WEATHER
Weather Extremes: Assessment of Impacts on Transport Systems and Hazards for European Regions

Deliverable 2
Vulnerability of Transport systems
Main report

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WEATHER D2: Vulnerability of Transport Systems

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EXECUTIVE SUMMARY

The WEATHER project

Records of reinsurance companies clearly highlight the rising damages caused by natural catastrophes and extreme weather events, which can at least partly be attributed to climate change. While many studies focus on CO2 mitigation in transport, research on the vulnerability of the sector on climate driven effects, namely extreme weather events, is coming up only recently. Little knowledge has so far been developed on the economic costs of climate and extreme weather driven damages to transport, and even less evidence is available on the options, costs and benefits of adaptation measures. Thus there is a need for European studies addressing local conditions.

In front of this background the WEATHER project aims at analysing the economic costs of more frequent and more extreme weather events on transport and on the wider economy and explores the benefits and costs of suitable adaptation and emergency management strategies for reducing them in the context of sustainable policy design. The research is carried out by an international team of eight European institutes. The project runs for 30 months from November 2009 until April 2012. The weather project is funded by the 7th RTD framework program of the European Commission and is supervised by the Directorate General for Research.

Objective and structure of this report

Deliverable 2: “The vulnerability of transport systems” is the first report published by the WEATHER project. It describes research results on impacts of the various types of weather extremes on the different modes of transport. Emphasis has been taken to translate the partly very heterogeneous and fragmentary information on the impacts of climate change and weather extremes on transport systems into Europe-wide cost estimates. These figures can, and shall, only provide house numbers on the order of magnitude of costs imposed by extreme weathers on transport systems.

The structure of this Deliverable follows the complex background works underlying the assessment of climate change costs for the European transport system.

Firstly, in the PART A of this Deliverable, four sections have been included, introducing the general accounting framework, discussing the evidence from major climate models on the likely development of extreme weather events, presenting results on network criticality modelling and providing an overview of the first weather workshop on vulnerability issues.

Then, the PART B summarizes the conclusions of the assessment of the extreme weather events for seven transport modes. The corresponding full reports have been
included in detailed modal annexes. Finally, the PART C draws conclusions in terms of cross-comparisons of costs assessments among transport modes.

The General Accounting Framework

For each of the four modes (road, rail, waterborne and air) we consider the following categories of damages:

- Infrastructure damages and impacts on infrastructure maintenance, wear and tear and operations, e.g. snow removal, cleaning, small-scale repair measures, etc.
- Vehicle fleet damages and impacts on the costs of service provision, e.g. additional personnel, energy costs or vehicle preparation.
- User travel time costs, including time for freight movements, and perceived service quality, e.g. reliability, crowding and temperatures in vehicles.

Traffic safety, i.e. the number of killed, severely and slightly injured transport users.

The research concentrates on singular weather events which clearly exceed the long-term average of comparable meteorological activities over the annual mean or related to the specific season, which have considerable negative impacts on assets and operations, or which affect human health or lives. The following table gives an overview of the categories of extremes considered here.

General issues

In terms of future development of extreme weather events, the annual mean temperatures in Europe are likely to increase more than the global mean. Seasonally, the largest warming is likely to be in northern Europe in winter and in the Mediterranean area in summer. Minimum winter temperatures are likely to increase more than the average in northern Europe. Maximum summer temperatures are likely to increase more than the average in southern and central Europe.

The analysis of Climate Models reveals a temperature increase in Europe, with changes to 2050 being relatively moderate compared to expected Climate Change impacts in 2100. Since the THER project takes a shorter perspective - 2050 -, impacts are expected to be considerably higher in 2100. Additionally, the statistical significance of the changes is lower.

Annual precipitation is very likely to increase in most of northern Europe and decrease in most of the Mediterranean area. In central Europe, precipitation is likely to increase in winter but decrease in summer. Extremes of daily precipitation will increase in northern Europe. The annual number of precipitation days is very likely to decrease in the Mediterranean area. Risk of summer drought is likely to increase in central Europe and in the Mediterranean area. The duration of the snow season is very likely to shorten, and snow depth is likely to decrease in most of Europe.
### Categories of events

<table>
<thead>
<tr>
<th>Event</th>
<th>Explanation</th>
<th>Relevant region and / or season</th>
<th>Relevant for transport segments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Temperature</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat</td>
<td>Several consecutive days exceeding 35°C with single days exceeding 38°C</td>
<td>Northern countries not accommodated to high temperatures</td>
<td>Rail tracks and services, Public transport, Roads and road users</td>
</tr>
<tr>
<td>Frost</td>
<td>Several consecutive weeks remaining below -5°C daily minimum</td>
<td>Middle and southern European states not accommodated</td>
<td>Inland navigation, Roads and railways, Airports</td>
</tr>
<tr>
<td>Rainfalls</td>
<td>Strong single event or consecutive day exceeding 200 mm</td>
<td>All Europe, particularly severe in mountain areas</td>
<td>Roads and road users, Rail tracks and services</td>
</tr>
<tr>
<td>Snow</td>
<td>Longer period with snow level exceeding a given minimum</td>
<td>Southern and middle Europe with varying thresholds</td>
<td>Road users, Rail services, Airports</td>
</tr>
<tr>
<td>Hail</td>
<td>Hail with bigger hailstones</td>
<td></td>
<td>Road users</td>
</tr>
<tr>
<td>Drought</td>
<td>Several consecutive dry weeks</td>
<td>Southern and partly middle Europe</td>
<td>Inland navigation</td>
</tr>
<tr>
<td><strong>Precipitation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Wind</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Storms</td>
<td>Events with wind speeds exceeding a certain level</td>
<td>British Islands, middle Europe</td>
<td>Road users, rail services, Aviation</td>
</tr>
<tr>
<td>Storm surges</td>
<td>Wind speeds and water levels exceeding certain levels</td>
<td>North-western Europe along coast lines</td>
<td>Roads and road users, Rail tracks and services, Ports and shipping, Airports and aviation</td>
</tr>
<tr>
<td><strong>Atmosphere</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fog</td>
<td>Longer periods with frequent sight below a certain distance</td>
<td>Mountain and northern coast line</td>
<td>Road users</td>
</tr>
<tr>
<td>Ash could</td>
<td>Volcano ash or similar concentration the atmosphere</td>
<td>All Europe</td>
<td>Aviation</td>
</tr>
<tr>
<td>Wild fires</td>
<td>Uncontrolled fires covering bigger areas</td>
<td>Southern Europe</td>
<td>Roads and road users, Rail tracks and services, Aviation</td>
</tr>
<tr>
<td><strong>Consequences</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floods / flash floods</td>
<td>Water levels exceeding a given threshold</td>
<td>All Europe around river systems</td>
<td>Rail tracks and services, Roads and road users, Inland navigation, Airports</td>
</tr>
<tr>
<td>Flash floods</td>
<td>Flooding in less than 6 hours</td>
<td>Geomorphic low lying areas</td>
<td>Rail tracks and services, Roads and road users, Inland navigation, Airports</td>
</tr>
<tr>
<td>Mass movement (dry)</td>
<td>Slipping ground (landslides) or avalanches</td>
<td>Mountain areas</td>
<td>Rail tracks and services, Roads and road users, Inland navigation, Airports</td>
</tr>
</tbody>
</table>

The **criticality of networks** was assessed for the road networks of Germany, Greece and the Netherlands, reflecting very different European transport environments. The method application is based on datasets from the European transport model TRANSTOOLS, using the VISUM model for network flow assignment. The simulations show that in first place the non-availability of access links to the major
national agglomerations is most critical. In second order, cutting off major trans-
national trunk roads lead to high costs of detouring. But in general it can be con-
cluded that the vulnerability of the dense European road network is limited due to a
high degree of redundancy. This will look different for the rail, air and particularly in-
land navigation networks, which are less dense and / or services on them are highly
inter-connected.

**Impact assessment by mode of transport**

**Road** sector vulnerability towards weather extremes builds on three pillars. In a first
step 974 damage reports from super-regional newspapers and transport undertak-
ings in six countries from 2000 to 2010 were assessed and generalized. These were
supplemented by an elasticity model relating literature findings to meteorological in-
dices of extremes. Total costs found are roughly €1.8 billion annually or roughly 0.1
€-Ct per vkm across Europe and all weather categories. Of these 35% relate to infra-
structure damages by heavy precipitation and floods alone, and winter and flood
consequences together create roughly 80% of annual mean costs.

The literature on **railways** and climate change concentrate on impacts of longer and
more extreme heat periods on track conditions and resulting impacts on operations
and users. The heat summer 2003 alone has caused 127 buckles and 130000 delay
minutes above average, costing €m1.8 to the UK. Additional problems can be caused
by frozen points, and damaged rails due to tension cracking. The assessment of Eu-
ropean media and transport sector data lead to €m7.0. per heavy precipitation event,
€m45 for permanent rain with flooding, €m0.9 per thunderstorm, €m2.5 per winter
storm and €m5.6. per avalanche. Of the dominating rain and flood costs 40% are
attributed each to infrastructure assets and to operations, while the remaining 20%
are borne by users through delays.

The vulnerability assessment of **urban public transport** has been focused on two
major flood events in eastern Germany: the Elbe flood 2002 costing €333 million of
which €83 are attributable to infrastructure reconstruction costs in Dresden and €230
million are reported for metro restoration in Prague, and the summer flood in 2010.

The assessment of weather consequences to the **aviation** sector concentrates on
the impact of airport winter maintenance and on accidents and delays to airlines and
passengers. Input data has been provided by EUROCONTROL’s delay database
and from EASA and were accompanied by information from media sector docu-
ments. The most affected actors are airlines and air passengers through delays,
bearing 70% of the estimated €360 million total costs per year. Further 27% are at-
tributed to aircraft damages and user health and life impacts in the course of
weather-inflicted accidents. From a regional perspective the most penalised area is
Western Europe, and in particular the North Sea coast (including the British islands).
For **maritime transport** studies commonly cope with the long-term effects of climate change. The most severe consequences arise from storms/hurricanes, followed by heavy rains, high wind speeds and, sometimes, hail, causing all kinds of damage, from infrastructure destruction to the impossibility of accessing the port, and extreme frost periods and icing, causing a temporary blockade of the port activities. The estimation process focuses on short-term costs from extreme events for two case studies for the winter storm Kyril in 2007. The Damage of the container ship *MSC Napoli* in the English Channel caused estimated costs of €3060. Total costs of the disruption of the Stena Lines connecting Rosslare in Ireland and Fishguard in the UK cost approximately €482493, with the main costs attributable to dropping fare incomes of €180754.

The extreme weather events that have the biggest impact on **inland waterway transport** are floods, causing high water levels and possibly resulting in a lack of bridge clearance and, if critical values are exceeded, in a disruption of traffic. Drought periods cause low water levels and resulting in lower load factors, lower speeds, more fuel consumption and possibly a disruption of traffic (in particular for bigger vessels) and finally ice cause severe delays or a blockade for the inland waterway vessels. Cost estimates have been performed for the Rhine and its neighbouring rivers based on Pegel Points and reports on ice days. Illustrative economic costs for floods in the Kaub area are estimated at €29.2 from 2003 to 2010.

**Intermodal transport** is partly affected less by weather extremes due to the heaviness of the infrastructures, but impacted more due the inflexibility of the system. The extreme weather events potentially affecting intermodal transport are flooding, landslides, avalanches, to the extent that they are causing delays in operations or interruptions in transport services. The assessment of intermodal transport vulnerability to climate change and extreme weather events leads to €6.8 p.a. borne by infrastructure managers (57%) and social actors (43%), i.e. the overall cost for the society due to additional accidents costs.

**Overview of Results**

In terms of the cost assessment, the following table provides an overall picture at EU level of the cost assessment of the weather extreme events by transport mode, type of stakeholder involved and type of extreme event considered. The total costs amount to about €2.5 billion yearly.
Generalization of extreme weather events costs for the European transport system (annual data in € m)

<table>
<thead>
<tr>
<th>Extreme weather event</th>
<th>Infrastructure Assets (m€)</th>
<th>Infrastructure Operations (m€)</th>
<th>Vehicle Assets (m€)</th>
<th>Vehicle Operations (m€)</th>
<th>User Time (m€)</th>
<th>Health &amp; Life (m€)</th>
<th>Total (m€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storm</td>
<td>76,10</td>
<td>22,60</td>
<td>5,10</td>
<td>1,40</td>
<td>63,00</td>
<td>5,30</td>
<td>174,10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter</td>
<td>248,80</td>
<td>126,30</td>
<td>81,30</td>
<td>12,50</td>
<td>125,50</td>
<td>164,90</td>
<td>759,30</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flood</td>
<td>630,10</td>
<td>21,90</td>
<td>24,40</td>
<td>30,01</td>
<td>93,70</td>
<td>21,50</td>
<td>821,61</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat&amp;drought</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>46,90</td>
<td>46,90</td>
</tr>
<tr>
<td>Total</td>
<td>1059,82</td>
<td>182,00</td>
<td>308,92</td>
<td>180,39</td>
<td>494,84</td>
<td>270,63</td>
<td>2496,60</td>
</tr>
</tbody>
</table>

(1) Average year 2000-2010.
(2) Average annual data 1999-2010
(3) Avalanches, winter storms and extreme heat events not included
(4) Average annual data 2003-2009, service providers costs
(5) Average data hurricane Kyrill 2007 from case studies, freight transport
(6) Average data 2009 freight transport without AT, CH, I, CZ, DE (already included in Rail)
(7) Including extreme temperatures (heat)
(8) Average annual data

As suggested by the several footnotes to the table, the cross-modal comparison of extreme weather events related costs is subjected to several caveats. For road, rail, air and combined (freight) transport average annual values are presented, while for maritime shipping and inland navigation only specific case studies have been assessed.

Furthermore, and most significantly, in some case the annual estimation is the result of the generalization at EU level of cost estimations available for given countries, using specific parameters and variables (traffic flows, number of container, etc), i.e. for the road and rail sectors, the intermodal transport (freight) and the air transport; in other cases the generalization has not been made possible, as for waterborne transport (inland waterways and maritime). When the generalization has not been made possible, a certain downward bias in the final results must be taken into account. And even when the generalization has been made possible, a certain downward bias is still possible due to lack of information, as for the costs suffered by the rail transport system because of extreme very cold days.
On the other hand, the table shows that of the €2.496 billion of total costs, about 97% are related to the transport modes for which the generalization at EU level has been carried out: road, rail, intermodal freight transport and air transport, whose total extreme weather related costs amount to €2.413 billion. This implies that the trends and the conclusions drawn below can be considered representative of the impacts suffered by the overall European transport system.

In general, infrastructure asset and operation account not surprisingly for the higher toll: 50% of the total costs (43% asset and 7% operations). The literature review has in fact stressed the fact that the likely most relevant implications arising from climate change concern planning, design, construct, operate, and maintaining of transport infrastructure (TRB, 2008). But also the burden suffered by users (due in particular to congestion and time losses to citizens and transport users) is quite relevant (about €450 million per year, corresponding to 20% of the total costs). The health costs amount to 12% of total costs, corresponding to €270 million per year.
1 Introduction

1.1 Introduction to the WEATHER project

Records of reinsurance companies clearly highlight the rising damages caused by the consequences of climate change, and in particular of natural catastrophes and extreme weather events. While many studies focus on CO2 mitigation in transport, research on the vulnerability of the sector on climate driven effects, namely extreme weather events, is coming up only recently.

Little knowledge has so far been developed on the economic costs of climate and extreme weather driven damages to transport, and even less evidence is available on the options, costs and benefits of adaptation measures. National adaptation programs of EU Member States, the US, Canada, New Zealand and the 4th assessment report of the IPCC provide only indicative measures and global fields of action. Thus there is a need for European studies addressing local conditions.

The third branch of WEATHER research is concerned with the role of transport systems for crisis/disaster management. In the transport literature, the term “emergency operations” spans a number of topics including logistics, traffic planning, and institutional issues. The major tasks under these topics are the transport of emergency vehicles and search-and-rescue teams, medical evacuation, and distribution of goods and local medical aid. In this field of research European evidence is already available.

1.2 Project objectives and work plan

In front of this background the WEATHER project aims at analysing the economic costs of more frequent and more extreme weather events on transport and on the wider economy and explores the benefits and costs of suitable adaptation and emergency management strategies for reducing them in the context of sustainable policy design. The research is carried out by an international team of eight European institutes, lead by the Fraunhofer-Institute for Systems and Innovation Research (ISI). The project runs for 30 months from November 2009 until April 2012. The weather project is funded by the 7th RTD framework program of the European Commission and is supervised by the Directorate General for Research.

The project work plan is broken down in two work packages for management dissemination and seven work packages on research:

- WP1: Weather trends and economy-wide impacts
- WP2: Vulnerability of transport systems
- WP3: Crisis management and emergency strategies
WEATHER D2: Vulnerability of Transport Systems

- WP4: Adaptation options and strategies
- WP5: Governance, incentives and innovation
- WP6: Case studies
- WP7: Policy conclusions and final conference

The WEATHER work packages are closely interlinked as sound adaptation and crises prevention strategies require the simultaneous consideration of various aspects of weather trends, transport economics and policy design. Of utmost importance for the weather research are contacts to transport operators and the insurance sector. For this reason each of the core work packages organises workshops to discuss the project findings with transport professionals and academia.

1.3 The Objective of Deliverable 2

The Deliverable 2: “The vulnerability of transport systems” is the first report published by the WEATHER project. It describes research results on impacts of the various types of weather extremes on the different modes of transport. Emphasis has been taken to translate the partly very heterogeneous and fragmentary information on the impacts of climate change and weather extremes on transport systems into Europe-wide cost estimates. These figures can, and shall, only provide house numbers on the order of magnitude of costs imposed by extreme weathers on transport systems.

The results of Deliverable 2 provide the basis for the benefit-cost considerations of adaptation measures in later stages of the project. Thus, total cost values are of a general interest for the WEATHER research. Even more important than total figures of weather related costs is their structure and variability. With the differentiation by mode, category of extreme and region within Europe we derive hot spots, for which adaptation measures shall be investigated with particular attention. Accordingly, Deliverable 2 feeds into all other branches of the WEATHER project:

- Work Package 1: “Weather trends and economy-wide impacts” is provided the basic economic data and requirements for generating prognoses of extremes and their impacts on transport and the economy. In order not to anticipate sophisticated scenario results, this report disclaims to present forecasts of transport-related costs due to weather impacts. This will be done in the frame of Deliverable 1.

- Work Package 4: “Adaptation Strategies” and consequently Work Package 5: “Governance, Incentives and Innovation” get direct guidance on the hot spots to be investigated concerning the design and implementation of adaptation strategies.

- Work Package 6: “Case Studies” will on the one hand re-visit the partly rather general assumptions on costs and cost variability in the present research, but will
on the other hand get information which cost elements to look at in more detail at the single study cases.

In the following, a brief overview of the Work Package 2 methodology and of its structure are given.

1.4  **Structure of Deliverable 2**

The structure of this Deliverable follows the complex background works underlying the assessment of climate change costs for the European transport system.

Firstly, in the PART A of this Deliverable, four sections have been included:

1. the general accounting framework that represents the overall methodology of the WEATHER project, e.g. terminology, assessment principles, etc

2. an overview of the most important Climate Change models, whose outcomes are crucial for the assessment of future climate change impacts in Europe by type of extreme weather events

3. an introduction to the methodological approaches to the impact assessment of extreme weather events on transport networks for a sample of European countries (road network)

4. a brief account of the first WEATHER Workshop on the vulnerability of the transport sector to climate change and related extreme weather events.

Then, the PART B summarizes the conclusions of the assessment of the extreme weather events for seven transport modes. The corresponding full reports have been included in the WEATHER D2 Detailed Report.

Finally, the PART C draws conclusions in terms of cross-comparisons of costs assessments among transport modes.
PART A: GENERAL TOPICS

2 The General Assessment Framework

The general assessment framework constitutes the overall methodology of the weather project. It sets the dimensions to be covered and provides guidance on the selection of input values and the design of the modal assessment models. However, as data availability and the organisation of the transport modes strongly diverges it was decided by the project steering committee to give freedom to the single modes to adapt the GAF to the specific needs. Thus, for more detailed, mode specific discussions it is referred to the annexes 3 to 9 to this report. Here we introduce some general notations and dimensions of the risk assessment concept.

2.1 The concept of systemic risks

Before discussing the structure of the GAF we need to introduce a number of core expressions to be precise on what we talk about throughout the document. These expressions more broadly define the common terminology around the research field of systemic risks and risk assessment.

The main concept of the systemic risk terminology is illustrated by Figure 1. A more detailed description of the concepts is then provided by Table 1.

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Figure 1: Terms and concepts of systemic risk theory
<table>
<thead>
<tr>
<th>Term</th>
<th>General explanation</th>
<th>Example “storm surges and coastal roads”</th>
</tr>
</thead>
<tbody>
<tr>
<td>System</td>
<td>Physical or social elements and their inter-relationships to be investigated</td>
<td>Urban and rural transport infrastructures in EUR29 countries, passenger and freight services and traffic on these networks and their inter-relationships</td>
</tr>
<tr>
<td>Threat</td>
<td>External events, system condition or interactions with external systems which might exert negative effects upon the system under consideration</td>
<td>Extreme weather events (storms, storm surges, precipitation, i.e. rain and snow, fog, heat, drought) and consequential events (floods, spring floods, landslides, ice, wild fires)</td>
</tr>
<tr>
<td>Intensity</td>
<td>Probability and likely severity of a particular threat in general</td>
<td>Scenarios of extreme weather and consequential events for European regions</td>
</tr>
<tr>
<td>Exposure</td>
<td>Probability and likely severity of a particular system element getting hit or affected by a threat</td>
<td>Probability of extreme events affecting networks and services, taking into account geographical location, topology and man-made protection measures</td>
</tr>
<tr>
<td>Impact</td>
<td>Potential negative or positive effects of the exposure on the system</td>
<td>Damages to assets, accidents or longer travel time; accelerated thawing of ice covers due to raising mean temperatures</td>
</tr>
<tr>
<td>Vulnerability</td>
<td>Potential negative effects of the exposure on the system</td>
<td>Expected reinvestment, repair and additional maintenance and operation needs, accidents and additional road user travel time</td>
</tr>
<tr>
<td>Resilience</td>
<td>Ability of a system to recover from a damage</td>
<td>Crises management, communication strategies, traffic management, maintenance and reinvestment organisation</td>
</tr>
<tr>
<td>Risk</td>
<td>Risk results from the application of exposure levels to the vulnerability of a system element</td>
<td>Probability of damages in physical or monetary units due to extreme weather events now and 2050</td>
</tr>
<tr>
<td>Damage</td>
<td>Specific negative impact experienced by a system</td>
<td>Records of repair and replacement costs, additional accidents and user costs due to extreme events e.g. between 1990 and 2010.</td>
</tr>
<tr>
<td>Adaptation</td>
<td>Measures to decrease the vulnerability or enhance the resilience of the system w.r.t. the exposure situation</td>
<td>Technical measures (elevation of ditches, strengthening of road layers, etc.) and organisational improvements to improve system resilience (as above)</td>
</tr>
<tr>
<td>Mitigation</td>
<td>Measures to eliminate threats or to calm their intensity w.r.t. the system exposure situation</td>
<td>Technologies and policies to reduce CO2 emissions from transport to reduce global temperature increase and its effect on weather activity.</td>
</tr>
</tbody>
</table>
The manifold impacts of extreme weather events on transport depend on:

1. the mode, type, function and occupation of transport network elements,
2. their geographic and topographic environment and
3. the type and severity of weather impact

The proposed systematic of these three groups of characteristics is discussed in turn. The resulting matrix of potential impacts is huge and will contain many irrelevant or less significant fields. The identification of the remaining “hot spots” is subject to a final step.

2.2 Dimensions of the assessment framework

2.2.1 Time horizon

This report concentrates on the economic impacts of intensive weather conditions on current transport networks and activities. The base year for costs is 2010. The results of the cost computations shall provide the basis for predictions of possible costs (or benefits) or altering weather conditions until the target year 2050. These forecasts will be carried out in later stages of the project as climate and weather scenarios have been agreed and finally quantified. An introduction into the results of current climate models is provided by the following section.

2.2.2 Transport modes

The WEATHER research generally looks at all modes of transport, however with varying intensity. These are:

- **Road**: European perspective derived from country-specific data.
- **Rail and urban public transport (UPT)**: discussion of case-specific results.
- **Aviation**: coverage of Europe by assessing Europe-wide statistics.
- **Maritime and inland navigation**: sector-specific focus on a few countries.
- **Intermodal transport**: European focus by generalising sector information.

2.2.3 Categories of extreme weather considered

The research concentrates on singular weather events which clearly exceed the long-term average of comparable meteorological activities over the annual mean or related to the specific season, which have considerable negative impacts on assets and operations, or which affect human health or lives. Table 2 gives an overview of the categories of extremes considered here.
## 2.3 Assessment principles

The assessment of weather-related impacts requires two steps: the recording of damages and the application of an economic evaluation framework on this quantita-
tive dataset. Further, the issue of generalisation of country- or event-specific findings to larger geographical entities is of particular interest when trying to grasp the size of the problem.

2.3.1 Recording damages

For each of the four modes (road, rail, waterborne and air) we consider the following categories of damages:

4. **Infrastructure** damages and impacts on infrastructure maintenance, wear and tear and operations, e.g. snow removal, cleaning, small-scale repair measures, etc.

5. **Vehicle fleet** damages and impacts on the costs of service provision, e.g. additional personnel, energy costs or vehicle preparation.

6. **User** travel time costs, including time for freight movements, and perceived service quality, e.g. reliability, crowding and temperatures in vehicles.

7. **Traffic safety**, i.e. the number of killed, severely and slightly injured transport users.

As far as possible we use weather-inflicted damages reported by infrastructure operators, service providers or user associations. But as damage records for the transport sector in many cases do not exist or are not publically available, in addition we apply a media research in selected countries. The subsequent sections on single modes show the current state of knowledge concerning the respective relevant impacts by the above impact categories.

2.3.2 Assessing economic impacts

In case the original sources of damage reporting provide with cost values we take these. Otherwise a simplistic but workable procedure is applied to estimate missing data and economic costs. We use the following very cause assumptions and procedures:

8. **Infrastructure damages**: We start from standard cost values for infrastructure construction by construction element taken from the IMPACT (2008), GRACE (2006) and UNITE (2002). If no state of damage is reported we only consider the costs of resurfacing and equipment renewal. To separate standard renewal costs from weather-related damages we take only the share of the asset’s remaining life time or 50% of not available. Capital costs are considered by a default value of 10% upon the replacement or repair costs.

9. **Infrastructure operations**: Here we do not have standard cost values available, as these will strongly differ between categories of weather extremes, regions and the organisational structure of the infrastructure company.
10. **Vehicle damages**: Cost values are based on prices for new vehicles, of which we apply 50% to reflect age and partial damages. In further steps these will be cross-checked to insurance reports of material damages.

11. **Vehicle operation costs** comprise of costs for additional heating and cooling in case of temperature-related events or of fuel, personnel and depreciation in case of detouring. Respective cost values are provided by automobile associations for passenger cars or HGVs and can be derived from balance sheets of transport service providers. The time and distance of detouring is estimated by the TRANS-TOOLS network database. If the number of vehicles affected is not given, national average traffic volumes per type of infrastructure are taken.

12. **User time costs** are computed like vehicle operating costs using standard cost values from the IMPACT and HEATCO projects. If not available by modal statistics, default values for delays and detours are also taken from the TRANS-TOOLS model. Besides national infrastructure load rates, national vehicle occupancy figures are provided to transfer vehicle delays into passengers or freight units.

13. **Users’ discomfort** arises from over-crowding, excessive or too low temperatures in vehicles. We have not found a reliable method for valuing these effects and thus exclude comfort-related impacts from the assessment.

14. **Accident impacts** on human health and life are assessed by standard cost values for death casualties, severe and slight injuries derived in recent European studies. Usually the number of fatalities and injuries associated with extreme events are well documented.

The default values shall help to set the order of magnitude of transport related weather consequences in relation to total damages reported by re-insurance companies and to the costs and benefits of adaptation and crises preparation measures to be estimated in the course of the project.

An example on the analysis, data sources and potential issues arising from WEATHER research project, with reference to the Road sector is provided in the following section.
3 Climate and Weather Scenarios for Europe

3.1 Projected main Climate Changes

This chapter reviews the most prominent Climate Change models and analyses its impacts on extreme weather events. The analysis relies mainly on the IPCC A1B and A2 Scenarios with projections of Climate Change to 2050 and 2100.

The A1 storyline describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies.

The A2 scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities, with fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower.

The following projects/publications were used to assess the impacts of climate change on extreme weather conditions: IPCC AR4 (Christensen 2007, Alcamo 2007, Meehl 2007), ENSAMBLES ((van der Linden et al 2009), PRUDENCE (Christensen 2007) and ESPON 1.3.1 (Schmidt-Thomé 2006). Next to these, a number of additional papers were reviewed to retrieve further information.

Table 3 lists the outputs from the Prudence assessments for North Europe (NEU) and South Europe and Mediterranean (SEM): Here the changes in mean temperature and precipitation averaged for the period 1980 to 1999 period and the 2080 to 2099 period of A1B Scenario are presented. Computing the difference between these two periods, the table shows the minimum, maximum, median (50%), and 25 and 75% quartile values among the 21 models, for temperature (°C) and precipitation (%) change.

The table gives as well information about the duration (in years) until the changes are statistically significant at a 95% level. Additionally, Table 3 presents the frequency of extreme weather events.
Table 3: Main climate changes for Europe in 2080-2099 compared to 1980-1999

<table>
<thead>
<tr>
<th>Region</th>
<th>Season</th>
<th>Temperature Response (°C)</th>
<th>Precipitation Response (%)</th>
<th>Extreme Seasons (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Min 25 50 75 Max T yrs 25 50</td>
<td>Min 25 50 75 Max T yrs</td>
<td>Warm 10 Wet</td>
</tr>
<tr>
<td>NEU</td>
<td>DJF</td>
<td>2.6 3.6 4.3 5.5 6.2 8.2</td>
<td>40</td>
<td>9 13</td>
</tr>
<tr>
<td></td>
<td>MAM</td>
<td>2.1 2.4 3.1 4.3 5.3</td>
<td>35</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>JJA</td>
<td>1.4 1.9 2.7 3.3 4.0</td>
<td>25</td>
<td>-31</td>
</tr>
<tr>
<td></td>
<td>SON</td>
<td>1.9 2.6 2.9 4.2 5.4</td>
<td>30</td>
<td>-5</td>
</tr>
<tr>
<td>75N,40E</td>
<td>Annual</td>
<td>2.3 2.7 3.2 4.5 5.3</td>
<td>25</td>
<td>0</td>
</tr>
<tr>
<td>SEM</td>
<td>DJF</td>
<td>1.7 2.5 2.6 3.3 4.6</td>
<td>25</td>
<td>-16</td>
</tr>
<tr>
<td></td>
<td>MAM</td>
<td>2.0 3.0 3.2 3.5 4.5</td>
<td>20</td>
<td>-24</td>
</tr>
<tr>
<td>30N,10W</td>
<td>JJA</td>
<td>2.7 3.7 4.1 5.0 6.5</td>
<td>15</td>
<td>-53</td>
</tr>
<tr>
<td></td>
<td>SON</td>
<td>2.3 2.8 3.3 4.0 5.2</td>
<td>15</td>
<td>-29</td>
</tr>
<tr>
<td>40N,40E</td>
<td>Annual</td>
<td>2.2 3.0 3.5 4.0 5.1</td>
<td>15</td>
<td>-27</td>
</tr>
</tbody>
</table>

(i) Source: Christensen et al 2007, 4th AR Working Group I, Chapter 11

Annual mean temperatures in Europe are likely to increase more than the global mean. Seasonally, the largest warming is likely to be in northern Europe in winter and in the Mediterranean area in summer. Minimum winter temperatures are likely to increase more than the average in northern Europe. Maximum summer temperatures are likely to increase more than the average in southern and central Europe.

(ii) Source: Christensen 2007, p 875

Figure 2: Temperature increase 2080-2099 compared to 1980-1999

The analysis reveals a temperature increase in Europe, with changes to 2050 being relatively moderate compared to expected Climate Change impacts in 2100. Since this WEATHER project takes a shorter perspective - 2050 -, impacts are expected to be considerably higher in 2100. Additionally, the statistical significance of the changes is lower.

Annual precipitation is very likely to increase in most of northern Europe and decrease in most of the Mediterranean area. In central Europe, precipitation is likely to
increase in winter but decrease in summer. Extremes of daily precipitation will increase in northern Europe. The annual number of precipitation days is very likely to decrease in the Mediterranean area. Risk of summer drought is likely to increase in central Europe and in the Mediterranean area. The duration of the snow season is very likely to shorten, and snow depth is likely to decrease in most of Europe.

**Annual DJF  JJA**

![Graph showing precipitation increase](image)

(iii) Source: Christensen 2007, p.875

Figure 3: Precipitation increase 2080-2099 compared to 1980-1999

### 3.2 Extreme weather events and natural disasters

For the period 1998–2009, EEA (2010) reports 576 disasters due to natural hazards causing near to 100 000 fatalities, and close to EUR 150 billion in overall losses. During this period, more than 11 million people (out of a population of 590 million, approximately, in the EEA member countries) were somehow affected by disasters caused by natural hazards. Extreme temperature, storms and floods made up nearly 90% of all natural disasters.

According to EEA (2010), the number of disasters in Europe has been showing an upward trend since 1980, largely due to the continuous increase of meteorological and hydrological events.

The trend is depicted in Figure 4.
Figure 4: Disasters due to natural hazards in EEA member countries, 1980–2009

3.3 Climate Change impacts on extreme events

Meehl (2007) states that “the type, frequency and intensity of extreme events are expected to change as Earth’s climate changes, and these changes could occur even with relatively small mean climate changes. Changes in some types of extreme events have already been observed, for example, increases in the frequency and intensity of heat waves and heavy precipitation events.”

In a warmer future climate, there will be an increased risk of more intense, more frequent and longer-lasting heat waves. The European heat wave of 2003 is an example of the type of extreme heat event lasting from several days to over a week that is likely to become more common in a warmer future climate. A related aspect of temperature extremes is that there is likely to be a decrease in the daily temperature range in most regions. It is also likely that a warmer future climate would have fewer frost days (i.e., nights where the temperature dips below freezing). Growing season length is related to number of frost days, and has been projected to increase as climate warms. There is likely to be a decline in the frequency of cold air outbreaks (i.e., periods of extreme cold lasting from several days to over a week) in NH winter in most areas.

In a warmer future climate, most Atmosphere-Ocean General Circulation Models project increased summer dryness and winter wetness in most parts of the northern middle and high latitudes. Summer dryness indicates a greater risk of drought. Along with the risk of drying, there is an increased chance of intense precipitation and flooding. This has already been observed and is projected to continue because in a
warmer world, precipitation tends to be concentrated into more intense events, with longer periods of little precipitation in between. Therefore, intense and heavy downpours would be interspersed with longer relatively dry periods. Another aspect of these projected changes is that wet extremes are projected to become more severe in many areas where mean precipitation is expected to increase, and dry extremes are projected to become more severe in areas where mean precipitation is projected to decrease.

In concert with the results for increased extremes of intense precipitation, even if the wind strength of storms in a future climate did not change, there would be an increase in extreme rainfall intensity. In particular, over land, an increase in the likelihood of very wet winters is projected over much of central and northern Europe due to the increase in intense precipitation during storm events, suggesting an increased chance of flooding over Europe and other mid-latitude regions due to more intense rainfall and snowfall events producing more runoff. The increased risk of floods in a number of major river basins in a future warmer climate has been related to an increase in river discharge with an increased risk of future intense storm-related precipitation events and flooding. Some of these changes would be extensions of trends already underway.

There is evidence from modelling studies that future tropical cyclones could become more severe, with greater wind speeds and more intense precipitation. Projections also indicate as probable an eastward extension of the Atlantic storm-track into Europe. This is the reason for the increase of winds in central Europe, increase in precipitation in Northern Europe. This extension has already been observed in the last decades. A number of modelling studies have also projected a general tendency for more intense but fewer storms outside the tropics, with a tendency towards more extreme wind events and higher ocean waves in several regions in association with those deepened cyclones. Models also project a poleward shift of storm tracks in both hemispheres by several degrees of latitude.

### 3.3.1 Precipitation extremes

IPCC observes “in northern Europe and in central Europe in winter, where time mean precipitation is simulated to increase, high extremes of precipitation are very likely to increase in magnitude and frequency. In the Mediterranean area and in central Europe in summer, where reduced mean precipitation is projected, extreme short-term precipitation may either increase (due to the increased water vapour content of a warmer atmosphere) or decrease (due to a decreased number of precipitation days, which if acting alone would also make heavy precipitation less common). … However, there is still a lot of quantitative uncertainty in the changes in both mean and extreme precipitation.” (Christensen 2007)
Räisänen (2004, p 25) conducted simulations on the changes of extreme precipitation (Figure 5) and observed that “maximum precipitation increases even in most of those areas where the mean annual precipitation decreases. Disregarding the small-scale noise, the change in maximum precipitation varies less between different parts of Europe and the different scenario simulations than the change in mean precipitation... An increase in heavy precipitation in a warmer climate is a remarkably robust model result.”

(iv) Source: Räisänen 2004, p26

Figure 5: Changes (%) in the largest one-day precipitation 2080-2099 compared to 1980-1999, A2 scenario and different climate models

3.3.2 Land Slides

The Climate Change model simulate increases in average precipitation and in precipitation extremes. Since heavy rainfall events are frequent triggering factors for landslides, the following trends can be assumed according to EEA (2010):

- Increase in the number of debris flows from high intensity rainfall, together with soil erosion and degradation phenomena, as a consequence of increases in temperatures and aridity;
- Decline in activity for slow landslide phenomena due to the drop in the total average annual rainfall and the consequent decrease in the recharge capacity of the water tables;
- Increase in deformations of slopes (rock falls due to freeze thaw, debris flows, earth flows) in areas which are now covered by permafrost and
therefore substantially stable, following progressive increases in temperature and the consequent reduction in permafrost and glacial areas. For the time being

### 3.3.3 Avalanches

An analysis of the avalanche records in the Swiss Alps shows that natural avalanche activity has not changed over the last 70 years (EEA 2010). Climate Change is, however, having a more and more pronounced effect at altitudes below 1 000 m, where a significant temporal as well as spatial reduction of snow coverage is already taking place. In contrast, no trend is visible at higher altitudes. Further increases of temperature obviously reduce the period during which large avalanches can occur. However, the occurrence of large avalanches is not governed by general climatic trends but rather by short term weather events, such as particularly intense snow falls during a couple of days, possibly linked with strong winds or a rapid temperature increase with rainfall at high altitudes. Such marked weather periods will possibly become more frequent with climate change. The percentage of wet snow avalanches is expected to increase relative to dry snow avalanches. An increase or decrease in the size of the avalanches should not be expected, as avalanche size is governed by the release height and release area, which are hardly influenced by climatological developments but mainly by the topography and shear strength of the snowpack. From the conflicting tendencies described above — reduced snow coverage as against possibly more heavy precipitation events — it is currently still difficult make a clear scenario projection for the long term development of avalanche hazards under a changing climate.

### 3.3.4 Storm

According to IPCC “extreme wind speeds in Europe are mostly associated with strong winter cyclones the occurrence of which is only indirectly related to the mean circulation. Nevertheless, climate change models suggest a general similarity between the changes in average and extreme wind speeds. Regarding extreme winds, some authors found an increase in extreme wind speeds for western and central Europe. Extreme wind speeds increase for the area between 45°N and 55°N, except over and south of the Alps. This could generate more North Sea storms leading to increases in storm surges along the North Sea coast, especially in the Netherlands, Germany and Denmark. Two models with gust parameterisation estimate an increase of up to 20% of the number of storm peak (defined as gust≥8 Bft) events over Central Europe in the future. Leckebusch (2008) found positive trends for both the severity of storms during the historic period (1960–2000), and under climate change conditions. Additionally an increase in the spatial extent of storms is diagnosed, amounting up to about 10 % between present day and the scenario climate.
Rockel et al (2007) research the change in total number of storm peak events over Europe from 1961–1990 to 2071–2100 for two models as shown in Figure 6. Both models simulate an increase in the number of events over land areas in Western, Central and Eastern Europe. A decrease is modelled in the other parts of Europe, which are mostly over the ocean.

**Model**

<table>
<thead>
<tr>
<th>Model</th>
<th>CHRM</th>
<th>CLM</th>
</tr>
</thead>
</table>

(v) Source: Rockel et al 2007, p 273

Figure 6: Change in total number of storm peaks (gusts larger 8 Bft, in %) 2080-2099 compared to 1980-1999

### 3.3.5 Snow

According to IPCC (Christensen et al 2007) is “the overall warming very likely to shorten the snow season in all of Europe. Snow depth is also likely to be reduced, at least in most areas, although increases in total winter precipitation may counteract the increased melting and decreased fraction of solid precipitation associated with the warming. The changes may be large, including potentially a one-to-three month shortening of the snow season in northern Europe and a 50 to 100% decrease in snow depth in most of Europe by the late 21st century. However, snow conditions in the coldest parts of Europe, such as northern Scandinavia and north-western Russia and the highest peaks of the Alps appear to be less sensitive to the temperature and precipitation changes projected for this century than those at lower latitudes and altitudes.”

Raisänen (2004) conducted simulations on extreme winter temperatures and reveals that in many areas, this change exceeds the average winter warming by a factor of
two or three. This indicates a decrease in wintertime temperature variability. The likely main reason for the large increase in minimum temperature is dramatically reduced snow cover in the scenario simulations. In south-western Europe, notably the Iberian Peninsula, the difference is much smaller than further northeast because snow is rare and the lowest temperatures are relatively high even in the control runs.

RH-A2  RE-A2

Figure 7: Change of the lowest minimum temperature (in °C) 2080-2099 compared to 1980-1999, according to different climate models

As warming increases in the future, mountain regions where snowfall is the current norm will increasingly experience precipitation in the form of rain. For every degree Celsius increase in temperature, the snow line will on average rise by about 150 m. Although the snow line is difficult to determine in the field, it is established that at lower elevations the snow line is very likely to rise by more than this simple average estimate. For a 4°C shift in mean winter temperatures in the European Alps, as projected by recent regional climate model simulations in Europe under the A2 emissions scenario, snow duration is likely to be reduced by 50% at altitudes near 2,000 m and by 95% at levels below 1,000 m.

Where some models predict an increase in winter precipitation, this increase does not compensate for the effect of changing temperature. The extent of continental glaciers is more affected by increases in summer temperature than by possible increases in the amount of winter snow. Even in the presence of great amount of winter precipitation, the glacier may reduce their mass if summer temperature are too high. This may apply to climate projections over the Alps. Reductions in snow cover that will have a number of implications, in particular for early seasonal runoff, and the triggering of the annual cycle of mountain vegetation.
3.3.6 **Maritime ice cover**

The Baltic Sea is likely to lose a large part of its seasonal ice cover during this century. Using a regional atmosphere-Baltic Sea model, the average winter maximum ice extent decreased by about 70% (60%) between 1961 to 1990 and 2071 to 2100 under the A2 (B2) scenario. The length of the ice season was projected to decrease by one to two months in northern parts and two to three months in the central parts. Comparable decreases in Baltic Sea ice cover were projected by other studies.

3.3.7 **Summer temperature extremes**

Climate change has already influenced the frequency and intensity of extreme temperature events. High-temperature extremes like hot days, tropical nights and heat waves have become more frequent. The number of warm extremes has been increasing twice as fast over the last 25 years. This is in line with the general trend in Europe, warming more than the global average. EEA (2010) counts 19 major events of temperature extremes from 1998 to 2009 in Europe.

Along with the overall warming and changes in variability, heat waves are very likely to increase in frequency, intensity and duration (Christensen 2007). The development of summer heat extremes in 1990, 2050 and 2100 are depicted in the ENSEMBLES project (van der Linden P et al 2009) as given in Figure 8. The maps show projected average number of summer days exceeding the temperature (heat index) threshold of 40.7°C. The maps show that the impact in 2050 is still moderate compared to 2100.

![Projected average number of summer days exceeding the apparent temperature (heat index) threshold of 40.7°C](image)

Source: van der Linden et al 2009, p.75
“In summer, the warming of large parts of central, southern and eastern Europe may be more closely connected to higher temperatures on warm days than to a general warming...Interannual temperature variability is likely to increase in summer in most areas. However, the magnitude of change is uncertain, even in central Europe where the evidence for increased variability is strongest. In some PRUDENCE simulations, interannual summer temperature variability in central Europe doubled between 1961 to 1990 and 2071 to 2100 under the A2 scenario, while other simulations showed almost no change. ...Simulated increases in summer temperature variability also extend to daily time scales.” PRUDENCE simulations and find that “a general increase in summer daily temperature variability is evident, especially in southern and central parts of Europe, with the highest maximum temperatures increasing more than the median daily maximum temperature” (Christensen 2007).

### 3.3.8 Droughts

The combined effects of warmer temperatures and reduced mean summer precipitation would enhance the occurrence of heat waves and droughts (Alcamo et al 2007). The risk of drought is likely to increase in southern and central Europe. By contrast, the same studies do not suggest major changes in dry-spell length in northern Europe. Countries in central Europe will experience the same number of hot days as currently occur in southern Europe and Mediterranean droughts will start earlier in the year and last longer. The regions most affected could be the southern Iberian Peninsula, the Alps, the eastern Adriatic seaboard, and southern Greece. The Mediterranean and even much of eastern Europe may experience an increase in dry periods by the late 21st century.

Table 3 presents as well the frequency (%) of dry summers in 2100. While in the North of Europe only 2% of the summers in 2080 to 2099 are expected to be dry, in the South this share reaches 42%. Figure 9 maps the projected change in the difference of maximum dry spell length for the Mediterranean region under the A1B scenario for the time period 2021–2050 relative to the 1961–1990 mean. The largest increase of drought hazard may be expected in Portugal, South West Spain and South Greece.
3.3.9 Wild Fires

The risk of wild fires concentrates not only on the Mediterranean Countries, but affects as well Romania and Poland. Climate Change will induce risk increases similar to the drought risk above: the effects concentrate on selected regions in the Mediterranean: Portugal, West Spain, South Italy and parts of Greece.
4 Criticality Assessment

4.1 Setting the scene

Over the last years, great attention has been placed on the issue of assessing the impacts of climate change and extreme weather events on the society, on several economic sectors and on transportation networks in particular. It is broadly acknowledged that transport constitutes a special field of the overall economic activity, since not only represents a great share of it but also influences and contributes to the regular function and every-day operations of the other sectors. This is the main reason behind the realization of numerous studies, aiming to assess the impacts of extreme weather events on transport networks.

However, when it comes to examine the impacts of extreme weather events to transport networks, many different problems and questions emerge. First of all, transport networks of different transport modes have little similarities, at both constructional and operational level (e.g. the maritime network and the road network). Second, the impacts from transport networks’ malfunctions (or closures) of the various modes differ to the amount of economic losses that cause. This means that there is different magnitude (and thus different economic results) from closing a central rail station of the rail network in comparison to the closure of some kilometres of the national road network. For such kind of different scenarios, the comparison and the evaluation is proved to be an extremely difficult and demanding process. Last but not least, even for the same transport network, it is acknowledged that not all parts of a transport network are of the same importance. E.g. certain ports are more important than others (in terms of size or/and traffic), some parts of the road network are more critical than others etc. It can be concluded that the examination of the impacts from extreme weather events to transport networks conceals a high degree of difficulty in many levels.

In the framework of the current section, the concept of transport networks criticality has been tackled. More specifically, the major contribution is the development of a methodology for assessing the road network criticality. The road sector has been chosen for study case as it can be modelled with sufficient reliability, which is not the case for other modes, due to its dominant role in the transport sector and because of its importance for crises and emergency management. Moreover three countries have been selected as case studies: Greece, Netherlands and Germany. The selection of countries reflects different road transport environments: high dense metropolitan areas (the Netherlands), a structurally diverse country (Germany) and a more sparkly populated country with a challenging topographical environment (Greece).
The proposed method is proved particularly useful for a broad spectrum of cases that include network management, namely from defining suitable adaptation plans for extreme weather events, organizing crisis and emergency management and responding to terrorist attacks to simple traffic information and management procedures.

4.2 Literature review

The performance of transport networks and the criticality of network components have been studied by several researchers. Taylor and D’Este (2007) have proposed a methodology for obtaining the vulnerability of each component of the network. The methodology is applicable on the level of national networks. The authors emphasize the differences between reliability and vulnerability: reliability is related to the connectivity of the network while vulnerability is related to the consequences of failure. In their model, nodes are vulnerable and links have criticality values. An application of the proposed method on the Australian road network is presented. Kim and Lee (2006) identify the crucial infrastructure from national economic functional viewpoint, reflecting the spatio-temporal characteristics of the economy. In the model of Kim and Lee criticality of each link is analyzed for earthquakes, defining zones and using the national highway network and economic data for calculating criticality values. Nagurney et al (2009) propose a new methodology for calculating criticality of network links, using the total demand of the network and the difference in the travel time as consequence of the closure of a link. The notion of network vulnerability in relation to extreme events is presented in (2007). The author proposes not to act in the structural vulnerability “there is no way to reduce the hazard or it is unknown (e.g. for terrorist attacks) and that constructions are already built and maintained in an optimal way” but to act in the functional vulnerability, defined as “the consequential degree and duration of capacity reduction”. The author applies the proposed method in order to identify vulnerable locations of the road infrastructure in a German state, taking the passengers on each link as the potential damage and using the methodology presented in Nagurney et al (2009) for calculating the criticality of each link.

4.3 Criticality of transport networks

4.3.1 The distinction between Transport network criticality and vulnerability

It is important to provide a definition and differentiation between vulnerability and criticality for transport networks. For the scope of the present study vulnerability of a network element is defined as its physical sensitivity to extreme events. Criticality of a network element, on the other hand, is a term associated to the entire network per-
formance, indicating the relative importance of the independent network components: road sections (links) and intersections (nodes) to the entire network efficiency. Thus, criticality answers to the question of which parts of a network are the most ‘important’ (critical) for the regular function of the network, while vulnerability indicates which parts of a network are the most ‘sensitive’.

Therefore, the criticality assessment of a transport network provides a hierarchy of transport network components in relation to their importance, which in combination with vulnerability data or indicators of transport infrastructure, can lead to the identification of the ‘hot-spots’ of the transport system, in relation to potential damages or failures of the network.

4.3.2 Methodological approach for assessing the criticality of transport networks

The overall objective of the proposed methodological approach is to indicate the most ‘important’ (critical) components of a transport system. It is assumed that transport networks (of all modes) can be represented by a set of links and nodes. Thus, the aim is to define which of the respective links and nodes possess the most critical role in the performance of the overall transport system.

To achieve this, a two-level approach is proposed; firstly to assess the criticality of the different transport networks (upper level - networks of different modes) and secondly to assess the criticality of the components of the same transport network (low level - mode internal critical assessment). These two distinct methodological steps are described in more detail hereafter.

4.3.3 Criticality assessment for different transport networks

The output of the first phase depends on the ‘economic importance’ of the respective modes for a specific area extent. The ‘economic importance’ of the different transport modes is defined as the total economic production quantity that is created from the regular function of each transport infrastructure. In order to optimally allocate a certain amount of money for adaptation strategies to different transport modes, the relative portion of the economic product of each transport mode must be computed. The amount assigned to each transport mode is equal to its relative portion of the total social (economic) benefit of transport infrastructures for each area extent. Different socio-economic benefits of modes can be defined as a, b, c, d and e while the relative portion $R_i$ per transport mode is equal to:

$$R_i = \frac{i}{\sum B},$$

where $i=\{a, b, c, d, e\}$,
a, b, c, ..., e the economic benefits (product) of different transport modes

\[ B = \text{economic benefit (product) of each transport mode} \]

\[ \Sigma B = a + b + c + d + e, \]

This simplistic method can provide a first priority setting for resources allocation between the different transport modes (and their respective transport networks). A step further from this priority setting is to define the critical components for intervention in the same transport network.

### 4.3.4 Mode-internal criticality assessment

The criticality assessment of a transport network (and road in particular) is the main contribution of the present section. The proposed criticality assessment is distinguished from the one of different networks, since it can also constitute a stand-alone method. Moreover, it follows a totally different methodological approach depending on the respective transport network mode.

The proposed methodology is applicable specifically for the road networks (and under certain conditions for the rail network as well) since it is the only mode of transport that its infrastructure is very dense (many different options/routes for going from point A to point B) as well as the links of the network need to be constructed (unlike air and maritime transport that the (constructed) network is restricted only to nodes). Therefore the particularity (and difficulty) of assessing the critical components of a road network is obvious, since road constitutes the only mode with these specific characteristics. On the contrary, for the other modes, more simplistic approaches can be adopted, since no traffic assignment procedures are needed, and the criticality assessment is depended totally on the traffic volumes (and their economic impact) of the nodes (ports, airports) and not the links. This is the reason that in the present study the principal objective is to describe a method capable of identifying the critical links of road networks (that can also be used for rail in cases where the network is very dense and alternative (traffic) assignment options exist).

### 4.3.5 Brief description of criticality assessment methodology for road networks

In this paragraph, the link criticality assessment methodology is described briefly, which finds direct applications to the identification of the critical components of the road transport networks. However, it is noteworthy, that due to factors such as land use and case specific special social needs (e.g. isolated islands) the following steps cannot be applied to local networks. For all other types of area extent (regional, national and international networks), the methodology can be applied and provide the valid results. A brief description of the method approach is presented herein:
1. The Origin-Destination demand matrices are assigned on the road network, using given network data (ODs, centroids, connectors, links, nodes). For each OD, demand is assigned on the network according to a user equilibrium criterion.

2. The overall Network efficiency ($\epsilon$) is computed, based on A. Nagurney’s Unified Network Performance Measure, which constitutes the base case scenario (network efficiency with no link closures).

3. One link of the network is removed and the (new) Network efficiency of the road network is computed again. Iteratively, this process is repeated for each link of the network in order to compute the Network efficiency for each removed link.

4. The importance of each network component (link) is computed, based on A. Nagurney’s Network Component Importance ($I$).

This criticality index for each link ($I$) represents the difference of the network’s efficiency after the link(s) removal in relation to the initial (normal) condition of the network. It can be assumed that the lower the $I(g)$ indicator is (values near zero), the more important is the removed link(s) and the higher the $I(g)$ is (values near one), the less important is the link(s) removed. For surpassing this reverse characteristic, the final indicator that provides the significance - importance of each link is provided as:

$$\text{Link Importance (L_im)} = 1 - I.$$ 

A more detailed description of the method, along with the necessary data sets and assumptions is provided in the D2 WEATHER Detailed Report.

### 4.4 Application of the criticality assessment method

Two different applications of the methodology are presented in the following paragraphs. Firstly, the proposed network criticality method has been applied for the criticality assessment of the road networks of Greece, Germany and Netherlands. Then, modeling exercises with hypothetical scenarios of link closures have been conducted for each country for isolating the effect from link deteriorations and closures.

Thus, this chapter will provide getting an idea of the number and the typical location of critical links in European road networks and the order of magnitude of the additional time losses and travel kilometers is the purpose of the following section.
4.4.1 Critical assessment of the road networks of Greece, Germany and Netherlands

The method application has been based on datasets from TRANSTOOLS [5] for the three countries, using VISUM [6] as the traffic assignment computation tool. A detailed description of the datasets used and the basic assumptions is presented in the Annex to the WEATHER Detailed Report. The application of the method to the three road networks provided the hierarchy of the links, based on their importance ($L_{im}$), as presented in Maps 1, 2 and 3 that follow.

4.4.2 Results and conclusions

The assessment of network criticalities for the national road network of Greece provides some first useful indications, in case of link failures (Map1). These are:

1. A general observation is that the main arterial of the national road network is of high importance, as well as the road connections between the main arterial with the inner (urban) network. Especially the connections in the northern Greece, where the density of the network is not high, gain significant importance. This is a very logical result, since possible road closures of these parts of the network will result major detours through the urban and rural road networks.

2. The connections of the main land with Peloponnesus (through the Rio-Antirio bridge and the Athens-Korinthos corridor) are both very significant for the road network efficiency of Greece, since the closure of either one of these connections entails very high detours and delays for drivers (see scenarios of link closures of the next paragraph).

3. Along the main road corridor of Greece from Athens to Thessaloniki, the criticality of the national road network differs in importance. Specifically, the northern part of the national road (approaching Thessaloniki) seems to be more critical than the part near Athens. This interesting result can be explained by the different density of the road network, and namely, a link closure in the broader Athens area will not create many delays due to the different alternatives (roads) that exist. On the contrary, the northern national road network, and especially in the area of Tempi (see scenarios of the next section), does not have many alternative routes and potential link closures at these points could entail major detours and travel time delays.

The assessment of network criticalities for Germany highlights two different types of network parts, which are critical in case of disruption (Map 2). These are:

1. Links around the big agglomerations. From the map the locations of the four most densely urban areas, i.e. Berlin, Hamburg, Cologne and the Ruhr area, Munich and Stuttgart are visible. Here the closure of urban access link will have a great
impact on the overall performance of the network due to the affected traffic volume alone. This is remarkable as usually around big agglomerations the network density is high and thus multiple alternative travel routes exist. But in the case of the listed agglomerations considerable congestion makes these detouring options less attractive or impose even more time losses by adding to anyway critical levels of service.

Relevant connecting rouges in remote areas. Examples from the computation are the route from Munich to Austria in the very south-east, the Baltic sea motorway (A20) around Rostock in the north-east, the connection from Cologne and Aachen to the Netherlands in the north-west or finally the south-western routes through Rheinland-Palatinate and the Saarland to France and Luxembourg. All these routes are characterized by a moderate traffic volume, but little alternatives. Accordingly, detouring is time consuming and thus boosts the criticality indicator upwards.

For the Netherlands (Map 3) the same analysis as for Germany holds:

1. Around the big agglomerations, in particular Rotterdam and Arnheim into the direction of Utrecht is a particularly critical area. This is not surprising as the Port of Rotterdam is the heart of European maritime shipping and at the same time an important population centre. Surprisingly not all of the heavily congested Randstad region is equally critical in terms of road closures, which confirms the conclusion that the specific role of the Rotterdam port strongly determines the model outputs.

2. Following the pattern identified for Germany, the critical inter-urban links can be identified in rather sparkly populated remote area. Such, the criticality assessment delivers the road link between Zwolte and Assen / Groningen in the north and from Einthoven and Venlo to Germany in the south-western corner of the country as particularly costly in terms of deterioration or closure.
Figure 10: Criticality assessment for the network of Greece
Figure 11: Criticality assessment for the network of Germany
Figure 12: Criticality assessment for the network of Netherlands
4.5 Application of the method for simulating scenarios of road failures in the three networks and assessing the impacts

In this application, various scenarios of link closures have been tested for calculating and comparing the impacts on the networks. For each scenario, the new traffic volumes and the respective travel times were calculated, providing useful insights in relation to the different groups of links. The overall results for each scenario are presented in Table 1 that follows. A more detailed presentation of the results is provided in the Annex of the WEATHER Detailed Report.

The methodological approach followed the same rationale; a first scenario ran in VISUM for the road network of each country, which constituted the base case scenario (with no link closures - normal conditions). All base case characteristics of the road networks were computed (total veh/kms, veh/hours). Then, iterative runs have been realized, one for each different scenario (group of links closure). Each scenario has given different results in terms of time delays (in comparison with the base case scenario), total veh/kms and total veh/hours realized.

The results shall provide additional detour distances and times by network characteristic and demand level to the assessment of costs of extreme weather events in the road sector. Further the results shall raise general awareness towards impacts of extreme weather events, which might get more severe and more frequent in the future.
### Table 4: Results for the base case scenarios (with no link closures)

<table>
<thead>
<tr>
<th>Country</th>
<th>No of links modeled</th>
<th>Total length (kms)</th>
<th>Total Vehicle Kilometers (annual, in millions)</th>
<th>Total Vehicle Hours (annual, in millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>6.540</td>
<td>53.935</td>
<td>142.703,03</td>
<td>1.500,72</td>
</tr>
<tr>
<td>Netherlands</td>
<td>1.336</td>
<td>7.842</td>
<td>35.919,68</td>
<td>510,91</td>
</tr>
<tr>
<td>Greece</td>
<td>415</td>
<td>8.811</td>
<td>8.686,85</td>
<td>82,83</td>
</tr>
</tbody>
</table>

### Table 5: Overall presentation of results from different scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Number of closed links</th>
<th>Length of closed links (kms)</th>
<th>Number of vehicles affected (annual, in millions)</th>
<th>Increase of Vehicle Kilometers (annual, in millions)</th>
<th>Increase of Vehicle Hours (delay) (annual, in millions)</th>
<th>Percentage Increase of Vehicle Hours (delay) (annual, in millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany - Motorway A8 (Stuttgart - Ulm - Augsburg - Munich)</td>
<td>3</td>
<td>18.613</td>
<td>17.19</td>
<td>161.85</td>
<td>3.03</td>
<td>0.20%</td>
</tr>
<tr>
<td>Germany - A5 Mannheim to Switzerland (Rhine Axes)</td>
<td>3</td>
<td>18.814</td>
<td>13.09</td>
<td>307.38</td>
<td>15.46</td>
<td>1.03</td>
</tr>
<tr>
<td>Germany - Hamburg Elbe Bridges with Link to Lübeck and Berlin</td>
<td>4</td>
<td>23.274</td>
<td>27.23</td>
<td>140.76</td>
<td>5.28</td>
<td>0.35%</td>
</tr>
<tr>
<td>Germany - A5 Berlin: Motorway Access from Potsdam / western Germany</td>
<td>6</td>
<td>35.04</td>
<td>-38.34</td>
<td>63.65</td>
<td>4.02</td>
<td>0.27%</td>
</tr>
<tr>
<td>Germany - Ruhr Area - Cologne: Several parallel links</td>
<td>6</td>
<td>28.33</td>
<td>43.01</td>
<td>175.73</td>
<td>10.74</td>
<td>0.72%</td>
</tr>
<tr>
<td>Germany - Motorway and parallel national routes Dresden - Berlin</td>
<td>5</td>
<td>43.96</td>
<td>29.23</td>
<td>-38.99</td>
<td>5.86</td>
<td>0.39%</td>
</tr>
<tr>
<td>Germany - Dutch border, Aachen, Düren</td>
<td>5</td>
<td>15.44</td>
<td>36.83</td>
<td>-22.75</td>
<td>2.84</td>
<td>0.19%</td>
</tr>
<tr>
<td>Germany - Munich - Rosenheim - Austrian border (Brenner)</td>
<td>6</td>
<td>62.04</td>
<td>28.41</td>
<td>70.50</td>
<td>4.80</td>
<td>0.32%</td>
</tr>
<tr>
<td>Netherlands - South-West Netherlands</td>
<td>2</td>
<td>15.66</td>
<td>5.59</td>
<td>286.39</td>
<td>4.94</td>
<td>0.37%</td>
</tr>
<tr>
<td>Netherlands - South Netherlands</td>
<td>3</td>
<td>35.76</td>
<td>49.63</td>
<td>173.59</td>
<td>14.52</td>
<td>2.92%</td>
</tr>
<tr>
<td>Netherlands - Central Netherlands</td>
<td>4</td>
<td>28.36</td>
<td>83.22</td>
<td>1,080.71</td>
<td>41.01</td>
<td>8.03%</td>
</tr>
<tr>
<td>Netherlands - North Netherlands</td>
<td>4</td>
<td>95.26</td>
<td>31.85</td>
<td>524.22</td>
<td>21.04</td>
<td>4.12%</td>
</tr>
<tr>
<td>Netherlands - North-East Netherlands</td>
<td>1</td>
<td>8.92</td>
<td>6.34</td>
<td>88.85</td>
<td>1.42</td>
<td>0.28%</td>
</tr>
<tr>
<td>Greece - Rio-antig</td>
<td>1</td>
<td>3</td>
<td>3.52</td>
<td>2,000.77</td>
<td>35.33</td>
<td>29.90%</td>
</tr>
<tr>
<td>Greece - Athens-Korinthos</td>
<td>1</td>
<td>52</td>
<td>10.12</td>
<td>700.58</td>
<td>8.16</td>
<td>8.96%</td>
</tr>
<tr>
<td>Greece - Tempi</td>
<td>1</td>
<td>80</td>
<td>2.93</td>
<td>101.32</td>
<td>1.86</td>
<td>2.20%</td>
</tr>
</tbody>
</table>
5 Workshop 1: Transport System Vulnerability

To date, two workshops have been carried out in the framework of the WEATHER project turning around the topic of transport sector vulnerability to climate and weather:

- Kick-off workshop 17.11.2009 in Brussels and
- Workshop 1, 14.9.2010 in Brussels

The following paragraphs provide a brief overview of the contents of the workshops. The respective presentations may be accessed through the weather website at [www.weather-project.eu/weather/inhalte/proj-events.php](http://www.weather-project.eu/weather/inhalte/proj-events.php).

5.1 The Insurance Sector

At the WEATHER kick-off workshop on November 17th 2009 in Karlsruhe, Petra Löw (Munich-RE) emphasized the climate change research for the insurance business. The NatCatSERVICE database contains roughly 26000 entries back to 1950 and covers overall and insured losses, but does not differentiate between sectors. The main driver for the strong increase of damages and victims reported are socio-economic factors rather than climate change. But the extraction of climate trends is enforced in cooperation with the London school of Economics. Main difficulties are encountered with national biases in data reporting and the long delays in data provision, which in some cases exceeds 10 years. Transport is generally encoded under the heading “marine business”; specific evaluations of transport losses in the heat summer 2003 lead to insured losses due to the interruption of transport activities of €40 million.

5.2 Road and urban public transport

Among the various climate conditions affecting the Swedish road sector, Kenneth Natanaelsson (Trafikverket) lists temperature, rainfall, wind, winter, flooding and sea level rise. But among these impacts related to water are the most costly. A detailed assessment of landslide activity raises major safety concerning in the southern Part of Sweden already in the near future. Major impacts of storm surges and intensive rain on small catchment areas on bridge will cause high costs. Improvement of competences and knowledge on vulnerabilities and the review of rules and regulations is the necessary way forward to prevent from major losses. Presented is the Swedish risk assessment model including direct and indirect risk, such as the impact of delayed or cancelled trips on companies and their reputation).

©©Roberto Arditi (SINA on behalf of ASECAP, the Association of European Toll Motorway Operators) highlights the importance of roads to access emergency areas,
commonly substituting other modes. Thus, the restoring of road sections may be very rapid, as in the case of the Autostrada Turin – Milan after the summer flood 2000 taking only 14 days. A means of increasing knowledge on infrastructure conditions and damages is the equipment of vehicles with LASER measurement technology for high-speed road observation and the instant generation of digital maps through point clouds. In snow conditions motorway capacity per lane may drop by 75%, entailing long-range traffic obstructions. Due to climate change the number of very hot days will increase with impacts on road construction practices and the thermal expansion of bridge joints and pavements. On the other hand a decrease in very cold days may positively impact snow removal costs and the environmental impact from salt. But the main problems will be encountered with increased precipitation causing floodings, overload of drainage systems, wash-out, landslide affecting the structural integrity of roads, bridges and tunnels.

Matthew Webb (TfL) presented TfL’s strategy for assessing and adapting to climate change. Climate conditions assumed until 2050 include temperatures rise by 3°C with -30% to -40% rainfalls in summer, +1.5 to -2.3°C and +25% to -30% rainfalls in winter, rising sea level and more extreme events. Most penalising events in the recent past were the summer heat 2003, 2007 rainfalls and the longest frost and snow periods in the two past winters (2009/2010 and 2010/2011. The list of risks of assets to climate change identified by TfL embraces tracks, drainages, bridges, embankments, signals, stations, green estate, surface and interchanges. Most important in the process of adapting to changing climate conditions is the internal and external communication, time table setting, emergency planning and the consideration of customer comfort. Existing activities by TfL include flood risk assessment, road drainage works, underground groundwater management and tunnel cooling. Early results from TfL’s risk assessment report suggest that all weather risks, including heat, snow and ice, and high winds are manageable with some consideration in the rail sector. Concerning underground very hot days and rain and flooding are serious risks with a very high likelihood to occur in the future and a high impact level.

5.3 Rail and intermodal freight transport

In the second session on railway and intermodal transport at the September workshop Chris Baker (University of Birmingham) discussed findings of the FUTURENET project funded under UK’s EPSRC “Adaptation and resilience to climate change” programme. The effects of high temperatures on track (buckling, etc), the effects of high rainfall on earthworks, the effects of extreme precipitation levels on current drainage systems, and the effects of extreme winds on the overhead system are the major effects that are
likely to be of concern to the railway industry in future. Hot dry summers impact the UK rail system by increased track buckling, desiccation of track earthworks, increased ventilation problems on underground railway systems and increased vegetation because of longer growing season. Warmer, wetter winters cause increased surface water and flooding and increased frequency of landslips, scours and washouts. Related costs in the London underground system between 1999 and 2004 caused costs due to passenger delays of around €10 million. Increasing in the frequency of extreme storms including intense rainfall and extreme winds increase the likelihood of dewirement, of train overturning derailment and of accidents or network disruption and track blockage. The FUTURENET project looks at these impacts in detail and seeks to work out solutions to improve the resilience of UK transport systems to changing climatic conditions.

French experiences with the vulnerability of railway infrastructure was presented by Samuel Brunet (RFF). Problems encountered include increased rain- and snowfalls resulting in damage on earthworks and structures, more and more serious storms resulting in troubles in electric and signalling systems and causing in tree falling and catenary injuries. Humidity affecting tunnel and earthwork fragility, and flooding imposing additional risk on embankments, fundaments, seawalls and electric facilities and further consequences of changes in precipitation patterns. Temperature-related problems include heatwaves as well as general changes in temperature (rail dilatation, electric systems failures). Consequences include dryness with increased risks for structure fundaments on clay and nearby rivers. On the contrary, coldwaves cause rail contraction, problems with catenaries and ice in electric systems. A study assessing the three main lines in the Aquitaine Arc (Bordeaux) should be finalised by the 2nd quarter of 2011 with similar studies to follow.

Turning towards combined road-rail freight transport, Martin Burkardt (UIRR) stresses the several problems railway operations encounter under adverse weather conditions. Weather extremes have effects on infrastructure (e.g. lines, overhead lines), on terminal operation (swinging loads), on rolling stock and on loading units due to falling trees/branches, inundation of rail tracks and routes. Because of storms accompanied with falling trees etc. there are delays or stops of operation. Transalpine Railways have to handle landslides, avalanches and storms. Due to weather extremes transalpine railways close tracks in winter. Example: in the year 2002 there were landslides on the route line Bellinzona - Luino - Gallarante (DE – CH – IT) – the landslides cause two closure of this route for several weeks. Afterwards to line Bellinzona – Luino – Gallarante was reconstructed with galleries and fixing slopes. The monetary impact of operational disruptions and infrastructure damages are widely unknown and should be approached by current research activities.
5.4 Air transport

Henrik Littorini (Swedavia) highlights two reports dealing with the consequences of climate change for the Swedish air transport sector: “Vulnerability analysis report from the aviation sector” (LFV, Swedish Civil Aviation Authority, 2007) and “The Consequences of Climate Change and Extreme Weather Events” (Swedish Government Official Report, 2007). Among the several weather and climate impacts assessed by these reports, in the past decade storms during winter season are the main extreme weather events that has (during short periods of time) affected Swedish air traffic. The main problems of heavy snowfalls are visibility, friction and passenger access to the airports. While current measures include a over-dimensioning of snow clean-up and cooperation with road and rail authorities, climate forecasts indicate less snowfall for Scandinavia. Flooding and sea level rise is only considered problematic for a few smaller airports with old or under-dimensioned storm water systems and drainages. in the coming 50 years adaptation costs of €20 million are estimated to cope with the projected increase in precipitation, but these will largely part of continuous renovation activities. Frost is the main determinant for the dimensioning of runway superstructures. As climate models indicate warmer winters there are not additional costs of climate change to be expected. The problem of ice is more differentiated: there will be more days calling for de-icing and skid prevention, but less in the southern part. The overall need for de-icing and skid reduction will thus decrease, associated with cost savings of €5 million annually in 2050. A major problem for aviation are thunderstorms causing cross-winds and the drop of power supply. The lack of alternative airports in easy reach, the non-availability of reserve power systems and the dependency on computer systems makes airports particularly vulnerable. Adaptation costs are probably high, while information of climate models on the development of thunderstorms is hardly available. Finally, ash is raised being a problem to different parts of aircraft, as the measurement of ash concentration is still not satisfying and due to lacking co-ordination in the European airspace.

The perspective of air traffic control was introduced by Rachel Burbidge and Dennis Hart (Eurocontrol) by stressing on the impacts of the past winter. Reported are drops of aircraft movements by 0.5% in Frankfurt and heavy delays, cancellations and flight rerouting in Paris. The seasonal difference in weather-related ATFM-delays are considerable: the shares at all AFTM delays have e.g. varied between 17.6% in December 2009 to 55.0% in January 2010, clearly indicating the winter storm Daisy over Europe. But ATFM delays are primary delays which are the result of an imbalance between demand and available capacity en-route or at airports and thus depend more on airport and en-route capacities than on weather. At annual primary departure delays roughly 4% are due to AFTM-related weather and another 6% are reported weather delays by
the airlines. Total annual delay costs amounted to €1.5 billion in 2008. Future challenges of ATC are three times more traffic, safety and environmental improvements by 10% while cutting costs by 50%. This shall be reached by a co-operative trajectory management of flight paths. Therefore, MET services need to move from a problem-focused view and the wait-and-see approach using information systems designed in the 1950s towards as system of “mapping uncertainty with a high level of confidence”. In this system weather delays will not be prevented, and thus become more predictable. Climate change was considered a problem for the first time in the Eurocontrol work “Challenges of Growth” 2008 by discussing sea level rise impacts for airports, increased storminess and climate-driven demand changes. In Europe 34 airports are at risk through sea level rise with impacts on runway capacity, ground transport access routes and global knock-on effects. A useful indicator for storminess is the Convective Available Potential Energy (CAPE), indicating a strong increase (3 days / a) until 2020, but a potential fall under current conditions until 2050. For spring and autumn predictions show significantly increasing trends until 2020 as well as 2050.

5.5 Inland navigation and maritime shipping

In a final session Nina Nesterova and Jan Kiel presented the study teams approach to address the economic costs of weather extremes for inland navigation and maritime shipping. The main treats identified for IWW are droughts, floods and ice periods, causing suspensions of navigation and imposing considerable costs to the future development of the sector. For maritime shipping the main stresses are heavy rain, storms, floods and ice periods. Infrastructure damage statements of the ports and insurance reports will most likely uncover considerable burdens.
PART B: MODAL ASSESSMENTS

6 Road infrastructure and operators

6.1 Evidence from literature

A literature review was conducted on the impacts of extreme weather conditions on the road sector. The review revealed that a large number of studies had been conducted in the USA, Australia and New Zealand, while European research may be regarded as rather piecemeal.

1. Damages to infrastructure assets: Various studies from North America and Australia estimate the weather impacts on the road infrastructures. The shares vary from 10% to 72% which is due to the different climatic conditions and road types. Damages may be caused by (i) precipitation and floods, (ii) storms, and (iii) winter conditions. Even though large evidence from North America and Australia is provided, general conclusions costs are difficult to draw, since local conditions vary, and often special events are described.

The US Federal Highway Administration estimates the repair costs on its network caused by snow and ice at 5 bn US$ annually. With an average of 81 frost days, the damages amount to 62 m US$ per frosty day. One of the most severe weather conditions caused extensive flooding in parts of England in from December 2009 to January 2010 and March 2010. The total cost to return the road network to its prior condition amount to £3.743m, which is 5,714 £ per kilometre. The effects of strong winds are rarely researched. However, some evidence from the hurricane Katrina in New Orleans 2005 might be used as exemplary evidence.

2. Infrastructure management and operations: Winter maintenance is an essential cost component of infrastructure management and operations. Norway spends roughly 30% of its maintenance budget for winter maintenance, Slovenia reports a share of 50%, while in Switzerland these costs can amount to 15% - 25% of total annual maintenance costs.

In Germany winter maintenance on federal roads ranges between 2,000 and 10,000 Euro per kilometre on highways. Average cost amount to 5,000 €/km on motorways and 1,300 €/km on land highways. A regression over the number of snow days reveals that on motorways the fixed annual costs amount to €4251 per km and variable costs
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per snow day of €99. In result we receive 28% weather-related costs at motorways and 25% at federal trunk roads.

3. **Vehicle assets**: The literature on weather impacts on vehicle assets is scarce. Some evidence may be found about hail storms. A thunderstorm in Australia in 1999 entailing winds, rains, and in particular, a large hail, damaged 24,000 homes and 70,000 automobiles along its path. The insured loss totalled AUD$1.7 billion (US$1.04 billion), and this cost remains the largest absolute insured loss in Australian history. The damage costs for hail on cars may be considerable. Car receive 30-400 dents during a hail storm. Insurances prefer a method to mechanically buckling the dents without destroying the varnish of the car. The costs in Europe amount to 40-70€ per dent. Thus minimum costs amount to 1200 Euro. The insurance costs for hail damages in the USA amount to 2000-3000 US$.

4. **Safety issues**: Even though research has shown that motorists adjust their road behaviour during bad weather, there is overwhelming evidence, that accident risks increases during rains and snow. In this case the research evidence stems from Europe countries: Research in the Netherlands which gives clear indications that precipitation and temperature are the most important factors, when examining the relationship of weather and road safety in both summer and winter. A great amount of precipitation, as either rain or snow, generally accompanies a higher victim rate for all modes of transport, and a smaller exposure, especially for cyclists.

The more rain, snow, or hail falls, the less the friction of the road surface. Rain can lead to dynamic aquaplaning. A layer of water on the road surface can cause the vehicle to lose contact with the road surface and to skid. The chance of aquaplaning depends on the skidding resistance of the road, but of course also on the vehicle’s speed and tyre tread depths. Based on literature, one can assume that the crash rate approximately doubles during rain.

Research in the USA. reveals that in terms of crash frequency, rate, and severity; wet weather is far more dangerous than winter weather. Drivers travel much slower when faced with winter weather, compared to rainy weather. However, ice on Dutch National State Roads increases the number of accidents of between 77% and 245%. These findings are confirmed through research in the USA.

Evidence linking high temperatures to road crashes is sparse. A German study found out that with increasing heat above 27° the average accident rates in urban areas increases by 11%, with 32° by 22%. In rural areas the increase is much lower. Here extreme heat above 37° increases accident rates by 18%.
5. Congestion and delays: Research on the impacts of bad weather conditions on road congestion and delays has been intensively done in the USA, while little evidence may be found in Europe. The US Federal Highway Administration concludes that rain causes wet pavement, which reduces vehicle traction, manoeuvrability, visibility distance and thereby prompt drivers to travel at lower speeds causing reduced roadway capacity and increased delay.

Various studies in the USA reveal traffic flow reductions due to winter conditions. The flow reductions range between 7% and 56% and speed reductions between 3% and 40%. Research in Europe observes reduced traffic speeds by 7% in the Netherlands and capacity reduction by 10%-60% during snowfall on German motorways.

Research in the Netherlands reveals that strong winds reduce traffic speed by about 3 percent on average. During rains speed are reduced by 2%-17% according to several studies in the USA.

6. Impacts of Climate Change on the Road Sector: Warming winter temperatures will bring about reductions in snow and ice removal costs, lessen adverse environmental impacts from the use of salt and chemicals on roads and bridges, extend the construction season, and improve the mobility and safety of passenger and freight travel through reduced winter hazards. Expected increases in temperature extremes, however, will have less positive impacts. More freeze–thaw conditions may occur, creating frost heaves and potholes on road and bridge surfaces and resulting in load restrictions on certain roads to minimize the damage. With the expected earlier onset of seasonal warming, the period of springtime load restrictions may be reduced in some areas but is likely to expand in others with shorter winters but longer thaw seasons. Periods of excessive summer heat are likely to increase wildfires, threatening communities and infrastructure directly and bringing about road and rail closures in affected areas. Longer periods of extreme heat may compromise pavement integrity (e.g., softening asphalt and increasing rutting from traffic) and cause thermal expansion of bridge joints, adversely affecting bridge operation and increasing maintenance costs.

The most immediate impact of more intense precipitation will be increased flooding of coastal roads. Low-lying bridge and tunnel entrances for roads, rail, and rail transit will also be more susceptible to flooding, and thousands of culverts could be undersized for flows. Engineers must be prepared to deal with the resulting erosion and subsidence of road bases and rail beds, as well as erosion and scouring of bridge supports. Interruption of road traffic is likely to become more common with more frequent flooding. When precipitation falls as rain rather than snow, it leads to immediate runoff and increases
the risk of floods, landslides, slope failures, and consequent damage to roadways, especially rural roadways in the winter and spring months.

### 6.2 The incident cost database

To bridge the non-availability of systematic damage records in the largely public European road network we have conducted a review of press and transport sector publications in Germany, Austria, Switzerland, Italy, the Czech Republic and the UK, containing 974 incident reports for the years 2000 to 2010. In conjunction with the evidence from literature and further data sources, the damage cost database shall help the entrepreneurial and social costs of extreme weather events to infrastructure providers, transport operators, users and society.

Where not directly reported, entrepreneurial and social costs were assessed by a set of standard cost values. These are defined along weather extreme and consist of simple, as well as more complex composite events and provide default costs to each of the six transport sector elements. The sections in turn go through selected assessment principles of the standard cost values and their generalisation:

**Road infrastructure assets** are subject to multiple stress factors, including traffic, physical aging and weather. We distinguish between sudden destructions due to floods or storms, where we apply 50% of the gross asset value for age deterioration, and partial damages, were usually traffic, insufficient maintenance and weather are responsible for damages. Here we deduct the weather-related share by another 50%.

**Table 6: Evaluation principles for infrastructure assets**

<table>
<thead>
<tr>
<th>Event category</th>
<th>Type of impact</th>
<th>Net cost value</th>
<th>Cost allocation</th>
<th>Regional disparities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flood</td>
<td>Inundation and landslides on roads and bridges</td>
<td>Average damage data from ASFINAG (AT), CZ, FR (Loire 2000) and DE (Elbe 2002)</td>
<td>Sudden damage, mainly repair costs: 100% allocation to weather</td>
<td>Assessment of specific events; differentiation by GDP/capita</td>
</tr>
<tr>
<td>Storms</td>
<td>Mainly damages to bridges</td>
<td>Data from US (Katrina, Rita 2005)</td>
<td>Continuous deterioration (50%) and mix of impacts (70% weather related)</td>
<td>Higher gross damage with lower allocation per frost day in southern areas</td>
</tr>
<tr>
<td>Winter conditions</td>
<td>Deterioration of pavements and main course</td>
<td>Damage reports from German communities: 7800€/km average, 2000€/km coastal area</td>
<td>Continuous deterioration (50%) and mix of impacts (70% weather related)</td>
<td>Higher gross damage with lower allocation per frost day in southern areas</td>
</tr>
<tr>
<td>Heat</td>
<td>Softening, cracking and bubbles in pavement</td>
<td>Standard pavement costs from German accounts (500 k€/km)</td>
<td>Age (50%) and weather (Australia / US): 40%</td>
<td>Only relevant for central Europe and Scandinavia</td>
</tr>
</tbody>
</table>
**Infrastructure operating costs** contain costs of public administrations for traffic control or the removal of trees and other objects from the roads after storms and floods. Here, average values for public services are estimated. The dominating cost block, however, is winter maintenance. Here a regression of maintenance costs for German roads over seasonal snow days delivered valuable costs of €99 per snow day for motorways and €22 for trunk roads.

Table 7: Evaluation principles for infrastructure assets

<table>
<thead>
<tr>
<th>Event category</th>
<th>Type of impact</th>
<th>Net cost value</th>
<th>Cost allocation</th>
<th>Regional disparities</th>
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</thead>
<tbody>
<tr>
<td>Flood</td>
<td>Traffic police and clearing of road section</td>
<td>Public service costs around 10'000 €/day and section</td>
<td>Full allocation to event (marginal costs)</td>
<td>Relevant across all EU; no major differences</td>
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<tr>
<td>Storms</td>
<td>Traffic control, removal of items (trees) on roads</td>
<td>8000 €/day and section, 500 €/fallen tree</td>
<td>Particularly for storm surge areas (western Europe, UK/IE))</td>
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<tr>
<td>Winter conditions</td>
<td>Snow and ice control; recording of accidents and medical services</td>
<td>Per road-km 1500€ (local roads) - 6000€ (motorway)</td>
<td>30% of average costs: 500€/km – 2000 €/km</td>
<td>Scandinavia: similar; Mediterranean: lower</td>
</tr>
<tr>
<td>Heat</td>
<td>Some traffic control after</td>
<td>Not relevant</td>
<td>Not relevant</td>
<td>Central Europe only</td>
</tr>
</tbody>
</table>

In case of private road transport **vehicle operating costs** in first instance consist of the costs of fuel consumption due to stop-and-go traffic and detouring of closed road sections. From statistics of the German Automobile Club (ADAC) and the Association for haulage, logistics and disposal (BGL) we derive marginal operating and fuel consumption costs of 0.23 €/km for cars and 0.70 €/km for lorries.

The assessment of user time and safety costs is based on (Maibach et al. 2008). For detours and wait time values of travel time savings of €11/pass-hour and €36/lorry-hour are assumed. Safety impacts are assessed by a standard risk value of €1.63 million per fatality, €212 thousand for severe injuries and €16300 for slight, of which 30%, 70% and 100% respectively are allocated to weather issues.

Figure 13 presents the very aggregate results of the road cost model for this period. Total weather-inflicted costs are estimated with €3.4 billion for the six countries within the past decade or €343 million per year. Formally, these costs apply to roughly 230 million inhabitants representing 44% of EUR29 population, 24% of its road network, 47% of domestic haulage and 51 of passenger kilometres on roads.
The media review is biased by data availability on country level, but the results provide a good basis for analysing the most penalised transport sector elements and the most expensive weather categories. Exceptions are storms at the North Sea coast and heat, were additional information is expected from the weather case studies.

6.3 The hybrid model for cost generalisation

The incident database (IDB) results were generalised to the European level through the consideration of country-specific indices of extremes derived from the ESPON project, GDP per capita, as well as road network lengths and vehicle kilometres.

In parallel, literature findings have been utilised to establish cost estimation and transfer rules for a number of weather impacts on transport. This “extremes elasticity model” (EEM) derived average cost figures per network or vehicle kilometre and related to the duration and intensity of extremes. The latter was derived from the ECA&D database. For each of the 29 countries extremes for ice days (Tmax<0°C), slow days (snow cover >1 cm) and heat days (Tmin>20°C) were defined via the 90 percentile year in the period 1960 to 2010. Very heavy precipitation days (>200 mm) were taken as such as extremes.

The final results for road transport are composed of both data sources, the Incident Databas (IDB) and the Extremes Elasticity Model (EEM). Table 8 illustrates the combination of the two sources.
Table 8: Data availability for cost generalisation

<table>
<thead>
<tr>
<th>Overview of the availability of cost estimates in road transport due to extreme weather conditions:</th>
<th>Rainfalls</th>
<th>Floods/flash floods</th>
<th>Mass movements</th>
<th>Extratrop. cyclones</th>
<th>Storm surges</th>
<th>Hall and hail storms</th>
<th>Frost periods</th>
<th>Snow</th>
<th>Winter Storms</th>
<th>Heat periods</th>
<th>Droughts</th>
<th>Wild fires</th>
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<tr>
<td>EEM: Extremes elasticity model</td>
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<td>IDG: Incident Database Generalisation</td>
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<td>Infrastructure assets</td>
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<td>Infrastructure operations</td>
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<td>Vehicle assets</td>
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<td>Transport service operations</td>
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<td>Safety issues</td>
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<td>Congestion and delays</td>
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Data sources: EEM IDB Both No data Irrelevant

6.4 Total costs for Europe 2010

Total costs amount to roughly €1.8 billion in an average year. Related to passenger and freight performance in the 29 countries considered, this is roughly 0.1 €-Cent per vehicle kilometre. To put this value into relation: motorway tolls in many European countries raising them range between 5 and 10 €-Ct./km. Moreover, the costs of CO₂ emission amounts to roughly 1 €-Ct/vehicle-km.

Heavy rain and floods account for the highest mean annual costs, followed by winter conditions with only little difference. Both account for roughly €800 million annually. Storms and storm surges (€175 million) and heat, drought and wild fires (€47 million) appear of comparably limited importance.

By far the most hit transport sector element are infrastructure assets (53% of total costs), followed by user time losses (16%) and safety implications (13%). Looking at both dimensions, rain and flood impacts on road infrastructure, accounting to 35% of total costs, dominate all other consequences of weather extremes. Most affected related to vehicle kilometres are Scandinavia and France.

Turning towards the regional distribution of costs we can identify the hot spots for weather extremes in the central altitude of continental Europe reaching from France to
Mid Europe and the alpine region. The low values for the British Islands and East Europe can be explained by the data situation of the incident database.

Figure 14: Generalised costs by sector element and weather category

![Annual mean costs by type of extreme](chart1.png)

Figure 15: Generalised costs by climate region and category of extreme

![Annual mean costs by climate zone](chart2.png)

Given the incompleteness of data and the generally high uncertainties it is important to note, that these rough cost estimates can only denote extremely coarse house numbers of the true costs of weather extremes to their current extent. But even if the true range is between one and three or even four billion Euro annually the significance towards other cost categories will not alter.
7 Rail infrastructure and operators

7.1 Evidence from literature

The latest review of high summer temperatures due to climate change on buckling and rail related delays in the south-east Kingdom is provided by the FUTURE-NET project (K. Dobney, C. J. Baker, A. D. Quinn and L. Chapman, 2009). Estimates have shown that 20% of all unplanned delays on the UK rail network are the cause of present day adverse weather conditions. Due to climate change weather related problems such as buckling, flooding due to inadequate drainage, sudden earthworks failure, scour at the base of bridges and damage to overhead wires; Eddowes et al., 2003) will occur with increasing frequency on the network.

Increased incidences of rail buckles are associated with extreme high temperatures. In the UK extreme high temperatures becoming an increasingly frequent occurrence. As a consequence of extreme high temperature the number of buckles, and therefore delays, will increase if the track is maintained to the current standard.

A buckle is any track misalignment serious enough to cause a derailment (ORR, 2008). Although railway track is pre-stressed to withstand a reasonable temperature range (Chapman et al., 2006, 2008), extremes of temperatures can cause both jointed track and continuously welded rail to buckle due to the forces produced by the metal expanding. The threshold at which a rail may buckle is highly dependent on the condition of the track. Tracks in good condition would not be expected to buckle until 39°C ambient air temperature. In contrast for track in bad condition the track is at risk at 25°C.

An additional increase in delays can also be noted at lower temperatures. Cold weather poses an alternative set of problems for the rail network such as frozen points, and damaged rails due to tension cracking.
Figure 16: Number of delay minutes attributable to ‘buckle’ events recorded in the ADB\(^1\) for London and the south-east and the maximum temperature reached on the day of occurrence.

![Graph showing the relationship between maximum daily temperature and delay minutes.]

**Weather analogues: the 2003 heat wave**

August 2003 was an exceptionally hot month in Europe and caused a great deal of damage in many sectors. This extreme weather can clearly be detected in the ADB where 137 railway buckles were reported compared to the long-term average of 30 in the south-east region of the United Kingdom. From the period between 14 May and 18 September 2003, 165 000 delay minutes were considered attributable to heat-related incidents. This figure is significantly higher than for the summer of 2004 which is considered ‘normal’ with only 30 000 delay minutes recorded. The difference between the 2 years is largely attributed to the exceptionally hot conditions during August 2003.

The cost of the 130 000 additional delay minutes was estimated to be in the region of £2.2 million, which gives an average outlay of £16.70 per delay minute. However, this figure is conservative. It is based on UK-wide averages used to derive the cost of a delay minute based on train-related delays. It does not include the cost of materials or labour for infrastructure repairs. An analysis of the cost of weather related seasonal delays performed by Rail Safety and Standards Board used a notional value of £50 per delay (Eddowes \textit{et al.}, 2003). The evident limitations of deriving a cost based solely on average train and passenger profiles indicates that using the value of £50 cost per delay minute will produce more realistic costing.

\(^1\) ADB (alterations database) is a record of all incidents that have caused delay minutes on the railway in the United Kingdom.
7.2 Cost estimation methodology

Entrepreneurial costs. Extreme weather events have been selected out of the gathered databases and media reviews. Data entries have always been clustered to one weather event. So for instance all cases described in the Swiss database that belong to one weather event are clustered and finally summed up to one cost value (even if the costs have been calculated for each case separately).

Infrastructure damages. Rail infrastructure damage or replacement costs are either taken over from existing data bases and information from media reports or calculated for those cases where damage or replacement costs are not reported.

The calculation for these damages without existing cost information is based on the following indicators:

- Replacement costs per average track-kilometre (not network-kilometre!)
- Information on destroyed network-length
- Information on type of network (single-track or multiple track respective main line or secondary line)

Increased service operation costs. Increased operating costs can be caused by different reasons:

- Detouring costs of passenger transport (costs for rail replacement bus services)
- Revenue loss if passengers are not able to use the railway at all (no installation of a rail replacement bus service) or if passenger use other modes (private cars) or cancel their trips due to missing "normal" rail services.
- Detouring costs of freight transport (detouring of long distance freight via other rail routes)
- Costs for cleaning up the rail track due to heavy snow falls

Costs for Cleaning up of tracks. The last part of the operation costs to be considered are only relevant for closure of rail tracks due to heavy snow fall – the necessary additional snow cleaning to be able to open the tracks as soon as possible. For this calculation it is necessary to know the affected network length per event that has to be cleaned and the average cost per network-km for snow cleaning. The first information is partly available from the media review and data sets. For those cases where such information is not available average values from similar events have been taken over.
Quantification of user costs. Vehicle operations costs.

To be able to calculate this it is necessary to provide the following information:

- Average rail ticket price per km
- Average car operation costs per vehicle-km
- Average occupancy rate of private cars
- Average persons per train
- Average trains per section
- Average distance per train trip
- Average persons changing from trains to cars due to the event

Time losses due to infrastructure closures. Passenger transport. For the estimation of the additional time that customers of the rail passenger transport system have to spend due to the interruption of service provision caused by extreme weather events again the different possible reactions of the customers have to be taken into account:

- Customers using the rail replacement bus service (if it is provided)
- Customers changing from trains to car during the interruption of service provision and
- Customers cancelling their trips.

Freight transport. For the calculation of the time losses the following information is necessary:

- Time costs per ton-hour
- average km per ton (tkm/ton)
- detouring route length extension factor
- average km/ton with detouring
- additional km per transported ton
- average speed of freight trains
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7.3 Results and conclusions

The total costs are summarised per event type to give an overview on average costs caused by an event.

Table 9: Bandwidth of costs per costs type and weather event type for selected countries

<table>
<thead>
<tr>
<th></th>
<th>Heavy rainfalls with consequent events</th>
<th>Permanent rainfalls with consequent events</th>
<th>Thunderstorms</th>
<th>Winter-storms</th>
<th>Avalanches</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>capital costs</strong></td>
<td>min 0,00</td>
<td>1,97</td>
<td>0,00</td>
<td>0,00</td>
<td>0,00</td>
</tr>
<tr>
<td></td>
<td>max 2,81</td>
<td>50,37</td>
<td>0,04</td>
<td>0,04</td>
<td>0,09</td>
</tr>
<tr>
<td></td>
<td>average 0,73</td>
<td>18,13</td>
<td>0,02</td>
<td>0,01</td>
<td>0,04</td>
</tr>
<tr>
<td></td>
<td>median 0,26</td>
<td>2,06</td>
<td>0,02</td>
<td>0,00</td>
<td>0,04</td>
</tr>
<tr>
<td><strong>operational costs</strong></td>
<td>min 0,15</td>
<td>3,40</td>
<td>0,49</td>
<td>0,20</td>
<td>0,16</td>
</tr>
<tr>
<td></td>
<td>max 18,82</td>
<td>40,29</td>
<td>0,63</td>
<td>5,94</td>
<td>7,36</td>
</tr>
<tr>
<td></td>
<td>average 3,84</td>
<td>16,62</td>
<td>0,56</td>
<td>1,65</td>
<td>3,76</td>
</tr>
<tr>
<td></td>
<td>median 1,56</td>
<td>6,17</td>
<td>0,56</td>
<td>0,58</td>
<td>3,76</td>
</tr>
<tr>
<td><strong>user costs</strong></td>
<td>min 0,10</td>
<td>2,01</td>
<td>0,29</td>
<td>0,12</td>
<td>0,08</td>
</tr>
<tr>
<td></td>
<td>max 11,96</td>
<td>23,79</td>
<td>0,29</td>
<td>2,48</td>
<td>3,47</td>
</tr>
<tr>
<td></td>
<td>average 2,44</td>
<td>9,84</td>
<td>0,29</td>
<td>0,86</td>
<td>1,78</td>
</tr>
<tr>
<td></td>
<td>median 1,01</td>
<td>3,73</td>
<td>0,29</td>
<td>0,40</td>
<td>1,78</td>
</tr>
<tr>
<td><strong>Total costs</strong></td>
<td>min 0,26</td>
<td>7,37</td>
<td>0,82</td>
<td>0,35</td>
<td>0,23</td>
</tr>
<tr>
<td></td>
<td>max 31,97</td>
<td>114,46</td>
<td>0,93</td>
<td>8,42</td>
<td>10,92</td>
</tr>
<tr>
<td></td>
<td>average 7,00</td>
<td>44,60</td>
<td>0,87</td>
<td>2,52</td>
<td>5,58</td>
</tr>
<tr>
<td></td>
<td>median 2,69</td>
<td>11,96</td>
<td>0,87</td>
<td>1,40</td>
<td>5,58</td>
</tr>
</tbody>
</table>

In addition to this the average costs of track closure per day and section (used for the calculation of the costs) and the average infrastructure damage costs per km (including the information on damage costs reported by the selected media data bases and the railway companies) are presented.
Table 10: Unit costs for calculation of impacts

<table>
<thead>
<tr>
<th>WEATHER</th>
<th>Unit costs for calculation of impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>average replacement costs per affected network-km</td>
</tr>
<tr>
<td>Mio EUR/km</td>
<td>Mio EUR/km</td>
</tr>
<tr>
<td>2.55</td>
<td>0.13</td>
</tr>
</tbody>
</table>

An extrapolation of weather-related costs of the rail system to Europe is extremely difficult due to the strong dependence on construction levels and maintenance and operating policies. Nevertheless the detailed Annex 4 on rail transport discusses data needs and options for value transfer across regions and over time.

With some very simple rules the results of the railway vulnerability assessment have been extrapolated to the EUR-29 countries. This was possible for avalanches, storms and floods (including landslides). From assessments of the European Environment Agency the numbers and severity (in terms of costs) of events were taken and multiplied by the respective unit cost values by Table 9.

Table 11: Preliminary extrapolation of railway damage costs to Europe

<table>
<thead>
<tr>
<th>Event of extreme</th>
<th>Unit costs (m€)</th>
<th>Average annual costs (m€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category</td>
<td>Infra-structure</td>
<td>Operations</td>
</tr>
<tr>
<td>Avalanches Major</td>
<td>9</td>
<td>0.04</td>
</tr>
<tr>
<td>Storms Very large</td>
<td>32</td>
<td>0.01</td>
</tr>
<tr>
<td>Major</td>
<td>41</td>
<td>0.01</td>
</tr>
<tr>
<td>Floods Major landslides</td>
<td>54</td>
<td>0.73</td>
</tr>
<tr>
<td>Major floods</td>
<td>55</td>
<td>18.13</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total costs are roughly €300 million per year. The largest part (€175 mill.) is borne by operators, while the rail passenger and freight forwarders carry the least part (€75 mill.). The dominant weather category is major floods, causing 80 % of damages.

However, due to the omission of storm winters and heat problems these results only reflect a friction of the real damages the railway sector has to bear. An extended assessment of Europe-wide costs will revise these figures later in this project.
8 Urban Public Transport

8.1 Evidence from literature

The EC-funded research project STAR-TRANS analyses the vulnerability of urban transportation networks. UPT networks are complex and all parts of them are in principle vulnerable to weather extremes. UPT link and node elements may be internal (e.g. part of a tramway line or stops), connecting elements (e.g. access footway) or part of supporting technology, such as energy supply or telecommunication.

- Energy supply further consists of several sub-elements, e.g. fuelling systems, electric power plants, transformer substations, contact wires, power rails and cables. Energy is also necessary for communication services. Energy supply might be interfered by extreme weather events and has to be guaranteed by all means. Moreover, telecommunication including, telephony, telegraphy and television as well as radio communication (broadcast systems) have to be secured when operating a UPT network as they are essential for security as well as for operational purposes. Finally, meta-structures like traffic control centres are essential when managing emergency situations, but are vulnerable to breakdowns of energy supply or of the communication system.

- Disruptions of services due to current weather situations could be eased by time buffers; however operators are often not willing to plan tolerant as this would require extra staff and rolling stock. Disruptions in services are largely borne by passenger in case of monthly ticket users, while single ticket users might reschedule their journeys imposing financial losses to the UPT provider. In extreme situations, whole sub-networks may be separated into parts, but the necessary reorganisation process requires standby staff and means of transport in decentralized depots. Further personnel are needed for increased repair measures.

- Increased user costs comprise the value of additional waiting time and the cost due to a higher accident risk. If passengers are unable to plan their journey due to unknown delays or unpredictable risks, they may alter their preferred means of transport.

Early results of the Adaptation Report by Transport for London confirm that virtually all elements of the local transport system are subject to a certain risk of climate change. Hotter and dryer summer season and possibly wetter winters together with more frequent extreme events impose particularly high risks to the underground system.

- Heat periods include problems with key track, signals, & communications assets and staff & passengers.
• Rain and flooding cause problems to tracks and signalling systems and overload key infrastructure drainage.

8.2 Cost estimation methodology

The contribution on extreme weather related costs in Urban Public Transport (UPT) touches analyses for London, but focus on German events from 2000 to 2010. Interviews have been carried out among the German Bundesland Saxony, being the region with most losses due to the European Flooding in 2002.

Literature on UPT costs due to extreme weather situations is only available for single extreme events, such as the European floods in August 2002. For this case governmental reports and scientific as well as non-scientific analyses exist. All other events are mostly documented by newspapers, which cover such catastrophes at a broader view not only taking the traffic sector into account.

Used internet sources are accident databases of statistical offices (Saxony, Germany, Europe, UN) as well as online archives of newspapers and governmental press releases. The four major Saxon UPT providers were asked to deliver figures on weather-related financial losses (for profiles of the companies see Annex A):

General statements are that summaries on smaller, regular events are not easily available as causes for repair and maintenance measures are usually not documented. Facts and figures are often spread across the organisation, so carrying out such analyses would mean intensive research work for those companies. Thus, analyses have only been prepared for larger events, where governmental aids were needed (larger flooding 2002/2006/2010, storm “Kyrill”, thunderstorms).

8.3 Results and generalisation

The review of impacts of weather extremes on public transport remains rather qualitative. The results are thus not included into the total cost matrix and can in no way be extrapolated to Europe. Nevertheless, the available cost figures from the selected damage events are presented by Table 12.

Table 12: Damage cost figures for urban public transport in Germany for selected events

<table>
<thead>
<tr>
<th>Event</th>
<th>Location</th>
<th>Impact description</th>
<th>Damages</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002 summer flood</td>
<td>Saxony, communities</td>
<td>Roads and bridges</td>
<td>€464 mill</td>
</tr>
<tr>
<td></td>
<td></td>
<td>UPT</td>
<td>€69 mill</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Event</th>
<th>Location</th>
<th>Impact description</th>
<th>Damages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thereof district Dresden</td>
<td>Valid for January 2003 (Striefler et al. 2003)</td>
<td>€66.8 mill</td>
<td></td>
</tr>
<tr>
<td>Saxony, state</td>
<td>State roads and bridges</td>
<td>€113 mill</td>
<td></td>
</tr>
<tr>
<td>Dresden</td>
<td>roads (307 cases)</td>
<td>UPT (full renewal), Valid for November 2010 (DVB 2010) thereof - infrastructures - vehicles &amp; ferries - buildings &amp; others</td>
<td>€202.8 mill, €99.2 mill, €83.8 mill, €13.4 mill, €0.5 mill</td>
</tr>
<tr>
<td>Prague</td>
<td>Metro restoration</td>
<td>€230.0 mill</td>
<td></td>
</tr>
<tr>
<td>Chemnitz</td>
<td>Track reconstruction</td>
<td>€22'000</td>
<td></td>
</tr>
<tr>
<td>Chemnitz</td>
<td>Quality inspection and repair (City-Bahn)</td>
<td>€197'000</td>
<td></td>
</tr>
<tr>
<td>Chemnitz</td>
<td>Chemnitz UPT track reconstruction</td>
<td>€280'000</td>
<td></td>
</tr>
<tr>
<td>Chemnitz</td>
<td>City-Bahn 3 week track repair, replacement bus service &amp; lost income</td>
<td>€150'000</td>
<td></td>
</tr>
<tr>
<td>Chemnitz</td>
<td>Asset damage due to hail</td>
<td>€24'000</td>
<td></td>
</tr>
<tr>
<td>Chemnitz</td>
<td>Overhead wires &amp; trees on roads</td>
<td>€16000</td>
<td></td>
</tr>
<tr>
<td>Albtal region (Karlsruhe)</td>
<td>Rail infrastructure (track/wires)</td>
<td>€ 6-digit</td>
<td></td>
</tr>
</tbody>
</table>

The review of extreme weather related costs in UPT revealed that documentation of cost is not focused on weather extremes so far – at least for the interviewed UPT providers in Saxony. Costs of larger extremes, like those of August 2002, have been documented carefully, as most UPT providers depended on governmental aids for reconstruction measures. However, “normal” weather extremes and their consequences are accepted up to now.

With rising risks of extreme weather events, it is necessary to estimate the development of additional costs. A unified documentation scheme of extreme weather related costs would be helpful.
WEATHER D2: Vulnerability of Transport Systems

9 Airports and air services

The winter seasons 2009/2010 and 2010/2011 as well as the volcano ash cloud over Europe in April have made the past year a very interesting study case for the sensitivity of transport systems to adverse weather conditions. In particular aviation had to suffer from these conditions by closing down important hubs during the most severe winter days and by completely closing parts of the European airspace in spring 2010.

9.1 Evidence from literature

US figures suggest that the total costs of air traffic management (ATM) disruptions amounts to US$41 billion, of which 70% (US$28 billion) are attributable to weather. Of these, US$19 billion could be avoidable (EUROCONTROL 2009a). The same source reports annual costs of €900 mill. for Europe. Among the most critical phenomena are convective weather conditions, i.e. thunderstorms. For Europe, similar figures are still lacking, but are foreseen to be generated under the Single European Sky (SES) research agenda (EUROCONTROL 2009b).

Convective weather poses a problem for the efficient airspace and airport operation. Thunderstorms and related phenomena can close airports, degrade airport capacities for acceptance and departure, and hinder or stop ground operations. Convective hazards en route lead to rerouting and diversions that result in excess operating costs and lost passenger time. Lightning and hail damage can remove aircraft from operations and result in both lost revenues and excess maintenance costs. With 2001/2002 data from the U.S. it is estimated that the vast majority of the warm season delays are due to convective weather (DOT 2002).

Airport operations: The strong and persistent winter conditions in the end of 2010 caused problems in supply with de-icing substances and the clearance of movement surfaces to reach an acceptable breaking action at major European airports. A review of winter maintenance practices at Scandinavian and Canadian airports clearly indicates that three factors are decisive for avoiding winter-related problems: an early recruiting and training of staff for winter maintenance, use of high quality equipment in sufficient quantity and the availability of sufficient runway capacity to perform maintenance. In particular the latter point seems problematic for the major hub airports.

Aircraft damages: Following Kulesa (2002) aircraft damages can result from a number of weather phenomena: lightning and hail in Thunderstorms, turbulences of all type (convective and non-convective weather) in all altitudes. Major impacts arise from sudden accelerations of the aircraft affecting the aircraft itself and its passengers and light-
ning and hail damage can remove aircraft from operations and result in both lost revenues and excess maintenance costs.

**Airline operations:** Airlines and their customers are generally affected by all problems encountered by airports and air traffic management. Thunderstorms and related convective weather reduce airport capacity, result in a suspension of refuelling, up- and off-loading of baggage to aircrafts and can increase en-route operating costs by re-routing flight paths. Lightning and hail damages can further result in lost revenues and excess maintenance costs. These effects impose delays, cause additional fuel and other costs and imply safety impacts for all classes of aircraft. A statistical analysis of flight schedule data of two US airlines (Rosen 2002) concludes that (1) hub-and-spoke airline schedules, and thus hub airports, are much more affected by weather impacts than point-to-point systems or smaller airports, and that snow constitutes the major challenge for flight operations. The extra costs for detouring hurricanes have been estimated by Quan et al. (2002) for the U.S. ranging from US$51000 to US$225000.

**Delays:** Weather, in particular poor visibility, low clouds and strong winds at the destination airport, is responsible for approximately 35% to 50% of non-airline related delays, costing approximately €900 million annually (ICAO 2009). EUROCONTROL statistics show, while in the winter months (December to February) weather-related delays range between 13% and 17%, their contribution to total delays ranges about 4% or less in the summer months with a small peak of AFTCM delays in autumn which could be caused by storm activities. The comparison between flight performance in the US and in Europe (EUROCONTROL, FAA 2009) reports extreme weather being responsible for 1% of delayed flights in the U.S., and concludes the same order of magnitude for Europe. EUROCONTROL (2005) look a bit deeper into weather phenomena around airports and finds the following share at weather-related AFTCM delays: wind: 27%, visibility / fog: 35%, and other weather, in particular winter conditions: 38%.
Source: Fraunhofer-ISI with data from EUROCONTROL

Safety: Quan et al. (2002) analyses studies on fatal aviation accidents in extreme weather and concludes, that in most cases spatial disorientation with low visibility are caused by a too high level of self confidence of the pilots. ICAO (2010) estimate for Europe that nearly 20% of all accidents and nearly 8% of fatalities are weather-related. According to EASA (2009) the accident category with the highest shares of fatal accident is “controlled flight into terrain (CFIT),” were in most cases adverse weather conditions were prevalent, such as reduced visibility due to mist or fog. The multi-decade accident statistics in PlaneCrashInfo (2011) show two major impacts of weather on flight operations: affecting the pilots and affecting the aircraft and its manoeuvrability itself. Weather-related pilot errors have caused 16% of fatal crashes from the 1950s to the past decade, while another 12% of fatal accidents were caused by other weather-related factors.

9.2 Cost estimation methodology

The cost estimation process focuses on five cost elements: Airport winter maintenance, airline operating costs and user time losses due to delays and aircraft damages and user deaths and injuries due to aircraft accidents. The methodology is drafted in brief.

Airport winter maintenance uses average personnel and equipment costs identified for Scandinavian airports and relate them to traffic volumes and additional cold and snow days in extreme winters across Europe. The average cost of winter maintenance per ATM is €116.
Aircraft damage costs are estimated on the basis of EASA assessments of accidents related to weather extremes. From internet sources average prices of aircrafts have been collected. It is assumed that 50% of these costs are already written off and a further 50% is subtracted to acknowledge that accidents usually have several causes. As the EASA database provides the degree of severity of accidents capital losses have been estimated. In total the database contains 88 accidents over the EUR29 territory from 2000 to 2010.

Figure 18: Monthly distribution of weather-related air accidents over EUR29

Source: Data provided by EASA, 2011

Airline delay costs are computed on the basis of a database on delay causes provided by EUROCONTROL-CODA. The data contains the average delay per movement for the IATA delay groups 71, 72, 73, 75, 76 and 77 by month from January 2007 to December 2010. Each of these delay groups shows a characteristic slope across the year, allowing identifying typical weather patterns. We thus allocate weather categories by seasons and delay group. A regional allocation is then made by allocating the weather-specific delays using ESPON and ECA&D indices of extremes. According to EUROCONTROL (2004) a value of €36 per delayed flight and minute is assumed.
User delay costs: Delay accounts are taken from airline operating costs. The structure of passenger delay costs due to extreme weather conditions is therefore considered identical to the costs to airlines. These are assessed using a passenger value of time of €21/h out of the range of €16 to €32/h suggested by Maibach et al. (2008).

User safety costs: The costs of fatalities and injuries in air accidents are taken from the EASA dataset already applied to assess aircraft damage costs. The database contains the number of fatalities and injuries, which are assessed by €m1.65 per death casualty, €150000 per severe injury and €10000 per slight injury. The regional allocation is given by the place of the aircraft crash and the allocation to weather extreme is done on a seasonal basis as for plane damages.

9.3 Results and conclusions

With €360 million overall annual costs imposed by extreme weather conditions, i.e. adverse weather exceeding currently expectable seasonal conditions, on air transport are considerable in absolute terms. But when relating them to industry estimates of total weather inflicted costs (€900 million p.a.) or relating them to aircraft movements (€36 per ticket), they appear to be of a less significant level. The inclusion of further cost categories like flight cancellations or cargo related costs may significantly impact their absolute values and lead to more considerable values for the aviation industry and their customer.
The most affected actors are airlines and air passengers through delays. Already now they bear 69% of total costs. But safety costs are, although safety standards and procedures are well developed in aviation, still significant with 27% of total costs.

The most pressing cost drivers are strong winters with much snow and storms. Convective weather conditions seem, surprisingly, not to have a significant impact on air punctuality and safety. But the allocation procedures applied here are rather course and may over-express one or another type of extreme.

Figure 20: Aggregate results by cost category and weather extreme

![Annual costs by extreme and cost category](image)

*Source: Fraunhofer-ISI, 2011*

From a regional perspective the most penalised area is Western Europe, and in particular the North Sea coast (including the British islands). First, these regions are most directly affected by weather activities entering Europe from the Atlantic Ocean. Second, the relatively mild but varying climate makes infrastructure operators, including airport authorities; take less care for effective but expenses winter preparation measures.

The conduction of these cost estimates has been challenged by numerous data availability and quality problems and methodological caveats. Thus, the level of uncertainty is rather high. But for purposes of benchmarking to other modes and to work on future climate change consequences these indicators are considered to be fully sufficient. However, more in-depth studies in cooperation with the aviation industries could uncover more precisely the vulnerable elements of airports, airlines, air traffic management and their customers.
10 Maritime transport

10.1 Evidence from literature

In our literature review we have focused on six main information sources:

1. research projects of international institutions;
2. articles in scientific magazines (maritime transport and meteorological issues);
3. insurance-related companies and media;
4. reports of consulting companies on catastrophe management;
5. general news media sources;
6. news on the port’s websites.

Over the last years, large international organizations have been focusing more and more attention on the possible impacts of climate change on the different economy sectors, including transport. In this framework, a lot of research projects were initiated focusing on the impact of climate change on the different transport modes, including maritime transport.

For example, in the framework of the PESETA project (Projection of Economic Impacts of climate change in Sectors of the European Union based on the bottom-up analysis) sea-level rise projection was done and possible economic and physical effects induced from it were studied. The ESPON project (the Spatial Effects and Management of Natural and Technological Hazards in Europe) studies the main technological and natural hazards, their geographical scope and spatial effects. Projects like ASTRA (Developing Policies and Adaptation Strategies to Climate change in Baltic Sea Region) assess impacts of the climate change in the concrete region and sectors.

Another study, performed by OECD focus on assessing the climate change impacts on port cities (Assessing climate change impacts, sea level rise and storm surge risk in port cities: a case study on Copenhagen). All these reports are more focused on long-term effects of the climate change on the different transport sectors and make an overview of recent extreme weather events as an example of the on-going tendency.

From the above mentioned literature, the most relevant extreme weather events for maritime transport are:
Storms/hurricanes, followed by heavy rains, high wind speeds and, sometimes, hail, causing all kinds of damage, from infrastructure destruction to the impossibility of accessing the port;

- Extreme frost periods and icing, causing a temporary blockade of the port activities.

Therefore, the subsequent literature review was focused on these extreme weather events and their impacts on maritime transport. A number of scientific articles, studying different effects and meteorological evolution of the EWE’s were reviewed. These articles provide good background information about events, sometimes estimation of the losses and very often results in the prospects of future trends. A very useful information source is insurance companies’ reports and media (e.g. Munich Re Group, Lloyds list, Guy Carpenter).

10.2 Cost estimation methodology

As the impacts of an EWE on maritime transport do not have a regular character and are hard to forecast (especially from hurricanes), it is hard to determine a systematic costs calculation approach. Infrastructure damages are recorded at the level of ports and can be verified through the concerned port websites. Transport service providers and transport user costs are difficult to generalize as they are individual for each event. Specifics of maritime transport for that sector, is that transport users can wait a couple of days for cargo delivery, therefore these delays are not crucial. They only cost running costs of ships (fixed costs).

In our estimation process we have focused on the short-term costs from extreme weather events, which occur directly after the event. In section 3.1 of the detailed annex the elements for the cost assessment approach for different maritime transport actors are presented. The EWE bound costs vary for a shipper of maritime cargo and for a ferry operator (ro-ro) and therefore are presented in different paragraphs. As extreme low temperatures have more impact on MT in long-term scale (increase in port maintenance costs, type of vessels operating, rates on ice-breaking services, etc) and are not usually characterised by the infrastructure damage or suspension of navigation, we further illustrate our approach on the case of the windstorm/hurricanes.

**Port operator costs.** Input information for the assessment of port operator costs can first be verified through the media review for each particular EWE. Usually port websites provide information on damage produced by the Extreme weather event. Furthermore, interviews with port authorities and terminal operators can be done for the assessment of the additional cost components.
The EWE type specific costs for the port operator would consist of the following main components:

1) Idle operation costs (due to interruption of port loading/unloading activities)
2) Damage costs (costs due to possible damage of facilities, navigation hinders, environmental pollution)
3) Rescue costs (costs due to rescue of vessels and people in trouble)
4) Missed incomes (no port dues collected due to annulated ferry trips)

The total costs for the port operator would thereby represent a sum of all these components. Box 1 presents these costs in more detail.

**Box 1. Total costs of Port operator**

\[
\text{Total Costs (PO)}^2 = \text{Costs (Idle)} + \text{Costs (Damages)} + \text{Costs (Rescue)} + \text{Missed Income (annulations)}
\]

Where,

\[
\text{Costs (Idle)} = \text{Costs (idle personnel)} + \text{Costs (idle facilities)}
\]

\[
\text{Costs (Damages)} = \text{Costs (damaged infrastructure)} + \text{Costs (polluted environment)}
\]

\[
\text{Costs (Rescue)} = \text{Costs (rescue personnel)} + \text{Costs (rescue means)}
\]

\[
\text{Missed Income (annulations)} = \text{Port duty (ferry)} \times \text{Number of annulated calls}
\]

**Cargo vessel operator costs.** The EWE type specific costs, that the shippers of maritime cargo can expect, may consist of the following main components:

1) Ship anchoring costs (forced anchoring due to interruption of port loading/unloading activities and disruption of navigation)
2) Queuing costs (extra waiting due to queuing at the terminal)
3) Damage costs (vessel or cargo)
4) Fines for polluting the environment
5) Rescue bill

---

2 Important to mention, that the magnitude of each of these costs component is proportional to the following EWE bound factors:

\[
\text{Costs (Idle)} = f_1(T_2 - T_1)
\]

\[
\text{Costs (Damages)} = f_2(V, T_2 - T_1)
\]

\[
\text{Costs (Rescue)} = f_3(V, T_2 - T_1)
\]

\[
\text{Missed Income (annulations)} = f_4(T_2 - T_1, V, \text{Tariff})
\]
For each particular case it is necessary to check who is paying the penalty in case of Force Major events, and does the rescued shipper have to reimburse the rescue costs afterwards. The total costs for the cargo shipper would usually be a sum of all the above-mentioned components (Box 2).

### Box 2. Total cost of cargo vessel operator

\[ \text{Total Costs(CO)}^3 = \text{Costs(Anchor)} + \text{Costs(Queue)} + \text{Costs(Damages)} + \text{Fine} \quad (2) \]

Where,

\[ \text{Costs(Anchor)} = \text{Costs(idle crew)} + \text{Costs(missed income)} + \text{Penalty(late delivery)} \quad (2.1) \]

\[ \text{Costs(Queue)} = \text{Costs}_Q(\text{idle crew}) + \text{Costs}_Q(\text{missed income}) + \text{Penalty}_Q(\text{late delivery}) \quad (2.2) \]

\[ \text{Costs(Damages)} = \text{Costs(ship repair)} + \text{Costs(damaged or losted cargo)} \quad (2.3) \]

\[ \text{Fine} = \text{Fine (IMO tariff) or Fine(country specific fine regulations)} \quad (2.4) \]

* for the ease of the assessment the costs for paying the rescue bill by the shipper in trouble are ignored.

Source: NEA

**Ferry operator costs.** For the ferry operator the crucial and relevant effect caused by this EWE type, is the forced cancellation of the scheduled ferry services during the extreme weather event. This has the following costly implications:

1) Missed income (return of sold tickets to passengers choosing for other travel options)

2) Catering and accommodation for stranded passengers (as far as it is foreseen in the rules)

As in previous cases, the total EWE bound costs for the ferry operator would be a sum of the abovementioned components (Box 3).

### Box 3. Total cost for Ferry operator

\[ \text{Total Costs(FO)} = \text{Costs(missed income)} + \text{Costs(catering & accommodation)} \quad (3) \]

3 Again, the magnitude of each of these costs component is proportional to the following EWE bound factors, terminal characteristics, lucky timing and regulations in force:

\[ \text{Costs (Anchor)} = f_0(T2-T1) \]

\[ \text{Costs (Queue)} = f_0(1/C_T, N_T \cdot S_T) \]

\[ \text{Costs (Damages)} = f_0(V,T2,T1) \]

\[ \text{Fine (pollution)} = f_0(V,T2,T1) \cdot \text{Fine tariff} \]

Where: \( C_T \) = spare capacity; number of queuing ships \( N_T \) (in front of a shipper concerned) and ship sizes \( S_T \) (per DWT category).
The missed income for the ferry operator:

\[ \text{Costs(missed income)} = NRT_p \times \text{TicketPrice} + \sum_i (NRT_{v,i} \times \text{VehicleTicketPrice}_i) + \text{Income(on-board shopping)} - \text{Tax(port)} - \text{Costs(crew)} - \text{Costs(fuel)} \]  

(3.1)

Where

\[ NRT_p \] – number of returned traveller tickets,

\[ NRT_{v,i} \] – number of returned vehicle tickets per vehicle pricing category i.

Source: NEA

10.3 Results and conclusions

Case study 1. The windstorm Kyrill occurred in January, 2007 and lasted in some regions for more than 24 hours. It was referred to as a widely spread extra-tropical cyclone with hurricane-strength winds. For the demonstration of the proposed costs estimation methodology we have focused on two specific study cases:

Case 1: Damage of the container ship MSC Napoli in the English Channel on the 18\textsuperscript{th} of January, 2007, including the damaged cargo onboard and the environmental pollution;

Case 2: Disruption of ferry services on the connection ‘Rosslare-Fishguard’ between Ireland and the UK on January 17\textsuperscript{th} and 18\textsuperscript{th}, 2007.

The following estimated costs can be claimed:

- Claimed ship damage: € 17.5 mln
- Claimed cargo damage: € 2.1 mln
- Fatality claims: € 0

Therefore; the total costs of the accident for the MSC Napoli would be in the range of € 3.060 mill.

Case study 2. The ferry connection between Rosslare in Ireland and Fishguard in the UK was severely affected by the windstorm Kyrill in the late hours on January 17\textsuperscript{th} and throughout the day on January 18\textsuperscript{th}, 2007. The costs experienced by the operator Stena Line due to the cancellation of the scheduled sailings on the Rosslare-Fishguard connection on January 17\textsuperscript{th} and 18\textsuperscript{th}, 2007 are the following. The total costs of the disruption period for Stena Lines will therefore approximate € 482.493.
### Income:

<table>
<thead>
<tr>
<th></th>
<th>January 17</th>
<th>January 18</th>
</tr>
</thead>
<tbody>
<tr>
<td>Income sold tickets:</td>
<td>€ 85,880</td>
<td>€ 94,874</td>
</tr>
<tr>
<td>Income vehicle fares:</td>
<td>€ 85,277</td>
<td>€ 116,410</td>
</tr>
<tr>
<td>Income sold facilities:</td>
<td>€ 5,938</td>
<td>€ 7,058</td>
</tr>
<tr>
<td>Income onboard shopping:</td>
<td>€ 13,749</td>
<td>€ 20,887</td>
</tr>
<tr>
<td>Costs crew:</td>
<td>€ 22,100</td>
<td>€ 22,100</td>
</tr>
<tr>
<td>Depreciation costs:</td>
<td>€ 4,110</td>
<td>€ 4,110</td>
</tr>
<tr>
<td><strong>TOTAL COSTS</strong></td>
<td>€ 217,054.</td>
<td>€ 265,438</td>
</tr>
</tbody>
</table>
11 Inland waterways transport

11.1 Evidence from literature

We have followed a three step approach in our literature review. First of all, our objective was to receive the general understanding of how large the impact is of extreme weather events (EWE) on inland waterways transport (IWT). Secondly, we have focused our literature analysis on the EWE’s which have the strongest impact on IWT. Finally, we have further delimited our research to the navigable European rivers.

Searching for the impacts of the EWE’s on IWT in media and literature provided us with the first impression on the frequency of occupancy of different events and the scope of impact they might have. In our literature review we have looked through extensive projects that have been executed by international organisations and financial institutions (EU, the World Bank, UNECE, etc), websites of the River Basin commissions and other river organisations, EU national IWT agencies and responsible authorities, at the outcomes of the major conferences and newsletters of the IWT related projects (the overview of the information sources is in Annex A). These sources provide extensive and comprehensive general information about rivers, navigation conditions and weather event occurrences on rivers.

As outcomes from initial research, the EWE’s that have the biggest impact on the IWT are:

- **floods** causing high water levels and possibly resulting in lack of bridge clearance and, if critical values are exceeded, in a disruption of traffic;

- **drought** periods causing low water levels and resulting in lower load factors, lower speeds, more fuel consumption and possibly a disruption of traffic (in particular for bigger vessels);

- **ice** causing severe delays or a blockade for the inland waterway vessels.

Therefore, the literature review was further focused on spotting the biggest floods, droughts and extreme cold periods. Recent work from the ECCONET project (FP 7, European Commission DG MOVE) was also taken into account.

A lot of information (especially on floods and droughts) and some databases are available for public use, but there is not much information which describes specific economic impact on inland waterways and its operators. At the same time, the available information is important as it gives the general qualitative description of the event,
global estimation of the event costs in terms of damaged property (buildings and farm lands) and casualties.

11.2 Cost estimation methodology

Infrastructure providers costs (infrastructure damages and increase from operating costs) have been estimated case by case, through the evidence found in the literature and media. Per case a specific literature/media review on the river port or river stretch needs to be done to see if there were any infrastructure damages recorded. Port websites, river basin commission websites, insurance reports can be of a big use. In case more details are necessary, interviews with infrastructure managers (e.g. waterway operators, port authorities) have been carried out to describe the impacts and relevant costs for infrastructure operators due to extreme weather events. If no information is available through the mentioned sources, these costs are considered as non identified.

Damage to vehicles have been recorded only if any indication of it is found in media/literature sources. The gathered information will be checked with concerned operators and will then be further reported.

As the effects of floods/ice periods on the IWT differs from those of droughts, two different cost calculation approaches have been developed in order to estimate the economic impact on the transport service providers. Costs calculations for the transport operators from floods and ice periods are developed around calculations of volume of different types of goods transported in the area where navigation was interrupted, number and types of ships which circulate per day in the area concerned, costs of the waiting time for ships and other parameters as detailed in the Inland Waterway Annex to this report. For the calculation of the impact of the drought period, the ship draught parameter is very important. Therefore, the calculations take into consideration the drought severity, ship draught measurements, volume of goods transported in the drought area, costs of waiting time of ships and other parameters. In both cases, the critical parameter to have is the number of days that navigation was suspended.

The costs for the transport users (time losses through system capacity and infrastructure closure) are highly dependent on the duration of the extreme weather event. The first reaction will be to postpone the transports and in the case of the short service interruption (which often takes place during floods) transport users do not record any substantial additional costs. However, in case of a flood or drought period exceeds a certain time period, the transport user will pay surcharges for the transport service provider or even will shift the cargo to other modes of transport, e.g. rail or road transport. In that case, the transport costs can increase significantly: both for the transport user,
who has to pay substantial higher freight rates and/or need to find an emergency measure and for the transport service provider who will have missed transport volumes. The situation however will be different for each user and also depends on the value of the goods and the stock levels. It would require a very detailed assessment to make an estimation. Such detailed assessments are planned in 2011 in the ECCONET project (June 2011). Therefore, a knowledge transfer is recommended as soon as results from ECCONET become available.

The costs from time losses through system capacity depend a lot on the EWE duration. They can have an impact both on transport service providers and transport users. For the first ones, these costs are already taken into account in the methodology of transport service provider’s costs calculation. The estimation of the transport user’s losses through the reduced system capacity will be done in June 2011 within the ECCONET project, as described beforehand. Therefore, these costs are not assessed within this deliverable.

The costs from infrastructure closure occur in two cases: because of the infrastructure damage or because of the obligatory suspension of navigation due to the high or low water levels.

Therefore, the first case will be assessed only if any infrastructure damage is identified in previous phases. The second case is already included in the assessment of transport service provider’s costs.

External accident costs have an impact on IWT in the case if there was environmental damage on IWW due to the EWE or there were social costs from persons injured or dead involved in the inland waterways industry. In the quantification of the external accident costs we are following the same approach as for the infrastructure damage costs. Literature/media review for each particular case is done and if there is no information on time loses because of the infrastructure closures, accident or environment damage costs, then these costs are considered as not identified.

11.3 Results and conclusions

The river Rhine and its tributes (Neckar, Mosel, Saar) were chosen to illustrate calculation methodology of the impact of floods/ice periods and droughts on inland waterways transport.

The Rhine river is one of the longest (about 1232 km) and most important rivers in Europe, which crosses the territory of the Netherlands, Germany, and Switzerland. Through its main tributes, the Rhine is also connected to France and Austria. More
than 63% of the goods volume transported by IWT in Europe is done via Rhine route\(^4\) and this volume continues to grow.

The structure of goods transported by IWT on the Rhine varies. The Rhine is for example used for hinterland distribution of energy (coal and oil) as well as for the supply of raw materials for industries (e.g. steel plants located along the Rhine). Moreover, there is a vast network of container terminals along the Rhine linked to the maritime container flows via seaports. There is for instance, a lot of transport of oil and oil products. Detailed data on the transportation on the Rhine can be found in the Market Observation Reports provided by the CCNR (see [http://www.ccr-zkr.org/](http://www.ccr-zkr.org/)).

The water level observations on the Rhine are done at so called “Pegel” points. The assessment of all the costs in this study is further made for the Kaub pegel point, which is considered to be the most critical for the Rhine river and determines the load factor of vessels that perform transports to/from the upper Rhine (e.g. Basel, Mannheim, Stuttgart area).

**Floods.** In order to delimitate concrete flood areas on the Rhine, we use water level measurement points on the Rhine and its tributes ([www.elwis.de](http://www.elwis.de)). Using historic data available\(^5\) for the period 2000-2010 it is possible to determine the days when water level exceeded the HSW mark for each of the pegel points. If the HSW value was exceeded, then no navigation was possible in this area. Following this approach we were able to determine if during the period 2001 – 2010 the water levels observed at Kaub pegel point were exceeding its HSW indicator.

**Droughts.** The selection of drought periods can also be based on the daily water levels for certain bottlenecks. Bottlenecks on the Rhine are for example the stretch at Kaub and Ruhrort. The pegel value is used to determine the actual water level\(^6\). The difference between the pegel value at Kaub and the possible draft of a moving vessel is 85 cm. That is why for the further definition of drought periods we are adjusting recorded water levels to 85 cm. Afterwards this level is compared with the maximum empty draught of the vessel.

**Ice periods.** The waterway managers provide information on the number of days when there was a suspension of navigation due to ice. Available information is quite general.

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\(^5\) [http://www.wetteronline.de/dldlpeg.htm](http://www.wetteronline.de/dldlpeg.htm)

\(^6\) [http://www.wetteronline.de/dldlpeg.htm](http://www.wetteronline.de/dldlpeg.htm)
for the Upper Rhine, Middle Rhine, Neckar, Saar and Mosel, but does not provide detailed information on what particular part of the river is concerned (Annexe D). Kaub pegel point is situated in the Middle Rhine area. During the period of analysis (1990-2010) there were no ice periods to consider.

The estimation of economic loss on IWW from floods in Kaub area is presented in the following table.

Table 13: Summary of economic impact from floods and droughts on Kaub area, mln euro

<table>
<thead>
<tr>
<th>Cost category/ mln euro</th>
<th>Flood 2001</th>
<th>Flood 2002</th>
<th>Flood 2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infrastructure damage</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Infrastructure operating costs</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Damage of vehicles 1)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Service provision</td>
<td>0,9</td>
<td>0,3</td>
<td>0,5</td>
</tr>
<tr>
<td>Time loss through system capacity 2)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Time loss through infrastructure damage 2)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>External accident costs 1)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>TOTAL costs, euro</strong></td>
<td>0,9</td>
<td>0,3</td>
<td>0,5</td>
</tr>
</tbody>
</table>

1) not identified
2) not relevant

Therefore, the total economic loss per year can be attributed to the transport service provider’s personal loss, when taking the small number of days when suspension of navigation took place around the Kaub area, due to floods into consideration. The estimation of economic loss from droughts in the Kaub area is presented in the following table.

Table 14: Summary of economic impact from droughts in Kaub area, mln euro

<table>
<thead>
<tr>
<th>Cost category/ mln euro</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infrastructure damage</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Infrastructure operating costs</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Damage of vehicles 1)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Service provision</td>
<td>9,8</td>
<td>1</td>
<td>7,5</td>
<td>4,7</td>
<td>0,9</td>
<td>5,5</td>
</tr>
<tr>
<td>Time loss through system capacity 3)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Time loss through infrastructure damage 3)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>External accident costs 1)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>TOTAL costs, euro</strong></td>
<td>9,8</td>
<td>1</td>
<td>7,5</td>
<td>4,7</td>
<td>0,9</td>
<td>5,5</td>
</tr>
</tbody>
</table>

1) not identified
2) not relevant
3) not estimated
12 Intermodal transport

12.1 Evidence from literature

The literature review on the impacts of climate change and extreme weather events on transport vulnerability has stressed the general lack of available impact assessments (e.g., Koetse, M.J, Rietveld, P. (2009). In such a context, the situation for intermodal transport may be considered even worse.

The basic reason relies on the fact that the case of the relationship between climate change and intermodal transport vulnerability basically implies the consideration of the interchange and transhipments facilities and infrastructures involved in this type of transport, and the way in which they are affected by extreme weather events.

The concepts of “intermodal transport” can be defined as “the movements of goods in one and the same loading unit or vehicle which uses successively several modes of transport without handling of the goods themselves in changing modes”, according to the definition of The European Conference of Ministers of Transport (ECMT) and the European Committee for standardisation (CEN).

The most important implication is that the goods have to be transported in one loading unit from the loading at the beginning until the unloading at the end of the transport chain, without handling the goods themselves. Containers, swap bodies, trailers, semi-trailers and whole trucks (backpack traffic or rolling highways and roll–on roll-off) are allowed to transport the goods and are transhipped at terminal and interchanges points.

The analysis of the intermodal transport vulnerability to climate change carried out in this report is primarily focused on intermodal freight transport, due to the fact that the intermodal passenger transport infrastructures, e.g. airports, ports and rail stations, are already taken into account in the dedicated sections of this Deliverable, i.e. Airports and air services, Maritime and inland ports and Public Transport.

It should be stressed that the vulnerability to heavy storms, rain, ice is in general lower than in other transport means, e.g. trucks in pure road transport, due to the heaviness of the intermodal transport infrastructures described in the above table (track keeping in line vehicles, gantry cranes, intermodal wagons, loading units, terminals).

On the other hand, the less flexibility of intermodal freight transport network, i.e. due to a limited number of lines in the railway network that are able to meet the technical requirements allowing combined transport (e.g. Seidelman C., 2010), makes the inter-
modal transport more vulnerable to rail lines interruptions caused for example by avalanches.

The following tables provide a qualitative evaluation of the climate change weather related events and their likely impacts on intermodal transport (operation and infrastructure).

Table 15: Qualitative assessment of climate change impacts on intermodal transport

<table>
<thead>
<tr>
<th>Potential Climate Change extreme weather events</th>
<th>Impacts on Intermodal land transportation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperatures increases in very hot days and heat waves</td>
<td><strong>Mild</strong>: Vehicle overheating and tire deterioration</td>
</tr>
<tr>
<td>Change in seasonal precipitation and flooding patterns</td>
<td><strong>High</strong>: Frequent interruptions, increases in weather related delays</td>
</tr>
<tr>
<td>Increase in drought conditions</td>
<td><strong>Medium</strong>: Wildfires reducing transport activities</td>
</tr>
<tr>
<td>Increased intensity in storms, winds and waves</td>
<td><strong>High</strong>: Debris on road and rail lines, interruptions</td>
</tr>
</tbody>
</table>

Source: Adapted from Committee on Climate Change and U.S. Transportation, National Research Council (2009)

The table shows that the extreme weather events potentially affecting intermodal transport are flooding, landslides, avalanches, to the extent that they are causing delays in operations or interruptions in transport services. Damages from extreme temperatures, winds and intense precipitations can be considered of minor importance, due to the heaviness of intermodal infrastructures. However, it should be considered that heavy rain and winds can hamper terminal operations with swinging loads, ultimately reducing productivity and causing delays.

12.2 Cost estimation methodology

Infrastructure damages. On February 2002, at Colmegno near Luino a landslide made the railway line as well as the road unusable. The Swiss intermodal operator and UIRR-member Hupac on 27 February explained the situation due to the interruption of the lines in Chiasso and Luino. 10 daily trains were sent via Lötschberg/Simplon and the Domodossola border, 2 daily trains go via Austria and Brenner, and 10 daily trains stopped in the southern Swiss terminals Chiasso, Lugano and Stabio (near Chiasso).
Hupac was forced to equip the terminals in Tessin (southern canton in Switzerland) with further cranes and personnel to achieve higher lifting capacity.

The total interruption of the lines in Chiasso, made clear how important a definitive line reconstruction on the line Bellinzona – Gallarate via Luino was in order to allow the further development of combined transport flows.

Estimates of the construction costs for similar infrastructure lines in the Alpine crossing of Gotthard and Lotshchberg amount to 90-100 M€/km (RFI, 2007).

**Increased infrastructure operating costs.** Literature review has stressed the lack of evidences on the impacts of climate change and changes in weather conditions on infrastructure operating costs. In fact, this appears to be more an engineering that an economic issue (Koetse, M.J, Rietveld, P. (2009), whose access to information, evidences and impact assessment is in general limited. Available evidences have been provided in the context of the Arctic Climate Impact Assessment, with reference to areas with permanent and discontinuous permafrost (Instanes, A; et al. (2005).

However, despite the lack of evidences, the review of climate change related events and the available studies have pointed out that infrastructure maintenance costs are likely to increase relative to those at present, due to the impacts of climate change.

The hypothesis assumed in this evaluation is that the increase of maintenance costs due to the impacts of climate change (extreme weather events) is something about 10%-20%.

According to the RECORDIT project outcomes (2003), a detailed classification of intermodal costs (including maintenance costs at terminal and transhipment points) was carried out along three pan-European intermodal corridors: the Freight freeways corridor (Patras-Gothenburg); the Tri-modal corridor (Genoa-Manchester); the Door-to-door corridor (Barcelona-Warsaw). Intermodal transport requires the use of terminals at the interface between modes, and sometimes between the same modes. In the case of rail to rail transfers, at €2000 costs, the RECORDIT project showed the lowest cost at an average €27 per movement of a 40’ container. Road-rail transfers were rather higher at €36. In the case of inland waterways and short sea shipping even higher figures were reported rising to around €60 with a figure of €166 quoted for the case of a transfer between an inland water vessel and a ship.

The following table summarises the detailed maintenance costs by each RECORDIT corridor (in € 2010 costs) and the resulting average costs assumed as standard cost per Loading Unit transported (A Class 40’ container).
Table 16: Average maintenance costs per Loading Unit (€2010)

<table>
<thead>
<tr>
<th></th>
<th>Genova-Manchester</th>
<th>Patras-Gothenburg</th>
<th>Barcelona-Warsaw</th>
<th>Average costs per LU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance of quay-rail cranes</td>
<td>37.3</td>
<td>12.9</td>
<td>23.3</td>
<td>24.5</td>
</tr>
<tr>
<td>Maintenance of marshalling locomotive</td>
<td>10.7</td>
<td>3.7</td>
<td></td>
<td>7.2</td>
</tr>
<tr>
<td>Storage cranes maintenance</td>
<td>5.3</td>
<td>1.8</td>
<td>2.6</td>
<td>3.3</td>
</tr>
<tr>
<td>Personnel costs (monitoring of infrastructure, marshalling control staff, rail crane personnel, etc)</td>
<td>214.1</td>
<td>88.8</td>
<td>137.2</td>
<td>146.7</td>
</tr>
<tr>
<td>Total</td>
<td>267.5</td>
<td>107.1</td>
<td>163.2</td>
<td>181.6</td>
</tr>
</tbody>
</table>

Assuming the average maintenance costs of €181.6 per Loading Unit, the hypothesis is that the additional impacts of the extreme weather events on infrastructure maintenance costs range between +10% and +20%, corresponding to an average increase by €18 per loading Unit.

**Increased costs of service provision.** Assuming 100 as the final intermodal service price for the user (shippers or forwarders), the following table shows the share of these costs on the final price in the three RECORDIT corridors.

Table 17: Share of climate change sensitive infrastructure items on the final price (€2000 prices)

<table>
<thead>
<tr>
<th></th>
<th>Genova-Manchester</th>
<th>Patras-Gothenburg</th>
<th>Barcelona-Warsaw</th>
<th>Average share on final price per LU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance and use of infrastructure</td>
<td>17.2%</td>
<td>12.1%</td>
<td>9.4%</td>
<td>12.2%</td>
</tr>
</tbody>
</table>

The impacts on the final cost for service provision will range between +0.5% and +0.8%.

**12.3 Results and conclusions**

The following table generalizes the results at EU level. The assessment of intermodal transport vulnerability to climate change extreme weather events leads to €6.8 million
of annual costs, borne by infrastructure managers (57.0%) and social actors (43.0%), i.e. the overall cost for the society due to additional accidents costs.

Table 18: Annual costs (mil. €) by affected actor groups

<table>
<thead>
<tr>
<th>Type of event</th>
<th>Annual costs (mil. €) by affected actor groups*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Infrastructure managers</td>
</tr>
<tr>
<td>Floods, avalanches</td>
<td>2.1</td>
</tr>
<tr>
<td>Storms, winds, waves</td>
<td>1.3</td>
</tr>
<tr>
<td>Extreme temperatures</td>
<td>0.5</td>
</tr>
<tr>
<td>Total</td>
<td>3.9</td>
</tr>
</tbody>
</table>

*The reference year is 2009

The allocation of costs by type of event, due to the lack of quantitative evidences through significant case studies, has been conducted through qualitative insights from the literature review. Storms, winds and strong waves, accounting by 50% of total costs, are considered to exert a relevant influence of operational activities (use of infrastructure, loading and unloading, Origin/Destination trips, etc). The same can be said for floods and avalanches, accounting for 35% of total costs, to the extent that their impact is particularly relevant in interrupting services and extreme temperatures (16% of total costs), causing accidents and higher maintenance costs.
PART C: CONCLUSIONS

13 Compilation of results

The following table provides an overall picture at EU level of the cost assessment of the weather extreme events by transport mode, type of stakeholder involved and type of extreme event considered. The total costs amount to € 2.5 billion yearly. Thereof, €1.8 billion are computed for road, € 361 million relate to air and € 306 to the rail sector. Minor costs are incurred to maritime transport (€20 million), inland waterways (€ 4 million) and intermodal freight transport (€2 million).

Table 19: Generalization of extreme weather events costs for the European transport system (annual data in € m)

<table>
<thead>
<tr>
<th>Extreme weather event</th>
<th>Infrastructure Assets (m€)</th>
<th>Infrastructure Operations (m€)</th>
<th>Vehicle Assets (m€)</th>
<th>Vehicle Operations (m€)</th>
<th>User Time (m€)</th>
<th>Health &amp; Life (m€)</th>
<th>Total (m€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storm</td>
<td>76.10</td>
<td>22.60</td>
<td>5.10</td>
<td>1.40</td>
<td>63.00</td>
<td>5.90</td>
<td>174.10</td>
</tr>
<tr>
<td>Road (1)</td>
<td>0.07</td>
<td>12.05</td>
<td>6.28</td>
<td></td>
<td></td>
<td></td>
<td>18.39</td>
</tr>
<tr>
<td>Maritime (5)</td>
<td>2.10</td>
<td>17.99</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20.08</td>
</tr>
<tr>
<td>Intermodal (6) (7)</td>
<td>0.53</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.25</td>
</tr>
<tr>
<td>Air (8)</td>
<td>53.80</td>
<td>34.30</td>
<td>38.40</td>
<td>28.30</td>
<td></td>
<td></td>
<td>154.80</td>
</tr>
<tr>
<td>Winter</td>
<td>248.80</td>
<td>126.30</td>
<td>81.30</td>
<td>125.50</td>
<td>164.90</td>
<td></td>
<td>759.30</td>
</tr>
<tr>
<td>Road (1)</td>
<td>0.04</td>
<td>3.38</td>
<td>1.60</td>
<td></td>
<td></td>
<td></td>
<td>5.02</td>
</tr>
<tr>
<td>Intermodal (6) (7)</td>
<td>0.21</td>
<td>12.00</td>
<td>57.70</td>
<td>64.60</td>
<td>1.90</td>
<td></td>
<td>0.42</td>
</tr>
<tr>
<td>Air (8)</td>
<td>11.20</td>
<td>12.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>147.40</td>
</tr>
<tr>
<td>Flood</td>
<td>630.10</td>
<td>21.90</td>
<td>24.40</td>
<td>30.01</td>
<td>93.70</td>
<td>21.50</td>
<td>821.61</td>
</tr>
<tr>
<td>Road (1)</td>
<td>4.87</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>4.87</td>
</tr>
<tr>
<td>Rail (2) (3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>282.55</td>
</tr>
<tr>
<td>Intermodal (6) (7)</td>
<td>0.32</td>
<td>26.50</td>
<td>29.60</td>
<td>0.20</td>
<td></td>
<td></td>
<td>59.50</td>
</tr>
<tr>
<td>Air (8)</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IWW (4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat &amp; drought</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Road (1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>46.90</td>
</tr>
<tr>
<td>Total</td>
<td>1059.82</td>
<td>182.00</td>
<td>308.92</td>
<td>180.39</td>
<td>494.84</td>
<td>270.63</td>
<td>2496.60</td>
</tr>
</tbody>
</table>

(1) Average year 2000-2010.
(2) Average annual data 1999-2010
(3) Avalanches, winter storms and extreme heat events not included
(4) Average annual data 2003-2009, service providers costs
(5) Average data hurricane Kyrill 2007 from case studies, freight transport
(6) Average data 2009 freight transport without AT, CH, I, CZ, DE (already included in Rail)
(7) Including extreme temperatures (heat)
(8) Average annual data
As suggested by the several footnotes to the table, the cross-modal comparison of extreme weather events related costs is subjected to several caveats.

Firstly, the reference year is different. In some case, the year is estimated as an average of several years, e.g. for inland waterways (2003-2009), in others the estimate is simply based on a one-year observation, e.g. for maritime (2007).

Furthermore, and most significantly, in some case the annual estimation is the result of the generalization at EU level of cost estimations available for given countries, using specific parameters and variables (traffic flows, number of container, etc), i.e. for the road and rail sectors, the intermodal transport (freight) and the air transport; in other cases the generalization has not been made possible, as for waterborne transport (inland waterways and maritime). When the generalization has not been made possible, a certain downward bias in the final results must be taken into account. And even when the generalization has been made possible, a certain downward bias is still possible due to lack of information, as for the costs suffered by the rail transport system because of extreme very cold days.

On the other hand, the table shows that of the € 2.496 billion of total costs, about 97% are related to the transport modes for which the generalization at EU level has been carried out: road, rail, intermodal freight transport and air transport, whose total extreme weather related costs amount to € 2.413 billion. This implies that the trends and the conclusions drawn below can be considered representative of the impacts suffered by the overall European transport system.

Taking all that in the duly account, the table does not show double-counting, for example the climate change costs suffered by intermodal freight transport do not include the costs assessment estimated under the rail transport mode. Concerning intermodal transport in general, it must be stressed that the climate change impacts incurred to the intermodal passenger transport and public transport network (buses and coaches) have not been generalized to the overall European level, due to the lack of case studies and literature evidences on the matter.

In terms of the type of stakeholders affected by the extreme weather events, infrastructure asset and operation account not surprisingly for the higher toll: 50% of the total costs (43% asset and 7% operations). The literature review has in fact stressed the fact that the likely most relevant implications arising from climate change concern planning, design, construct, operate, and maintaining of transport infrastructure (TRB, 2008). But also the burden suffered by users (due in particular to congestion and time losses to
citizens and transport users) is quite relevant (about €450 million per year, corresponding to 20% of the total costs). The health costs amount to 12% of total costs, corresponding to €270 million per year.

In terms of the most relevant weather events, floods and winter account for the higher share on total costs, corresponding respectively to 47% and 36% of the total costs. (see Figure 21).

Figure 21: Comparison of total results by type of event
The damages arising from storms correspond to 15% of the total costs. As concerns heat impacts (2% of the total costs) we must consider a certain downward bias, as here less accurate and information for economic assessment are available.

In terms of impacts on transport modes, the most significant impacts affect the road sector (72%, due to the relevant impacts on infrastructure asset and operations) and the air sector (15% of the total costs, mainly due to the impacts on users and operators caused by delays -). In conclusion, the figures reported in Table 19 report on the average annual costs for selected types of weather extremes.

But apart from all methodological difficulties the results allow to indicate the most vulnerable elements and the most costly impacts per model of transport. These are:

- Infrastructure damages due to floods and multiple impacts of harsh winter conditions in the road sector,
- consequences of durable rainfalls on rail infrastructure and operations,
- storms on maritime operations and floods on user time losses in road navigation,
- winter conditions and storms for intermodal freight infrastructures and safety and
- storms and winter conditions on air operations and punctuality.

These findings will feed into the forthcoming steps of the WEATHER project. The economic figures either in terms of total annual costs across Europe or specific costs per
event and region will provide the basis for the assessment of the level of saving potential of adaptation measures. On a regional level the findings will be re-visited by the cases studies to be carried out.
14 Conclusions and outlook

14.1 Comparison of objectives and results

The following section compares the objectives of the WP2 “Vulnerability of transport systems”, as indicated in the WEATHER Technical Annex, and the results of the Deliverable 2 "The vulnerability of transport systems", which has been specifically designed to address the objectives of the WP2.

**Objective 1: Identify the vulnerable elements of the transport sector and the specificities of each mode and of intermodal processes with respect to different extreme weather events (sub-objective 2)**

*Results of the Deliverable.* The Deliverable has identified specific weather events (Chapter 2.2.3) which clearly exceed the long-term average of comparable meteorological activities over the annual mean or related to the specific season, which have considerable negative impacts on assets and operations, or which affect human health or lives.

The above weather events have been related to all modes of transport. These are:

- Road: European perspective derived from country-specific data.
- Rail and urban public transport (UPT): discussion of case-specific results.
- Aviation coverage of Europe by assessing Europe-wide statistics.
- Maritime and inland navigation: sector-specific focus on a few countries.
- Intermodal transport European focus by generalising sector information (only freight transport).

**Objective 2: Quantify the entrepreneurial costs of extreme weathers for transport operators**

*Results of the Deliverable.* The cost assessment has been carried out according to an evaluation framework (Chapter 2.3.2) including the following cost items and main assumptions:

- Infrastructure damages: We start from standard cost values for infrastructure construction by construction element taken from the IMPACT (2008), GRACE (2006) and UNITE (2002). If no state of damage is reported we only consider the costs of resurfacing and equipment renewal. To separate standard renewal costs from weather-related damages we take only the share of the asset's remaining life time or
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50% of not available. Capital costs are considered by a de-fault value of 10% upon the replacement or repair costs.

- Infrastructure operations: Here we do not have standard cost values available, as these will strongly differ between categories of weather extremes, regions and the organisational structure of the infrastructure company.

- Vehicle damages: Cost values are based on prices for new vehicles, of which we apply 50% to reflect age and partial damages. In further steps these will be cross-checked to insurance reports of material damages.

- Vehicle operation costs comprise of costs for additional heating and cooling in case of temperature-related events or of fuel, personnel and depreciation in case of detouring. Respective cost values are provided by automobile Associations for passenger cars or HGVs and can be derived from balance sheets of transport service providers. The time and distance of detouring is estimated by the TRANS-TOOLS network database. If the number of vehicles affected is not given, national average traffic volumes per type of infrastructure are taken.

- User time costs are computed like vehicle operating costs using standard cost values from the IMPACT and HEATCO projects. If not available by modal statistics, default values for delays and detours are also taken from the TRANS-TOOLS model. Besides national infrastructure load rates, national vehicle occupancy figures are provided to transfer vehicle delays into passengers or freight units.

- Users’ discomfort arises from over-crowding, excessive or too low temperatures in vehicles. We have not found a reliable method for valuing these effects and thus exclude comfort-related impacts from the assessment.

- Accident impacts on human health and life are assessed by standard cost values for death casualties, severe and slight injuries derived in recent European studies. Usually the number of fatalities and injuries associated with extreme events are well documented.

**Objective 3: Estimate and predict the social costs of extreme weathers affecting transport**

**Results of the Deliverable**. The current costs of weather extremes are summarised in the Table 18 in the Conclusions section. The footnotes to the table guide to a correct interpretation of the cost assessment. It turns out that the extreme weather events amount to about € 2.5 billion yearly, estimated along a ten years time span (2000-2010).

The prediction of costs to 2050 has been addressed by reviewing the results of major climate models and by indicating sensitivities and forecast procedures for the main transport modes. Quantitative predictions will be carried out in the framework of WP4 as soon as the meteorological results from WP1 are available.
Objective 4: To deepen the insight into the vulnerabilities of transport infrastructure and system operation to extreme weather events within a WP2 Workshop with transport professional will be organised. The workshop will cover infrastructures, passenger, and freight services within each mode. For each topic key presentations from transport professionals will be invited.

Results of the Deliverable. The WP2 Workshop was held on 14.9.2010 in Brussels (Chapter 5). The Workshop has addressed all the transport modes, taking stock of the contributions of the following specialists:

- **Road and urban public transport:**
  - Kenneth Natanaelsson (Trafikverket) Swedish Maritime Association, providing a detailed assessment of landslide activity in the southern Part of Sweden, current and in the near future.
  - Roberto Arditi (SINA on behalf of ASECAP, the Association of European Toll Motorway Operators) highlighting the importance of roads to access emergency areas.
  - Matthew Webb (Transport for London) presenting TfL's strategy for assessing and adapting to climate change.

- **Rail and intermodal freight transport:**
  - Chris Baker (University of Birmingham) discussing findings of the FUTURENET project funded under UK's EPSRC “Adaptation and resilience to climate change” programme.
  - Samuel Brunet (RFF, French Rail Infrastructure Manager), discussing problems encountered through increased rain- and snowfalls resulting in damage on earthworks and structures.
  - Martin Burkardt (UIRR) stressing the several problems railway operations encounter under adverse weather conditions.

- **Air transport sector:**
  - Henrik Littorin (Swedavia) highlighting two reports dealing with the consequences of climate change for the Swedish air transport sector.
  - Rachel Burbidge and Dennis Hart (Eurocontrol) stressing the impacts of the past winter episodes on the air sector.

- **Inland navigation and maritime shipping:**
  - Nina Nesterova and Jan Kiel presented the study teams approach to address the economic costs of weather extremes for inland navigation and maritime shipping.
14.2 Overall achievement

The comparison of planned and actually achieved results within this work package of the WEATHER project reveals that the goals have been met. Furthermore, for the first time it has been possible to establish a cross-modal and cross-regional comparison of the economic costs of weather extremes on the transport sector for Europe. This enables to set transport’s role as a victim of climate change into perspective and provides a benchmark for suitable cost-efficiency-ratios of adaptation strategies.

Nevertheless, the results are not fully comprehensive, as not all cost categories and modes have been looked at with equal intensity. Subsequent work in this project, parallel research in this area currently funded by DG-RTD and DG-MOVE as well as future activities should help closing gaps and deepening the analyses initiated by this study.

14.3 Interpretation and outlook

The moderate results found by this study amount to 0.1 €-Ct per passenger car kilometre on European roads or roughly 30 €-Ct per air ticket. These are far below the costs for infrastructure provision and maintenance, system operation or climate gas emissions. The current results acknowledge that there are considerable total costs, which are even more dramatic when looking at single large events. But they also reveal that the policy priorities should be on mitigating GHG emissions and on easing the burden of world regions, which are more vulnerable than Europe and which have less economic resources to cope with the consequences of climate change.

The outlook to 2050 and beyond appears different for the various transport modes and weather categories. We see different growth rates of population, and thus of transport activities, in the various areas of the Union. While Northern Europe, the British Islands and France envisage a further population increase, Germany, Eastern and Southern Europe are heading towards stagnation or even a decline of inhabitants. These are confronted with differing impacts of climate change on our weather. While heat and storm and rain, entailing wild fires and floods, will increase, winter conditions will soften. Thus, some areas particularly in Mid Europe may see an overall decline of weather related costs – or a shift towards different hazards. A quantitative analysis of the future trends of total and average costs of weather extremes will be provided within Deliverable 4 on Adaptation Strategies of the WEATHER project.
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