Doll, C.

Assessing and Treating the Risks of Weather Extremes on Transport inside and outside Europe

Review Results

General remarks:

Organization and length of the paper needs to be improved and repeating material needs to be removed.

Response: The reviewers seem to have commented on an older version of the paper. I had uploaded a revised and cleaned version – I think but I am not sure about this – within the deadline for full paper submission. Nevertheless, with 30 pages the paper will is way too long. and Thus I have made an attempt to clarify the message of the paper by removing the extensive discussion on adaptation options. I hope this improves the paper and maybe even lifts it up to a “B” score.

In the following I respond to the very helpful comments of both reviewers in detail.

Reviewer 1

This is an interesting paper based on what seems to be a report that has been, as far as I can tell, carried out and reported well. However, the paper needs to be much more focused in order to make a good conference paper. It is too long, with 34 pages, which is well over the limit of 20 pages. The length is partly caused by material being repeated: for example Figure 1 appears on Pages 17 and 23 and Sections 3.2 and 4.2 appear to be identical.

Response: The revised version has already eliminated these duplications. But – as indicated above – we have further reduced the length of the paper by completely removing the former Section 3 and by completely re-writing the text from Section 4 onwards.

More use could be made of table to summarise some of the key information.

Response: Key information are in fact figures 1 and 2. And we would prefer keeping them in figure form to better convey the geographical locations of hot spots in Europe (also for non-European readers).

The data in Figure 1 would be much easier to understand in a table.

Response: No. See above.

On Page 3, Paragraph 2, it says that natural hazards have been rising five times over thirty years in North America, with very high increases elsewhere in the world. These are extraordinarily high rates and ought to be explained.

Response: This truly strange statement had been removed already in the second version submitted in late 2012.

ADB on Page 9 has not been explained as far as I can see.

Response: Already removed in version of October 2012

It is not clear where the figure of 130 000 at the top of Page 10 comes from.

Response: Response: Already removed in version of October 2012

It would be useful to have some indications of the basis of the figures in the Cost Categories on Page 11.

Response: We cut out the section as this was meant as an example only. Going deeper into the methodology would prolong the paper further.

It is rather frustrating to see the figures implied by Figure 1 but no discussion: why does France have the highest average costs for aviation, for example? Why do the Mediterranean Area countries have higher costs for rail than much of Western Europe?

Response: We have added some discussions before figure 1.

Section 3.2 (and 4.2) on the Forecast Method does not explain the method used for forecasting. It should do.

Response: Section 3 is on results. The forecastiing method has been explained in Section 2.2. Section 4 was removed.

Similarly, the differences between the two studies shown in Figure 3, particularly for Road, are not really explained. Why does EWANT have much higher accident costs for road? The text does not seem to explain it.

Response: It's a pitty – but we have removed this comparison. We try leading this discussion in a different paper.

Whilst it may not be possible to give detailed policy recommendations in Section 6.2, what is shown there is disappointing.

Response: Correct. We have completely re-written the recommendations section.

Overall, this paper needs to be rewritten as a conference paper, with its own set of objectives, outline of the methodology, analysis and conclusions. It reads too much like a 'cut and paste job' based on a report. The audiences for a WCTR paper and the report are very different: the paper should be rewritten to reflect this.

Response: We think we have done so.

Reviewer 2

"This paper is a summary of a European project WEATHER assessing the current impact of extreme weather conditions on transport system and provides some cost estimates as well as some future projections. The paper is interesting but need: first, much more organization, most striking is the fact that section 4.2 is a copy of Section 3.2 and Section 4.1 is a copy of part of section 3.1, the authors should re-organize all the paper before re submitting.

Response: Done – see introductory remarks.

Second, there are endless assumptions which are not supported (see some examples in my detailed comments below), together with the lack of organization of the paper, the authors may want to focus on one aspect but explain this one aspect well and support the analysis, for example focus only on road.

Response: We have left in rail and air. But we have removed the comparison of the WEATHER and EWENT study and have cut out the case study discussions in the adaptation section. Should be clearer now.

Some comments: Taking an average value of time for weather affect may underestimate the cost of these effects, as travel time delays are only one problem of time loss due to weather conditions, what about time spend by simply not being able to get to work etc… time for tentative arrangements etc….

Response: Correct. We have added a respective remark to page 5.

The paper states that ""it was not distinguished between passenger and freight transport as most impact of extreme weather are anyway on infrastructure."" This is not clear to me, still the cost implication a damaged infrastructure can have on freight and passenger transport can vary significantly.

Response: We have written this in a rather lax way. Internally we have calculated passer and freight costs, but we did not show them in the final results for simplicity reasons. Text was changed accordingly.

Section 3.2. ""Forecast Method"" doesn´t really provide much details at the forecast method which would be interesting, but rather provides some main results.

Response: Method is described in Section 2.2; 3.2 heading was corrected

Section 3.3, what is included in ""social cost""? and how the values for these costs were derived?

Response: Section was removed

Section 3.4, where do the cost elasticities come from?

Response: Section was removed.

The paper is UNORGANIZED, section 4.2 is a copy of Section 3.2 and Section 4.1 is a copy of part of section 3.1 "

Response: As stated in the introduction, these issues had already been solved in the previously submitted version of the paper.

I thank the reviewers for the valuable critique. I hope – and believe - these changes make the paper acceptable for being presented in Rio.

Claus Doll, 15.5.2013.

Assessing and Treating the Risks of Weather Extremes on Transport in Europe – Findings from the WEATHER Project.

Paper submitted to the 13th WCTR Conference,
July 15th-18th 2013, Rio de Janeiro, Brazil
Submission date: October 31st 2012

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Re-submission date: 24.2.2013

Abstract
The assessment of current impacts of extreme weather conditions on transport systems reveals considerably high costs in certain locations. Prominent examples for Europe are the big floods in Germany 2002 and the UK 2007, the heat waves in 2003 and 2007, the winter seasons 2009/2010 and 2010/2011, or the extratropical cyclones Lothar in 1999 and Kyrill in 2005. But across the entire European transport sector the resulting annual damage costs of two to three billion Euros found by the WEATHER project seem to be manageable and climate models predict rather modest changes in the key parameters until 2050. Departing from these insights the paper tries to take a look until the mid of the century by combining the key questions on the state of climate and weather extremes with the outlook of feasible adaptation strategies in the transport sector. We find that the most powerful options to get more resilient cruise around information, organization and co-operation, rather than requiring costly infrastructure investments.

Keywords: Climate change, weather extremes, transport, damage costs, vulnerability, impact projection

1 Introduction

1.1 Background

The past 15 years have been characterised by a high density of record breaking weather extremes in Europe. In 1999, 2007 and 2010 the extratropical cyclones Lothar, Kyrill and Xynthia damaged wide areas of France and Germany and in 2002, 2005, 2006 and 2010 major floods affected Germany, Poland, the Czech Republic, Bulgaria and their neighbours. The heat waves 2003 and 2007 caused major wildfires with considerable problems for settlements, human health and transportation, and after a long period of mild winters the cold spells and snow storms 2009/2010 and 2010/2011 challenged all transport modes and public services. These events are recorded and assessed by several sources, including the analysts of the big reinsurance companies (Munich RE 2011) or emergency management database (EM-DAT) of the Leuven University (Guha-Sapir et al., 2012). According to the EM-DAT database within the decade 1999 to 2008 400 extreme meteorological and hydrological events were counted killing 77371 people and costing 113.6 billion euros. Related to the roughly 500 million inhabitants of Europe this is roughly 23 euros of damage costs per person and year.

The causes of this trend are manifold. In the past century, and in particular in the recent decades, accumulated values have increased, building standards have become more risky, the migration trend towards big coastal cities is persistent and observation and reporting techniques of damages have substantially improved (World Bank, United Nations 2010). If prevention is not significantly improved, the estimated global damages towards the end of the century may increase to 134 billion euros, which is three times today's level. The report concludes, that prevention measures are not necessarily expensive: information of citizens and better maintenance of infrastructures at risk could be carried out with little additional costs.

A recent study on the topic by Munich RE (2012) reveals that, even when correcting for these manmade risk increases, a clear trend for rising impacts of natural hazards can be read out of statistical data, which may give evidence to the first measurable footprint of climate change on human societies. Among all world regions, the most significant rise of damages has been observed in the United States.

1.2 Objectives and structure

With this paper we take a look into the current state and the future of the exposure of European transport systems to the consequences of climate change and weather extremes. We approach the questions: which are the main drivers of weather related costs of road rail and air transport, how will they most likely develop and how big are the uncertainties of their development. The analysis is built on the results of the recently finalized research project WEATHER, funded under the 7^{th} RTD framework programme of the European Commission.

The WEATHER project was started in December 2009 with the aim of quantifying the private and social costs of weather extremes on transport for the entire European Union, all modes and a large variety of weather phenomena. To that time only some fragmented assessments of the costs of natural hazards on transport have been available mainly from overseas (TRB (2008) for the US, Lemmen and Warren (2004) for Canada and Gardiner et al. (2009) for New Zealand). Although these studies took the national perspective, non of the sources was able to report on the overall economic costs which climate change and extreme weather events impose on the transportation sector across the respective countries. Reliable damage cost information, however, is essential for prioritizing transport adaptation activities against other public duties, including adaptation in different sectors, as well as to balance funding between adaptation and mitigation strategies. The WEATHER project thus constitute the first multi-lateral exercise of this type.

Section 2 delves into the rationale and methodology of the WEATHER damage estimates, and Section 3 provides the results. Presented are the figures for the period 1998 to 2010 and the forecasts to 2040 to 2050 for European road, rail and air transport. Section 4 then turns to potential adaptation strategies and Section 5 eventually analyzes the deviations between the findings of the WEATHER and the EWENT project and draws conclusions for research funding and transport policy.

2 Accounting Principles and Dimensions

This section looks into the methodology applied by the WEATHER project for estimating today’s damages imposed by extreme weather conditions on transport systems and for forecasting these to the period 2040-2050. A detailed description of methodological issues, data sources and results is provided by Enei et al. (2011) for current costs and by Przyluski et al. (2011) for the period 2040-2050.

There are several ways of approaching the economic costs of weather extremes. First, one can analyze the incidents which happened in the past and derive statistical measures of damage probabilities. In this case no detailed mapping of weather phenomena is required; it has just to be agreed on which types of incidents are considered and which impacts shall be accounted for. Second, one can make use of statistical relationships between weather variability and transport sector costs. The derived damage cost functions then have to be applied to current or future weather and climate patterns in order to arrive at area wide damage cost values.

Within the WEATHER project both approaches have been mixed to determine current damage costs to the transport sector. However, with regard to data situation, details of the methodology varied considerably by weather phenomenon, mode of transport and type of impact.

2.1 Dimensions of the accounting framework

In the subsequent sections we go across the most relevant dimensions of WEATHER accounting framework:

1. Cost categories:

According to the WEATHER assessment framework, the direct impacts of meteorological hazards and their consequences on transport were expressed by six cost categories. These describe impacts on durable infrastructure assets, transport service provision and users. These categories and the basic approach of valuation are given in turn:

- *Infrastructure assets* were assessed by current replace-ment costs, multiplied by the age structure of the assets. Using German data, these are €8.7 million per kilometer for completely destroyed motorways and €2.55 million per km for railway lines. Depending on the intensity of the extreme and the type of damage, a deduction of this value was applied.

- *Infrastructure operations* were estimated at €1,000/h for police and traffic control on motorways, €5,000/h for fire brigade missions and €43,600 for operation and revenues losses per railway section.
- *Vehicle damage costs* are derived from insurance statistics for roads, and aircraft industry reports for aviation, also considering the age structure of the vehicles involved.
- *Vehicle operations* and *time delays* were assessed by average detour lengths derived from network models and by applying values of travel time delays of around €13/h and passenger taken from Maibach et al. (2008). In the study we did disregard the economic losses for trips which need to be cancelled or postponed. This important issue should be looked at in further studies.
- *Accidents*: Assessed are the immaterial costs of injuries and fatalities by the value of a statistical life (VSL) of €1.6 million per death casualty and 15% of that for severe injuries. On top of these, medical treatment, production losses and administrative costs are calculated according to van Essen et al. (2011).

2. Weather phenomena:

Considered are basically all types of weather extremes; ranging from heat and cold, precipitation, snow and hail, storms and storm surges to consequent events like floods, landslides, avalanches and wild fires. In total we have identified eleven basic types of extremes, which were then classified into four categories of typical extreme weather and climate conditions in order to reduce the degree of complexity in the assessment process. These four categories can further be classified into sudden hazards and longer periods of unfavorable conditions.

The decisive question in this context is: What is extreme? In meteorological terms, extreme denotes conditions which differ significantly from the normal seasonal and regional conditions in terms of severity and/ or duration. In order to avoid complex geographically and seasonally differentiated threshold values for the various weather events, the analysis applies the impact approach. According to this, conditions are extreme when impacts or costs cannot be managed by local authorities or the affected market players. An indication for this lack of coping capacity is the reporting of the incident and its consequences in supra-regional media. The four classes of extremes and their treatment in the WEATHER accounting framework are:

- *Rain&Floods*: Primary weather phenomena in this category embrace persistent as well as strong convective rainfalls. However, as for most cost categories rain itself is not a problem we concentrated on its consequent events, which are general floods, flash floods, landslides and other mass movement. These cause damages to infrastructures and vehicles and in consequence entail operational reactions, such as detouring and delays, impacting service operating and user time costs. In the WEATHER accounting framework we considered all flood and mass movement incidents reported by transport operators and supra-regional media to be extreme. An exception to this approach are road accidents, for which rain intensity matters. Here we took relationships of crash and fatality rates with respect to rain intensity from literature sources.
- *Ice&Snow* describes winter conditions including cold spells, heavy snow fall, snow storms and avalanches. In contrast to Rain&Floods, this category of weather events and their consequences constitutes a normal seasonal phenomenon across large parts of Europe. Thus, not each break-out of winter is to be considered to be extreme. What makes winter conditions unusual hard depends on regions: while Scandinavian and Alpine countries are used to long snow and frost periods, several weeks of snow cover are rare in Mid Europe and virtually impossible in Southern Europe. In the WEATHER accounting framework it was decided to consider only the 10 percent longest winters in a particular region as extreme. Out of these, only the numbers of ice and snow days above the 90 percentile winter of the respective region are accounted for in economic terms. Only for this fraction of winter days, increased winter maintenance expenses, vehicle damages, user delay and accident rates are assessed. An exception are infrastructure damages, which accumulate over longer winter periods and thus have to be considered for the entire duration of the 10% longest winter seasons.
- *Storms* mainly comprise the category of extra-tropical cyclones, occurring in late summer and autumn. Winter storms are allocated to the category Ice&Snow in case they appear together with snowfall or very low temperatures. As

Rain&Floods, all storm events reported in supra-regional media are included in the WEATHER assessment framework. Specific threshold levels of wind speeds, durations or spatial extensions are not considered.

- *Heat&Drought*: In first instance we consider persistent periods of hot days with the lowest night time temperature exceeding 25°C or very low amounts of rainfall. Consequences are increase car crash rates, low water for inland shipping or heat stress for infrastructures and vehicles. An important consequent event here would be wild fires, but their damage and disruption potential on transport has not been investigated systematically in the WEATHER project.

The four categories of weather extremes and their basic characteristics are presented in Table 1.

Table 1: Categories of weather extremes

Category of events	**Events and consequences contained**	**Relevant regions**	**Relevant transport sector impacts**
Ice&Snow	Frost spells Deep snow cover Avalanches	Central and northern Europe, mountain areas	Airports, roads, rail tracks, channels
Rain&Flood	Persistant rainfalls Hail Flood / flash floods Mass movements	All Europe, particularly mountain areas	Roads and rail tracks; inland navigation
Storm	Extratropical cyclones Winter / snow storms Storm surges	Western Europe, coastal areas	Rail aviation operations, sea shipping
Heat&Drought	Heat spells Droughts Wildfires	Continental eastern and particularly southern Europe	Inland navigation, rail and road infrastructure

Source: Fraunhofer ISI

3. Modes of transport

Considered were all modes of transport, namely road, rail, aviation, inland navigation and maritime shipping. Besides infrastructure related issues costs were computed separately for passenger and freight transport, but for reasons of readability of the results we have decided to show only total results per mode. A special case, however, was combined road-rail freight transport, which was considered a separate mode. The application of the weather cost assessment methodology varied considerably between:

- *Road*: here two assessment approaches have been mixed to cover an as wide as possible range of hazards and cost categories. For six European countries 980 damage reports from supra-regional media and road operators have been evaluated. In addition, a broad literature review has delivered cost functions and thresholds for snow, rain and heat impacts on traffic performance and safety.
- *Rail*: For the rail sector only the incident database (IDB) approach was applied. Through operator data for specific incidents in Austria, Switzerland, the Czech Republic and Germany average costs and cost deviations per type of event for the most critical weather phenomena could be derived.
- *Aviation*: Airport winter management was assessed by valuating snow and ice days above the 90 percentile winter with average unit costs per flight from Scandinavia. Delay and safety costs to airlines and passengers were estimated using EUROCONTROL and EASA data. Here we have been somehow inconsistent to the road sector and to airport management as we did assess all weather related costs for aircraft operations, not only those above the 90 percentile winter.

4. Climate zones:

Derived from Christensen … we have subdivided Europe in eight climate zones:

- Alpine Arc (AL): Switzerland, Austria and Slovenia
- British Islands (BI): UK and Ireland
- France (FR),
- Mid Europe (ME): Germany and the Benelux countries
- Europe East (EA): Poland, Czech R., Slovakia, Hungary, Romania and Bulgaria
- Mediterranean area (MD): Italy, Greece and Malta
- Iberian Peninsula (IP): Spain and Portugal and
- Scandinavia (SC): Scandinavian and Baltic countries

To apply the EEM approach and to translate IDB results for the sample countries to all Europe, weather data of the past decades was collected from the ECA&D database for each climate zone. In each zones we averaged across the weather stations located close to the biggest cities. A mapping of the eight climate zones is given by Figure 2 in Section 4.

2.2 Generalization and forecast methodology

For projecting the intensity of weather extremes in the coming four decades results derived from six RCM models, run done by the ENSEMBLES project (van der Linden, 2009) and described by the EWENT project are used. Transport volumes were available in passenger and ton kilometres for cars, busses, trucks, freight and goods trains and aircrafts from 1990 to 2050 from the GHG-TransPoRD reference scenario (Fiorello et al., 2012). The cures indicate clearly that Europe will grow with different speeds, lead by the transformation countries in Eastern Europe (EA), while the mature markets with a poor demographic outlook in mid Europe (ME) nearly stagnate. The ASTRA model does not provide infrastructure values in terms of capital bound in durable assets. Thus we estimate this to grow with between 50% of demand in the road and air networks with partly tight capacity to 25% of demand in rail. In the latter case we assume that through operative processes much demand can be absorbed without the need to carry out huge investment programmes.

To link forecasts of extremes and transport projections cost elasticities have been estimated. The cost elasticities (Eta) are chosen on the following assumptions:

1. Winter impacts cause massive costs mainly at their onset (Eta=0.5)
2. Rain, flood and storm events: accommodation effects are less likely (Eta=0.8)
3. Heat periods start causing costs to operators and users (Eta = 1.5)

Results for the current period (1998 to 2010) and the coming decades (2040 to 2050) are presented in Section 4.

3 Results of the Accounting Framework

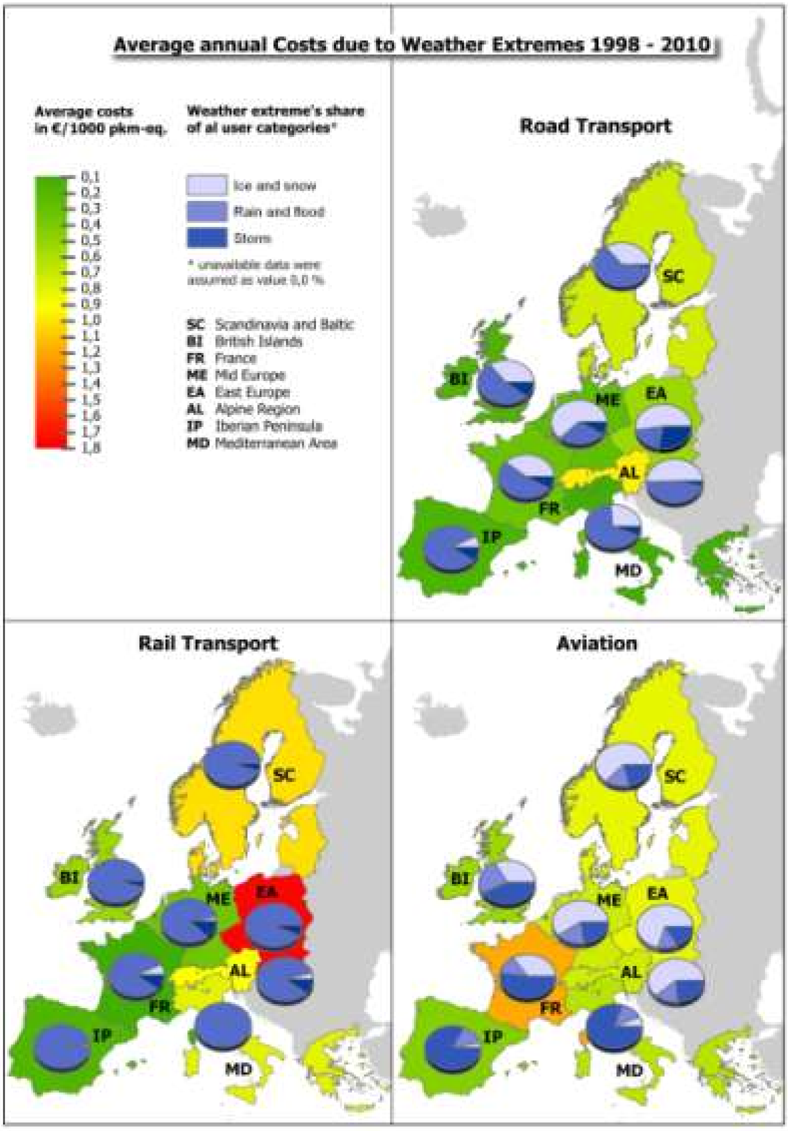
3.1 Damage estimates 1998 to 2010

Deliverable 4 (Adaptation Strategies) of the WEATHER project (Doll et al., 2011) has identified the most critical parts of European transport networks and operations by applying a simple set of indicators. These are the average damage costs borne by a unit of traffic performance, measured in passenger kilometre equivalents (pkm-eq.). Considering infrastructure and vehicle capacity demand this is computed by pkm + 0.3 tkm for land transport and pkm + 10 tkm for aviation. The results for road, rail and air transport are plotted in Figure 1.

Road and Rail infrastructures are mainly endangered by storm surges in coastal regions, flash floods and land slides in mountain areas, general floods across all Europe and winter conditions in Mid Europe and the British Islands. Above, in combination with bad maintenance, high or low temperatures (especially changes between below and above zero degrees Celsius) cause damages to roads. Events like landslides, heavy rainfall, storms and snow mostly cause operational difficulties due to cleaning measures. In summary, impacts are highest in mountain areas due to the high values of infrastructures and the difficult geometries for water and mass movement run-off paths. However, concerning rail, Eastern Europe with old and partly under-financed networks in combination with harsh continental climate conditions are by far most vulnerable (Nurmi et al., 2012). Additionally we receive high damage indicators for southern European and Scandinavian rail networks mainly due to hydrological hazards, which are of major concern in Sweden and northern Italy.

Airports are mainly penalised by high winds and fluctuating annual weather patterns in central Europe and the British Islands. As a high share of flights in Europe is international, network effects cause to spread the impacts across climate regions. With the attempt to trace back delays to the climate zone mainly responsible for them, we receive by far the highest costs for France, as this incorporates several climate zones within one country.

Figure 1: Average damage cost estimates 1998 - 2010 by mode and climate zone



Source: Fraunhofer ISI

The results found by the WEATHER 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.

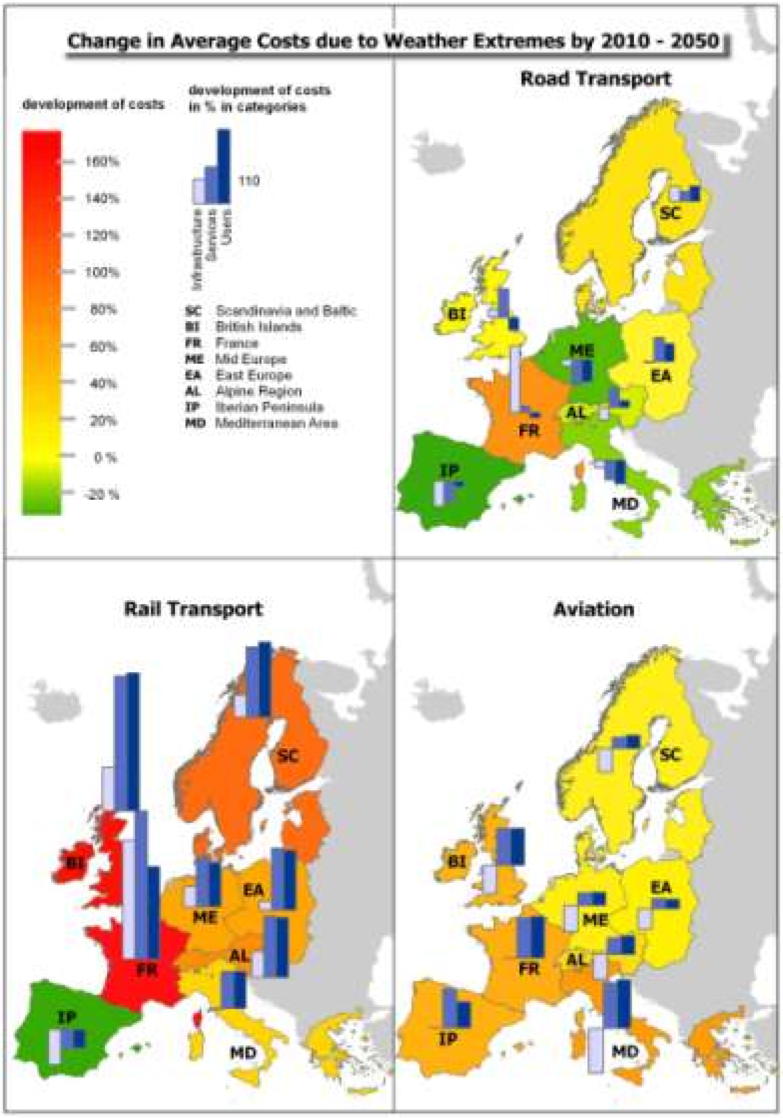
3.2 Damage forecasts to 2040 to 2050

In the coming four decades, the damage costs increase in rail transport will be most expressed, followed by air and road. The most suffering user groups are, against intuition, not infrastructure operators but train operators and passengers. In the forecast period 2040 - 2050 they face nearly double the damage costs they bear currently.

Despite the general increase in burdens, however, there will also be winners of the changing climate. These are, not surprisingly, those suffering from heavy winter conditions. These are largely transport infrastructure owners and rail operators in Alpine regions and Scandinavia. Reduced severity of winters in countries with traditionally high volumes of snow may, on the other hand, reduce preparedness in these countries and increase winter maintenance costs. Also when regarding the development of average damage costs per pkm-eq., rail operations in France and the UK appear to be most vulnerable in future terms to changes in weather and climate patterns.

When breaking down the damage cost estimates of €2.4 million p.a. to passenger and ton kilometres, we arrive at rather modest damage costs of extremes in the past decade of between €0.10/1000 pkm-eq for the Mediterranean area and €0.96/1000 pkm-eq. in the Alpine region. These costs omit the impacts of more intensive heat waves with all consequences, sea level rise along coastal zones and will most probably rise in the coming 50 to 100 years, as the 2°C global warming target seems to be out of reach. However, with the proposed mix of incentives and investment measures these costs of inaction can be significantly reduced (Doll et al., 2011).

Figure 2: Average damage cost forecasts 2040 - 2050 by mode and climate zone



Source: Fraunhofer ISI

4 Considering system adaptation

The above damage cost figures are estimated under ceteris paribus assumption. This means, we did not assume any adaptation taken place towards mid of the century. This assumption is, however, not realistic as transport networks are constantly maintained and information and communication technologies will play a much more important role than is currently the case.

In the WEATHER project we have looked at options to adapt the transport sector to variations in climate and weather patterns between now and 2050 in two ways. First, a broad review of literature sources, interviews and workshops has provided a general inventory of adaptation options. In parallel, a series of European and world wide case studies has been carried out to understand the determinants of good crises management. Here we focus on the generic assessment of adaptation strategies to get a better idea of which impacts of weather extremes may be mitigated best in the decades to come.

4.1 Methodology for identifying efficient adaptation measures

Adaptation to climate change and weather extremes can be implemented in several stages of a rather complex setting of institutions, interactions and partly diverging short-run and strategic planning processes. In the WEATHER project we have structured the complexity of implementing adaptation strategies by looking at four typical decision levels and groups of institutions based on expert interviews and literature screening.

- Planning: strategic considerations covering long time horizons.
- Infrastructures: Investments, maintenance and operations by infrastructure companies
- Vehicles: design of more resilient, reliable and comfortable vehicles.
- Operations: operations and training by transport companies.

For each of the four categories we have identified suitable adaptation measures based on a literature review, sector interviews, an expert poll and a stakeholder workshop. In total around 300 single measures have been identified and grouped into 62 categories. These are rather evenly distributed across modes and activity fields, with most measures found for infrastructures and service operations. 29 groups of measures are enhancing the resilience of transport systems across all categories of hazards by improved weather forecasts, staff training, vertical integration of information flows and command and control structures, as well as on inter-modal and inter-company cooperation. Table 2 shows the counts of groups of adaptation measures by mode and activity field.

Table 2: Size of the adaptation measure data set

Number of measures	**Activity fields**				
Modes	**Planning**	**Infrastructure**	**Vehicles**	**Services**	**TOTAL**
Road	5	10	2	5	22
Rail and transit	1	6	6	3	16
Aviation			3	3	6
Shipping		5	3	3	11
Multiple	2	1		4	7
TOTAL	**8**	**22**	**14**	**18**	**62**

Source: Fraunhofer ISI

For the evaluation of the measures a multi criteria assessment (MCA) framework has been developed and applied. We did not apply a sophisticated benefit cost analysis due to the great variety of modes, market settings and climate zones to be considered, because the wider costs and benefits of the measures beyond the transport sector are partly too complex to be traced within given time and budget limits and due to data availability restrictions. For the MCA we have identified five assessment categories: the risk reduction potential (or benefit) of the measure, the flexibility of reacting on changing risk patterns, the feasibility and acceptability of the measures, its wider economic, environmental and social impacts, and finally its life cycle costs. The criteria per measure and their weights for calculating the measures' final scores have been assessed based on literature work, a targeted workshop on adaptation, a poll among 37 experts in the field and - where necessary – expert judgment by the project team. Through this process, highest weights have been found for the risk reduction potential and the cost efficiency criteria.

4.2 Results of the WEATHER adaptation measure assessment

With the expert evaluations and the weights of the five assessment criteria we were finally able to rank the 62 groups of adaptation measures. However, given the great uncertainties associated with the wide geographical and meteorological scope covered by the WEATHER project, the results of this MCA exercise only denotes a semi quantitative output.

The measures ranked highest constitute a rather diverse collection of very specific technical measures, such as locomotive equipment and nano-materials for aircraft wings, next to broad recommendations on co-operations and the internal organization of institutions and companies. But all of the measures presented have in common, that no huge additional investments are required and that the co-benefits besides climate adaptation are considerable. For instance the equipment of locomotives with modern communication technologies meeting the European Train Control System (ETCS) standard brings about higher safety levels and allows a more flexible usage of rail network capacity. The different approaches of vertical and horizontal co-operation of undertakings and institutions might increase the competitiveness and efficiency of the European logistics and passenger transport sector in total and contingency planning and staff training in companies may improve the identification of employees with their company.

The other end of the ranking is occupied by rather expensive investment measures. Among the bottom ten measures identified by the MCA approach we find dykes and sea barriers, pavement of unpaved roads, shift of infrastructures to less risky routes or elevating buildings and key equipment. However, despite the low ranking of these measures by the MCA, in some regions with high risk levels, investments in protection systems might be superior to information and organization measures.

These results are supported by the 11 WEATHER case studies. We thus can conclude, that most likely the direct impacts of weather extremes on users, in particular in scheduled transport modes, will be mitigated by information technologies and horizontal and vertical co-operation strategies. As service and user costs across all modes account for roughly 80% of current damage costs (Figure 1) and will rise most to 2050, the potential of mitigating the most significant impacts of severe weather events is suggested to he high by our results.

5 Conclusions

The analyses of current damage costs of extreme weather impacts on road, rail and air transport have shown that the scheduled modes, and here in particular rail, are more vulnerable than the road sector. This is partly due to the network effects of interruptions in rail and air together with the high safety standards in these modes, the higher flexibility in individual road traffic and the enormous costs associated with building and maintaining railway networks. On the geographical level we see that costs are highest were networks are old and in poor maintenance conditions.

Our methodology of defining extremes and of estimating costs can be questioned. Cost estimates are mainly based on media reports and on a limited number of operator data for a sample of mid and southern European countries. When comparing our findings to that of the parallel project EWENT we see large differences, suggesting that the WEATHER findings denote the very lower end of the scale.

Looking to 2050 we see a mixed picture, Due to the milder winters to be expected, which currently accounts for around 40% of costs, in particular road transport will face declining weather-related costs. But again, rail transport shows the most unfavourable results. Costs towards mid of the century per passenger and ton transported will significantly rise in case no counter-measures are undertaken.

The review of potential adaptation strategies has found the good news, that in particular the scheduled modes rail and air will profit from better information and communication technologies, keeping carriers as well as their customers better informed of risks and suitable coping strategies. The second part of the picture, i.e. vertical and horizontal co-operations between companies, modes and authorities, however, is potentially more difficult to implement. Although high side benefits are found by the MCA assessment, we can suspect that for strategic reasons transport companies will be rather reluctant to closely co-operate with competitors.

Here can be a lever point for successful adaptation policies. If state or local institutions manage to implement joint agreements or platforms for data exchange and emergency management, passengers and freight forwarders will profit. Some of the WEATHER international case studies, namely the treatment of hurricane Irene in New York and Swiss adaptation strategy, have impressively demonstrated the power of preparedness, good information and decisive action.

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