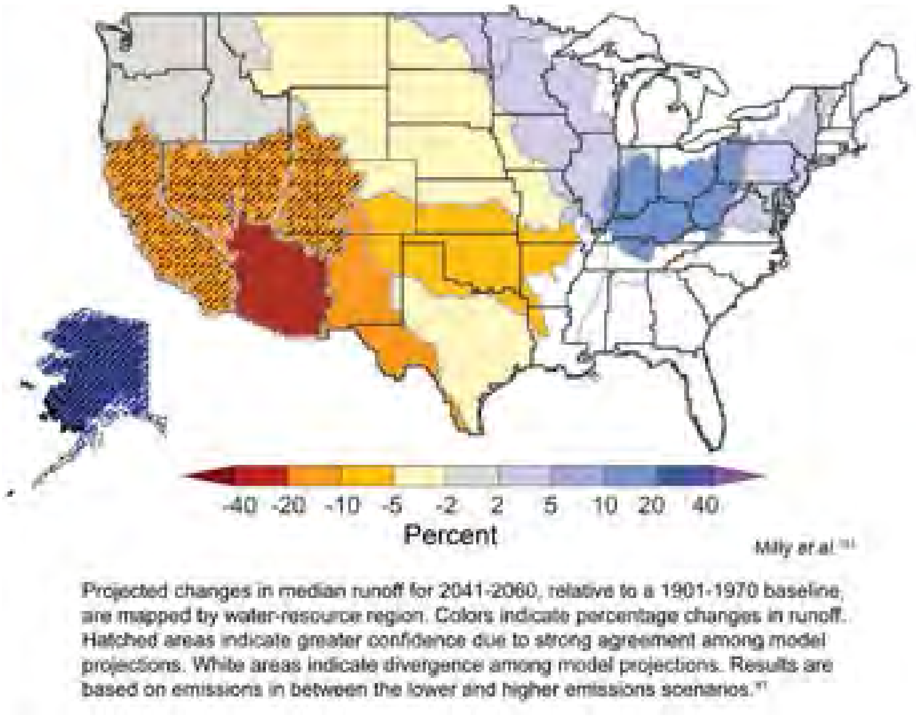

Figure 29 Projected changes in median runoff for 2041-2060 (relative to 1901-1970). Hatched areas show good agreement and white areas poor agreement between model projections. Results are based on emissions between the lower and higher emissions scenarios (Milly et al., 2008).

Studies on the effect of climate changes on the British railway network (e.g. RSSB, 2010) also suggest that infrastructure will be impacted severely, with impacts including track and line side equipment failure, flood scours at bridges and embankments due to high river levels and culvert washouts, landslides, as well as problems associated with personnel safety and the accessibility of fleet and maintenance depots. Costs related to extreme precipitation and floods and other extreme events, which are already estimated as £50 million a year, could increase to up to £500 million a year by 2040s (e.g. Rona, 2011; 2012). Road networks are also expected to be severely affected by the projected increases in heavy rainfall and flooding, with diverse impacts on the different types of pavement, asphalt and concrete, which would require adaptive maintenance practices such as construction of adequate drainage and the use of permeable pavements and polymer modified binders (e.g. Willway et al., 2008).

The costs to the United Kingdom of Great Britain and Northern Ireland transport network associated with flooding has been estimated to be substantial and will continue to increase, if there are more instances of flooding as a result of increased heavy precipitation under future climate change (Hooper and Chapman, 2012). The cost of flood-related traffic disruption on roads has been estimated as at least €123,000 per hour delay on each main road affected (Arkell and Darch, 2006). If there is more frequent flooding in the future as a result of increased heavy precipitation, then it is likely that these costs will increase significantly (Hooper and Chapman, 2012).

Figure 30 Distribution (projected number and percentage) of the United States of America highway bridges at risk from increased peak flows due to climate change (Emission Scenario A1B, 100-year event, 24-hour precipitation for the period 2046-2065 (Wright et al., 2012).

Seasonal snow cover is likely to continue shrinking at a global scale. For Europe, projections of changes in annual snowfall days on a basis of a multi-model ensemble are shown in Fig. 31. The multi-model mean shows decreases in days with snowfall exceeding 1 cm across Europe, whereas days with snowfall above 10 cm show increases in large tracts of northern Europe and decreases in most other regions. There is, however, considerable uncertainty in these projections due to large differences between the upper and lower limits of the model projections (EEA, 2012).

Because snow cover is sensitive to snowfall as well as temperature increased snowfall will not necessarily translate into thicker snow cover. A recent study (Kjellström et al., 2011) has projected a reduced number of snow cover days in N. Europe (55 – 70 °N, 4.5 – 30 °E) of up to 40–70 days in 2071–2100 compared to the baseline period 1961–1990, with the projections depending on the emission scenario and model. Despite the projected decrease in long--term mean snow water equivalent (SWE) in the N. Hemisphere, model simulations have also indicated occasional winters of heavy snowfall, which will however become increasingly uncommon towards the end of the 21st century. Significant reductions in snow mass in Europe are likely to occur in Switzerland, the alpine Italy, the Pyrenees, the Balkan and the Turkish mountains (e.g. López-Moreno et al., 2009; Soncini and Bocchiola, 2011). In these areas, such changes may have very significant effects, as melt waters contribute up to 60–70 per cent of annual river flows (EEA, 2012).

Figure 31 Projected changes in annual snowfall days in Europe (EEA, 2012) from 6 models for the emission scenario A1B. (a) Mean of changes in annual snowfall (1 cm) days from 1971-2000 to 2041-2070; and (b) mean of changes in annual snowfall (10 cm) for the same future and baseline periods.

Finally, extreme winds, which are often, but not exclusively, associated with tropical storms, are also projected to be more catastrophic in the future (e.g. Emanuel, 2005; Rahmstorf, 2012). Such events can cause overtopping on defenses and flooding at coastal and estuarine railways (RSSB, 2010), damage port facilities, such as cranes and loading terminals, affect offshore drilling platforms, refineries, and pipelines, flatten or destroy agricultural crops-, thus, indirectly affect the transportation industry - induce more frequent interruptions in air services, damage airport facilities such as terminals, navigational equipment, perimeter fencing and signs, damage road and railway infrastructure through wind-generated debris and stress road and rail operations (e.g. Karl et al., 2009, Kamburow, 2011). In addition, changes in the wind and wind-wave directional patterns (see e.g. Callaghan et al., 2008) may also have important implications on, for example seaport operations and safety, as well as the integrity of coastal road and rail infrastructure. However, wind patterns are notoriously difficult to predict with confidence. For example, recent modeling efforts have suggested no, or a moderate increase in the wind extremes across Europe (Fig. 32), but with significant discrepancies between predictions by different models (Vajda et al., 2012).

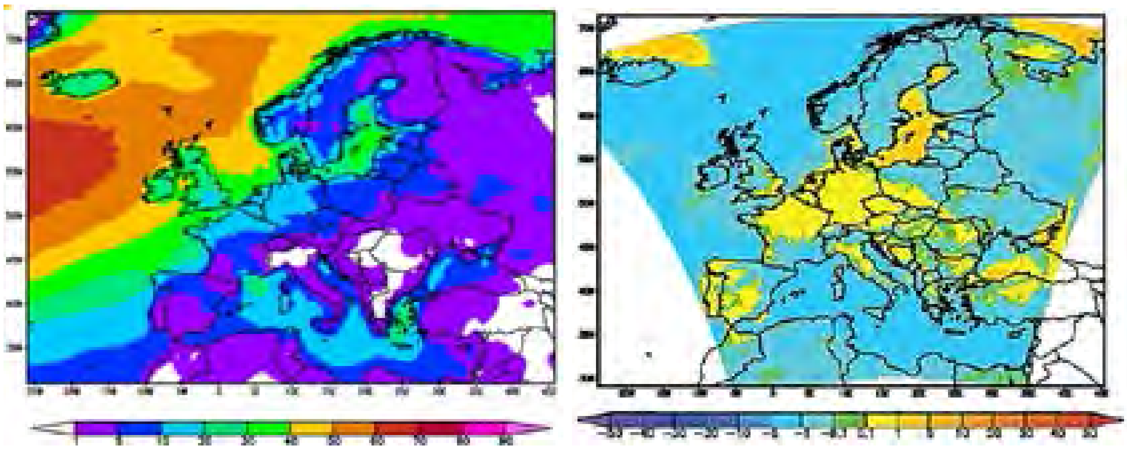

Figure 32 (a) Average number of days per winter (DJF) with wind gust exceeding 17 m/s during 1971-2000; and (b) multi-model mean of changes in wind gust days for the same threshold by 2041-2070 (Vajda et al., 2012).

2.4 Heat waves and Droughts

Heat waves, which is to say extended periods (days to weeks scale) of abnormally hot weather, may have substantial impacts to transport services and infrastructure, potentially being quite devastating (Hooper and Chapman, 2012). For example, the European 2003 heat wave (which was accompanied by precipitation deficits of up to 300 mm in many regions of the western and central Europe (Trenberth et al., 2007)) led to a considerable reduction in soil moisture through intensive surface evaporation/evapotranspiration and created strong feedbacks (Beniston and Diaz, 2004). The hot and dry conditions led to many large wildfires and crop failures; the (uninsured) economic losses for the EU agricultural sector have been estimated as € 13 billion, resulting in very substantial associated losses for the transport industry. On the other hand, the associated extreme Alpine glacier melt prevented catastrophically low flows in the Danube and Rhine rivers (Fink et al., 2004). The 2003 heat wave cum drought in Europe affected settlements and economic services in a variety of ways, creating different stresses on water supplies, food storage and energy systems. Many major rivers (e.g. the Po, Rhine and Loire rivers) were at record low levels, resulting in disruption of inland navigation, irrigation and power-plant cooling (Beniston and Díaz, 2004), whereas the punctuality of the French railways fell to 77 per cent from 87 per cent the previous year. Due to this disaster, France implemented a heat prevention plan, which appeared to work satisfactorily in the following (2006) heat wave (e.g. Pascal, 2008). In the SE England roads, tarmac 'melting/bleeding' occurred in the summer of 2003. Minor roads became slippery as loose stones rose to the surface due to excessive heat (Standley et al., 2009). In addition, the United Kingdom of Great Britain and Northern Ireland railways suffered excessive delays (165,000 delay minutes in the period 14/05- 18/09 compared to only 30,000 delay minutes for the same period in 2004) (Hunt et al., 2006).

Although the 2003 heat wave did not cause generalised damages that could call into question the integrity and resilience of roadways and other civil engineering structures - mostly localized problems, due mainly to clay soil shrinkage - (ONERC, 2009), the effects of more frequent heat waves could be severe. Long and repeated periods of extreme summer heat (sustained air temperatures over 90 °F - ~32 °C) can damage roads through asphalt softening that could lead to rutting from heavy traffic (Field et al., 2007). Extreme heat waves can also deform rail tracks, causing derailments and speed restrictions. Derailments can

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occur when a buckled section of track is not detected on time. In order to prevent them, rail operators issue blanket slow orders, to achieve safety margins above which speed restrictions must be applied. These safety margins are controlled by the Critical Rail tracks Temperatures (CRTs)[10]. A recent European study (EC, 2012a) has estimated significant increases in the 21st century of the number of days per year that the maximum temperatures (Tmax) in Europe will exceed CRT30 (Fig. 33), suggesting increases in delays/operational costs.

In the United Kingdom of Great Britain and Northern Ireland, hot dry summers can be expected to have effects on the railway system, such as (a) increased buckling of tracks (b) desiccation of track earthworks (c) greater requirements for air conditioning systems (d) increased ventilation problems on underground railway systems and (e) increased leaf fall issues due to longer plant growing seasons (Baker et al., 2010). Concerning rail buckling, as climate change is predicted to significantly modify United Kingdom of Great Britain and Northern Ireland temperatures, particularly in respect of the frequency of extreme high temperatures, the number of rail buckles, and thus of delays, are expected per year are likely to increase if tracks are maintained to the current standards (Dobney et al., 2009).

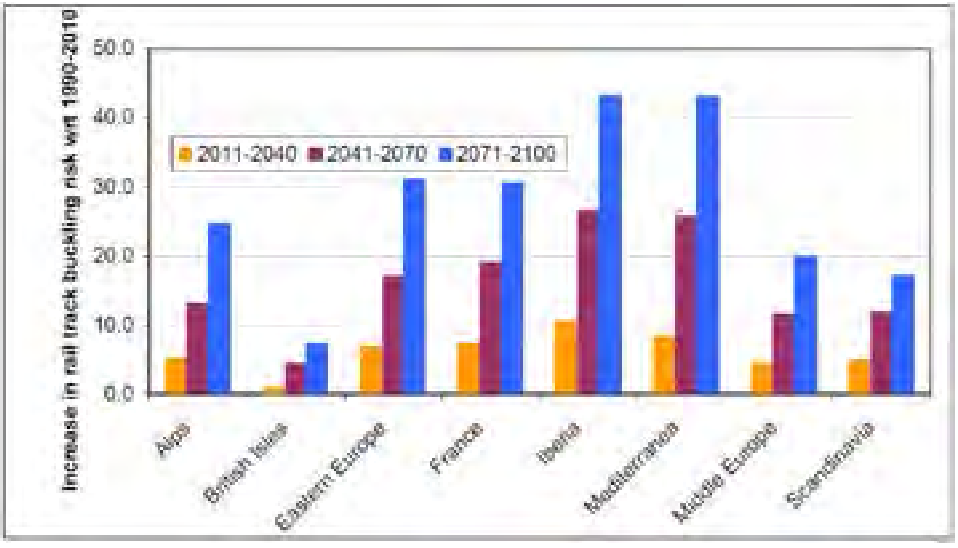

Figure 33 Average annual number of extra days with Tmax over the Critical Rail track Temperature CRT30 (i.e. temperature imposing 30 km/h speed restrictions) in the future, compared with the current situation (scenario A1B) (EC, 2012a).

Therefore, rail buckling is regarded as a main priority, together with flooding and coastal inundation, and the industry (Network Rail) together with the Regulator (ORR) and the DfT are working to agree adaptation measures that are going to be implemented during the planned 'Control Period 5' (2013/14 to 2018/19) and monitored at the highest level.

Temperatures above 100 °F (about 38 °C) can lead to other transport equipment failure. Drier and hotter summers will lead to road pavement deterioration/subsidence, affecting pavement performance and resilience (e.g. Scott Wilson, 2009; PIARC, 2012). There can be reductions in the lifetime of the road asphalt (Meizhu et al., 2010), thermal expansion and increased movement of concrete joints, protective cladding, coatings, and sealants on bridges and airport infrastructure and stress in the bridge steel (Arkell and Darch, 2006; USDOT, 2012a). Vehicle overheating and tire deterioration are additional concerns (National

[10] Critical Rail track Temperatures (CRT) denote the critical temperatures above which speed limits apply; for example CRT70 and CRT30 denote the critical temperatures above which speed restrictions of 70 km/h and 30 km/h, respectively, should be applied.

Research Council, 2008). With regard to road pavements, a study by the UK Highways Agency (UK Highway Agency, 2008) has shown that higher temperatures can seriously affect roads. As a result of these projections, road surface specifications in the United Kingdom of Great Britain and Northern Ireland have been amended to withstand higher temperatures (DEFRA, 2012). It is expected that as these design changes are being made now, the costs will become embedded, so that there will not be sudden requirements for a large investment in relevant adaptation measures in the future.

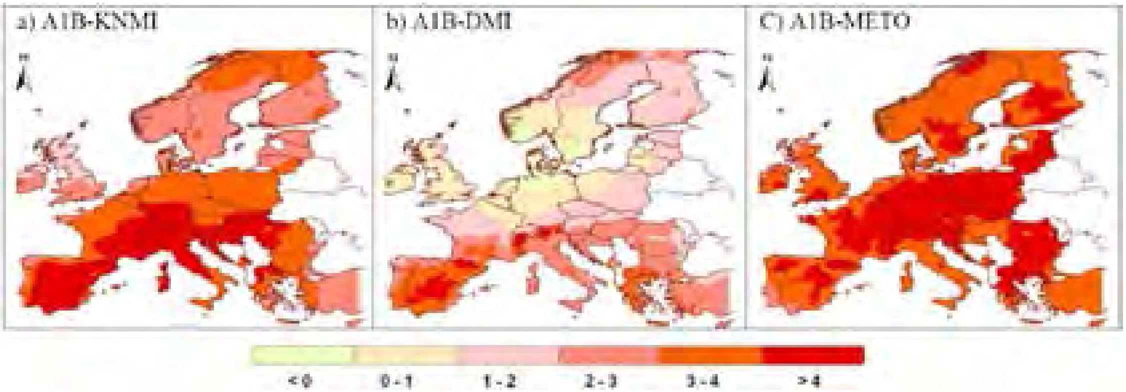

Figure 34 Change in the 7-day maximum pavement temperature in the different European climate zones, in the case of the A1B scenario (comparison between the periods 2040-2070 and 1990-2010) (EC, 2012a).

A recent European study (EC, 2012a) has used model predictions (e.g. Fig. 34) to provide annual costs to upgrade asphalt binder for different climate temperature scenarios. The study suggested that, for example the A1B scenario, the additional cost for the EU27 would be 38.5 – 135 million € per year by 2040-2070 and 65-210 million € per year by 2070-2100. Nevertheless, it must be noted that at least road surfaces are typically replaced every 20 years and, thus, could accommodate climate change at the time of replacement (SREX, 2012).

High temperatures are also likely to increase refrigeration requirements and related costs for goods in transit, particularly in the warmer areas of the ECE region (e.g. Kafalenos et al., 2008). Increases in the number and frequency of very hot days (see e.g. Fig. 12) are also expected to limit construction activities due to health and safety concerns (e.g. Karl et al., 2009).

Rising air temperatures increase evaporation contributing to drier conditions, particularly in regions associated with decreasing precipitation in terms of magnitude and/or frequency. Therefore, droughts are expected to be an increasing problem in several ECE areas, such as the South West United States of America and the South Eastern Europe (IPCC, 2007a, b); this, in turn, may have impacts on transportation. Wildfires are projected to increase, especially in the SW United States of America and South Europe (Fig. 35), threatening transport infrastructure and resulting in road and rail closures. There is also an increased likelihood of mudslides in areas that have been deforested by wildfires. Airports could also suffer due to wildfire-induced decreases of visibility.

On the other hand, warmer winters could result in reductions in snow and ice removal costs, extend the construction season and improve the mobility/safety of passenger and freight. The projected decrease in the number of very cold days could reduce ice accumulation on vessels, decks, riggings, and docks, ice fog and ice jams in ports. Conversely, the greater number of freeze-thaw days projected for the northern regions could result in road and bridge damages (e.g. National Research Council, 2008).

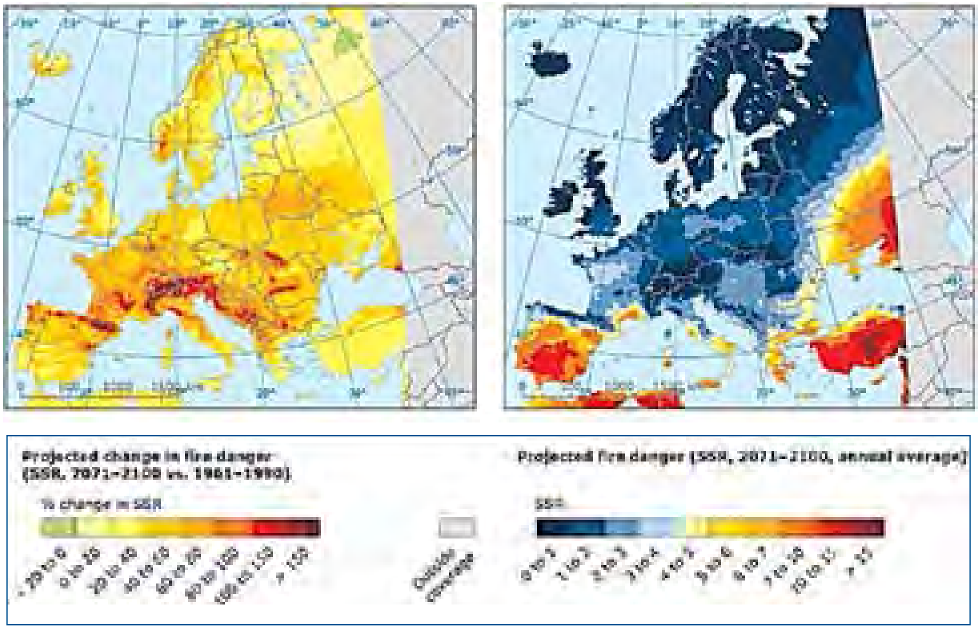

Figure 35 Projected changes in fire danger expressed as Seasonal Severity Rating (SSR)[11], based on projections of Regional Climate Model (RCM) RACMO2 driven by the Global Climate Model (GCM) ECHAM5 for the SRES A1B scenario (EEA, 2012). The results suggest that climate change could lead to a marked increase of fire potential in SE and SW Europe, as well as the Black Sea region.

Rising temperatures could also affect airport facilities and runways in particular, although airports in the northern regions could benefit from reductions in the cost of snow and ice removal. More temperature extremes may create operational difficulties, such as greater energy consumption by planes on the ground. They could also affect aircraft lift, as hotter air being less dense reduces the lift produced by the wing and the engine thrust. Thus, planes would require faster take offs and, thus, longer runways. In the case of airport with short runways, payload restrictions, flight cancellations and service disruptions could be instigated. A recent study indicates a 17 per cent reduction in freight carrying capacity for 747s at the Denver airport by 2030 and a 9 per cent reduction at the Phoenix airport due to increasing temperature and water vapor (Karl et al., 2009).

Inland waterways (IW) can be seriously affected by low water levels during heat waves (Fig. 36). Projections show that although until 2050 transport in the European inland waterways will not be significantly affected by CC (Siedl, 2012), in the later part of the century there could be serious problems due to decreased river discharges (Fig. 37). This could result in fewer routes, shorter shipping seasons, reduced cargo carrying capacities and increased fuel costs (t/km), as well as increased accidents from vessel grounding (e.g. Siedl, 2012; Turpjin, 2012). In such cases, freight movements could be seriously impaired, and extensive and expensive dredging could be required to maintain shipping channels (e.g. Karl et al., 2009; Krekt, 2010).

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[11] 11 The SSR index is the seasonally averaged daily severity index (that is based on the Canadian Fire Weather Index -FWI), which is deemed to be linearly related with fire suppression difficulties. The Seasonal Severity Rating (SSR) index allows comparison of fire danger from year to year and from region to region and although it is dimensionless, values higher than 6 can be considered in the extreme range.

Figure 36 Impacts of the 2003 drought on the inland waterways of France. With red are shown waterways where navigation was closed and with yellow waterways where navigation was restricted on the 30th August 2003 (Leuxe, 2011- source VNF).

Research was launched in 2013 with funding from the French Ministry of Ecology, Sustainable Development and Energy. This project, entitled "GEPET'Eau" (Eric Duviella – EMD Douai – Armines), helps to meet the transport objectives of National Plan for Adaptation to Climate Change. The proposed approach involves waterways modelling which makes possible water level forecasts and adaptive management. More generally the tool allows management of the water resources in different watersheds. Two goals are sought. First, ensure the water level requirements for an increase in the use of inland waterways networks as an alternative to land transport. Secondly, improve the efficiency of the management of water resources. The economic and service fallout for Voies Navigables de France (VNF) and socio-economic benefits for local authorities is expected at the end of this project.

Recent research (the EU FP7-ECCONET Project) has assessed impacts of climate change on inland waterway transport, as well as potential adaptation measures (see also Heyndrickx and Breemersch, 2012). The project used the Rhine–Main–Danube (RMD) corridor as a case study, focusing on low water conditions. It has been found that over a period of 20 years, the average annual loss due to low water levels has been about €28 million, with the 2003 extreme low water conditions associated with a loss of €91 million (see also Jonkeren et al., 2007). Results based on projections from different climate models have shown no significant effects on low flow conditions for the RMD until 2050, whereas the upper Danube might experience a moderate increase in such conditions. The study has also estimated that dry years may lead to a 6–7 per cent increase in total transport costs compared to "wet" years (see also EEA, 2012).

A PIANC (2006) report has suggested that the IW transport sector has higher capability to respond to such CC drivers than the maritime sector, since in most countries adequate relevant infrastructure exists to control water flows/runoff. At the same time, inland navigation requirements should be viewed against competing needs for water supply, flood control, hydro-power, and irrigation.

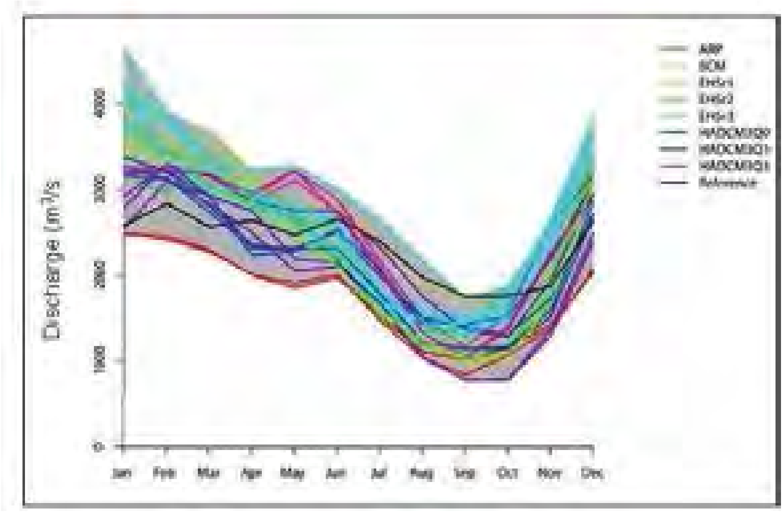

Figure 37 Projections 30-year-long monthly means of river discharge for Lobith (Rhine) for the period 20171-2100 according to different climate models. All models show significant decrease in the summer mean flow. (Ben van de Wetering, 2011).

2.5 Arctic Seas and Permafrost

The decline in the Arctic sea ice extent (see Fig. 15) may have both positive and negative consequences for transport. Thinning and decreases in the extent of the sea ice may be considered as an opportunity for the transport industry (e.g. Bennet, 2011). In addition to the projected longer Arctic shipping seasons and the potential opening of the North West (NW) Passage (see Fig. 15) that may shorten considerably certain shipping routes with substantial economies in, for example fuel costs, climate change may result in opening of new ice-free ports and improved access to natural resources in remote Arctic areas. However, there could also be higher costs for new support services, changes in demand and supply of transport services and considerable costs to link Arctic ports to major national and international inland transport networks (e.g. Bennet, 2011). Thus, the next few decades might prove to be quite unpredictable for shipping services through the new Arctic routes due to a number of factors, including amongst others: (a) the high interannual variability of the sea ice extent in the Canadian Arctic and (b) the loss of sea ice from the shipping channels of the Canadian Archipelago that might allow more frequent intrusions of icebergs that would impede shipping through the NW Passage (ACIA, 2005).

At the same time, lower water levels at the Great Lakes and the St. Lawrence Seaway in North America due to increased evaporation in a warming climate are likely to increase costs, as ships will not be able to carry as much cargo as before. A recent study has shown that, by 2050, there will be a 13-29 per cent increase in shipping costs for the Canadian commercial inland navigation due to these lower water levels (National Research Council, 2008). In addition, degradation of coastal roads and railways is projected due to increased coastal erosion induced by (a) wave action at the ice free coasts and (b) coastal permafrost thawing (e.g. Lantuit and Pollard, 2008). Construction and maintenance costs could also increase to restore related damages to infrastructure, equipment and cargo, whereas higher energy consumption in ports and other terminals, as well as challenges to service reliability are expected (e.g. Crist, 2011).

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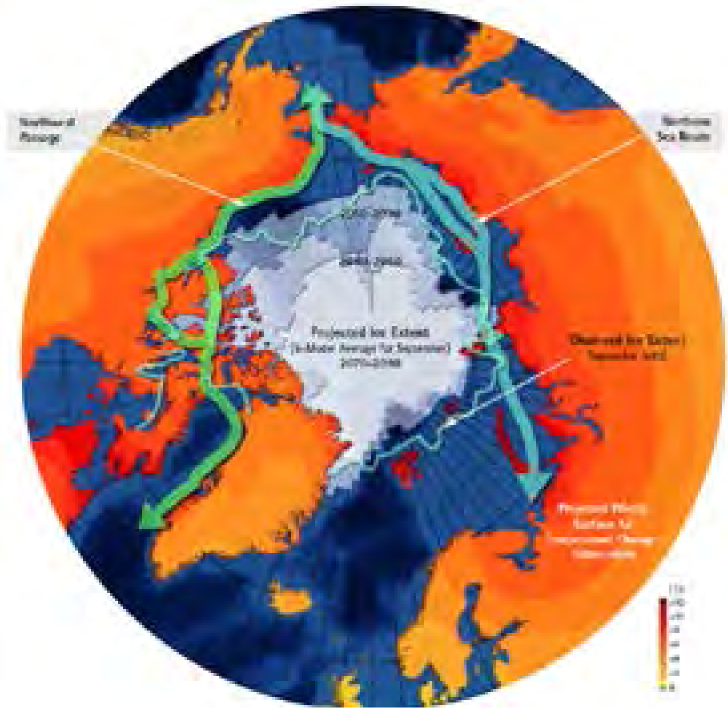

Figure 38 Projected (2090) permafrost distribution in the northern ECE region compared with that of the beginning of the 21st century (ACIA, 2005)

Climate warming leads to permafrost degradation, such as seasonal frozen soil thawing (to 0.4-0.8 m depth) and a northward shift of the isotherm (Fig. 38) that characterizes the southern permafrost boundary (e.g. Sherstyukov, 2009). Changes in the permafrost distribution and the freezing and thawing cycles is likely to increase the risk of natural hazards, such as rock falls, debris flows and ground subsidence (Huggel et al., 2012), can damage building foundations and disrupt the operation of vital infrastructure. Climate change may lead to shrinkage of the total permafrost area by 10-12 per cent in the next 20-25 years, with the southern permafrost borders moving 150 - 200 km to the north (Anisimov et al., 2004). In Alaska, Daanen et al. (2012) have suggested that the observed acceleration of permafrost movement over the last 30 years is likely related to Active Layer deepening and permafrost warming due to climate change.

Model projections (forced with the A1B emission scenario) indicate that the temperature at the top of the permafrost will increase substantially by the end of the 21st century and that the near-surface permafrost in the low elevation Alaskan interior will almost disappear (Streletskiy et al., 2012). Finally, a recent study (Zhang et al., 2012) that took place in Ivvavik National Park, Yukon, Canada, has also predicted significant decreases in the permafrost cover.

The challenges permafrost thawing presents for transportation are considerable (e.g. Field et al., 2007; Qingbai et al., 2008). Permafrost thawing causes settling of the roadbeds and frost heaves at the roadways that affect the integrity of the structures and their load-carrying capacity. In northern areas of the ECE region, Alaska for example, many highways are already located in areas with discontinuous patchy permafrost, resulting in substantial maintenance costs (e.g. Karl et al., 2009). When permafrost thaws, roads buckle and vehicles are only allowed to drive across certain roads when the ground is frozen solid. In the past 30 years, the number of days when travel is allowed has decreased from

200 to 100 days per year (Karl et al., 2009). Currently, more than 1200 road miles and ~ 90000 people are susceptible to > 50 per cent permafrost (Fig. 39) and, thus, susceptible to permafrost thawing impacts.

Bridges are particularly sensitive to movements caused by thawing permafrost and are often much more difficult than roads to repair and modify. Thus, climate change considerations are even more critical in the design of these facilities than is the case for roads. In addition, temporary ice roads and bridges, which are used in many parts of the northern territories to access communities and provide support for the mining and oil and gas industries, are also under stress. Rising temperatures have already shortened the season during which these critical facilities can be used. Moreover, rail networks that are located in permafrost terrains can be affected, through frost heaving and thawing- induced subsidence that can affect parts of their tracks, increasing substantially maintenance costs (ACIA, 2005).

Finally, airports built on permafrost will require major repairs and relocation, if their foundations are compromised by thawing. A recent study (Larsen et al., 2008) has estimated that the cost of maintaining Alaska's public infrastructure will increase by 10-20 per cent (by $ 4 - $ 6 billion) in 2030 due to warming, with roads and airports accounting for about half of this cost. Additional costs will be involved in the maintenance of pipeline systems. As most of these systems were designed in the early 1970s on the basis of the then climate and permafrost condition, they will need continuous monitoring and maintenance and repairs (Karl et al., 2009).

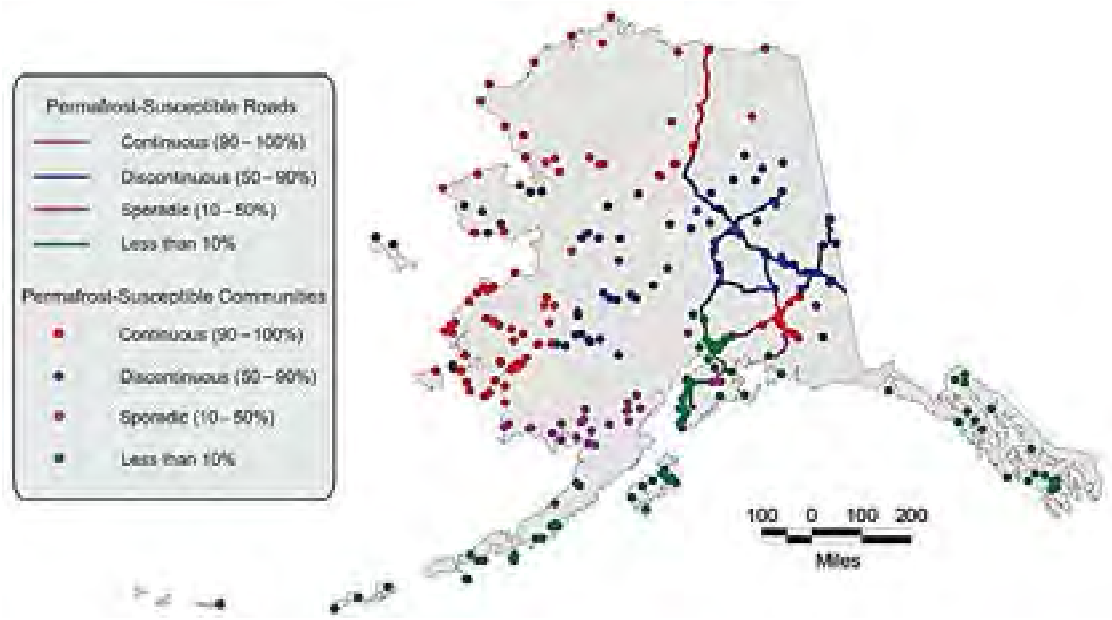

Figure 39 Permafrost susceptible roads in Alaska (USARC, 2003)

2.6 Implications from changes in transport demand (indirect implications)

It should not be forgotten that the transport industry is a demand-driven industry. Climate change can have significant effects in, almost all, sectors of economy, and thus affect indirectly transport services and, thus, international transport networks. For example, commodity transport will be certainly affected, as significant changes in production (and its spatial distribution) are predicted under a changing climate. For example, the productivity of crop/livestock is extremely vulnerable to climate change. The United States of America crop yields could decrease by 30 – 46 per cent over the next century under slow global warming scenarios, and by 63 – 82 per cent under the most rapid global warming scenarios (Thornton and Cramer, 2012).

Schlenker and Roberts (2009), who studied the temperature effects in the United States of America corn (41 per cent of the global production), soybean (38 per cent of the global production) and cotton, have predicted yield increases with temperatures of up to 29 - 32 °C, and sharp decreases above these temperatures. They found 79, 71, and 60 per cent reductions in yields, respectively, under the rapid warming scenario and 44, 33, and 25 per cent reductions under the slower warming scenario. Similarly, the yields of wheat, the most important plant-derived protein source - mean annual per capita consumption ~ 76 kg in 2008–2010, are predicted to decrease in most parts of the world (Gbegbelegbe et al. 2012), with warmer temperatures and more frequent extreme temperature events (but see Varshney (2011) for negative feedbacks by the elevated CO_2 levels). Recent evidence suggests that modeled rates could be significantly underestimated (Lobell et al. 2012).

At the same time, demand for wheat in the developing world is projected to increase by 60 per cent by 2050 (Rosegrant et al. 2009). Concerning Europe, a study by Supit et al. (2010) have shown that changing temperature and radiation patterns will likely affect the European crops. Impacts will vary depending on the crop (e.g. Fig. 40), but the general trend is projected to be negative for S. Europe and positive for N. Europe (EEA, 2012).

Popular tourism destinations are generally remote, requiring increased volumes of passenger and goods transportation by sea and air. At the same time, tourism has, over recent years, increasingly become synonymous with beaches (Phillips and Jones, 2006), a coastal landform that is under an increasing threat of climate change-induced erosion (SREX, 2012). In addition to beach erosion, inundation of tourist infrastructure in coastal areas due to climate extremes (e.g. Snoussi et al., 2008), salinization of the groundwater

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resources due to sea level rise, overexploitation of coastal aquifers (e.g. Alpa, 2009) and changing weather patterns (Hein et al., 2009) will pose additional stresses to an industry (e.g. Rigall-Torrent et al., 2010; Pacheco and Lewis-Cameron, 2010) that will also have to deal with climate change impacts on vital transport infrastructure such as seaports, airports and coastal roads (see ECLAC, 2011; Velegrakis, 2012). Therefore, shocks to tourist flows and related transport are projected, due also to adjustments in consumption preferences and regional income reallocation. At the same time winter sport industry attracts millions of tourists each year, generating in for example Europe nearly € 50 billion in annual turnover (EEA, 2012). The widespread reductions in snow cover projected over the 21st century (see Section 2.2) will affect snow reliability and consequently the length of the ski season. Substantial reductions of naturally snow reliable ski areas have been projected for the Alps, for several areas of Europe (e.g. Endler and Matzarakis, 2011). In Table 4, a summary of potential climate change impacts on transportation is presented.

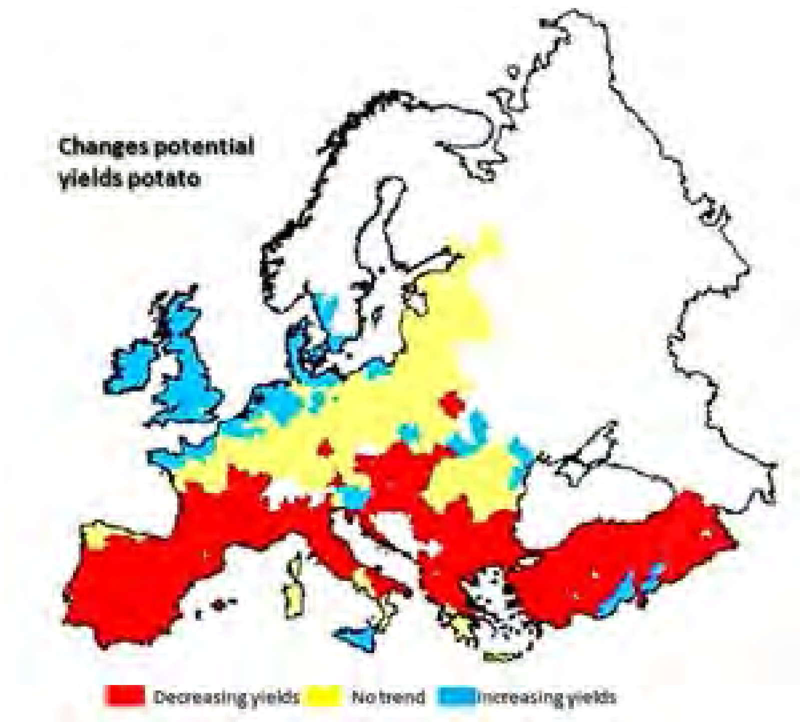

Figure 40 Long term simulated trend of the potato yield in Europe (Supit et al., 2010). Key: blue, significant increase; red, significant decreasing yields .

Table 4 Summary of potential climate change impacts on transportation (the list is not exhaustive).

Factor	Impacts		
Temperature	**Road**	**Rail**	**Ports, IW and airports**
Factor	**Impacts**		
Temperature	Road	Rail	Ports, IW and airports
Higher mean temperatures; Heat waves/ oughts;Increased variability in warm/cool days	Thermal pavement loading/ degradation; asphalt rutting; thermal damage of bridges; increased landslides in mountains; asset lifetime reduction; increased needs for cooling (passenger/freight) and, thus, fuel; shorter maintenance windows; increased construction and maintenance costs; changes in demand	Track buckling; infrastructure and rolling stock overheating/failure; slope fires and failures; electronics and signaling problems; speed restrictions; asset lifetime reduction; higher needs for cooling/ fuel; shorter maintenance windows; increased construction and maintenance costs; demand changes	Damage to infrastructure, equipment and cargo; higher energy consumption for cooling cargo; lower water levels and restrictions for inland navigation; air transport payload restrictions; warmer weather will reduce snow/ice removal costs and extend the construction season
Permafrost degradation and thawing; Reduced arctic ice	Road buckling; decreases in travelling days; slope instability and embankment failures; coastal erosion affecting coastal roads	Rail track damages; slope instability and embankment failures; freight and passenger restrictions	Damages in port and airport infrastructure; longer shipping seasons-NSR; shorter shipping routes-NWP/less fuel costs, but higher support service costs
Precipitation	Road	Rail	Ports, IW and airports
Changes in the intensity/freque ncy of extremes (floods and draughts)	Inundation; increased landslides and slope, earthwork and equipment failures; impacts on vital nodes e.g. bridges; poor visibility that increases accidents; more frequent slush flows; delays; changes in demand	Submersion, bridge scouring, problems with drainage systems and tunnels; landslides; underground flooding; embankments/ earthwork damages; operational problems; delay, changes in demand	Land infrastructure inundation; damage to cargo and equipment; navigation restrictions in inland waterways due to droughts;
Winds/thunder storms	Road	Rail	Ports, IW and airports
Changes in frequency and intensity of events	Damages to fence; road accidents	Damages to installations and catenary; overvoltage; disruption to operations	Problems in vessel navigation and berthing in ports
Sea level/storms	Road	Rail	Ports, IW and airports
Mean sea level changes;	increased risks of coastal inundation and erosion	Bridge scour, Installations/ Catenary damage,	infrastructure/cargo damages from inundation and wave energy
Increased destructiveness of storms/storm surges; Changes in wave energy and direction	affecting coastal roads; temporary inundation, Unusable roads during storm surge	Restrictions/Disruption of train operation, Embankments/ Earthwork flooding	changes; higher port construction and maintenance costs; sedimentation in port/ navigation channels; effects on key transit points (e.g. the Panama Canal); people/ businesses relocation, insurance issues

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Chapter 3. Questionnaire Analysis

For the purposes of the present study, a questionnaire survey has been undertaken in order to better understand and assess perceptions, capacities and activities related to climate change impacts and relevant adaptation policies/measures. A questionnaire consisting of 44 questions (see Annex IV) was sent out to Governments and Organizations by the UNECE secretariat and 34 responses were received (see Annex V). An analysis of these responses is presented below.

3.1 Level of awareness, information availability on climate change impacts

On the question of the extent to which the respondents consider climate change as a problem for transport [Q1, see Annex V], 62 per cent of the respondents answer that it is viewed as a serious problem (rating above 6 in a 1 - 10 scale) in their country and region. Moreover, almost one third (31 per cent) of the respondents consider that climate change presents a current and near future challenge (0 - 15 year time scale), whereas almost 80 per cent consider that climate change will present problems within the next 30 years [Q2]. If the transport infrastructure planning, design and construction time lines are considered, together with the long life span of the infrastructure elements and the projected climate change (Fig. 41), then the respondents seem to suggest that there is an urgent need for relevant initiatives, now. At the same time, 54 per cent of the respondents consider that the level of knowledge/awareness on the climate change impacts on transport is rather poor in their country/region of origin [Q3].

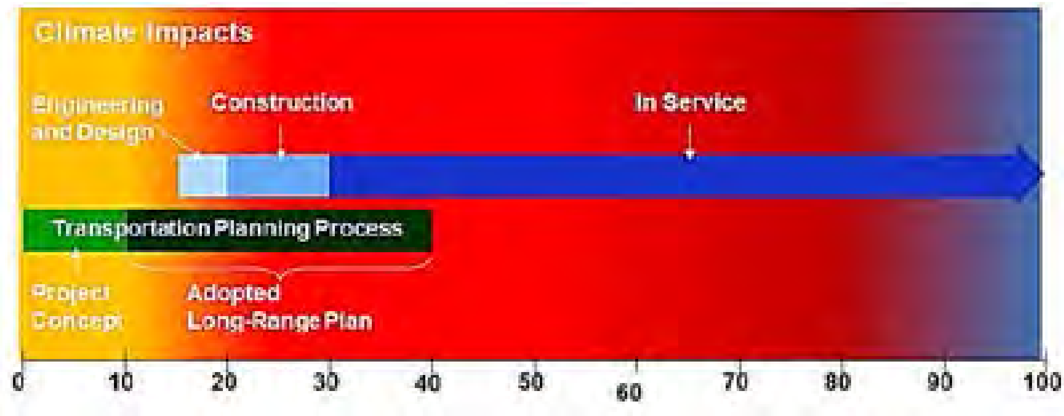

Figure 41 Transportation infrastructure time lines compared to climate change time lines (CCSP, 2008). Due to the long processes and the long life time of infrastructure, climate change impacts must be taken into account at the early stages of the planning, design and construction.

An interesting point that emerged from the answers was on the main target audiences when raising awareness about climate change impacts on transport (Fig. 42). 38 per cent of the respondents consider that public regulatory bodies, ministries and local authorities, should be targeted, whereas a very considerable fraction (43 per cent) are convinced that the target audience for raising awareness should ideally be industry operators, investors, managers and infrastructure providers. At the same time, only 16 per cent of the respondents find that very important stakeholders, such as the users, transport companies and the general public, and the insurance industry should be targeted for raising awareness.

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These answers suggest that the respondents believe that either it is the awareness of the regulatory bodies and the transport industry that is in question, or that the users and the insurance industry do not play a significant role in this debate. It must, however, be pointed out that such 'top-down' approach on the target audiences may just reflect the demography of the respondents (more than three quarters of the respondents are from Governments).

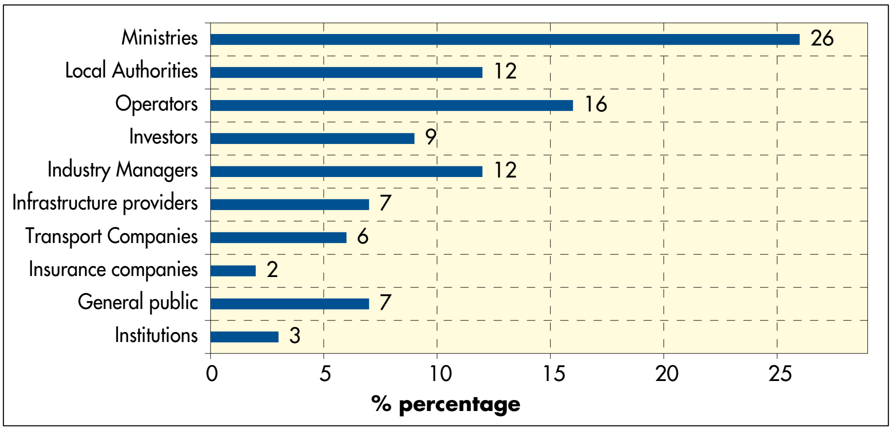

Figure 42 Main target audiences for raising awareness on climate change impacts on transport according to the Questionnaire respondents.

With regard to the severity of the impacts of the weather/climate factors (rising temperatures, extreme events, droughts, floods, sea level rise and storm surges, thawing permafrost etc) on transport, the respondents appear to be divided, with 52 per cent considering the impacts severe (they rate them > 6 in a 1 - 10 scale) and the remainder relatively mild (rating < 6 in a 1-10 scale) [Q5]. In terms of transport mode, 54 per cent of the respondents answer that roads and railways bear the brunt of the climate/weather-induced impacts [Q6]. Impacts on sea and inland water navigation, air transport and logistics centers are considered important by only 15, 9, 11 and 4 per cent, of the respondents, respectively.

Concerning the existence of specific assessments of the vulnerability of transport modes, networks, operations, infrastructure etc. to weather and/or climate change factors, a clear majority of 65 per cent of the respondents answer positively [Q7]. Similarly, 63 per cent of the respondents answer that their country or organization has carried out assessments of potential climate change impacts, but only 50 per cent are aware of studies estimating costs of actual or potential damages to transport infrastructure [Q8]. The impacts of floods and rising temperatures on infrastructure appear to be those mostly studied. This can be explained by the fact that these factors affect mostly roads and railways (see also Section 2). Nevertheless, 59 per cent of the respondents are also aware of studies concerning the effects of sea level rise and storm surges on coastal transport infrastructure (Fig. 43). With regard to impacts on transport operations or services, floods are also the factors mostly studied, followed by extreme winds, rising temperatures and sea level rise and storm surges. In comparison, heat waves do not appear to have been a widespread study objective accounting for only 33 per cent; although climate change projections indicate an increase in their frequency and duration in the 21st century (see also Section 3.4). Finally the low priority of studies on the effects of permafrost thawing may simply reflect the geographical constraints of the impacts as well as the respondent demography. According to the respondents, the major limiting factor for the study of climate change impacts on transport is the lack of funds and competing priorities (51 per cent) [Q9]. Interestingly, lack of awareness amongst the general public is also mentioned as a reason by 22 per cent of the respondents (but see answer to Q4).

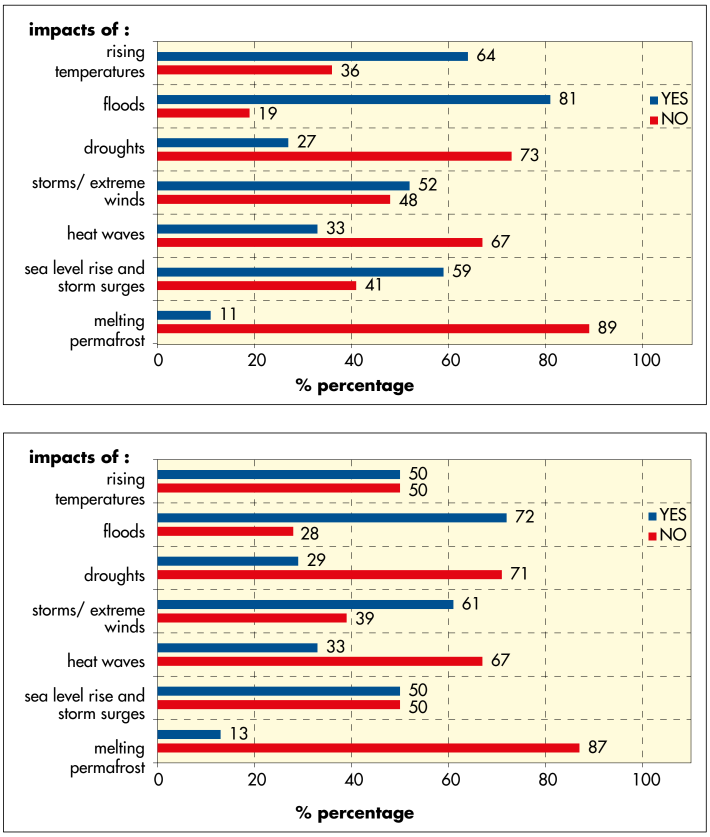

Figure 43 Respondents' awareness of studies on specific weather/climate change impacts on (a) transport infrastructure and (b) transport operations and services.

According to the respondents, the most important actors in the study, research and dissemination of information on climate change impacts on transport [Q10] should be the Environment and Transport Ministries, followed by Engineering Institutions and Universities. International Organizations are also regarded as important (Fig. 44), whilst the role of private companies is considered less important (rating > 8 on a 1 - 10 scale of 55 per cent). Potential increases in tourism and agricultural production are cited as the most important opportunities for transport that may arise in response to climate change. Some respondents identified also as opportunities the demand or creation of new jobs in the construction and retrofit of the transport infrastructure, in the research and development of climate proof and resilient infrastructure and the transport planning and policy sector [Q11].

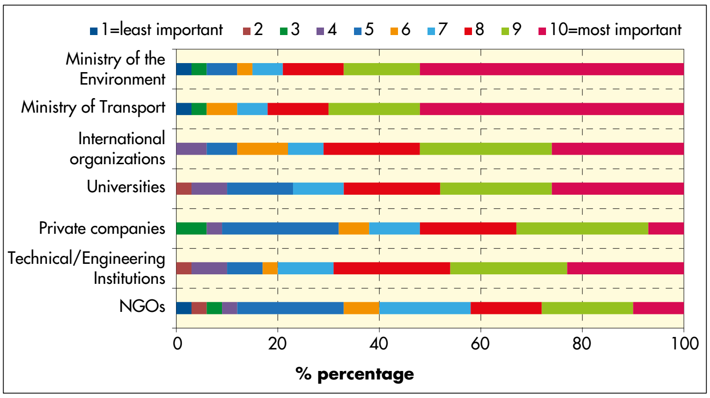

Figure 44 Extent to which actors/entities are considered important for the study/research/ dissemination of information on climate change impacts on transport.

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3.2 Level of preparedness and existing and planned transport adaptation policies, measures and initiatives

With regard to a general adaptation strategy to climate change impacts, 36 per cent of the respondents answer that their country or organization has implemented or adopted one, 34 per cent that a strategy has been planned and the remainder 30 per cent that there is none so far or 'they do not know' [Q12]. Similar answers were provided on the question of whether the respondents' countries or organizations have transport specific adaptation plans [Q14]. 47 per cent of the respondents' state that a cost-benefit analysis with regard to any climate change adaptation plans or strategy [Q13] has been conducted (22 per cent) or is planned to be conducted (25 per cent). The majority of 53 per cent, however, indicate that such an analysis has not been planned or conducted (28 per cent that they are not aware of any). On the question of the effectiveness of any transport specific adaptation strategy adopted, the relatively few relevant answers provided a mixed picture, with only 15 per cent rating the plans as very effective [Q15]. It also appears that there is a 'mixed bag' of answers concerning the evaluation strategy and methodology regarding adaptation measures [Q16]: 39 per cent of the respondents have not provided answers, whereas the remainder indicate that the evaluation methods in place are progress reports (14 per cent), performance measures (14 per cent), comparisons with standards (6 per cent), ongoing risk assessments (6 per cent), monitoring gas emissions (6 per cent), monitoring indicators (6 per cent) and scientific monitoring (6 per cent).

On the question of what concrete actions have been, or are planned to be taken to build transport network resilience to climate change impacts [Q17], about 25 per cent of the answers provided suggest that no response actions have been or are planned to be taken, whereas the remainder appear to be aware of or have taken a large variety of adaptive actions or measures, reflecting both the arising needs and their field of competence (Fig. 45). These appear to be related to some or great extent to the investment, design and construction and operation of the networks [Q18].

However, no further details were provided. Interestingly, one respondent suggested that building TEN -T networks would be a step forward in building resilience in the transport networks (see, however, Section 4.15).

Concerning the inclusion into the planning or design of new transport infrastructure of considerations of climate change effects (e.g. extreme events, increased rainfall, rising sea levels, etc.) [Q19], the large majority of the respondents state that such effects are considered to some (59 per cent) or to a great extent (28 per cent). According to the respondents, the main best practices/lessons with respect to transport adaptation to climate change [Q20] are related mostly to the awareness and assessment of future impacts (22 per cent), effective planning (9 per cent) and the cooperation between all stakeholders (10 per cent). Regarding the development and/or planning of emergency response systems [Q21], the majority of the respondents state that their country or organization has already adopted and implemented emergency response systems for the transport sector as a whole and/or the transport sub-sectors, separately. Finally, it appears that according to the respondents' knowledge, the insurance industry has integrated climate change considerations into products offered to the transport sector/industry in few cases and only to some extent (29 per cent).

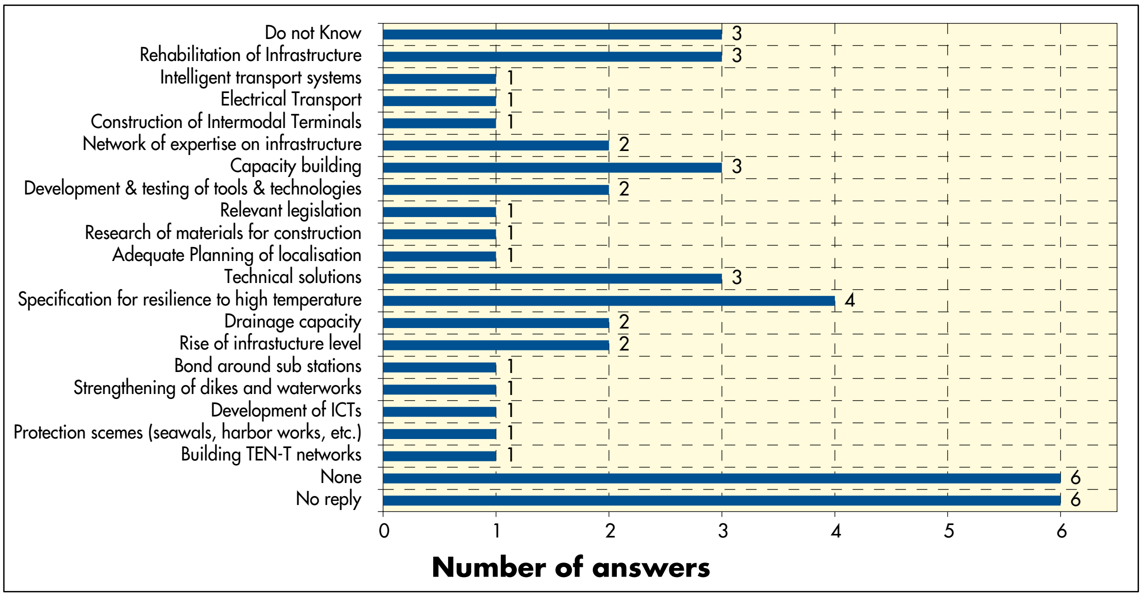

Figure 45 Response measures taken or planned to be taken to build resilience in the transport networks.

3.3 Information data and research needs and other requirements, including financing

The issues of data and research needs as well as of financing are fundamental. The type of information/data or predictions that can be most valuable for achieving effective preparedness and designing adequate responses to climate change impacts on transport [Q23] have been identified by the respondents to be mostly related to precipitation (28 per cent), temperature (24 per cent), extreme land winds (23 per cent) and coastal storm surge and sea level rise (20 per cent). It appears again that the impacts of floods, rising temperatures and extreme winds on transport infrastructure and services are those that the respondents are mostly concerned with, as these factors have impacts mostly on the road and rail infrastructure and services. It must be noted, however, that as the impacts of these factors on transport are those mostly studied (see Fig. 43), the respondents may be of the view that much more should be done in terms of the monitoring and prediction of these factors. The respondents also state that the best sources of relevant information are the Public Authorities and National agencies (42 per cent in combination), followed by relevant Institutions (13 per cent) and Universities (7 per cent) [Q24]. It is worth mentioning that the suitability of International and European Agencies as sources of relevant information is rated as very low (5 per cent); this view is difficult to reconcile with the significant role that the respondents assign to International Organizations in the study, research and dissemination of information on climate change impacts on transport (see Fig. 44).

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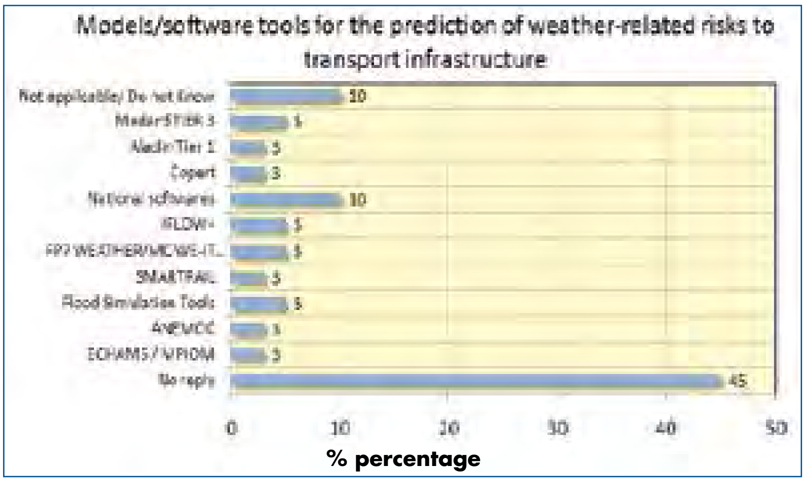

Figure 46 Models/software tools identified (by some of the respondents) for the prediction of weather-related risks to transport infrastructure *[Q28]*.

In terms of data/information availability [Q25], the rating of the respondents appears to be negatively skewed i.e. more respondents rate the availability as poor (6 per cent) and bad (27 per cent) than very good (9 per cent) and excellent (9 per cent). Similarly, with regard to suitability, relevance and quality of the available data/information [Q26], the rating of the respondents is negatively skewed: poor, 6 per cent; bad, 27 per cent; good, 40 per cent, very good, 15 per cent, and excellent rating, 6 per cent. More than half of the respondents (58 per cent) appear not to be aware of the existence of operation models and software tools, able to predict weather-related risks to transport infrastructure [Q27], whereas a considerable minority (42 per cent) appears to know of such tools (see Fig. 46). This suggests that there is an urgent need of further cooperation and wider dissemination of the relevant information and tools within the ECE region.

The funding mechanisms and sources, both existing and potential, to support the study of impacts and adaptation activities identified by the respondents [Q29] relate mostly to the public purse: 22 per cent of the respondents mention National funds, 17 per cent EU funds, and 11 per cent International funds, with few of the respondents suggesting potential funding from private investors (5 per cent), donations (5 per cent) and/or existing initiatives (7 per cent). It is worth mentioning that 1/5 of the respondents do not identify any existing and/or potential funding mechanism, again suggesting the need for further cooperation and wider dissemination of the relevant information within the ECE region. Regarding the specific priority areas that require further attention to enable effective adaptation strategies in transport [Q30], the respondents rate more highly (Fig. 47) the determination of impacts (15 per cent), the vulnerability assessments (10 per cent), research and funding (12 per cent) and the adaptation of strategies/technologies (10 per cent) and the development and installation of advance warning systems (9 per cent). It appears that there is a clear message for a need for further research and study on the risks of climate change and its impacts on transport and on effective warning and adaptation measures.

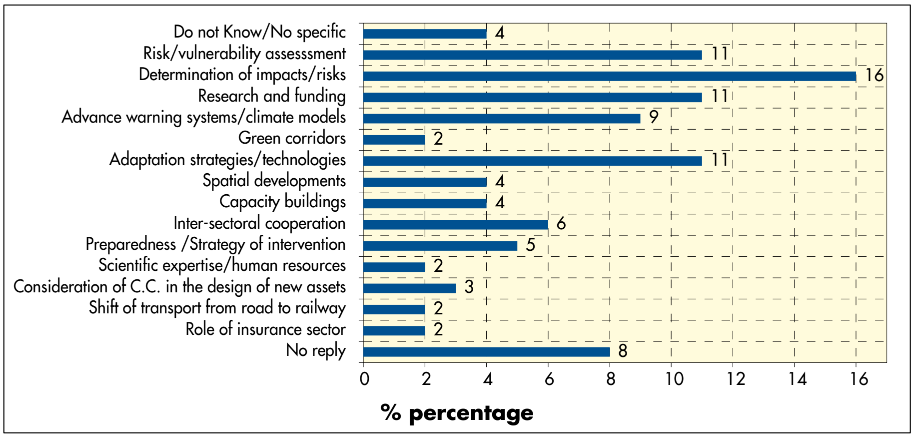

Figure 47 Specific priority areas requiring further attention according to the respondents.

3.4 Collaboration mechanisms at national/local, regional and international levels

According to the respondents, the most useful mechanisms of cooperation in order to address in a structured and coordinated manner the issue of climate change adaptation for transport [Q31], are detailed in Fig. 48. The answers appear to be diverse with the non-committing answer '*cooperation between actors*' being the most common (25 per cent). It is, nevertheless, interesting that several responses advocate the establishment of networks of infrastructure experts (9 per cent), multilevel working groups (9 per cent) and Government/ Institution partnerships (18 per cent), as well as inter- ministerial and transnational cooperation.

At the same time, a large fraction of the respondents do not find the current level of cooperation at the national and local level adequate with only 34 per cent state that the cooperation level is very good or adequate [Q32]. The situation does not improve when there is scale shift to regional and sub-regional cooperation. In this respect, although it appears that there is a policy and practice of exchange of relevant information [Q33], only 22 per cent of the respondents appear to be satisfied [Q34].

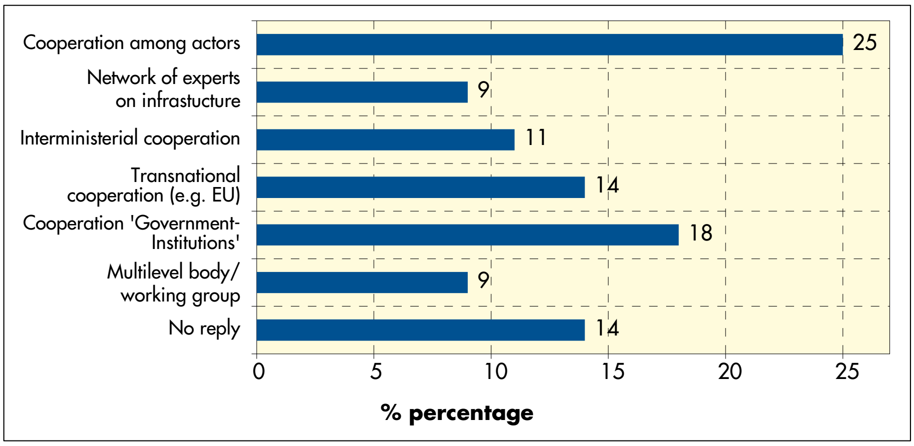

Figure 48 Useful mechanisms of cooperation to address transport adaptation to climate change, according to the respondents.

In comparison, the respondents are more satisfied with the cooperation at the international level, with 42 per cent stating that this is very good or adequate [Q36] and they also detail methods [Q37] for this cooperation to be upgraded (Fig. 49). Finally, in response to the question whether amendments to certain regional agreements within the ECE region merit serious consideration with a view to promoting or facilitating climate change adaptation of transport networks, 32 per cent of the respondents answer positively, 10 per cent consider this a possibility and 10 per cent answer in the negative.

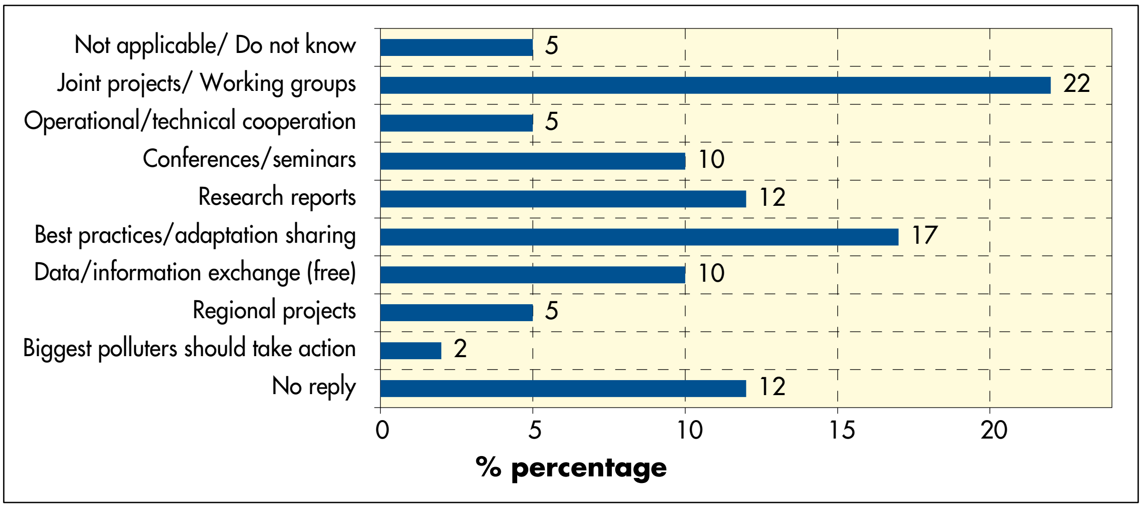

Figure 49 Proposed types/methods of international cooperation that can be usefully used to address climate change impacts and adaptation requirements.

Gara de Nord, Bucuresti, Heavy Snow and Blizzard in january 2008 © Club Ferroviar

3.5 Specific questions for road and rail infrastructure and inland waterways

On the question of awareness and understanding of the public administrations and organizations of the vulnerabilities of current road and rail infrastructure to natural hazards [Q38], a significant fraction (42 per cent) of the respondents answer outright positively. Nevertheless, it appears that there is a scope for raising awareness, as many respondents (34 per cent) do not provide any answer and 24 per cent would like the awareness or understanding to increase. Similarly, when the question becomes more detailed (i.e. what is the likelihood of a stretch of road or railroad to be damaged by a flood and what are the consequences), only 44 per cent of the respondents appear to be relatively well informed on the specific risks and likely consequences [Q39]. In addition, on the question of the establishment of mechanisms to assess current levels of risk [Q40], only 23 per cent of the respondents provide outright positive answers, with a further 18 per cent stating that they are in the process of establishing one or that mechanisms exist only for specific occasions.

A clear pattern emerges out of the answers to questions concerning climate change and variability effects on the inland waterways [Q41-44]. In respect of all these questions, 50-70 per cent of the respondents do not provide answers, probably due to the particularities of this transport mode and the demography of the respondents (i.e. responses from countries or organizations with no or little inland waterway infrastructure and services). The remainder of the responses appear to suggest that climate change effects could be significant and diverse (e.g. Fig. 50), but manageable.

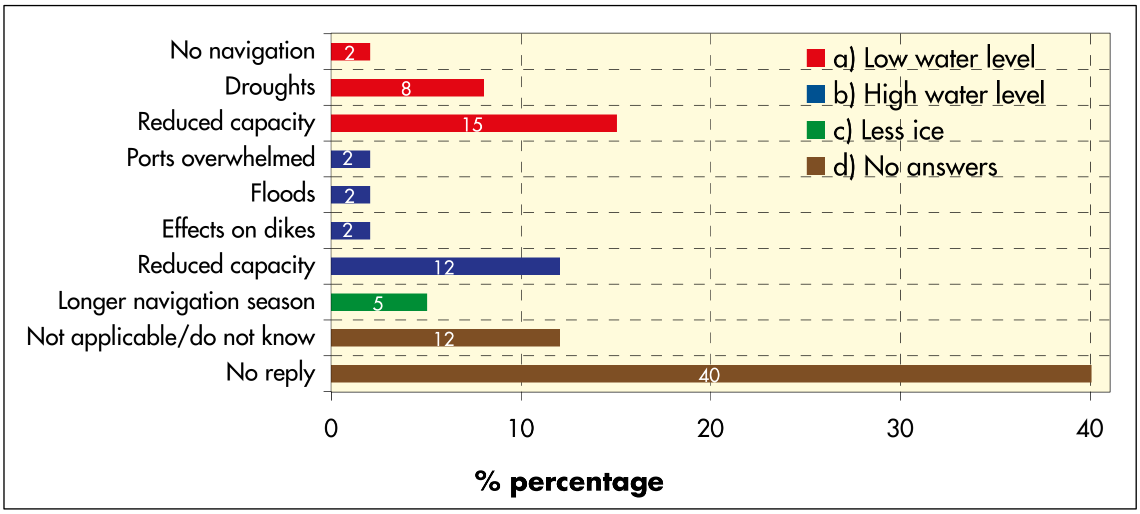

Figure 50 Diversified effects of climate change on the inland waterway infrastructure and services.

Putna Seaca Rail Bridge, Romania. Damaged by Floods in 2005 © Club Feroviar

Chapter 4. Potential adaptation measures to climate change impacts

4.1 Introduction

International transport is widely recognized as a trade and mobility enabler, a social development driver and an engine of growth. On the other hand, the ever increasing freight and passenger transport volumes[12] are associated with adverse impacts on the environment, energy consumption and climate. For example, transport currently accounts for about 62 per cent of the global oil consumption, which is projected to grow by about 1.4 per cent per year till 2035 with transport accounting for about 82 per cent of the global liquid fossil fuel consumption (IEA, 2012; UNCTAD, 2012). This may have, amongst others, significant energy security (e.g. Haydock and Kollamthodi, 2009) and emission policy implications[13]. If these patterns are left unchecked, there will be an increased potential for the deterioration of the environmental and energy conditions that will eventually undermine economic development and growth. It is for this reason that climate change mitigation has become increasingly important on the international policy agenda, including for work under the auspices of the UNECE-ITC (e.g. Rothengatter, 2009). As growing freight and passenger transport will increase traffic congestion and pollution risks as well as costs[14], a mobility strategy that is sustainable, energy-efficient and as environmentally-friendly as possible, is urgently required.

There is no market integration/globalization without integrated transport networks. This widely- accepted premise has been behind the common transport policy principles set out in for example the founding treaties of the European Union (see e.g. EC, 2012b) and many ECE initiatives. In order to establish an effective, integrated multimodal network throughout the ECE region, efficient land, sea and air international transport networks should be established that will allow goods and people to circulate easily, safely and quickly between Member States, also ensuring effective connections to other international trade partners (see e.g. Fig. 16 and 19). An obvious option is the optimal combination of various modes of transport such as co-modality within the transport chains, which will promote technical innovation and a shift towards the most sustainable, energy efficient and least polluting modes of transport[15]. At the same time, evolving sustainable transport strategies should

[12] For example, there have been estimations suggesting that commercial freight transport (in tons x km) will triple by 2050 (UNCTAD, 2012).

[13] The transport sector currently accounts for about 13 per cent of all GHG emissions (about 25 per cent of the CO_2 emissions); these emissions have been projected to increase by 1.7 per cent per year until 2030 (UNCTAD, 2012). In the USA, GHG emissions from transportation account for about 28 per cent of the total emissions (in CO_2 eq) (http://www.epa.gov/climatechange/ghgemissions/sources/transportation.html).

[14] For example, the cost of EU infrastructure development to match the demand for transport has been estimated at over €1.5 trillion for the period 2010-2030. The completion of the TEN-T network requires about €550 billion until 2020, € 215 billion of which has been earmarked for the removal of the main bottlenecks (http://ec.europa.eu/transport/themes/sustainable/index_en.htm).

[15] Emissions for freight by transport mode (in kg CO_2 per ton x km): Road transport (> 35 t lorries) 0.051-0.091; diesel trains 0.017-0.069, electric trains 0.019-0.040; bulk carriers 0.0025-0.008, container ships (< 8000 TEU) 0.013-0.020; Ro-Ro vessels, 0.050-0.060; air long haul transport (> 1600 km) 0.57-0.63 (Crist, 2012, see also http://www.airportwatch.org.uk/?page_id=3262 (accessed 17.08/2013)). Emissions for passengers by mode (in kg CO_2 per passenger for each km): Passenger cars 0.124, two wheelers 0.083, city buses 0.067, coaches 0.034; rail transport 0.045; maritime transport 0.043; air transport 0.130 (http://knowledge.allianz.com/mobility/transportation_safety/?813/which-transport-methods-produce-most-emissions, accessed 17/08/2013).

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certainly consider the very significant impacts that climate change and variability may have on transport infrastructure and operations, and plan for effective adaptation measures.

Adaptation measures aim to reduce vulnerabilities and increase the resilience of transport systems to climatic impacts. Resilience refers to the ability of a system to withstand negative environmental impacts without losing its basic functions. In the transport context, resilience does not only concern the physical robustness and durability of infrastructure, but also the ability of the transport system to recover from an incident quickly and at minimal cost. Adaptation measures may thus be considered as 'insurance policies', which are planned and implemented in order to limit future operational and rehabilitation costs incurred by incremental climatic changes, such as temperature and the mean sea level rise, and/or extreme weather events. It must be also noted that adaptation to climate change does not involve only managing risks. It may also offer opportunities to develop innovative and technologically advanced transport infrastructure systems and services.

Most of the present transport infrastructure has been developed under national policy regimes. There are several factors that determine national and regional adaptation options, including amongst others risk assessments and short, mid- and long-term financial implications. To identify priorities for climate change adaptation, facilities must be first classified in terms of their criticality within the transport network (e.g. Potter, 2012) and according to the difficulties and costs involved to make them climate resilient. Facilities that face manageable risks would require risk management and emergency response planning. Termination of a facility should be a last resort, if risks are too complex to deal with, or if relocation could be managed logistically and financially. For example, ports form crucial links of international supply chains, are costly to protect and very difficult to relocate. At the same time, adaptation options will rely on financing, the availability of which from public, 'hybrid' or private entities may prove to be an important determinant of the adaptation policy approaches (e.g. O'Toole, 2008; Parker et al., 2013).

Developing effective adaptation strategies to climate change impacts on transport requires both policy action and collaborative research. Well targeted vulnerability studies, empirical studies and assessment of projected risks and related costs are a first step toward bridging knowledge gaps and identifying priority areas. Such studies have been carried out mostly at the national level and some of those will be briefly presented later in this Chapter.

4.2 Approaches to adaptation policy

Under a changing and variable climate, the resilience of the international transport networks requires integrated approaches that involve several public authorities and Governments and other transport stakeholders from different climatic regions. A review of adopted adaptation approaches and measures (Eisenack et al., 2011; 2012) as well as the findings of the present study (see Chapter 3) show the prevalence of a 'top-down' policy pattern, where a public or 'hybrid' entity/operator initiates, or expected to initiate, actions that will address the adaptation problem.

The development and implementation of adaptation plans and technical measures forms a strategic choice, the different approaches to which are outlined below. The *'no action'* choice (i.e. taking the risk and not planning and implementing relevant technical adaptation measures) although may result in short-term financial savings, may also incur large medium- and/or long- term costs, particularly if the country, or areas of the country, is located in a region considered as a climatic change 'hot spot'. Costs can be direct and

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indirect. Direct costs and losses include human life and injuries, damage to infrastructure as well as consequent reconstruction and rehabilitation. Indirect costs are associated with the varied implications of damaged and/or under-operating transport networks to social life, trade and economy.

It is generally recognized that the *'no action'* option may be tempting, particularly under the current financial conditions. First, public operators may prefer to fund projects having direct benefits that are immediately recognizable by the citizens. In comparison, projects involving climate change adaptation are mostly costly investments for the future. Secondly, it may be difficult for a public operator or a Government to give greater priority to climate adaptation action they may result in relatively higher costs initially, particularly when there are other competing transport policy objectives such as investing in transport networks that could facilitate trade and social connectivity. In such cases, adopting less costly infrastructure standards may present some immediate benefits (e.g. low cost, operational roads) and, thus, be regarded as a pragmatic strategic decision. However, the 'no-action' option will likely result in transport infrastructure failures and damages that will impact on: (a) the national and regional economy (b) social development (c) safety and security and (d) communications and connectivity. In this case, recovery and rebuilding time will be crucial for the magnitude of such impacts, whereas the urgency inherent in the rehabilitation of damaged transport infrastructure is likely to increase costs as normal procedures cannot be followed easily under duress. Such considerations should be taken into account during the cost/benefit analysis of planning and adopting technical adaptation measures (Fig. 51).

For example, the French government believes that if a country does not prepare to adapt to climate change, it will incur costs and damages to the transport sector, as in other sectors, which are much higher than the effort required to adapt economic sectors.

Indeed, man and nature no doubt have the ability to spontaneously adapt to the changes brought about by climate change. However, what are the costs and how long will this adaptation last? If climate change is now obvious, there are still uncertainties about the extent of its impact and the rhythm of its development. This is why France adopted a national adaptation plan that combines practical anticipation and surveillance measures as well as to improve knowledge of the environment.

The French National Climate Change Adaptation Plan was adopted by the State government in July 2011. Given the uncertainty surrounding climate change predictions, evaluations and anticipated impacts, several priorities have guided the drafting of the plan:

(a). Increasing current knowledge in all fields, including the use of a socio-economic approach

(b). Defining methodologies for mainstreaming adaptation

(c). Reinforcing observation and alert mechanisms.

The French experts estimated that climate change impacts all modes of transportation networks. Adaptation is made necessary by the transportation networks and equipment's long duration of use. Various measures have been identified. They provide climate change impact analytical means prevent vulnerabilities of transportation systems and prepare the improvement of resistance and resilience of existing and future infrastructure to ensure continuity and security of the transport services. The actions in the French national plan concern mainly the review of technical standards - revision of construction standards for instance - and operation and maintenance of transport infrastructure standards. They also

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concern the implementation of network vulnerability assessment and risk analysis. To implement this program it is essential to have an assessment of climatic conditions provided by the state which is shared and rolled out at regional level or local (sea level, waves, rainfall, temperature, snow, wind, flow of rivers).

A Pro-active approach to climate adaptation in transport implies a conscious decision to invest in developing and implementing requisite adaptation plans, strategies and measures in the face of climate change impacts. This option appears to also be challenging, not only due to costs but also because it cannot be easily replicated in all environments and is not a 'one-size fits all` exercise. Although previous initiatives and lessons learned should certainly be considered and carefully analyzed, detailed risk assessments that take into account down-scaled climate change factors as well as issues of criticality, sensitivity, exposure and vulnerability of the particular transport system and infrastructure should be undertaken. Such assessments should be followed by cost-benefit analyses associated with investment in climate adaptation in transport under different climatic change scenarios. Lessons learned from different regions show that different locations within one country and regions may require different adaptation response measures. For example, engineering measures adopted by the Japanese railways to respond to the frequent 'freezing' of the signaling systems (Mizukami, 2012) as well as the construction of protective structures (e.g. gabions and concrete walls at the slope toes) to reduce the speed of avalanche-induced debris flows proposed for the northern European roads (e.g. Hudecz, 2012) should be studied by other transport networks. However, these case studies should be modified to reflect differences in local characteristics, including of current and future climatic mean and extreme records as well as their potential impacts.

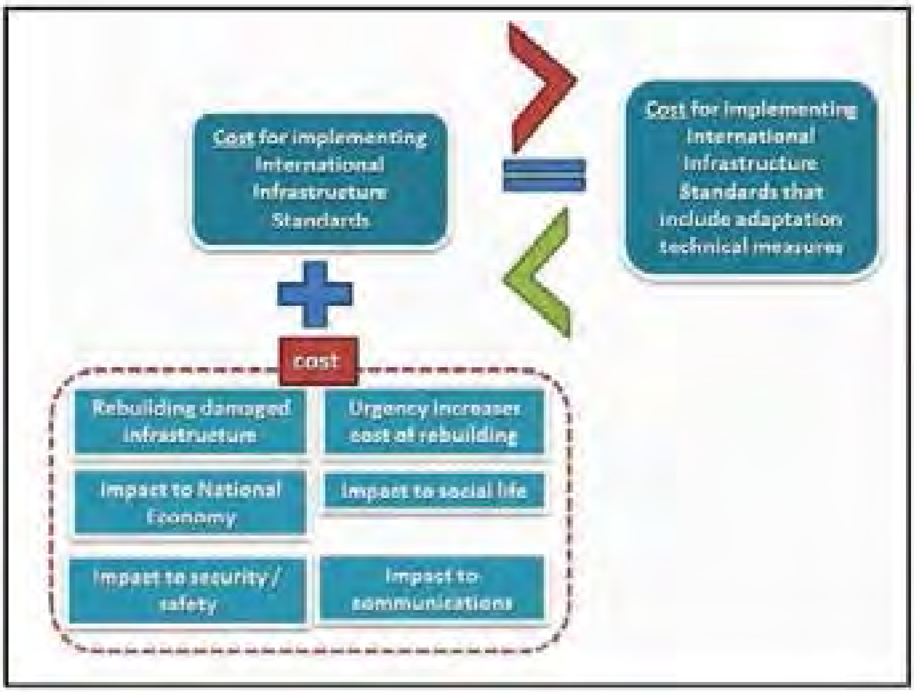

Figure 51 Decision making on cost of building transport infrastructure (Analysis by the ECE secretariat).

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Strategic approaches to technical adaptation measures appear to be controlled by economic considerations with significant constraints impeding a global adoption of technical adaptation measures to projected climate change impacts. In some cases additional factors could also be at play such as when dealing with infrastructure construction standards which depend also on the operational environment i.e. the existence of specific regulation instruments[16] and/or the availability of additional and specific financing. In the absence of specific regulation, economies under stress are more likely to invest in transport infrastructure projects that do not take into full account climate change impacts, unless specific financing becomes available. In comparison, growing economies are more likely to promote a transport infrastructure that integrates new standards that reflect climate change factors and enable adaptation, although financial costs may still influence decisions. As previously noted, replicating adaptation approaches and measures, without undertaking beforehand detailed national or local risk assessments could be problematic.

Table 5 Likely interactions of climate change factors with transport infrastructure (UK Royal Academy of Engineering, 2011). Likely infrastructure damage and probability of a climate change-related impact are each scored as high, medium or low. It must be noted that (a) impacts from recurrent or cumulative events will be different from that of an one-off event; (b) consistent adverse conditions will support mitigating investment, but sporadic events, even if more extreme, will probably not; (c) impacts from climate change is different in different geographic areas, and different types of infrastructure have differential resilience e.g. traffic diversion away from a damaged road is far easier than that involving a damaged airport; (d) climate change might lead to changes in vegetation, which in turn might impact on infrastructure; (e) seasonal demand on infrastructure might add to stress ;and (f) climate change might lead to changes in land use which in turn might require infrastructure changes.

	CLIMATE CHANGE POTENTIALLY IMPACTING TRANSPORT INFRASTRUCTURE																											
ENERGY INFRA STRUCTURE AFFECTED	High temp		Low temp		Water table rise		Sea level rise		Storm surge		Prolonged Rainfall		Flood		Drought		Snow		Extreme Wind		Electric storm		Frost		Fog		Soil shrinkage	
	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P
Roads	M	H	M	L	M	M	M	L	H	H	H	H	H	M	H	M	H	H	H	M	L	L	H	M	H	M	H	H
Pedestrian routes	L	L	M	L	L	L	L	L	L	L	L	L	H	L	L	M	H	H	L	L	L	L	M	M	L	M	L	M
Cycling paths	L	L	M	L	L	L	L	L	L	L	L	L	H	M	L	M	M	H	L	L	L	L	M	M	L	M	L	M
Surface rail	L	H	L	L	M	M	M	M	H	M	H	H	H	M	L	M	H	H	H	M	L	L	M	M	M	M	M	M
U/G rail	L	M	L	L	L	M	L	L	M	M	H	M	M	M	L	M	H	L	L	L	L	L	L	L	L	L	M	M
Airport	M	H	M	M	L	M	L	L	M	M	M	M	H	M	H	M	H	M	H	M	H	M	M	M	H	M	M	M
Air ways	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	H	H	H	H	L	L	M	M	L	L
Terminals	L	L	L	L	M	M	L	L	M	M	M	M	M	M	H	M	M	M	L	L	L	L	L	L	M	L	L	L
Coastal infrastructure	L	L	L	L	M	H	H	H	H	H	M	L	H	H	L	L	L	L	M	M	L	L	L	L	H	M	L	L
Seaports	L	L	L	L	L	M	H	H	H	H	M	M	H	M	H	M	L	L	L	L	L	L	L	L	H	H	L	L
Inland waterways	L	L	M	L	L	M	M	M	H	M	H	H	H	M	H	M	L	L	L	L	L	L	H	M	L	L	H	M
Embankments	L	L	L	L	H	M	L	L	H	M	H	H	H	M	M	M	M	M	L	L	L	L	M	M	L	L	H	H
Tunnels	L	L	L	L	M	M	L	L	M	M	M	M	H	M	L	M	L	L	L	L	L	L	L	L	L	L	M	L
Bridges	M	H	M	L	L	M	L	L	H	M	H	M	H	M	M	M	M	L	M	H	L	L	L	L	L	L	M	L
Pipelines	L	L	L	L	L	M	L	L	H	L	H	M	H	M	L	M	L	L	L	L	L	L	L	L	L	L	M	M
Control systems	M	M	L	L	L	M	M	M	H	M	H	M	M	M	L	M	L	L	L	M	M	M	L	L	L	L	L	L
SatNav	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	H	H	L	L	L	L	L	L
Oil Distribution	L	L	L	L	M	L	H	M	H	M	M	M	H	M	L	L	M	M	L	L	L	L	L	L	L	L	L	L
Gas Distribution	L	L	L	L	M	L	H	M	H	M	M	M	H	M	L	L	M	M	L	L	L	L	L	L	L	L	L	L
Electric car recharge network	L	L	L	L	L	L	L	L	M	M	H	M	H	H	M	M	M	L	L	L	H	M	L	L	L	L	L	L
CO_2 transport	M	M	L	L	M	M	L	L	M	M	M	M	H	M	L	L	L	L	L	L	L	L	L	L	L	L	L	L

[16] For example, revision of the guidelines for Trans-European Transport Networks was finally agreed , in June 2013 (http://europa.eu/rapid/press-release_IP-13-478_en.htm); this agreement may advance the legislative proposal for a relevant EU Regulation (EU COM(2011) 650 final/2, see http://eur- lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0650:REV1:EN:PDF). According to the proposed Regulation, the vulnerability and resilience of infrastructure to a changing climate should be given adequate consideration in all future trans-European transport projects.

4.3 Selected examples of adaptation approaches and measures in transport

Against this background, the following section presents in overview some relevant technical adaptation measures in transport that have been implemented or currently planned by different countries, organizations with implications for various modes of transport infrastructure, equipment, services and operations, including road, rail, inland waterways and seaports. This approach has been deemed more appropriate, as there are varied levels of reliance on and strategic interests in different transport modes, depending on location and climate change projections.

It should be noted at the outset that transport systems are vulnerable to different climate change impacts, as they comprise many different sub-systems with each being vulnerable to a range of climatic hazards (see Chapter 2 and Table 5). Roadways that comprise roads, pedestrian routes and cycle paths face major threats from prolonged rainfall and downpours, floods, heat waves, droughts, snow and frost, extreme winds and fogs and, in the coastal areas, from storm surges. Railways also face major threats from storm surges in coastal and estuarine settings, downpours, floods, heat waves, snowfall, extreme winds, and high humidity that can affect trackside equipment. Rail terminals may be also vulnerable to floods, droughts and extreme temperatures, whereas underground railways in coastal areas may be also vulnerable to storm surge- induced flooding (see e.g. Fig. 21). Coastal infrastructure, such as seaports, is particularly vulnerable to sea level rise, storm surges and waves, floods, extreme winds, heat waves and fog, whereas inland waterways and ports are vulnerable to exceptionally high and low river flows, droughts as well as ice and frost that may induce soil shrinkage and embankment failures.

4.3.1 Technical adaptation measures for roads

In 2011, 75 million cars were sold globally, bringing the total number of vehicles to approximately 1 billion. This number is expected to increase very considerably by 2020, with a large proportion of these new vehicles operating on the roads of developing countries (ECE statists 2012). Moreover, the number of people living in cities is expected to reach 6 billion in the next 40 years, signaling a pressing need to assess and address relevant future trends and requirements, including adaptation to climatic changes that will affect the quality of road transport and the safety of road users.

In addition, the importance of road transport for international freight trade should not be underestimated. Road transport accounted for about 46 and 83 per cent of the intra-EU goods and passenger transport, respectively (EC, 2012b), whereas according to the statistics of the International Road Transport Union (IRU), road transport carries on average more than 80 per cent of the inland freight volume. This accounts for over 6,000 billion tons km of goods per year in only the EU, the United States of America, the Commonwealth of Independent States, China and Japan. In modern economies, 85 per cent of road freight tonnage is carried over distances of 150 km or less, for which there is rarely an economically viable alternative. Finally, it should be noted that although more than 80 per cent of the global trade in goods by volume is transported by sea (see also Section 4.6), this cargo is almost always also transported by road to or from a port and/or warehouse under an intermodal transport contract. It appears, therefore, that the vast majority of at least the containerized freight transport includes a road leg.

A number of challenges are facing road freight transport, including the need for efficiency improvement (by e.g. better integration with other transport modes), innovative transport services and intelligent transport systems as well as for the development of resilient infrastructure that guarantee wide access and mobility under changing climatic conditions. Technology has the potential to greatly assist the sector in meeting meet such challenges in terms of ensuing a more efficient use of infrastructure, advanced transport management, a smaller carbon footprint and more climate-resilient roads[17]. For example, smart logistics can reduce track 'empty' journeys which currently accounts for nearly 25 per cent of the total journeys, whereas advanced navigational aids and other management systems can reduce journey times, ease congestion, offer track-and-trace monitoring for vehicles and cargos and advance interoperability standards. Specialized R&D projects can produce more energy-efficient engines and less emissions; for example the so-called Euro-VI standard for engines (mandatory as of 2014) has been designed to reduce emissions by more than 60 per cent (EC, 2012b).

Climate change impacts on road transport are associated with the safety, operation and maintenance of road infrastructure and systems. Main impacts are both direct (e.g. pavement deterioration, deformation, subsidence and landslides, problems with accessibility due to floods and erosion) and indirect (economic, environmental, demographic, spatial planning). Each of these impacts requires different technical and operational adaptation measures, including new heat thresholds for road surfaces and bridge expansion joints, edge-strengthening of road embankments, incorporation of steel grids in the road structure, elevation of roads, bridges and tunnels above the flood and snow fields and development of 'submergible' road pavements, tolerant to frequent flooding (Tsampoulas, 2012, see also http://www.worldhighways.com/). Approaches to integrate climate change considerations into the road design and operation include: (i) risk assessments that evaluate the exposure, vulnerability, resilience and adaptation responses of the road systems (ii) planning of timeframes (consideration of longer-term climate CC effects during the planning processes) and (iii) dedicated adaptation strategies (see also PIARC, 2012).

Against this background and while not intended as an exhaustive list, some relevant adaptation measures implemented or planned in certain ECE States (the United Kingdom of Great Britain and Northern Ireland, the United States of America and Canada) are outlined below. They provide good examples of policies and practices that are being considered in the field of climate change adaptation in road transport.

4.3.1.1 United Kingdom of Great Britain and Northern Ireland

The UK Highways Agency has undertaken several studies in recent years with a view towards assessing the potential risks that climate change poses to the operation, maintenance and improvement of the road network. These have resulted in the publication of the 2009 Highways Agency Climate Change Adaptation Strategy and Framework and the subsequent Climate Change Risk Assessment documents in August 2011 (UK Highways Agency, 2009; 2011). Table 6 provides examples of some of the climate change-related risks that may impact on the United Kingdom of Great Britain and Northern Ireland highways and their associated consequences as reflected in the above mentioned reports.

The Highways Agency's Adaptation Framework Model (HAAFM) provides a 7- stage process (Fig. 52) that identifies activities that will be affected by a changing climate, as well

[17] See also PIARC, 2012. It is also interesting to note that although there is mounting evidence for the need of R&D to achieve more climate-resilient roads, this is not reflected in the research priority areas recently proposed by the European Union Road Federation (ERF, 2013).

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as associated risks and opportunities and preferred options. In more detail the HAAFM: (i) is aligned with the Highways Agency's corporate objectives (ii) focuses on the activities of the Highways Agency and how these need to adapt (iii) identifies priorities for action (iv) integrates, where possible, current Highways Agency processes and procedures (v) establishes clear responsibilities (vi) facilitates strategic oversight of progress and the management of residual risk and (vii) offers flexibility to accommodate changing demands and developments in climate science.

Table 6 Highways Agency high level climate-related risks to corporate objectives

Risk	Examples
Reduced asset condition and safety	Assets deteriorate more quickly due to changes in mean climatic conditions; assets are more seriously damaged as a result of more extreme climatic events
Reduced network availability and/or functionality	Need for restrictions on the network to maintain safety; increased need for road works
Increased costs to maintain a safe, serviceable network	Construction, maintenance, repairs and renewal or retrofitting required more often; new (and expensive) solutions required in designs and materials, components, and construction costs
Increased safety risk to road workers	Increased risk to construction and maintenance workers and traffic officers due to climatic change (work during extreme events and undertaking of more 'risky' activities)
Increased program/quality risks due to required changes in construction activities	More onerous design requirements; new technical solutions required with higher uncertainty, affecting project programmes and/or quality
Current internal operational procedures not appropriate	Effects of climate change require new operational and business processes, new skills and competences
Increased management costs	Need for more staff; more frequent (expensive) incidents; need for more research into coping with climate change

With regard to prioritizing adaptation measures, it has been suggested that action timelines are controlled by the design life cycle of assets/activities (Fig. 53). Climate-induced impacts that will become material further into the future should be considered against the renewal cycle of assets, so as to enable adaptation measures to be implemented closer the time that climate change effects become material. For example, CCTV cameras and road signs that have a short renewal cycle (see Fig. 53) should be a low priority for early action, whereas assets and activities with long design lives should be given early attention, as there may be no opportunities for intervention in the future.

According to the report, early adaptation action is advisable if the following criteria are met: (a) long times required to plan/implement adaptation measures (e.g. time needed to enable research or to introduce changes to policy and standards) (b) significant planning required due to needs to work on many different network locations and (c) climate-proofing concerns expensive assets with long design lives which will clearly benefit from future climate resilience.

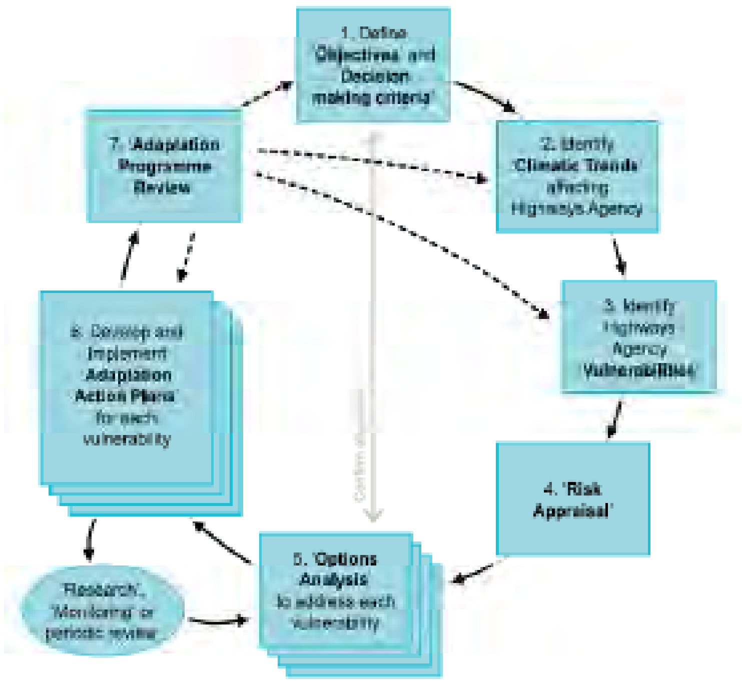

Figure 52 Highways Agency Adaptation Framework Model (UK Highways Agency, 2009).

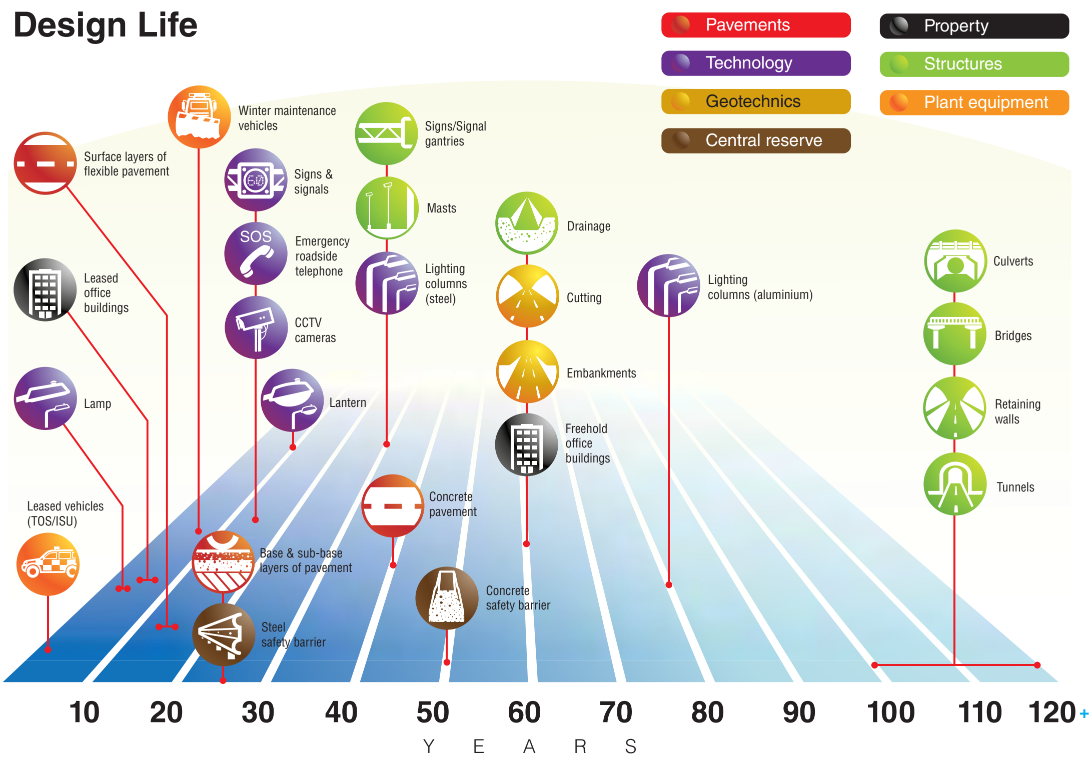

Figure 53 Design lives of assets (UK Highways Agency, 2011).

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4.3.1.2 The United States of America

The United States of America transportation system includes about 4 million miles of public roads (http://www.nationalatlas.gov/transportation.html). The Federal Highway Administration (FHWA) has provided funding to select grantees to support infrastructure and/or system vulnerability and risk assessments at a regional scale (completed in December 2011), which will enable State transportation authorities and Metropolitan Planning Organizations (MPOs) to apply the lessons learned to their own vulnerability assessments. FHWA will use the pilot projects to finalize a conceptual model framework for vulnerability and risk assessment. This framework will be disseminated to State and local partners, before used in additional pilots. It has been decided that Federal-aid funds could be used for climate change adaptation activities, if these are factored in the State and MPO transportation decision-making processes (USDOT, 2012b). In addition, the Federal Highway Administration has held peer exchange workshops with MPOs and relevant State authorities, focused on effective approaches to considering climate change adaptation in metropolitan and state wide transportation planning processes.

Climate change and variability effects on the United States of America roads are mostly related to hotter days, higher wind speeds, intense precipitation and floods, increased coastal storm intensity and sea level rise (Potter, 2012). According to a recent study on the flood vulnerability of the United States of America road bridges (Wright et al., 2012); most bridge failures are due to scouring, which causes riverbed erosion and, thus, instability in the bridge foundations. Road bridges form vital components of the national transport system, and the study revealed that 129,000 bridges are currently deficient, 48,000 - 96,000 bridges will be at risk by 2055 (from increases in the intensity of the 1 in a 100-year return flow) and 66,000 - 117,000 will be at a worrying state by 2090 (see also Section 2.2 and Fig. 30).

A climate risk screening process for transport was proposed in a study for the Federal Highway Administration which includes: (i) criticality assessment of all transport assets (ii) sensitivity assessment of all critical assets (iii) exposure assessment of all critical and sensitive assets and (iv) concentration of all assets that are critical, sensitive and exposed. Possible adaptation solutions include, amongst others, the construction of storm surge barriers and strengthening of the bridges and substructures, the accommodation of rising flood waters by structure elevation, increased and more frequent maintenance, flood tolerance improvements, more frequent dredging, asset retreat and relocation, as well as flexibility of planning through reductions in irreversible investment and lease lengths (National Research Council, 2008). It has been also suggested (e.g. Potter, 2012) that risk assessments combined with adaptation responses could lead to greater resilience. Integration within existing planning and risk management procedures is deemed to be able to produce improved overall outcomes. Finally, past experience indicates that: (i) decisions on actions should be taken as fast as possible (ii) extreme events of low-probability should be carefully considered, as these can have very serious consequences (iii) integration of existing paradigms is a key factor (iv) the often varying opinions of stakeholders matter and v) there should be a focus on robust actions.

Table 7 summarizes the climate change adaptation considerations for road transport infrastructure in the United States of America.

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Table 7 Potential Climate Changes, Impacts on Land Transportation, and Adaptation Options (see National Research Council, 2008)

CC Factor	Operations/Interruptions	Infrastructure	Changes in Operations	Changes in Design and Materials	Other
Temperature: increases in very hot days and heat waves	Limitations on construction activity periods due to health and safety concerns; restrictions typically begin at 29.5 0C (85 0F); heat exhaustion possible at 40.5 0C (105 0F)	Impacts on pavement and concrete construction	Shifting construction schedules to cooler parts of the day	Development of new, heat-resistant paving materials	
	Vehicle overheating and tire deterioration	Thermal expansion on bridge expansion joints and paved surfaces		Greater use of heat tolerant street and highway landscaping	
		Impacts on landscaping in highway and street rights-of- way			
		Concerns for pavement integrity, e.g., softening, traffic-related rutting, migration of liquid asphalt; sustained air temperature over 32°C (90°F) is a significant threshold			
Temperature: decreases in very cold days	Changes in snow and ice removal costs and environmental impacts from salt and chemical use (overall reduction, but increases in some regions)	Decreased utility of unimproved roads that rely on frozen ground for passage	Reduction in snow and ice removal		
	Fewer cold-related restrictions for maintenance workers		Construction and maintenance season extension		

CC Factor	Operations/Interruptions	Infrastructure	Changes in Operations	Changes in Design and Materials	Other
Temperature: increases in Arctic temperatures		Thawing of permafrost, causing subsidence of roads, bridge supports (cave-in), and pipelines	Shortening of season for use of ice roads	Use of insulation in the road prism	Relocation of sections of roads to more stable ground
		Shorter season for ice roads	Lengthening of potential construction season Increased use of sonars to monitor streambed flow and bridge scour	Use of different types of passive refrigeration schemes, including thermosiphons, rock galleries, and "cold culverts"	
Temperature: later onset of seasonal freeze and earlier onset of seasonal thaw	Changes in seasonal weight restrictions	Reduced pavement deterioration resulting from less exposure to freezing, snow, and ice, but possibility of more freeze–thaw conditions in some locations	Relaxation of seasonal weight restrictions Shortening of season for use of ice roads		
	Changes in seasonal fuel requirements				
	Improved mobility and safety associated with a reduction in winter weather				
	Longer construction season				

CC Factor	Operations/Interruptions	Infrastructure	Changes in Operations	Changes in Design and Materials	Other
Sea level rise, added to storm surge	More frequent interruptions in travel on coastal and low lying roadways due to storm surges	Inundation of roads in coastal areas		Elevation of streets, and bridges	Relocation of sections of roads
	More severe storm surges, requiring evacuation	More frequent or severe flooding of underground tunnels and low-lying infrastructure		Addition of drainage canals near coastal roads	Protection of high value coastal real estate with levees, seawalls, and dikes
		Erosion of road base and bridge supports		Elevation and protection of bridge, tunnel, and transit entrances	Strengthening and heightening of existing levees, seawalls, and dikes
		Bridge scour		Additional pumping capacity for tunnels	Restrictions on most vulnerable coastal areas regarding further development
		Reducedclearance under bridges			Increases in insurance premiums to restrict development
		Loss of coastal wetlands and barrier shoreline, land subsidence			

CC Factor	Operations/Interruptions	Infrastructure	Changes in Operations	Changes in Design and Materials	Other
Precipitation: increase in intense precipitation events	Increases in weather related delays	Increases in flooding of roadways, and subterranean tunnels	Expansion of systems for monitoring scouring of bridge piers/abutments	Protection of critical evacuation routes	Greater use of sensors for monitoring water flows
	Increases in traffic disruptions	Overloading of drainage systems, causing backups and street flooding	Increase in monitoring of land slopes and drainage systems	Upgrading of road drainage systems	Restrictions on flood plain development
	Increased flooding of evacuation routes	Increases in road scouring washout, support structures, and landslides/mudslides that damage roadways	Increases in monitoring of pipelines for exposure, shifting, and scour in shallow waters	Protection of bridge piers and abutments with riprap	
	Disruption of construction activities	Impacts on soil moisture levels, affecting structural integrity of roads, bridges, and tunnels	Increased requirements for real-time monitoring of flood levels	Increases in culvert capacity	
	Changes in rain, snowfall, and seasonal flooding, affecting safety/ maintenance operations	Adverse impacts of standing water on road bases Increases in scouring of roadbeds/ pipeline damages	Integration of emergency evacuation procedures into operations	Increases in pumping capacity for tunnels	
				Addition of slope retention structures and retaining facilities for landslides	
				Changes in rainage capacity standards for new infrastructure and rehabilitation (e.g., assuming an 1 in 500-year rather than 1 in a 100-year storm)	

CC Factor	Operations/Interruptions	Infrastructure	Changes in Operations	Changes in Design and Materials	Other
Storms: more frequent and intense hurricanes (Category 4–5)	More debris on roads, interrupting travel and shipping	Greater probability of infrastructure failures	Emergency evacuation procedures that become more routine	Changes in bridge design to tie decks more securely to substructure/strengthening foundations	Strengthening and heightening of levees
	More frequent and potentially more extensive emergency evacuations	Increased threat to stability of bridge decks	Improvements in ability to forecast landfall and trajectory of hurricanes	Increases in drainage capacity for new transportation infrastructure or major rehabilitation projects (e.g., assuming higher return periods)	Restrictions in the further development of vulnerable coastal locations
		Increased damage to signs, lighting fixtures and supports	Improvements in monitoring of road conditions and issuance of real-time messages to motorists	Removal of traffic bottlenecks on critical evacuation routes and building ofmore system redundancy	Increase in flood insurance rates to help restrict development
		Decreased expected lifetime of highways exposed to storm surge	Improvements in modeling of emergency evacuation	Adoption of modular construction techniques where infrastructure is in danger of failure	Return of some coastal areas to nature
				Development of modular traffic features and road sign systems for easier replacement	

4.3.1.3 Canada

The responses of the Canadian transport sector to adapt to climate/weather variability and change are associated mainly with infrastructure protection, and mobility and safety maintenance and enhancement. Concerning roads, weather/climate sensitivities are to be considered in the design and construction standards and protocols (e.g. CCIADC, 2004). For asphalt-surfaced roads, temperature variability must be considered in the selection of asphalt cements and asphalt emulsions for surface-treated roads to mitigate traffic-associated rutting under high temperatures and thermal cracking under cold temperatures.

Increased frequency and intensity of hot days may increase incidents of pavement softening and traffic-related rutting, as well as migration of liquid asphalt, flushing and bleeding, to pavement surfaces from older or poorly constructed pavements. Asphalt rutting may be exacerbated during extended periods of summer heat on roads with heavy truck traffic. In such cases, more advanced and expensive asphalt cements may be required to achieve higher heat tolerance. Road thermal cracking from frost and damages due to higher frequencies of freeze-thaw cycles may result in the premature deterioration of road pavements, primarily where sub-grades are composed of fine- grained, saturated material. Such damages can be mitigated by, for example, polystyrene insulation such as that placed under a section of the Dempster Highway. Adaptation measures to deal with short and/ or uncertain ice road seasons may include increased reliance on barge transport during summer, more robust construction and maintenance of ice roads to extend their seasonal life, construction of all-season roads and the use of monitoring systems such as Advanced Road Weather Information Systems (ARWIS) to monitor and predict road and weather conditions and thus reduce salt use (CCIADC, 2004).

It should be noted that in comparison to the study of climate change mitigation, much less research has been undertaken on climate change adaptation, except in permafrost regions (Infrastructure Canada, 2006).

4.3.1.4 France

According to a study conducted in 2009 (SETRA et LCPC – Contributions au Rapport interministériel – Coûts des impacts du changement climatique et de l'adaptation en France – MEEDDM) by the French Ministry of Sustainable Development, damage can be observed in case of an increase in average temperature and longer periods.

This study shows that the pavement as a whole has fared pretty well against the heat wave and has not led to widespread disorders involving the sustainability of pavement structures or bridges. However, information gathered did reveal a number of disorder spots on pavements and structures.

On bridges, drought caused disorders by triggering the removal of soil and backfill, including clay works. There are reported cases of cracking in certain bridges and embankments subsidence. No widespread disorder was detected on structures at the end of the 2003 heat wave.

It is also possible to observe cracking down, due to the drying of soil. It is important to note that the roads of France have a homogeneous design for their anchoring layer (North and South are similar). It is mainly the surface layer which will differ and be adapted to the "types of climate." Only the sizing and rutting is really concerned by climate change.

The climate would have a negligible impact on the roads, except for a traffic patterns between 300 and 750 trucks a day (T1 traffic). In the apprehension of material behaviour, climate parameter is secondary with respect to the traffic.

As a result:

(a). The number of cases affected by a change in "type of climate" seem limited

(b). Traffic is the main criterion for defining the pavement solicitation

(c). The altitude is also a factor that has perhaps more impact than the climate

(d). The criterion of "low temperature" has a sizing effect. In fact, pavements display greater vulnerability with increasing cycles of freezing and thawing.

The influence of high temperatures on the mechanical behavior of pavements generally is as follows:

(a). The phenomenon of soil desiccation causing problems lifting the floor is even more worrying if there is no widespread disaster after this heat wave.

(b). Rutting appears on enrobés. This is an investigation of the 2003 heat wave, which reduces the significance of the results was performed.

In short, regarding the road and bridges:

(a). Coatings and cold mixes have sweated more sharply in the summer of 2003.

(b). A significant increase is observed for pavements based on hydraulic binders, in fractures with the appearance of beads due to "buckling" slabs. This is linked to high temperatures. A certain number of localized problems were observed, caused by clay soil shrinkage-swelling.

Another study (2008-2009- Vulnérabilité du territoire national aux risques littoraux pilotée par le CETMEF en lien avec les CETEs de l'Ouest et Méditerranée ; contributions au Rapport interministériel sur le coût des impacts du changement climatique) focused on the vulnerability of road infrastructure about risk of coastal flooding. Mapping of low areas is an important indicator to determine the vulnerability of coastal areas to coastal flooding. In this approach to topographic areas, the Centennial extreme levels are termed "low areas". The impact of climate change on the extent of these areas of vulnerability is captured by mapping areas under the current extreme levels Centennial + 1 m. This simulates what will potentially be overwhelmed by a centennial event if the sea level raised 1m areas.

A hypothesis where the sea level rises by 1m at horizon 2100 was adopted. For a permanent submersion, we consider that those works located at a height below the coastline +1m are under threat. The cost could equal the loss of property value. From information taken from the BD Topo Pays® database relating to transport infrastructures located at a height below the 100-year submersion height + 1m, and by basing the estimate of average linear property cost at EUR 10M per kilometre of road surface and the cost of repair at around EUR 250000/km, the overall rise in sea level of 1m will represent a property cost for mainland A-roads, excluding motorways and loss of use, that could reach up to EUR 2 billion. Table 8 below shows the linear infrastructure in each of the three low-lying areas. They are aggregated at the national level according to the nature of the system concerned: highways, roads (RN), county roads, other (local roads). They are based on the total assets, thereby locating the issues relating to each category of road.

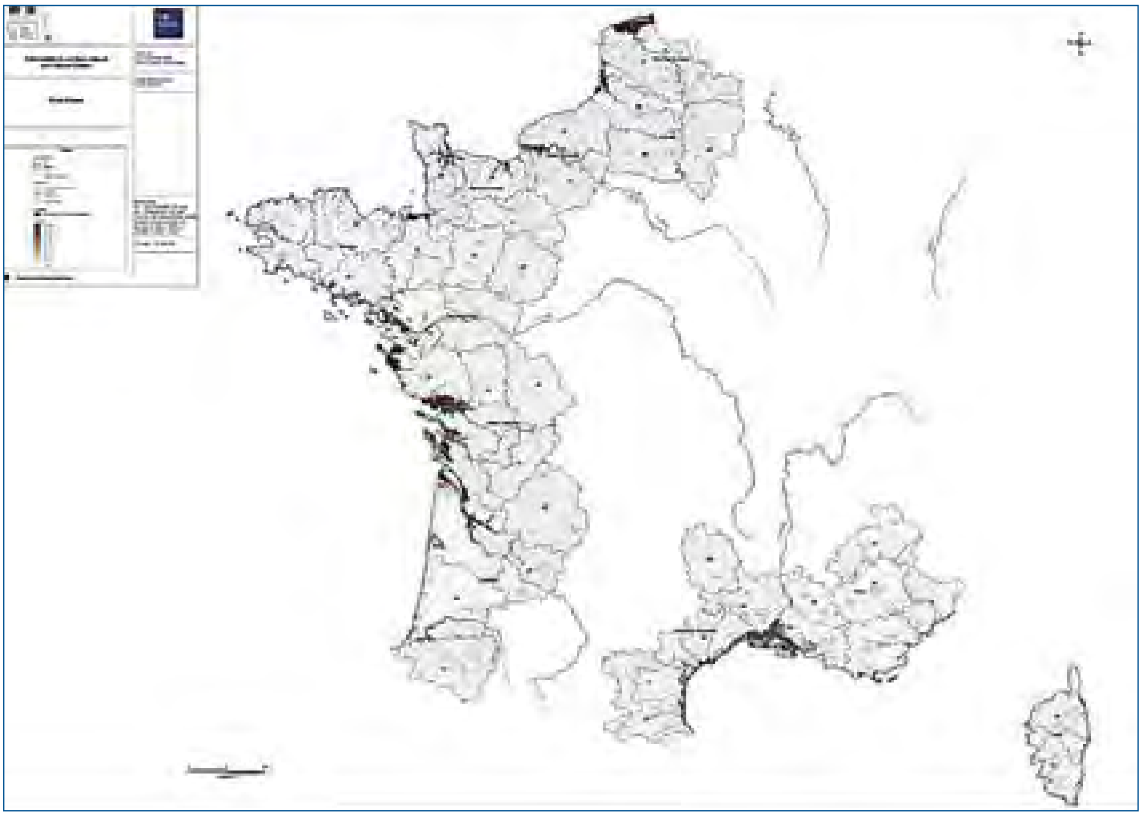

Figure 54 Vulnerability of coastal risks to French territory - Mapping lowlands

Table 8 Linear located in each of the three lower zones road and rail infrastructure (in km) in France (without taking into account the existing protect ive structures. calculation by reference to current centennial sea levels)

	Niveaux marins centennaux -1m	Niveaux marins centennaux	Niveaux marins centennaux +1m
Autoroutes % du linéaire national	160 1,3%	301 2,5%	355 2,9%
Routes Nationales % du linéaire national	79 0,7%	148 1,3%	198 1,7%
Départementales % du linéaire national	2074 0,5%	3314 0,9%	4338 1,1%
Autres % du linéaire national	7032 1,12%	11559 1,84%	15522 2,47%
Voies ferrées % du linéaire national	812 2,6%	1482 4,8%	1967 6,3%

Low areas cover increasingly wide areas. Structures located in the “marine Centennial Levels - 1 m” column are all included in the “marine Centennial Levels” column. Structures located in the “marine Centennial Levels” column are all included in the “Levels marine Centennial m + 1” column.

This approach shows greater potential vulnerability as a percentage of network, highways and local roads.

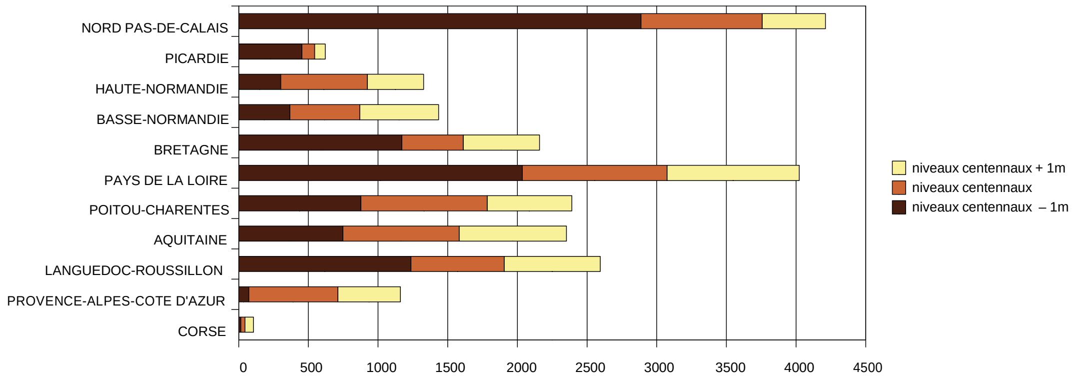

Figure 55 Linear transport infrastructure in low-lying areas along the regions in France, in kilometers.

4.3.2 Technical adaptation measures for railways

Rail transport accounts for a significant proportion of good and passenger transport (about 10.2 per cent and 6.3 per cent of the intra-EU goods and passenger transport, respectively see EC, (2012b)), and offers economies of scale and, in view of its low energy and carbon intensity, helps mitigate GHG emissions[18]. However, a considerable shift to this mode of transport in the future at the international level will depend on effective interoperability[19] and high efficiency and safety standards (see e.g. http://ec.europa.eu/transport/modes/rail/index_en.htm). In its 2011 White Paper for transport, the European Commission presented its vision to establish a Single European Transport Area (SERA) by 2050, which will be driven by an integrated approach to remove administrative, technical or regulatory obstacles. Consequently, a set of relevant proposals was adopted within the 4th Railway Package (01/2013), which places innovation at the center of the railway management and operation. In this initiative, which will have important implications for the ECE international transport networks, has been recognized that integration is necessary to generate the step-by step changes in service quality, capacity and productivity that are crucial to the SERA.

Scattered research and development will slow the market uptake of innovative solutions and will not deliver the necessary improvements in capacity, safety, reliability and life-cycle costs. Pooling of all relevant research and innovation resources from both the rail sector and research establishments and universities will be necessary (http://ec.europa.eu/transport/media/consultations/doc/2013-shift2rail/background.pdf).

[18] It should be noted that although at the operational level rail can transport freights at a fra ction of the energy and GHG emissions of other transport modes (see Crist (2012) and ftn 11), energy costs and GHG emissions involved in new infrastructure development should be also taken into consideration (Hill et al., 2011). Rail infrastructure consists of various elements, including stations, ballast, track, tunnels, bridges, overhead line equipment (OLE), signaling and telecommunications, electrified third rails, and road crossings and culverts; their construction has different requirements in costs, energy and GHG emissions, depending on the routing. These differential requirements are the main basis for a wide range of figures quoted in the literature for the proportion of overall lifecycle costs and GHG emissions due to new rail infrastructure development (O' Toole, 2008).

[19] Interoperability is defined as the capability to operate on any stretch of the rail network without any difference. The competitiveness of the freight railway system is constrained by differences between States in terms of stock, technology, signaling systems and safety regulations. In the EU, Directive 2004/50/EC focuses on establishing common standards for signaling and control systems, telematic systems for freight services, the operation and management of rolling stock intended for international freight, and staff qualifications.

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If future infrastructure and operating policies, technical standards and intervention thresholds remain roughly similar to those of today, then increasing traffic levels and changing weather patterns may create problems for railway systems at both national and international levels in the next 50 years. It appears that is no longer sustainable to continue to design, build, operate and maintain infrastructure systems using standards based upon historic weather patterns. As railways have a very long life time and constructed to withstand natural hazards, such as the 1-in-100-year flood estimated at the design phase, climate change-associated increases in the frequency and intensity of extreme events are likely to test the capacity of the rail system and increase costs (Nolte et al., 2011). Climate change impacts for the rail sector are projected to be significant, requiring integrated policies (Lochman, 2012), systematic mapping of climate vulnerabilities and development of effective planning and synergies (Lindgren et al., 2009). Impacts include more frequent and intense precipitation, floods, wetter winters and dryer summers, higher temperatures and heat waves, storms and storm surges, higher wind forces and thunderstorms. Such phenomena are set to increase the occurrences of rail line flooding, bridge scouring, embankment failure and rail buckling. Further consequences include the degradation of electricity transmission, slope fires and overheating of rolling stock and damage to installations, over-voltage and effects on signaling. New and innovative construction methods should be used for different regions, such as the cooling embankments and controls of heat conduction, radiation and convection that have been used to mitigate the impacts of thawing permafrost in the Qinghai-Tibet Railway (Qingbai et al., 2008).

While the technical issues related to climate change impacts on railways are fairly well known, an overall framework for the quantification of the likely climate change effects on the railway industry is lacking, as is a method for assessing which are the most critical effects to which resources should be allocated (Baker et al., 2010). It is considered that the main types of infrastructure vulnerable to the climatic changes are: tracks (extreme temperature); earthworks (extreme precipitation); drainage (extreme precipitation); overhead line equipment (extreme winds); and coastal and estuarine protection schemes (sea level rise and storm surges). In order to identify approaches and measures that may be considered in the climate-proofing of the international rail networks, some efforts undertaken by public and private entities at the national level are summarized below.

4.3.2.1 United Kingdom – Network Rail

In the United Kingdom of Great Britain and Northern Ireland, railway operations will be significantly affected by climate change (Baker et al., 2010), and the industry will need to adapt in a variety of ways over the coming decades. From the UKCIP02 predictions, three potential climate change categories can be defined: hotter, drier summers; warmer, wetter winters; Increased frequency of extreme storms. These three categories can provide a useful framework for a discussion of potential climate change effects. In a 2003 report, the Railway Safety and Standards Board (RSSB, 2003) has identified the following major effects that are likely to be of concern to the United Kingdom of Great Britain and Northern Ireland railway industry in the future: high temperature effects on tracks (buckling, etc.); effects of high rainfall on earthworks; effects of extreme precipitation levels on current drainage systems; and effects of extreme winds on the overhead systems.

Hot dry summers are projected to have adverse effects on the United Kingdom of Great Britain and Northern Ireland railway system: (a) increased buckling of train tracks (b) desiccation of track earthworks (c) greater need for air conditioning systems (d) increased ventilation problems on underground railway systems (e) increased vegetation because of

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longer growing season and (f) leaf fall issues. The increased frequency of warm wet winters is projected to affect the rail system by: (a) increased flooding of the network and strain on drainage systems (b) damage to earthworks and failure of saturated embankments and (c) track circuit problems. There may also be some benefits, such as decreases in snow- and ice-related and low temperature incidents.

High winds may: (a) increase the likelihood of de-wirement (i.e. pantographs losing contact with the overhead wires); increase the possibility of train overturning and derailment; and induce accidents or network disruption due to tree falls. Finally, a 0.3 – 0.4 m sea level rise can have major consequences for railway systems both in estuarine and coastal locations. An overview of the climate change impacts, their timeline and consequences (Tables 9 and 10) and potential adaptation solutions (Table 11) is given below.

Table 9 Overview of asset risks for railways (Network Rail, 2011).

Climate Impact	Risks	Safety Impact	Performance impact	Likely CC Negative Impact	Long or Short Term?
Heat	Air conditioning failure in carriages	Low	Medium	High	Short
Heat	Track buckling	High	High	High	Long
Heat	Speed restrictions due to buckle	Low	High	High	Long
Heat	Use of heat watchmen for buckle	Medium	High	High	Long
Heat	Floating electrical earth caused by a low water level	High	High	High	Long
Heat	Reduced window of opportunity for work – renewal and maintenance - due to	Low	Medium	High	Long
Heat	Reduction in track quality due to less maintenance	Low	Medium	High	Long
Heat	Staff working conditions in hot weather	High	High	High	Long
Heat	Earthworks desiccation	Low	Medium	High	Long
Heat	Effect of heat on swing bridges	Low	Low	High	Long
Heat	Contact wire sagging at terminal	Low	High	High	Long
Heat	Reduced transformer life	Low	Low	High	Long
Heat	Solar gain affecting line side equipment Signaling, Power, Telecoms	Med	High	High	Short
Increased rainfall	Increased flooding generally	Low	High	High	Long
Increased rainfall	Flooding at stations	Low	Medium	High	Long
Increased rainfall	Flooding at depots	Low	Medium	High	Long
Increased	Flooding affecting plant and	High	High	High	Short
Increased	Flooding caused by poor drainage	Low	High	High	Long
Increased	Flooding at bridges – scour/	High	High	High	Long
Increased rainfall	Flooding in tunnels	Low	Medium	High	Long

Climate Impact	Risks	Safety Impact	Performance impact	Likely CC Negative Impact	Long or Short Term?
Increased rainfall	Flooding - Track Circuitry/ Automatic Warning Systems/ Line side cabinets and equipment	Low	High	High	Short
Increased rainfall	Pluvial (surface water) flooding	Low	High	High	Long
Increased rainfall	Increased rainfall causing high surface run off	High	High	High	Long
Increased rainfall	Rising ground water level	High	High	Medium	Long
Increased rainfall	Scour due to high river levels Cabinets	Medium	High	High	Long
Increased rainfall	Safety of workforce in extreme flood conditions –	High	High	Low	Short
Increased rainfall	watchmen at flood sites	Medium	Low	High	Long
Cold	Heave caused by freeze thaw	Low	Low	Low	Long
Cold	Rock fall caused by freeze thaw	High	High	Low	Long
Cold	Freeze thaw action on bridges	Medium	Low	Low	Long
Cold	Ice in tunnels	Low	Medium	Low	Short
Cold	Broken Rails	Medium	High	Low	Short
Cold	3rd rail ice and snow	Low	High	Low	Short
Cold	Snow and ice on the track	Low	High	Low	Short
Cold	Slips, trips and falls, ice & snow	Medium	High	Low	Short
Wind	Effect of wind on bridges and traffic on bridges	Low	Low	Low	Long
Wind	Effect on equipment (OLE, signal, telecoms) structures, station canopies etc.	Low	Low	Low	Long
Wind	Effect of wind on freight trains	High	Medium	Low	Long
Wind	Lifting with crane in wind	Low	Medium	Low	Long
Wind	Change in direction and speed affecting trees	Medium	Medium	Low	Long
Wind	Contact wire/ pantograph	Low	Medium	Low	Long
Sea level rise and increased storminess	Sea defenses	Low	Medium	High	Long
Insolation/ heat/ rainfall/ wind	Increase and change in vegetation type	High	High	Medium	Long
Insolation/ heat/ rainfall/ wind	Floral Adhesion	Medium	High	Low	Long

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Climate Impact	Risks	Safety Impact	Performance impact	Likely CC Negative Impact	Long or Short Term?
Insolation/ heat/ rainfall/ wind	Vegetation – Showing Clear When Occupied track circuitry from leaves	Medium	High	Low	Long
Insolation/ heat/ rainfall/ wind	Vegetation - Signal sighting	High	High	Low	Long
Wind	Trees growing on the line side – obstruction risk		High	High	Long
Insolation/ heat/ rainfall/ wind	Loss of a safe Cess from vegetation encroaching	Medium	Low	Medium	Long
Insolation/ heat/ rainfall/ wind	Vermin – signaling	High	High	Low	Long
Increased humidity	Corrosion of rails	Medium	Low	Low	Long
Increased humidity	Corrosion of bridges	Low	Low	Medium	Long
Various	Incident Response	Low	Medium	High	Short
Various	Failed trains and impact on passengers	Medium	High	High	Long

Table 10 Summary of asset and operational priority topics; priorities will be subject to continuous review (Network Rail, 2011).

Climate Impact	Cluster	Consequence
Heat	Track	Management of track buckle risk
Heat	Track	Reduced window of opportunity to carry out maintenance/ renewals work due to heat
Heat	People	Passenger health from train failure in extreme temperatures, including heat and cold
Heat	People	Impact on freight from train failure in extreme temperatures, including heat and cold
Heat	People	Staff working conditions, e.g. use of heat watchmen
Heat	Power/ Signaling/ Telecoms	Sag in tethered overhead line systems at terminal stations
Heat	Power/ Signaling/ Telecoms	Heat affecting line side equipment; specifically signaling and telecoms equipment
Heat	Power/ Signaling/ Telecoms	Floating electrical earth leading to stray earth currents caused by dry ground/low groundwater
Rainfall	Fluvial flood	Track and line side equipment Failure
Rainfall	Groundwater flood	Track and line side equipment Failure
Rainfall	Fluvial flood	Track and line side equipment Failure

Climate Impact	Cluster	Consequence
Rainfall	Fluvial flood	Scour and water effects at bridges
Rainfall	Fluvial flood	Scour at embankments due to high river levels and culvert washout
Rainfall	Fluvial flood	Safety of workforce carrying out inspections during an extreme flood event
Rainfall	Fluvial flood	Landslides
Rainfall	Fluvial flood	Accessibility of fleet and of maintenance depots
Insolation/ heat/ rainfall/ wind	Vegetation	Change in type, poor adhesion, and track-circuit non-activation
Insolation/ heat/ rainfall/ wind	Vegetation	Falling trees causing obstructions
Sea level rise and storms	Coastal and estuarine defenses	Wave overtopping and flooding at defended coastal and estuarine railways

Table 11 gives examples of significant hazards as experienced in the UK rail network, with potential solutions (both 'hard' engineering and 'soft' management systems). The solutions identified are already in use, or proposed for use, at the United Kingdom of Great Britain and Northern Ireland rail network.

Table 11 Significant hazards and potential solutions (Dora, 2011; 2012 see also Annex III)

Hazard	System affected	Issue	Potential Solution
Sea level rise and increased storminess	Coastal railway	Damage to sea wall – breach, flooding and derailment risk	– Rebuild wall to appropriate standards – Introduce a sea-state forecasting system
Sea level rise and increased storminess	Coastal railway	Overtopping waves damaging/ affecting vehicles	– Rebuild wall to appropriate standards – Introduce a sea-state forecasting system
Extreme, intense rainfall	Soil cuttings – landslip	Obstruction in cutting derailment risk	– Map water concentration locations – Understand earthwork structural condition – Understand drainage location, condition and criticality – Improve earthworks and/or drainage through investment – Target drainage management
Extreme, intense rainfall	Bridges - scour	Bridge foundations become undermined leading to bridge collapse and derailment risk	– Understand bridge scour likelihood – Install scour protection – Introduce flood risk monitoring linked to flood agency forecasts – Monitor river levels
Extreme, intense rainfall	Signaling and Power line side systems	Track becomes flooded, critical line side equipment fails	– Map water concentration locations – Improve earthworks and/ or drainage through investment – Target drainage management

Hazard	System affected	Issue	Potential Solution
Extreme heat	Track	Buckling causing derailment risk	– Keep a register of track condition related to locations – Impose speed restrictions at 'compromised' sites – Restrict ballast disturbance activity during hot weather – Paint rails white at critical locations
Extreme heat	Signaling and Power line side systems	Software/component Reliability	– Use active or passive cooling of equipment cabinets – Position cabinets in shade – Re-specify and replace equipment
Extreme heat	People	Heat stress	– Recognize length of exposure to heat and the impact on individuals, adjust rosters accordingly – Train staff and recognize differences between indoor and outdoor working – Recognize impacts on sleep patterns and fatigue
Extreme heat	Vehicles' equipment	Software/component Reliability	– Paint vehicle in light color – Use active or passive cooling – Avoid locating equipment on roofs
Rapid variation in heat	Signaling and Power line side systems	Software/component Reliability	– Make use of high thermal inertia design – Position cabinets in shade – Re-specify and replace equipment
Extreme heat	Overhead line	Sag in contact wire	– Strengthen mast and wire system
Increased wind speed	Overhead line	Sideways displacement of contact wire	– Strengthen mast and wire system

4.3.2.2 United States of America

The United States of America transportation system includes 120,000 miles of major railroads (http://www.nationalatlas.gov/transportation.html). Climate change will affect the United States of America railway infrastructure and operations in different ways, as the network spans different climatic zones. In recent years the climate adaptation has become an important issue for the Federal Railroad Administration (FRA), which will consider potential climate impacts and adaptation during future rail planning and corridor program development. It has been planned that adaptation to climate change and variability should be considered in future FRA grants regarding infrastructure planning and development (USDOT, 2012b). In addition, FRA together with Amtrak will initiate a pilot climate risk and vulnerability assessment – which is due to finish by the end of 2013 - to determine potential climate change impacts on assets, in order to incorporate a comprehensive climate change analysis in future funding decisions to improve and maintain the railway network. In addition the plan provides for outreach activities, such as meetings with States and railroads, focused on promoting the incorporation of climate change consideration into rail planning and operation.

Table 12 summarizes the climate change adaptation considerations for rail transport infrastructure as identified by the National Research Council (2008).

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Table 12 Potential climate changes, impacts on rail transportation, and adaptation options (National Research Council (2008).

CC Factor	Operations/Interruptions	Infrastructure	Changes in Operations	Changes in Design and Materials	Other
Temperature: increases in very hot days and heat waves	Time constraints on construction activities due to health/safety concerns; typical thresholds: 29.5 0C (85 0F); heat exhaustion possible at 40.5 0C (105 0F)	Rail-track deformation; air temperature above 43°C (110°F) can lead to equipment failure	Shifting construction schedules to cooler parts of the day	Greater use of continuous welded rail lines	
Temperature: decreases in very cold days	Regional changes in snow and ice removal costs and environmental impacts from salt and chemical use)		Reduction in snow and ice removal		
	Fewer cold restrictions for maintenance work		Extension of construction and maintenance season		
Temperature: increases in Arctic temperatures		Permafrost thawing, causing subsidence of rail beds, bridge supports (cave-ins), and pipelines	Lengthening of potential construction season	Use of different types of passive refrigeration schemes (e.g. thermo-siphons)	Relocation of rail line sections to more stable ground
			Increased use of sonars to monitor streambed flow and bridge scour		
Sea level rise, added to storm surge	More frequent interruptions in travel on coastal and low lying rail lines due to storm surges	Inundation of rail lines in coastal areas		Elevation of bridges, and rail lines	Relocation of sections of rail lines inland
	More severe storm surges, requiring evacuation	More frequent or severe flooding of underground tunnels and low-lying infrastructure		Addition of drainage canals near coastal railroads	Protection of high value coastal real estate with levees, seawalls, and dikes
		Bridge scour		Elevation and protection of bridge, tunnel, and transit entrances	Strengthening and heightening of existing levees, seawalls, and dikes
		Reduced clearance under bridges		Additional pumping capacity for tunnels	Restriction of most vulnerable coastal areas from further development

CC Factor	Operations/Interruptions	Infrastructure	Changes in Operations	Changes in Design and Materials	Other
		Loss of coastal wetlands and barrier shoreline			Increase in flood insurance premiums to restrict development
		Land subsidence			
Precipitation: increase in intense precipitation events	Increases in weather related delays	Increases in flooding of rail lines and subterranean tunnels	Expansion of systems for monitoring scour of bridge piers and abutments	Protection of critical evacuation routes	Greater use of sensors for monitoring water flows
	Increases in traffic disruptions	Overloading of drainage systems,	More monitoring of slopes and drainage systems	Protection of bridge piers and abutments with riprap	Development restrictions in flood plains
	Increased flooding of evacuation routes	Increases in damages to rail bed support and landslides/ mudslides that damage tracks	Increases in monitoring of pipelines for exposure, shifting, and scour in shallow waters	Increases in culvert capacity	
	Disruption of construction activities	Impacts on soil moisture, affecting structural integrity of bridges and tunnels	Increases in real-time monitoring of flood levels	Increases in pumping capacity for tunnels	
	Rain/snowfall changes and seasonal flooding affecting safety/ maintenance		Integration of emergency evacuation procedures into operations	Addition of slope retention structures and retaining facilities for landslides	
				New, improved standards of drainage for new infrastructure and major rehabilitation projects (e.g. assuming 1-500-year instead of 1-100-year storm)	
Storms: more frequent strong hurricanes (Category 4–5)	More debris on rail lines, interrupting travel	Greater probability of infrastructure failures	Emergency evacuation procedures that become more routine	Bridge design changes to tie decks securely onto substructure	Strengthening/ heighte ning of levees

CC Factor	Operations/Interruptions	Infrastructure	Changes in Operations	Changes in Design and Materials	Other
Storms: more frequent strong hurricanes (Category 4–5)	More frequent and potentially more extensive emergency evacuations	Increased threat to stability of bridge decks	Improvements in ability to forecast landfall and trajectory of hurricanes	Increases in drainage capacity for new infrastructure or major rehabilitation projects (e.g., assuming higher periods)	Restriction of further development in vulnerable coastal locations
		Increased damage to signs, lighting fixtures and supports	Improvements in monitoring of rail conditions and issuance of real-time warnings	Removal of bottlenecks on critical evacuation routes and building of more system redundancy	Increase in insurance premiums to restrict development in flood prone areas
			Improvements in modeling of emergency evacuation	Adoption of modular construction techniques where infrastructure is in danger of failure	Return of some coastal areas to nature
				Development of modular traffic features	

4.3.2.3 Canada

Rail infrastructure in Canada is highly susceptible to temperature extremes, as rail tracks may buckle under extreme heat. Nevertheless, extreme cold conditions appear to be currently more problematic for railways than extreme heat, as is the case with the Canada roadways, resulting in higher frequencies of incidents of broken railway lines and frozen switches, and higher rates of wheel replacement. On balance, it is expected that climatic change-induced impacts will be manageable in Canada (CCIADC, 2004) and might even provide modest benefits for the rail infrastructure, except in permafrost regions (see below).

For transportation and other structures built on permafrost, a number of lessons have been learned over the past decades. For example, failure to incorporate appropriate design standards and to regularly maintain the rail line between The Pas and Churchill, Manitoba in the early 20th century resulted in significant damages, as subsidence and frost heave twisted and displaced rail sections. Presently, although construction over or through permafrost is based on careful route selection, decisions do not commonly take into consideration future climatic changes, due in part to insufficient information. There are, however, several measures concerning the longevity of infrastructure constructed on permafrost. Another possibility is to construct temporary facilities, which can be easily relocated. Such practices have associated costs, but illustrate the existence of capacity to deal with variable climate in a highly sensitive environment.

Rail companies also have winter operating plans and procedures for dealing with winter conditions that cost millions of dollars each year. These include such measures as snow removal, sanding and salting, track and wheel inspections, temporary slow orders and personnel training. While milder or shorter winters are expected to benefit rail operations, more relevant research is required in order to identify and quantify such benefits (Infrastructure Canada, 2006).

4.3.2.4 Japan – East Japan Railway Company

In Japan, the railway sector is also part of the country's seismic monitoring system. Sensors measuring changes in salt dissolved in the groundwater below the rails measure subtle and intense earth movements and are linked to the earthquake warning system. Intense storm events (e.g. Mori et al., 2013) and the sea level rise may also modify shear stresses, possibly increasing the seismic activity risk. Climate change impacts that will increasingly affect railway operations are projected to be related to: (i) heavy downpours, causing flooding, scouring, groundwater level rises and landslides (ii) strong winds, causing derailments (iii) high coastal wave activity, causing coastal erosion and collapse of protection walls along coastal rail tracks (iv) heavy snowfalls, causing avalanches and falling trees and (v) earthquakes, heat waves and thunderstorms (Mizukami, 2012, see Annexes II and III).

Major countermeasures developed and implemented by the JR East are:

- *Greater resilience of the network* (e.g. Fig. 56) to heavy precipitation (by e.g. slope reinforcement, scouring protection schemes), strong winds (by e.g. installation of windbreak fences and screens, growth of windbreak forests) and heavy snowfalls (by e.g. anti-avalanche schemes, increased availability/use of snow removal equipment, anti-snow measures on trains and growth of snow protection forests) .
- *Installation of monitoring systems*, consisting of various environmental and engineering sensors (i.e. anemometers, about 11 per 100 km rail line), water (about 8 gauges per 100 km rail line), rain (about 8 gauges per 100 km rail line), snow and temperature

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gauges, scouring and landslide detectors and seismographs (about 4 per 100 km rail line) that can provide real- time information to operation control centers that prescribe speed restrictions and/or traffic suspensions when necessary.

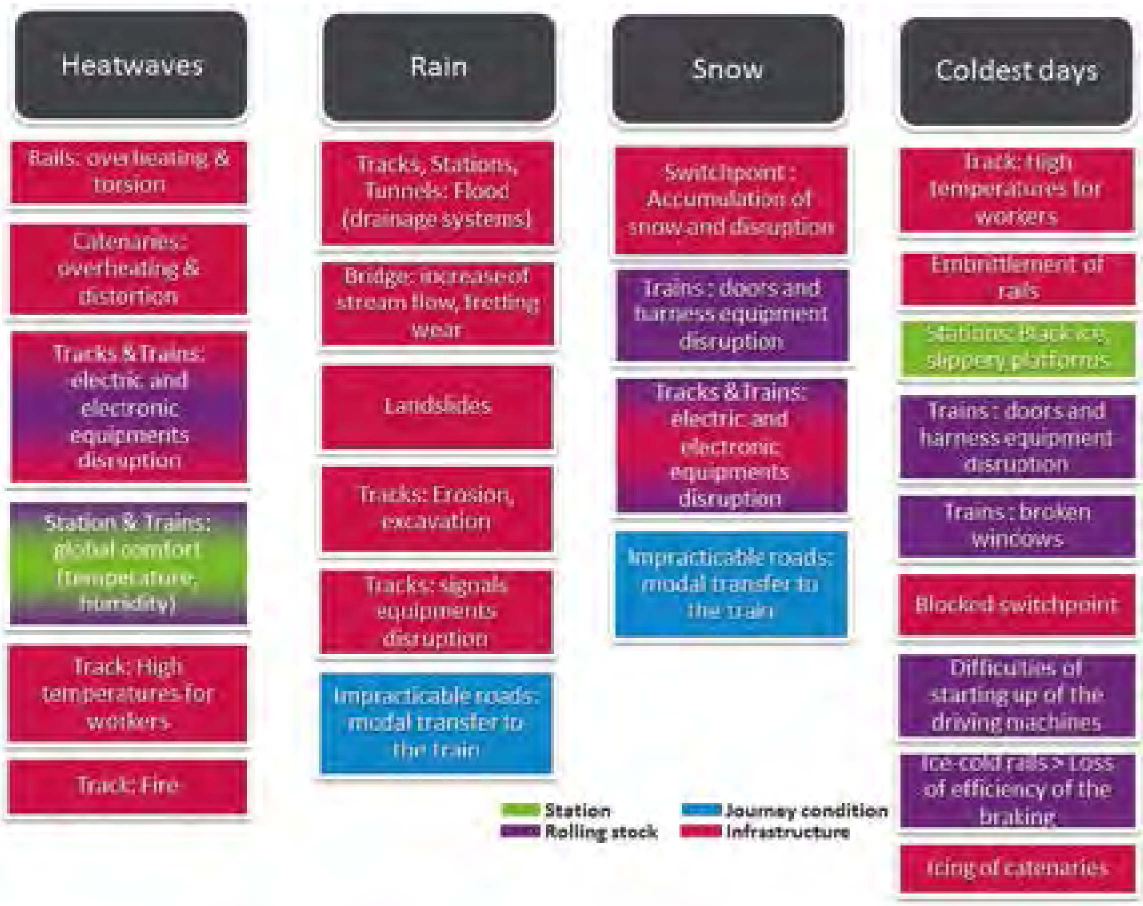
- *Education and training schemes* for the JR East personnel
- *Research and development* in its dedicated Disaster Prevention Research Laboratory, which studies the mechanisms of natural disasters, provides risk assessments and develops observation and detection methods, countermeasures and technical standards and designs practical measures using past experience.

Figure 56 (a) Scouring protection (b) Slope reinforcement (c) Windbreak fence/screen and (d) anti-avalanche facilities.

4.3.2.5 France – SNCF

In SNCF, climate change risks and impacts have been studied in detail since 2009 ('Grenelle Laws'). SNCF has made a major contribution to the development of the French Climate Change National Plan, as: (i) it invests heavily in rolling stock with a life cycle of about 40 years and stations with an even longer life cycle and, thus, such assets need to be reasonably climate-proofed in the long-term (ii) operational risks should be reduced and resilience increased and (iii) climate change may cause behavioral modifications and introduce opportunities.

Table 13 Impacts of climate change on railways (Kaddouri, 2012)



The French Framework for Adaptation includes four main actions. Action 1 deals with the review and adaptation of technical standards for construction, maintenance and operation of transport networks (infrastructure and equipment) in continental France and French overseas territories. Action 2 studies the impacts of climate change on transport demand and the consequences for reshaping the transport market. Action 3 defines a methodology to diagnose vulnerabilities of the infrastructure and the land, sea and airport transport systems. Finally, Action 4 seeks to establish the vulnerability of land, sea and air transport networks in continental France and in French overseas territories and to prepare strategies of appropriate and phased responses to local as well as global climatic changes. Table 12 shows Climate Change impacts according to the SNCF analysis (Kaddouri, 2012, see also Annex II), whereas Table 13 details risks under higher temperatures or heat waves and potential adaptation measures.

Table 14 Possible adaptation measures for impacts of higher temperatures/heat waves (Kaddouri, 2012).

Risk	Impacts	Potential adaptation measures
Overheating of passenger cars	Discomfort/uneasiness of personnel and passengers	Longer preparation of trains Higher specifications of air conditioning Ventilation improvements (ex. VMC turbo fan) For moderate-speed vehicles (ex. trams), ventilation without air conditioning (e.g. Tram in La Réunion)
Damages and premature wearing of train electronics / track signaling systems	Loss of reliability	More frequent maintenance Tougher specifications
Engine overheating	Loss of power of traction units	Slowdown of traffic
Vegetation die out (droughts)	Fires along the tracks Presence of animals along the tracks, searching for pasture	Planting of less flammable species Coordination with Civil security for fire prevention Fences along the tracks 'cow-catchers' at the front of the locomotives
Northward migration of certain insects due to warming	Infestation of passenger cars (e.g. ventilation systems, sleeper trains)	

4.3.3 Technical adaptation measures for inland waterways

Inland Waterway Transport (IWT) is controlled by river hydrology and its dynamics. Future projections (e.g. dryer summers and wetter winters) indicate that there may be impacts on IWT, particularly after 2050 -'far future scenarios'- (Turpijn, 2012, see also Annex III and Sections 2.3 and 3.5). Such impacts are associated mostly with both summer low levels (in e.g. the Middle Rhine R., the RMD Canal and the upper Danube R.) and winter high flows. Some positive effects are also projected, mostly associated with potential decreases in river ice. In addition to the environmental factors, industry trends (e.g. the trend towards larger vessels) may also increase the IW transport sector vulnerability in the case of increased and protracted low river flows and levels, as well as costs for lock renewal. Transportation costs have been found to rise quickly under low water conditions, with the costs per t km rising by a factor of about 3 when water levels fall from 4 to 2 m; when water levels fall below 1.6 m most inland waterway transport becomes impossible. It appears that considerations related to infrastructure and autonomous transport economics dominate the climate change adaptation discussion within the sector (Turpjin, 2012).

4.3.3.1 *Weather-related effects on inland navigation network and potential adaptation responses*

Inland waterway transportation requires international co-operation to safeguard against climate change and variability beyond that envisaged for the other transport modes, as climate effects on rivers always migrate downstream. Therefore, the objective of European FP7-ECCONET Project "Effects of Climate Change On the inland waterway NETwork" (commenced on 01/2010) (www.ecconet.eu) has been to integrate the expertise from 10 partners from 5 countries with respect to the current/future environmental conditions (e.g. meteorology, hydrology), infrastructure, operation, services and economics in order to assess Climate Change impacts on the European transport network, and particularly on the Inland Waterway network such as the Rhine and Danube rivers[20] (Table 15).

Table 15 Impacts of climate change to the major Inland Waterways of EU (Heyndrickx and Breemersch, 2012).

Phenomenon	Period	Middle Rhine	RMD Canal	Upper Danube
Low flow	1950-2005	Positive effect	No effect	Positive effect
	2050	No effect	unknown	Negative effect
	2090-2100	Negative effect	Negative effect	Negative effect
High Flow	1950-2005	No effect	No effect	No effect
	2050	Negative effect	No effect	No effect
	2090-2100	Negative effect	No effect	unknown
River Ice	1950-2005	Positive effect	Positive effect	Positive effect
	2050	No effect	Positive effect	Positive effect
	2090-2100	No effect	Positive effect	Positive effect
Visibility	1950-2005	Positive effect	Positive effect	Positive effect
	2050	unknown	unknown	unknown
	2090-2100	unknown	unknown	unknown

Low water levels on Inland Waterways can have significant financial costs. For the Rhine R. (see Heyndrickx and Breemersch, 2012, see also Annex II) it has been shown that costs rise quickly under low water conditions, with the average costs per ton/km becoming almost three times higher when water levels fall from 4 to 2 m; below 1.6 m, most inland waterway transport becomes impossible. Major impacts of low water levels or droughts include insufficient navigation conditions, increases in accidents (groundings), increased fuel consumption per t/km and low flow velocities and increased sedimentation. High water

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[20] Some of the major navigable rivers are found in EU territory. The April 2013 EU Strategy Proposal for Climate Change adaptation may assist in providing a framework for the adaptation of inland transport infrastructure including inland waterways and inland ports. http://eur- lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2013:0216:FIN:EN:PDF. See also Lochman (2012)

levels or floods, although a short lasting phenomenon, may cause suspension of navigation, changes in river morphology, changes in channel sedimentation patterns, aggradation and damages to towpaths, banks and flood protection schemes. Finally, bouts of ice in the waterways may also cause suspension of navigation, create problems in the lock operation and damage navigation signs (Heyndrickx and Breemersch, 2012; Siedl, 2012).

Proposed adaptation measures are associated with: (i) IWT fleet adaptation (e.g. introduction of lightweight structures, adjustable tunnels, extractable buoyancy elements, side blisters, flat hulls) (see Table 16 and Fig. 57) (ii) infrastructure (information and dredging, waterway engineering) (Fig. 58) (iii) improved predictions (water level trends/forecasts) and (iv) more efficient logistics (e.g. coupling convoys, co-operation with other transport modes). An initial assessment shows that the most promising measures are related to the introduction of flat hulls (multiple screw push boats), the upgrade of small vessels to continuous operation and the use of coupling convoys (see also Annex II).

Table 16 Fleet adaptation measures and their preliminary assessment (Heyndrickx, and Breemersch, 2012)

Measure		Primary effect	Preliminary assessment
A1	Lightweight structure	Reduction of own weight causing lower draught	Further research necessary on technical solutions
A2	Adjustable tunnel	Navigation in lower water levels	In combination with A1
A3	Side blisters	Payload gain between 115 and 260 tones	Theoretical approach, handling provides to be difficult
A4	Flat hulls (multiple screw push boats)	Draught reduction from 1.7 to 1.4 meter	Promising approach especially for push boat technology, even at increased construction cost
B1	Small instead of large vessels	Small vessels are less water sensitive	Goes contrary to scale effect
B2	Upgrade of small vessels to continuous operation	Increased performance	Promising approach
B3	Coupling convoys	Redistribution of load	Promising due to increased scale effect
C1	Strategic alliance between IWT and other modes	Co-operation with other modes	Capacity limits of rail and high prices make this difficult

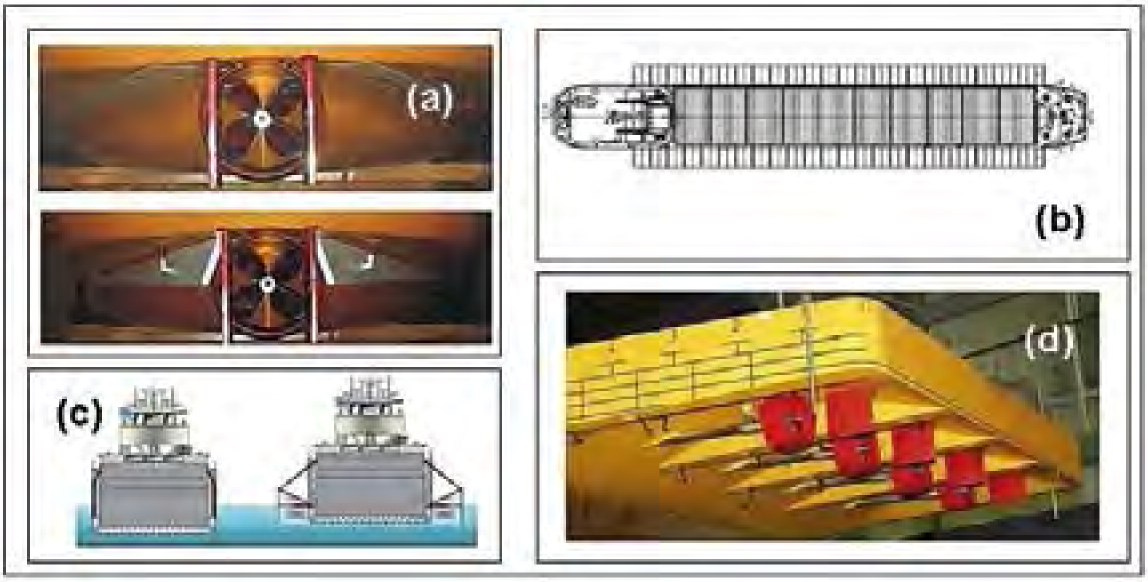

Figure 57 Adaptation measures for the IW fleet (Heyndrickx and Breemersch 2012): a) Adjustable tunnel aprons, to be retracted into the hull if the ship utilizes its full draft in deep water (above) and extracted when the ship operates in low water (below) (b) general arrangement plan of a IW vessel with laterally extractable buoyancy elements (c) Cross section of a IWT vessel with laterally extractable buoyancy elements and (d) close view of buoyancy elements.

With regard to morphological changes of the inland waterways induced by climatic changes, bed degradation will continue to increase if unchecked and new river morphology adaptation measures will be required (e.g. Fig. 58) together with improved river management practices. The costs of infrastructure adaptation to bed degradation have been estimated to be similar to those required to arrest bed erosion (Turpjin, 2012).

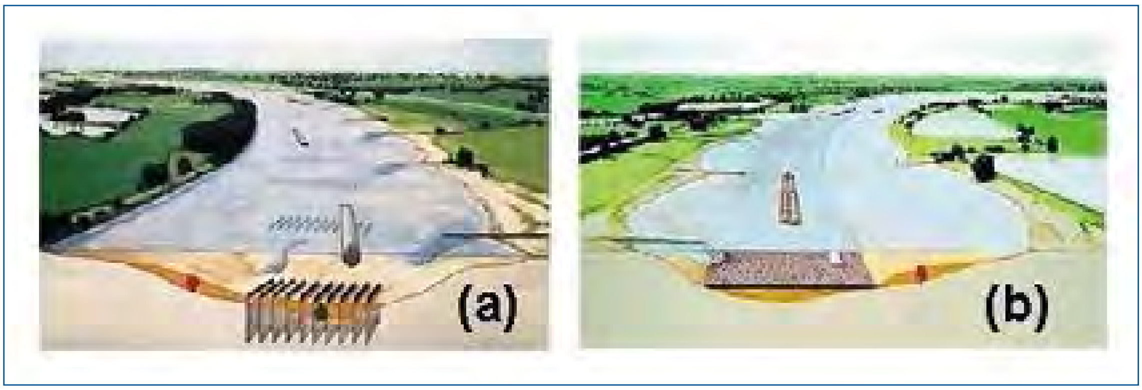

Figure 58 River bed degradation can have significant impacts on navigation, especially at river locations with fixed layers, such as (a) bottom vanes and (b) fixed layers (Turpjin, 2012). In these cases, the engineering works must be rearranged or retrofitted.

An example (Pilot Project Witzelsdorf, see Siedl (2012)) of waterway infrastructure adaptation has shown that river engineering works may require adaptation. In this case, old riverbank groynes were removed and replaced by new groynes with improved design (Fig. 59), and the river banks were restored; the scheme resulted in more favorable flow dynamics and lesser scouring at the groyne heads.

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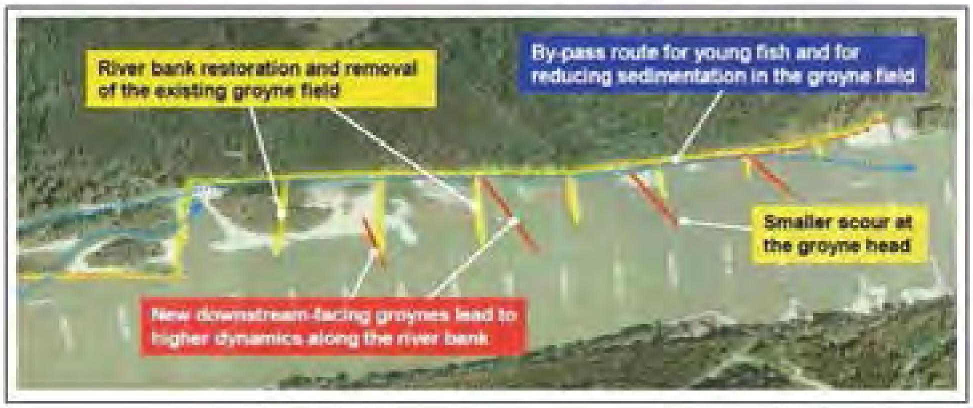

Figure 59 Adaptation river engineering methods used in Pilot Project Witzelsdorf (Siedl, 2012). The old groynes (yellow) were removed and replaced by new groynes of improved design to change favorably the river flow and sediment dynamics.

Concerning Integrated waterway management, the same study has suggested that IWT is controlled by 'fairway maintenance' cycles, that involve measures such as: (i) regular river bathymetry monitoring (ii) timely river dredging that takes into consideration the natural processes (fish breeding times, no removal of gravel from the river bed) and (iii) on-line bathymetric and flow information for the waterway users. This management should involve the provision of fairway conditions in accordance with internationally agreed parameters and short/medium and long term adaptation measures.

In the following sections, brief summaries of some national adaptation plans are presented.

4.3.3.2 United States of America

There 25,000 miles of commercially navigable waterways in the USA. In terms of the international IW network, the Saint Lawrence Seaway Development Cooperation (SLSDC) has been working on a Climate Change Adaptation (CCA) Plan for actions that will integrate reviewed climate adaptation considerations into its operations and services. The Plan will include coordinating adaptation plans with partnering agencies, in view of an integrated co-operation with the Canadian Seaway (USDOT, 2012b).

There has been an engineering review of the mechanical, electrical and hydraulic systems of lock operations has found that in order to safeguard these systems from extreme high and low water levels, certain modifications will be required. SLSDC's Asset Renewal Program (ARP) plans to renew all essential components that will safeguard the system in extreme conditions, including ice flushing systems, hydraulic lock operating equipment, heating systems to safeguard against extreme cold conditions, and drainage systems to safeguard against flooding (USDOT, 2012b).

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4.3.3.3 Canada

Adaptation measures are focusing on locks (see also Section 4.5.2). Climate change and variability impacts will affect lock operation, with deeper and wider locks needed to safeguard against extreme level conditions; another alternative for e.g. the Great Lakes–St. Lawrence Seaway system would be to invest in vessels that require less draft. Dredging is a common response to low water levels which is currently used extensively to manage drought impacts; however, climate change impacts may require changes in the frequency and intensity of dredging with potential higher financial and environmental costs (CCIADC, 2004).

4.3.3.4 The Netherlands

Results from two Dutch research programs ('The impact of climate change to inland waterway transport and the competitive position of the port of Rotterdam' (2011) and 'Protecting the Netherlands against high-water and taking care for sufficient fresh water for the users of the fresh water system' (to 2014)) have provided information on climate change-related effects on Inland Waterways. These studies have indicated that although the main impacts on inland navigation, decreasing load capacities and rising transportation costs, will be relatively low until 2050 (Turpjin, 2012; see also Annex III.7),

4.3.4 Technical adaptation measures for seaports

Shipping has been one of the key factors of economic growth throughout history, being also an important source of revenues and jobs. For example, 80 per cent of EU world trade is carried by sea whilst short sea shipping carries about 40 per cent of intra-EU freight; in addition, 400 million sea passengers pass through the EU ports each year, with shipping being the lifeline of islands and peripheral regions (http://ec.europa.eu/transport/modes/maritime/index_en.htm). Fuelled by strong growth in container and dry bulk trades in 2011, world seaborne trade grew by about four per cent in 2011 taking the total volume of goods loaded worldwide to 8.7 billion tons (UNCTAD, 2012). Therefore, appropriate policy approaches are needed in order to ensure the continuous performance of the maritime transport system and its contribution to the world economy (e.g. Asariotis and Benamara, 2012).

Seaports are likely to bear the brunt of climate change impacts (see Section 2.1). Nevertheless, and despite the inherent international dimension of shipping (see e.g. Fig. 16), the assessment of risks and associated adaptation measures to advance port resilience to climate change is a newcomer in the international transport policy debate[21]. Relevant actions taken in this respect include a global survey of world seaports carried out by the International Association of Ports and Harbors (IAPH) and the American Association of Port Authorities (AAPA). These port industry associations surveyed their members to ascertain how administrators feel climate change might impact their operations, what sea level changes might create operational problems, and how they plan to adapt to the emerging environmental conditions (IAPH/AAPA, 2010). Results show that members are particularly concerned with the climate change impacts, but generally feel that more specific information from the scientific community is required in order to make good decisions. Interestingly, although the vast majority of ports considered climate change adaptation to be an issue that the ports community should address, only 34 per cent of respondent ports felt sufficiently informed about the climate change challenge and related implications for ports (Inoue, 2012; Becker, 2012).

About half of the surveyed ports reported that they had taken some steps to prepare for potential climate change effects. However, although the design lifetime of many capital projects is about 50 years which is well within the horizon for many predicted climate change scenarios, capital planning cycles are typically 5 to 10 years. In addition, the scientific community has not yet been able to provide climate change information on the local scale necessary for port planning. For instance, reliable predictions of sea level rise for specific ports and coasts are not yet available, as is the case for local storm wave patterns and intensities. Therefore, uncertainties for specific impacts and the long time scales make

[21] For example, climate change resilience has not been not included in the strategic goals/recommendations of the EU Maritime Transport Policy until 2018 (EC, 2009), or mentioned explicitly in the 2013 EC communication (EC, 2013). In comparison, climate change mitigation involving shipping emissions is often taken into consideration (see e.g. Directive 2012/33/EU 'Sulfur content of marine fuels').

investment decisions difficult. The survey results indicate that, on a global scale, most ports are only at the first stages of considering adaptation to climate change. Therefore, there is a scope for the scientific community to engage with the seaport sector in order to promote resilience and efficiency in the coming century.

Ports are expanding[22]. For example, about half of the surveyed ports said that they will complete major infrastructure projects within the next decade, but 75 per cent of the respondents declared that these projects take into account the 1-in-100 year storm event. As these are large scale projects with a design life of several decades, these standards appear not to be adequate as climate change is likely to decrease the return period of the extreme storm event (see also Section 1.3). These results highlight one of the most challenging aspects of planning for climate change. Given that the capital facilities planning horizon is short relative to the most widely accepted predictions of sea level change, planning solutions rarely include sea level change considerations. However, incremental strategies could be developed that do not inadvertently complicate or prevent future planning for climate change.

Figure 60 Plans for Port Protection and Expansion (IAPH, 2010; Becker, 2012)

Only a small percentage of ports appear to have upcoming projects, such as new breakwaters or storm barriers, which would reinforce their defenses against flooding and wave damage (see also Fig. 59). It must be noted here, that specific seaport risks associated with climate change are not fundamentally different from historic risks; however, the risk level will likely change.

The United States of America Maritime Administration (MARAD) plans to incorporate by the end of 2013 climate change adaptation considerations into internal reviews, especially with regard to port infrastructure projects, shipyard grant application evaluations, and Agency facility modifications. It has also begun outreach efforts to facilitate the adoption of climate change considerations by stakeholders (USDOT, 2012b). A recent Australian Study (McEvoy and Mullett, 2013) has highlighted the requirements for assessing the resilience

[22] Ports key transportation nodes. One of the concrete measures of the EU White Paper (Action 4) for achieving a competitive and resource efficient transport system in the 2020-2030 horizon is the inclusion of 82 major EU ports in the core infrastructure network to be implemented by 2030 (TEN-T). http://ec.europa.eu/governance/impact/planned_ia/docs/2013_move_016_future_eu_ports_policy_en.pdf

of seaports to climate change. They have divided the assessment process into 6 stages i.e.: Stage 0, getting started and executive support; Stage 1 establish the port context; Stage 2 identify current vulnerabilities and future risks; Stage 3 analyze and evaluate risks); Stage 4 identify and prioritize adaptation options; and Stage 5 monitoring and evaluation of adaptation measures.

In this study, several innovative adaptation actions have been identified, with further opportunities to improve logistics flow, manage infrastructure lifecycles and reduce potential hazards, as additional co-benefits to building climate resilience. It was found that building climate change adaptive capacity involves developing the organizational ability to respond effectively to climate change challenges, involving awareness raising, skill development, data collection and monitoring and research. It was also suggested that implementation of adaptation actions is concerned with taking practical steps to reduce vulnerability to climate risks or develop opportunities. It includes technological, engineering change, design and maintenance, planning, insurance measures and management system change (see Table 16). Other studies have suggested specific practical steps for example the reduction of wind loads, by building permanent wind walls along berths or using stacked containers to provide wind protection. Stacked containers to heights up to 13–15 m has been shown to decrease wind velocities by up to 25 per cent and wind loads up to 30 per cent (Paulauskas et al., 2009).

Effective seaport adaptation requires detailed, down-scaled research on the climate change risks (e.g. long-term and short-term sea level rise, changes in the wave regime that may affect the penetration of long waves into the port and changes in the flow and sedimentation patterns) (e.g. Becker et al., 2013). Such research requires large human and financial resources. It could be beneficial to conduct a number of cases studies (see e.g. Stenek et al., 2011) that can provide guidance on how best to evaluate effects and adaptation options.

A number of seaports have already taken some steps toward adaptation. For instance, the Port of Rotterdam (Netherlands) has developed together with other stakeholders the Rotterdam Climate Proof Programme which aims by 2025 to make Rotterdam 'fully' resilient to impacts of the climate change impacts (Rotterdam Climate Initiative, 2013). The adaptation strategy focuses amongst other on flood safety, ship accessibility, adaptive building and the urban water system. New port developments are designed to be climate-proof and climate change assessments are integrated into the port's spatial planning together with knowledge development (Vellinga and De Jong, 2012). The Port of San Diego (California, The United States of America) has developed a 'Climate Mitigation and Adaptation Plan', together with surrounding communities that share responsibility for emergency response, critical utilities protection, and storm water drainage (Port of San Diego, 2013; Messner and Moran, 2013). The assessment methodology includes a risk evaluation framework that considers likelihood and consequence of impacts. The above studies and initiatives demonstrate integrated and collaborative approaches to climate change responses for ports and port regions. Nevertheless, much more remains to be done and different approaches will have to be devised and tested to cater for the variety of conditions facing ports at a global level (Becker et al., 2013).

Table 17 Australian port adaptation strategies (After McEvoy and Mullett, 2013)

Action Area	Adaptation Action
Technological	Targeted investment in technology (e.g. for cranes that can safely operate under stronger wind gusts)
	Refrigerated storage specifications to meet higher temperature demands, using less energy intensive alternatives
	Renewable/low emission energy to avoid power disruptions and increased energy costs; such developments are already happening e.g. fuel cells for mobile logistics elements/ cooling refrigerated cargo and photovoltaic cells for buildings
	Automation of logistics procedures
Engineering	Procurement of assets (e.g. gantry loaders, conveyor belts, shore cranes) needs to be assessed against the future operational environment
	Storage facilities need to be upgraded to accommodate future extreme events
	Assess/upgrade drainage systems to cope with more intense downpours
	Ongoing hydrographic monitoring to identify dredging requirements
	More robust systems (e.g. dust suppression systems) to cope with higher winds
	Incremental growth/reconfiguration of breakwaters to deal with higher sea levels and waves
	Raise of roads/ rail lines in and out of seaports to avoid flooding
Design and maintenance	Encouraging necessary modal shifts to improve resilience by removing reliance on redundant elements of the supply system Ensure climate changes (e.g. sea level changes, higher storm surges) are included in future design specifications of all port infrastructure elements Ensure ports have a proactive infrastructure and asset management plan that considers asset life cycles Working in partnerships with city governments and supply chain logistics providers to appropriately plan and design connected logistics hubs resilient to regional climate change Investigate diversification of trade into climate resilient commodities
Insurance	Collaboration with the insurance industry to quantify risks is necessary in order to appropriately insure against risks that cannot be mitigated effectively.
Management systems	Climate change considerations should be incrementally introduced in environmental, emergency and risk management systems, by updating policy elements, incorporating training on climate change impacts into ongoing training, considering appropriate strategies/metrics for different management systems and updating legal compliance elements regularly Develop 'pandemic' plans as part of the emergency preparedness and response system

4.4 Summary and discussion

The above brief review has shown that adaptation for climate change and variability impacts on transportation is a newcomer on the international transportation policy agenda. While some research relating to climate change impacts on transport and related adaptation requirements has been undertaken and although a number of adaptation responses and plans have been implemented or are currently planned by public authorities and industry operators in various countries, much work is, nevertheless, still needed to improve understanding of key issues at the interface of transport and the climate change challenge. Most of existing research efforts have taken a modal approach, although there are also indications for a more integrated approach in the future[23]. At the same time, it appears that there has been little effort to date to address the issue of climate resilience of international transport networks[24] at a regional and global level.

Climate change and variability affects road transport in terms of safety, operation and maintenance of road infrastructure and systems. Different direct (e.g. pavement deterioration, deformation, subsidence and landslides, problems with accessibility due to floods and erosion) and indirect (economic, environmental, demographic, spatial planning) impacts require different technical and operational adaptation measures. This includes new heat thresholds for road surfaces and bridge expansion joints, strengthening of embankments, incorporation of steel grids in the road structure and elevation of roads, bridges and tunnels above the flood plains. Approaches to integrate climate change considerations into road design and operation include assessments of exposure, vulnerability and resilience, planning of timeframes and the formulation of adaptation strategies.

Climate change already affects railway operations in different regions, with the effects of heat waves, flooding and high winds expected to increase in the future. Heavy precipitation and flooding may undermine earthworks and strain drainage systems, whereas high winds can damage overhead lines. Existing studies in several countries, including those mentioned above seem to have a common denominator as regards how to best deal with the consequences of climate change for railways. At the core of the adaptation strategies is the improvement of infrastructure resilience by putting in place safeguards for quick recovery of rail systems in the case of extreme weather events. Technological innovations in construction and changes in operational procedures to incorporate projected effects of climate change appear to be the preferred *modus operandi* for the development of new railway infrastructure.

Inland Waterway Transport (IWT) is controlled by river hydrology and its dynamics. It appears that considerations related to infrastructure and transport economics dominate the sector's climate change adaptation discussion. In Europe, future projections indicate climate change impacts on IW T, particularly after 2050, which will be associated mostly with summer low river levels and winter high flows. Proposed adaptation measures are mostly related to fleet adaptation and the monitoring or rehabilitation of the river or canal bed morphology. In comparison, North American adaptation responses focus mostly on the locks of the Great Lakes-Saint Lawrence Seaway, which are projected to be significantly affected by future climatic change and variability.

[23] For example, the United States of America Gulf Coast Study (Annex I.13)

[24] Transport networks are highly valuable assets. For example, the UK road network was valued in 2005 as the UK single most valuable asset, with the value of the major trunk roads and motorways estimated as approximately £ 62 billion (Hooper and Chapman, 2012).

Ports are likely to bear the brunt of climate change impacts given, in particular their location on coasts, low lying areas and deltas as well as their high valued infrastructural assents and concentration of economic activities (see Section 2.1). Nevertheless, the assessment of risks and associated adaptation measures to advance port resilience to climate change has not yet found its place in the center of the international transport debate. Results by industry surveys (e.g. IAPH) show that ports are particularly concerned with the climate change impacts. Nevertheless, port operators also appear to believe that additional and more detailed research is required in order to plan and invest effectively in port resilience.

Considering International transport networks, the review undertaken in the present study has shown that effective, integrated, multimodal networks are required in order to facilitate efficient, safe and quick international movement of goods and people. However, to date little coordinated effort has been undertaken to assess the impacts of and the design adaptation responses to the projected climate change and variability at the international level (e.g. EC, 2012). Although there are inherent difficulties to such an exercise, such as the high spatio-temporal variability of climate, the varied administrative and technical backgrounds, differential financial constraints as well as the limited relevant information (e.g. the 'data paradox', see Potter (2012)), sustainable international transport strategies should evolve to take into account climate change and variability impacts on international transport infrastructure and operations, and to plan for effective adaptation measures.

In order to develop a comprehensive international transport network within the ECE region, Member States, infrastructure developers and managers as well as other stakeholders would have to pay particular attention to measures that are necessary to: (i) provide missing links and remove bottlenecks (ii) remove administrative and technical barriers to network interoperability, ensuring optimal integration of the transport modes and accessibility for the whole region (iii) implement intelligent transport systems for traffic management, multimodal scheduling, tracking and tracing services, capacity planning and integrated online reservation and ticketing services (iv) ensure high environmental performances/ minimal environmental impacts, quality of services and efficient traffic flows (v) promote state-of-the-art technological development that will increase fuel security and decrease carbon emissions and (vi) maintain and improve the quality of infrastructure in terms of efficiency, safety, security, and climate and disaster resilience.

For the ECE region, it would appear that climate change resilience requires as first a step a detailed mapping of the ECE international transport networks and corridors, including those planned, such as those of the TEN-T program (see http://ec.europa.eu/transport/themes/infrastructure/index_en.htm). Furthermore, there is a need to identify the region's critical transport nodes and assess their sensitivity to different climate change impacts depending on location and for different climatic scenarios. This exercise will likely enable informed decisions to be made, not only in terms of priority actions and design standards, but also in terms of co-modality as well as shifts towards the most sustainable, energy efficient and resilient transport modes.

Baja Town, Floods of Danube, Hungary 2013. Photo by Mr. Otto Michna

Baja Town, Floods of Danube, Hungary 2013. Photo by Mr. Otto Michna

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Chapter 5. Conclusions and Recommendations

5.1 Introduction

Although climate change impacts on various human activities have been considered by both governments and international organizations for some time now, relatively little attention has been paid to the assessment of climate change impacts on international transport networks and operations as well as on potential adaptation measures. It is noted that Parties to the United Nations Framework Convention on Climate Change (UNFCCC) are inter alia committed to take action to adapt to CC (here in the meaning of human induced CC). Issues related to adaptation have increasingly been discussed in sessions of the UNFCCC constituent bodies and relevant decisions have been taken. It is also noted that the international community has recognized that appropriate climate information and services are not always available. To address this gap governments have decided in a decision taken by the Extraordinary World Meteorological Congress, to implement the WMO-led Global Framework for Climate Services (GFCS). However, on the basis of the recent work undertaken at national and, in few instances, at supra-national level as well as by the transport industry, it has been shown that climate change–induced weather conditions may have significant implications for the infrastructure of international transport networks and, thus, the functioning of the global and regional economy and livelihood. In response to these considerations, integrated strategies at national and supra-national levels have recently started to emerge as e.g. the recent (April 2013) European Union Climate Change Adaptation Strategy, which seeks to make the EU more climate-resilient. For the transport sector, the strategy focuses on the assessment of costs, benefits and impacts of adaptation, the enhancement of knowledge, the fostering of standards and guidelines, and the collection and sharing of best practices.

Recognizing the need for concerted action, experts from various countries, international organizations and academia, under the auspices of the United Nations Economic Commission for Europe established a Group of Experts on Climate Change Impacts and Adaptation for International Transport Networks. The Group met six times , and (a) discussed relevant information for the ECE region and beyond, and analyzed and identified potential climate change impacts on transport infrastructure and transport services across the broader supply-chain (b) collected and analyzed information about the current level of awareness and preparedness, the availability of relevant information and tools, the existing and planned transport adaptation policies, measures and initiatives, and on the research needs, financing requirements and the collaboration mechanisms at national, regional and international levels (c) reviewed relevant national initiatives, case studies and research projects (d) exchanged experiences on mode-specific adaptation measures that may mitigate transport network vulnerability;(e) identified existing best practices in national policies for risk management and the enhancement of transport network resilience (f) recognized the need for an increased awareness about the assessment of the CC impacts and adaptation measures and (g) assessed the contribution of the climate change adaptation to the development of broader guidelines and best practices in the transport sector.

5.2 Climate change trends projections and impacts

5.2.1 Trends and projections

Concerning the current climate trends and future projections, a long-term increasing trend in the mean air temperature is already clear. Precipitation has been also changing, but in a more complex manner, with some regions becoming wetter and others dryer. Such trends are predicted to hold or even pick up pace in the future. A decreasing, but non-uniform, trend in the snow cover can be discerned. A most damaging side-effect of the temperature increases concerns a substantial rise in the mean sea level, due to ocean thermal expansion, the melting of the Greenland and Antarctic ice sheets and the glacier and ice caps as well as changes in the terrestrial water storage. Since the 1860s, sea levels have increased by about 0.2 m, with satellite information showing a progressive increase in the rates since the 1990s.

Changes in the average climate conditions can also lead to fluctuations in the frequency, intensity, spatial coverage, duration, and timing of weather and climate extremes, which can, in turn, modify the distributions of the future climatic conditions. Extreme events (e.g. storms, storm surges, floods and droughts and heat waves), as well as changes in the patterns of particular climatic systems such as the monsoons, can have at smaller spatio-temporal scales, more severe impacts on transport networks than changes in the mean variables. One of the clearest trends appears to be the increasing frequency and intensity of heavy downpours; climate models project the continuation of this trend, with heavy downpours that occur presently about once every 20 years being projected to occur every 4-15 years by 2100, depending on location.

Concerning river floods, these appear to present a very significant hazard, particularly for central and eastern Europe and for central Asia. However, their trends are better assessed at a regional and local scale. There is also evidence to suggest increases in the frequency and intensity of heat waves, i.e. of extended periods of abnormally hot weather. Heat waves are often associated with severe droughts, which are generally becoming more severe in some regions.

One of the major causes of the observed temperature increases is considered to be the increasing atmospheric concentrations of greenhouse gases-GHGs (i.e. water vapor, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O)), which absorb heat reflected back from the Earth's surface and, thus, increase the heat storage in the Earth system. Since the industrial revolution, atmospheric concentrations of the GHGs have been steadily increasing, being now higher than they have been for some million years. For example, the CO_2 concentration has surpassed the 400 ppm (parts per million) milestone for the first time in at least the last million years in early May 2013. Global warming can be amplified by reinforcing feedbacks, i.e. climate change-driven processes that can induce further warming. For example, previously inert carbon reservoirs (e.g. the tropical peat lands and the vast CH_4 stores of the Arctic permafrost) can be mobilized by increasing temperatures and release more CO_2 and/or CH_4 to the atmosphere. The rapid reduction in the spatial coverage of Arctic Ocean ice, particularly during summer may also affect climate, as sea ice reflects most of the impinging radiation from the sun back into the atmosphere in contrast to the sea water; an ice-free Arctic Ocean may accumulate sun radiation that will reinforce global warming.

Climate change (e.g. mean sea level rise, warmer water temperatures, higher intensity of storms and storm surges and potential changes in the wave regime) may severely impact coastal infrastructure and services, such as ports and other coastal transport hubs and networks. Daily port operations can be directly influenced by storm surges and backwater, resulting in port closures. Recent studies have assessed the population and assets exposure of 136 port cities with more than one million inhabitants, finding that tens of millions of people and assets with a value in excess of $25,000 billion may be exposed to coastal flooding by 2050. Coastal inundation will have significant impacts on coastal transportation infrastructure by rendering it unusable for the flood duration and significantly damaging terminals, intermodal facilities, freight villages, storage areas and cargo and, thus, disrupting intermodal supply chains and transport connectivity for longer periods. Ports, which form key-nodes in international transport networks and link international supply-chains, will be particularly impacted, due mostly to the long life-time of their key infrastructure, their exposed coastal and/or estuarine location, and their dependence on trade, shipping and inland transport that are also vulnerable to climate change.

Precipitation changes may result in stream flow changes that are likely to affect roadways, railways, rail and coach terminals, port facilities, and airports. There can be direct damages during the event, necessitating emergency responses. There can also be effects on the structural integrity and maintenance of roads, rail lines, bridges, tunnels, drainage systems, telecommunication and traffic management systems necessitating more frequent maintenance and repairs. Increases in heavy precipitation events and floods will cause more weather-related accidents due to vehicle, road and rail tracks damages as well as poor visibility, delays, and traffic disruptions in the already congested networks. Ports will be also vulnerable to short-term rain-induced flooding, whereas extreme precipitation-induced silting could reduce navigation channel depths, leading to a considerable increase in dredging costs. Inland waterways can suffer navigation suspensions, silting, changes in river morphology and damages of banks and flood protection schemes, whereas increased delays and cancellations of flight operations due to airport flooding are also likely, together with effects on the structural integrity of runways and other specialized airport infrastructure.

Extreme winds can damage coastal and estuarine railways, damage port facilities (e.g. cranes and loading terminals), destroy agricultural crops and, thus, indirectly affect the transport industry, induce more frequent interruptions in air services and damage airport facilities such as equipment, perimeter fencing and signs, damage road and railway infrastructure (through e.g. wind-generated debris) and stress road and rail operations. In addition, changes in the wind and wind-wave directional patterns may also have important implications on e.g. seaport operations and safety.

Heat waves may also have substantial impacts to transport services and infrastructure. The hot and dry conditions may lead to wildfires and crop failures, stress water supplies, food storage and energy systems and increase refrigeration requirements. Heat waves can also damage roads, deform rail tracks and desiccate track earthworks and cause lengthy delays through speed restrictions. Airport facilities, runways and operations will be also affected as will inland waterway transport. The decline in the Arctic Ocean ice extent may allow the opening of new shipping routes, but also alter demand and supply of regional transport services and significantly increase the costs for linking Arctic ports to major national and international inland transport networks. Arctic warming may also lead to changes in the permafrost distribution and the freezing and thawing cycles that can damage building foundations, cause frost heaves at roadways and rail lines, and affect the integrity of bridges and other transport structures and their load-carrying capacity.

5.2.2 Impacts on Transport modes

Demand for transport services grows in line with the global economy, trade and world population. As transport is a demand-driven industry, climate change-induced changes in e.g. population distribution, commodity production and its spatial distribution, tourism patterns and trade and consumption patterns can also have significant implications for transport. Therefore, climate change presents significant challenges, for both freight and passenger transport. Some of these challenges are summarized below for the different transport modes.

Road Transport

The projected climate change will certainly impact on the infrastructure, operations, safety and maintenance of the road systems, affecting all network managers and users. Main impacts include both direct (e.g. pavement deterioration and deformation, damages and subsidence in permafrost areas, general structural damage, traffic disruption and accessibility problems for tunnels and bridges caused by floods and bank erosion) and indirect (economic, environmental, demographic, and spatial planning). Road infrastructure will also suffer from asphalt rutting and/or melting, thermal expansion of bridge joints, landslides and bridge scouring or undermining. Consequently it is crucial to prepare for such effects and a move towards the so-called 5th Generation Road/Forever Open Road that is climate change -adaptable (see PIARC (2012) and Annex II) should be considered.

Rail Transport

The rail sector is already affected by climate change with hotter summers, wetter winters, strong winds and sudden switches of seasons causing increased traffic disruption and higher costs of network maintenance and traffic as well as higher energy consumption. Main impacts include rail buckling, rolling stock overheating and failure, signaling problems, increased construction and maintenance costs, embankment and earthwork failures, bridge scouring, overwhelming of the drainage systems and speed restrictions, delays and operation disruptions. As such impacts are possible to increase in the next decades, effective climate change adaptation strategies are required that will include vulnerability assessment and mapping, maintenance and emergency planning, dedicated R&D actions and the introduction of effective design guidelines and protocols for lines construction using improved new technologies and for the rolling stock.

Inland waterways

As relatively small changes are projected for the mean water levels of inland waterways until 2050, climate change impacts are not expected to be significant until then. However, the foreseen greater temporal and spatial variability in water levels can certainly create problems, particularly after 2050 that require integrated waterway planning, investments, maintenance and management. Main impacts include restrictions and cost increases due to very low and high water levels, land infrastructure inundation, and sedimentation issues in navigation channels as well as building new water reservoirs.

Seaports

Seaports, key nodes of the international transport networks, will bear some of the worst impacts of climate change due to its nature – placement at the edge of seas and land - and probably mean sea level rise and higher and more frequent storm surges. The majority of seaport locations are currently vulnerable to coastal flooding, a situation that is foreseen to deteriorate in the future; at the same time, estuarine ports will be also vulnerable to fluvial floods and droughts. Main climate change impacts include

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infrastructure, equipment and cargo damages from inundation and wave energy changes, increases in the energy consumption for cooling cargo, changes in transport patterns due to the potential development of new shipping routes (e.g. Arctic Ocean lanes), higher port construction and maintenance costs, changes in flow and sedimentation patterns in ports and navigation channels and insurance issues. A recent focused questionnaire survey to IAPH/AAPA members has shown that (a) respondents were highly concerned about climate change impacts, but not well informed (b) port design standards do not sufficiently take account of climate change considerations although seaports contain very substantial and expensive infrastructure with a long service life and (c) the great majority (97 per cent) of the respondents believed that they will face significant problems by a sea level rise of 0.5 m, or greater.

5.3 Recommendations

In the transport sector, climate change adaptation has so far not been given the appropriate attention. Some member States have worked in this field since years. Others just started their activities or will do so in future. However, most of the respondents (> 75 per cent) to the questionnaire survey, undertaken as a part of the present study, foresee that climate change is likely to have considerable impacts on transport in the next 30 years. To avoid significant future expenditures it appears that policy makers and stakeholders should address this issue as a matter of urgency. A clear understanding of the climate change potential impacts, risks and vulnerabilities appears to be both a first step and a prerequisite for the design and construction of resilient transport infrastructure and their management systems in future. It must be noted that the transport sector of the developing and poorly-diversified economies will be particularly vulnerable not only to catastrophic, large-scale extreme events but also to 'slow-burning' stresses due to the projected higher average temperatures and mean sea levels and more frequent flooding and/or droughts.

Adaptation action aims to reduce vulnerabilities and increase the resilience of systems to climatic impacts. In the transport sector, resilience refers not only to the physical strength and durability of the infrastructure that allows it to withstand adverse impacts without losing its basic functions, but also to its ability to recover quickly and at minimal cost. It follows that potential climate change broader economic and development policies involving the transport sector. Developing effective adaptation strategies for climate change impacts on international transport requires policy action, investments efforts and collaborative research. Well targeted vulnerability studies, empirical studies and assessments of projected risks and related costs are deemed as a necessary first step towards bridging the current knowledge gap and identifying and defining priority areas.

Efforts to assess risks and potential impacts on the transport sector may result in the development of practices and recommendations for adapting to already experienced and projected climate change impacts.

The following general recommendations are based on experiences gained so far and on scientifically confirmed potential manifestations of climate change impacts. With regard to Government action, it is considered that a necessary prerequisite for the development and formulation of effective climate change adaptation strategies should be a clear understanding and systematic mapping of the transport sector vulnerabilities to climate change that are determined by 3 main factors: the nature and the extent of climate change, the transport system sensitivity and the required capacity to adapt to changes. It is recommended that:

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(i) Governments, in collaboration with owners and operators of transport infrastructure (e.g. port authorities, private rail companies) and International Organizations should establish inventories of critical and sensitive nodes of the transport infrastructure to assess whether, where and when projected climate changes might have significant consequences.

(ii) Climate change should be incorporated into the long-term capital improvement plans, facility designs, investment works, maintenance practices, operations, engineering practices and emergency response plans.

(iii) Transport infrastructure and services are subject to many regulations; therefore, in order to accommodate climate change adaptation measures, institutional and regulatory adaptation may also be necessary. In this respect, the 2007 EC Directive on the assessment and management of flood risks presents a good example. According to the Directive EU member States are required to bring into force relevant laws, regulations and administrative procedures in order to prepare flood hazard and risk maps, management plans and implementation measures for coastal areas and river basins in their territory.

(iv) Transport infrastructure planners and designers together with transport infrastructure managers, vehicle and rolling stock manufacturers should take into account from the planning stage, climate change projections and their potential impacts at both global and regional scales. It is also important that effects of potential diverse goals should be assessed when designing adaptation responses, in order to avoid conflicting measures.

With regard to adaptation strategies, there are the following general recommendations:

(i) Without effective adaptation strategies and actions, the present resilience of transport networks may prove to be insufficient in the near-medium future. Therefore, pro-active capacity. Such strategies should include short- and long-term objectives and measures, take into account economic constraints and have 'Readiness', 'Resilience' and 'Recovery' (RRR) as guiding principles.

(ii) It is strongly recommended for adaptation actions to take place within integrated natural hazard management frameworks. Such frameworks should be able not only to pro-actively address the present weather-related challenges and disruptions, but also to design and build mid- to long-term climate change adaptation measures. Moreover, it appears that building upon current management systems that already deal with the present weather and climate related adverse impacts is more likely to create a working adaptation framework. Climate change adaptation programs that are not connected to present business operations are probably to face significant adoption and implementation problems.

(iii) Well-structured nationally as well as internationally integrated databases of digitized network data, disruption hotspots and incidents, management and maintenance plans and asset management practices could form the core of an efficient natural hazard management system for the transport sector. Such databases should be maintained and updated and supplied with necessary and innovative (software) tools that can project future risks in order to form an integrated tool to assist climate change adaptation in the transport sector.

(iv) Possible climate change impacts should be considered at the early stages of planning and included in risk and vulnerability assessments. In assessing future conditions with the aim of prioritizing adaptation measures, current practices and methodologies should be complemented with more innovative and future-orientated approaches. Future projects should integrate climate change considerations into their asset design and maintenance planning.

Although the present report deals with the adaptation of the transport sector to climate change, issues relevant to Climate Change mitigation should always be kept in mind.

(i) Adaptation is not an alternative to reducing GHG emissions. Global emission monitoring is considered necessary to constrain the rate and magnitude of climate change and, consequently, reduce costs and increase the effectiveness of the climate change adaptation measures.

(ii) Many fundamental decisions regarding both climate change adaptation and mitigation will be influenced by cost-benefit assessments. Presently, such assessments are constrained by uncertainties in the quantification of significant environmental, social and economic impacts; therefore, reducing such uncertainties, where possible, should become an urgent integrated research priority.

(iii) The possibility of developing synergies with GHG emission mitigation and other environmental objectives should be investigated further. Consideration might be also given to addressing, for instance, how modal transportation planning might assist in the climate change mitigation objectives.

The present study has shown that there are significant information and knowledge gaps that must be filled by appropriate research and service provision. Concerning this issue, the following recommendations are presented:

(i) The study of Climate Change impacts and adaptation requires integration of a wide range of disciplines, including those of law, natural and social science, engineering and economics. Although integration in the context of an uncertain future is challenging, it is also necessary in order to obtain results that could assist individuals, communities, governments, international organizations and the industry to deal with the adverse impacts of climate change.

(ii) Focused research should be undertaken for different climate change impacts. These studies could be complemented by case studies on the potential economic, social and environmental consequences and the cost/benefits of adaptation options. For example, the riverine flood risk on road and rail networks could be assessed by detailed studies that will model the potential extreme flood hazard in the ECE region under different scenarios of climate change and transpose it on the ECE road and rail networks in order to identify flood'hot spots'.

(iii) Initial assessments of the transport sector vulnerabilities are possible without a detailed knowledge of future climatic changes; these assessments can be based upon the analysis of the sensitivity to past climatic variability and the current capacity of the systems to absorb disruption and adapt to changing conditions. Therefore, it is possible to define coping ranges and critical thresholds. Scenarios of climate and socio-economic changes present a range of plausible futures that provide a basis for the assessment and management of future risks. Uncertainties regarding the nature and the extent of future climatic changes should serve to focus on adaptation measures that address current vulnerabilities through expanding coping ranges and increasing adaptive capacity.

(iv) It is worth highlighting that in view of the interconnectedness and interdependence of economies in a globalized trading system, the special needs of developing counties, and particularly Small Island Developing States, should also be taken into consideration.

(v) It is important to foster cooperation between the UNECE and other relevant International Organizations and Agencies, in particular with United Nations Framework Convention on Climate Change (UNFCCC), and the Global Framework for Climate Services (GFCS) of the World Meteorological Organization, in order to institute a process for better communication among transport professionals, climate scientists, and other relevant scientific experts, and establish, if possible, a clearing house for transport-climate change relevant information. Bearing in mind the global nature and implications of the climate change on transport sector as well as the importance to take into account climate change challenges when international transport norms and standards are discussed in the ITC and in its subsidiary bodies, UNECE is to take the initiative and contact the Partners Advisory Committee of the GFCS. Sharing of best practices for addressing potential impacts of climate variability and change in the transportation sector is also warranted.

With regard to the different transport modes, there are the following recommendations:

Road Transport

(i) Road owners should implement a systematic approach to define risks and assess consequences at network level (e.g. by identifying flood-prone hotspots and temperature sensitive network sections), and initiate the development of strategies to mitigate such risks in a cost-effective manner, using costing models that incorporate climate change scenarios.

(ii) Need to incorporate climate change considerations into the road design, construction and operation should include (a) risk assessments that evaluate the exposure, sensitivity, vulnerability, resilience and adaptation responses of the road systems, (b) planning of timeframes that consider longer-term climate change effects, and (c) adaptation strategies, including implementation procedures.

(iii) National policies for road transport should include awareness raising and good practice sharing schemes, as well as more strategic and long-term approaches to spatial planning.

Rail transport

(i) In the longer term, there may be ways in which the railway industry might assist in the mitigation of the projected climatic changes through addressing sustainability issues. The results could, for example, help railways managers in determining how existing assets could be most effectively managed, whether revised design standards for new assets could be beneficial, and how current operational measures might be best adapted.

(ii) A constructive way forward is to begin quantifying changes related to safety risk and traffic delays that are likely to be induced by unforeseen weather events. This should take into account:
- Different types of sensitive infrastructure and their spatial distribution (e.g. track, drainage, overhead electrification equipment);
- Historical quantitative information on e.g. delays caused by weather-related incidents;
- Current values used in risk models for weather-related precursors to hazardous events and predicted harm to people;
- Available quantitative estimates of likely changes in the occurrence of extreme events based on current industry intervention levels (temperature, flood levels, wind gust speeds etc.).
- Common education and awareness improvements, starting within the railway industry staff.

(iii) Railway infrastructure and rolling stock are generally robust, but train operations can be still severely affected by extreme weather (e.g. delays due to safety requirements and limits). Although currently such risks are generally modest, they are also likely to increase under a changing climate that may affect the frequency and intensity of extreme weather events.

(iv) The impacts of more frequent extreme storms and, in particular, of intense downpours, heat waves, floods and extreme winds on the rail network might be considered as escalations of the present situation. Such effects have been already studied to varying degrees but mostly for the purposes of assessing accident risks in the design process, rather than for assessing climate change impacts and for the precautionary measurements.

(v) Rail infrastructure is designed to be used over long periods of time (often > 100 years). Therefore it seems reasonable that climate change adaptation needs should be considered well in advance. A good example of relevant practices is the engineering innovation related to adaptation to the effects of thawing permafrost, which will be exacerbated by the projected increases in global temperature, such as sinkholes causing railway crack and heave. The world's longest high-elevation railroad (the Qinghai-Tibet railway- 'The Permafrost Express'- in China) involves engineering and design innovations adapted particularly for permafrost environments, that can be considered applicable in other regions.

Inland Waterways

Inland Waterway transport will not be significantly affected by climate change until 2050, there appears to be a sufficient time window to assess adaptation options in ports design, fleet design, integrated waterway planning and management and logistics. The following activities appear to be beneficial:

(i) Improvement and integration of the future waterway infrastructure development.

(ii) Definition of integrated planning principles that involves experts from different disciplines (e.g. navigation, hydrology, engineering, freshwater ecology and economics).

(iii) Development of concrete guidelines for activities that can assist in the implementation of integrated planning principles with regard to inland waterway infrastructure projects.

(iv) Information on existing (and on-going) practices and innovations concerning vessel design and waterway engineering.

Seaports

Seaports should be at the top of in the priority list for climate change adaptation responses, as they face increased climate change-induced risks (e.g. sea level rise), are almost impossible to relocate and are indispensable links of the international supply chain.

(i) Facilities that face manageable risks might require mostly risk management and emergency response planning. Termination of port facilities should be the last resort and only if vulnerabilities are deemed to be too high and complex to deal with, or if port relocation costs could be managed.

(ii) To understand the significance of climate change-induced risks for a given port, it is necessary to analyses the factors affecting the port performance and evaluate climate change impacts taking into account existing vulnerabilities, critical thresholds and climate change assessments / forecasts.

(iii) The extent of climate change impacts on ports will vary greatly, though there are some key risk areas that all ports should consider. There will be considerable differences in the nature and level of climate change risks and opportunities among ports depending on their location (e.g. ports affected by long waves, ports prone to tropical or extra-tropical cyclones, or ports in permafrost areas).

(iv) Ports also vary considerably in terms of functionality. Climate change might have different implications for ports with cargo handling and warehousing functions compared to those providing exclusively pilotage, navigation and dredging services, or for cruise and passenger ports or for leisure marinas.


Putna Seaca Rail Bridge, Romania. Damaged by Floods in 2005 © Club Ferroviar

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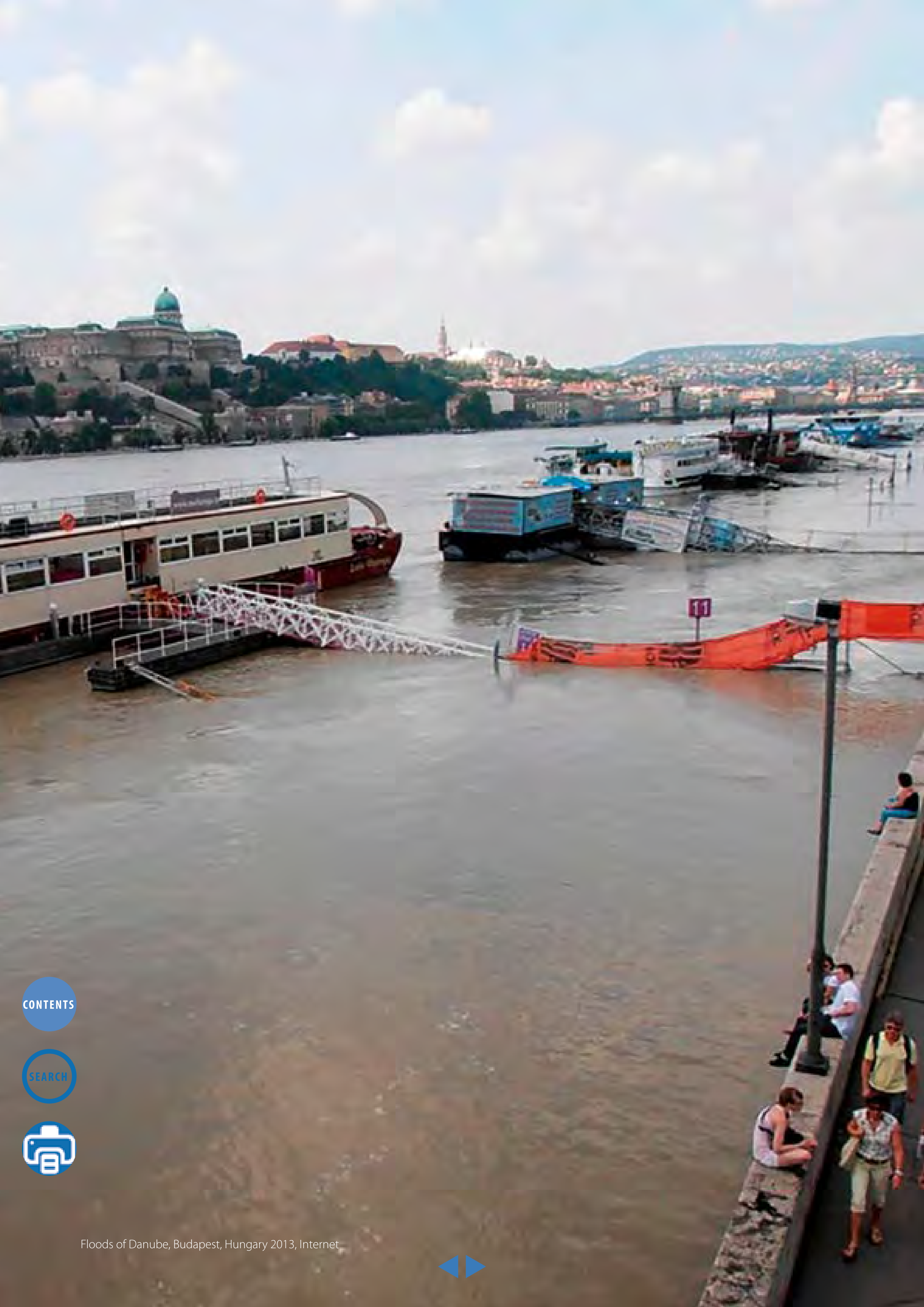

Floods of Danube, Budapest, Hungary 2013, Internet

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ANNEXES

Annex I: Select Studies on Climate Change Impacts on Transport

Enhancing the climate resilience of international transport networks requires an improved understanding of the specific impacts that climate change may have on infrastructure, as well as services and operations across the different modes of transport. However, despite the potentially important broad implications of adverse climate change impacts on transport, detailed relevant research available in the public domain appears, at present, to be limited. In addition, although several studies have addressed climate change impacts on transportation infrastructure generally and possible adaptation measures (e.g. in the United States of America, Canada, European Union, the United Kingdom of Great Britain and Northern Ireland, France and Australia), they have been mostly not mode-specific or focusing on international transport networks.

In respect of adaptation to climate change in the transport sector, a recent review of the available literature by the Potsdam Institute for Climate Impact Research (Eisenack et al., 2011) reveals that the majority of potential adaptation actions address in particular road and, to minor extent, rail transport. In addition, adaptation measures were rarely found to be specific with regard to particular technological solutions, planning frameworks, monitoring approaches, information provision, research and education capacity building and financing and investment for new or modified infrastructure; there have also been few proposals for policy instruments with the exception of spatial planning.

Some of the particularly pertinent studies are briefly summarized in this Annex. These include select studies and case studies with a particular focus on specific modes of transport, i.e. road, rail, inland waterway transport and ports, as well as studies that take a more integrated approach.

I.1 Scottish road network climate change study (Galbraith et al., 2005)

Following numerous landslides in 2004, the Scottish Minister for Transport commissioned 2 studies to consider issues arising from these events. Here, the findings of the second of these studies are presented, which are associated with the potential climate change trends in Scotland and how these may affect the road network.

The report summarized the historical information available in relation to extreme weather events and how this has been taken into account in the design/operation of the road network. It then assessed the implications of current climatic change predictions, including work commissioned specifically for this study. Key climate variables (e.g. temperature and rainfall) that may have significant impacts on road networks were modeled, and predictions were provided for 30-year periods, i.e. the 2020's, 2050's and 2080's. The general conclusion was that although the climatic changes expected in Scotland in the near future (i.e. in the 2020's) are relatively small, even these small changes may warrant significant adjustments of current practices. In addition, the report noted that climate changes are likely to become more substantial over the longer term. However, as the uncertainty of predictions increases with time, the recommendations presented focused on responding to climatic changes predicted for the near future.

The findings of the report with regard to considered climate change trends are broadly as follows: Temperatures are expected to increase, resulting in higher summer temperatures and fewer freezing winter days. Annual precipitation is projected to show little overall change, but winter rainfall is predicted to increase, summer rainfall to decrease and snowfall to become less. Wind speeds are predicted to slightly increase and fog occurrence to decrease, but these predictions carry significant uncertainty. Coastal flooding is expected to increase, particularly when storm surges are included within the assessment.

A particular concern has been the predicted increase in winter rainfall; this may result in drainage systems failings. To address this concern, it was recommended that: (i) the design storm parameters used in surface water drainage designs are revised to allow for predicted increases (ii) the design storm parameters used in culvert and river bridge designs are revised (iii) locations with a history of road flooding to be identified and potential solutions to be evaluated on a cost/benefit basis, with priority for those locations with frequent flooding (iv) pre-emptive clearance of debris from drainage channels and watercourses to be carried out in areas of increased flood risk and (v) further research to be undertaken to improve estimations of catchment runoffs, in order to enable guidance on risk- based design approaches including evaluation of alternative solutions on a cost/benefit basis.

In addition, recognizing the opportunity afforded by the proposed expansion of the Variable Message Sign (VMS) network, and developing weather prediction technology, it was recommended that: '…*consideration be given to using VMS's to provide a greater level of locally relevant information to road users on predicted severe weather events, expressed in terms of probability of occurrence*'. It was noted that actions are already in place to address some of the issues identified, such as the development of a *High Winds Strategy* for the trunk road network. Finally, it was suggested that agreements with other UK road authorities are necessary in order to address in an integrated manner certain issues, such as changes in design standards.

I.2 The effect of climate change on 3CAP's highway networkpolicies/standards (Scott Wilson, 2009)

The report summarizes the findings of a project commissioned by a consortium of 3 United Kingdom of Great Britain and Northern Ireland Counties (3 Counties Alliance Partnership-3CAP) to assess the effects of climate change on their highway policies and standards. The project uses climate change predictions by the UK Climate Impacts Programme (UKCIP) for 2050, and risk and probability management approaches. Key UKCIP predictions for the United Kingdom of Great Britain and Northern

Ireland climate change are used: (i) annual average temperatures will increase (ii) summers will become hotter and drier (iii) winters will become milder and wetter (iv) soils will become drier on average; (v) snowfall will decrease; (vi) heavy and extreme rainfalls will become more frequent and (vii) there could be more extreme winds and storms.

On the basis of above projections, significant impacts are expected for the construction/ maintenance of Local Authority highways. Drier and hotter summers will lead to pavement deterioration/subsidence, whereas wetter winters and more frequent downpours will result in more frequent floods in low-lying areas and flood plains, and a higher risk of landslides. This will also affect pavement performance and resilience, drainage capacity and condition, utilities and highways structures such as bridges, culverts, road signs and street lighting. Increased storminess and occurrence of extreme winds can have safety implication, and increase the likelihood of deposition of debris on the highways from adjacent damaged structures and trees. The study has found that existing highway construction and maintenance policies and standards are typically based on historical climate data. For the road network to be resilient in a changing climate, future climate predictions should be incorporated in both policies and standards.

Local authorities should take into account their physiography, geology and risks particular to their area when developing relevant adaptation plans. The project has provided a comprehensive, local risk- and probability-based assessment of the vulnerabilities to climate change, both now and in the future, and identified effective adaptation responses in order to achieve particular levels of climate change adaptation for Local Authorities (NI 188).

A Risk and Probability Assessment of the effects of climate change on the highway network has identified effects posing the biggest risks from climate change to the highway network: (i) pavement failure from prolonged high temperatures (ii) increased length of the growing season leading to prolonged and/or more rapid growth of the soft estate (iii) lack of capacity in the drainage system and flooding of the network (iv) surface damage to structures from hotter and drier summers (v) scour to structures from more intense rainfall/floods (vi) damage to pavement surface layers from more intense rainfall (vii) subsidence and heave on the highway from more intense rainfall (viii) scour and damage to structures as a result of stronger winds and increased storminess (ix) severe damage to light-weight structures from stronger winds and increased storminess and (x) less disruption by snow and ice due to warmer winters.

These risks (amongst others) have been used to assess and prioritize adaptation responses as a part of an adaptation plan for 7 key policy areas: (1) 'bridges and other structures' (2) 'drainage' (3) 'grass cutting' (4) 'materials' (5) 'resurfacing' (6) tree and hedge maintenance' and (7) 'winter maintenance'. The adaptation options developed in response to the identified risks have undergone a structured multi-criteria analysis using 13 evaluation criteria, such as cost–capital requirements, technical feasibility, practicality, political acceptability, sustainability of the response, risk level of 'no action', scale/impact of the response and resource/skill/knowledge capacity to implement adaptation. The highest scoring responses were reviewed by 3CAP Authorities and the feedback was used to form a climate change adaptation plan (i.e. Level 3 of NI188) for the region, including implementation timetables.

I.3 Dealing with the effects of climate change on road pavements (PIARC, 2012)

This study was defined in the PIARC Strategic Plan 2008 – 2011 approved by the Council of the World Road Association. In 2008, PIARC Technical committee (C4.5 Earthworks) produced a report entitled 'Anticipating the Impact of Climate Change on Road Earthworks'. Several of its observations and recommendations have been reproduced in the 2012 report.

The report focuses on climate change impacts on road infrastructure and on providing guidance on: (a) the assessment of the vulnerability of road pavements to direct climate change impacts and (b) the identification and prioritization of potential relevant adaptation measures, that could be applied immediately and/or phased in over time, so as to avert negative consequences on the road network serviceability. The report reviews the effects of the changes in precipitation, temperature, sea level rise/storm surges and wind intensity on road structural integrity and strength and bearing capacity.

A Questionnaire Survey conducted to assess the degree of concern and the level of readiness of the road sector respondents from 21 States revealed that there are concerns regarding both increases and decreases in precipitation. Heavy downpours may affect the structural integrity of pavements, necessitating load restrictions, and cause landslides and road closures, whereas droughts may dry the sub-grade affecting the pavement durability. Coastal States have also raised concerns about rising sea levels which, when combined with storm surges, could lead to coastal flooding and road closures. In addition, concerns have been expressed on the increased frequency in the number of freeze-thaw cycles that could lead to frost heave, cracking and pot-holing. Finally, concerns have been raised with regard to the impacts of higher temperatures that could increase rutting and bleeding in bituminous-bound pavements during heat waves.

Guidance is provided on the procedures of risk and vulnerability assessments. Five basic steps are proposed: (i) identification of potential climate change effects (ii) assessment of the climate change impacts on the road pavement vulnerability (iii) appraisal of risks and identification of potential solutions and strategies to address vulnerabilities (iv) implementation of effective adaptation plans and strategies and (v) monitoring and measure review. In addition, the report suggests ways to improve relevant managerial skills. Policy implications regarding responses to potential climate change impacts, dealing with uncertainty/risks, adaptation of design rules and specifications, traffic management and safety are also discussed.

Main findings of the report include the following.

- The short and long-term effects of climate change may necessitate more frequent maintenance/rehabilitation/reconstruction, affecting the budgets of road owners and operators.
- Road owners and operators should implement a systematic approach to define risks and assess consequences at network level, and initiate the development of strategies to mitigate these risks in a cost-effective manner using costing models that incorporate climate change scenarios.
- Together with the latest available climate change projections, climate analogues should be used to gain a better understanding of potential pavement engineering solutions that could be adopted from elsewhere.
- Differentiation should be made between existing and new infrastructure. The outcomes of the risk analysis can suggest actions concerning the design of new infrastructure that require immediate attention (e.g. the redesigning of drainage systems). For existing infrastructure, assuming that climate will only change gradually over time, adaptation strategies could be phased in over time, during e.g. the periodic maintenance and rehabilitation of the road network.
- Besides protecting the value of assets, road user and worker safety should also feature as a prominent issue in any climate change risk assessment and response strategy.
- In addition to the adaptation of new and effective road pavement design rules and specifications, operational response to climate extremes may also have to be

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improved, in order to respond effectively to emergencies, impose necessary load restrictions, clear debris/divert traffic and put in place efficient communication strategies to inform road users.

The report concludes that in regions which are, or will become, vulnerable to climate change, there may be significant implications on the operation costs of road networks as well as the road users. Planning for the already known and projected impacts should be pursued without delay.

I.4 Rail safety implications of weather, climate and climate change (RSSB, 2003)

This report was commissioned by RSSB as part of the Rail Safety Research Program. The overall aim of the study was to assist Railway Group members understand better the implications that climate change may have on their operations. The research was designed to: (i) identify the current status of knowledge concerning climate change impacts on railway safety, including gaps in that knowledge (ii) define what work is required to fill those gaps and (iii) specify the work required to determine how the railway industry should respond to climate change-associated threats.

The report covered the following: (a) a summary of current information and research, highlighting developments in global, regional and local climate research (b) current documentation and databases within Network Rail and RSSB and (c) a qualitative assessment of the effects of predicted climate change scenarios on railway infrastructure. The report also listed individuals, organizations, websites, reports and databases concerned with climate change as a set of references.

Particularly relevant parts of the RSSB response are detailed, for ease of reference:

While there is uncertainty about climate change, RSSB considers that the UK Climate Impacts Program (UKCIP) provides acceptable sets of assumptions. The projections used are for the decade of 2080, i.e. a future timeline within the design life expectancy of much of the present infrastructure. The main predictions used are:

- average temperature to rise by at least 1 - 2 ºC
- precipitation to reduce by 5 -15 per cent overall, but with higher winter and lower summer rainfalls and possibly more extreme downpours
- average wind speeds to rise by 4 - 10 per cent, with also a possible increase in the number of severe events sea level to rise 0.2 - 0.6 m, depending upon emission scenario and the rate of the United Kingdom of Great Britain and Northern Ireland NW/SE land tilt.

The report contains qualitative information on the likely effects. It is considered that the main types of infrastructure vulnerable to the climatic changes are:

- tracks (vulnerable to extreme temperatures)
- earthworks (vulnerable to extreme precipitation)
- drainage (vulnerable to extreme precipitation)
- overhead line equipment (vulnerable to extreme winds)
- coastal and estuarine infrastructure (protection/defenses) (vulnerable to sea level rise).

It is noted that due to large amount of work undertaken into weather, climate and climate change, it is difficult to pin-point specific knowledge gaps that could be relevant to railway infrastructure. Nevertheless, the following main 'gaps' were identified:

- uncertainty in future predictions (the uncertainty varies according to weather elements)
- the likelihood of increase in the frequency and intensity of extreme events
- work directly related to the railway sector
- potential impacts of the sea level rise, which are predicted to be substantial and exacerbated in some areas by the continuing United Kingdom of Great Britain and Northern Ireland NW/SE land tilt and storm surges.

It should be noted that individual railway locations may be disproportionately affected by climate change. These will need systematic identification.

Recommendations for future action

Railway infrastructure and rolling stock are generally robust, but the safety performance of train operations can still be affected by extreme weather events. Although the risk is generally low, it is not low enough to be considered as negligible, especially if the number and intensity of extreme weather events increases. Therefore, further research is justified.

There should be more formal links between RSSB and relevant government and research organizations (for example the Environment Agency and the Department for the Environment, Fisheries and Rural Affairs) to maintain an up-to-date review of current work at a national level. There are potential advantages for the rail sector, as RSSB could then exert greater influence on the specifics of such work and thinking. Links should also be strengthened with those concerned with reducing rail GHG emissions and other sustainability matters. RSSB could provide a focus for information on climate change matters for Railway Group members (RGMs).

It is considered that the most constructive way forward is to begin quantifying the changes to safety risk and traffic delays that are likely to result from extreme weather events. This should take into account:

- different types of infrastructure and how widespread they are (for example, track, drainage, overhead electrification equipment)
- historical quantitative information on delays caused by weather-related incidents
- current values used in the RSSB risk model for weather related precursors to hazardous events and the predicted consequential harm to people
- best available quantitative estimates of likely changes to extreme events based on current industry intervention levels (air temperature, flood level, wind gust speed).

Assessments of safety performance could be based on the methods and models developed for assessing such as the effects of vandalism on railway safety performance. Specific research projects related to climate change should be initiated to: (a) understand better the effects of climate change on trackside vegetation and (b) identify more clearly how railway locations are most likely to be affected by the rise in sea level. Consideration could also be given to addressing how the railway industry could best help in mitigating the predicted climate change, possibly in conjunction with other transport undertakings.

The above proposals are considered as an effective way to advance research, by providing more quantitative assessments of the likely effects of climate change on safety performance and by gaining more detailed knowledge in specific areas. In the longer term, there may be ways in which the railway industry might assist in mitigating the predicted climate changes through addressing sustainability issues. The results of this further work could, for example, help RGMs in determining how existing assets would be most effectively managed, whether revised design standards for new assets would be beneficial, and how operational measures might best be adapted.

I.5 Climate change and the railway industry: a review (Baker et al., 2010)

This article discusses the role that railways could play in reducing overall GHG emissions and focuses on the effect of climate change on the operation of United Kingdom of Great Britain and Northern Ireland railways in the next few decades and the adaptation measures that will be required. Some of the key issues highlighted include the following.

Hot dry summers can be expected to have effects on the United Kingdom of Great Britain and Northern Ireland railway system, such as: (i) increased buckling of tracks (ii) desiccation of track earthworks (iii) greater requirements for air conditioning systems (iv) increased ventilation problems on underground railway systems and (v) increased leaf fall issues due to longer plant growing seasons. Most of these issues were considered to be well understood in technical terms.

The increased frequency of warm wet winters can be expected to have adverse effects on the United Kingdom of Great Britain and Northern Ireland railway system, such as: (i) increased network flooding and strain on drainage systems (ii) damage to earthworks and failure of saturated embankments and (iii) track circuit problems. There will also be some beneficial effects, in particular a decrease in snow-, ice- and very low temperature-related incidents. Again most of these issues were considered to be well understood in technical terms. There will always be pressure for increasing flood protection levels and, thus, a balance must be struck between the costs of additional flood protection and drainage improvement schemes and the, sometimes, very considerable costs of the incidents themselves.

It has been noted that the effects of the increasing frequency of extreme events and, in particular, of intense downpours and extreme winds on the rail network are, to an extent, an escalation of the effects of current extremes. High win effects include: (i) increased likelihood of dewirement (ii) increased possibility of train derailment and (iii) accidents or network disruption due to trees and debris deposited on the tracks. These effects have been studied to varying degrees, some quite thoroughly, but usually for the purposes of assessing accident risk during the design process, rather than climate change considerations. It has been also found that even a 0.3 – 0.4 m sea level rise can potentially have major consequences, both for railway systems in estuarine sites and for coastal lines. The need for increased levels of protection for underground services e.g. the London Underground is clear, particularly as the level of protection provided by the existing London flood defenses (e.g. the first Thames Barrier) has been predicted to decrease substantially over the next few decades.

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It was also noted that while the technical issues are fairly well understood, an overall framework for the quantification of the likely impacts on the railway industry is lacking, as is a prioritizing method i.e. deciding on which are the most critical effects to which resources should be given a priority allocation.

The article concluded that, with respect to the effects of climate change on the railways, there is a need for overall system modeling to properly evaluate the major climate change risks to railway operation and to prioritize the use of resources. Reference was also made to the scope and purpose of some on-going relevant research. The article also noted that the potential impact of significant alterations in meteorological hazards must be assessed across all transport modes, and not just rail transport. To this end, it was stated: "*Such an assessment should be driven by the economic benefits of an efficient national transport network, the costs associated with disruption, and the concurrency of the lifespan of many near-term infrastructural developments with the timeframe for climate change. Consideration must also be given to the technological development of the transport network itself. Climate change impacts are not simply a function of weather events, but also of the network's vulnerability. Further, 'studies to assess climate change impacts suffer from serious weakness if by default they merely assume that the projected future climates will take place in a world with a society and economy similar to today'. However, the drivers for transport demand are not well understood, let alone their vulnerability to climate change*".

I.6 ARISCC Adaptation of railway infrastructure to climate change (Nolte et al., 2011)

The IZT (Institute for Futures Studies and Technology Assessment Berlin) analyzed a climate change adaptation strategy for the International Union of Railways (UIC) together with some of the major European railway infrastructure companies (see www.ariscc.org) under the framework of the ARISCC.

The aim of the UIC-ARISCC project was to prepare rail infrastructure for weather and climate related hazards. The basic premise of the ARISCC project is that as railways have a very long life time (and constructed to withstand natural hazards, such as the 1-in-100-year flood estimated at the design phase), climate change-associated increases in the frequency and intensity of extreme events are likely to test the capacity of the rail system and increase costs.

A key finding of the project has been that adaptation actions have to take place within an integrated natural hazard management framework. Such framework should be able not only to pro-actively address today's weather-related challenges and disruptions, but also to design/build mid- to long- term climate change adaptation measures. Only solutions which tackle current railway everyday operations are being implemented. As, the majority of good practice examples shows, building upon management systems that already deal with the today's weather/climate related impacts is more likely to create a working adaptation framework; climate change adaptation programmes that are not connected to current everyday business operations will hardly see implementation, as experts interviews have confirmed.

Outcomes of the project include: (i) an update and extension of an existing survey on the current status of adaptation of European railways to climate change (ii) a guidance document on integrated natural hazard management (iii) an extensive collection of good practices and (iv) two case studies using regional climate models for the identification of future regional climate loads and existing vulnerabilities of railway infrastructures.

The ARISCC guidance document for Railway Infrastructure Managers for an integrated natural hazard management comprises the following elements: (1) weather Information and warning (2) documentation and assessment of past events (3) natural hazard mapping (4) monitoring and documentation of the status of infrastructure (5) vulnerability mapping (6) risk assessment and risk management (7) regional climate models and future climate loads and (8) adaptation recommendations.

A range of general and specific recommendations are made in the report, including the following.

- Without an adaptation strategy and adaptive action, the present resilience of railways may prove to be insufficient in the near and medium future. Therefore, it is recommended to develop a pro-active adaptation strategy to systematically build up adaptive capacity. The strategy should include short- and long-term objectives and measures and has to take into account economic constraints. The guiding principles of the integrated strategy should be: Readiness, Resilience and Recovery (RRR).
- As a short- to mid-term option, engineering specifications should be reviewed to improve the resilience of the railways systems, including the efficiency of drainage systems, flood protection and protection against heat waves. The objective should not be with regard to particular assets of the rail network, but to the improvement of the overall resilience of the system.
- A core part of an efficient natural hazard management system is a well-structured and integrated database for asset management, maintenance planning, disruptions, digitized network data and incidents. For current operation, adaptation to climate change aspects should be integrated into current maintenance planning. For future projects, adaptation should be integrated into the design of assets. This can be achieved by integrating adaptation into the early stages of current planning processes. There is a wide range of practical adaptation measures ranging from warning systems and monitoring to improving maintenance standards, reinforcing protective structures and changing standards. Prioritization of measures and finding the optimum combination for a project or a railway line depends on many factors such as the types of assets, time scales, route importance, financial constraints, cost/benefit ratios, etc. Soft measures such as real time monitoring of vulnerable sections and rapid alert systems may have much better cost/benefit ratios than hard engineering solutions.
- The implementation of an integrated natural hazard management starts as a process of capacity building for the adaptation of the railway company to climate change. This process can be improved through better communication of information and knowledge.

I.7 Impacts of Climate Change: A focus on road and rail transport infrastructure (EC, 2012)

The report (by the EC Joint Research Centre JRC-IPTS) represents the first EU-wide assessment of the future vulnerability of transport to climate change, with a special focus on the road and rail infrastructure. It reviews the types of climate impacts expected to increase weather stress to transport, and assesses possible risks and damages under plausible climatic trends derived from climate models for different scenarios. Four case studies were selected. The analysis concerned future exposure, vulnerability and adaptation, in relation to different

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aspects of climate change (e.g. extreme precipitation and floods, heat stress, sea level rise) and infrastructure type (roads, rail track, bridges). The risk assessment methodology/indexes were consistent in all cases (e.g. the 7-day maximum pavement temperature, number of days exceeding critical thresholds for assessing rail buckling risk, risk of inundation). Regions and infrastructures at risk – or critical infrastructures were identified and mapped.

Finally, an EU-wide techno-economic analysis has been applied, by combining different types of spatial information and analysis, including:

- climate data and stress factors (e.g. rail track and road pavement temperature, extreme precipitation)
- transport information for the EU27 member States (transport infrastructure, networks, transport activity, TRANSTOOLS model, TELEATLAS, GISCO)
- physical information and projections (e.g. mean sea level rise, storm surge and wave heights, coastal topographic data (DIVA), hydrological data (JRC/IES), soil types (ESDB database)
- engineering data and information on the underlying deterioration & damage mechanisms, maintenance practices and costs (mainly EU and the United States of America data sources).

Select key findings of the study include the following.

- Weather stress represent 30 - 50 per cent of the current road maintenance costs in Europe (€ 8-13 billon/yr.); 10 per cent of these costs (about € 0.9 billion/yr.) are associated with extreme weather events alone, particularly heavy downpours/floods.
- At the EU27 aggregated level, future road degradation from changes in the average precipitation will increase only slightly; however, the more frequent downpours and floods projected for different European regions could result in extra costs (€ 50 - 192 million/yr. for the period 2040-2100 - A1B scenario), whereas maintenance cost reductions due to milder winters are also projected for some areas.
- Increasing average temperature could require changes in maintenance operations and practices and extra costs for adaptation.
- Climate change will result in higher average temperatures and more frequent extreme high temperatures, which can potentially e.g. enhance the risk of rail track deformation and buckling, damage the rolling stock and introduce speed restrictions.
- More frequent extreme precipitation events are projected in several regions in Europe; these are expected to impact road infrastructure, intensify bridge scour risk, slope instability and embankment failure and increase road accidents.
- The costs of the road adaptation measures (road pavement and river bridges) under the A1B scenario have been estimated as € 314 - 560 million/year; damage costs that could be avoided by such adaptive measures could be several times higher (for instance, the cost of a bridge failure could be 2 - 10 times higher than the cost of the bridge itself).
- The most commonly applied measure to mitigate rail derailment in case of heat-induced rail buckling is speed restriction, which have been found to cause only minor delays and costs; under unchanged maintenance practices, the extra costs resulting from warmer summer conditions have been estimated as € 20 - 28 million/yr. by 2040-2070 and about € 50 - 130 million/yr. by 2070-2100, with only a small variation across different emission scenarios.
- Protection of river bridges may be needed over the next decades for about 20 per

cent of the inventory, to mitigate scour risks associated with increasing stream flows; future costs for bridge protection against scour risks have been estimated as € 0.38 - 0.54 billion/yr. (80 per cent for road and 20 per cent for rail bridges)[25].

- Under a 1 m sea level rise about 5400 km of coastal roads in Europe (about 4 per cent of the coastal road network) could be at risk of permanent or temporary inundation, with low lying countries/areas (e.g. the Netherlands, Belgium, N. Germany) being under higher inundation risk; considering a € 6 million/km average cost for motorway reconstruction, the total asset value at risk of permanent inundation has been estimated as € 18.5 billion.

I.8 Climate change and navigation: Waterborne transport, ports and waterways (PIANC, 2006)

This study reviewed climate change impacts on maritime and inland waterway (IW) navigation, including sea level rise, wind and wave action, storm surge propagation, storms, ocean circulation, ice conditions, river water supply and quality, extreme hydrological conditions, and coastal, estuarine and river hydrodynamics/morpho-dynamics. Potential adaptation and mitigation responses were identified. Navigation contributions to GHG emissions were discussed, along with opportunities to play a part in decreasing anthropogenic GHGs and, through use of alternative fuels, other pollutants.

With regard to IW navigation, the report noted that this sector is more capable to respond to climate change forcing than the maritime sector, since, in most cases, there is adequate infrastructure to control river water flows. At the same time, complex political, social, and environmental factors appear to control the balance of inland navigation requirements against competing needs for water supply, flood control, hydro-power, and irrigation.

According to the report, climate change factors affecting directly IW navigation are precipitation and air temperature; these factors and their effects are discussed in some detail. It is suggested that climate change impacts on rivers, channels and canals may be moderated through changes in operational flow control and/or channel modifications. Amongst other things, the report highlighted that the associated operational changes will require legal and environmental analysis, as IW navigation is connected to and competing with other water users. Also discussed is the relevance of flood control measures, of changes to existing maintenance practices (e.g. channel and bank stabilization and dredging), and of increased automation.

The report concluded that some of the adaptation responses will require additional investment and/or cause higher operational costs (i.e. might be subject to economic constraints), in addition to legal and/or technical limitations; therefore costs and benefits of the individual measures/responses that may be part of a portfolio of measures should be carefully assessed.

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[25] It is interesting to note that the costs in the EU27 are estimated to be much lower (by a factor 2 to 3) than those in the USA (see Study I.13 (Wright et al., 2012)). This may be explained by the differences in size and other particularities of the bridge inventories of the EU and the USA.

I.9 Climate Risk and Business: Ports–Terminal Marítimo Muelles el Bosque Cartagena, Colombia (Stenek et al., 2011)

The study was commissioned by the International Finance Corporation (IFC) to help develop knowledge, tools and methods for analyzing climate-related risks and opportunities and evaluating adaptation responses, focused on the case of the *Terminal Maritimo Muelles El Bosque* (MEB), in Cartagena, Colombia. It analyzed climate related risks and opportunities facing the IFC's client *Muelles el Bosque*, and provided a quantitative assessment of climate impacts and related adaptation responses. While the study focused on the impacts on this specific port, it also briefly explored how other ports in Colombia and elsewhere can expect to be affected by climate change. The report noted that infrastructure and transport operations are among the sectors most exposed to climate change, and in turn are critical to national economic performance, growth and development. Ports play a vital role in the world economy, as much as 80 per cent of goods traded worldwide are transported by sea, whereas ports in developing countries handle more than 40 per cent of the total containerized traffic, of which a significant portion relates to export of goods produced in the country. Therefore, the impacts of climate change on ports are likely to have much wider socio-economic implications.

Select key findings of the study include the following.

(a) In general, the physical infrastructure at ports, and port activities, may be highly vulnerable to changes in climate. Climate change could result in (a) changes in the level and patterns of shipping, (b) increased flooding affecting port operations and causing damage to stored goods, (c) reduced navigability of access channels and (d) business interruptions. Nevertheless, some ports could also benefit commercially, if they can demonstrate resilience to disruption from climate events. In addition, higher temperatures may benefit ports in cold regions, by increasing the length of the shipping season. To understand the significance of climate change-induced risks for a given port, it is necessary to analyses the factors affecting the port's success and evaluates climate-related impacts, taking into account existing vulnerabilities, critical thresholds and climate change projections.

(b) The analysis undertaken for the study has found that the materiality of climate change impacts will vary greatly, though there are some key risk areas that all ports should consider. There will be considerable differences in the nature and level of climate change risks and opportunities between ports depending on the characteristics of their locations, e.g. in areas that are tropical or extra- tropical cyclone-prone, or permafrost areas. Furthermore, ports vary considerably in their functionality. Climate change might have different implications for ports with cargo handling and warehousing functions compared to those providing exclusively pilotage, navigation and dredging services, or for cruise and passenger ports.

(c) The analysis undertaken for the case study port has shown that climate change can have material business implications for ports. Though some of the risks analyzed in this study are likely to be specific to the case study port, some of them could still be of broad relevance to the global industry.

Based on the findings of the study on Muelles el Bosque terminal and a comprehensive literature review, a checklist was prepared to assist port operators to identify climate-related risks and possible adaptation options. The Checklist:

- categorizes climate impacts risks and opportunities according to the key operations undertaken at cargo ports (navigation, berthing, goods handling, etc.), along with other factors related to port performance, such as demand, insurance availability and environmental and social performance
- gives an overview of the climate-related sensitivities and thresholds of cargo ports in general, and also outlines some impacts which are specific to ports in particular environments (e.g. tropical and polar regions)
- provides a list of adaptation measures which can be considered by port operators in response to climate change risks and opportunities: these include actions that help to build adaptive capacity such as improved monitoring of climate impacts, as well as the implementation of physical adaptation measures such as modifications to port infrastructure.

I.10 Future resilient transport networks (FUTURENET): Assessing transport network security in the face of climate change (Bouch et al., 2012)

The study has been based on the premise that although transport networks will face increasing threats from climate change, identification and protection of all vulnerable infrastructure assets is not a realistic response. It suggests a different approach that is based on the assessment of network resilience; thus, it proposes the development of a network resilience assessment methodology.

FUTURENET is a multi-partner, multi-disciplinary research project, investigating the development of a methodology that would be sufficiently generic to be applied to any transport network. It considers the projected climate changes in 2050, and assesses the impact of these changes on principal modes of transportation, i.e. road, rail and air. The project involves a number of research components including investigations of: (i) the influence that climate change might have on travel demand and behaviour (ii) modeling of transport failure modes and associated triggers and thresholds (iii) 'generation' and application of climate and weather events to transport networks in order to assess vulnerabilities (iv) development of a network resilience assessment methodology and (v) the application of systems engineering techniques to methodology development.

I.11 EU Initiative (TEN-TEU) for the integration of the EU Transport Infrastructure

Transport infrastructure is a fundamental premise for the smooth operation and integration of the EU internal market. In the 27 Member States, there are 5 million km of paved roads (65.1 thousand km of motorways), 212.8 thousand km of rail lines (110.5 thousand km electrified), and 42.7 thousand km of navigable inland waterways. The total investment on transport infrastructure during the period 2000-2006 was € 859 billion. As most of this transport infrastructure has been developed following national policies, there is a need to establish a single, multimodal network that integrates land, sea and air transport networks; thus, a Trans-European Transport Network policy has been designed to build the missing links and remove bottlenecks and to ensure the future sustainability of the transport networks by considering issues of energy efficiency needs and the climate change challenges. In this context, the Trans-European Transport Network Executive Agency

(TEN-T EA) was established in 2006 to manage key transport infrastructure projects, in close collaboration with the EC DG Mobility & Transport. The Agency assures the management/implementation of the Trans- European Transport Network (TEN-T) program, which is supported financially by the EU (through the TEN-T Program, the Cohesion Fund, the European Regional Development Fund and European Investment Bank's loans and credit guarantees).

The investment requirements to complete and/or modernize the trans-European network are very substantial, estimated as over € 1.5 trillion for the period 2010-2030. The TEN-T network requires about € 550 billion until 2020 (€ 215 billion for removal of the main bottlenecks). Given the scale of the investment, it is necessary to strengthen coordination in the network planning and development at a European level, in close collaboration with national governments. 30 Priority Projects (PP) have been identified on the basis of proposals from the member States and are included in the Union guidelines as projects of European interest; they are to be completed by 2020. Most of these projects relate to rail and combined rail and road projects; there are also 2 inland waterway (IW) transport projects and 1 maritime project. Five of these, large-scale, Priority Projects have already been completed (PP5- 2007, PP9-2001, PP10-2001, PP11-2000 and PP14-2009, see http://tentea.ec.europa.eu/en/ten-t_projects/30_priority_projects/).

It is interesting to note that although the policy seeks to ensure future sustainability of the transport networks by considering climate change challenges, it appears that, the assessment of these challenges and the design of adaptive measures have not been priorities in the projects, with the notable exception of the 2 internal waterway transport projects (PP18 Waterway axis Rhine/Meuse- Main-Danube and PP30 Inland Waterway Seine-Scheldt). These projects, classified as 'complexity projects', aim to connect all the major inland waterway basins (Rhine/Meuse-Main-Danube, Seine- Scheldt) in order to integrate inland waterways into the EU's transport network (see also Annex II).

Both projects are particularly exposed to changes (floods and droughts) in the river water levels and, thus, issues related to risks and the design/implementation of adaptive measures are considered important and dealt with.

I.12 Climate change, impacts and vulnerability in Europe 2012.An indicator-based report (EEA, 2012)

The 2012 European Environment Agency (EEA) report presents information on past and projected climate change and related impacts in Europe, based on a range of indicators. It follows earlier EEA (2004 and 2008) indicator-based assessments of climate change impacts and vulnerability. Where feasible, indicators covering a wide range of themes and sectors are presented for the EEA 32.

Member States. These indicators are based on both *in situ* and remote sensed monitoring programs, national and EU research projects and global initiatives. The report also assesses the vulnerability of the European human society and health as well as ecosystems and identifies European regions most at risk from climatic changes. Moreover, the report addresses issues of indicator uncertainty. The report mainly aims at providing a knowledge base for the development and implementation of adaptation strategies and actions at both national and EU levels (see also the EEA indicator management system and the European Climate Adaptation Platform Climate-ADAPT: http://climate-adapt.eea.europa.eu).

A report chapter (Chapter 4.6) is focused on the impacts of climate change to transport services and infrastructure. There, it is stated that these impacts are mainly negative, with only some positive effects such as decrease in the polar ice cover that may forge new transport sea routes. A table of the main impacts is provided, related to changes in temperature, precipitation, wind, lighting strikes and thunderstorms and vegetation factors. Some key messages include the following:

- data on past climate related impacts on transport are mostly restricted to individual extreme events; attribution to climate change is generally not straightforward the availability of information on the future risks of climate change for transport in Europe has improved recently, due to some EU research projects focusing on climate change, extreme weather events and inland water transport
- climate change is projected to have adverse (but also beneficial) impacts on transport depending on the region and transport mode projections suggest that rail transport will face the highest (percentage-wise) increase in costs from extreme weather events, with the United Kingdom of Great Britain and Northern Ireland, the Central Europe, France, the Eastern Europe and Scandinavia being projected to be most adversely impacted.

Finally, there are 3 significant EU projects (FP7 ECCONET, WEATHER and EWENT) related to the climate change impacts on transportation networks. Findings from these projects are presented in Annex II and have been also included in the main part of the report.

I.13 The United States of America Gulf Coast study

The United States of America Gulf Coast Study aims to provide a comprehensive assessment of how climate change will affect transportation in the United States of America Gulf coast, an area with critical seaports for the United States of America (import/export of industrial, commercial, and agricultural products, as well as oil and gas). The ultimate goal of this research, planned to be carried out in three distinct phases, has been to provide knowledge/approaches that could enable transportation planners/managers to better understand the risks, adaptation strategies, and trade- offs involved in planning, investment, design, and operational decisions.

The objective of Phase I (completed in 2008) was to conduct a preliminary assessment of the risks and vulnerabilities of transportation in a segment of the United States of America Gulf coast, on the basis of the collation/collection and integration of various information – physiography, hydrology and coastal hydrodynamics, land use and cover, past and projected climate, current population and trends, and transportation infrastructure. The Phase II of study (2010-2013) aimed to conduct an in- depth assessment of risks to transportation at selected locations, reporting on implications for long range plans and impacts on safety, operations, and maintenance. It has also aimed to provide a risk assessment methodology and identify techniques to incorporate climatic and other environmental information in transportation decisions; thus, its objective has been to enhance the regional decision makers' ability to understand potential impacts on specific critical components of infrastructure and to evaluate adaptation options. Finally, Phase III will identify and analyses adaptation and response strategies and develop tools to assess these strategies, while identifying and evaluating future research needs.

I.13.1 Gulf Coast study, Phase I (CCSP, 2008)

The report presents the results of a Phase I of the assessment of climate change-induced potential impacts on transportation systems for the central Gulf Coast between Galveston, Texas and Mobile, Alabama which contains multi-modal transportation infrastructure that is critical to regional and national transportation services. It considers issues such as climate effects on the design, construction, safety, operations, and maintenance of transportation infrastructure and systems, including critical questions regarding how changes in temperature, precipitation, storm events, and other aspects of the climate may affect roads, rail, airports, transit systems, pipelines, seaports, and waterways.

Historical trends and future climate scenarios were used to establish a context for examining the potential effects of climate change on all major transportation modes within the region. Climate changes anticipated during the next 50 - 100 years for the central United States of America Gulf coast include mean sea level rise, warming temperatures, changes in precipitation patterns and increased storm intensity. The effects of sea level rise in most coastal areas is projected to be exacerbated by the high rates of land subsidence at the Mississippi delta, which is accounted for in this assessment. The significance of these climate factors for transportation systems was assessed.

Main findings include the following:

Warming temperatures are likely to increase the costs of transportation construction, maintenance, and operations. More frequent extreme precipitation events may disrupt transportation networks through flooding. The increased relative sea level rise of the area (currently greater than 9 mm/year in some areas along the coast) will make existing infrastructure more prone to permanent and/or frequent inundation from tropical storms/storm surges – 27 per cent of the major roads, 9 per cent of the rail lines, and 72 per cent of the ports are built on land with an elevation of or below 1.2 m (4 feet). Therefore, increased storm intensity may lead to infrastructure damage and service disruption: more than half of the area's major highways (64 per cent of Interstates; 57 per cent of arterials), almost half of the rail miles, 29 airports, and virtually all seaports are below 7 m (23 feet) in elevation and subject to flooding and possible damage due to hurricane-induced storm surges.

I.13.2 Gulf Coast study, Phase II (USDOT, 2012)

While Phase I took a broad look at the entire Central Gulf Coast region and provided a "bird's eye view" of the climate-related challenges, Phase II focused on a single Metropolitan Planning Organization-MPO region (Mobile, Alabama).

The purpose of the second phase study has been to evaluate which transportation infrastructure components are most critical to economic/social functions, and assess the vulnerability of these components to weather events and long-term changes in climate. Phase II also developed tools/approaches that the South Alabama Regional Planning Commission (which includes the Mobile MPO) and other public and private system operators can use to determine which systems need to be protected, and how best to adapt infrastructure to the potential impacts of climate change. As many transportation modes (including highways, seaports, railways, airports, as well as pipelines) are well represented in the study area, the United States of America Department of Transportation intended to create a template for an assessment process that can be replicated in other regions of the country.

Primary Phase II activities included:

- identification of critical transportation assets in Mobile County
- evaluation of projected climate change effects (changes in temperature, precipitation, storm surge, and sea level rise) for the Mobile County
- investigations of the relationships between climatic changes and impacts to infrastructure
- combination of information on critical assets with climate information to assess vulnerability
- detailed engineering and risk assessments for the most vulnerable assets and cost/benefit analysis of adaptation strategies
- utilization of the lessons learned through this work to develop generic screening tools and approaches that could be employed by other regions to identify which transportation systems need to be protected, and how to protect and adapt those systems.

The main findings (to date) of the study are summarized below:

- higher mean temperatures result in more rapid deterioration of pavements, requiring changes in repair and maintenance schedules, whereas increases in the duration and frequency of the extreme temperature events can increase rail buckling and pavement rutting and shoving
- more frequent/intense heavy precipitation events can cause immediate damages, as well as problems in the structural integrity and maintenance of roads, bridges, drainage systems, and tunnels, necessitating more frequent repairs and reconstruction
- the connectivity of intermodal systems – including goods movement to and from seaports – can be disrupted even if short segments of roadways and railways are flooded
- severe precipitation can cause delays in air travel
- stream flow changes are likely to have the most significant effects on roadways, but may also impact rail lines, port operations, airport facilities and bus and train terminals
- Mobile's critical transportation assets, have been found to be minimally exposed to mean sea level rises of 0.3 and 0.75 m, as only 0 - 2 per cent of critical assets of each transportation mode will be exposed, whereas under a high-range scenario (2 m rise), exposure of critical assets of each transportation mode will range from 2.6 to 50 per cent
- the extent of storm surge inundation of critical transportation assets will be much greater than that due to long-term sea level rise which, however, will compound the severity of storm surge inundation storm surges can severely impact transportation systems, with critical assets (e.g. roads, bridges, rail lines, airports and seaports) becoming unusable, or of less capacity, even after the waters recede, due to severe damage to assets, supporting infrastructure (e.g. utilities and telecommunications), and/or access routes
- with regard to the fractional extent of exposure, critical seaport facilities have been found to be the most vulnerable, with 74 – 100 per cent of them predicted to be inundated due to storm surges (depending on the scenario)
- critical rail lines have been also found to be highly vulnerable due to their coastal location, with 57 – 80 per cent of critical rail-miles predicted to be under inundated risk

- pipelines have been found to have the lowest fractional extent of exposure (3 – 16 per cent of pipeline-miles exposed), whereas exposure varies for critical roadways (16 – 62 per cent of the critical roadway length)
- one of the two critical transit facilities, the GM & O Transportation Center and the critical Mobile Downtown Airport were found to be under inundation risk, under all storm surge scenarios.

I.14 The Polish method of assessing the sensitivity of transport to climate changes (Prof. Barbara RYMSZA)

The paper presented[26] is a result of research and analyses carried out in Poland to identify potential climate changes which may affect the functioning of road, rail, air and inland waterway transport.

For the purpose of the analysis, Conventional Climate Categories (CCCs) were proposed as well as a scale of transport sensitivity to climate impact (Tables 1 and 2).

Table 1. Conventional categories of climate with significant influence on transport sector:

Item.	CCC	Simplified description of the factors consist within the category
1	2	3
1.	frost	very low temperature, frozen ground , ice cover for water- course, glazed frost
2.	snow	intensive falls at low temperature, snow storms, snow cover, hailstorms
3.	rain	intensive rain falls at plus temperature, existence of flooding or drowning
4.	wind	very strong winds and atmospheric discharge (storm, hurricane, whirlwind, differences of atmospheric pressure, turbulence)
5.	heat	very high temperature, sunshine
6.	fog	phenomenon limited visibility, fog, low base of clouds, volcanic dust (ash)

Table 2. Scale of climate sensibility influence on the element of construction sector

Degree	Conditions	Characteristic of influence
1	2	3
0	neutral	favourable or neutral conditions
1	impede	conditions are impeding function, there are perceptible conditions which are impeding function of sector
2	limitative	very difficult conditions, there are not only difficulties but also damages, which are limiting function of sector
3	make impossible	conditions make the function of indicated element of sector impossible

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[26] The article is an outcome of the KLIMADA project "Development and implementation of the Strategic Adaptation Plan for sectors and areas sensitive to climate changes" undertaken by the Institute of Environmental Protection –National Research Institute, commissioned by the Minister of the Environment and financed by the National Fund for Environmental Protection and Water Management.

The feasibility of the delivery of a transport service in the context of the climate impact being witnessed currently was determined on the basis of a literature analysis and questionnaire surveys. The results are shown in Table 3.

Table 3. The range of influence of CCC on transport sector

Item	CCC	Infrastructure	Means of Transport	Social Comfort
Sensibility of the elements of road transport				
1.	frost	2	2	2
2.	snow	3	1	2
3.	rain	3	1	1
4.	wind	3	2	1
5.	heat	2	1	2
6.	fog	1		2
Sensibility of the elements of rail transport				
1.	frost	3	1	1
2.	snow	3	1	1
3.	rain	3		1
4.	wind	3		
5.	heat	1		1
6.	fog			2
Sensibility of the elements of inland water transport				
1.	frost	3	2	3
2.	snow	2	2	
3.	rain	2		1
4.	wind	2	2	2
5.	heat		2	1
6.	fog		2	2
Sensibility of the elements of air transport				
1.	frost	2	2	1
2.	snow	3	1	1
3.	rain	1	1	1
4.	wind	2	2	2
5.	heat	1	2	1
6.	fog		2	1
	1 - impede	2 - limitative	3 - make impossible	

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Impact of climate changes

It was concluded that transport facilities (including material/design solutions, operating conditions, fuel and consumables used) and social comfort (in terms of service performance conditions, reliability, timeliness, safety and passenger comfort, service and cargo) can be adjusted to changing conditions on an on-going basis. On the other hand, the adaptation to climate change should be phased-in gradually mainly with regard to transport infrastructure, which is built for a long service life (e.g. 100 years).

Poland is a country with a moderate climate. The way climate impacts on transport infrastructure is taken into account, is defined by building standards (including the Eurocodes). They contain the National Annexes, in which climatic zones are described with regard to snow and wind loads, ground freezing depth, air temperature (summer and winter) and rainfall.

The climatic zones provided for in the standards and the values of the parameters describing climate impact on built structures have evolved as a result of many years of research. The standard values were benchmarked against climate changes forecast by the ICM Team of the University of Warsaw for the territory of Poland until 2090.

The simulations performed made it possible to track changes (the average and the 90th percentile) in the parameters describing the different CCCs. An example result is shown in Table 4 and in Figs. 1 and 2 in the form of maps generated for successive 20-year periods.

Fig. 1. Change in the number of days with temperature Tmin < 0oC (the average)

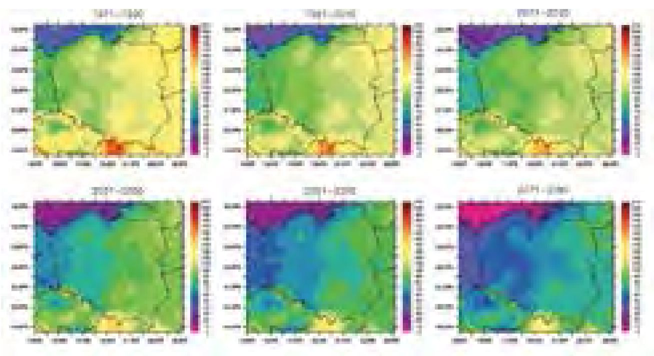

Fig. 2. Change in the number of days with temperature Tmin < -20oC (the 90th percentile)

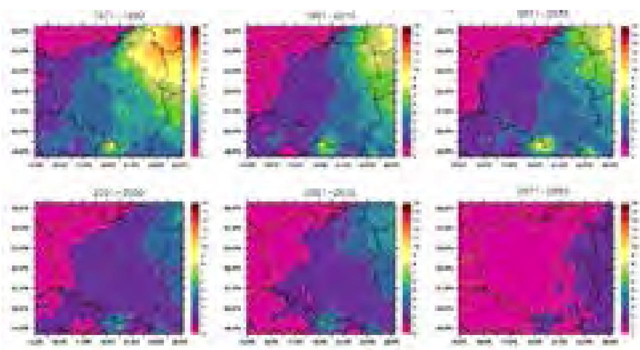

Table 4. Predicted average values of climate factors describing climate changes in Poland

CCC	Parameter	Average value			
		2010	2030	2050	2070
frost	Number of days per year with temperatures Tmin < 0oC	101,70	96,82	81,93	72,15
	Number of days per year with temperatures Tmin <-10oC	13,39	11,12	7,56	6,38
	Number of days per year with temperatures Tmin <-20oC	0,7	0,68	0,34	0,3
	Number of degree days per year Tthreshold < 17oC	3379	3236	3005	2803
snow	Number of days per year with snow cover	75,37	63,43	51,16	43,6
rain	Maximal daily precipitation [mm/d]	28,59	31,11	32,17	32,93
	Length of the longest period with precipitation 1mm/d [days]	8,72	8,77	8,84	8,66
	Number of periods with a drop bigger than 1mm/d, longer than 5 days [-]	2,77	2,99	3,11	2,91
	Number of days per year with precipitation less than 10mm	9,96	9,76	10,35	10,53
	Number of days per year with precipitation more than 20mm	1,76	2	2,2	2,24
wind	Average daily velocity of the wind v [m/s]	4,22	4,22	4,22	4,21
	Number of days per year with wind of the velocity vmax> 10m/s]	43,1	42,88	42,66	42,51
	Number of days per year with wind of the velocity vmax> 15m/s	6,58	6,34	6,37	6,33
	Number of days per year with wind of the velocity vmax> 20m/s	0,76	0,74	0,78	0,77
heat	Average daily temperature T [oC]	8,11	8,63	9,33	10,10
	Number of days per year with temperature Tmaz > 25oC	29,80	35,56	37,49	46,28
fog	Lack of parameters of estimation	-	-	-	-

An analysis of predicted climate changes shows that:

- warming will take place, expressed by an increase in the average daily temperature and a decrease in the number of cool days,
- the period of snow cover on the ground will be shorter,
- precipitation will increase, expressed by an increase in the maximum daily precipitation and the number of days with extreme precipitation,
- the climate parameters shown in the paper will feature high variability in relation to extreme values.

The results presented shows that by the end of the 21st century climate changes are envisaged which consist of progressive warming, yet the greatest threat may come from extreme rainfall. The wind forecasts give rise to doubt, as they provide for no changes in wind impact in terms of average values. In regard to the period of snow cover, the forecasted significant shortening of the period should be taken with a great degree of caution. Despite climate warming, snowy winters may also occur, and this should be provided for, especially in the Central European climate.

The result of the analysis of climate changes was expressed by the sensitivity of transport infrastructure in the various transport modes as presented in Table 5.

Table 5. Sensibility of transport infrastructure for climate influence

Item	UKK	Sensibility of infrastructure			
		Road transport	Rail transport	Inland water transport	Air transport
1	2	3	4	5	6
1.	Frost	2	3	3	2
2.	Snow	3	3	2	3
3.	Rain	3	3	2	1
4.	Wind	3	3	2	2
5.	Heat	2	1		1
6.	Fog	1			
		1 - impede	2 - limitative	3 - make impossible	

The sensitivity of transport infrastructure shown in Table 5 demonstrations that road and rail infrastructure displays greatest sensitivity to snow, rain and wind, while frost can prevent rail transport and inland navigation operations.

The adaptation measures aimed to limit the negative impact of climate changes on the transport sector should concern, in particular:

- adjusting the standards used in designing built structures for climate changes,
- monitoring the cost of prevention and remedying of damage caused by climatic factors,
- monitoring the actual climate changes.

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Annex II: International Conference on Adaptation of Transport Networks to Climate Change (June 2012, Alexandroupolis, Greece)

In Annex II, the summaries of the presentations in the UNECE International Conference on Adaptation of Transport Networks to Climate Change which took place on the 25th and 26th of June 2012 in Alexandropoulos, Greece are presented together with the Conference Conclusions and Recommendations. The proceedings of the Conference, including the original presentations and all other conference material can be found on the UNECE website at http://www .unece.org/trans/main/wp5/wp5_conf_2012_june.html

II.1 Climate change: Overview of the scientific background and the potential impacts affecting transportation (A.F. Velegrakis, Department of Marine Sciences, University of the Aegean, Greece)

All available scientific evidence suggests that there have been significant changes in the climatic conditions since the 19th century, which have been attributed to both natural and anthropogenic factors (i.e. increased emissions of GHGs). Although these changes are characterized by significant spatio-temporal variability, since 1880 the mean temperature has risen by about 0.8 °C and the global sea level by about 0.2 m. These trends are projected to continue well in the future with their rates likely to be controlled by future GHG emissions and, ultimately, by socio-economic developments and policy choices. Changes in the mean climate can lead also to changes in the frequency, intensity, spatial coverage, duration and timing of weather and climate extremes, potentially resulting in unprecedented extremes; these can, in turn, modify the patterns and distributions of the future climatic conditions, resulting in climatic feedbacks and, potentially, to catastrophic 'tipping points'.

Climate change will have significant impacts on coastal areas (rising mean and extreme sea levels and, thus, increasing coastal erosion and inundation) and flood plains (more intense floods caused by extreme precipitation events). Heat waves, droughts and permafrost thawing in arctic regions are also expected to increase in frequency and duration, whereas, in some regions, shifts are projected in the storm frequency and/or destructiveness. These climatic changes will have significant impacts on both the infrastructure and operations of the transport sector. Key assets with long lifetimes and operations are concentrated in areas that will likely be significantly affected. Thus, significant impacts on transport infrastructure and operations are projected for the coastal areas, due to increased coastal erosion and floods and inundation, higher port construction and maintenance costs, changes in the sedimentation patterns in ports and navigation channels, changes in or relocation of population and businesses, labor shortages and insurance issues. In river flood plains, increased flooding and inundation and/or damage risks for vital transport nodes such as bridges as well as impacts on the inland waterway (IW) navigation are also expected for some regions. At the same time, the extreme heat waves and droughts projected for some regions can damage rail tracks and road pavements, result in higher energy consumption in ports and other terminals, challenge operations in inland waterways, affect service reliability in a variety of transport modes and affect equipment, cargo and maintenance costs. In polar

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areas, there will be challenges to transportation systems and patterns, due to melting of the arctic ice and permafrost thawing. Finally, it must be also noted that as transport is demand-driven there can also be indirect impacts (e.g. from climatically-driven changes in agriculture and tourism).

In recent years, the climate change challenge to the transport sector seems that gains attention. In the ECE region, studies have been commissioned to assess the effects of the climate dynamics on the different modes and key infrastructure of transportation. It appears, however, that much more work is needed in order to assess the risks and decide on and design and implement cost-effective adaptation responses.

II.2. Opportunities to raise awareness on adaptation for international transport networks through UNFCCC Secretariat (E. Resende, Adaptation Programme, UNFCCC)

The UNFCCC negotiations on policy development concerning Climate Change Adaptation were enhanced with the establishment of the Cancun Adaptation Framework. The Framework comprises three important work streams of the Cancun Conference (2010): the work programme on Loss and Damage, the Adaptation Committee and the National Adaptation Plans. This landmark mechanism has led to broader discussions for effective tools and mechanisms to assist countries, particularly those that are most vulnerable to the adverse impacts of climate change. Parties are and will keep developing the activities to make new work streams fully operational. The outcomes of each of the work streams are envisaged to engender coherent and efficient support to adaptation at the international, national and sub-national levels.

Prior to the establishment of the Cancun Adaptation Framework, knowledge on climate change adaptation has been catalyzed and disseminated through the Nairobi Work Programme on impacts, vulnerabilities and adaptation (NWP). The NWP had/has the objective to assist countries, particularly those most vulnerable, to make informed decisions in their efforts to build resilience and adapt to climate change. The work programme relies on a cost-free partnership initiative of nearly 300 partner organizations, including NGOs, research institutions and private sector companies from all around the world that generate and disseminate knowledge on adaptation. This is a major hub for organizations to make a public stake through Action Pledges about their activities on adaptation, while informing the Parties to the Convention on their efforts and allowing other organizations to learn about their activities. The NWP also includes a dedicated initiative involving the private sector, the Private Sector Initiative (PSI). The PSI has the goal to raise awareness about the importance of the private sector to adaptation at large and to highlight the need for private companies to adapt to climate change in a sustainable and profitable manner (for more information on the NWP and its PSI, visit unfccc.int/nwp and join for free).

The National Adaptation Programmes of Action (NAPAs) form another key instrument that provides a process for Least Developed Countries (LDCs) to identify priority activities that respond to their urgent and immediate needs to adapt to climate change – those for which any delay would increase vulnerability and/or costs at a later stage. The database of projects can be found at unfccc.int/4583. *PSI database of case studies: Examples of CC adaptation in the European transport sector.*

(a) The International Union of Railways has undertaken an extensive feasibility study to analyze climate change impacts on the rail transportation infrastructure and to take stock of on-going and planned work on climate change adaptation in the European, Canadian, Australian and Indian railway companies, including case studies of the United Kingdom of Great Britain and Northern Ireland West Coast and the German Rhine Valley. This led to the development of the Adaptation of Railway Infrastructure to Climate Change (ARISCC) Project (see also I.10), which provides information on the potential adaptation costs and damages. ARISCC is a toolbox for identifying vulnerable assets and locations for a given timeline, and assessing options for adopting standards to climate proof new and existing infrastructure to climate change impacts.

(b) RIMAROCC (Risk Management for Roads in a Changing Climate) is a European methodological approach, funded by 11 National Road Administrations, through the ERA- NET Road research programme. The RIMAROCC method is designed to be general and to meet the common needs of road owners and road administrators in Europe. The method seeks to present a framework and an overall approach to adaptation to climate change.

(c) A dedicated weather information and weather warning system has been developed and implemented by ÖBB, Austria's national rail service. The InfraWeather online portal provides access to general weather information, forecasts as well as weather warnings. A map shown on the user interface gives an overview of the Austrian railroad system. Using new forecast models and radar techniques, weather extremes can be forecasted on a scale of 10 km and in some cases at even lower scale, when there are significant meteorological and/or relief (mountain crests, valleys etc.) divides. The flood forecasts integrate the river water level of the rivers with meteorological data and warnings can be sent 12 hours in advance. The snowfall forecast includes the amount of snowfall in the next 24 to 72 hours for each warning point.

In a nutshell

- the transport sector is perceived as a major contributor of global warming
- adaptation is essential to the transport sector
- the transport sector is a major stakeholder in the adaptation efforts
- there are opportunities to highlight the vulnerability of the transport sector and its potential to contribute in addressing climate change through the UNFCCC secretariat.

Concerning the latter, there are opportunities for collaboration with the UNFCCC Secretariat to raise awareness for climate change adaptation by:

1. engaging with the Nairobi work programme and becoming a partner organization
2. submitting Action Pledges to the Nairobi work programme
3. engaging with the Private Sector Initiative of the Nairobi work programme
4. assessing NAPAs for the least developed countries and providing support.

II.3 Natural hazard experiences and counter measures in the Japanese railways (Y. Mizukami, East Japan Railway Company)

East Japan Railway Company (JR East) was established as a reform of the Japanese National Railways in 1987 and consists of a 70 line-network with 7512 line km of rail track and 1689 stations and serves 17 million passengers per day (13000 trains/day). Half of its capital investment is spent on safety. It is notable that, in 2010, 20 per cent of the safety expenditure was related to countermeasures for natural hazards, amounted to about 40,000 €/km (FY 2010). Natural hazards affecting the JR East are related to: (i) heavy downpours, causing flooding, scouring, groundwater level rises and landslides (ii) strong winds, causing derailments (iii) high coastal wave activity, causing coastal erosion and collapses of protection walls along coastal rail tracks (iv) heavy snowfalls, causing avalanches and falling trees and (v) earthquakes, heat waves and thunderstorms

Major countermeasures developed/implemented by the JR East are:

- *Greater resilience of the network* to heavy precipitation (by e.g. slope reinforcement, scouring protection schemes), strong winds (by e.g. installation of windbreak fences and screens, growth of windbreak forests) and heavy snowfalls (by e.g. anti-avalanche schemes, increased availability and use of snow removal equipment, anti-snow measures on trains and growth of snow protection forests).
- *Installation of monitoring systems*, consisting of various environmental and engineering sensors (anemometers, water, rain, snow and temperature gauges, scouring and landslide detectors and seismographs), that provide real-time information to an operation control centre that prescribes speed restrictions and/or traffic suspensions when necessary.
- *Education and training schemes* for the JR East personnel.
- *Research and development* in its dedicated Disaster Prevention Research Laboratory, which studies the mechanisms of natural disasters, provides risk assessments and develops observation and detection methods, countermeasures and technical standards and designs practical measures using past experience

II.4 Climate Change Adaptation: impact and requirements for the rail sector (L. Lochman, Community of European Railway and Infrastructure Companies – CER)

In 2009, the EC published the White Paper "Adapting to climate change: Towards a European framework for action", which defined the strategy for mainstreaming Climate Change adaptation in the policies of the EU and its member States and introduced requirements for relevant EU financing. In that document, little attention was placed on transport-related CC impacts. However, following several calls for the correction of this deficiency, it is expected that transport sector will be at the center of European strategy concerning CC adaptation (the 2013 Strategy). CER, who has already launched a dedicated CC adaptation working group through which the railway sector exchanges best practices, potential policies, standards and funding opportunities, has joined the EU Climate Change Adaptation Steering Group that advises/supports the EC work on the preparation of its 2013 Strategy, the main objective of which is a more climate-resilient EU. The 2013 Strategy is expected to be based on: (i) assessing the costs, benefits and impacts of climate change adaptation (ii) the enhancement of relevant knowledge (iii) fostering the use of standards and guidelines and (iv) collating and sharing best practices.

In the 2011 Transport White Paper "Roadmap to a Single European Transport Area", an upgraded rail sector is envisaged, which will be able to increase its passenger and freight market share over middle distances (greater than 300 Km) by 2050. In order to achieve this, a functional, multimodal TEN-T core network by 2030 and a complete EU high speed, quality and capacity network by 2050 are being planned. In this context, the rail sector is committed to a more climate resilient railway system, the increased capacity of which will be also able to absorb the increased traffic resulting from transport modal shifts.

The rail sector is already affected by climate change, with hotter summers, wetter winters, strong winds and sudden switches of seasons causing increased traffic disruption and energy consumption. As such impacts are expected to increase in the next decades, effective climate change adaptation strategies, dedicated R&D actions, maintenance plans and vulnerability mapping and the introduction of climate change requirements for rolling stock are required. For the rail sector, climate change adaptation is a very important issue and task forces and/or dedicated strategies have been already established, as well as R & D activities. The Project ARISCC (Adaptation to Railway Infrastructure and Climate Change, see also I.10), for example, provides a broad collection of examples of good practice for integrated natural hazard management.

Climate change mitigation and adaptation measures are both necessary. At the moment, transport is the only EU sector with increasing CO_2 emissions. However, the rail sector reduces Greenhouse Gas emissions, despite being a low-carbon mode of transport. The rail sector is unilaterally committed to further reductions of its CO_2 emissions by 30 per cent and 50 per cent (relative to 1990) by 2020 and 2030, respectively, with a long-term vision to strive towards carbon-free train operations by 2050.

In order the European railway system to adapt to climate change, existing standardization needs to be modified. The sector's main message is that a complete mapping of the existing standards and regulation is required in order to identify gaps between the current situation and a resilient railway system. Well-focused research and development activities are also needed, for example within the framework of Horizon 2020. If the long life cycle of the rail system components (typically 20-30 years for trains, 30 years for ballast formation and 75 years for bridges) is taken into account, then standardization must be widely supported and commence as soon as possible. Major rail system elements to be considered include ballast formation, catenary, earthworks, slab track, drainage systems, water ducts and bridges.

The rail sector supports the European institutions and key stakeholders in identifying policies and priorities to enhance climate change resilience of the rail systems. CER will continue to foster exchanges of best practices among its members and support decision-makers in finding the best solutions in terms of integrating climate change adaptation into EU policies, standards and funding opportunities. Opportunities in the next EU multi-annual financial framework that promotes adaptation include the TEN-T Reform/Connecting Europe Facility (with an additional 10 per cent co- financing rate for actions enhancing climate resilience), the Cohesion Policy and the Horizon 2020 – The Framework Programme for Research and Innovation (2014 – 2020).

II.5 Mobility & Climate change, what does it mean for a sustainable mobility provider (A. Kaddouri, SNCF Climate & Energy Contact, Sustainability Department)

SNCF's 2011 revenue was about 32.6 billion € from 5 divisions/activities. (1) SNCF-INFRA, which includes rail network management, operation maintenance on behalf of RFF (high-speed line) and engineering of primarily rail infrastructures. Part of this activity is focused in France and part engineering in Europe, Asia, the Middle East, Africa, the Americas (5.3 billion €). (2) SNCF- Proximities, that includes public urban, outer urban and regional transport for daily commuters. This activity includes Regional Express (TER), the Paris area and Intercity services in France, Europe, the United States of America, Canada and Australia (12.3 billion €). (3) SNCF-VOYAGES, that includes high speed passenger rail transport in Europe (7.3 billion €). (4) SNCF-GEODIS, which includes station management and development. This is independent from carrier activity and is globally multi-modal (120 countries, 5 continents, 9.4 billion €). (5) SNCF-GARES & CONNEXIONS, which includes station management/development, independent from carrier activity, concentrated in 3000 French stations. AREP subsidiary operates internationally (1.2 billion €).

The projected warming temperatures, longer summer heat waves, cooler winters and more frequent extreme events will inevitably have an impact on SNCF activities, travelling, working conditions, maintenance operations and regulation. In March 2012, more than 40 per cent of French people thought climate change is the most significant environmental risk, with 7 out of 10 respondents declaring awareness with regard to Climate Change and its potential threat to their activities (survey IFOP for WWF France). In SNCF, climate change has been studied since 2009 ("Grenelle Laws").

SNCF decided to contribute to the development of the French climate change National Plan for three main reasons:

- SNCF invests heavily in (amongst others) rolling stock ('life expectancy' of about 40 years) and stations (even longer life expectancy) and, thus, these assets need to be reasonably climate-proofed in the long-term
- SNCF wants to reduce operational risks and to increase the resilience climate change may cause behavioral modifications and introduce opportunities.

According to the method described by de Perthuis et al (Economic Aspects in Adaptation for Climate Change, 2010), SNCF tries to identify all relevant climate change impacts for its operations as well as vulnerabilities and adaptation schedules. With this information, SNCF could propose adaptation alternatives for each impact, taking into consideration alternatives with a global vision: short term actions with long time effects (standardization etc), flexible responses to increase robustness of the railway system under potential climate scenarios (e.g. virtual mobility or alternative mobility solutions, crisis management under evolving climate), long term activities (e.g. climate crisis governance) and 'no-regrets' responses. Each Division of SNCF Group has to define its own plan and to coordinate with global governance. SNCF's climate change adaptation plan comprises also points regarding mitigation to reduce GHG emissions. The plan involves accurate risk cartography associated with local effects on adaptation policies, while it also tackles global aspects concerning mitigation. It is necessary for those involved in the railway planning, design, construction, and operation to understand how future climate will impact these sub-systems.

Decisions for adaptation can be differentiated into: (a) actions bound to the climate change timetable and the construction of new infrastructure, stations and rolling stock and

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(b) actions for climate-proofing using rehabilitation and protection from existing climate change risks.

SNCF's plan has set requirements to address climate change impacts, and adaptation is currently implemented at various levels of governance. The 'Climat D Rail' project has provided some relevant studies regarding CC adaptation. In October 2011, identification of CC impacts, vulnerability and adaptation schedules were set out and in January 2012, adaptation alternatives concerning impacts were identified. In March 2012, scenarios towards the future (social, economic, environment, mobility, etc.) were examined and in June 2012, plans for each SNCF Division and for global governance were formulated.

The SNCF Adaptation Plan in short includes:

- risk and opportunity cartography;
- climate proofing in investment/design, inspection and maintenance standards review, updating of prevention plans and crisis management and development of alternative mobility solutions; and
- climate governance with stakeholders, awareness of regional authorities, development of climate communication with customers and climate crisis exercises.

SNCF invests approximately 2 billion €/year on trains, stations and high speed lines (RFF). Future challenges include eco-design for trains/stations, production tools resilience and crisis management. Opportunities from e.g. new tourist demand (short/middle distance) and benefits from low GHG emission/low energy consumption are identified. Finally, it is noteworthy that even in the absence of climatic change, modifications of the current transport demand/offer, infrastructure and journey conditions will be necessary due to expected changes in tourist destinations, population distribution and agricultural production.

II.6 Adaptation measures & requirements to prevent impacts of climate change on road networks. The case of Attica Tollway (D. Mandalozis, Attikes Diadromes SA)

Temperature records show a significant temperature rise, which already has significant effects on the climate; these effects are expected to become more severe in the following decades. In Greece, the consequences of a 2°C warmer climate are projected to be a reduction of summer rainfall by about 30 per cent, 2-plus weeks of heat wave/year in the N. Aegean islands, 6-plus weeks/year risk of forest fires, stresses on agriculture and water and an overall threat to 50 per cent of plant species. Adaptation to climate change impacts appears to be absolutely necessary. In the case of transport infrastructure, and roads in particular, a move towards the so called 5th Generation Road/Forever Open Road that is climate change-adaptable is necessary.

Attica Tollway ("Attiki Odos"), one of the most modern roadways in Greece, is located at the Greater Athens area. It has a total length of 65 km, within a service/side road network of 150 km. There are 3 lanes per direction, plus an emergency lane and 56 tunnels. Flood protection works currently cover 67 km of the whole network. Attica Tollway (and its operating Company Attikes Diadromes S.A.) has won several prizes for its carbon footprint mitigation program (CO_2 emissions reductions by 10 per cent since 2009) and operation (Prize "Decibel d' Or", 1st Global Road Achievement Award, Green Recognition in "my climate Awards 2011").

Attikes Diadromes S.A. tries to identify and incorporate effective climate change adaptation measures. The projected climate will certainly affect road infrastructure, causing asphalt rutting, melting, thermal expansion of bridge joints, landslides, bridge undermining and general structural damage and it is, thus, crucial to prepare for such effects. Even though such effects are not presently particularly evident, systems have already been put in place to ensure that the Attica Tollway will be able to adapt. Currently, Atrtica Tollway adaptation responses include flood protection and management, pavement maintenance, installation and operation of environmental (e.g. meteorological) monitoring stations and proactive management.

In order to address extreme rainfall events and flooding, an extensive sewerage and flood protection scheme has been included in the design for the collection of the superficial runoff, as there are few remaining natural receptors in this area. The operation company is responsible not only for the maintenance of the 67 km-long flood protection works of the tollway itself, but also for the flood protection of neighboring areas of Athens that are threatened by floods. Concerning road pavement maintenance and adaptation measures, it is important to note that, as far as road asphalt maintenance is concerned, it is much more effective to maintain it early, rather than wait for major problems to occur. Maintenance costs can increase 4 or 5 times in the case of already damaged pavements. Climate change complicates road asphalt maintenance, as more frequent maintenance cycles are required.

Cost-effective road maintenance cycles require the collection of variety of data. Attikes Diadromes SA keeps a tight schedule of measurements regarding various pavement parameters, using e.g. falling weight deflectometers (FWDs), laser profilers, grip testers and ground penetrating radars (GPRs) to measure layer thicknesses, structural indicators, roughness, rutting, skid resistance and texture on some, or all, traffic lanes and in both traffic directions. Time series have already been collected for these parameters in regular intervals along the motorway, while for some parameters there is also seasonal (twice per year) information; such monitoring is necessary to reveal trends and provide timely warning for maintenance needs that may arise from climate change effects. In addition, a network of meteorological stations positioned along the motorway provides real-time information on the prevailing weather conditions and keeps records of extreme events. Generally, the approach is proactive, risk factors for different scenarios are assessed and the condition of the motorway is evaluated on a day-to-day basis, as well as following extreme events. The objective is to create a resilient road through prevention and/or modification of equipment and materials that will be able to allow for climate change effects, without compromising safety and comfort.

Finally, it is worth mentioning that Attikes Diadromes SA realizes that in order to create an adaptable road that is both safe and functional, Life-Cycle Analysis must be incorporated in the process. Life- Cycle Analysis is directly linked with design life/maintenance cycles and overall costing in road projects. When addressing CC effects, the choice of materials that allow road infrastructure to adapt effectively to these effects without raising maintenance costs unnecessarily is very important.

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II.7 Impacts and Adaptation Requirements of Road Networks (D. Tsamboulas National Technical University of Athens - NTUA)

Climate change impacts on road transport are associated with the safety, operation and maintenance of road infrastructure and systems, affecting all network users. Main impacts include both direct (pavement deterioration, deformation and subsidence, disruption, problems with accessibility, floods, erosion) and indirect (economic, environmental, demographic, spatial planning) impacts. These are mostly related to changes in temperature, precipitation, wind and storm intensities and patterns, permafrost thawing and sea level rise. Approaches to incorporate climate change considerations into the road design and operation include: (i) risk assessments that evaluate the exposure, vulnerability, resilience and adaptation responses of the road systems (ii) planning of timeframes (consideration of longer-term climate change effects during the planning processes) and (iii) adaptation strategies. International adaptation actions and policies from UNECE member States as well as from other countries (Canada, Denmark, the United States of America, Japan, Australia, and New Zealand) are reviewed, together with conceptual models from the United Kingdom of Great Britain and Northern Ireland Highways Agency and the United States of America's Federal Highway Administration (FHWA).

Good practices and adaptation measures are highlighted. These are related with design issues, pavement performance, frost damage, freeze and thaw cycles, frost heave, permafrost thawing, sea Level rise, flooding, road and bridge erosion, slope failures, landslides and avalanches. Potential low- medium cost measures are presented, including vegetation thinning, improvement and maintenance of drains, strengthening of embankments, preparation of surface runoff management plans, risk assessment and replacement of vulnerable trees and lightweight structures.

It is proposed that climate change considerations should be included into day-to-day engineering management and integrated into policy and regulation. Design standards should be reviewed in order to cope with new climate conditions. Adaptation measures should be cost-effective and sustainable. The development of a framework that will allow both acceptable levels of service during extreme weather events and swift recovery to normal operating conditions after the events is urgently required. National policies should include awareness raising and good practice sharing schemes. As the EU White Paper on adapting to Climate Change also suggests, more strategic and long-term approaches to spatial planning will be necessary in road transport.

II.8 U.S. Transportation and ClimateC hange: Addressing the Adaptation Challenge (J. Potter, ICF International)

Climate Change effects on roads are mostly related to hotter days, higher wind speeds, intense precipitation, increased coastal storm intensity and sea level rise. The work undertaken within the framework of the Gulf Coast Study, Phase II is presented (see also Annex I). The study goals have been to: (i) provide essential information on local, multi-modal impacts in a single Metropolitan Planning Organization to inform Long-Range Transport Planning and (ii) develop tools that can be applied by transportation agencies at the national level. A climate risk screening process for transportation is proposed, which includes: (i) criticality assessment of all transportation assets (ii) sensitivity assessment of all critical assets (iii) exposure assessment of all critical and sensitive assets; and (iv) concentration of all assets that are critical, sensitive and exposed.

In the case of the Gulf Coast Study, Phase II, the screening of critical assets has been carried out through data mining from infrastructure inventories, socio-economic information and expert judgments, whereas tools like transportation modeling, redundancy testing and stakeholder inputs are also used. During the sensitivity assessment, design standards, historical and geographical analogues and expert inputs are utilized and a sensitivity matrix (scoring matrix) is developed as a basic tool. Finally, in order to assess exposure, down-scaled climatic model data, weather extremes and indicators of relevance are used together with sea level rise and storm surge exposure analysis and adaptive capacity analysis. Flood maps under different scenarios of sea level rise and storm surge are produced that distinguish between incremental, but permanent, and catastrophic, but transient, impacts. The lack of necessary data and/or the abundance of not very relevant data (the data paradox) have been noted as major obstacles.

Recent projections of potential climate change by the United States of America regions (United States of America Federal Highway Administration-FHWA) and a risk framework for New York City (impacts on infrastructure in terms of magnitude and likelihood) are presented. Possible adaptation solutions are proposed, including: (i) the construction of storm surge barriers and strengthening of the bridges/substructures (ii) the accommodation of rising flood waters by structure elevation, increased maintenance, flood tolerance improvement and more frequent dredging (iii) asset retreat and relocation; and iv) flexibility of planning through the reductions in irreversible investment and lease lengths.

It is suggested that risk assessments combined with adaptation responses could lead to greater resilience. Integration within existing planning and risk management procedures is deemed that can produce improved overall outcomes. Finally, past experience indicates that: (i) decisions on actions should be taken as fast as possible (ii) extreme events of low-probability should be considered with care as these can have very serious consequences if occurred (iii) integration of existing paradigms is a key factor (iv) the (often varying) opinions of stakeholders matter and v) there should be a focus on robust actions.

II.9 Waterway infrastructure adaptation (N. Siedl, Via Donau – Österreichische Wasserstraßen-Gesellschaft mbH)

An overview of the weather-related effects on inland navigation, an assessment of measures related to integrated waterway planning and management and adaptation measures based on the experience gained through the Trans-European Transport Network (TEN-T) Priority Project 18 ("Rhine/Meuse-Main-Danube RMD Waterway" are presented .

Weather related effects on inland navigation are mostly related to: (i) droughts/low water levels and flows, which may cause insufficient navigation conditions and increase accidents (groundings) and fuel consumption (ii) high water levels/floods, which may cause suspension of navigation, changes in riverine sedimentation patterns and morphology and damages in towpaths, banks and flood protection schemes and iii) ice conditions, which may result in suspension of navigation, prevent lock operation and damage navigation signs. Nevertheless, the results of the study suggest that Inland Waterway transport will not be significantly affected by CC until 2050. Integrated waterway planning and management appears to be a viable option, with the following measures being proposed:

- improved and integrated understanding on the future waterway infrastructure development
- definition of integrated planning principles, which involves different experts (in economics, navigation, river engineering and ecology)

- the development of concrete guidelines for activities that will assist in the implementation of integrated planning principles with regard to waterway infrastructure projects
- information on existing good practices

An example (Pilot Project Witzelsdorf) of waterway infrastructure adaptation is presented. In this case, old riverbank groynes were removed and replaced by new groynes with improved design, and the river banks were restored. This scheme resulted in more favorable flow dynamics and lesser scour at the groyne heads.

Concerning Integrated waterway management, this is strongly related to 'fairway maintenance' cycles, that involve particular measures, such as: (i) regular monitoring with high-tech hydrographic survey equipment and data processing (ii) timely river dredging that takes into account the natural processes (breeding times, no removal of gravel from the river bed) and (iii) on-line bathymetric and flow information for the waterway users.

Integrated waterway planning and management should involve the provision of fairway conditions in accordance with internationally agreed parameters. Short, medium and long term adaptation measures should include integrated infrastructure maintenance, cost-effective use of the current inland water and improved design of the future fleet, better waterway management, use of ICT and appropriate and well design engineering measures.

II.10 Climate Change and Inland Waterways; the issue of morphology and subsidence (B. Turpjin, Dutch Ministry of Infrastructure and the Environment-Rijkswaterstaat)

Results from two research programs related to the Climate Change effects on the Dutch inland waterways are presented: (i) "The impact of climate change to inland waterway transport and the competitive position of the port of Rotterdam" (2011) and (ii) "Protecting the Netherlands against high-water and taking care for sufficient fresh water for the users of the fresh water system" (up to 2014).

Future impacts on the discharges, water levels and inland waterway navigation of the Rhine River are projected to be related to lower water discharges and levels, leading to restrictions in loading capacity, rising costs and potential modal shifts to road and rail. Issues related to the river morphodynamics are particularly highlighted, with both river bed subsidence and/or uplift creating problems to navigation, particularly as these are spatially variable. Bed level degradation (due to bed sediment erosion) can greatly impact river navigation, especially at locations where the river bed has been fixed. Technical solutions that can modify favorably the river thawed and cross-section (e.g. bottom vanes, fixed layers and bend way weirs) are presented.

These studies have indicated that the main impacts on inland navigation (decreasing load capacities and rising transportation costs) will be relative low until 2050. Nevertheless, bed degradation will continue to increase (if unchecked) and new river morphology adaptation measures will be required together with improved river management practices. The costs of infrastructure adaptation to bed degradation have been estimated to be similar to those required to arrest bed erosion.

II.11 Climate change and adaptation to inland waterways (C. Heyndrickx and T.Breemersch, Transport & Mobility Leuven)

The objective of European FP7-ECCONET Project "Effects of Climate Change on the inland waterway NETwork" (starting date 01/2010), led by Transport & Mobility Leuven (www.ecconet.eu) has been to integrate the expertise from 10 partners from 5 countries with respect to the current/future environmental conditions (e.g. meteorology, hydrology), infrastructure, operation, services and economics in order to assess Climate Change impacts on the European transport network, and particularly on the Inland Waterway network (Rhine and Danube rivers).

Inland Waterway Transportation (IWT) is controlled by river hydrology and its dynamics. In this context, future projections (dryer summers and wetter winters) indicate that there can be significant impacts on the IWT (if unchecked), particularly in the second half of the century ('far future scenarios', i.e. after 2050). Such impacts are associated mostly with both summer low (in e.g. the Middle Rhine R., RMD Canal and the upper Danube R.) and winter high flows. Some positive effects are also projected, mostly associated with river ice dynamics. In addition to the environmental factors, industry trends (e.g. the trend towards larger vessels) will also increase the IWT sector vulnerability in the case of increased/ protracted low river flows (and levels); transportation costs have been found to rise quickly under low water conditions, with the costs per t/km rising by a factor of about 3 when water levels fall from 4 to 2 m; when water levels fall below 1.6 m most inland waterway transport becomes impossible. It appears that considerations related to infrastructure and autonomous transport economics dominate the CC related threats for the sector.

Proposed adaptation measures are associated with: (i) IWT fleet adaptation (e.g. introduction of lightweight structures, adjustable tunnels, side blisters, flat hulls) (ii) infrastructure (information and dredging, waterway engineering) (iii) improved predictions (water level trends/forecasts); and (iv) logistics (e.g. coupling convoys, co-operation with other transport modes). An initial assessment shows that the most promising measures are related to the introduction of flat hulls (multiple screw push boats), the upgrade of small vessels to continuous operation and the use of coupling convoys.

II.12 Ship passage through the Vosporus Strait and Development of a multimodal transport corridor for the connection of the Aegean and Black Seas (Alexandroupolis Port Authority and Alexandroupolis and Kavala Port Authorities)

A review of the nautical and safety challenges of the Vosporus Strait, together with statistics on the use of the Strait is presented. Main findings of this study include:

- there are very significant challenges in the navigation through the Vosporus Strait, particularly for the large vessels, due to the complex navigation channel morphology hydrodynamics;
- the increased safety regulated for the Strait has as a result increasing 'waiting times' which may reach 5-7 days, depending on the type and size of vessel and the time period;

- the average number of ships through the Strait has been during the last 15 years 49.200 ships per year or 135 ships per day (with a peak in the period 2004-2006); and
- 60 per cent of the navigating the Strait ships are general cargo vessels, followed by tankers, bulk carriers and container carriers.

In recent years, two N. Greek ports (Kavala and Alexandroupolis) have commenced discussions with the Black Sea ports of Burgas and Varna (Bulgaria) for a possible cooperation in the field of intermodal transportation. Initial meetings (June and October 2011) have shown that the freight transport and the cruise sectors are those with the higher potential. Concerning freight transport, the initial idea is to develop an intermodal transportation corridor (Sea2Sea Corridor) with key nodes the above mentioned Greek and Bulgarian ports. In further meetings in 2012, it was decided to develop a proposal in order the Sea2Sea corridor to be included in the EC Program of Trans- European networks; this corridor is envisaged that will include the following sections:

- two Mediterranean maritime transport hubs (Kavala and Alexandroupolis ports) which will integrate the corridor to the Mediterranean routes
- rail transport legs that will connect the two Greek ports with the ports of Burgas και Varna in Bulgaria (and the port of Russe in Danube)
- two Black Sea maritime transport hubs (Varna and Burgas) that will connect the Sea2Sea corridor to other Black Sea ports.

This international transport network will have a lot of competitive advantages. Currently, the Mediterranean/Black Sea connectivity is serviced through the Vosporus Strait which, however, is already under a lot of pressure (increased traffic, costs and long delay times). It is estimated that the Sea2Sea corridor could operate as an alternative route with the following benefits:

- increase the competitiveness of the wider region as a trade gateway to C. Europe
- increase the competitiveness of the (4) Greek and Bulgarian ports and the interconnecting rail network
- strengthen the current Trans-European transportation network with the operational connection of the 'Motorway of the Sea' of the E. Mediterranean with the Axis 7 of the European Rail Network' and the TEN-T PP18 Waterway axis Rhine/Meuse-Main-Danube
- contribute to the economic development of the wider region.

II.13 Adaptation of Transport Networks to Climate Change (L.B. Barbeau, Mauritius Ports Authority)

The maritime industry has been a catalyst for the globalized trade and economy, particularly since the advent of containerization, which has revolutionized the transport system due to its door to door transport capacity and integration with the other transport modes. Today, the maritime sector controls the transportation of goods, as 80-90 per cent of all transported goods are moved via the maritime industry (for at least one leg of the journey). With respect to climate change, although there may be some new trade/transport opportunities for some countries through e.g. new routes (and the shorter distances involved), such as the ice-free Northern Passage, for other countries climate change effects could be crippling.

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Mauritius belongs to a large group of nations called Small Island Developing States (SIDS). Port Louis is strategically located at the crossroads of important maritime routes, such as Far East-Africa and Europe-Australia. The port is also the only maritime gateway of the country for external trade (99 per cent) and contributes significantly to the country's GDP. In addition, Port Louis offers vital connectivity to Indian Ocean islands and the surrounding region. The region is subjected to tropical storms, mainly during summer, which, in some areas, can be associated with extreme weather conditions. These extreme events frequently induce flooding of the port terminals which, in turn, reduces stevedore productivity and may cause turn round calls of container vessels, force trade shifts to other ports, increase costs and damage the island's economy.

Adaptation to the climate change effects is of primary importance. Unfortunately, SIDS do not always have the information and expertise to design climate-proof quays and breakwaters, which, in any case, are generally beyond their financial resources; local expertise is rarely available and SIDS have to rely on friendly countries or international organization for assistance. Additional capital investment is urgently needed for the construction and upgrading of appropriate wave protection schemes that can withstand deteriorating extreme wave conditions. In addition, quays which are normally built at about 2.5 m above chart datum will have to be raised to avoid flooding under rising mean sea levels and storm surges.

SIDS feel already the severity of climate change impacts. More intense and frequent coastal flooding and deteriorating coastal erosion have already created very severe problems in these states. Their dependence on maritime transport and the large investment needed for port upgrading and retrofitting induce very significant stresses. SIDS have an urgent need for the training/emergence of local scientists/engineers who will be able to monitor changes and design appropriate measures in a local scale, and not for consultants coming in and out of the countries, as is the common approach. Capacity building is of primary importance, as SIDS will be able to: (i) acquire local expertise in both technical and regulatory (legal) matters (ii) carry out risk assessments and ship inspections/control and (iii) develop climate-proofed hubs and regional ports with mega carriers and smaller vessels working in tandem to serve a specific region. Finally, the development of 'Green Ports' that will be able to rely on renewable (e.g. solar, wave and wind) and locally available energy sources is also a positive measure.

II.14 Climate change and ports: Qualitative analysis of consequences, plans, and requirements (A. Becker, Stanford University)

A brief background on the climate change impacts on seaports is provided, together with the results of a focused climate change adaptation survey (Questionnaire survey). Seaports are multi-scale economic engines, providing jobs, critical resources and facilitation of goods and energy trade (80-90 per cent of the world's freight is being moved by ships and, thus, through ports). Port development depends on various conditions (e.g. availability of deep water and/or protected harbors, possibility of multi-modal connections). Some of port locations are highly vulnerable to flooding, storm surges and sea level rise, particularly as climate projections indicate that sea level may rise up to 0.75-1.9 m and today's 100-year flood may occur every 3 years in 2100.

A questionnaire consisting of 30 questions was sent out on summer of 2009 to 350 IAPH/AAPA members. Ninety-three responses were used for further analysis. Key findings of this analysis include: (i) the respondents seem to be concerned about climate change impacts, but feel uninformed about the matter (ii) although ports form very significant and with long-life infrastructure, their design standards do not take account of climate change considerations - it has been interesting to learn that only 16 per cent of the respondents are considering upgraded storm protection schemes in their next 10-year construction plan and (iii) the great majority (97 per cent) of the respondents declared that they would have problems in the case of a 0.5 m, or greater, sea level rise.

The survey also revealed that, although the general climate change impacts on ports are generally understood, specific consequences are not. For this reason, two highly vulnerable (from tropical storms) United States of America ports (Gulfport, Mississippi and Providence, Rhode Island) have been chosen to investigate further the matter. Storm impacts were divided into 6 groups: (i) debris;(ii) direct damage; (iii) business consequences (iv) local/ regional consequences external to port (v) damages to intermodal systems and supply chains and (vi) environmental degradation. One hundred and twenty-five unique strategies were mentioned that might increase port-resilience. It seems, however, that multiple actors from the public and private sectors will be needed to implement these strategies.

Finally, it appears that (i) quantification of the true climate change consequences on ports is a rather difficult problem (ii) CC impacts/consequences may occur out of the career and lifetime of the decision makers, confusing issues of responsibility and (iii) the next steps should include strategies, timetables and clear responsibility allocation.

II.15 Climate change related impacts on the transportation of the Caribbean SIDS (A.F. Velegrakis, Department of Marine Sciences, University of the Aegean, Greece)

Recent research suggests that previous climate change forecasts and particularly those related to the intensity and frequency of extreme events in the Caribbean region may have to be upgraded. Such events have very damaging consequences for the infrastructure of the Caribbean SIDS which has been mostly designed for typical weather patterns and could be particularly vulnerable to reinforced extreme conditions. The climate change exposure of the Caribbean SIDS is deemed very high, due to the concentration of population, industry and services (e.g. tourism) and transport facilities at the coast, an environment that is going to bear the brunt of climate change effects in the region due to the long term sea level rise, increasing air and sea surface temperatures and ocean acidification that result in habitat losses and higher environmental risks and increases in the destructiveness of tropical storms and in coastal flooding.

International (maritime and air) transportation are the lifelines of the economies of the Caribbean SIDS. However, both transport infrastructure and services are likely to be seriously affected by Climate Change. Port facilities will be incrementally affected by higher mean sea levels and storm surges, suffering more frequent inundation and delays/interruption of shipping services. Jetties and breakwaters protecting ports will be less efficient, requiring raising and/or strengthening. Increasing sea levels will cause greater tidal prisms, stronger currents and more intense foundation scouring and/or silting. Heavy precipitation events can induce landslides and disruption of the coastal (and mountain) road networks. Higher mean temperatures and more persistent heat waves will affect runways (heat buckling) and aircraft lift, resulting in payload restrictions, cancellations and disruptions; thus, runways will require length extension, which may not be always feasible due to spatial constraints. For the above reasons, recent case studies indicate very substantial climate change-induced impacts for transportation in the Caribbean SIDS (ECLAC, 2011).

Transport is a demand-driven activity. In the case of the Caribbean SIDS, demand is founded on international tourism, with international visitors flying to the Caribbean Islands for the 'sun and sand' experience. In fact, travel and tourism form a very substantial proportion of the GDP of the Caribbean SIDS (in most cases exceeding 25 per cent and in many cases being over 45 per cent, see ECLAC (2011)). However, most Caribbean beaches are under a deadly threat of CC-driven retreat and erosion, which in many Caribbean islands averages 0.5-1.0 m/yr (see Cambers, 2009; Peduzzi et al., 2013). If these erosion rates persist for some more years, then most Caribbean beaches will be destroyed, tourism incomes will collapse and local economies and development will be devastated. Obviously, this will have very negative repercussions to the regional international transportation services.

As both transportation infrastructure and services and demand face very large climate change challenges in the region, major adaptation measures are urgently required. First, more accurate predictions of the climate change-related impacts in the region are needed in order to obtain realistic risk assessments. Secondly, building local capacity is of paramount importance in an area that will have to face large technical and economic challenges (see e.g. Peduzzi et al., 2013); this will require international assistance and financing. Thirdly, science-based policies must be urgently formulated and adopted that will take into consideration the specifics of the region. Finally, concerning transportation infrastructure, building resilience is an imperative, as relocation of assets is, in most cases, not an option.

II.16 Adaptation of Transport Infrastructure and services. The Work of UNESCAP (P. O'Neill, United Nations Economic and Social Commission for Asia and the Pacific, UNESCAP)

Six strategic areas for transport are identified: Green growth, economic connectivity, sustainable development, MDCs, disaster preparedness and climate change. In his new 5-year action agenda the UN Secretary-General identifies sustainable transport as one of the 5 building blocks of sustainable development. The relevant objectives of the agenda are to: (i) advocate/raise awareness (ii) enhance good practice sharing (iii) assist in the development of national sustainable transport strategies (iv) increase capacity and (v) form partnerships. Focus areas include integrated transport planning, urban transport policies, technologic innovation, promotion of inland and coastal waterways and financing sustainable transport projects.

Understanding the risks, adaptation of existing transport infrastructure, resilience and adaptation of future plans are considered to be specific actions towards a sustainable transportation network, which shall include integration of the road, rail, shipping and port networks, border-crossing facilitation and the development of intermediate dry ports. UNESCAP encourages the member States to get an agreement concerning the Asian Highway Network on standards and specifications, maintenance and monitoring. In addition, UNESCAP monitors the progress made and provides technical assistance for upgrading plans concerning safety. It also encourages the completion of the Trans-Asian railway network. The construction of its missing links is expected to cost about $25 billion.

UNESCAP's vision involves a safe, clean and affordable transport industry. It promotes measures, including: decreasing of the carbon footprint in materials and fuel consumption; utilization of climate change funds (e.g. for clean buses); planning of less private and of more public transport projects (e.g. BRT and LRT Rail); promotion of policies/investment in non-motorized transport (e.g. pedestrian and cycling transport); emission controls and impact mitigation and preserving ecosystem services. It suggests specific actions such as adaptation to lower carbon footprint materials (substitution, where possible, of construction materials such as cement and metals by natural materials), and construction techniques (more labor-based and less energy intensive, use of local materials, construction of 'perpetual pavement' with long life-times, sub-grade stabilization). Special emphasis is given on the protection of the environment (natural construction solutions), and the disaster preparedness, management and response/rebuild. In conclusion, there is a need for: (i) understanding the risks and likely costs (ii) adopting affordable plans to adapt and upgrade existing infrastructure and (iii) planning resilient, affordable and strategic transport infrastructure for the future challenges.

II.17 Climate Change and Adaptation of Ports and Transport Logistics: The Kaleidoscope (Adolf Ng, Hong Kong Polytechnic University)

Climate Change adaptation for ports requires: (i) an accurate definition of the issue (ii) recognition of the major challenges and obstacle; (iii) identification of areas and regions that are the most prone to the CC impact; (iv) prioritization of possible actions and (v) taking steps to establish international 'best practices'. In addition, awareness-raising is urgently needed as port and transport operators do not appear to be sufficiently aware, particularly in the case of secondary, or 'regional', ports. There are also many gaps in information related to climate change factors and impacts at local and regional levels, which will impede efforts to design relevant and appropriate response measures.

Case studies (e.g. rising sea levels and storm surges in the Gulf of Mexico, extreme cold and ice events in Tianjin port, N. China, melting arctic ice in Siberia and climate change–induced changes in agricultural production and fisheries in Tasmania) suggest that there is a large variability in climate change factors and impacts associated with transport networks. There is a lot of discussion on 'rising sea levels' and the 'increasing frequency and destructiveness of hurricanes and tropical storms'. Moreover, the discussion largely focuses on container ports along the 'track lines' of international trade and/or on 'hotspots'. However, the issue is clearly more complex as it involves also questions on the willingness and capacity for adaptation, logistics and supply chains, port-region relationships, resource sustainability, coastal management, marine biodiversity and the well-being of local communities. There is a concern that peripheral regions which usually have less financial resources and less sophisticated port infrastructure will be able to face such challenges.

Responsibility for policy and response actions should be shared throughout the transport networks, as many adaptation efforts are usually restricted within particular transport sectors and modes. A major challenge is associated with the question how to ensure that different transport sub-sectors share similar vision and standards in order to formulate complementary solutions for the whole supply chain. It appears that the issue of climate change impacts on ports is not necessarily a 'port problem' but a 'port system problem'.

II.18 Innovative Solutions for Climate Change effects on Transport Networks (R. Sfakianaki, Ministry of Infrastructure Transport and Networks, Hellenic Republic)

Climate Change impacts on the transport networks will increase generalized costs on various transport modes, are expected to cause GDP losses and need to be addressed through strong and early actions. The target should be the improvement of the resilience of the transport networks, the reduction of maintenance costs, the extension of the life time of infrastructure and greater capacity. Regarding road networks, some classic methods and practices to increase resilience are reviewed. It is suggested that the risk of flooding should be addressed by early decisions on potential adaptation strategies. There is a growing body of research in this area that is mostly associated with numerical modelling, flood simulation tools and monitoring and information systems. Railway networks, although they are relatively safe, CC-induced failures (e.g. bridge scouring/damages and landslides) can have large consequences such as life loss, huge replacement costs or network closures. The SMARTRAIL project that provides a holistic approach and proposes measures towards a reliable, safe, cost-efficient and sustainable rail network is reviewed. It is concluded that the innovative models produced in the project may assist managers to: (i) make rational decisions (ii) use effectively limited funds and (iii) help in the long-term maintenance of rail infrastructure.

Ports will be affected by sea level rise, storm surges and extreme weather conditions and coastal flooding. In the case of Greece, which has approximately 16300 km of coastline and more than 1000 ports and vessel shelters, the main problem is related to storm waves and surges which can cause coastal flooding. Coastal engineering solutions that have been effective or catastrophic (e.g. construction of breakwaters, seawalls, gabions which have actually caused erosion in the surrounding coast) are presented. Future coastal engineering practices should be based on appropriate and accurate coastal monitoring systems in order to provide effective coastal management. The method of the Polytechnic University of Catalonia (UPC) that has been developed to evaluate coastal vulnerability to storms is referred to as an example.

Early actions (on increasing capacity and extending the life time of infrastructure), holistic approaches (whole-life cycle analysis, integration of successful practices, incorporation of climate parameters in design), promotion of innovation and technology in early warning systems, new tools for strategic plans and dynamic responses to the CC impacts are measures that may assist in the sustainable development of the transport infrastructure. Policy adjustment measures will be required that will deal with: (i) definition of functionality (ii) future designs; (iii) promotion of practical/innovative solutions (iv) strategic land use and networks decisions (v) sectorial integration (vi) fostering European regulation for effective coastal management and (vii) the development of a pertinent CC observatory.

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II.19 Climate Change Impacts and Adaptation options for Transport Networks in Greece (N. Mitsakis, Centre for Research and Technology - Hellenic Institute of Transport, CERTH-HIT)

CERTH-HIT has extensive experience in the assessment of climate change impacts, including the WEATHER and MOWE-IT projects and its contribution to the Study for the Bank of Greece *Environmental, economic and social impacts of climate change in Greece*. Based on this experience, CERTH-HIT suggests that what is currently required in climate change impact assessment studies is multi-disciplinary cooperation between transportation engineers, meteorologists, transport economists, policy makers and financing institutions. This cooperation will allow more accurate projections of impacts, more effective risk, vulnerability, and criticality assessments of transport networks and quantification of impacts at network level in order to estimate costs.

Parts of The Bank of Greece Study, which are related to transport, are presented with emphasis given to the methodology followed and some main findings. Following relevant climatic projections (e.g. projections of number of days with temperatures higher than 35 0C), the methodology pertinent to the transport sector that has been used followed 5 basic steps: (i) prioritization on the basis of vulnerability assessments of the infrastructure/services of the national transport network (ii) projections on the future transport demand (iii) assessment of climate change impacts and costs for the transport sector (iv) qualitative evaluation of impacts , suggestions for adaptation and mitigation and general conclusions and (v) policy recommendations. 4 Greek zones (western, central, eastern and island) were selected, where the national and regional road and rail networks have been studied, together with the 119 main ports and 43 airports. Main findings include:

- 1.5 - 6.6 per cent (depending on the zone) of the (approx. 9530 km) national and regional road network is found within 50 m from the coastline and at approximately the current sea level elevation
- future transport (passenger and freight) demand is projected to double until 2050, both at the national and the regional road networks
- depending on the adaptation scenario, costs due to rail and road infrastructure restructuring, repair and maintenance until 2050 is estimated as €115 - 346 million per year and 4 €billion flat, with similar costs to 2100 estimated at €195 - 595 million per year, depending on the adaptation scenario the projected mean and extreme temperature changes are expected to have significant negative impacts on the road infrastructure (e.g. pavement and structural element damages, reduced levels of comfort for passengers and personnel, higher demand for air conditioning).

The proposed transport policies in order to mitigate/adapt to these impacts include: (i) implementation of policies to reduce GHG emissions in the transport sector (ii) measures to reduce the of private vehicles (iii) elaboration of plans for pre-defined and organized traffic restrictions in urban areas during high temperature events (iv) 'quick-check' programs for targeted pavement maintenance (v) R & D for new types of road pavements (vi) re-planning and rearrangement of rail schedules to take into account expected events of high and very high temperatures

II.20 France takes actions: National Climate Change Adaptation Plan (NCCAP, 2011 – 2015) – Measures on infrastructures and transport systems (André Leuxe – General Directorate for Infrastructure, Transport and the Sea – French Ministry of Ecology, Sustainable Development and Energy)

The fight against climate change is a national priority and the President of the French Republic, François Hollande, announced in his opening speech to the Environmental Conference on 14 September 2012 that France offers to host the next International Conference on climate. "The goal is to reach a global climate agreement in 2015" and "France is fully engaged for this meeting to be successful".

I – The context:

Climate change is underway and its effects are being felt: "many natural systems are affected by regional climate changes" (IPCC, 2007). The message of science leaves no room for doubt as to the meaning of these changes even if there is still uncertainty about its magnitude. Profound changes are inevitable, regardless of efforts to reduce emissions of greenhouse gases deployed, due to the inertia of the climate system. They will affect many sectors: agriculture, forestry, tourism, fisheries, biodiversity, land, buildings, and transport infrastructure ... Climate change is becoming more than a scientific concern about the distant future. It is now a pertinent issue for policies at an international level.

The measures necessary to limit the extent of climate change by lowering our greenhouse gas emissions (mitigation), are the core of the French Climate Plan, adopted in 2004 and updated regularly (Article 2 of Law #2005-781 of 13 July 2005). While some actions towards mitigation have already been undertaken, adaptation to climate change has become a major issue that calls for a national mobilisation. The law #2009-967 of 3 August 2009 provides in Article 42 that "National Adaptation Plan for the different sectors should be prepared for 2011."

Humankind and nature may have the ability to spontaneously a least partially adapt to some extent- to the changes brought about by climate change. However, if we do not prepare for this change, it will induce costs and damages well above the planning effort. Therefore we must act today to reduce our vulnerability to climate variations in order to avoid high damage, be they environmental, material, financial or human. The economist Nicholas Stern estimated the cost of inaction between 5% and 20% of Gross Domestic Product (GDP) and that of action between 1 and 2%.

The NCCAP was adopted in July 2011 It defines various indicators to act as performance measures for annual monitoring. The assessment will be made public. An Evaluation Committee will report mid-term and in the end of the plan.

II – The measures in the action sheet "infrastructure and transportation systems" of the NCCAP:

The impacts of climate change on transport networks cover all modes. Adaptation is made necessary by the long duration of use of transport networks and equipment. Various measures have been identified. They provide climate change impact analytical means, prevent vulnerabilities of transportation systems and prepare the improvement of resistance and resilience of infrastructure - existing and future - to ensure continuity and security of the services transporting people and goods.

Action 1: Review and adapt the technical reference for construction, maintenance and operation of transport systems (infrastructure and equipment).

This is to ensure that the infrastructures which are built for a long period (some up to a century or more), according to the current references, adequately meet the evolutions which are expected as a result of average and extreme climate change conditions. It is the same for transport equipment. For new transportation projects, the match between the revised hazards and national, European and international technical references is essential.

Action 2: Investigate the impact of climate change on transport demand and the effects on the reorientation of transport supply.

Climate change could alter the medium and long term travel demand: origins and destinations related to the temporal distribution of flow and the geographic distribution of populations and activities, the attractiveness of tourist destinations... A prospective light should be put on possible developments in passenger and freight mobility and their impact on transport supply. The impact of urban morphology changes will also be studied.

The action comes in four steps on the evolution of the modal, geographic and temporal transport split:

– For long distance, foster research on the evolution of choice of locations of populations and activities as well as tourist destinations.
– For cities, study the link between planning policy and transport in the city.
– For the air transport, further analysis about air traffic trends in the framework of ICAO.
– For freight, study the evolution of the location of economic activity and major corridors.

Action 3: Develop a harmonised methodology to diagnose vulnerability of infrastructure and transport systems for land, sea and air transport.

Methods of analysis for the climate change vulnerability of transport networks are underdeveloped because this problem was addressed recently. Only risk analysis for some extreme events, specific to studied parts of the networks have been developed. Scientific and technical researchers are working with network operators, are working to establish methodological materials to facilitate the achievement of local studies for each network, and establish a state of vulnerability of the different networks and allow comparison on the basis of "criticality indices". Two steps for this action:

– Develop a methodology framework for transport networks for vulnerability analysis.
– Develop a methodology for vulnerability analysis adapted to networks and singular points (bridge, tunnel…)

Action 4: Establish the state of vulnerability of land, sea and air transport networks, on the mainland and overseas; prepare response strategies, progressive and tailored to the issues caused by climate change, both globally and regionally.

This is to make risk analysis for all transport infrastructures (road, rail, river, port and airport) in relation to climatic hazards for their design lifetime. Overseas regions or areas that are far from mainland (island, mountain valley bottom...) for which there is a single, possibly a high-capacity, infrastructure, have a potential vulnerability of their infrastructure service (airport, port, bridge, etc..). The change in average climate conditions and the increase in extreme event frequency and duration set new questions about liability and arbitration in choosing an adaptation strategy (retrenchment, construction, acceptance of a temporary unavailability and report towards other means of transport ...), the level of acceptable risk, the timing to invest and implement adaptation strategies. This action involves two measures:

- Conduct vulnerability studies.
- Facilitate a network of correspondents to build on the experiences and provide methodological support to infrastructure managers and transport operators.

III - Work in progress:

Part 1 of the action on the review of technical standards should be available by the end of 2013. Studies will be launched this year on the impact of climate change on users' behaviour (Action 2). Concerning Action 3, the report on vulnerability analysis methods of transport networks and structures should be completed in early 2014. Finally, two studies were undertaken in 2013:

- The "GEPET'EAU1" project in response to the 2012 call for projects launched by the IGCC2 research programme: this project aims to use modelling work to define predictive and adaptive management strategies regarding waterways and more generally the water resource in different watersheds. The goal is to allow normal traffic during low flow periods such as floods. This tool is developed by the Joint Centre Armines, the Ecole des Mines de Douai in connection with the Polytechnic University of Catalonia, Lyon's office of IRSTEA (Research Institute about Sciences and Technologies for Environment and Agriculture). It was initially designed for VNF (French Waterways Management Agency), Artois-Picardie Watershed Management Agency and DREAL Nord-Pas-de- Calais (Regional Directorate for Ecology, Planning and Housing, depending on the Ministry in charge of Transport) and should be transferable to other areas of the network operated by VNF.
- The modelling of the evolution of wave climate on the French coasts of La Reunion and the Antilles made in connection with the DGEC (Directorate General for Energy and Climate) by Saint Venant Laboratory EDF (major French electricity supplier), Ponts ParisTech School and CETMEF (French Technical Centre on waterways and the sea) should provide information on which parameters to take into account when modelling maritime climate over port sectors and coastlines. This research involves the construction of wave climatology on each coastal front of the Metropolitan France and Overseas, including the island of La Reunion. Indeed, the impacts of climate change on the climatology of seas, including in extreme conditions, are not known in La Reunion. The Antilles will also be studied for a second time.

1 Efficient management predictive and adaptive resource water of waterways in the context of climate change (Gestion Efficiente Prédictive ET adaptative de la ressource en Eau des voies navigables dans un contexte de changement climatique)

2 Managing impacts of climate change (Gestion des Impacts du Changement Climatique)

II.21 Conclusions and recommendations of the Conference

The United Nations Economic Commission for Europe (UNECE) Conference on "Climate Change Adaptation for International Transport Networks", kindly hosted by the Evros Chamber of Commerce and Industry and the Hellenic Chambers Transport Association, with the support of the Hellenic Ministry of Infrastructure, Transport and Networks and the Hellenic Ministry of Environment, Energy and Climate Change, was held in Alexandroupolis on 25-26 June 2012.

The Conference was opened on behalf of the Greek Ministry of Development, Infrastructure, Transport and Networks by Mr Nikolaos Malakatas, Director of Design and Studies of Road Works at the General Secretariat for Public Works and Mrs Eva Molnar, Director of Transport Division, UNECE. Mr. Christodoulos Topsidis, President of the Evros Chamber of Commerce and Industry, the leader of the Council of the Department of Eastern Macedonia and Thrace Mr Aris Giannakidis, as well as the Mayor of Alexandroupolis Mr Vaggelis Lambakis welcomed the participants. Finally, Prof. Dimitrios Tsamboulas delivered a welcome address on behalf of the Greek Minister of Development, Infrastructure, Transport and Networks, Mr Kostis Chatzidakis.

The Conference was fully supported by the Inland Transport Committee (ITC) of UNECE, which was represented by its chairman Mr. Jerzy Kleniewski.

The Conference was attended by 70 participants from the public and private sectors from Greece and other European and non-European countries, including delegations from the Ministries of Transport and Public Works of France, Kazakhstan, the Netherlands, Poland, Saudi Arabia, Spain and Ukraine. Among the Conference participants were also representatives from the United Nations Framework Convention on Climate Change (UNFCCC) Secretariat, the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP), the Community of European Railway and Infrastructure Companies (CER) AISBL, the Alexandroupolis Port Authority S.A., the Attica Tollway Operations Authority, the Attikes Diadromes SA, the Hellenic Institute of Transportation Engineers, Hellenic Institute of Transport of the Centre for Research and Technology Hellas (CERTH-HIT), the French Railway Company (SNCF), the East Japan Railway Company, the Forum of European National Highway Research Laboratories (FEHRL), the ICF INTERNATIONAL, the Mauritius Port Authority, the National Technical University of Athens, the Stanford University, the Hong Kong Polytechnic University, the University of the Aegean, the Via Donau – Österreichische Wasserstraßen Gesellschaft mbH, the Hellenic Chambers of Commerce and Industry, together with representatives of the local authorities and the business community. The representatives from mass media at national and local levels followed the sessions and participated in the Press Conference.

Climate change may be one of the greatest threats the planet is facing. There is now conclusive scientific evidence to substantiate claims that climate change presents serious global risks for water resources, food security, biodiversity, human settlement and development, health, living conditions, and international peace and security. It has been also recognized that climate change presents a significant and indeed imminent challenge for both freight and passenger transport. Climate change, therefore, demands an urgent global and coordinated response on multiple levels.

Rising sea levels, increased frequency and intensity of extreme storm waves and surges, droughts, increased temperatures and heat waves, cooler winters, extreme precipitation events and river floods, as well as the melting of permafrost pose serious threats to both coastal and inland transport infrastructure and services. Road pavements surfaces and other infrastructure, rail and airport infrastructure and operations, vehicles design and driving conditions, the inland waterway infrastructure and operations, the seaport and inland port infrastructure and operations are all likely to be impacted by climate change to a varying degree.

The distinguished speakers and participants in the Conference from UNECE and UNESCAP, Member States, intergovernmental and non-governmental organizations, as well as the transport industry, research and academia discussed issues related to risks, exposure and vulnerabilities of the international transport networks and related adaptation measures.

They all agreed that given the magnitude of the challenge, it is imperative that climate change impacts and related adaptation requirements be considered as a matter of priority, along with other transport-related initiatives aimed at mitigating global warming and in respect of which UNECE work is well advanced.

The exact definition of the term "adaptation" in particular was amongst the issues debated by the participants, who agreed that adaptation refers to "the ability of a system to adjust to climate change, including climate variability and extremes to moderate potential damage, to take advantage of opportunities, or to cope with the consequences". As a result, adaptation action aims at reducing vulnerabilities and increase resilience of transport systems.

Several experts from various countries shared their experience concerning sector-specific adaptation measures that have reduced transport network vulnerability. The participants were of the opinion that such examples of effective infrastructure adaptation to climate change could assist in the development of guidelines and/or best practices.

The participants:

- Agreed that there is an urgent need to prepare appropriate policy actions and exchange information about best practices.
- Observed that amongst the existing National Adaptation Programmes of Action (NAPAs), a process for Least Developed Countries (LDCs) to identify priority activities that respond to their urgent and immediate needs to adapt to climate change, developed under the United Nations Framework Convention on Climate Change, none had explicit references to transport infrastructure.
- Commented that the Green Public Procurement (GPP), a process through which public entities seek to procure goods, services and works with a reduced environmental impact throughout their life cycle, is certainly a step towards the right direction. They also noted that several countries have already decided to adopt the GPP for at least of 50 per cent of their supplied products.
- Observed that Concession Contracts of transport infrastructure, and particularly those relating to road transport, generally lack necessary climate change adaptation clauses.
- Noted that transport infrastructure planners/designers and transport manufacturers should take into account from the planning stage, climate change regional projections and their potential impacts. Furthermore, climate change should be incorporated into engineering management practices and integrated into national and international policies and regulations.
- Suggested that criticality screening of transport infrastructure is crucial to identify and successfully implement optimum adaptation measures.
- Observed that as small changes expected to mean water levels until 2050, climate change impacts on inland waterways are not expected to be significant; however, the greater temporal and spatial variability in water levels expected can create problems that require integrated waterway planning and management.
- Agreed that the development of effective adaptation strategies requires both collaborative research and the formulation of effective policies. Within this context, they welcomed the research methodology adopted by the ECONNET project, which combines climate and hydrological models with transport-economic models in order to identify effective adaptation measures for the inland waterways.

- Noted the work on climate change adaptation undertaken by the European Union: (i) the 2009 Adaptation White Paper, which aims at making the EU more resilient to climate change and (ii) the Adaptation Strategy that will be in effect by 2013 and will function as the Roadmap for the former. They also suggested that more strategic and long-term approaches to spatial planning will be required.
- Were informed on the specifics of the planned "Sea to Sea" Project, which aims to establish a rail connection between the Mediterranean and the Black Seas (Alexandroupolis-Burgas).
- Observed that Small Island Developing States (SIDS) face great climate change–induced challenges (such as tropical cyclones, storm surges and other extreme events) that can result to seaport and airport inundation and other damages affecting very significantly operations and services. At the same time, SIDS development depends on economic activities (e.g. tourism) that are going to be greatly affected by climate change; this can, in turn, have negative impacts on international transportation. These states are in need of financial and technical assistance from developed countries and international organizations, in order to build the necessary local capacity.
- Underlined that although several large port infrastructure projects are currently at their design/construction stage, their investment schemes/design standards do not generally incorporate climate change considerations. Port resilience would require capacity building, risk detection and management (e.g. emergency and/or evacuation drills) and risk transfer (increase of insurance cover, disaster relief etc).
- Observed that although climate change poses significant problems, might also provide opportunities (potential rise of new seaports, new destinations for tourism).
- Agreed that there is a need for more coordination between the different transport sectors and their respective initiatives to develop inter-mobility.
- Noted that several countries cannot, at this time, afford to implement adaptation plans, due to the very large investments required. It was, however, stressed that low-cost techniques, based upon an improved understanding of risks and their potential costs, could be adopted to adapt existing infrastructure.
- Observed the urgent need for stakeholders to fund adaptation plans, as well as the necessity for identifying innovative solutions.
- Suggested that transport networks should be preferentially positioned in areas less likely to be affected by climate change; in addition, strategic land use and integration of other sectors (e.g. agriculture and tourism) should be taken into account during the planning phase, using a holistic approach.
- Were informed on a study on costs and adaptation of Greek transport networks to climate change, funded by the Bank of Greece, in which more than 200 scientists – 4 dedicated to transport - of various disciplines took part.
- Two activities of related research efforts at EU level were shortly presented. The completed FP7 WEATHER project (Weather Extremes: Assessment of Impacts on Transport Systems and Hazards for European Regions) and the continuation thereof, the FP7 MOWE-IT project (Management of weather events for transport systems), which aim to assess and quantify impacts of climate change on transport networks.

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Considering transport networks adaptation to climate change as a problem which can only be tackled through collective efforts and cooperation at all levels, the participants agreed on the following recommendations:

1. The lessons learned during the conference should be disseminated to the other Government Entities of the countries participating in the Conference that are involved in transport network adaptation to climate change.
2. Adaptation practices in the transport sector should also be disseminated through the UNFCCC Nairobi work programme (NWP) by submitting an Action Pledge. The NWP provides a platform to organizations for knowledge sharing and networking.
3. Governments should be aware of the climate change and its impacts on transport networks; awareness should be raised on transport infrastructure adaptation to climate change and more effort should be put towards this direction.
4. There should be both collaborative research and policy actions to develop effective adaptation strategies for climate change impacts on international transport. Well targeted vulnerability studies, empirical studies and assessment of projected risks and related costs should be a first step towards bridging the current knowledge gaps and identifying priority areas.
5. There should be science-based policy formulation that takes into consideration the specifics of each region.
6. Investments specifically targeted for the adaptation of transport networks to climate change should become available, as adaptation of infrastructure is linked with higher than normal construction costs and, in addition, some States are not in position to financially undertake such plans.
7. In view of the above, further research and promotion of specific measures for affordable adaptation of transport infrastructure and transportation mobile to climate change should be conducted.
8. The results of the Conference should be promoted in order to assist in the development of guidelines to be followed by countries in all the United Nations Regional Commissions' geographical areas.

The participants expressed their gratitude to Evros Chamber of Commerce and Industry and the Hellenic Chambers Transport Association, for warmly hosting the conference in Alexandroupolis in such excellent conditions, the Hellenic Ministry of Infrastructure, Transport and Networks and the Hellenic Ministry of Environment, Energy and Climate Change for supporting the event, to speakers for having shared their experience and provided for possible solutions to improve the adaptation of transport networks to climate change, and UNECE for having organized the Conference.

The Conference proceedings, including presentations can be found on the UNECE website http://www.unece.org/trans/main/wp5/wp5_conf_2012_june.html

ANNEX III: Additional inputs to the Group of Experts on Climate Change impacts and adaptation on international transportation networks

III.1 Impacts of and adaptation to Climate Change on road and rail transport infrastructures (F. Nemry, H. Demirel, JRC/IPTS)

Disclaimer: The views expressed are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission.

Introduction

In the future, transport could be affected by one or several simultaneous changes in the climate conditions, including hotter summers, extreme precipitation events, increased storminess and sea level rise. If such impacts are not anticipated in future transport infrastructure design and maintenance, those changing weather conditions could, in some regions, accelerate their deterioration, increase severe damages risks, traffic interruption and accidents which could, on their turn, affect economic activities.

The JRC/IPTS has conducted a research about the future impacts from climate change on road and rail transport infrastructure and assessed three adaptation and vulnerability case studies[27]. It is one of the JRC study carried out in the framework of the JRC PESETAII project assessing the future impacts of climate change in Europe.

Method

The study has made use of available climate models based projections (FP7 ENSEMBLE[28]) for three distinct global emission scenarios (respectively low (E1), medium (A1B) and high (RCP8.5) emission scenarios) and regional model realizations. Technico-economic analysis has been applied at high geographical resolution for all Europe by combining different types of spatial information, including climate data and climate stress factors, transport information (transport infrastructure, network, and transport activity), physical information (e.g. sea level rise, coastal information, engineering process related information such as deterioration & damage mechanisms).

Main results

This research project has drawn some future trends regarding **changing exposure** of road and rail infrastructures to weather-induced risk under climate change, considering two future time intervals (2040-2070 and 2070-2100), and future **infrastructure deterioration and damage costs.** Costs associated with some selected **adaptation cases** were also assessed. This has been performed at high geographical resolution and higher aggregation level.

[27] Nemry F, Demirel H. Transport and Climate Change: a focus on road and rail transport infrastructures. EUR 25553 EN. Luxembourg (Luxembourg): Publications Office of the European Union; 2012. JRC72217

[28] http://www.ensembles-eu.org/

Future impacts on road infrastructures

Even though integrity and serviceability of transport infrastructure, including their resilience to current weather conditions, are key objectives in infrastructures construction and maintenance standards, complete avoidance of weather-induced infrastructure deterioration and failures is not economically feasible. For road transport infrastructures, weather stresses represent from 30 per cent to 50 per cent of current road maintenance costs in Europe (8 to 13 billon €/yr). About 10 per cent of these costs (~0.9 billion €/yr.) are associated with extreme weather events alone, in which extreme heavy rainfalls & floods events represent the first contribution.

The JRC/IPTS study concludes that, at EU27 aggregated level, average precipitation-induced normal degradation of road transport infrastructures will only slightly increase in the future. However, more frequent extreme precipitations (and river floods and pluvial floods) as projected in different regions in Europe could represent an extra cost for road transport infrastructures (50-192 million €/yr. for the A1B scenarios, period 2040-2100). Milder winter conditions are projected to result in reduced costs for road infrastructure (-170 to -508 million €/yr. for the A1B scenarios). On the contrary, increasing average temperature could require changes in maintenance operations and practices and represent extra costs for both road transports.

These costs provide a highly aggregated picture of the possible trends for road transport in Europe. More severe consequences at local or regional level are not excluded, implying both more significant increase in repairing and maintaining infrastructures spending, and indirect consequences (e.g. fatalities due to extreme weather events) where infrastructures would collapse. For instance, current patterns about extreme precipitation show a very uneven spatial distribution.

Vulnerability and adaptation

The study has analysed four case studies about future exposure vulnerability and adaptation, covering different aspects of climate change, infrastructure types and involved life spans.

Road Asphalt binder adaptation to reduce heat-induced road pavement cracking is the least costly measure and, given the relatively short life cycle (about 7 years), it is not expected to represent a major challenge for infrastructure planner.

Protection of *river bridges* against scour risk may be needed over the next decades for about 20 per cent of the river bridge stock because of increasing intensity of peak river discharges. Given the long bridge design life (greater than 100 years) and long maintenance planning cycle, future climate- related risk should be included in corresponding prior cost-benefit studies.

For heat-induced *rail buckling risk* and derailment risk, the most commonly applied adaptation measure consists in speed limitation. Today the delays implied by such a measure represent a small cost for transport. Due to more intense and frequent hot days in summer, this could induce more frequent trip delays for rail transport (doubled or quadrupled for the A1B and RCP8.5 scenarios respectively). Changing the track anchoring conditions could help reducing these delays, but a detailed assessment would be needed to validate such an option and assess its costs.

For the case of road infrastructure adaptations considered, compared with maintenance costs, the adaptation costs estimated for the A1B scenarios (314-560 million €/yr.) represent a small percentage of current road maintenance costs (1.2 per cent to 2.2 per cent). However, damage costs which would be avoided by such adaptation measures could be several times higher. The cost of bridge failure could easily reach 2 to 10 times the cost of the bridge itself.

This study has produced an initial estimate of future risk of sea level rise and *sea storm surges* on transport infrastructures. This assessed risk is based on infrastructure settled in areas lying below a level defined by the sum of sea level rise (1 m) and 100-yr sea storm surge height. For roads for instance, at European level, the infrastructure at risk of permanent or episodic inundation represents 4.1 per cent of the coastal infrastructure. The value of that infrastructure is estimated to ~18.5 billion €.

III.2 Climate Change Adaptation: impact and requirements for the rail sector (Libor Lochman, Executive Director CER)

The EU political context

The European Commission has taken concrete steps in the past years in raising climate change adaptation on the EU's political agenda. In 2009, the Commission published the White Paper "Adapting to climate change: Towards a European framework for action", which defined a strategy for the EU and its member States to prepare for the impacts of climate change. Regrettably, the paper did not pay enough attention to transport, despite the fact that a climate-resilient transport sector is vital for our daily lives. In 2010 the European Parliament took the issue on board and adopted an important Resolution (2009/2152(INI) which pointed out the lack of attention paid to the transport sector in the 2009 White Paper and, in line with the CER's proposals, called on the Commission to put the transport sector at the centre of the upcoming European strategy on climate change adaptation.

Since then, the European Commission has launched the preparation of a Climate Change Adaptation Strategy, which we expect to be published in March 2013. CER has been contributing to the Commission's work by providing input on the rail sector's activities on adaptation, the impact of climate change on companies' operations, and the sector's expectations from the EU institutions. In this regard, CER joined the EU Climate Change Adaptation Steering Group, which advises and supports the Commission in its work on the future strategy. We expect the Commission to focus on four main areas to make the EU more climate-resilient, namely: assess costs, benefits and impact of adaptation; enhance knowledge; foster the use of standards and guidelines; and collect and share best practices.

The rail sector has already undertaken a considerable amount of work in all of these areas and the European Commission is now aware about the important contribution that the sector can provide prior to the strategy, as well as for its implementation. CER launched also a dedicated climate change adaptation working group where railway companies exchange best practices and discuss on how to integrate climate change requirements in policies, standards and funding opportunities.

In parallel to climate change adaptation, it is important to stress that the EU has set an ambitious roadmap for the transport sector in its 2011 Transport White Paper "Roadmap to a Single European Transport Area". At the heart of the strategy, rail should become the backbone of EU transport system with a significant increase of the market share for both passenger and freight over middle distances (>300 Km) by 2050.

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It is key that this general political support for rail is reflected in the upcoming EU climate change adaptation strategy and in the implementation of the 2011 Transport White Paper. In parallel, the sector is committed to continue its work on making the railway system more climate-resilient and, at the same time, to adapt its ability and capacity to absorb new traffic as a result of modal shift.

Climate Change Adaptation: a reality for the rail sector High temperatures, heat waves and intense short time as well as extended rainfall are some of the consequences of climate change that the rail sector, as well as the whole society and economy, will have to increasingly face. This will also mean, for example, risks of increased traffic disruptions, increased energy consumption for air-conditioning systems in summer, high wind causing trains to blow over or loss contact with overhead wire. While these effects are already felt by the rail sector, the bigger impact expected by railway companies will happen in the next two-three decades.

For the rail sector, adaptation to climate change is a very important issue and many companies have already established task forces and/or dedicated strategies, as well as R&D activities. The two-year UIC project ARISCC (Adaptation to Railway Infrastructure and Climate Change) is a good example, in particular in providing a broad collection of good practice example for integrated natural hazard management. CER therefore welcomes the EU plan to move forward on policies on climate change adaptation and has engaged with both its members and EU decision-makers to make sure that all available resources and measures at EU level, as well as at national level, ensure that adaptation to climate change promotes an economically sound and sustainable transport sector, with a strong rail system as the backbone of the European transport system.

CER believes that policy measures supporting adaptation in the rail sector should be considered as a matter of priority in the future EU strategy, along with transport-related mitigation measures. Increased effort should be put towards increasing Governments' and local authorities' awareness on rail transport adaptation to climate change. At the same time, the EU should support research efforts by the rail sector to fill-in identified research gaps.

In this context it is important to stress that mitigation and adaptation are both necessary. This is even more relevant when considering that the transport sector accounts for 27 per cent of EU's greenhouse gas emissions. The EU strategy on adaptation is an opportunity to further stress that mitigation measures targeting the transport sector as a whole are necessary. At the moment, transport is the only sector in the EU where CO_2 emissions are increasing and this outweighs gains in emission reductions made in other sectors of our economy. The rail sector is the only one reducing the greenhouse gas emissions, despite being a low-carbon mode of transport. Moreover it has unilaterally committed to further reduce its specific CO_2 emissions from train operations by 30 per cent and 50 per cent compared to 1990 levels by 2020 and 2030 respectively, with in addition a more long-term vision to strive towards carbon-free train operations by 2050.

Standardisation is another key area where the cooperation between the EU institutions and the rail sector is vital. The European railway system is historically defined through a complex and vast hierarchical standardisation and regulation landscape.

In order to adapt the European railway system to climate change, the existing standardisation needs to be adapted or extended accordingly. In April 2012, CER organised a sectorial workshop on "Climate Change Adaptation: Reality and prospects for the rail sector". As one of the concrete outcomes of the workshop CER took the lead to define common goals for the sector and to support the Commission in view of the publication of the Commission's strategy in 2013.

The sector's main message on this issue is that a complete mapping of the existing standards and regulation is required to identify the gaps between the current situation of the rail system including rolling stock and infrastructure and the target system of a resilient railway system. The open points should then be closed by well-focussed research and development activities e.g. in the Framework of Horizon 2020. Taking into account the long life cycle costs of the rail system's components, typically 20-30 years for trains, 30 years for ballast formation and 75 years for bridges, the standardization work has to be well supported broadly and started as soon as possible allowing the periodic replacement of the existing and fatigue components by new, improved and climate change resilient elements of the rail system. The major elements of the rail system to be considered are: ballast formation, catenary, earthworks, slab track, drainage systems, water ducts and bridges.

Conclusion

Climate change impacts are becoming a reality and affect our economy, our environment and our mobility patterns. This makes mitigation measures more and more needed. At the same time, while mitigation efforts are necessary, they will also have to cope with increasingly intense and severe weather events, which already affect us today. Therefore, it is fundamental to couple greenhouse- gas emissions reduction policies with climate change adaptation measures and protection against extreme weather events.

The rail sector is ready to play a key role in supporting the European institutions and key stakeholders in finding the right policies and priorities to enhance the resilience of rail to climate change. CER will continue to foster the exchange of best practices among its members and support decision-makers in finding the best solutions in terms of integrating climate change adaptation into EU policies, standards and funding opportunities.

In April 2013, CER is planning to organise, together with the European Commission, a second sectorial workshop on railways and climate change adaptation. This will be a great opportunity to take stock of the activities done by the sector in the past year and to discuss the EU strategy on climate change adaptation, which is expected for publication in March 2013.

III.3 SNCF Business Case Study (Alexandre Kaddouri, SNCF Climate & Energy Contact, Sustainability Department)

In March 2012, more than 40 per cent of French people thought climate change is the most preoccupant environmental risk. During this survey, among 10 persons, 7 said to be aware about the effects of the climate change as a threat on their activities (survey IFOP for WWF France).

For SNCF, this subject is been studding since 2009 with the "Grenelle Laws". To contribute to the development of the French national plan for climate change, SNCF decided to contribute to this file for three main raisons:

- Each year, SNCF invests in the railway system (rolling stock of which life expectancy is about 40 years and stations with an even longer life),
- SNCF wants to reduce train exploitation risks and to increase the resilience of the railway system,
- Climate change could mean behaviours modifications and also mobility opportunities.

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According to the method described by *de Perthuis and al*, in Economic Aspects in Adaptation for Climate Change (2010), SNCF tries to identify for its activities all impacts of the global warming, vulnerabilities and adaptation schedule. With this background, SNCF could propose adaptation alternatives vs. each impact. In this framework, we could also choose some alternatives with a global vision: short term actions with long time effects (standardisation, …), flexible actions for increasing the robustness of the railway system linked with the potentials climate scenarios (virtual mobility or alternative mobility solutions, crisis management linked with climate evolution, …) long term actions (Climate crisis governance, …) and no regrets actions. Then, each division of SNCF group has to decline its own plan and to coordinate them with global governance.

Warmer temperatures, longer heat waves in the summer, cooler winters and more frequent extreme climate events will inevitably have an impact on SNCF daily activities, travelling and working conditions, maintenance operations as well as transport regulation.

SNCF's climate change adaptation plan points out several characteristics from mitigation to reduce greenhouse gas emissions. This plan sets up accurate risk cartographies having a local effect on adaptation policies while it tackles more global aspects in the case of mitigation. If these scenarios concerning the future climate and its impacts on infrastructure or rolling stock provide a window into the climate of the future, it is the task of those involved with planning, design, construction, and operation of the railway system to understand how climate change will impact those subsystems. There are also new techniques to learn and to apply in order to deal with problems with deep uncertainty. If we do so, the marginal cost of adapting to climate change can be more easily accommodated.

Decisions for adaptation are twofold: (a) actions bound to the climate change timetable and the construction of new infrastructure construction, new stations and the manufacturing of new rolling stockand (b) actions for climate proofing by rehabilitation and protection of the existing risks of climatic impact.

SNCF's plan has established requirements for addressing climate change and adaptation that are currently being implemented at various levels of governance.

Table III.1 SNCF Adaptation Plan in shortcuts

TO KNOW	• Risk and Opportunities Cartography
TO CHOOSE	• Climate proofing of investments and design, inspection and maintenance standards review • Updating of prevention plan and crisis management • Development of alternative mobility solutions
TO DECIDE	• Climate governance with stakeholders and awareness of regional authorities representatives • Development of climate communications towards customers • To carry out climate crisis exercises

Finally, climatic average evolution could also lead to modifications of transport demand, infrastructures needs and journey conditions, because of changes in tourist destinations, population distribution and agricultural production.

III.4 Technical measures to mitigate the impact of climatic change on railway operations (John Dora CEng FICE FRMetS, John Dora Consulting Ltd)

Background

Railway systems provide for a safe and resilient mode of transport, and safety procedures have evolved over the 180 years of modern railway history. Safety procedures are designed in the main to keep trains apart and so permit more frequent, faster and heavier trains. The impact of extreme or unusual weather on railway safety is minimal – traffic is restricted and can even cease when adverse weather conditions that may pose a risk to safety are recognised. However the consequences of safety-related restrictions are a less reliable service.

With climate change, weather patterns are expected to change, and currently acceptable levels of safety and reliability of service will become unacceptable should the resilience of the railway, as a system, remain the same.

Climate change is not the only change

Railways are increasingly being relied upon and are experiencing increasing traffic levels, as a shift to this sustainable mode of transport gets underway. In time – over the next 10 to 50 years, say - if infrastructure and operating policies, technical standards and intervention thresholds remain as they are, then increasing traffic levels and changing weather patterns will create severe reliability problems for railway systems. It is no longer acceptable to continue to design, build, operate and maintain infrastructure systems using standards based upon historic weather patterns[29].

Improving resilience and reliability

The UIC ARISCC[30] project and the RSSB TRaCCA[31] project both point towards developing improved understanding of railway vulnerability to weather, with a model methodology proposed in ARISCC that caters for natural hazards in a systemic way (Fig 1). TRaCCA makes the point that metrics require development and that system-wide risks are considered with systemically resilient designs bringing opportunities for higher benefit, lower cost solutions. While neither project looked in detail at technical solutions, the ARISCC model provides a basis for solving resilience issues.

By systematically reviewing information on current and past weather events, establishing and relating thresholds to system resilience and mapping the results, vulnerability maps can be produced which can be used to evaluate risks and priorities. Locations of more significant vulnerability can then be prioritised for investment.

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29 Institution of Civil Engineers, Dec 2012. Adaptation or climate change risks, London. http://www.ice.org.uk/topics/transport/Case-Studies/Climate-Change-mitigation-and-adaptation-challeng

30 Nolte R et al, 2011, ARISCC Adaptation of Railway Infrastructure to Climate Change Final Report, Paris. http://www.ariscc.org

31 Dora, JM, 2011. T925 TRaCCA Tomorrow's Railway and Climate Change Adaptation Final Report, Rail Safety and Standards Board, London. http://www.rssb.co.uk/SiteCollectionDocuments/pdf/reports/Research/T925_rpt_phase3.pdf

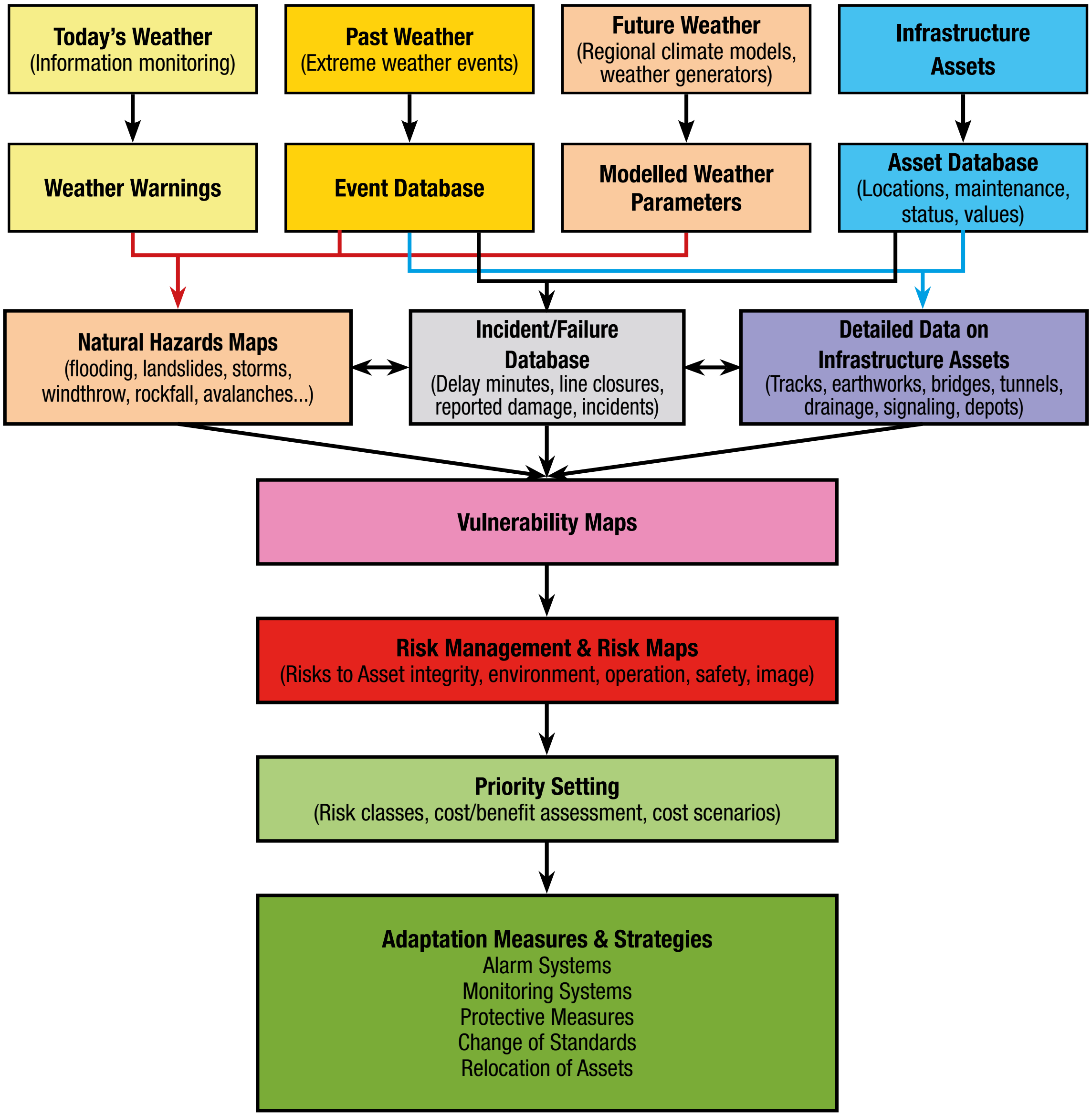

Fig. III.1 Elements, processes and information flows for an integrated natural hazard management

Table III.2 gives examples of significant hazards as experienced on the GB rail network, with potential solutions with both 'hard' engineered and 'soft' management systems shown. The solutions identified are in use, or are being proposed for use, on the GB rail network.

Table III.2 Examples of significant hazards as experienced on the GB rail network, with potential solutions

Hazard	System affected	Issue	Potential Solution
Sea level rise and increased storminess	f. Coastal railway	g. Damage to sea wall – breach, flooding and derailment risk	h. – Rebuild wall to appropriate standards – Introduce a sea-state forecasting system
i. Sea level rise and increased storminess	j. Coastal railway	k. Overtopping waves damaging/affecting vehicles	l. – Rebuild wall to appropriate standards – Introduce a sea-state forecasting system

Hazard	System affected	Issue	Potential Solution
m. Extreme, intense rainfall	n. Soil cuttings – landslip	o. Obstruction in cutting derailment risk	p. – Map water concentration locations – Understand earthwork structural condition – Understand drainage location, condition and criticality – Improve earthworks and/or drainage through investment – Target drainage management via strategic plans
q. Extreme, intense rainfall	r. Bridges – scour	s. Bridge foundations undermined leading to bridge collapse and derailment risk	t. – Understand bridge scour likelihood – Install scour protection – Introduce flood risk monitoring linked to flood agency forecasts – Monitor river levels
u. Extreme, intense rainfall	v. Signalling and Power line side systems	w. Track becomes flooded, critical line side equipment fails	x. – Map water concentration locations – Improve earthworks and/ or drainage through investment – Target drainage management via strategic plans
y. Extreme heat	z. Track	aa. Buckling causing derailment risk	bb. – Keep a register of track condition vs location – Impose speed restrictions at 'compromised' sites – Restrict ballast disturbance activity during hot weather – Paint rails white at critical locations
cc. Extreme heat	dd. Signalling and Power line side systems	ee. Reliability of software and components	ff. – Use active/passive cooling of equipment cabinets – Position cabinets in shade – Re-specify and replace equipment
gg. Extreme heat	hh. People	ii. Heat stress	jj. – Recognise length of exposure to heat and the impact on individuals, adjust rosters accordingly – Train staff as to hot weather health issues and mitigations – Recognise differences between indoor working and outdoor working – Recognise impact of hot weather on sleep patterns and fatigue
kk. – Extreme heat	ll. Vehicles' equipment	mm. – Reliability of software and components	nn. – Paint vehicle in light colour – Use active or passive cooling – Avoid positioning equipment in vehicle roof
oo. Rapid variation in heat	pp. Signalling and Power line side systems	qq. Reliability of software and components	rr. – Make use of high thermal inertia design – Position cabinets in shade – Re-specify and replace equipment
ss. Extreme heat	tt. Overhead line	uu. Sag in contact wire	vv. – Strengthen mast and wire system
ww. Increased wind speed	xx. Overhead line	yy. Sideways displacement of contact wire	zz. – Strengthen mast and wire system

Timing of adaptation investment

While the solutions identified in Table 1 may involve new investment, the phasing of investment is important. If investment is sequenced at new build or at the renewal stage of existing equipment, then the likely additional costs for adaptation can be incremental or zero. To adapt at equipment renewal stage is therefore a sensible option and has advantages particularly where equipment has a short life cycle. This concept has been catered for, for example, in Network Rail's technical specification for drainage systems renewals[32] where adaptation criteria are specified for drainage replacement whenever a major drainage design scheme is undertaken, whether for new work, renewal or refurbishment.

Conclusions

Railway systems provide for a safe and resilient mode of transport. With projected increases in railway traffic levels and future climatic changes, current policies, technical standards and intervention thresholds will need to change if severe reliability problems are to be avoided.

A better understanding of how current and past weather events have impacted railways is required, along with information on vulnerabilities, thresholds, location and risks.

Studies have shown that, while this understanding is still evolving, many technical solutions are available to railway engineers to improve railway system resilience and examples of 'hard' engineering and 'soft' management tools are given.

Investment in adaptation solutions, if timed to coincide with new works and 'routine' renewal activities, may require only incremental changes in budgets.

III.5 Impact of Climate Change on Riverine Waterway Transport (Bas Turpijn, Rijkswaterstaat/Directorate General for Public Works and Water Management, Ministry of Infrastructure and the Environment, The Netherlands)

In summer 2003, a low water depth record was reached at the Rhine River. Over several weeks, river discharges near Lobith had been below 1020 m3/s, the Agreed Low River Discharge (OLA). Many services faced restrictions, load capacity decreased and transport costs increased. This situation is projected to occur more frequently in the future under the projected climate, which can cave significant impacts on the operations of inland waterway transportation as well as the competitiveness of the sector. Rijkswaterstaat has undertaken several studies on this topic and has participated in the UNECE meetings on the impacts of climate change on the international transportation networks. This paper presents a short summary of this work.

In 2006, the Dutch Royal Meteorological Institute (KNMI) developed climate scenarios. Several key climate change characteristics in the Netherlands and surrounding areas are recognized in all these scenarios: rising temperatures; mild winters and hot summers will become more common; winters will on average become wetter; and extreme precipitation intensity will increase. KNMI developed a moderate scenario (G) and a warm scenario (W).

[32] Dora JM, 2010. Railway Drainage Systems Manual, internal Network Rail standard, London.

In addition, as changes in air circulation patterns are also expected, KNMI also developed scenarios under which there are changes in wind directions combined with moderate (Gp) or higher increases in temperature (Wp). All these scenarios are plausible and/or likely, with all having similar likelihoods.

Impacts on river hydrology

Changes in temperature and air circulation patterns will also influence river hydrology. In Figure III.2 the effects on the River Rhine discharges under different scenarios are shown for the near the year 2050. The projected lower discharges are likely to lead to lower water levels. Projections using the hydrological model SOBEK indicate a very significant drop in the water levels for the main rivers in the Netherlands. Under the G, W and Gp climate scenarios, impacts on the water levels appear to be low, whereas under Wp more severe. In this case, hydrological conditions similar to those of 2003 will occur annually. In summertime, water levels might sink to the so called Agreed Low Water Level (OLR) under which navigation is discouraged.

Impacts on inland waterway transport

The river Rhine is a main transportation axis in the Netherlands, with more than 100 million tonnes of freight being transported annually. If the low water levels recorded in 2003 occur frequently, this will have an impact on navigation: load capacity will decrease and large ships will be impeded to navigate. Transportation costs are expected to increase and, in a consequence, the competitive position of inland navigation will be jeopardized; this may also impacts on the competitive position of the Dutch seaports, especially Rotterdam. It must be noted that the market share of inland navigation is relatively high (about 20 per cent) in the modal split for hinterland transportation; higher transportation costs via inland waterways may cause a shift to seaports with lower dependency on inland navigation.

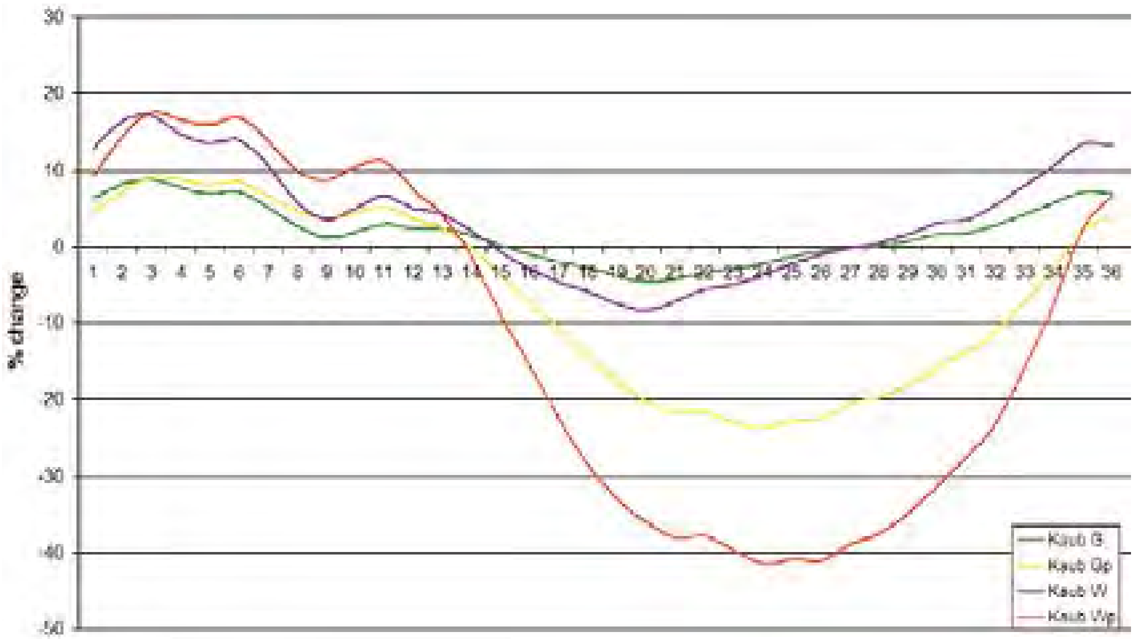

Fig. III.2 **Changes in River Rhine discharges near 2050 (source: Deltares, 2007). Key: G, moderate increase in temperature; Gp moderate increase in temperature and altered wind circulation; W higher temperature increase; and Wp, higher temperature increase and altered wind circulation**

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Within the research project “Knowledge for Climate”, the impacts of the Wp climate scenario on the transportation costs/modal shifts for the year 2050 have been investigated. Results based on literature reviews, stakeholder interviews and modelling indicate that transportation costs could increase up to 9 per cent in periods with low water levels with some transportation being postponed; this can lead to a modal shift 5 – 8 per cent in the years following 2050 for the Wp scenario. In all the other scenarios, impacts on inland navigation are predicted to low.

In the Netherlands, studies have also been undertaken regarding long-term climate change impacts (i.e. impacts for the period 2050-2100), the so called ‘Deltaprogram’. These studies provide the basis for a new national water plan (policy and measures) to prepare the Netherlands for long-term climate change.

Besides discharges, water levels are also influenced by bed elevation. The river bed level is not uniform along the river, due to geological (e.g. subsidence) and morphological processes and water engineering works (see e.g. Figure II.3). Over time, the river bed is also subjected to degradation, a phenomenon that is expected to continue in the future with significant impacts water depthsor levels. River experts of Rijkswaterstaat have suggested that water depths might decrease up to 0.6 m around the year 2030. This is equivalent to projections for the summer periods after 2050 (Wp climate scenario). Therefore, the on-going bed level degradation will, on the short term, have a higher impact than climate change.

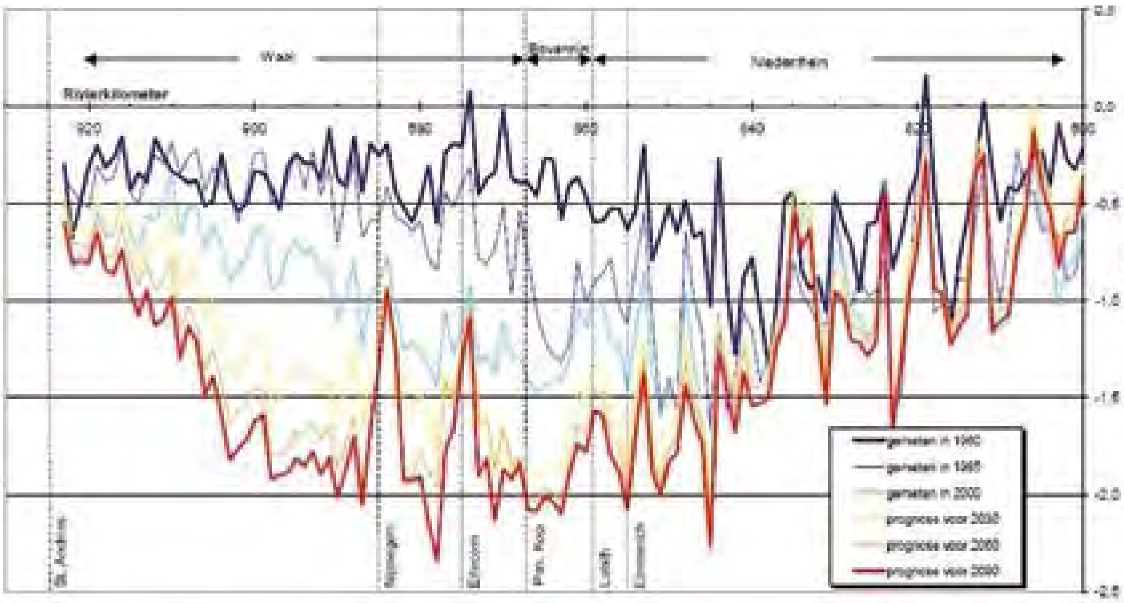

Fig. III.3 Cross section of the River Waal (source: Rijkswaterstaat, 2007).

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Conclusions

(a) Until 2050, the impact of climate change on inland navigation is expected to be low.

(b) After 2050, in the case of the Wp climate scenario (higher temperature increase) the impacts will be severe. Water levels are projected to be as low as those of 2003 every summer. This may lead to decreases in load capacity and increases in transportation costs. In consequence, the competitive position of inland waterway transportation, and also of the Dutch seaports, may be affected.

(c) In the case of the remainder of the climate scenarios studied, impacts are projected to be low up to 2100.

(d) The impact of on-going bed level degradation is more severe in the short term. Until 2030, water depths may decrease by about 0.6 m.

(e) Dealing with the impacts of bed level degradation is more urgent for inland navigation than with those of climate change, which are likely to be severe after 2050 in the case of the worst case scenario Wp.

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Annex IV: Questionnaire

CLIMATE CHANGE IMPACTS AND ADAPTATION FOR INTERNATIONAL TRANSPORT NETWORKS

Questionnaire

2012

UNECE Transport Division Experts Group

Date

Name | Position

Address | Organization

City | State | Zip Code | Phone Number

Country | Email

SUBJECT I. Level of awareness, availability of information and data on climate change impacts on transport

QUESTION 1. ***On a scale of 1-10 (1= not at all, 10= very much) to which extent do you consider climate change to be a problem for transport in your country/region?***

Not at all ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 Very Much

QUESTION 2. ***Please specify over which time-scale you consider climate change to be a problem.***

Please select

QUESTION 3. ***On a scale of 1-10 (1= no knowledge at all, 10= very good knowledge on all topics) how would you rate knowledge and level of awareness about the impacts of climate change on transport in your country region***

No knowledge at all ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 Very good knowledge on all topics

QUESTION 4. ***In your view, who should be the main target audience when raising awareness about climate change impacts on transport (e.g. ministries, industry managers, operators, investors, etc.)***

Please explain

QUESTION 5. ***As applicable, please indicate whether transport in your country has been impacted by any weather or climate factors (rising temperatures, extreme events, droughts, floods, sea level rise and storm surges, melting permafrost etc.).***

Not at all ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 Very Much

Please add more details and indicate intensity and frequency	

QUESTION 6. ***As applicable, please indicate whether the impacts relate to specific mode(s) of transport, or a network linking various transport modes and Logistics Centres?***

Please explain	

QUESTION 7. ***Has your country / organization undertaken any specific assessment of the vulnerabilities of transport (segments, modes, networks, operations, infrastructure, etc.) to various weather and/or climate change factors (rising temperatures, extreme events, droughts, floods, sea level rise and storm surges, melting permafrost etc.))?***

YES ☐ NO ☐

Please explain	

QUESTION 8. ***Has your country / organization conducted studies evaluating a) the implications of climate impacts on transport or b) estimated the costs of actual or potential damages to transport, in particular infrastructure?***

a. YES ☐ NO ☐ b. YES ☐ NO ☐

a. As applicable, please indicate which specific weather or climate change impacts on transport infrastructure have been/are being studied?

1.	Impacts of rising temperatures	Yes	☐	No	☐
2.	Impacts of floods	Yes	☐	No	☐
3.	Impacts of droughts	Yes	☐	No	☐
4.	Impacts of storms/extreme winds	Yes	☐	No	☐
5.	Impacts of heat waves	Yes	☐	No	☐
6.	Impact of sea level rise and storm surges	Yes	☐	No	☐
7.	Impact of melting permafrost	Yes	☐	No	☐
8.	Other impact (*please explain*)				

b. As applicable, please indicate which specific weather or climate change impacts on transport <u>operations/services</u> have been/are being studied?

1.	Impacts of rising temperatures	Yes	☐	No	☐
2.	Impacts of floods	Yes	☐	No	☐
3.	Impacts of droughts	Yes	☐	No	☐
4.	Impacts of storms/extreme winds	Yes	☐	No	☐
5.	Impacts of heat waves	Yes	☐	No	☐
6.	Impact of sea level rise and storm surges	Yes	☐	No	☐
7.	Impact of melting permafrost	Yes	☐	No	☐
8.	Other impact (*please explain*)				

<u>QUESTION 9</u>. *If there has been little or no study of climate change impacts on transport in your country, please indicate which, in your view, are the main reasons:*

1.	Lack of financing	☐
2.	Lack of interest from the responsible institutions	☐
3.	Lack of awareness among the general public	☐
4.	Lack of scientific expertise and human resources	☐
5.	Though interest in the topic existed, more pressing needs have taken precedence	☐
6.	Other impact (*please explain*)	

<u>QUESTION 10</u>. *On a scale of 1 - 10 (1 = least important, 10 = most important) to what extent do you consider is involvement of the following actors/entities important for the study/research/dissemination of information on climate change impacts on transport?*

	1	2	3	4	5	6	7	8	9	10
Ministry of the Environment	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Ministry of Transport	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
International organizations	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Universities	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Private companies	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Technical/ Engineering Institutions	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
NGOs	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Other (please specify)										
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

<u>QUESTION 11</u>. *In your view, what, if any, are the opportunities that may arise for transport in your country / organization in connection with climate change? (Examples could be e.g. increased tourism; growth in agricultural production…)*

Please explain

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SUBJECT II. Level of preparedness and existing and planned transport adaptation policies, measures and initiatives.

QUESTION 12. ***Has your country / organization adopted or is planning to adopt a general adaptation strategy to climate change impacts (not sector specific)?***

1.	Not at all	☐
2.	Planned	☐
3.	Already adopted	☐
4.	Adopted and implemented	☐
5.	Not applicable/Do not know	☐

Please explain

QUESTION 13. ***Has a cost-benefit analysis been conducted with regard to any climate change adaptation plans/strategy in your country / organization ?***

1.	Not at all	☐
2.	Planned	☐
3.	Already conducted	☐
4.	Not applicable/Do not know	☐

Please explain

QUESTION 14. ***Has your country / organization adopted or is planning to adopt a transport specific strategy for adapting to climate impacts?***

1.	Not at all	☐
2.	Planned	☐
3.	Already adopted	☐
4.	Adopted and implemented	☐
5.	Not applicable/Do not know	☐

Please explain

<u>QUESTION 15</u>. *On a scale of 1 to 4 (1 = not effective at all and 4 = very effective), please indicate how you would rate the results/effectiveness of any transport specific adaptation strategy adopted?*

Strategy (*please indicate*)	1	2	3	4	Please Explain
	☐	☐	☐	☐	
	☐	☐	☐	☐	
	☐	☐	☐	☐	
	☐	☐	☐	☐	
	☐	☐	☐	☐	

<u>QUESTION 16.</u> *How is (or will) the effectiveness of adaptation measures taken currently or in future be monitored/ evaluated?*

Please explain

<u>QUESTION 17</u>. *What concrete actions, if any, have been, or are planned to be, taken with a view to building resilience of transport networks to climate change impacts in your country / organization [in your field of competence]?*

Please explain

<u>QUESTION 18</u>. *Please explain and clarify the extent to which these actions relate to transport planning, investment, design, construction, operation, management and maintenance?*

	1 *(Not at all related)*	2 *(To some extent)*	3 *(To a great extent)*	4 *(Not applicable / do not Know)*
Planning	☐	☐	☐	☐
Investment	☐	☐	☐	☐
Design	☐	☐	☐	☐
Construction	☐	☐	☐	☐
Operation	☐	☐	☐	☐
Management	☐	☐	☐	☐
Maintenance	☐	☐	☐	☐
All of the above	☐	☐	☐	☐
None of the above	☐	☐	☐	☐

Other, please explain

QUESTION 19. ***If new transport infrastructure developments are being undertaken/planned, do relevant plans take into account climate change effects (e.g. extreme events, increased rainfall, rising sea levels, etc)?***

1.	Not at all	☐
2.	To some extend	☐
3.	To a great extend	☐
4.	Not applicable/Do not know	☐

Please explain

QUESTION 20. ***Based on the experience of your country [organization/company] what are, in your view, some of the main best practices and lessons that could be drawn with respect to adaptation action in transport?***

Please explain

QUESTION 21. ***Has your country [organization/company] developed or is planning to develop emergency response systems for a) all business sectors, b) the transport sector or c) transport sub-sectors?***

a.

1.	Not at all	☐
2.	Planned	☐
3.	Already adopted	☐
4.	Adopted and implemented	☐
5.	Not applicable/Do not know	☐

b.

1.	Not at all	☐
2.	Planned	☐
3.	Already adopted	☐
4.	Adopted and implemented	☐
5.	Not applicable/Do not know	☐

c.

1.	Not at all	☐
2.	Planned	☐
3.	Already adopted	☐
4.	Adopted and implemented	☐
5.	Not applicable/Do not know	☐

Please explain

QUESTION 22. ***Has the insurance industry in your country integrated climate change considerations into products offered to the transport sector/industry?***

1.	Not at all	☐
2.	To some extend	☐
3.	To a great extend	☐
4.	Not applicable/Do not know	☐

Please explain

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SUBJECT III. Information data and research needs and other requirements, including financing.

QUESTION 23. ***What are, in your view, the type of information, data or predictions that would be most valuable for achieving effective preparedness to climate change impacts and designing adequate adaptation responses in transport? (Multiple answers possible)***

Temperature-related	☐
Precipitation-related (e.g. rain, snow, fog, humidity, floods, etc.)	☐
Inland strong wind and storms	☐
Coastal storms/surges and sea level rise	☐
Other	☐

Please explain

QUESTION 24. ***What are the main data/information sources that are currently used for the purposes of studying climate change impacts/developing adaptation measures in transport?***

Please explain

QUESTION 25. ***How do you rate the availability of relevant data/information in your country on a scale of 1 - 5 where 1 is poor and 5 is excellent:***

1.	Poor	☐
2.	Bad	☐
3.	Good	☐
4.	Very Good	☐
5.	Excellent	☐
6.	Not applicable/Do not know	☐

QUESTION 26. ***How do you rate the suitability/ relevance/quality of relevant data/ information in your country? (on a scale of 1 - 5, where 1 is Poor and 5 is excellent):***

1.	Poor	☐
2.	Bad	☐
3.	Good	☐
4.	Very Good	☐
5.	Excellent	☐
6.	Not applicable/Do not know	☐

QUESTION 27. ***To your knowledge, are there any operational models/software tools that are used for the prediction of weather-related risks to transport infrastructure (e.g. forecasting storm surge impacts on ports or flood plain inundation)?***

YES ☐ NO ☐ I do not know ☐

QUESTION 28. ***If yes, please list the models/software tools, indicating for each the level of aggregation*** (*Tier 1, 2 or 3 according to the Intergovernmental Panel on Climate Change - IPCC tier 1, simplest method, activity data available to all countries; tier 2, technology-specific emission factor; tier 3, more detailed or country-specific methods. For more information see also unfccc.int/files/meetings/unfccc.../ipcc_good_practice_guidance.ppt*)

Please explain

QUESTION 29. ***Please identify any existing or potential funding mechanisms that could support further adaptation action in transport (including study of impacts)***?

Please explain

QUESTION 30. ***Overall, please indicate the specific priority areas that require further attention to enable effective adaptation strategies in transport and that are tailored for your local conditions?***

Please explain

SUBJECT IV. Collaboration mechanisms at national / local, regional and international levels.

QUESTION 31. ***Which existing or potential mechanism(s) for cooperation do you consider most useful in addressing the issue of climate change adaptation for transport?***
Please also state briefly your reasons, the type of cooperation/partners involved and the mode or type of transport infrastructure/service/operational aspect you are referring to?

Please explain

QUESTION 32. ***Do you consider the current level of cooperation at the national or local level adequate/ sufficient?***

1.	Not at all	☐
2.	Somewhat	☐
3.	Adequate / Sufficient	☐
4.	Very Good	☐

As appropriate, please indicate any specific suggestions for improvements/enhanced cooperation:

Please explain

QUESTION 33. ***Are regional or sub-regional cooperation and information exchange on climate change part of existing practice and policy in your country? If so, how much of this cooperation addresses transport in particular and in what ways?***

YES ☐ NO ☐

Please explain

QUESTION 34. ***Do you consider the relevant current level of cooperation at the regional/sub-regional level adequate/sufficient?***

1.	Not at all	☐
2.	Somewhat	☐
3.	Adequate / Sufficient	☐
4.	Very Good	☐

As appropriate, please indicate any specific suggestions for improvements/enhanced cooperation

Please explain

QUESTION 35. ***Do you think that possibility of amendments to existing UNECE infrastructure agreements*** *(*European Agreement on Main International Traffic Arteries (*AGR),* European Agreement on Main International Railway Lines (*AGC),* European Agreement on Main Inland Waterways of International Importance (*AGN),* European Agreement on Important International Combined Transport Lines and Related Installations *(AGTC))* ***merits serious consideration with a view to promoting/facilitating climate change adaptation of transport networks?***

Please explain

QUESTION 36. ***Do you consider the current level of cooperation at the international level adequate/ sufficient?***

1.	Not at all	☐
2.	Somewhat	☐
3.	Adequate / Sufficient	☐
4.	Very Good	☐

As appropriate, please indicate any specific suggestions for improvements/enhanced cooperation

Please explain

QUESTION 37. ***In your view, which type of further international cooperation would be of value in addressing climate change impacts and adaptations requirements?***

Please explain

Specific Questions for ROAD / RAIL transport / infrastructure

QUESTION 38. ***Does your public administration/company/organization understands current vulnerabilities of road / rail infrastructure in relation to natural hazards (****for example bridges that might be vulnerable to flood damage**) ?***

Please explain

QUESTION 39. ***If so, have these been related to risks priorities : like hood of occurrence v consequences of event? (****eg. what is the likelihood of a stretch of road / railroad to be damaged by a flood in terms of probability , and what the consequences would be?****).***

Please explain

QUESTION 40. ***Has a mechanism been set up to assess current levels of Risk?***

Please explain

Specific Questions for INLAND WATER TRANSPORT / infrastructure

QUESTION 41. ***What effects do you think will climate change have on the inland waterway infrastructure?***

Please explain

QUESTION 42. ***How significant will these effects be in comparison to already existing weather events (seasonal low-and high water periods)?***

Please explain

QUESTION 43. ***In your opinion, how far will climate change influence the transport flows on inland waterways and lead to a shift to other modes?***

Please explain

QUESTION 44. ***Which measures have you planned/adopted to make the IWT infrastructure / the sector resilient to the effects of climate change?***

Please explain

QUESTION 45. ***Please provide any additional comments/suggestions***

Send us your reply easily and quickly!

press the "print form" button, print your answers and send them by fax to +41 22 917 00 39 (secretariat's fax).

or press the "submit by email" button and your answers are sent automatically to the email of the secretariat. (it creates automatically an .xml file attached to a new email ready to be sent at the following email address: konstantinos.alexopoulos@unece.org)

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Transport Facilitation and Economics Section
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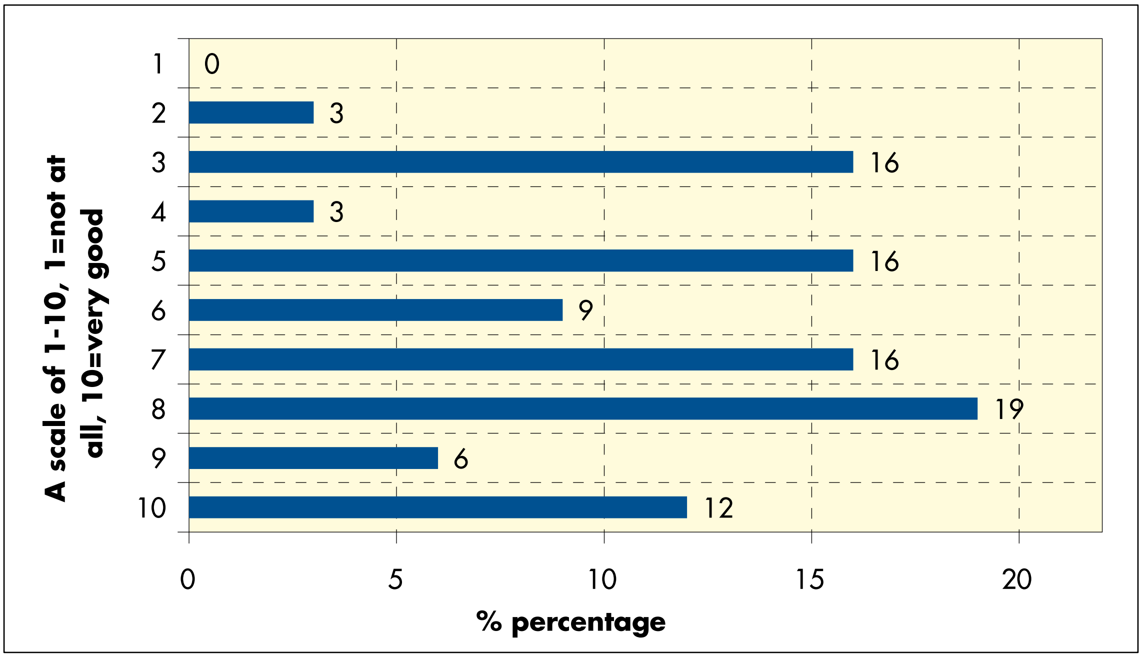
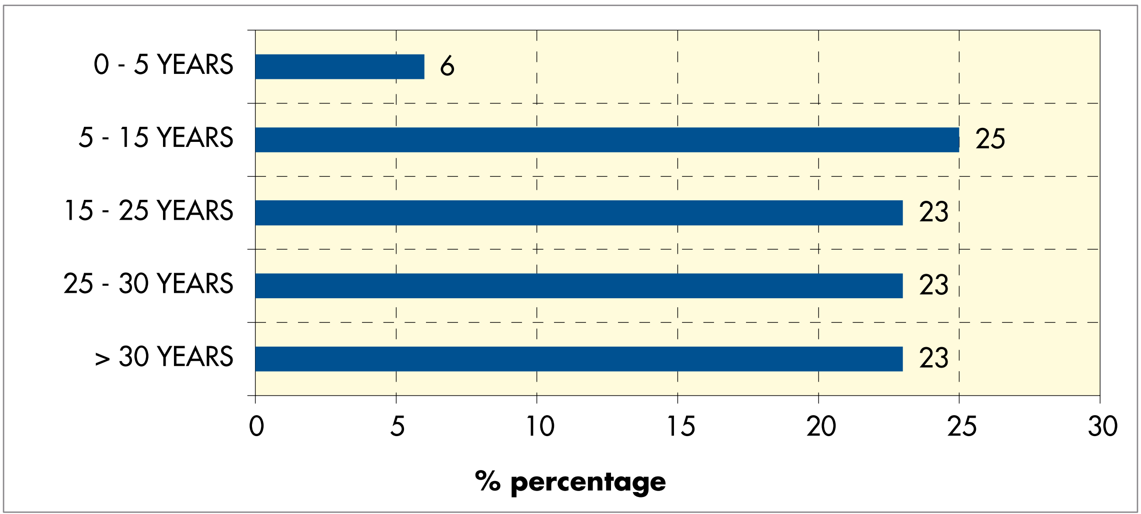
Annex V: Results of the Questionnaire Survey

QUESTION 1 On a scale of 1-10 (1= not at all, 10= very much) to which extent do you consider climate change to be a problem for transport in your country/ region?



QUESTION 2 Please specify over which time-scale you consider climate change to be a problem.



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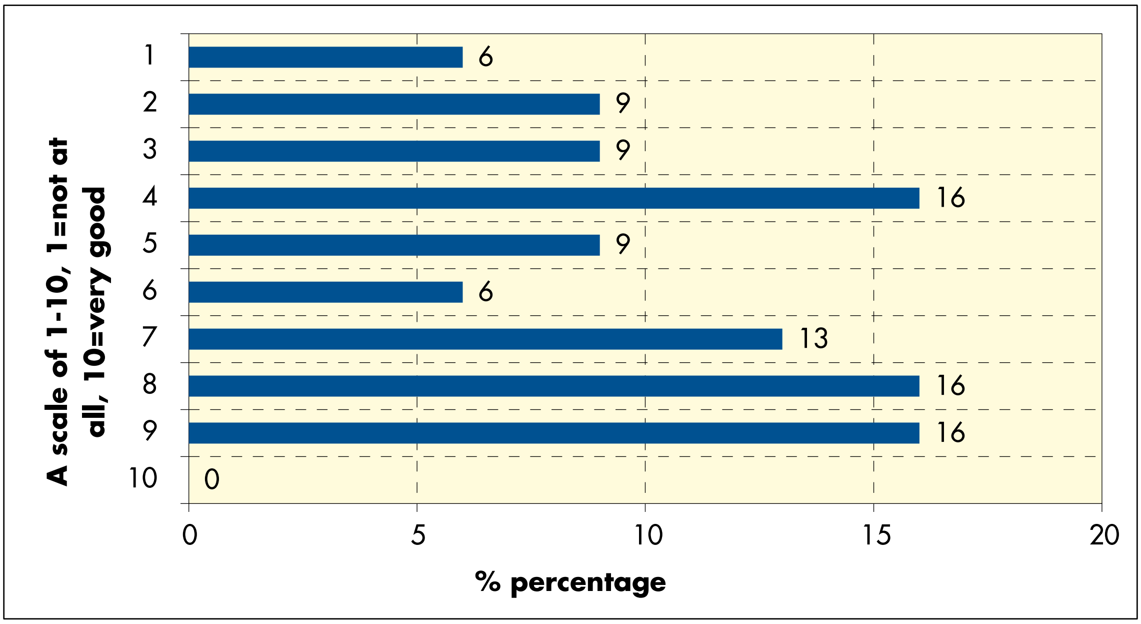
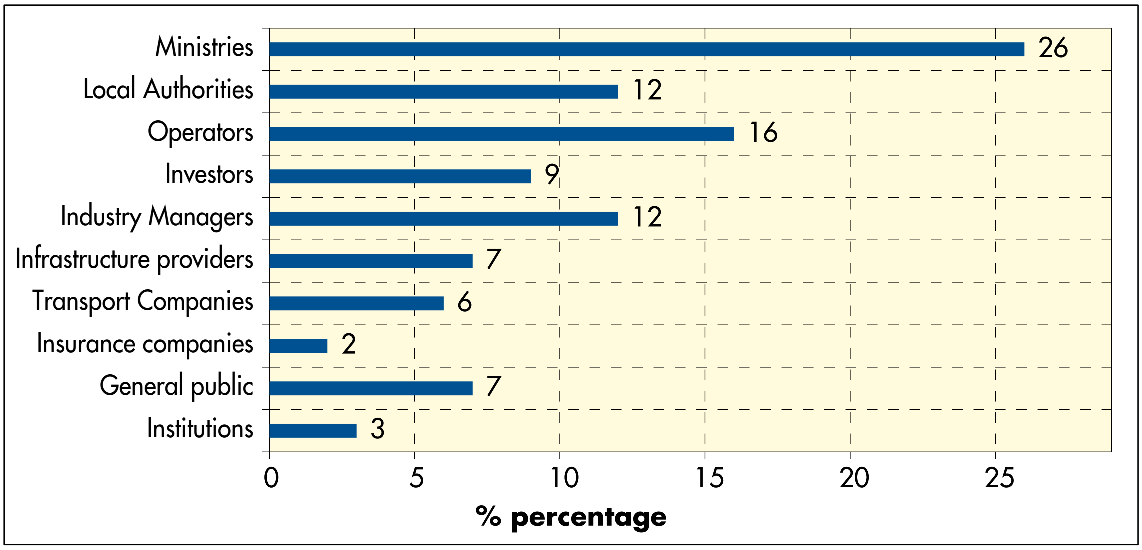
QUESTION 3 On a scale of 1-10 (1= no knowledge at all, 10= very good knowledge on all topics) how would you rate knowledge and level of awareness about the impacts of climate change on transport in your country region



QUESTION 4 In your view, who should be the main target audience when raising awareness about climate change impacts on transport (e.g. ministries, industry managers, operators, investors, etc.)



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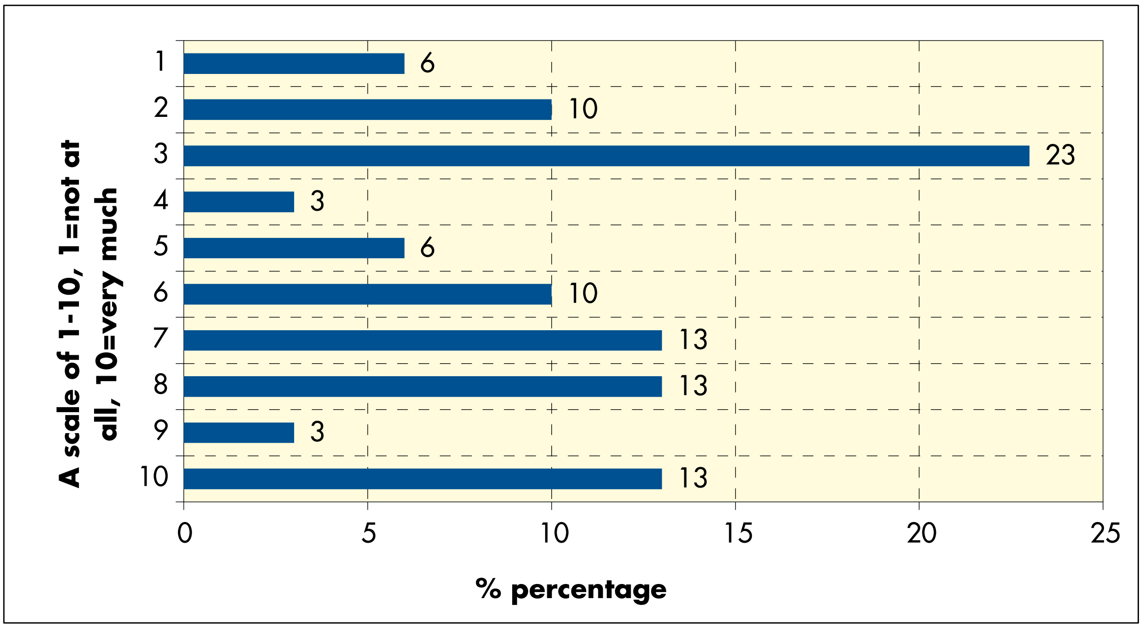
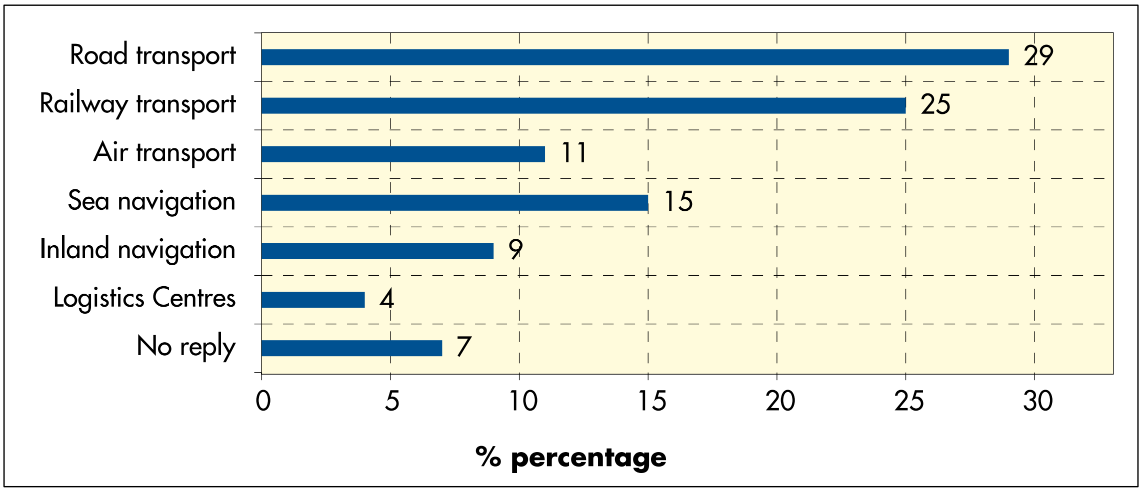
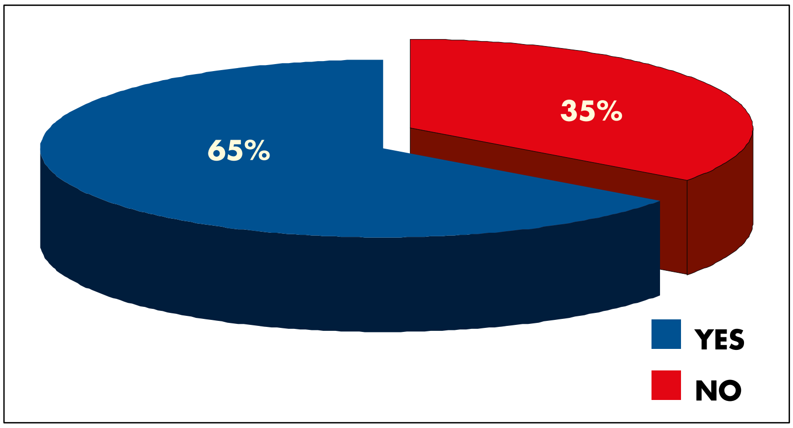
QUESTION 5 As applicable, please indicate whether transport in your country has been impacted by any weather or climate factors (rising temperatures, extreme events, droughts, floods, sea level rise and storm surges, melting permafrost etc.).



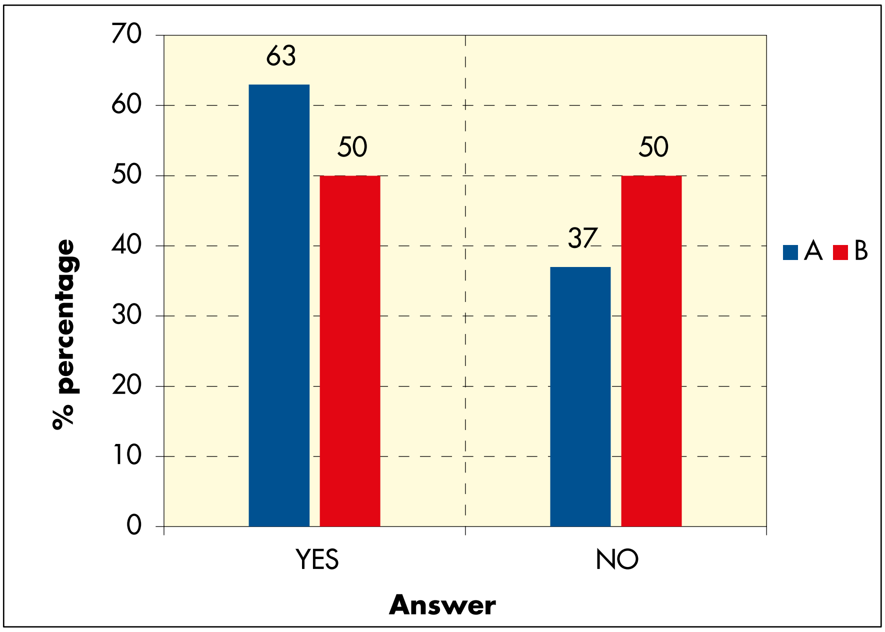
QUESTION 6 As applicable, please indicate whether the impacts relate to specific mode(s) of transport, or a network linking various transport modes and Logistics Centres?



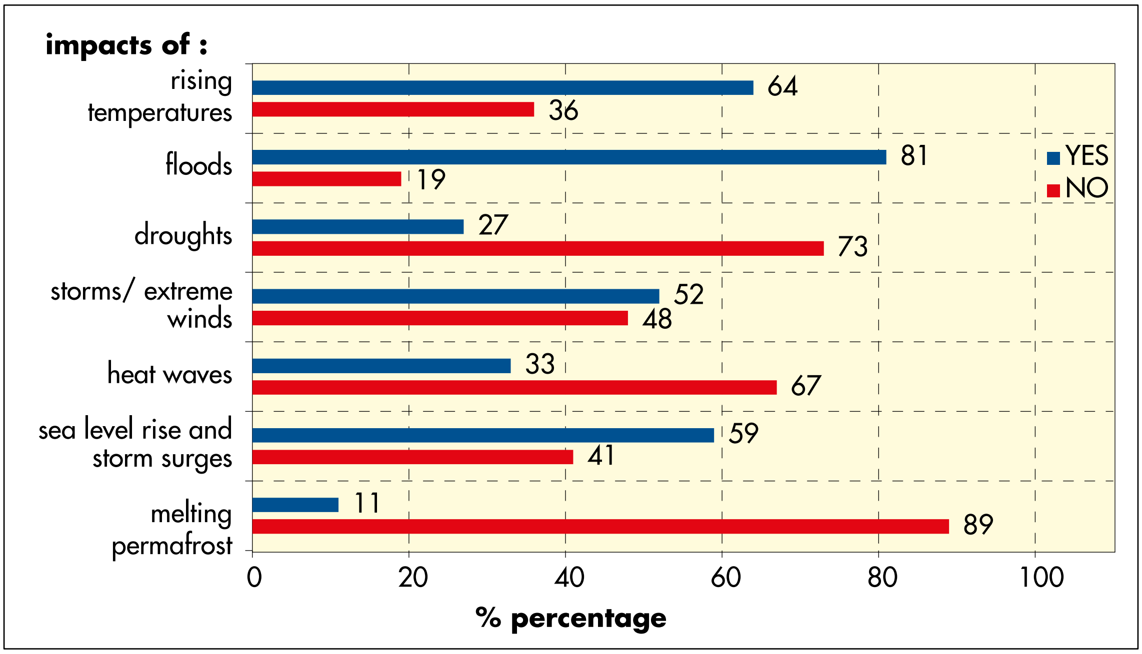
QUESTION 7 Has your country / organization undertaken any specific assessment of the vulnerabilities of transport (segments, modes, networks, operations, infrastructure, etc.) to various weather and/or climate change factors (rising temperatures, extreme events, droughts, floods, sea level rise and storm surges, melting permafrost etc.)?



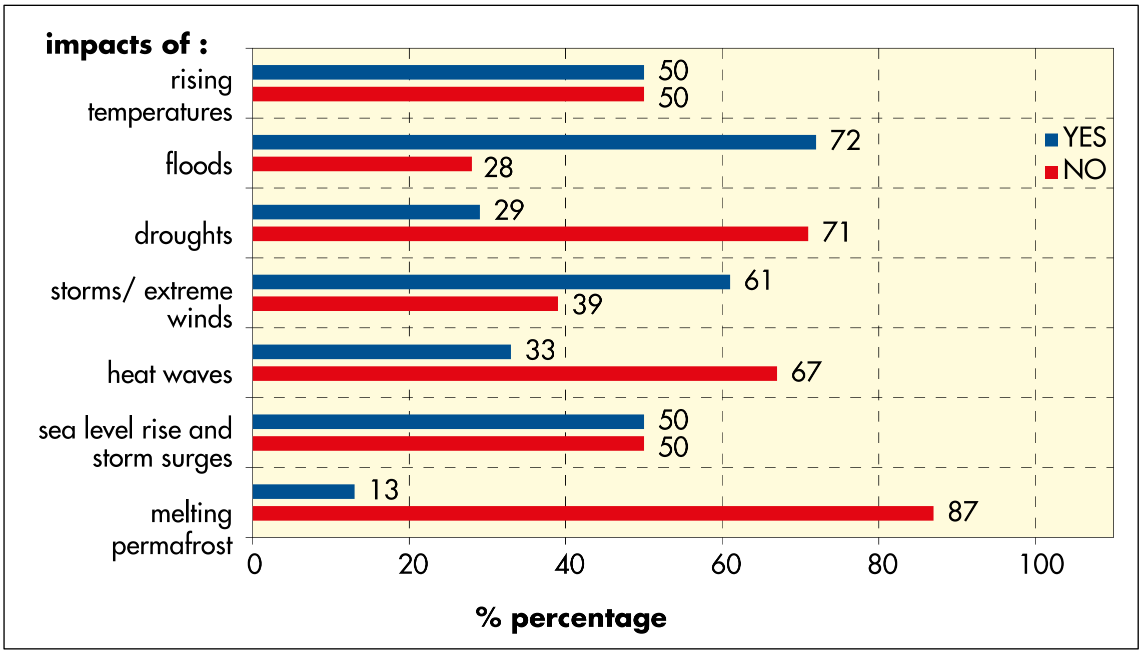
QUESTION 8 Has your country / organization conducted studies evaluating a) the implications of climate impacts on transport or b) estimated the costs of actual or potential damages to transport, in particular infrastructure?



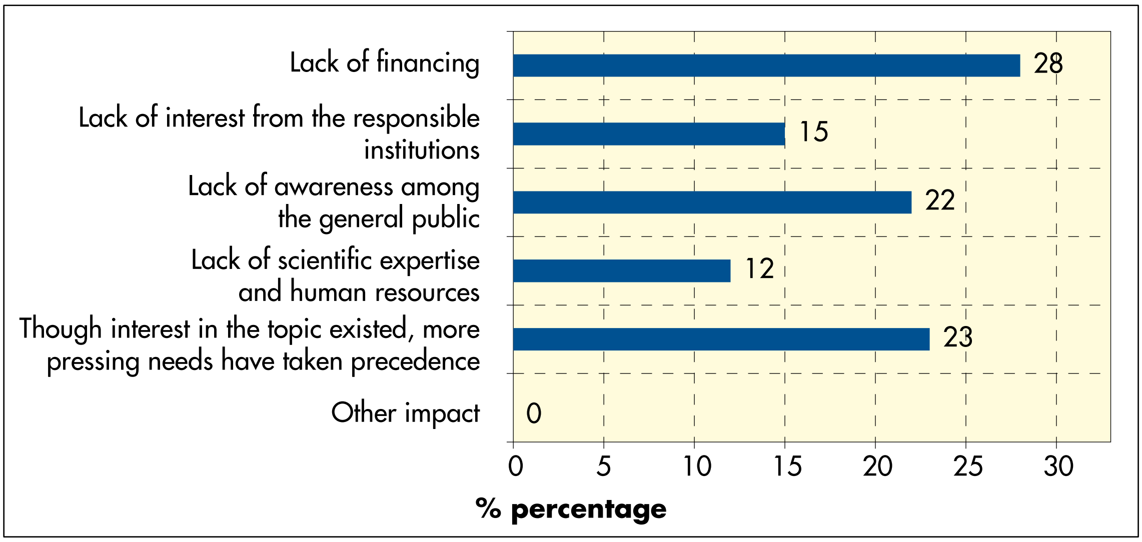
a. As applicable, please indicate which specific weather or climate change impacts on transport infrastructure have been/are being studied?



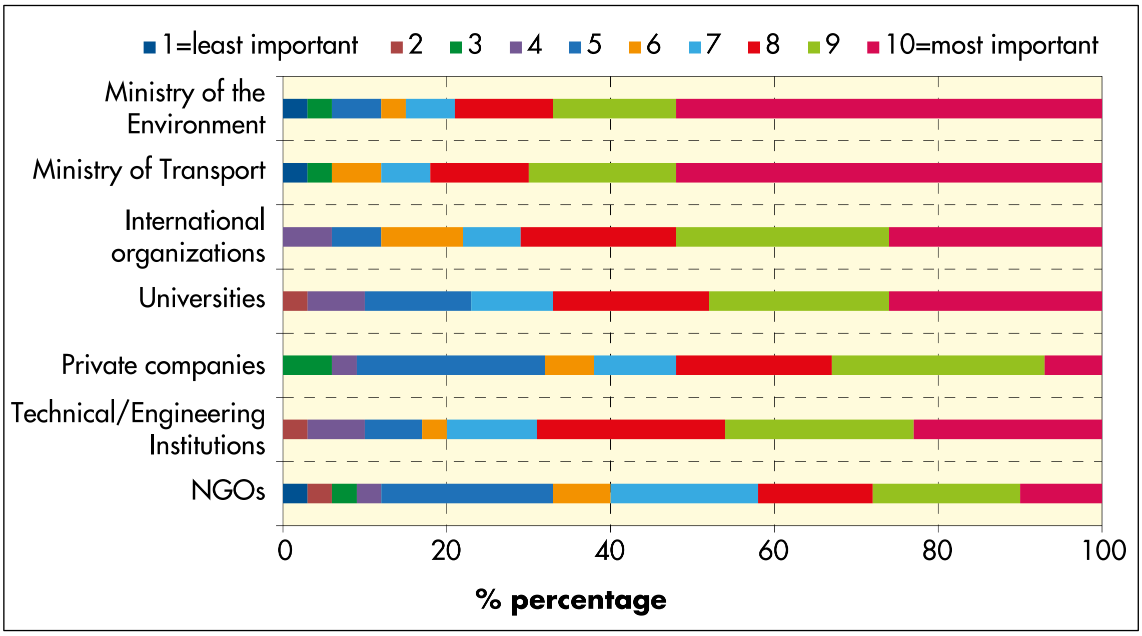
b. As applicable, please indicate which specific weather or climate change impacts on transport operations/services have been/are being studied?



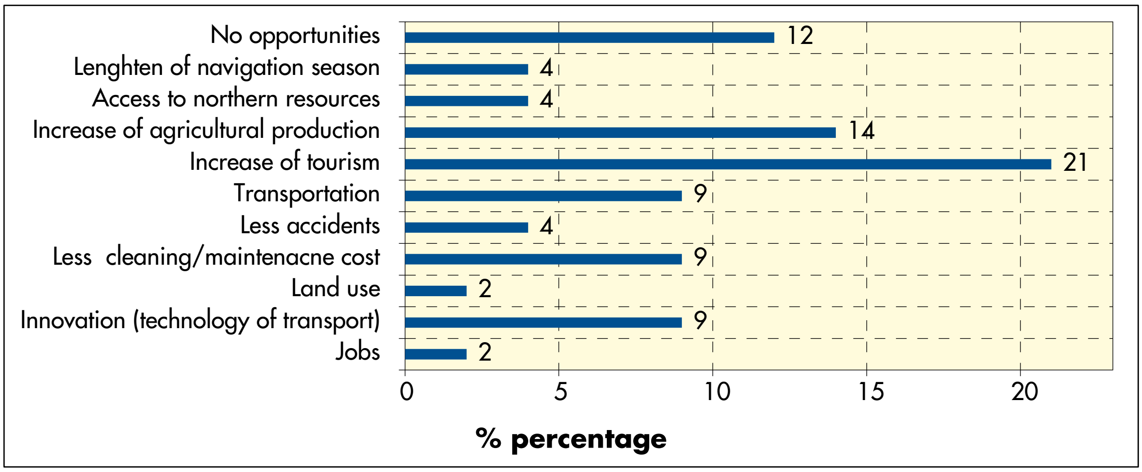
QUESTION 9 If there has been little or no study of climate change impacts on transport in your country, please indicate which, in your view, are the main reasons?



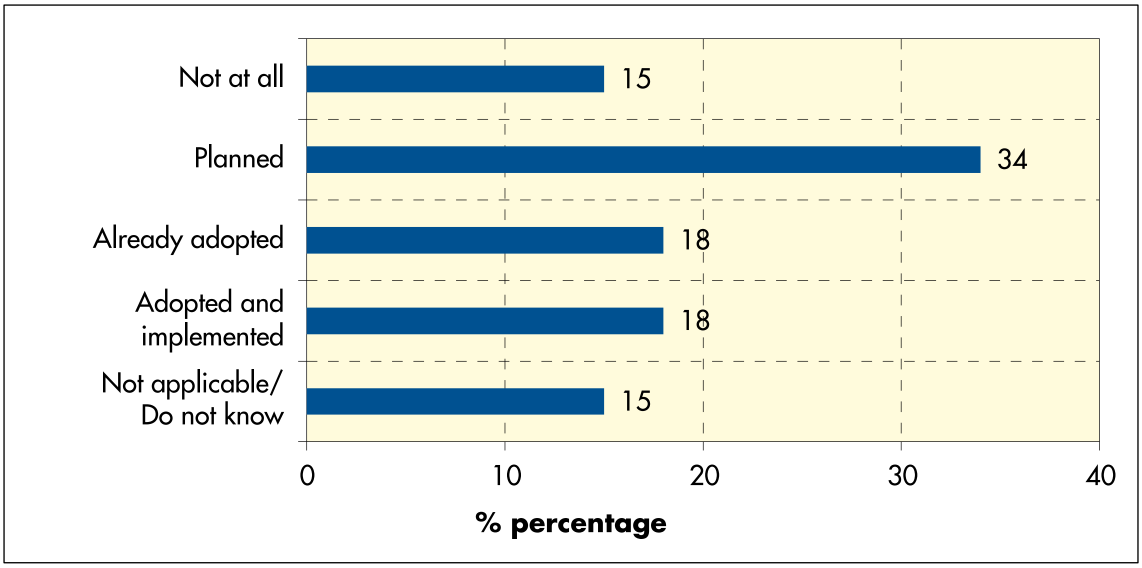
QUESTION 10 On a scale of 1 - 10 (1 = least important, 10 = most important) to what extent do you consider is involvement of the following actors/entities important for the study/research/dissemination of information on climate change impacts on transport?



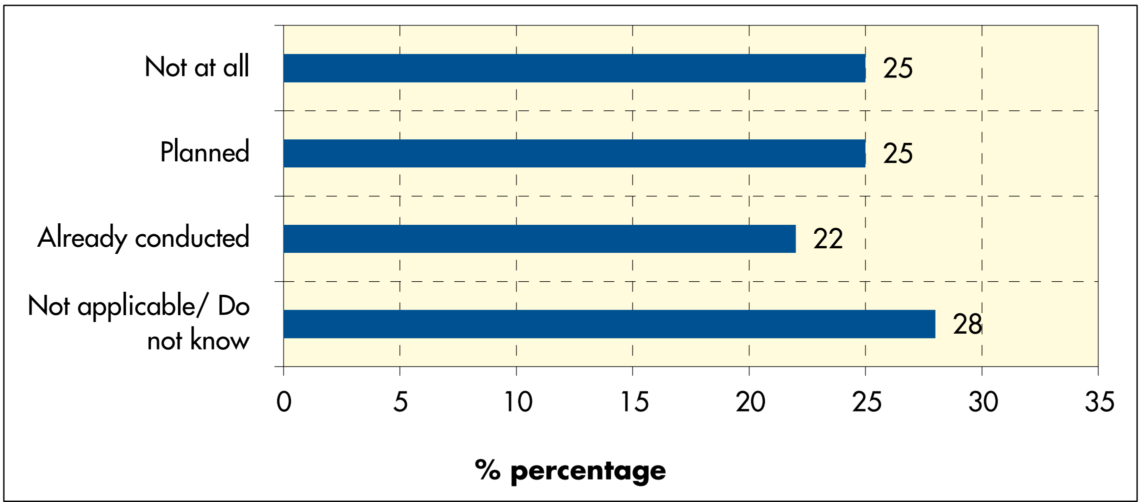
QUESTION 11 In your view, what, if any, are the opportunities that may arise for transport in your country / organization in connection with climate change? (Examples could be e.g. increased tourism; growth in agricultural production)



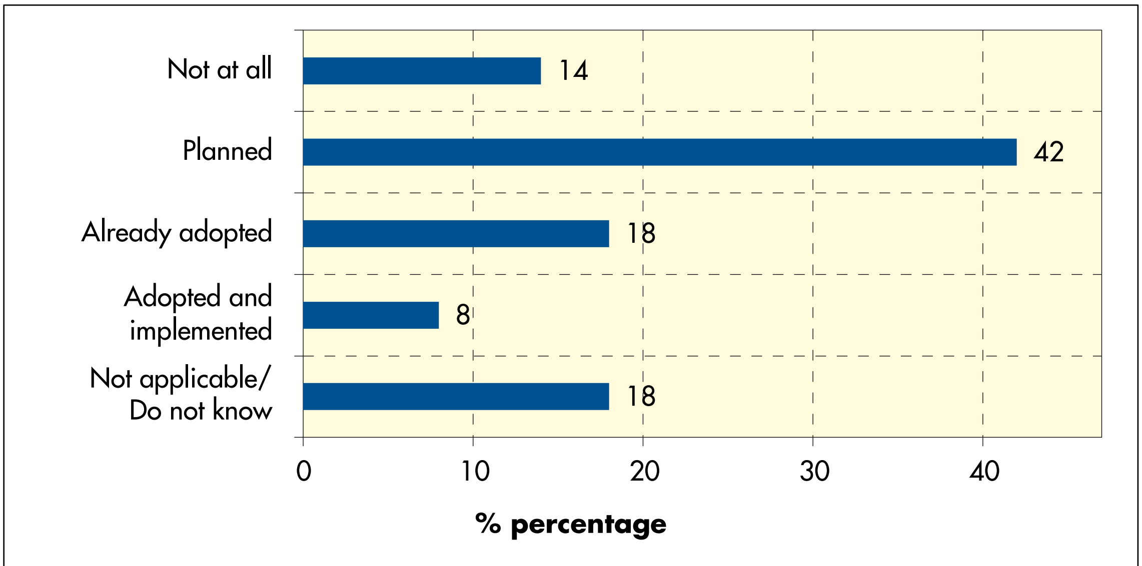
QUESTION 12 Has your country / organization adopted or is planning to adopt a general adaptation strategy to climate change impacts (not sector specific)?



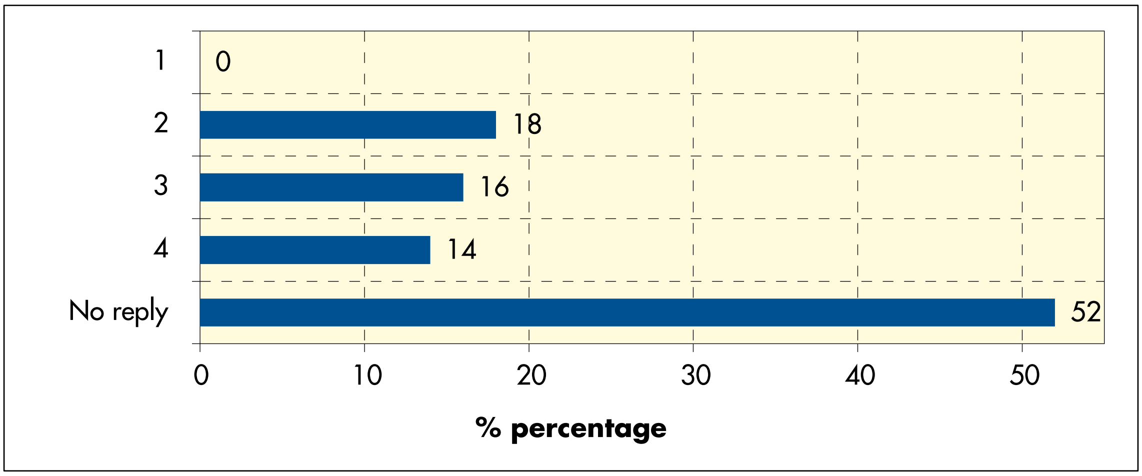
QUESTION 13 Has a cost-benefit analysis been conducted with regard to any climate change adaptation plans/strategy in your country/organization?



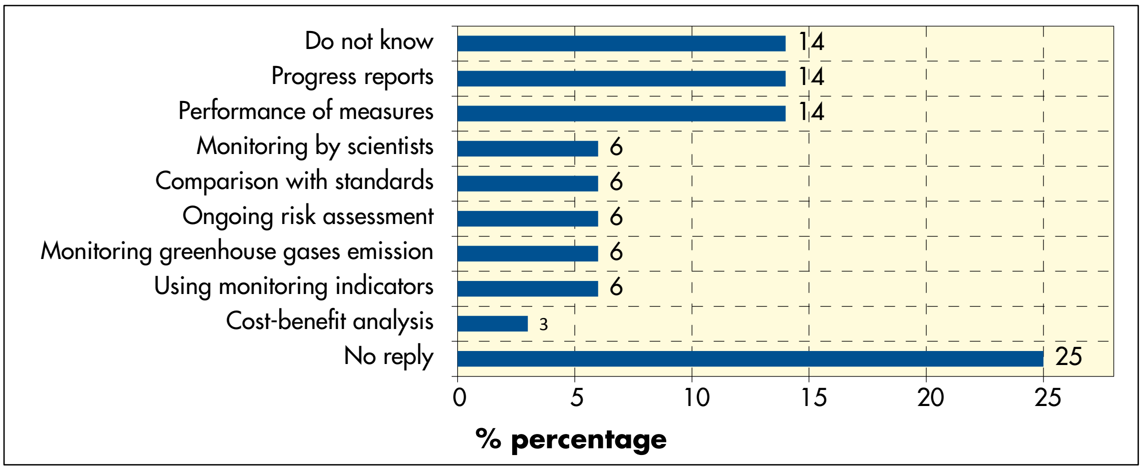
QUESTION 14 Has your country / organization adopted or is planning to adopt a transport specific strategy for adapting to climate impacts?



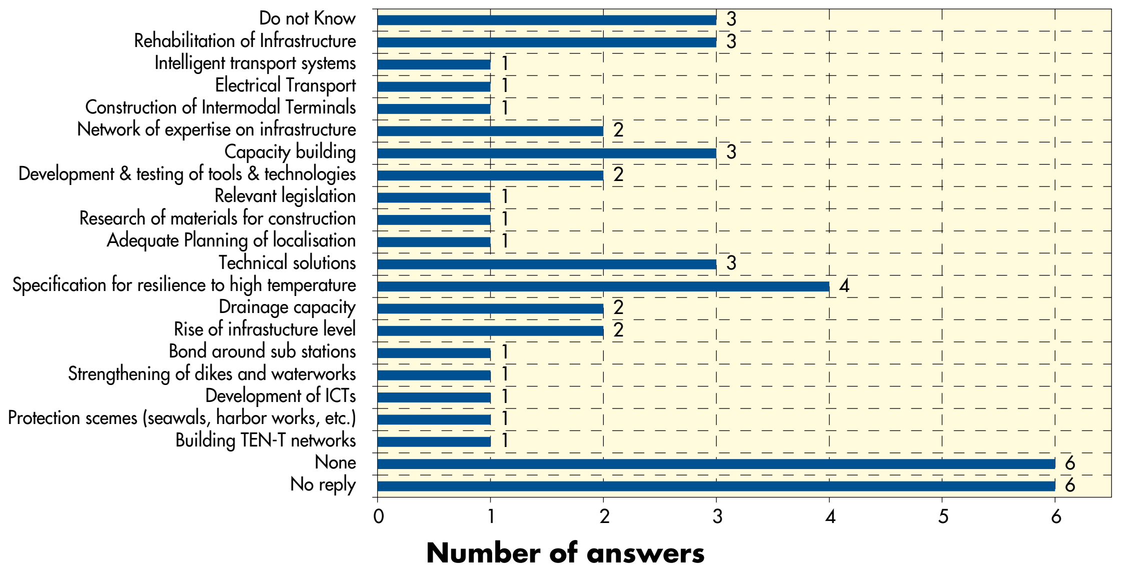
QUESTION 15 On a scale of 1 to 4 (1 = not effective at all and 4 = very effective), please indicate how you would rate the results/effectiveness of any transport specific adaptation strategy adopted?



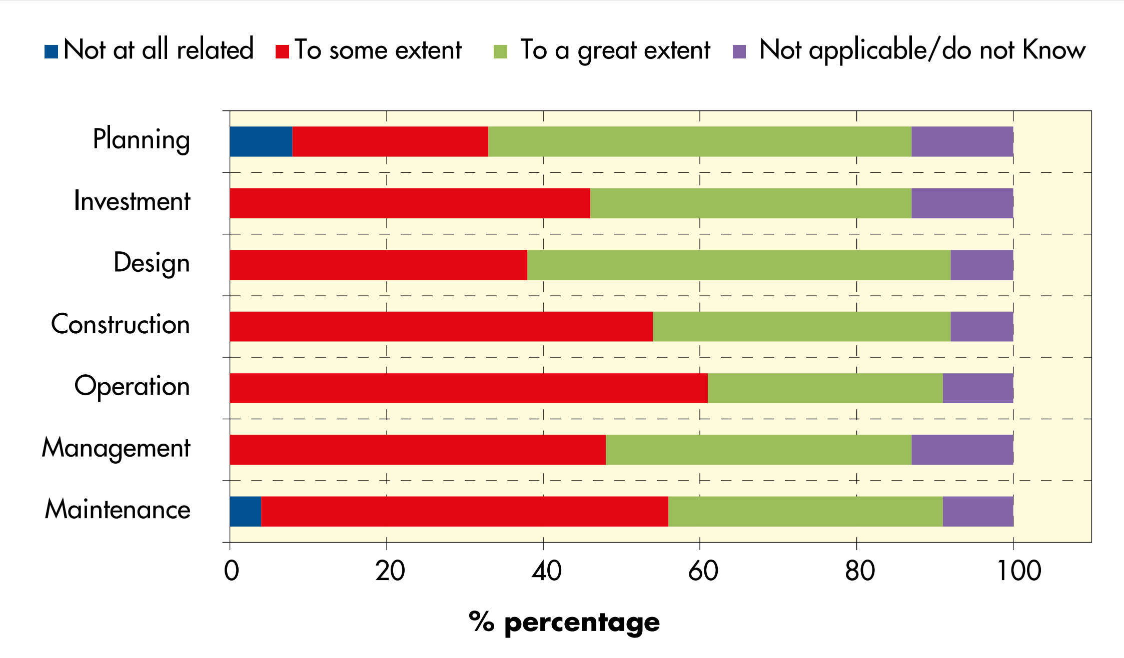
QUESTION 16 How is (or will) the effectiveness of adaptation measures taken currently or in future be monitored/ evaluated?



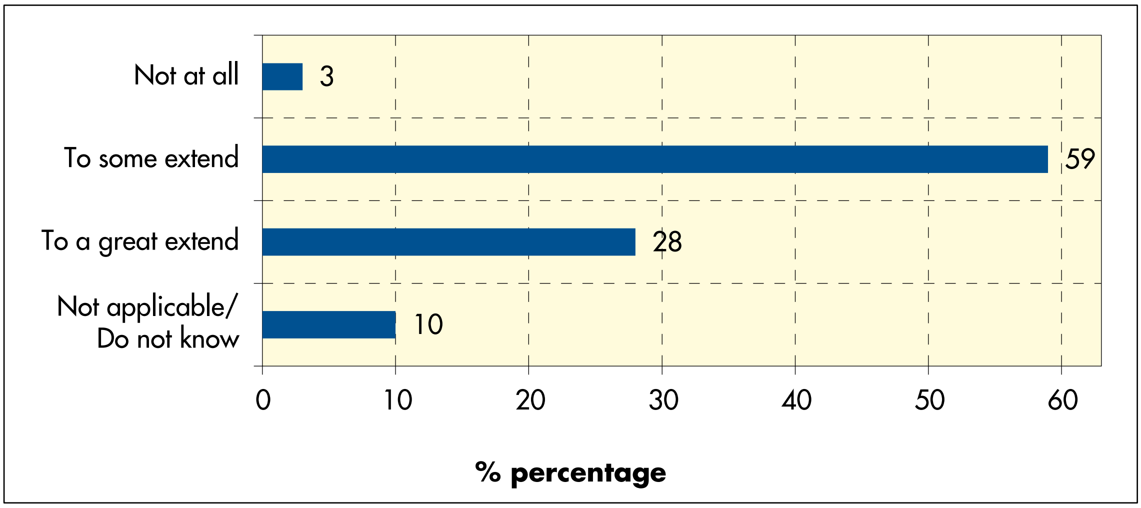
QUESTION 17 What concrete actions, if any, have been, or are planned to be, taken with a view to building resilience of transport networks to climate change impacts in your country / organization [in your field of competence]?



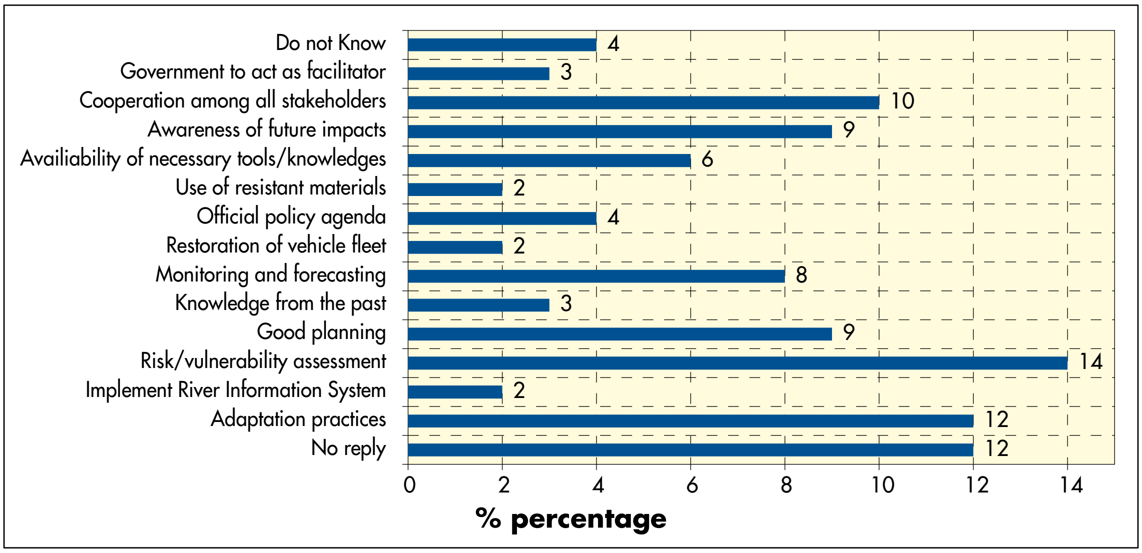
QUESTION 18 Please explain and clarify the extent to which these actions relate to transport planning, investment, design, construction, operation, management and maintenance?



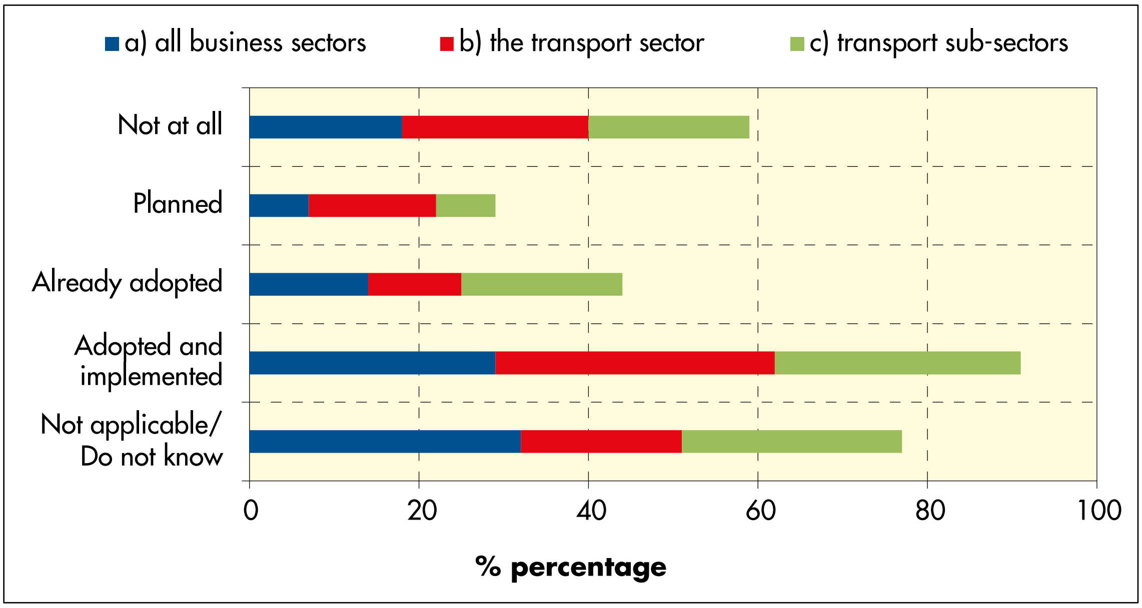
QUESTION 19 If new transport infrastructure developments are being undertaken/planned, do relevant plans take into account climate change effects (e.g. extreme events, increased rainfall, rising sea levels, etc.)?



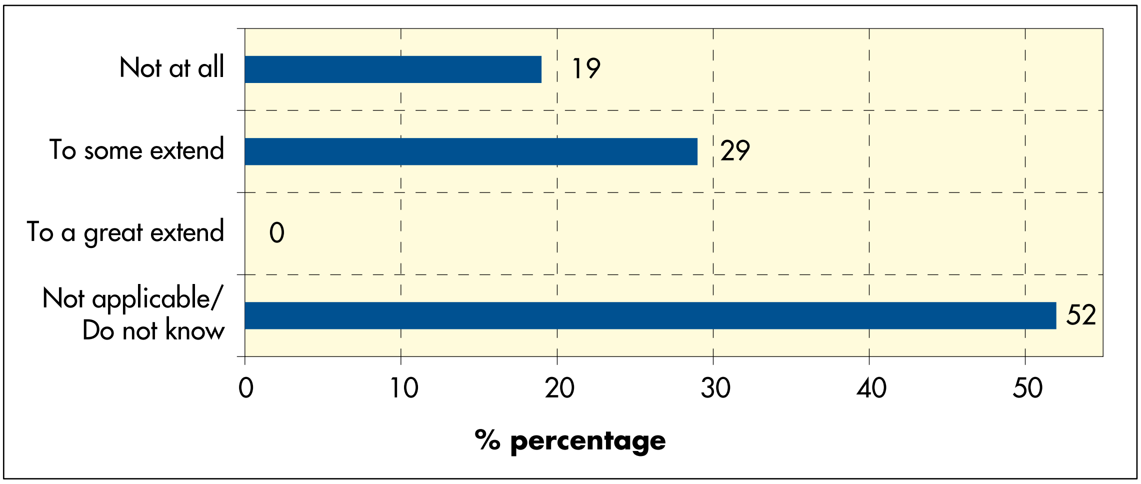
QUESTION 20 Based on the experience of your country [organization/company] what are, in your view, some of the main best practices and lessons that could be drawn with respect to adaptation action in transport?



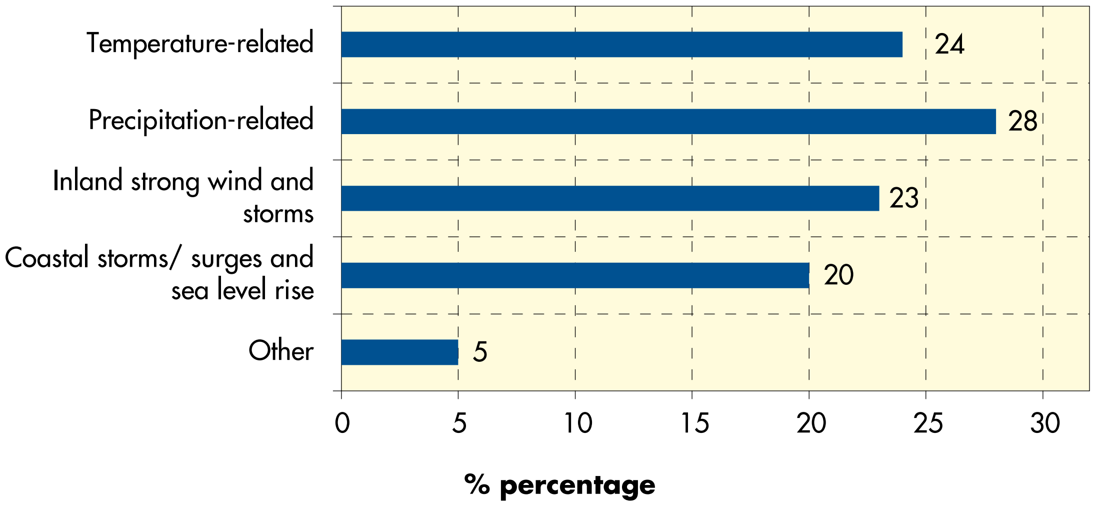
QUESTION 21 Has your country [organization/company] developed or is planning to develop emergency response systems for a) all business sectors, b) the transport sector or c) transport sub- sectors?



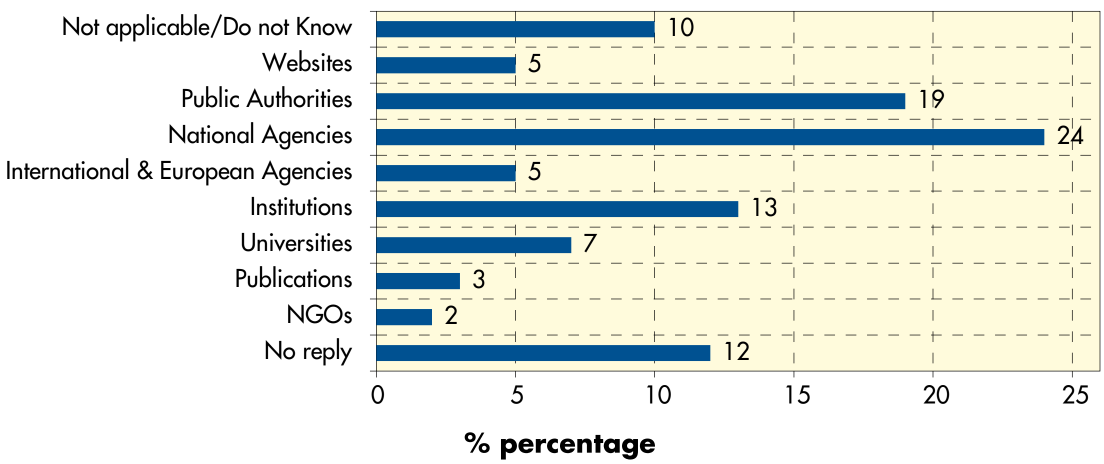
QUESTION 22 Has the insurance industry in your country integrated climate change considerations into products offered to the transport sector/industry?



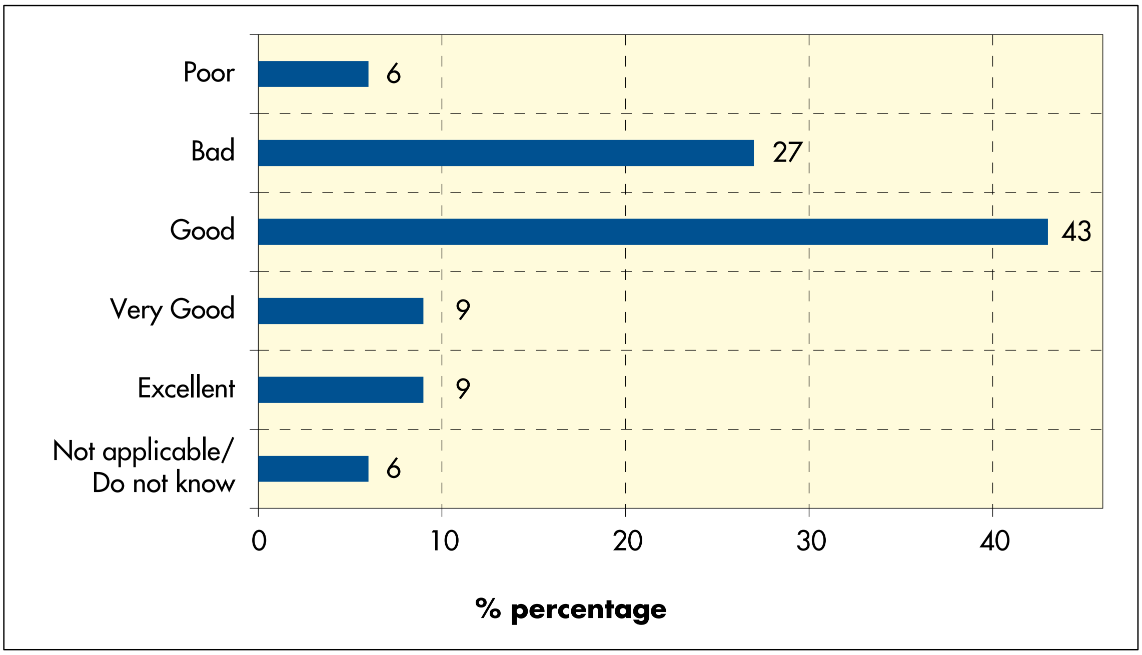
QUESTION 23 What are, in your view, the type of information, data or predictions that would be most valuable for achieving effective preparedness to climate change impacts and designing adequate adaptation responses in transport? (Multiple answers possible)



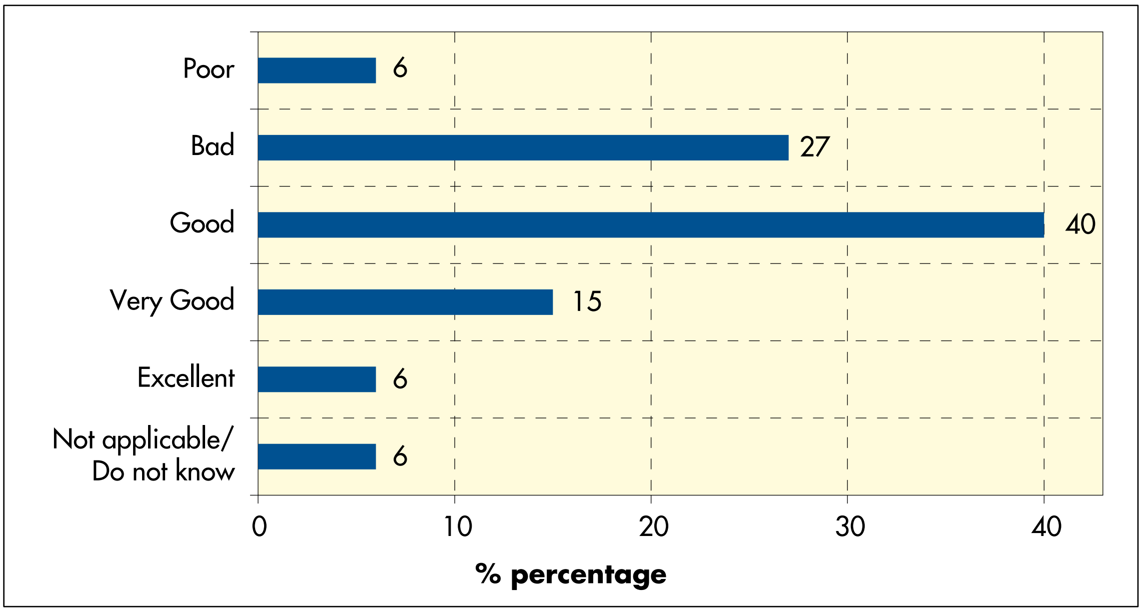
QUESTION 24 What are the main data/information sources that are currently used for the purposes of studying climate change impacts/developing adaptation measures in transport?



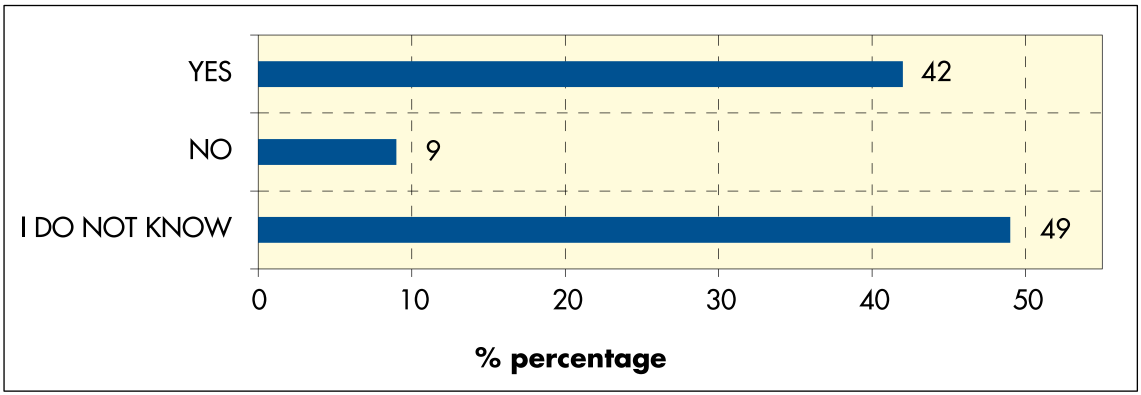
QUESTION 25 How do you rate the availability of relevant data/information in your country on a scale of 1 - 5 where 1 is poor and 5 is excellent:



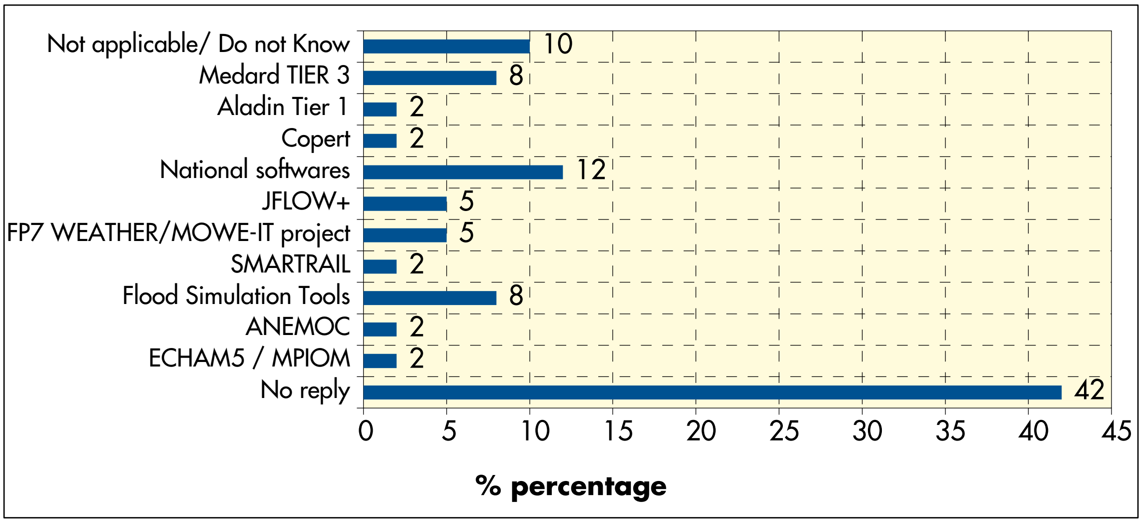
QUESTION 26 How do you rate the suitability/ relevance/quality of relevant data/ information in your country? (On a scale of 1 - 5, where 1 is Poor and 5 is excellent):



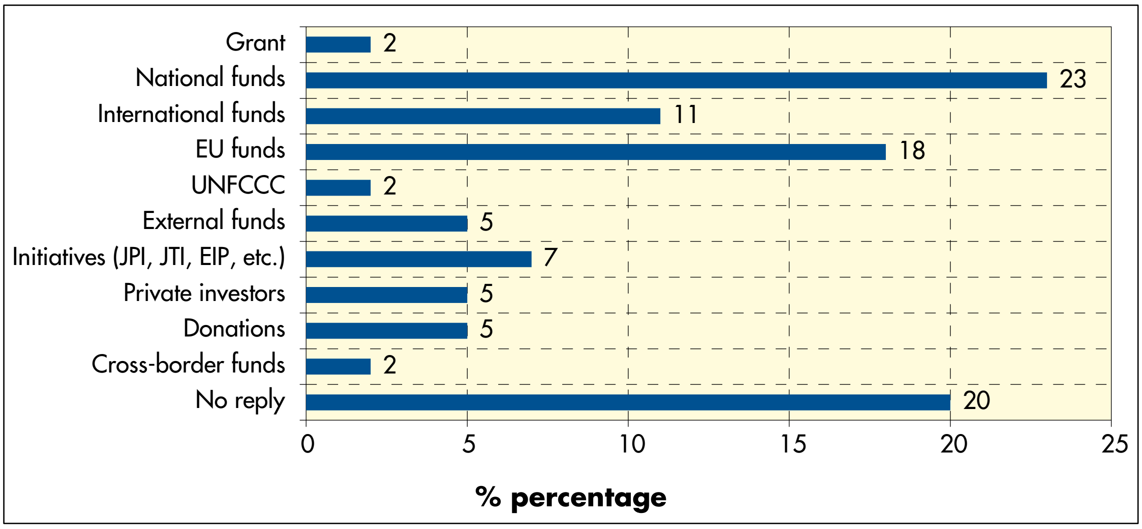
QUESTION 27 To your knowledge, are there any operational models/software tools that are used for the prediction of weather-related risks to transport infrastructure (e.g. forecasting storm surge impacts on ports or flood plain inundation)?



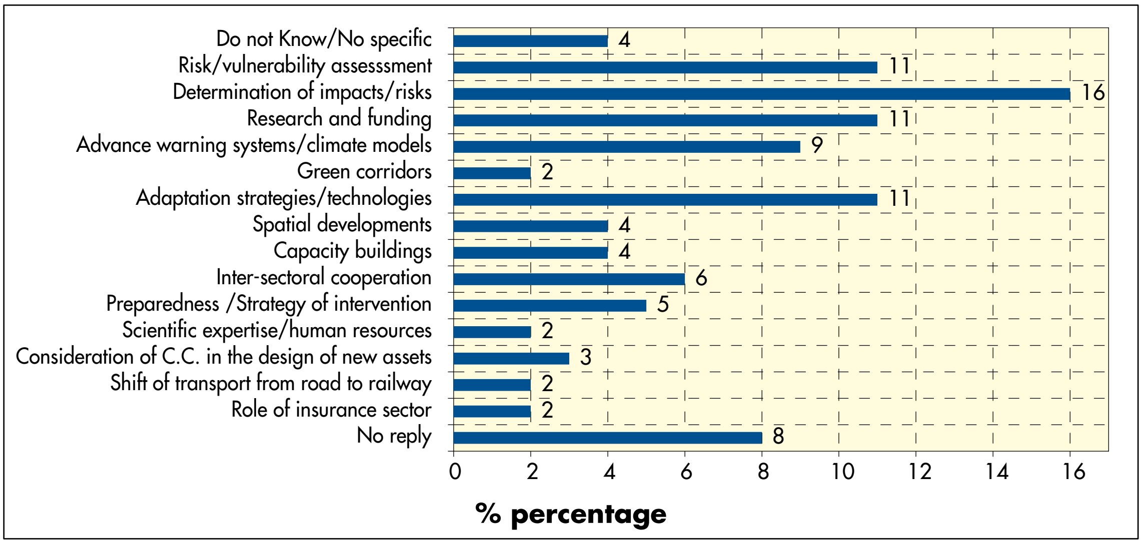
QUESTION 28 If yes, please list the models/software tools, indicating for each the level of aggregation (Tier 1, 2 or 3 according to the Intergovernmental Panel on Climate Change - IPCC tier 1, simplest method, activity data available to all countries; tier 2, technology-specific emission factor; tier 3, more detailed or country-specific methods. For more information see also unfccc.int/files/meetings/unfccc.../ipcc_good_practice_guidance.ppt)



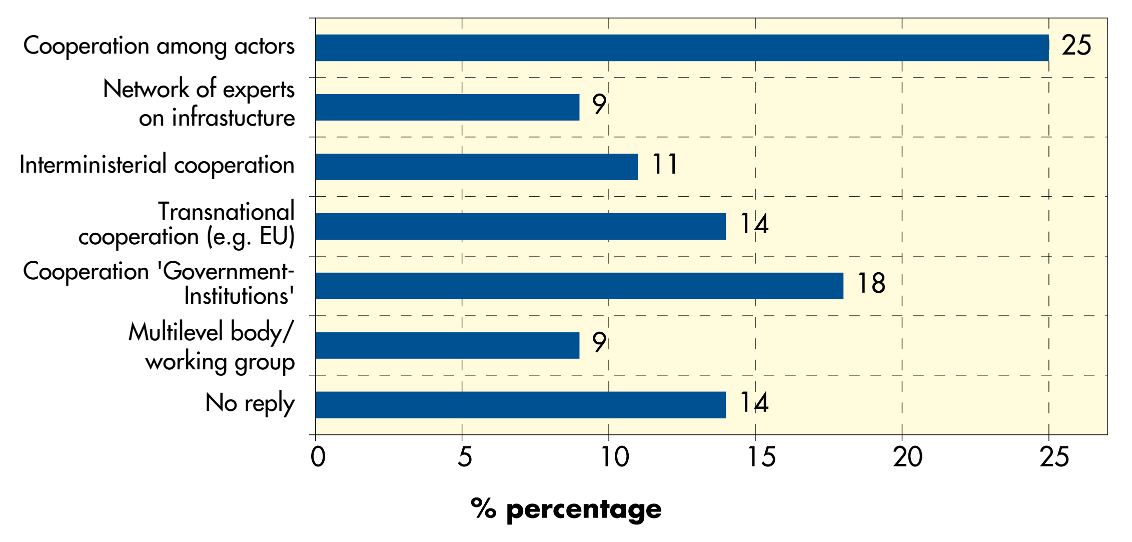
QUESTION 29 Please identify any existing or potential funding mechanisms that could support further adaptation action in transport (including study of impacts)?



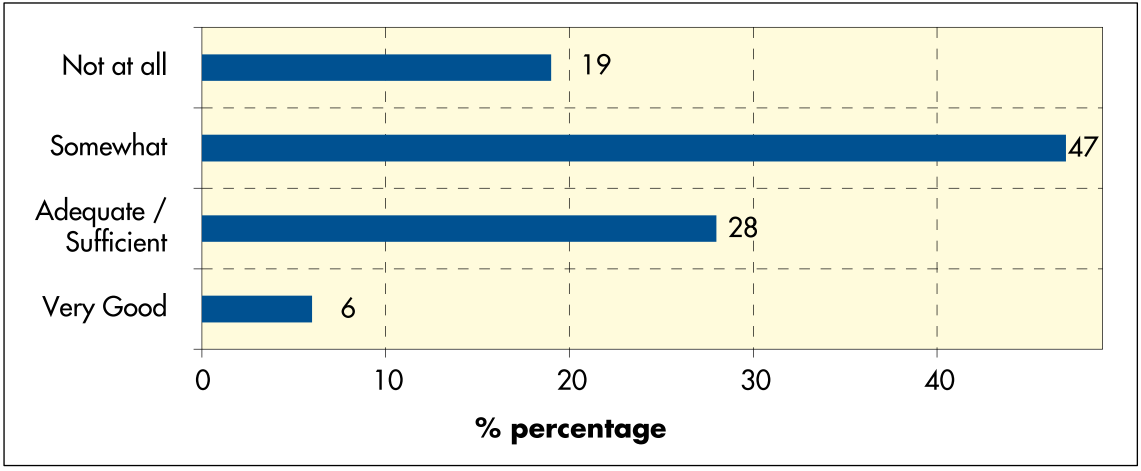
QUESTION 30 Overall, please indicate the specific priority areas that require further attention to enable effective adaptation strategies in transport and that are tailored for your local conditions?



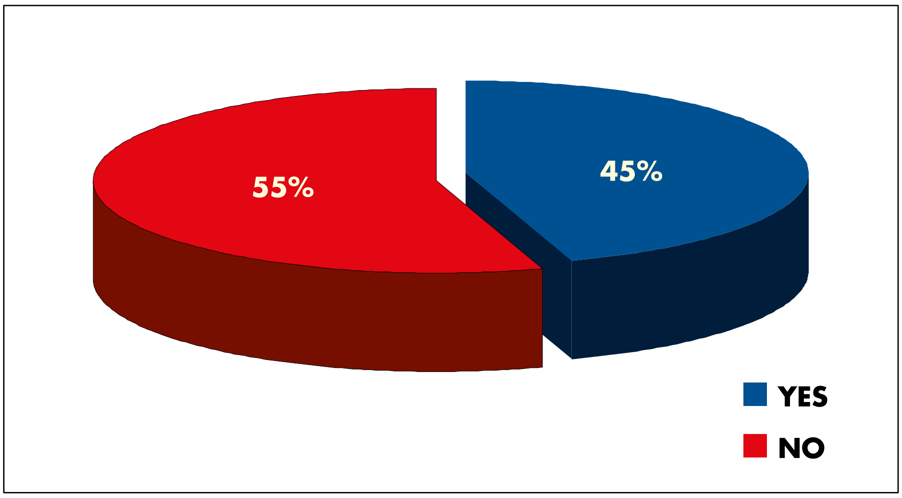
QUESTION 31 Which existing or potential mechanism(s) for cooperation do you consider most useful in addressing the issue of climate change adaptation for transport? Please also state briefly your reasons, the type of cooperation/ partners involved and the mode or type of transport infrastructure/service/ operational aspect you are referring to?



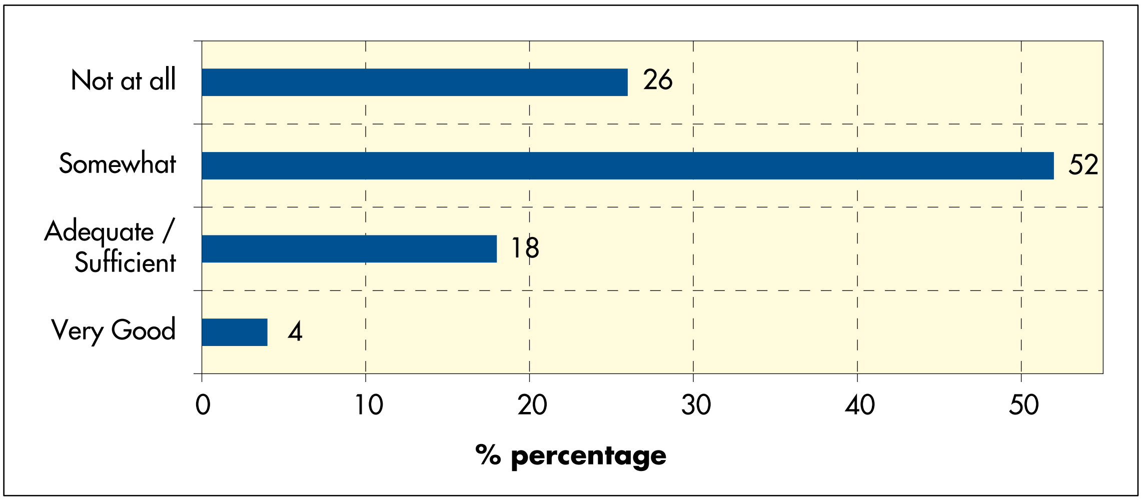
QUESTION 32 Do you consider the current level of cooperation at the national or local level adequate/ sufficient?



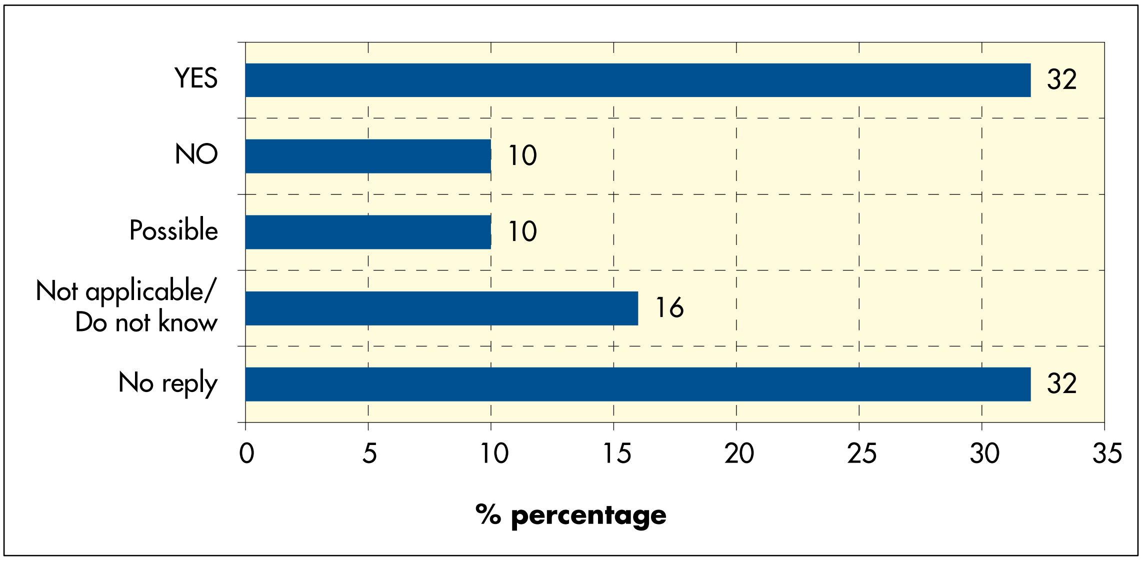
QUESTION 33 **Are regional or sub-regional cooperation and information exchange on climate change part of existing practice and policy in your country? If so, how much of this cooperation addresses transport in particular and in what ways?**



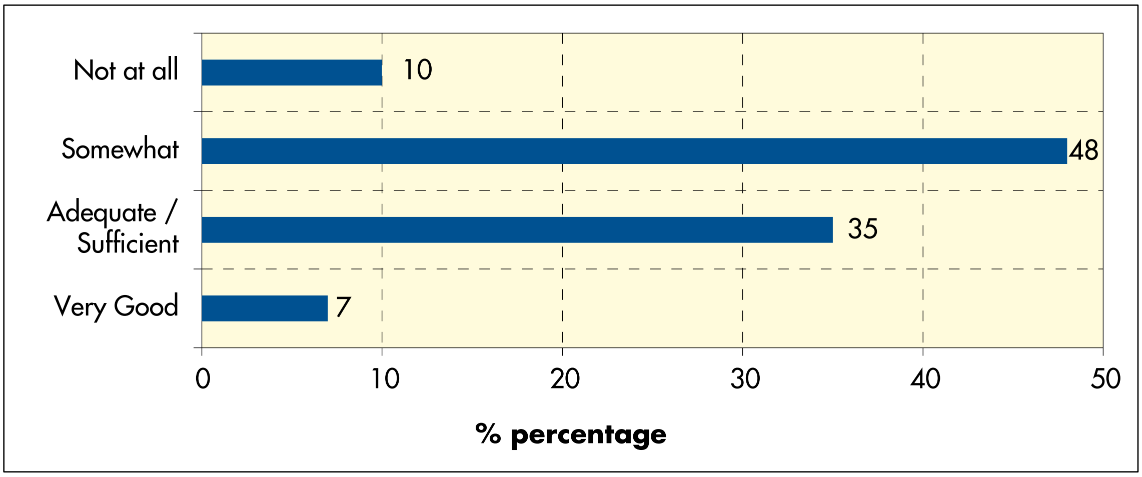
QUESTION 34 **Do you consider the relevant current level of cooperation at the regional/sub-regional level adequate/sufficient?**



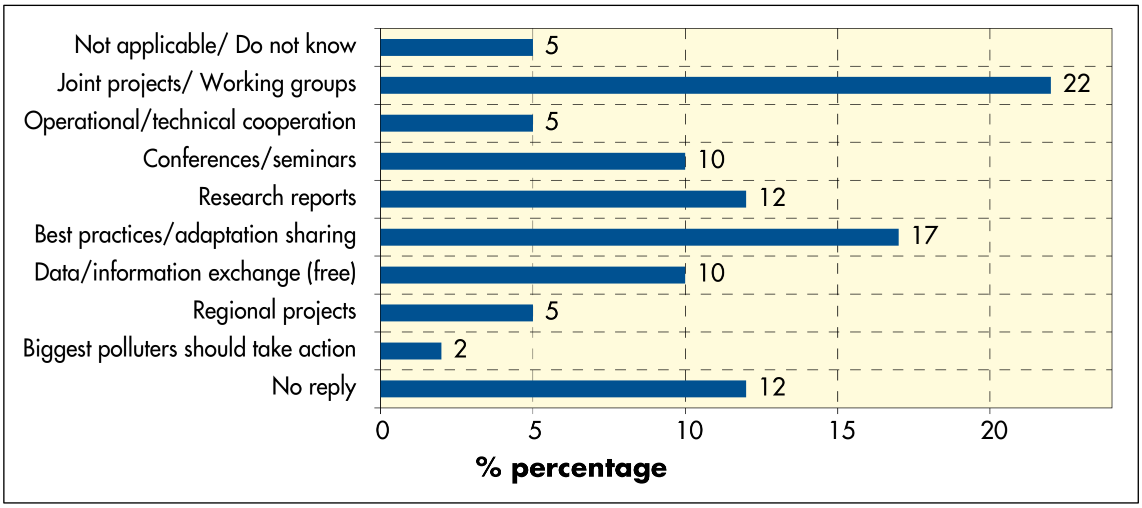
QUESTION 35 Do you think that possibility of amendments to existing UNECE infrastructure agreements (European Agreement on Main International Traffic Arteries (AGR), European Agreement on Main International Railway Lines (AGC), European Agreement on Main Inland Waterways of International Importance (AGN), European Agreement on Important International Combined Transport Lines and Related Installations (AGTC)) merits serious consideration with a view to promoting/facilitating climate change adaptation of transport networks?



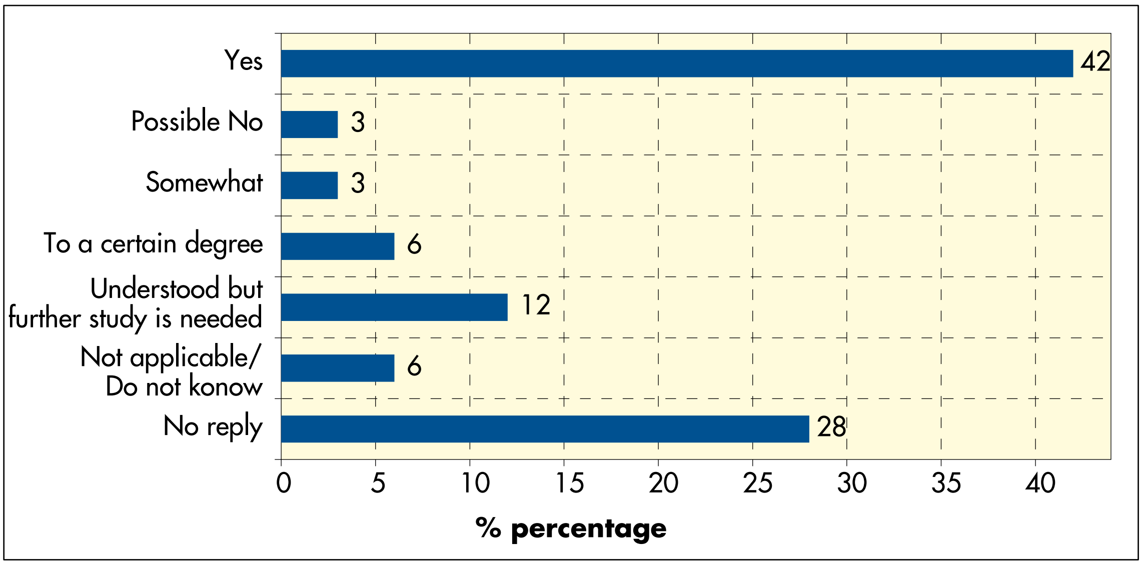
QUESTION 36 Do you consider the current level of cooperation at the international level adequate/sufficient?



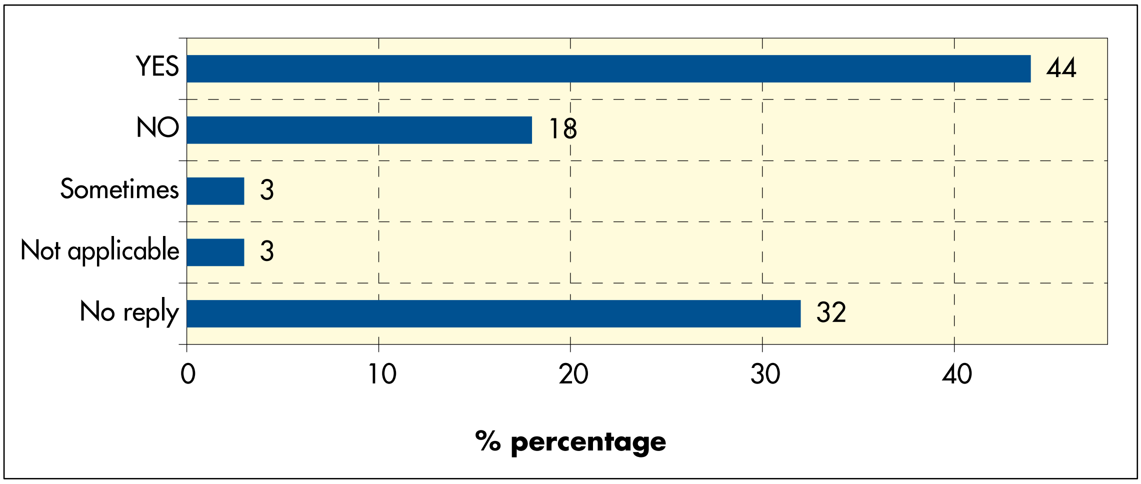
QUESTION 37 In your view, which type of further international cooperation would be of value in addressing climate change impacts and adaptations requirements?



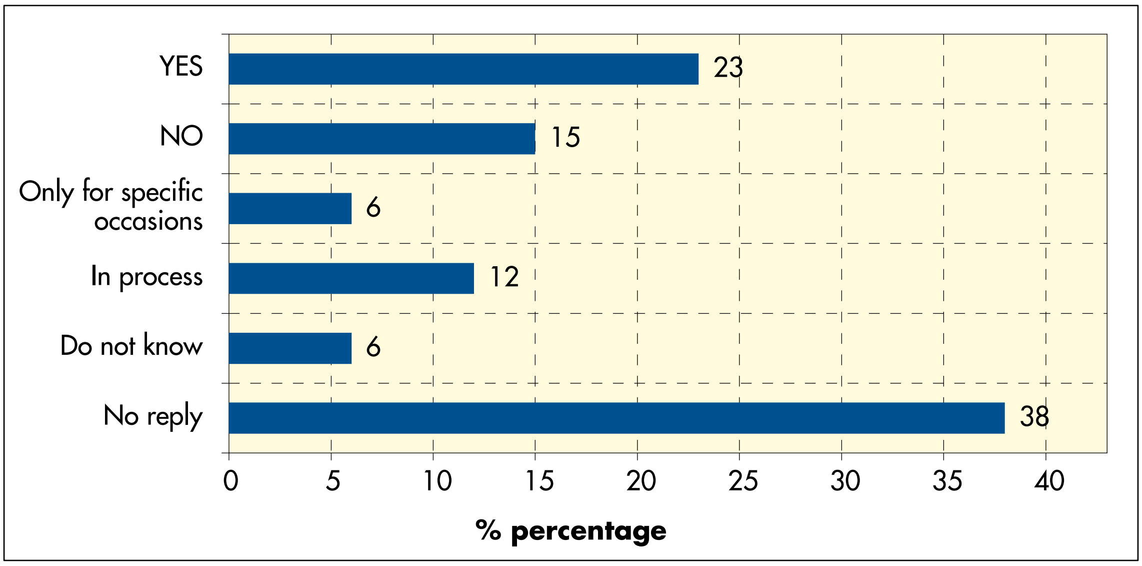
QUESTION 38 Does your public administration/company/organization understands current vulnerabilities of road / rail infrastructure in relation to natural hazards (for example bridges that might be vulnerable to flood damage)



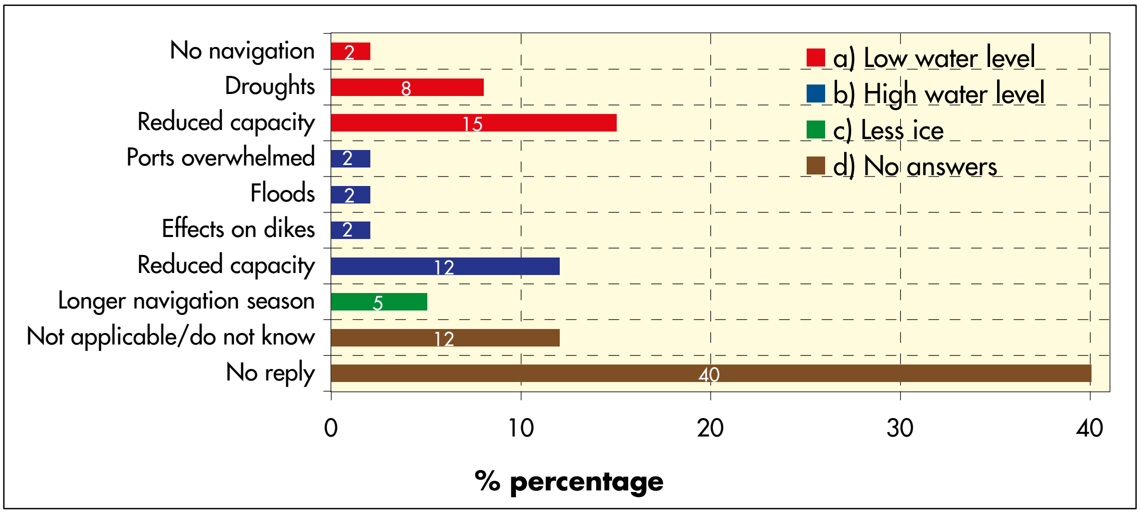
QUESTION 39 If so, have these been related to risks priorities: like hood of occurrence v consequences of event? (E.g. what is the likelihood of a stretch of road / railroad to be damaged by a flood in terms of probability, and what the consequences would be?)



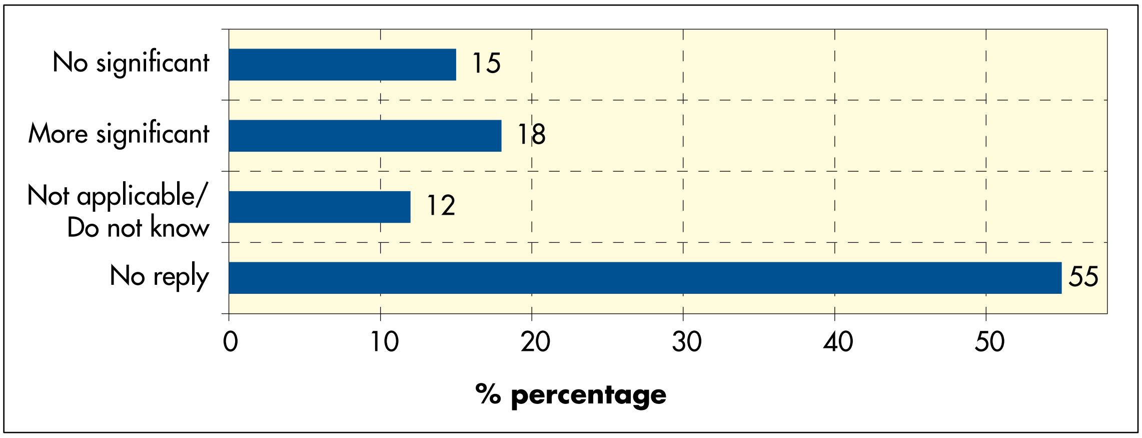
QUESTION 40 Has a mechanism been set up to assess current levels of Risk?



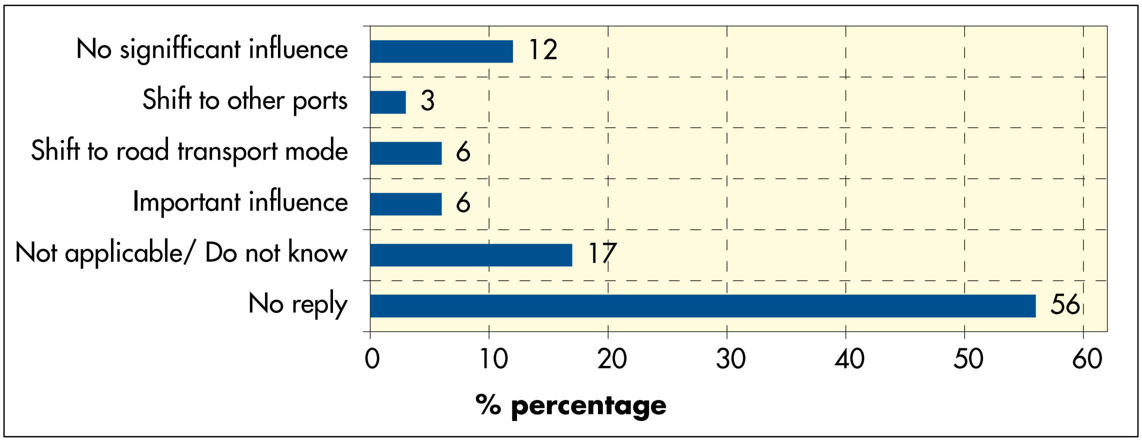
QUESTION 41 What effects do you think will climate change have on the inland waterway infrastructure?



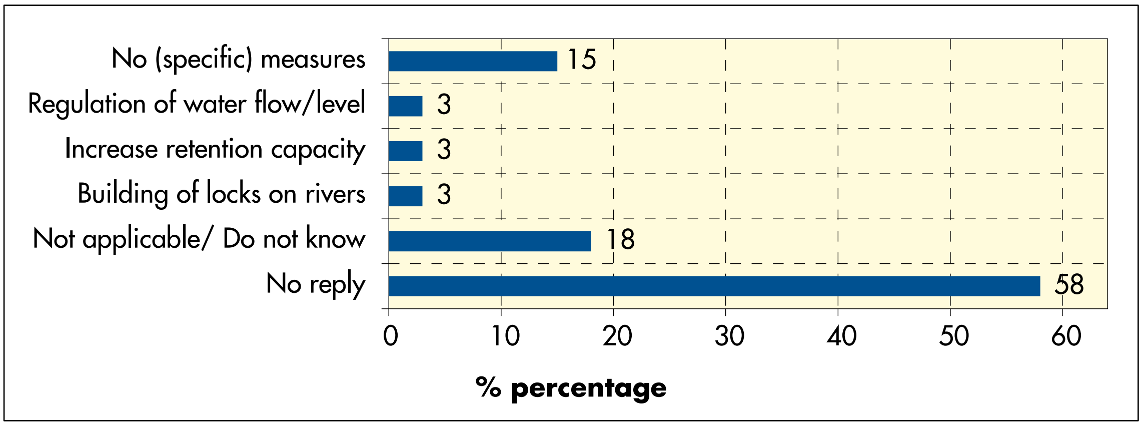
QUESTION 42 How significant will these effects be in comparison to already existing weather events (seasonal low-and high water periods)?



QUESTION 43 In your opinion, how far will climate change influence the transport flows on inland waterways and lead to a shift to other modes?



QUESTION 44 Which measures have you planned/adopted to make the IWT infrastructure / the sector resilient to the effects of di mate change



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Floods of Danube, Budapest, Hungary 2013, Internet (pp. 126, 188, 200).
Baja Town, Floods of Danube, Hungary 2013. Photos by Mr. Otto Michna (pp. 99, 100).
Shutterstock (pp. XX, XXII).

Climate Change Impacts and Adaptation for International Transport Networks

Among the many impacts of climate change the previously unforeseen strain on existing infrastructures and methods by which we do business or simply live our lives must be constantly revaluated. In this report we examine the effects on the transport sector, and what will have to be done to adapt roads, railways, inland waterways and ports.

The information for this report was meticulously analysed to identify where transport infrastructure and services will be affected. In order to create the most up to date picture, we reviewed national initiatives, case studies and research projects as well as experiences on adaptation measures specific to a variety of transportation mode. We also examined existing best practices in national policies for risk management and resilience enhancement.

Among the report's findings are impacts across a variety of modes of transport. For example, coastal transport infrastructure and services such as ports or other coastal transport hubs will be severely affected by a mean sea level rise, warmer water temperatures, higher intensity of storms and storm surges and potential changes in the wave regime.

Roadways, railways, rail and coach terminals as well as port facilities are likely to be affected by precipitation changes that could lead to stream flow changes. There can also be effects on the structural integrity and maintenance of roads, rail lines, bridges, tunnels, drainage systems, telecommunication and traffic management systems. This could necessitate more frequent maintenance and repairs.

Additionally, extreme winds can damage and stress road and rail operations, and damage port facilities such as cranes and loading terminals. The transport industry itself can even be indirectly affected by winds destroying agricultural crops.

The adaptation action described in this report aims to reduce these vulnerabilities and increase the resilience to climatic impacts. Our research, presented within, indicates that a pro-active approach to climate change adaptation means a conscience decision to invest in developing and implementing adaptation plans and strategies. This will be challenging not only due to costs but also because it cannot be easily replicated in all environments and is not a "one-size fits all" exercise.

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