WEATHER

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

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Deliverable 1

Weather Trends and Economy-Wide Impacts

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List of abbreviations

°C	degree Celsius
AL	Alpine region
ARIO	Adaptive Regional Input-Output Model
BI	British islands
bill.	billion (1000 million)
EA	Eastern Europe
EC	European Commission
EMDAT	Emergency Management Database run by the University of Leuven
FR	France
GAF	General Assessment Framework
IP	Iberian peninsula
IPCC	Intergovernmental Panel of Climate Change
m€	million euros
MD	Mediterranean region
ME	Mid Europe
mill.	million
Mn	million
PDF	Probability density function
pkm	passenger kilometre(s)
RCM	Regional Climate Mopdel
RCM	Regional Climate Model
SC	Scandinavia
SD	Statistical Downscaling
tkm	ton kilometre(s)
VA	Variance
vkm	vehicle kilometre(s)
WP	work package

EXECUTIVE SUMMARY

WP1in the framework of the WEATHER project

This document constitutes the third official publication of the WEATHER project and reports the results of Work Package 1: Weather Trends and Economy-Wide Impacts. It is concerned with three rather independent streams of work, which have emerged through the first 18 months of project elaboration. Parts of the results have already been utilised in pervious working steps or have even been published in project-internal working papers. In order to document the work done in the WEATHER project these aspects - namely the European climate scenarios and the general transport impact assessment framework - are summarised in this document.

Part 1: Development of Weather Extremes until 2050

Part 1: "*Weather Trends*", presents a synthesis of climate change scenarios of temperature and precipitation over Europe, for the periods 2021-2050 and 2071-2099(or 2080-2099) with respect to 1961-1990. Also, in this part are included the climate change projections over a small area –Northern Italy, results produced by statistical downscaling model (SD) developed at ARPA –SIMC. The projections, both at regional scale –European scale - and local scale (N-Italy) are referred to seasonal mean temperature and total amount of precipitations, as well as to extreme events of temperature and precipitation defined based on percentile thresholds (10^{th} and 90^{th} percentile). The emission scenario analysed is the IPCC scenario A1B

As concerns future changes of mean and extreme values over Europe, the simulations produced by Regional Climate Models (RCM) from Ensembles project (http://www.ensembles-eu.org/) have been analysed and described in the first part of the present deliverable. In order to try to quantify and reduce the uncertainties, a multi-model approach has been used in both cases, European scale (results produced by RCMs) and N-Italy local scale (results produced by SDs model). Analysing the outputs produced by the RCM from the Ensembles project (Van der Linden, 2009), the changes projected in annual mean air temperature over Europe (A1B scenario), vary between 0.5 and 2°C, for the period 2021-2050 with respect to 1961-1990. The magnitude of changes is greater to the end of the century, namely for the period 2071-2100, when the annual changes of mean air temperature could reach 3.5- 4°C with respect to present climate 1961-1990.

Summer is the season with "higher" changes, as concern mean and extreme temperature at European level in both period 2021-2050 and 2071-2099, the pattern of "warming" being more intense during summer over the Mediterranean area, where the projected increases in temperature could connect also to an increase in heat wave duration index.

Also, an important signal of changes, mean and extreme temperature, are projected for Scandinavian Peninsula especially during Winter and Autumn. For example, during winter the projections for the period 2021-2050 shows an increase in the 90th percentile of mean air temperature around 4°C, while the rest of Europe are expected to have an increase in winter 90th percentile of mean air temperature around 2.5°C.

Regarding the changes in precipitation, the simulations of *annual* amount of precipitation over Europe produced by regional climate models show a possible increase of precipitation over north and a decrease of precipitation in the south of Europe, during the period 2021-2050 with respect to 1961-1990, scenario A1B. The same configuration of changes but more intense is projected also to the end of the century, namely for the period 2071-2100 respect to 1961-1990, with a pronounced decreasing up to 20% in annual precipitation, especially in the Mediterranean area. Looking in details at seasonal level on extreme precipitation, the results show significant increase in 90th percentile of precipitation especially during winter and for the period 2080-2099 respect to 1961-1990 (scenario A1B), more pronounced over NE Europe (between 60-80%).

In the first part of D1 deliverables, also a statistical downscaling method (SD) has been developed by ARPA-SIMC, in order to estimate future changes in temperature and precipitation over Northern Italy (pilot area), at station level for the periods: 2021-2050 and 2071-2099 with respect to 1961-1990. The SD developed by ARPA-SIMC, is a multivariate regression based on Canonical Correlation Analysis. Observed data at around 75 stations that measured minimum and maximum temperature and around 90 stations for precipitation have been used in order to implement the SDs model. The climate change scenarios of seasonal minimum and maximum temperature obtained through SD models applied to the Ensembles simulations at station level, estimate an increasing of temperature over Northern Italy in all seasons, during both period. This increasing is around 1.5- 2°C in the mean value of seasonal minimum and maximum temperature, during the period 2021-2050 respect to 1961-1990, A1B scenario. The increasing is more intense to the end of the century and especially during summer, when could reach values around 3.5-4°C. An important signal of changes have been found also in 90th percentile of summer maximum temperature (increase around 7°C over n-Italy). In order to understand better the effect produced by the projected changes in minimum temperature, projections of the number of days with minimum temperature bellow 0°C(frost days) and number of days with maximum temperature bellow 0°C(ice days) have been constructed for both periods, at station level (stations from Emilia-Romagna region). The results emphasis a decrease in the number of frost days during winter, spring and autumn during both period, 2021-2050 and 2071-2100. The decrease is more pronounced in the second period and especially during winter, when the number of frost days could decrease up to 35 days respect to present climate.

As concerns the scenario of seasonal precipitation, the pattern of changes is complex, different from season to season and over N-Italy regions. A clear signal has been obtained during summer and especially at the end of the century, when the projections emphasis a reduction in summer precipitation around 40-50 % over N-Italy.

Part II: Economy-wide impacts

Assessing extreme weather events impacts on the economy is important for two main reasons. First, the overall impact of these events is still unknown, and only anecdotic evidence is available. A more analytic analysis thus appears necessary, especially to assess the potential impact on the economic trajectory of a region. Second, climate change may have an impact on the future characteristics of extreme weather events, influencing their intensity and frequency.

The impact of transport interruption is a particularly interesting aspect, because of the role of transportation of goods and persons, which makes all economic activities possible. Moreover, transport infrastructures are huge investments and are particularly weather sensitive. Therefore, small changes in how they are designed and managed could make a large difference in terms of total economic impacts from extreme events. With climate change, the adaptation of transport infrastructure is a major challenge. The purpose of the present report is to estimate the costs of extreme event on the transport sector, and on the wider economy through transportation indirect effects.

A particular aspect of extreme weather event is the fact that they are extremely local. As such, global climate models cannot be used to analyze future impacts. "Downscaling" methodologies have to be developed to answer this need. The report thus presents results from downscaling exercise to provide the climate information that is required to assess climate-change risks in the transport sector.

The "total cost" of an extreme event is the sum of all the costs to an economy. It usually encompasses the costs of destroyed capital, or the "direct" cost. However, during and after a natural disaster the economy does not function normally. This remains the case up to the completion of the reconstruction process, i.e. sometimes over years. These perturbations, including those arising from transport interruption, cause "indirect" costs that need to be estimated to assess the seriousness of an event. To do so, the second part of this report investigates the downstream consequences of transport interruption on the economy.

To do so, the following process is followed based around ARIO model (see Figure 1). ARIO is an Input-Output model, based on Input-Output tables, which particularity is to focus on inter-industrial transmission of economic perturbations. It has been used in various exercise to assess economy wide costs of economic disasters (e.g. Hallegatte, 2008). ARIO-T is a new version developed in the WEATHER project to account for transport capacity as a limiting factor of economic activity. In the present exercise, extreme weather events are impacting the economy through direct losses (i.e., capital destruction), and through transport disruption intensity and duration.

Thus, direct losses and transport disruption are input of the models, which provides as output an estimate of indirect losses output, for each type of disaster. Transport related indirect losses are obtained by subtracting indirect losses obtained without transport disruption.

It is crucial to stress the simplicity of economic models that are used to investigate disasters, when compared with the complexity of the mechanisms. Disasters are highly heterogeneous events, which are by definition exceptional and during which "normal" economic behaviors are not the norm. Markets are not at equilibrium, rationing is pervasive, basic needs are often at stake, exceptional solidarity in the affected population is common. With current knowledge, models are tools to understand the mechanisms, to assess the sensitivity of the cost to various characteristics of the event or of the affected regions, to analyze possible policies to reduce the cost of disasters. But quantified estimates remain extremely uncertainty, and should not be understood as "prediction."

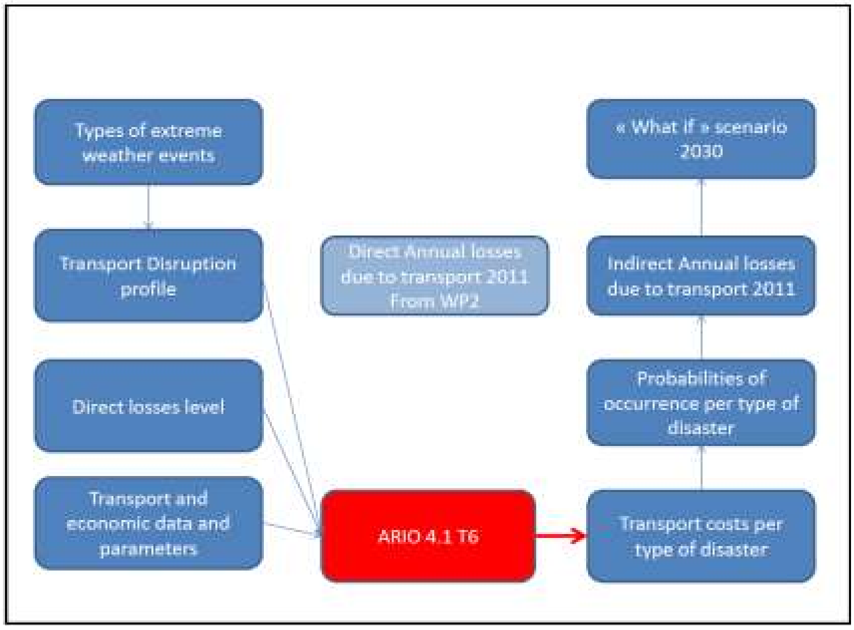


Figure 0-1: Methodology of indirect costs assessment

Type of Extreme Weather Event	Estimates of transport-related indirect costs, for three scenarios of direct costs, in millions Euros		
	Lower	Medium	Higher
Light Heatwave	0	0	0
Heavy Heatwave	18	19	20
Light Winter	0	0	0
Heavy Winter	0	0,090	0,159
Light Landslides/Alpine Hazards	9	9	70
Heavy Landslides/ Alpine Hazards	25	28	28
Light Flood	0	42	72
Heavy Flood	111	121	122
Storms	129	139	140
Total	291	359	452

Figure 0-2: Annual losses by category of event, and the annual total (based on EM-DAT historical frequencies)

Using EM-DAT to compute historical frequencies for each type of events, one can then estimate historical annual losses (see Table 1). Climate change can then be investigated using "what if scenarios", by modifying the intensity and frequency of different disaster types. This approach can provide an estimate of the impact of transport disruption on the economy, today and in the future (see Figure 3). According to this analysis – and with the care needed when using numbers produced with a very large uncertainty – the transport-related costs of extreme events are of the order of a few hundreds million Euros per year. Climate change could make this cost increase significantly, but the orders of magnitude are likely to remain unchanged.

Part III: Transport sector assessment framework

To get a better idea of the linkages and of methodological differences of the transport internal and wider economic damage analyses, the third part of the report reviews the methodology applied by the WEATHER Vulnerability Assessment (D2) in terms of total and average transportation cost indicators. Current burdens for the transport sector indicate annual costs around €2.5 billion. In a conceptual model rough forecasts to 2050 are made by transport mode, sector and geographical region.

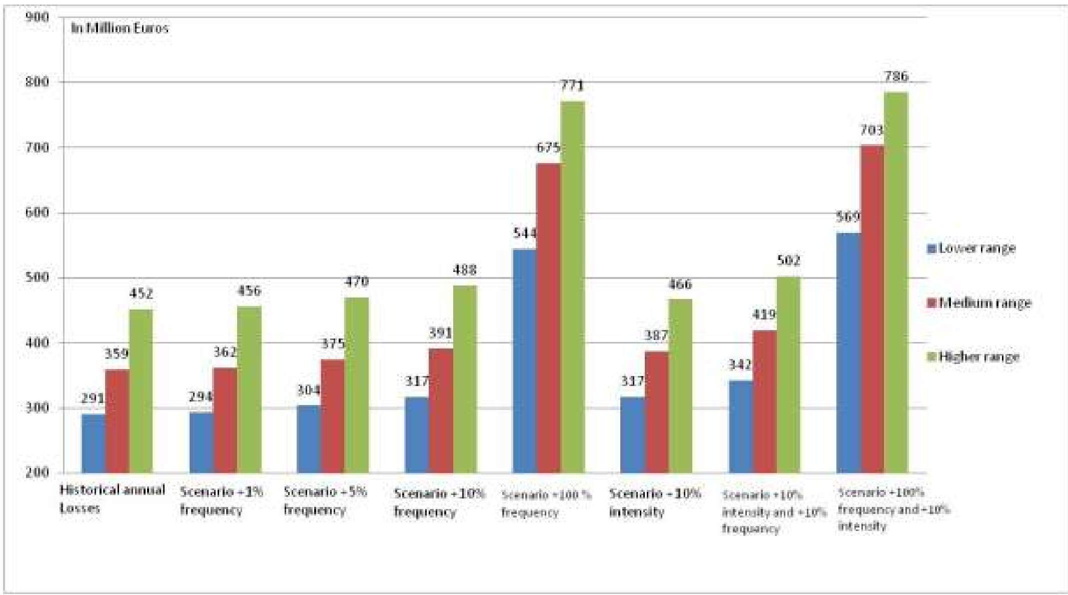


Figure 0-3: Annual direct losses due to transport related indirect costs in various "what-if" climate change scenarios

Calculations indicate that total damage and weather-inflicted system operating and user costs will increase by between 7 % for road transport and 72 % for rail by 2050. With a 47 % to 87 % increase in transport activities this implies a rise of average costs between 5 % (road) and 39 % (rail) due to weather extremes. Most hit are rail services in France and the UK. But due to the declining winter intensities and durations there will also be winners of climate change.

Table 0-1: Summary of forecast results for average transport sector costs due to weather extremes 2010 to 2050

Sector	AL	BI	EA	FR	IP	MD	ME	SC	EUR29
Road	-5%	3%	5%	54%	-17%	-13%	-21%	12%	5%
Infrastructure	-14%	9%	-1%	71%	-19%	-8%	-7%	13%	11%
Services	22%	30%	17%	7%	-16%	-20%	-31%	8%	-3%
Users	7%	-13%	13%	-6%	-4%	-24%	-28%	12%	-7%
Rail	41%	58%	25%	116%	-16%	13%	33%	52%	39%
Infrastructure	21%	24%	6%	106%	-28%	-1%	18%	16%	15%
Services	50%	75%	40%	132%	-15%	28%	43%	52%	50%
Users	49%	76%	39%	83%	-14%	28%	38%	55%	52%
Aviation	12%	26%	6%	31%	28%	36%	9%	8%	20%
Infrastructure	-19%	-21%	-15%	0%	0%	-34%	-21%	-19%	-20%
Services	13%	27%	8%	31%	30%	35%	10%	9%	22%
Users	14%	27%	7%	33%	20%	37%	11%	10%	21%

Source: Fraunhofer-ISI

1 Introduction

1.1 Introduction to the WEATHER project

The WEATHER Project starts from the broad picture of climate scenarios and breaks them down to specific regions. Economic growth models are applied to study the impacts on economy and society and the inter-relations between transport and other sectors. There has been much work in the recent years on possible costs of climate change on economy and society. However, due to the long life time of most climate gases in the atmosphere, the complex system of weather and climate interactions and given the manifold reaction schemes within the long time intervals over which climate change happens, the predictions of scenarios and effects differ widely.

The motivation for the WEATHER Project emerges from the great and still growing attention paid to the long term impacts of climate change and from the still large uncertainties on social and economic impacts and on options to ease their severity. 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 the use of intelligent transport systems, traffic planning and institutional issues. The major task under these topics is to keep infrastructures and critical facilities working under extreme (weather) conditions. Transport infrastructures and services take a particular role in this context as transport facilities are required for supply, rescue and maintenance operations. The overall objective would be to identify the optimal adaptation measures in relation to different geographical areas for coping with the negative impacts of extreme weather events on the transport sector.

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, 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 and 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
- 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 public sector (administrative agencies). For this reason each of the core work packages organises workshops to discuss the project findings with transport professionals and academia.

1.3 Position within the WEATHER project

This document constitutes the third official publication of the WEATHER project and reports the results of Work Package 1: Weather Trends and Economy-Wide Impacts. It is concerned with three rather independent streams of work, which have emerged through the first 18 months of project elaboration. Parts of the results have already been utilised in pervious working steps or have even been published in project-internal working papers. In order to document the work done in the WEATHER project these aspects - namely the European climate scenarios and the general transport impact assessment framework - are summarised in this document.

1.4 Structure and objective of the report

The structure of the report follows the three streams of work, contained under the domain of WEATHER Work Package 1. The overarching perspective of the analytical work presented in this report is to leave the very transport focussed view of the WEATHER project and take a more distant look on the nature and on the impacts of weather extremes in Europe. This is done by applying meteorological and macroeconomic models.

The report is structured as follows:

- Part I of the document deals with the issue of weather extremes downscaling methodology at the example of northern Italy and discusses scenarios of temperature and precipitation extremes for Europe.
- Part II investigates the impacts of transport systems vulnerability to weather extremes on the economy using the ARIO model. The framework of understanding is a macroeconomic framework with disruption understood as an economic shock.
- Finally, Part III summarises the General Assessment Framework (GAF) established as a guideline to record and evaluate transport sector disruptions caused by weather extreme. As the GAF has already been applied within Deliverable 2 (Vulnerability Assessment) the results of this work are reviewed and generalised to the European level here.

PART I: WEATHER TRENDS

2 Climate scenarios for Europe

Global Climate Model (GCM) represents one tool that are most widely used to generate climate change projections at global level. The GCMs evolve in the last time such as many processes from the climate system are well described by the new model generation, but their coarse spatial resolution, typically between 300 km to 100 km, requires downscaling for impact studies to smaller spatial scales. Two approaches of downscaling, *dynamical* and *statistical*, have been developed in the last time and the results reveal good potential for the construction of high-resolution climate change scenarios. *Dynamical downscaling* involves the nesting of a finer-scale regional climate model (RCM) within the coarser global climate model (GCM), while s*tatistical downscaling (SD)* involves the application of relationships identified in the observed climate, between the large-scale and smaller-scale, to climate model output. One of the main advantage of statistical downscaling technique is that could produce information at station scale or grid point, depends where impact information is required. As concerns the disadvantage, one of this is the fact that needs long observed time series, controlled from the quality and homogeneity points of view, in order to set-up the model. This technique *(SD)* is one tool adopted and developed by ARPA-SIMC in the present deliverables, in order to asses climate change scenario of temperature and precipitation over N-Italy at station scale.

One major problem for all models mentioned before is to try to quantify and reduce uncertainties. This was one aim of Ensembles project (http://www.ensembles-eu.org/), where climate change scenarios have been performed by applying all range of tools (*GCMs, RCMs, SD)* and using a common forcing derived from the A1B scenario of the IPCC (IPCC,2007), in order to eliminate the uncertainties due to emission scenario. In the project, around fifteen RCMs produced simulations at 25km spatial resolution with boundary conditions from around seven GCMs, and many statistical downscaling schemes were developed. The results obtained have been analysed in order to try to quantify and assess the uncertainties. The work done and the results obtained underlies that the use of multi-model approach and the construction of the ensemble mean (EM) is a good solution in order to reduce the uncertainties and to obtain a robust signal of climate change over the analysed area.

In this it task is presented an overview of the future projections of temperature and precipitation over Europe, using the multi-model approach, focused on the A1B emission scenario. The changes are referred in generally at two periods: 2021-2050 and 2071-2100 (or 2080-2099) with respect to 1961-1990.

2.1 Projections of future changes in mean and extreme temperature over Europe

Climate change projections of mean surface air temperature(T_{mean}) obtained using a high number of coupled atmosphere-ocean global climate models (AOGCM) and RCMs, show a possible increase in annual mean air temperature over Europe during this century (2011—2100), but more intense to the end of the period.

Analysing the outputs produced by the RCM from the Ensembles project (Van der Linden, 2009), the changes projected in *annual mean air temperature* over Europe (A1B scenario), vary between 0.5 and 2°C, for the period 2021-2050 with respect to 1961-1990 (figure 2-1a). The magnitude of changes is greater to the end of the century, namely for the period 2071-2100, when the annual changes of mean air temperature could reach 3.5- 4°C with respect to present climate 1961-1990 (figure 2-1b).

a) b)

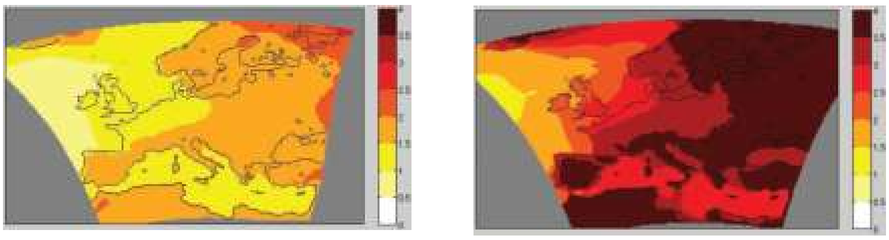


Figure 2-1: Projected changes in annual mean surface air temperature (°C) under A1B scenario, multi-model ensemble mean of RCM simulations, periods: 2021-2050 (a) and 2071-2100 (b) respect to 1961-1990 (source: http://www.ensembles-eu.org/)

As could be noted from Figure1, the pattern of changes is similar during both periods with higher magnitude of changes in Mediterranean area and over North-Eastern Europe, especially for the period 2071-2100 (Fig.2-1b).

Looking in detail at each season, the scenarios of mean air temperature over Europe show that warming is projected in each season, and for both periods (figures not shown). For example, during the period 2021-2050, the seasonal projected increasing vary between 0.5 and 2.8°C (figures not shown), with higher values (between 2.1°C -2.8°C) during *winter in NE part of Europe* and during *summer over Mediterranean area and southern Europe*. As concerns the period 2071-2100, the seasonal projected increasing of mean air temperature could reach value up to 6°C. One example is the Mediterranean area were it is expected that during summer the increasing could reach 5-6°C respect with1961-1990 period (A1B scenario).

What about the projection of extreme T_{mean} over the European area?

The extreme events are those events that fall in the tail of the statistical distribution and could be defined based on the percentile of time series. An increasing in the 10th, 50th and 90th percentile of mean air temperature has been projected by global and regional climate models, in all seasons and for different periods of time: 2040-2059, 2080-2099 relative to 1961-1990 baseline period (http://www.ensembles-eu.org/).

For example, as concern winter season it is projected a possible increasing in 10th percentile of mean air temperature over Europe between 2°C and 4°C, during the period 2080-2099 respect with 1961-1990 (figure 2-2a) under A1B emission scenario. More intense is the projected increase in winter 90th, as could be noted from figure 2-2b.

a) b)

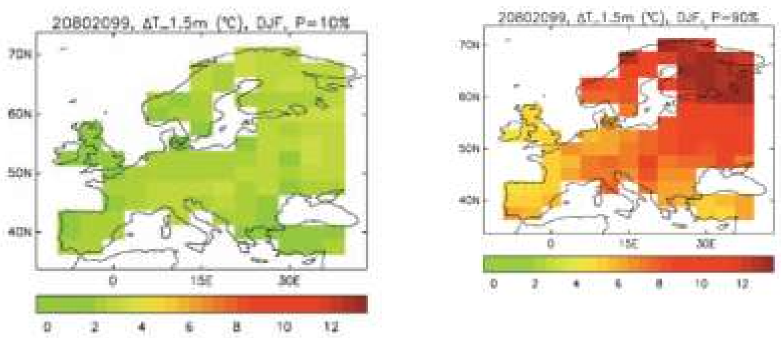


Figure 2-2: The ENSEMBLES probabilistic projection of 10th (a) and 90th (b) percentile of WINTER mean air temperature (DJF) over Europe under the A1B emission, period 2080–2099 relative to the 1961–1990 (source: http://www.ensembles-eu.org/)

An important signal of changes is also projected by RCM from Ensembles experiments during summer season. For example for the end of the century it is expected that the increasing in 10th percentile could reach 4°C (figure2-3a) while the increasing in the 90th could reach value of 9-10°C (figure 2-3b). As could be noted from figure 2- 3 the higher increasing is projected for Mediterranean area, in both 10th and 90th percentile of summer T_{mean}.

a) b)

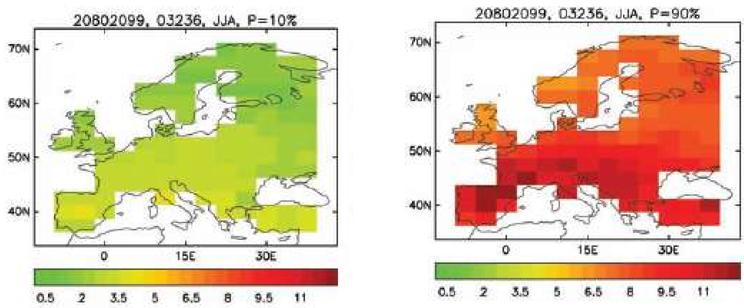


Figure 2-3: The ENSEMBLES probabilistic projection of 10th (a) and 90th (b) percentile of summer mean air temperature (JJA-10th and 90th T_{mean}) over Europe under the A1B emission, period 2080–2099 relative to the 1961–1990 (source: http://www.ensembles-eu.org/)

These projected increases not only in the central value of the distribution (50th percentile) but also in the “tails “, as presented before, could connect to a “shift” to “warmer values” of the distribution function of temperature, associated with changes in other extreme events. For example, Tebaldi et al. show a decrease in the number of frost days during winter season (Tebaldi et al 2006). Changes are expected also in snow cover especially during winter season (van der Linden 2009). The Ensembles RCM indicate that by 2100 snow cover is projected to reduce all over Europe and as concern the Alps area the decrease is much smaller above 2000m. As regards summer season, the projected increases in temperature could connect to an increase in heat wave duration index. Significant changes in heat wave duration is projected especially for the Mediterranean area (Giannakopoulos et al.,2009)

2.2 Projections of future changes in precipitation - mean and extreme values over Europe

The Ensembles simulations of annual amount of precipitation over Europe produced by global and regional models, show a possible increase over north and a decrease of precipitation in the south of Europe, during the period 2021-2050 with respect to 1961-1990, scenario A1B (van der Linden,2009). The same configuration of changes but more intense is projected also to the end of the century, namely for the period 2071-2100 respect to 1961-1990, with a pronounced decreasing up to 20% in annual precipitation, especially in the Mediterranean area. It is very important to know how are distributed these changes at seasonal level. In fact, the seasonal projections of regional climate models resulted from the multi-model approach, evidence that the larger increases in northern and central Europe are simulated in winter (figure 2-4a) while the largest decreases in the Mediterranean area and south of Europe are expected to occur during summer season (Figure2-4b).

The projected increases in winter precipitation over Northern Europe are dominated by increasing atmospheric moisture with warming, while warming during summer combined with reduced soil moisture connect to decreases in precipitation across southern Europe.

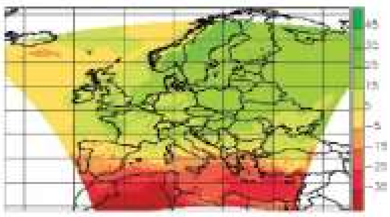
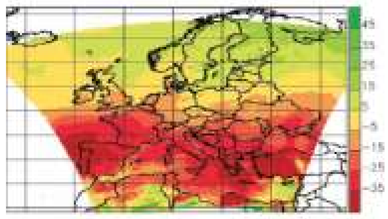
a)	b)
	

Figure 2-4: Winter (a) and summer (b) precipitation changes (%) over Europe for the period 2071-2100 respect to 1961-1990, under the A1B scenario, multi-model Ensemble Mean of RCM simulations. http://www.ensembles-eu.org/).

What about the projection of extreme precipitation over Europe?

The projections of 10th and 90th percentile of seasonal precipitation provided by RCM experiments reveal significant changes in both parameters over Europe, especially during winter and summer seasons.

As concerns winter, significant increases has been projected in 90th percentile of precipitation especially during the period 2080-2099 respect to 1961-1990 (scenario A1B), over all the domain of simulations, but more pronounced over NE Europe (Figure 2- 5a). As could be noted from figure 5a, also the “extreme” winter precipitation over the Alpine area are projected to increase during the above period. A similar pattern of changes in 90th percentile has been founded during summer but less intense than in winter, same period. Taking into account that the quantity of precipitation is projected to decrease over the Mediterranean area especially during summer (see figure 2- 4b) it’s very interesting to look also on the projections of the “lowest” percentile of precipitation, namely the 10th percentile. In fact, the RCMs simulations put in evidence a significant pattern of changes in summer 10th percentile, during 2040-2059 and 2080-2099, respect to baseline period 1961-1990. Analysing the map from figure 5b, that presents the future changes of 10th percentile of summer precipitation, could be noted a significant decrease of 10th percentile over the Mediterranean area during the period 2040-2059. A similar signal is expected to occur also to the end of century, namely 2080-2099 (map not shown).

a)	b)

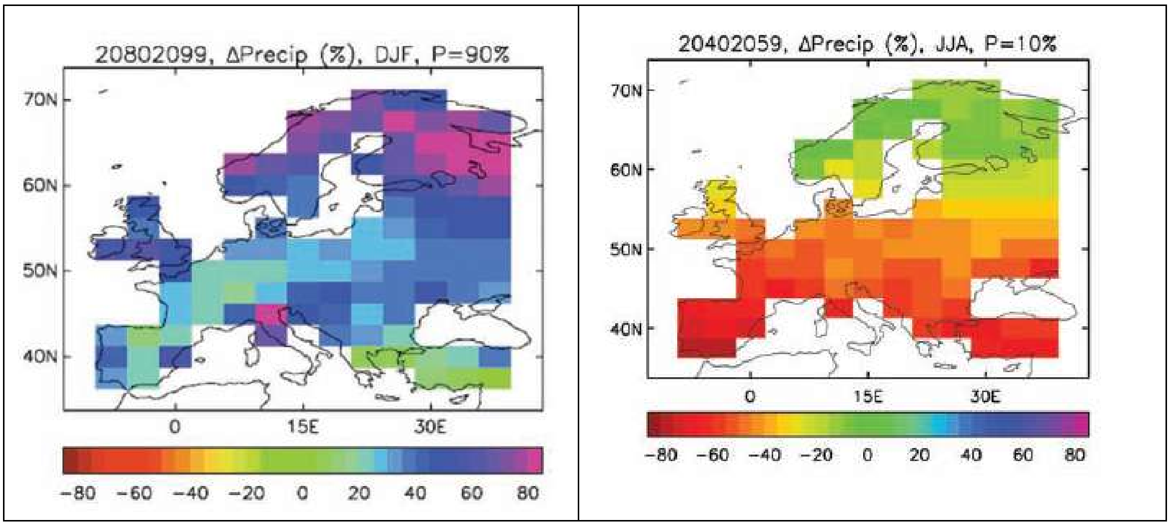


Figure 2-5: The Ensembles probabilistic projections of WINTER 90th percentile of precipitation (a) during the period 2080-2099 and SUMMER 10th percentile of precipitation (b) but for the period 2040-2059 under the A1B emission scenario, (source http://www.ensembles-eu.org/

3 Downscaling and regional climate models

3.1 Data and Methods

In WEATHER project a statistical downscaling method (SD) has been developed by ARPA-SIMC, in order to estimate future changes in temperature and precipitation over Northern Italy (pilot area), at station level for the periods: 2021-2050 and 2071-2099 with respect to 1961-1990. The SD developed by ARPA-SIMC, is a multivariate regression based on Canonical Correlation Analysis (Tomozeiu at al.,2007). In particular, large scale data (predictors: Z500, T850, MSLP) derived from ERA40 re-analysis (http://www.ecmwf.int/products/data/archive/descriptions/e4/index.html) for the period 1961-2002, and local scale data (predictand) have been used in order to set-up the model.

As concerns the local data these are represented by seasonal minimum and maximum temperature, frost days, ice days and total amount of precipitation computed at station level.

The canonical correlation analysis (CCA) has been used in order to identify predictor-predictand pairs of patterns which maximise the temporal correlation between the two corresponding patterns. In addition, the method offers a physical interpretation of the mechanism that controls the regional climate variability. In order to reduce the noise of the fields involved, before the CCA, the data sets are projected onto EOF_s (Empirical Orthogonal Functions) to retain only those modes explaining the most of the total observed variance. A subset of CCA pairs is then used in a multivariate linear model in order to estimate the predictand anomalies from the predictor anomaly field.

Observed data from around 75 stations for temperature (Figure 3.1) have been available at seasonal level over the Northern Italy, for the period 1961-2002 in order to set-up de SD model. In addition, observed daily minimum and maximum temperature from the Emilia-Romagna region over the period 1958-2002 have been available, such as seasonal extreme temperature, namely, number of frost days (Tmin<0°C) and ice days (Tmax <0°C), have computed and analysed. As concern the precipitation, observed data from around 90 stations distributed over n-Italy, have been used (map not shown) in order to construct future climate change projection.

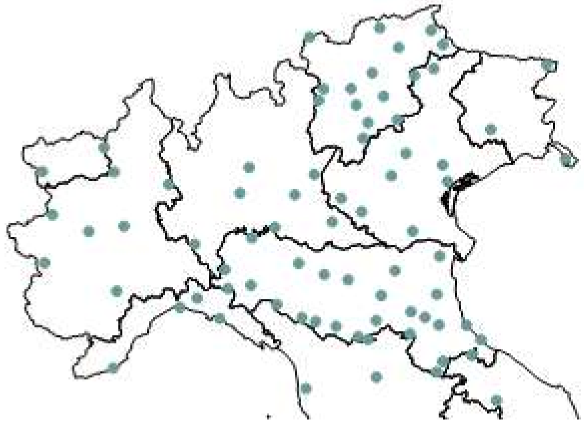


Figure 3-1: Map of stations with observed temperature used in the study.

Set-up of the Statistical Downscaling model with predictors from ERA-40

The models are built for each season and index, choosing each time a different subset of predictors from the fields extracted from the ERA40 re-analysis. All data are de-trended before being used. All models are calibrated on the period 1960-1978 and 1994-2002 and validated on the period 1979-1993, and only the best performing model is retained. The performance (skill) of the downscaling model is quantified at station level in terms of: Spearman rank-correlation coefficient (CORR) which is just the correlation coefficient calculated on the ranks of the two time series, root-mean square-error (RMSE) between observed and simulated index with bias removed and BIAS, defined as follow:

$$\text{RMSE}=\sqrt{\frac{1}{N}\sum_{i\in verificationperiod}\left[indices_{model}(i)-indices_{obs}(i)-BIAS\right]^2}$$

$$\text{BIAS} = \langle indices_{model}\rangle_{verification} - \langle indices_{obs}\rangle_{verification}$$

In order to reduce the uncertainties in the climate changes projection due to statistical downscaling methods, great part of the work was concentrated also on the selection of optimum statistical downscaling models. Analysing the skill of the model for each season and parameter it was founded that the performance of the models is dependent on:

1. the *predictors* , this means large-scale field, single or combined;
2. the *domain* (area) of predictors;
3. the *number of EOFs retained for the CCA*
4. *the number of CCA* components used in the regression model.

In order to solve the point 1, in this work has been tested single predictors, namely, T850, MSLP, and Z500 and then combined predictors : T850+MSLP and the predictors with higher skill has been retained for each season and index. As concerns the point 2, predictors for different windows were tested (see table bellow).

Domain of the predictors tested in the set-up of SDs

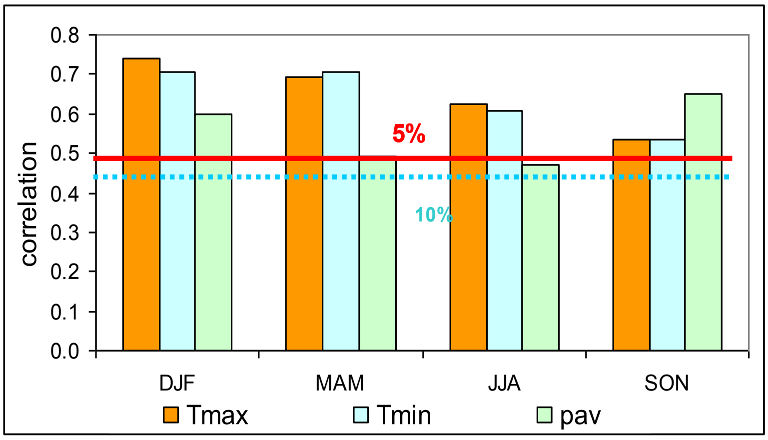
CODE	AREA (LONG./LAT.)
Area A	90°W-90°E / 0°N-90°N
Area B	60°W-60°E / 20°N-80°N
Area C	35°W-35°E /30°N-60°N
Area D	12.5°W-30°E / 30°N-55°N
Area E	5°E-35°E / 30°N-50°N
Area F	5°W-20°E / 37.5°N-50°N

The results obtained from this work underlay that in generally the T850 is a good predictor for temperature while MSLP is a good predictor especially for winter precipitation. As concerns the area of definition of the predictors, the ***Area D*** (12.5°W-30°E / 30°N-55°N) provide good skill for temperature, while predictors defined over a ***Area B*** for precipitation (winter season).

The test done in order to set-up the number of EOFS and CCA (point 3 and 4) involved in the construction of the final SDs model, underlies that the number could of EOFs and CCA pairs vary in function of season and index, but in generally this could be up to 5 EOFS/CCA for predictors and predictands.

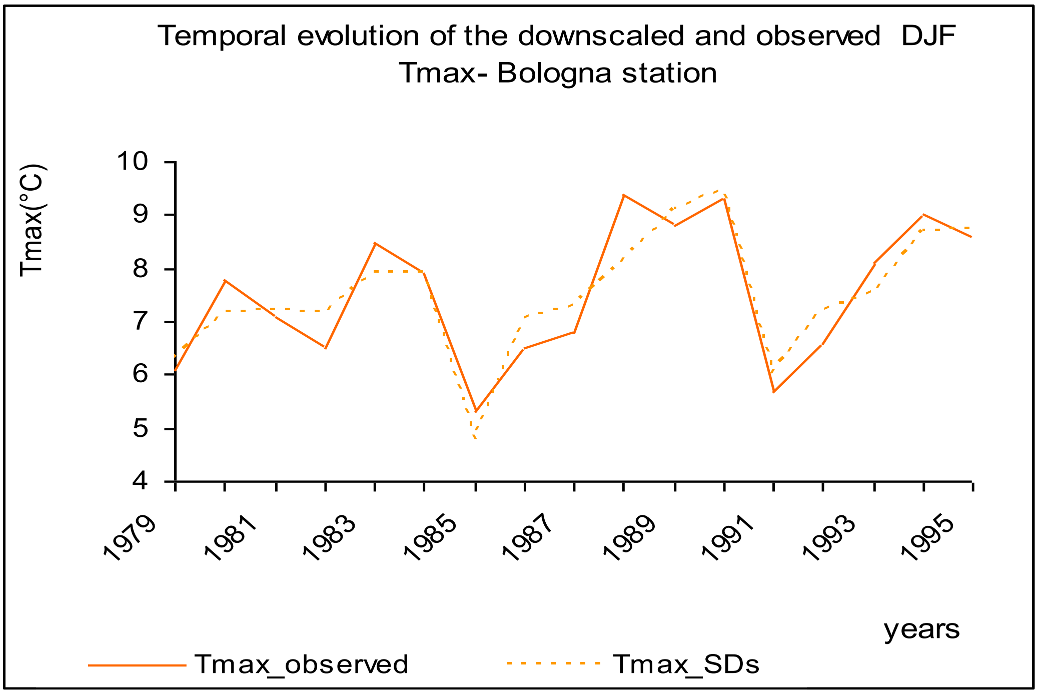
Figure bellow, shows like an example, the seasonal skill of the SDs model for maximum (T_{max}) minimum (T_{min}) temperature and precipitation (pav) from N-Italy (mean over all the stations). The skill of the model described by the correlation coefficients is computed between downscaled and observed time series during validation period, namely 1979-1993.

Correlation coefficients between downscaled and observed time series computed during the validation period (1979-1993)



As could be noted from the above figure that describe the skill of the SDs over N-Italy, good skill is obtained for maximum and minimum temperature in all seasons with significant correlation from the statistical point of view (0.05 significance level), while for precipitation the SDs performance is higher during winter and autumn (0.05 significance level) and less in spring and summer (0.1 significance level).

One example of downscaled time series is presented for Bologna station (51m aslp) in the figure bellow. The solid line represents the observed winter temperature at Bologna, while the dashed line represents the downscaled maximum temperature through the SDS constructed using as predictor the T850. As could be noted, good agreement is presented between the time series, that is in fact well justified by the skill score presented in the figure above.



The SD built for each season and index using observational data, are then applied to the predictors simulated by global climate models available form the Ensembles project, namely: INGV, EGMAM, ECHAM, IPSL, METO-HC, periods 2021-2050 and 2071-2099 (scenario a1B).

In this step is very important to analyse how the global climate model represents the predictors. The main characteristics of each GCM involved in the work are described in the table bellow.

The main feature of the ENSEMBLES STREAM1 GCMs simulations

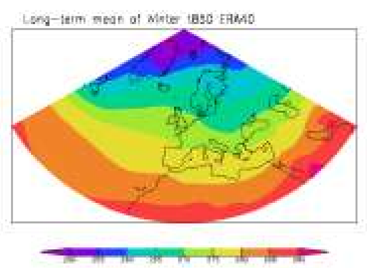
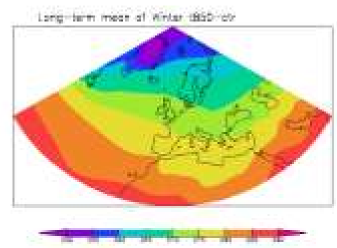
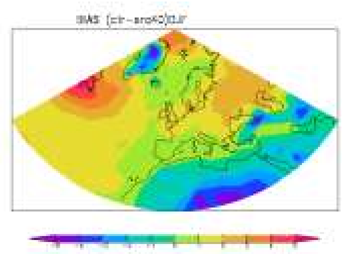
Model (Institution)	Atmosphere		Ocean	
	Model	Resolution/levels	Model	Resolution/levels
HadGEM1 (METO-HC)	HadGAM1	1.25°x1.875/ 38 levels	HadGOM1	0.33°- 1° 40 levels
IPSL – CM4 (IPSL+UCL-ASTR)	LMDZ - 4	2.5°x3.75° 19 levels	OPA8.1	0.5°-2° 31 levels
ECHAM5/MPI-OM (MPIMET+DMI)	ECHAM5	T63 31 levels	MPI-OM	1.5° 40 levels
INGV-SX (INGV-CMCC)	ECHAM4.6	T106 19 levels	OPA8.2	0.5°-2° 31 levels
EGMAM (FUB)	ECHAM4-MA	T30 19 levels	HOPE-G	0.5°-2.8° 20 levels
BCM2 (NERSC)	ARPEGE V3	T63 31 levels	MICOM 2.8	1.5° 35 levels

As could be noted, the models have different resolutions and characteristics. The performance of the GCMs to simulate the predictors in the control –run period was tested.

Thus, it was investigated how the AOGCMs, simulate the predictors (Z500, T850, MSLP) that will be used then in the SDs scheme. To this aim, it has been calculated bias and has been performed a short EOFs-analysis, taking as reference the predictors from ERA40 re-analysis over the control run period, namely 1961-1990.

The bias is computed as difference between long-term mean of the predictors, for example for T850, simulated by AOGCMs and ERA40. EOFs-analysis was focused on the first four EOFs (which explain most part of variance) and primarily addressed on computation of spatial correlation coefficients between AOGCMs and ERA40 EOFs. Figure bellow shows an example of BIAS computed for T850 fields using (presented in the right pannel) long term mean of T850 for INGV-SINTEX G data (

left) and ERA40 (middle), during winter seasons. As could be noted a negative bias is observed in T850 over the window that covers the Italian peninsula, in generally around 1-1.5°C. Such kind of analysis has been done for each predictors and seasons.

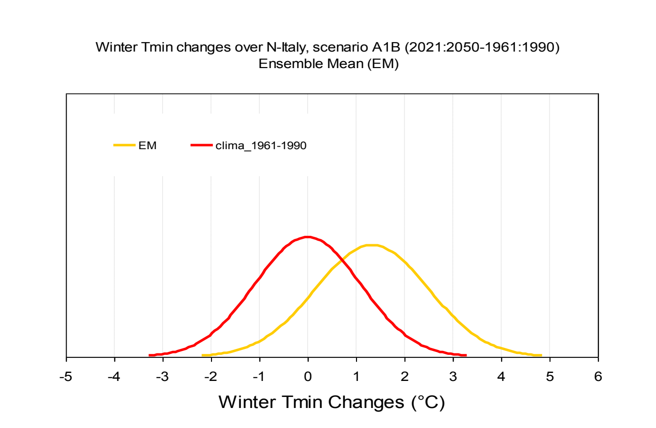
Winter T850- ERA-40 long term mean (1961-1990)	Winter T850- INGV-SX model Long term mean (1961-1990)	Winter T850 -BIAS Period: 1961-1990
		

Finally, the SDs has been applied to predictors projected by GCMs in order to compute future climate changes of temperature and precipitation at local scale. The signal of projections is presented at seasonal level over the studied area (mean over the stations) as: Probability Density Functions (PDFs) for temperature and cumulative density probability function (CPDF) for precipitation. An ensemble mean (EM) of climate projections have been computed for each field (temperature and precipitation)

3.2 Climate change projections of minimum and maximum temperature and precipitation over N-Italy

The climate change scenarios of seasonal minimum and maximum temperature obtained through SD models applied to the Ensembles simulations at station level, estimate an increasing of temperature over Northern Italy in all seasons, during the period 2021-2050. This increasing is in general around 1.5- 2°C in the mean value, as concern both variables, minimum and maximum temperature, period 2021-2050 respect to 1961-1990. Figure 3-2 presents an example of climate change scenario of winter minimum T_{min} (a), and summer maximum T_{max} (b) temperature over N-Italy.

a)	b)



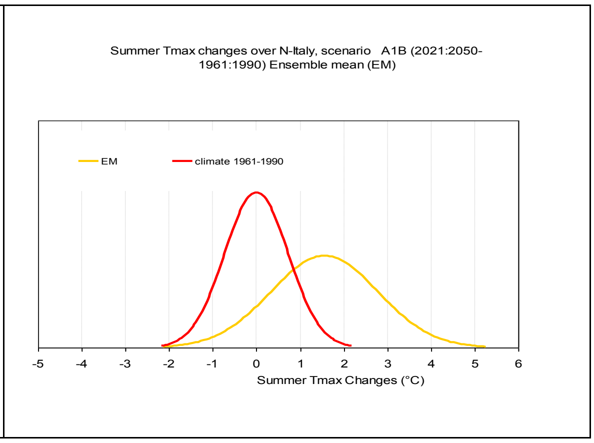


Figure 3-2: Ensemble probabilistic projections of winter (DJF) minimum temperature T_{min} (a) and summer maximum temperature(b) over N-Italy (mean over the stations) during the period 2021-2050 respect to 1961-1990, under A1B scenario .

As could be noted from Figure 3-2 (and b), a shift to the “right” of the PDFs is projected to occur by the Ensemble Mean, during the period 2021-2050 respect to present climate (1961-1990 - red curves). An important aspect that results from the above projections is that not only the mean value is expected to increase, but also the “lower” and “upper” percentile are expected to increase. This means that an increase in extreme temperature is expected during this period over N-Italy.

A similar shift of PDFs is expected to occur also to the end of the century, 2071-2100 in both minimum and maximum temperature, but with higher magnitude than the previous period. In fact, analysing in detail the seasonal projections of minimum and maximum temperature it was noted that in all seasons is expected an increase, more intense during summer. Figure 3-2, presents an example of climate change projections for the end of century, 2071-2099 respect to 1961-1990 in terms of PDFs , for winter minimum temperature (a) and summer maximum temperature (b)

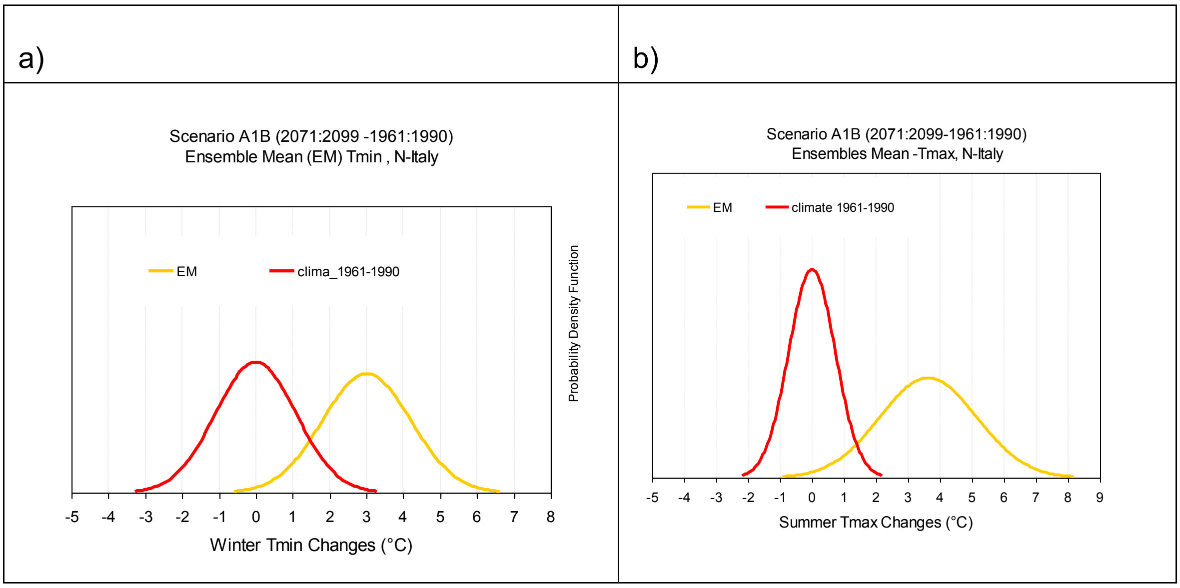


Figure 3-3: Ensemble probabilistic projections of winter minimum temperature (a) and summer maximum (b) temperature over N-Italy (mean over the stations) during the period 2071-299 respect to 1961-1990, under A1B scenario .

As could be noted, also for the end of the century shifts of the distributions are associated with changes in extreme values too.

In order to understand better the effect produced by this shift of the "tails" of the distribution on extreme climate events, climate change projection of the number of days with minimum temperature bellow 0°C(frost days) and number of days with maximum temperature bellow 0°C(ice days) have been done for both periods. This work was done only for the region were daily data were available, namely for Emilia-Romagna. Significant signal of changes has been obtained especially for the number of frost days from Emilia-Romagna region. During winter, spring and autumn the projections show a possible decrease in the number of frost days in both periods, more pronounced during 2071-2099. As could be noted from figure 3-4, this decrease is significant especially during winter and spring when the projected decrease could reach around 30 days in winter and around 20 days during spring.

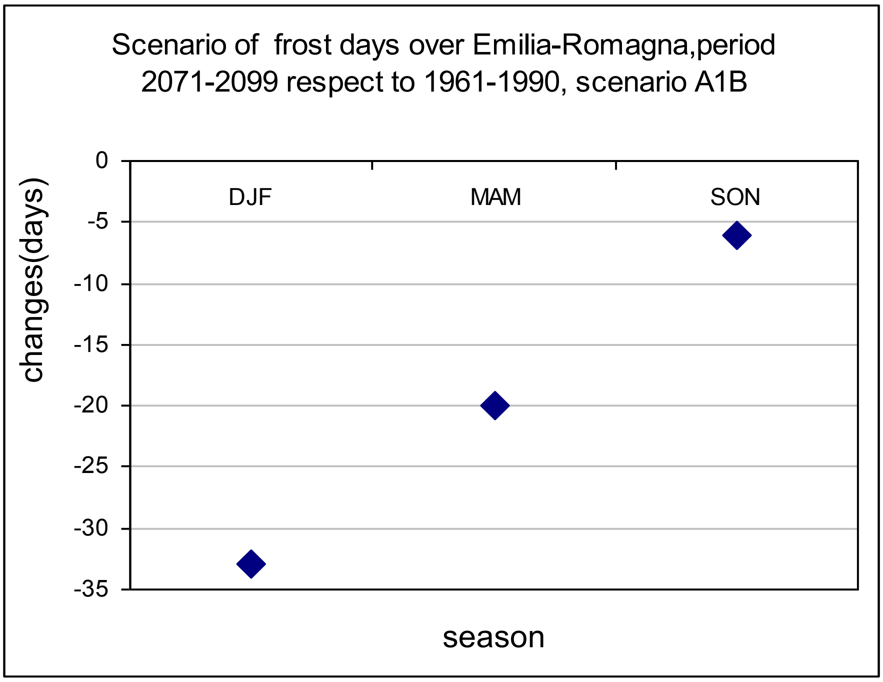


Figure 3-4: Climate change scenario of frost days over Emilia-Romagna region (mean over the station)-period 2071-2099 respect to 1961-1990

As concerns the signal of seasonal precipitation, the results show more intense changes especially in the second period, 2071-2099. In both periods, the pattern of changes is complex, different from season to season and over the regions, especially during winter, spring and autumn. During summer, a reduction in precipitation is expected to occur over great part of the studied area, around 40-50 % in the period 2071-2099 (Figure3-4).

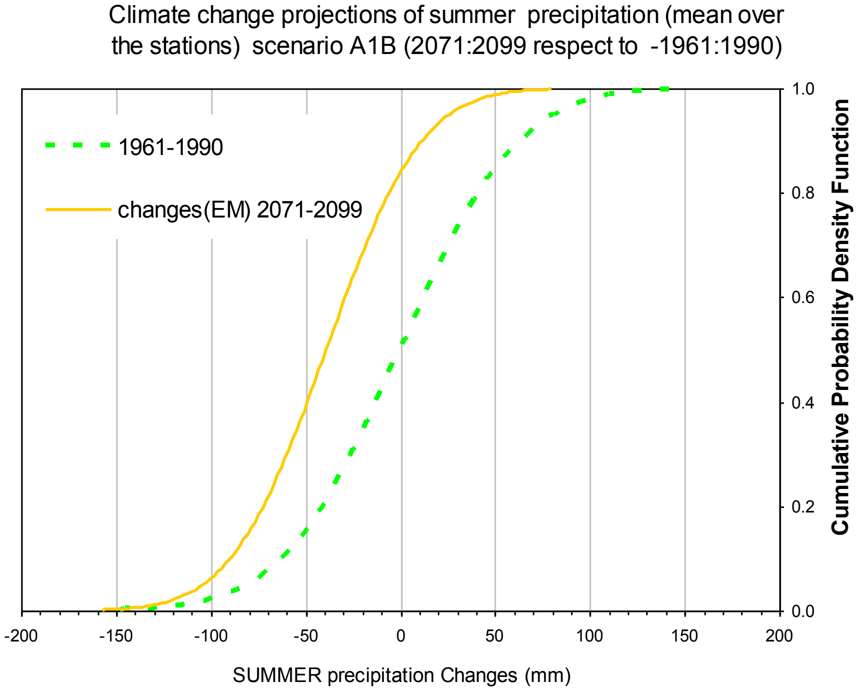


Figure 3-5: Climate change projections of summer precipitation over N-Italy.

3.3 Acknowledgements:

The ENSEMBLES data used in this work was funded by the EU FP6 Integrated Project ENSEMBLES (Contract number 505539) whose support is gratefully acknowledged.

PART II: ECONOMY-WIDE IMPACTS

4 Transport vulnerability, weather extreme and economy wide impacts

Evaluating indirect costs is by itself a complicated exercise for a singular event. In the following, we try in an exploratory exercise to evaluate annual indirect losses due to extreme weather events on the transport sector. The figures produced have to be taken carefully into account and cannot be used or reproduced without contextualization of the exercise.

4.1 “Economy-wide impacts”: a consideration of welfare

Costs of natural disasters are all the costs to an economy caused by a specific weather related events. They usually encompass the costs of destroyed capital, or direct costs. However, during and after a natural disaster the economy does not function normally. This remains the case up to the completion of the reconstruction process. These impacts are labeled economy-wide, and cause indirect costs.

The distinction between direct and indirect costs is common even though the boundary between them is often controversial. This distinction is often made on the basis of a difference of scale and temporal incidence. Indirect impacts are physically *indirect*, of wider scale and with longer incidence in time than direct impacts. This is why they are also called economy-wide impacts.

The consideration of economy wide impacts is increasing in economics of natural disaster. The main reason is that it takes into account the role of the recovery and as such of the resilience of the economy in the final losses.

Concepts and theory of economy wide impacts can be found in Hallegatte and Przyluski (2011). The perspective adopted here is a welfare perspective which considers that total losses are the indirect losses due to capital losses but also the costs of reconstruction, which takes out a fraction of consumption. In the process, the reconstruction path is particularly important as it acts as a stimulus on the economy, which depends of its flexibility and position with regard to economic cycle.

4.2 Vulnerability of the economy in the case of extreme events: understanding mechanisms

During and after extreme events, markets are not fully functioning. Prices do not longer function as governance mechanisms and quantity appears to be the main limitation factor. This, of course, depends of the scale of the disaster. If a marginal fraction of the housing stock is destroyed, people may be able to rent a place, even though for a higher price. However if an entire town is destroyed it is unlikely there are enough houses to meet the demand in a near future.

This is why the reconstruction phase, and particularly its length, is important. The capacity to reconstruct depends on capacity to supply with sufficient materials and to attract capital and workers. Thus, the constraint may be financial, but also technical. For large disasters, the demand for reconstruction is really high and cannot be met. Therefore, ripples effect in the economy can be observed through the length of the reconstruction phase.

Network effects can also have a crucial role in the final cost of a natural disasters. Network effects often occur when crucial intermediate sectors are directly affected. For instance, when a power plant is affected by a natural disaster, the direct costs of the the destruction of the plant can be low in comparison of the consequence of the lack of electricity for all industries and households supplied.

On the contrary, economic system can be flexible or more resilient. This is particularly the case when the capital is not fully used. In that case, the disaster has a stimulus effect. Production patterns can change, and output gains can be observed by correcting under optimal pre disaster situation. However, it has to be noticed that in this case the benefits could have been taken without bearing the direct costs of the disaster. Thus, natural disasters occurring in time of economic crisis can yield often positive results for the economy. On the contrary, when the economy is working with no idle capacity the costs to bear are particularly high.

These particular aspects of economy-wide impacts explain why they cannot be only derived from direct costs: there is no linear relationship between direct and indirect costs. Indirect costs tend to rise sharply and non-linearly.

Two methodologies are used to assess economy wide impacts: CGE models or Input Output model. The choice of I/O model is motivated by three main reasons. First, the disaster and post disaster period are not characterized by fully functioning market and equilibrium but mainly by various missing markets and by not fully functioning markets. Second, important effects of natural disasters are destruction of infrastructure. As public goods, they have a value that exceeds their replacement costs and they are not traded on a market. For instance, the cost of replacing a road does not address the question of the criticality of the road in the costing (as D2 puts forward). Third, CGE model often assume that the baseline is an optimal stock of capital, which may or may not be the case empirically. However, this is of crucial importance in the dynamics of losses and gains during the reconstruction phase as stated earlier in this section.

4.3 The particular role of transports in the economy

Transport system has a particular role in an economy and this through different spatial scale (urban, regional etc.). Transport is also important, as intermediary sector, for economic growth, development (Jones, 2011). Transport is considered as having a multiplier effect on the value added: it has indirect positive effect on the economy.

It directly impacts productivity, trade, and equilibrium on other markets, such as labour market or housing market.

The impact of transport perturbation is known at the micro level, on a traffic management perspective. In terms of system disruption, the direct costs and/or costs for infrastructure manager is known. Best knowledge is presented in D2.

But, the macro productivity hypothesis has not been really investigated so far: some companies cannot keep functioning fully with transport perturbation, reducing the local GDP not only in the short term, through a decrease in productivity which can last.

4.4 Factoring in climate change: working out the incidence

Climate change does obviously not change the role of transport on the economy. It does not change the incidence of transport perturbation on the economy. However, it can change the frequency and/or intensity with which transport systems are affected.

Thus, the cost of each event does not change, but potential change in occurrence makes it worth investigating the cost.

Climate Change incidence on extreme events is not straightforward and completely known. Some aspects are worth recalling.

- Change in temperature and hydrological regime concern extremes as well as median.
- Impacts on extreme events are not known with certainty
- Weather extremes exist under different forms in different contexts. From a point of view of impacts, weather is extreme as long as the disruption exceeds normal procedures and expectations.

This means that factoring in climate change is not central to the study of disruption impacts. The trend and structure of costs associated with extreme events may be modified with climate change: some extremes disappear, while some new ones appear.

The structural aspect of this change is not taken into account in this work. No socio economic baseline is taken into account, no adaptation is envisaged, and no shift of resources resulting from change is considered. Therefore, factoring in climate change in this work is only a final stage in a “what if scenario”: what if climate changes, with constant socio-economic structure and adaptation levels. This work mainly deals in detail with the impact of transport disruption in the current economy (No Climate Change Impacts baseline) and factor in at a later change (without proposing the baseline.)

4.5 Philosophy of the model and assessment

Deliverable 1 aims at providing economy wide losses due to transport disruptions generated by extreme weather events. The modeling exercise has proceeded the following ways:

- Disaster profile for input in ARIO are generated
- I/O tables and transport tables are created for ARIO
- ARIO assesses economic losses due to transport for each transport profile
- Probabilities associated with type of event lead to annual losses in today’s climate
- ‘What if’ scenario in increase of frequency and intensity lead to perspective for 2050 under climate change.

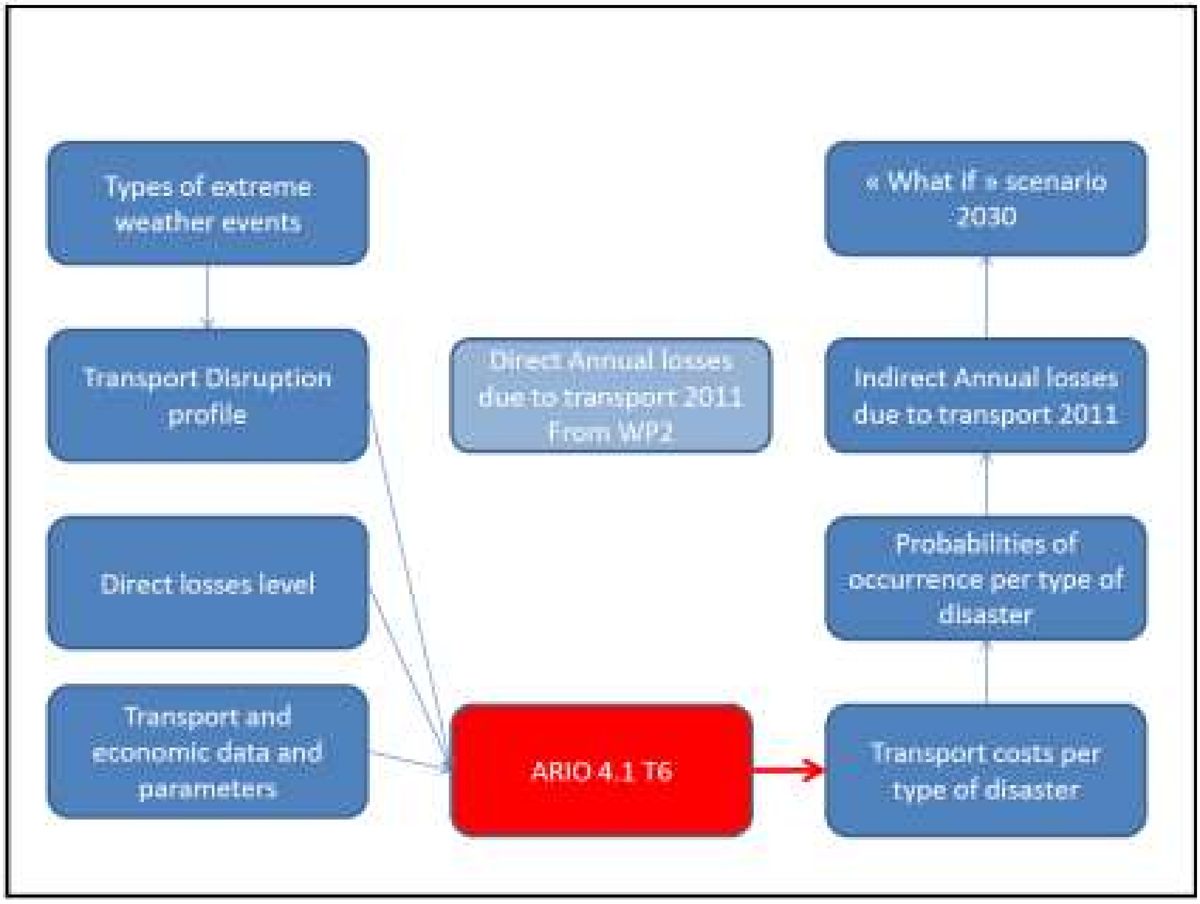


Figure 4-1: Process of the economic assessment of WP1

5 The ARIO model and input

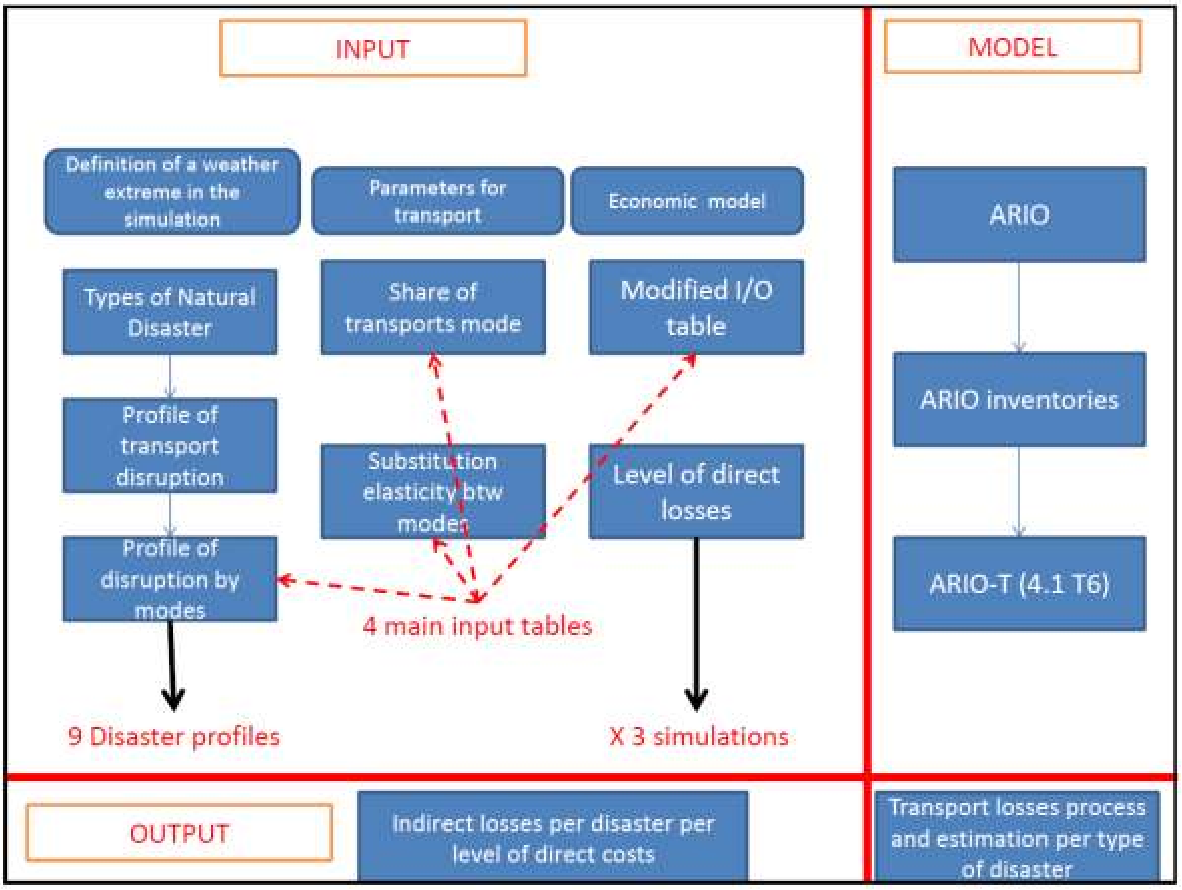


Figure 5-1: Sum-up scheme of work for simulating economic losses due to extreme weather events with ARIO 4.1 T6.

5.1 ARIO model

ARIO is first and foremost an economic model of natural disasters. If Natural Disasters have primarily an impact on human lives and assets, they also perturb the functioning of the economic system. ARIO aim is to evaluate the losses due to this perturbation, that is to say indirect losses or "economy wide" losses (Pelling et al., 2002, Lindell and Prater, 2003, Cochrane, 2004, Rose, 2004, and a review in Hallegatte and Przyluski, 2010).

ARIO is an Input-Output model, that is to say based on Input Output tables, which particularity is then to focus on inter industrial transmission of economic perturbation. This is in the line of intense existing research (e.g., Haimes and Jiang (2001); Bockarjova et al. (2004); Cochrane (2004); Okuyama et al. (2004)). However, the existing modeling exercises had shortcomings which can be sum-up as a lack of dynamics.

But, understanding the dynamics and costs of inter-industrial propagations becomes really important in a globally interconnected world. For instance, the Earthquake in

Japan does not only affect directly Japanese economy but also every industry selling to or supplying from Japan, in particular in specific sectors for which substitution possibility is weak. Global supply chains have increased this possibility of ripple effects. ARIO is designed to focus on these.

ARIO has then two specificities which make the model more dynamic than usual I/O model.

First, ARIO explicitly considers productive capacity, or *supply side*. Usually, the propagation of a shock in an I/O model is solely through the demand side, i.e *backward* effect. ARIO introduces through demand for reconstruction, rationing scheme, and adjustment of the productive capacity, *forward* ripple effect. Forward ripple effect are transmission to the economy of trade-offs concerning the productive capacity.

Second, ARIO introduces adaptive capacity, that is to say behavioral adaptation of agents to the shock aiming at minimizing its cost. This introduces flexibility in the model : consumers and producers respond to a lack of input by modifying their behaviour, for instance through substitution in supply or temporary overproduction.

These two particular aspects are central to the main mechanism of ARIO : the reconstruction demand. ARIO features the main particularity of natural disaster and assess its impact : direct capital losses. It means that after the disaster, productive capacity and demand for all sectors fall but for the reconstruction sector (after a certain delay). The reconstruction sector is overwhelmed by demand, and crowds out other sector productive capacity, which is temporarily detrimental for them (forward ripple effect). This reconstruction demand overcrowds as well other sector demand : it is a direct draw on the normal economy consumption. All the other sectors in the economy start producing again when their productive capacities are back to normal.

ARIO follows the precepts proposed in the first part of assessing indirect costs, i.e propagation in the economic system, as the main costs and factoring in adaptive capacity, that is to say resilience.

The first version of the ARIO model is presented in detail in Hallegatte (2008), which assesses indirect costs on Louisiane of Hurricane Katrina. A previous version of the model has been calibrated and used on several case studies : Hurricane Katrina (Hallegatte, 2008), Mumbai Floods (Ranger et al., 2011), Sichuan Earthquake (Wu et al., 2011). A new version has been developed for this project.

5.2 ARIO model in the WEATHER Project

5.2.1 From ARIO to ARIO-inventories (ARIO 4.1)

WEATHER project has helped highlighted limitations in ARIO modeling approach as in 2009.

First, to be on line with timescale of transport perturbation and smaller scale extreme weather events, the timestep of the model has been down from one month to one day. This is more in line with transport perturbations resulting.

Second, inventories have been introduced. Inventories are in practice the main flexibility option of businesses. This is highly visible when considering that in the last decades business model have been invented based on the way the supply chain was managed : 'just-in-time' management, 'outsourcing' of global supply chain, hedging for a 'quality supply chain' etc. This in itself encompasses transport problematic as transport's main role is today not only inter-industrial relation as such but supply chain logistics within a sector.

The importance of inventories is to our point of view symptomatic of the main difference between the economy in a normal state and during a natural disaster. Economics of natural disaster is marked by a physical shortage which includes rationing scheme and substitution mechanism. In this case, prices have no or little effect. When a motorway is closed because of water flooding it is not a case of paying 100 000 euros or not to go through: this is not possible (at least should not be…).

The modeling strategy to introduce inventories is inspired from Levine and Romanoff (1989) and Romanoff and Levine (1977, 1986, 1993) sequential interindustry model, taken further by Okuyama (2004) and Okuyama et al. (2004) in disaster assessment.

Introduction of inventories in ARIO changes the production profile in a disaster aftermath by adding up a new binding constraint. In the current version of the model, the production profile after disaster is bind by the production capacity, the demand (as in the first version of ARIO) and the inventories. The actual production in ARIO is the minimum of these possible productions at each point in time.

The description of the model ARIO-inventories and sensitivity analysis, or ARIO 4.1, is on Appendix of the present document, which is a copy of Hallegatte (2011, submitted). Important conclusions for the present modeling exercise are following.

" The ARIOinventory model represents explicitly production bottlenecks and input scarcity, models a flexibility in production capacity in case of scarcity (measured with an explicit scarcity index where CGEs use the price as a scarcity indicator), and introduce inventories as an additional flexibility in the production system.

"This makes it possible to distinguish between (i) essential supplies that cannot be stocked (e.g., electricity, water) and whose scarcity can paralyze all economic activity; (ii) essential supplies that can be stocked at least temporarily (e.g., steel, chemicals), whose scarcity creates problems only over the medium term; and (iii) supplies that are not essential in the production process (e.g., pens, some business services) and whose scarcity is problematic only over the long run and are therefore easy to replace with imports."

“One major limit of this model is the assumption of fixed IO coefficients and the use of a scarcity index over both the short and long terms. These assumptions appear acceptable in the immediate disaster aftermath, but are more questionable over the entire reconstruction period. Ideally, a model should be able to model the continuum between the short-term, with fixed technologies and sticky prices, and the long-term with technological substitution and market mechanisms. Also, the model focuses on production and available consumption, but cannot assess explicit welfare losses in absence of a modeling of consumer utilities.”

“ the model highlights the fact that heterogeneity within sectors has a large influence on production bottlenecks, and thus on total economic losses from natural disasters.”

5.2.2 ARIO –T : ARIO inventories with transport integration (ARIO 4.1 T)

To introduce transport in ARIO, the following strategy has been followed. Transport role cannot be fully assessed with transport economic sector in the economy. Indeed, the role of intermediary sector does not appear to the extent it should if this strategy is followed. Therefore, transport has to be modeled in the inter industrial relations. To do so, the first strategy followed was to decompose every sector of the I/O table in four different ones : one per each mode of transport used. However, this strategy faced a lack of data to this level of detail. Therefore, the share of transport by each mode is assigned in a transport table. This table gives for each relation from sector j to sector i, the modal share. In addition to this, a capacity table has been designed which gives the capacity of the transport system at each time step (one day).

Transport has then be introduced as a constraint on inventories. At each point in time (t), the sector (i) is assessing its inventories, and addressing orders to sector (j). The inventories the sector (i) is able to get is in ARIO-T depending on the current capacity of its usual transport mode of delivery.

Thus, the production of goods is affected by its capacity to be physically supplied in ARIO-T, and not only by the possibility to produce. What the model takes into account is the fact that supply may be produced at the end of the line but may not be able to be delivered. This is of particular importance because it is at the heart of effects to and from the affected economy.

Following the same general philosophy than ARIO, ARIO-T allows for adaptive behaviour from economic agents. If their usual mode of transport is crowded out, they can shift to another mode. However, they can only do so, if the usual users of their mode of substitution have not used full capacity. This seems coherent with practitioners experience feedback from stakeholders workshop run in the Weather project.

This practically leads to three distinct steps.

Explicit transport input

Based on data, modal tables (i,j) for each m mode, have been produced, in which each (i,j)represents the share of supply using each mode (m) of transport.

Transport sectors are distinct in 4 sectors.

Capacity tables are based on intensity and recovery profile of disasters. This follows a user approach of extreme events in transport as put forward during Weather working session. Appendix 2 describes this approach, reproducing input note to the weather project on this issue. Capacity table are for each day, the capacity of the transport system. To start with, there was only one capacity table for each type of disaster, it has then be refined by mode.

Transport in the economic model

Transport is introduced through the inventories equation from ARIO-inventories. The rest of the economic model of ARIO remains similar to description in Hallegatte (2008), and Hallegatte (2011, submitted).[1]

Final inventories equation from ARIO inventories :

$$S(i,j)(t+1) = S(i,j)(t) + \delta t [(O\square^{\uparrow} * \ (i,j) - A(i,j)\, P_{\downarrow} i^{\uparrow} a\ (t) \qquad (1)$$

Becomes

$$S(i,j)(t+1) = S(i,j)(t) + \delta t \square (O\square^{\uparrow} * \ (i,j) - A(i,j)\, P_{\downarrow} i^{\uparrow} a\ (t) + Supply\, tr(i,j)(t) \qquad (2)$$

Supply of goods i to industry j is given by :

$$Supply\ tr^{*}(i,j)(t) = \sum_{m=1}^{5} Supply(i,j) * \theta(i,j,m) * K_m^{*}$$

$\theta(i,j,m)$ is the structure of transport by modes (road, rail, air, water, other) of the supply from sector j to sector i. For instance, the sector i delivers the sector j using 85% road transport (mode 1) and 15% rail (mode 2) : $\theta(i,j,1) = 0{,}85;\ \theta(i,j,2) = 0{,}15$

Km is the ability of the mode m to transport goods and passengers.

$$K_m^{*} = \min\left(\frac{Ktr_m(\alpha)}{K(i,j,m)}\right)$$

1 Hallegatte 2008 can easily be found with the reference. Hallegatte (2011) is submitted and is available upon request.

Ktr_m is the capacity of each mode of the transport system to deliver the supply from the i sectors to the j sectors according to the modal structure of transport. α is the current capacity of the transport system, with α being equal to 1 when the mode (m) runs at full capacity.

$K(i,j,m)$ is for each mode m, the total things transported when the system is fully functional. It is then

$$K(i,j,m) = Supply(i,j) * \theta(i,j,m)$$

Thus, if $\alpha = \mathbf{1}$, $K_m^* = \min\left(\frac{Y(i,j)}{Supply\,(i,j)}\right)$ or the optimization of production according to demand in the relation between suppliers sectors and clients sectors, which at the equilibrium is one.

When the transport system is not fully functionning, i.e $0 < \alpha < \mathbf{1}$, the fraction of production of the sector j supplied to the sector i, depends of the capacity of transport system.

That is to say, that ARIO simply introduces the fact that inter industrial relation goes through transport, and depends on transport capacity. However, it does not only take transport system as a whole but does modal disintegration. This means that supply from sector j to sector i is affected as long as the mode of transport used in supply is affected by capacity issue.

Substitution strategy

The substitution strategy is implemented around $\mathbf{\Delta}$, elasticity between transport modes.

$$\mathbf{\Delta} = \frac{r\,dt}{m\,dt}$$

with m, transport mode originally preferred, and r mode of substitution.

Thus, when $K_m < \mathbf{1}$, substitution takes place.

$\mathbf{\Delta}$ is an exogenous parameter to the model, contained in a table of substitution capacity between all modes, with identity diagonal being equal to 0, one mode being not able to substitute itself.

5.3 Modeling exercise : data and important parameters

This section describes the methodological choice the model, the data used, the important parameters, and the modeling process (simulations). This does not encompass every step of the modeling exercise, only those necessary and useful for the results presented thereafter.

5.3.1 A stereotypical region

WEATHER project deals with extreme weather event in Europe. For using ARIO model this has had two main pitfalls :

Europe is diverse in terms of climate regime and extremes

ARIO is a regional model that is not accurate to run on the entire Europe

European regions have diverse economic structure which is important in I/O model

Several methodological choices, with consequences on the results, have been taken.

First, ARIO will run losses, and profiles, for a define number of types of disaster. The results by type will then be used to compute current annual losses and climate change "what if" scenarios. Therefore, ARIO does not combine disasters, it simulates one disaster on one economy.

Second, ARIO will not upscale to Europe. Indeed, natural disasters often affect one particular area at a time. However, the cost of each natural disaster is a cost to European value added as a whole. Therefore, what is really investigated in WEATHER is the repeated cost of each singular event. It is really different from usual ARIO use which focuses more on large scale events, often earthquakes. So here, each type of disaster will get a 'typical cost' for Europe. Impacts and direct effects are local, but the costs are larger.

Third, to be coherent with the idea to run on one region, each type of disaster, the region chosen has to be a stereotypical type of European region. It has to be coherent with the scale of weather extremes, but also the scale of economic assessment. Therefore, ARIO-T is based on data of Belgium (Eurostat). Indeed, the structure of the economy is diverse enough to not be specific. The structure of transport is varied by modes. Data is easily accessible in good quality. Thus, the stereotypical country is in fact Belgium.

5.3.2 Data and parameters

Data used comes from Eurostat. I/O table for Belgium has been reduced to 7 main economic sectors and 4 transport sectors. The reduction to 11 sectors has been done with consideration of the role of transport in each. For instance, services have been aggregated in only one sector, as they are likely to share the same modal structure.

Transport modal structure has been established based on Belgium Statistics Office. A general modal structure for Belgium has been derived (65% road, 8% air, 12 % rail, 10% water –inland and maritime- 5% others). Then, three types of economic sectors have been determined with variation around these figures.

Transport sectors have been dealt specifically according to their economic qualification. That is to say, road transport sector uses mainly road obviously. Then, public sector and services have been assigned with a higher share of road (80%) because it seemed more adequate to their type of activities.

Substitution between modes have been assigned according the following principles :

The easiest mode to shift to is road

Road and rail have some similarities which allow shift from road to rail (in particular road and rail corridor overlap)

Other substitution is default at 10%

Table 5-1: Matrix of substitution between modes

	Road	Air	Rail	Water	Other
Road	0	0,25	0,25	0,25	0,25
Air	0,1	0	0,1	0,1	0,1
Rail	0,2	0,1	0	0,1	0,1
Water	0,1	0,1	0,1	0	0,1
Other	0,1	0,1	0,1	0,1	0

5.3.3 Different simulations

Each type of disaster is evaluated with three different simulations :

No capital losses (transport losses only)

0,01% of capital losses

0,1% of capital losses

These three simulations are done to account for the specificity of ARIO as a natural disaster economic model. There is a non linearity between capital losses and indirect losses. As it accounts for this ripple effect, independently of transport perturbation, it is important to assess what can be accounted as transport specific effect, and what is the “natural disaster” only effect.

Simulations without any transport disruption give the following results. Obviously, the model being at equilibrium the scenario with no capital losses and no transport disruption does not produce any indirect costs!

Table 5-2: Baseline and scenario without transport losses.

	Direct losses (Mn)	VA losses (Mn)	VA variation
Scenario 0	0	0	0
Scenario 1	605	69	-0,026
Scenario 2	6 050	860	-0,32

The baseline is the scenario without natural disaster.

5.4 Natural disasters as input in ARIO-T

Natural Disasters are input in ARIO through profiles of disruption. A disruption profile is a combination of intensity and duration of the disruption.

To manage this, extreme weather events have been clustered through five types: heatwave (temperature and consequences –such as wildfire or drought), winter (temperature and consequences such as snowfall, ice etc), winterstorm/alpine hazards, floods and storms.

These types follow the proposition of Deliverable 2, and are then consistent with other modeling exercise in WEATHER.

To each type of disaster, profiles of disruption have been assigned. Two profiles have been assigned for each of the type, except storms, which makes nine disaster profiles in total. The following table presents the different profiles.

Table 5-3: Disaster and disruption profiles tested

Type of extreme	N°	Qualification	Description
Heatwave (temperature + consequenc	1	light	Uniforme reduction by 15% of capacity during 1 week
	2	heavy	Uniform reduction by 15% of capacity during 3 weeks
Winter (temperature + consequences	3	light	Uniform reduction by 10% of capacity during 3 days
	4	heavy	Uniform reduction by 40% of capacity during 1 week
Windstorms/Alpine Hazards/	5	light	Reduction by 10% during three days, and then evolving from 2% to 0% in 6 months
	6	heavy	Reduction by 40% during three days, and then evolving from 5% to 0% in 1 year
Floods	7	light	Reduction by 5% during three days, and then evolving from 3% to 0% in 3 months
	8	heavy	Reduction by 25% during three days, and then evolving from 10% to 0% in less than a 1 year
Storms	9		Reduction by 40% during three days, and then evolving from 5% to 0% in less than a year

Following, this general profiles of disruption, and after a first round of simulation, a disaster disruption profile by transport mode has been produced.

This has been done by variation around the general disruption profile. For each mode, the question asked has been: should it be more or less than the general profile of disruption? This has led to take into account specificity such as air transport disruption during storms. It has usually led as well to diminishing the disruption on road transport.

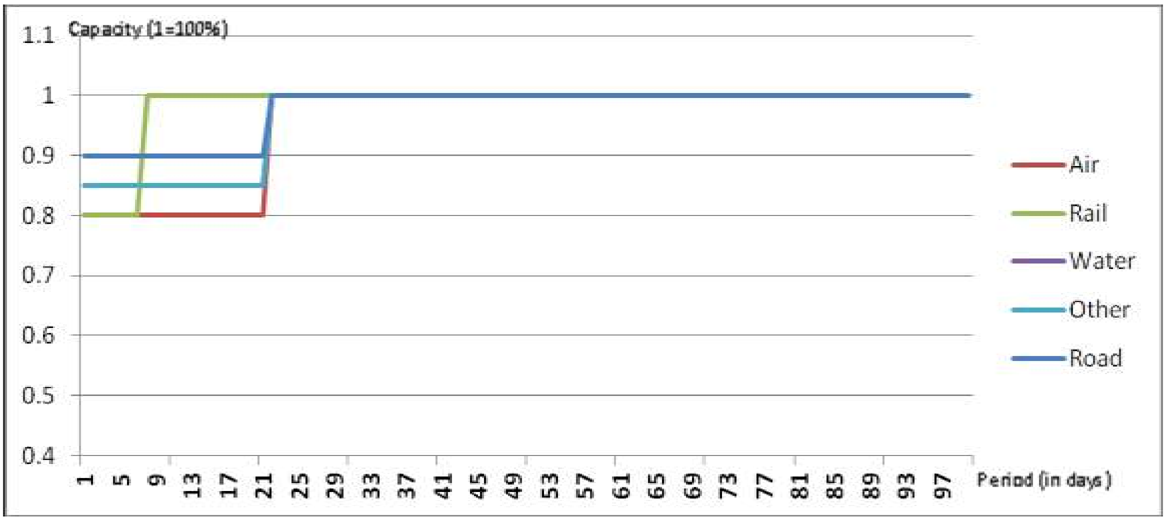


Figure 5-2: Example of disruption profile per mode : Disaster 2

Some conclusions can be drawn from the simulation refining the design of these profiles:

- Due to its importance in share of transport, road disruption is the most costly for the economy. However, it is also the most developed and redundant network which makes it less likely to have a substantial disruption.
- The length of the transport perturbation matters more in terms of final costs than the intensity of the disruption. For instance, diminishing the duration of disruption of three years going back to normal (from 5 to 0% of disruption) to one year lead to the estimation of a storm (D9) to drop from approx. € bn 19 to approx. € bn 8,2, more than a factor 2.

Obviously, some results are extremely sensitive to the disruption. On the one hand, it is a pitfall. On the other, disruption profiles are exogenous and can be changed if more precise data on disruption profiles were available.

5.5 What to expect and how to read ARIO-T results

ARIO-T proposes an understanding of the process of indirect losses due to transport disruption at the regional level. It differs from direct costs of transport disruption. It gives an first insight on transport and natural disaster economics.

The results give transport losses, but the model has strong limitations that need to be kept in mind when results are interpreted:

The first limit is linked to the transport tables (share by mode, capacity and substitution). The result is dependent on these tables, which are (at best) informed guesses. Improvement in input data related to transport and to interruption due to extreme weather events is needed.

The second limit is the use of a stereotypical region, which is a strong assumption. Different european regions with different characteristics would lead to different results.

The third limit is the way transport is implemented in the model, and the economic model of production. Our ability to model the economic system is extremely limited, and a model like ARIO is a highly simplified view of the reality. Also, other model parameters are highly uncertainty, and especially the heterogeneity and the substitution capacity (see Hallegatte, 2011). Changes in these parameters can transform results.

Finally, there is no assumption on structural modification of the economy, or socio-economic baseline: thus technical change and multiple equilibrium are neglected.

Then, the definition of extreme events retained here is not one of weather index. As such, ARIO is not coupled with any climate or weather models. The idea taken into account is the one of disruption. In our simulation, an event is extreme only to the extent it destroys capital and/or it interrupts transport.

ARIO produces losses per scenario for each interruption profile which are meant to represent each type of disaster. Then, aggregation of this disaster related losses to annual losses, and ‘what if’ climate change scenarios are derived, but not directly output of, from ARIO disaster related losses. This aggregation is done without any dynamics but with classic statistical aggregation: it is important to understand that ARIO model does not produce directly this result. Especially this mean that the underlying assumption is that it is never the same region which is hit by each of the disaster: there is no cumulative effect. At the same time, it also means that there is no adaptation between each disaster. Therefore, it is important that the figures produced are used as state of the art of this kind of exercise, and as order of magnitude but not as ‘certain’ costs.

Because of these limitations, the numerical values produced by the model should be used with care. The model is a tool to understand the consequences of transport interruption, to analyze the mechanisms involved, and identify solutions to reduce economic vulnerability. In the current state of knowledge, the model is not a *prediction model*, able to predict the cost of a event.

6 Results: Economy wide impacts per type of extreme weather events

Table 5 summarizes the costs per type of event. The first column is a short description of the disaster type; equivalence in terms of disruption in transport can be found in the previous section. The three scenarios are simulations based on the three types of direct costs as presented in table 3 in section 2. The scenarios are identical for every types of disaster. Indirect costs are the total VA losses, including transport losses but not only. The economic costs without transport disruption are presented in table 2. All indirect losses are not induced by transport disruption. Thus, costs of “no transport” scenario allow estimating transport only indirect costs, by substracting them from total VA losses. The last column of the table presents the economy-wide impacts of transport disruption per type of hazards.

Table 6-1: Transport induced indirect costs by type of disaster for three scenarios.

Disaster type	Scenarios	Direct(bn)	Indirect (bn)	Var VA (%)	Losses induced by transport (Mn)
Heatwave light D1	0	0	0	0	0,00
	1	0,605	0,069171	-0,0259	0,17
	2	6,05	0,85475	-0,3194	-5,25
Heatwave heavy D2	0	0	4,1018	-1,5329	4 101,80
	1	0,605	4,4135	-1,6494	4 032,80
	2	6,05	4,5227	-1,6902	3 662,70
Winter light D3	0	0	0	0	0,00
	1	0,605	0,068867	-0,0257	-0,13
	2	6,05	0,85381	-0,3191	-6,19
Winter heavy D4	0	0	0,19782	-0,0739	197,82
	1	0,605	0,18122	-0,0677	112,22
	2	6,05	0,85683	-0,3202	-3,17
Windstorm/Alpine/Landslide Light D5	0	0	0,99505	-0,3719	995,05
	1	0,605	0,98393	-0,3677	135,05
	2	6,05	1,0633	-0,3974	123,93
Windstorm/Alpine/Landslide Heavy D6	0	0	7,0687	-2,6417	7 068,70
	1	0,605	7,0613	-2,6389	6 999,70
	2	6,05	7,1141	-2,6586	6 254,10
Floods light D7	0	0	0,20286	-0,0758	202,86
	1	0,605	0,18739	-0,07	118,39
	2	6,05	0,85417	-0,3192	-5,83
Floods heavy D8	0	0	6,8946	-2,5766	6 894,60
	1	0,605	6,912	-2,5831	6 825,60
	2	6,05	7,1211	-2,6612	6 261,10
Storms D9	0	0	8,2997	-3,1017	8 299,70
	1	0,605	8,2926	-3,099	8 223,60
	2	6,05	8,4737	-3,1667	7 613,70

To start with, results are coherent with previous use of the model. Direct and indirect costs are related in a nonlinear manner.

Then, transport disruption presents the characteristic of a multiplier effect on the indirect costs of the events, that is to say disruption is a bottleneck in the economy affected with larger consequences than direct costs. However, this is not true inter alia.

The results can be clustered into two types of events:

- Events which have indirect costs induced by transport for less than € 200 millions with significant differences between the different scenarios.
- Events which concentrate all the estimations around the same figure, with quite high indirect costs induced by transport disruption

In the first case, the economic dynamics of the model appears to be the stronger driver. In these events there appears to be either no indirect losses induced by transport (D1 and D3), or low (D4, D4, D7).

Furthermore, **indirect losses induced by transport appear to be lower when direct costs are high**. In this case, the transport disruption shows to be not significant compared to the level of the natural disasters: the indirect costs without transport losses exceed the one with transport disruption. Thus, for this category of event the transport disruption as a significant impact economy-wide only if the economic cost is low. When production is low and reconstruction needs is high, transport is not the main bottleneck. If the level of production is low, the capacity to transport them does not matter: goods are not produced. In this situation, it does not mean that transport is not impacted; but it is not a bottleneck. Indeed, the importance of transport system as an intermediary sector seems to depend on its usage rate.

This means that transport systems may benefit from being protected against interruptions which are of low economic direct and indirect costs, because they are costlier. Indeed, during this type of transport only events the economic system is fully functioning. Each interruption is then substantially really costly. **When the direct costs are high, economic ripple effects are important and transport does not really matter in this case as production is lowered.** So, for this category of event they are really two cases: whether the economy is strongly affected as well, or not. Further investigation needs to be done in the role of transport system in the recovery path of the economy. Transport becomes a bottleneck when it is underdeveloped compared to production needs.

In the second case, the transport perturbation seems to be driving the results. This is the case for D2, D6, D8, D9, that is to say only “heavy” events. Transport induced indirect costs are in this case extremely high and they are note related in order of magnitude with direct or other indirect costs. In relation to the profile of disruption, it appears that **the duration of the event is an important driver of this cost.** This is according to what has been said in the precedent paragraph: **bottleneck in a fully functioning economy is costlier**. When the economy is fully functioning even a small perturbation of transport is extremely costly. Thus, in the case of large event, if transport disruption lasts longer than the economy recovers the cost rises. It is thus a question of adequacy between the reconstruction pace and the disruption profile. Further investigation in this could prove useful to know what to target in priority in a natural event aftermath.

Table 6-2: Investigating relation between order of magnitude of losses and disruption profile

Interruption Profile	Range of transport induced indirect costs Mn
Uniforme reduction by 15% of capacity during 1 week	0
Uniform reduction by 15% of capacity during 3 weeks	[3600-4100]
Uniform reduction by 10% of capacity during 3 days	0
Uniform reduction by 40% of capacity during 1 week	[0-197]
Reduction by 10% during three days, and then evolving from 2% to 0% in 6 months	[123-995]
Reduction by 40% during three days, and then evolving from 5% to 0% in 1 year	[6250-7050]
Reduction by 5% during three days, and then evolving from 3% to 0% in 3 months	[0-200]
Reduction by 25% during three days, and then evolving from 10% to 0% in less than a 1 year	[6250-6900]
Reduction by 40% during three days, and then evolving from 5% to 0% in less than a year	[7600-8300]

A relation between duration and indirect costs due to transport perturbation is not really surprising. Indeed, a long disruption can be assimilated to a drawback on productivity, affecting directly production level. VA profiles of the economy three years after the disaster in the nine cases in scenario 1 (Figure 4) is interesting to this regard. In fact, the costlier events are not only the longer perturbation, but a combination of sharp crisis, and long recovery path. For instance, the "heavy heatwave" profile (D2) is of a sharp crisis with a relatively quick recovery.

These recovery profiles show the combination of both the economic driver and transport driver in the trajectory. A main limit to a closer study of these and of the relation between economic and transport driver is the absence of explicit link in the model between direct costs and transport. It may then be possible that some simulations proposed in this exercise are not balanced with this regard, for instance direct costs are too high for the transport perturbation induced.

Table 6-3: Disasters ranking by transport high order losses

#	Extreme events which are the costlier through transport effect
1	Storm
2	Heavy Landslide/Alpine Hazards
3	Heavy Floods
4	Heavy Heatwave
5	Light Landslide/Alpine Hazards
6	Light Flood
7	Heavy Winter Event
8	Light Winter Event
9	Light Heatwave

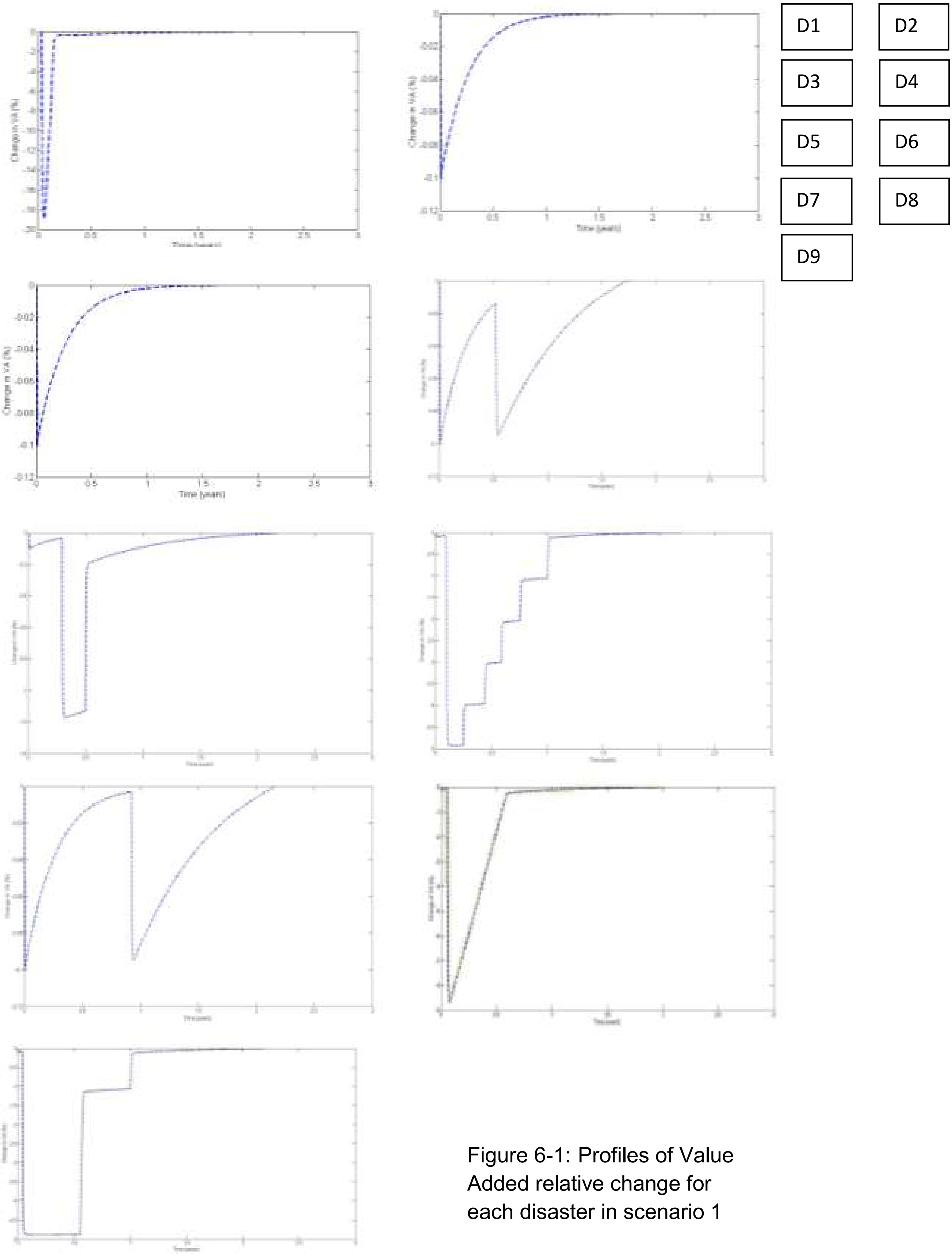


Figure 6-1: Profiles of Value Added relative change for each disaster in scenario 1

7 Annual Losses and Climate Change Scenarios

7.1 Annual Losses as in 2011 based on historical data

To calculate annual losses due to transport indirect losses related to extreme weather events, historical frequencies have been estimated by type of events using EM-DAT(EM-DAT: The OFDA/CRED International Disaster Database – www.emdat.be, Université Catholique de Louvain, Brussels (Belgium)).

For EM-DAT database, for an event to be a disaster one of the following criteria has to be fulfilled:

- Ten (10) or more people reported killed
- Hundred (100) or more people reported affected.
- Declaration of a state of emergency.
- Call for international assistance.

For the present work, events from 1940 to 2010 for northern, southern, eastern and western Europe are used. Two comments and limits on this :

- EM-DAT is claimed homogenous in collection from 1980 until now. For the precedent decades, information collected may have been scarcer leading to a potential collection bias.
- Delimitation of Europe is geographical rather than “political”. Therefore, it does not exactly match EU delimitations especially with regard to the Balkan area.

EM-DAT characterizes each disaster by a type and a subtype, and gives whenever possible direct costs. The database has been modified to fit our disaster categories, implying some recomposition. Three types of modifications have been made :

- Events with missing data for direct costs have not been considered
- Distinction between the 10% most extreme and the 90% other type has been done. The frequency of the 10% most extreme will be affected to the ‘heavy’ type, while the 90% less extremes are considered similar to our ‘light’ typt.
- ‘Storms’ in this work will only considers the 10% most extreme events and not consider the 90% else; consistently with what has been done throughout this work.

For estimating annual losses, historical frequencies per our typology of events are used, based on this work from EM-DAT. Database is available upon request. Further information about EM-DAT database is available on their website.

7.1.1 Historical frequencies of extreme events

Table 7-1: Historical frequencies from EM-DAT by type of extremes.

ARIO type of disaster	EM-DAT Frequency

Light Heatwave	0,148028962
Heavy Heatwave	0,004827031
Light Winter	0,094931617
Heavy Winter	0,000804505
Light Landslides/Alpines	0,069991955
Heavy Landslides and Alpines	0,004022526
Light Flood	0,354786806
Heavy Flood	0,017699115
Storms (10% most extreme)	0,01689461

The distinction between the 90% and the 10% is *de facto* a threshold of direct costs of around $1bn. This seems consistent with the type of distinction in mind in the economic model.

7.1.2 What are 'annual losses'

The annual losses due to transport disruption effect on the economy caused by weather extremes are calculated by multiplying the range of losses by individual event from ARIO with EM-DAT historical frequencies. What does it mean?

These losses are based on the period 1940-2010 as if extreme events were homogenously distributed per year. These losses are costs for Europe, understood as the geographical definition of EM-DAT. A natural disaster in our calculation affects independently each time a sub-region of Europe, which climate is a stereotypical European climate with all the types of extremes. There is no cumulative effect of natural disasters: the stereotypical region always recovers fully before being affected by another event. Each event provokes independent losses, annual losses are obtained by addition of these and weighted by historical frequencies.

Potential for long term adaptation or strategic change is not accounted for: precedent history does not foster adaptation. As such, annual losses are an abstract indication on the scale of the costs.

7.1.3 Range of annual losses 2011 per event and total

These results follow the simulation by scale of direct costs done for each event with ARIO. This gives an approximation of the range of costs taking into account the heterogeneity of events, which is not well considered through the historical analysis. $

Table 7-2: Estimation of annual losses by type of events and total

Type of Extreme Weather Event	Estimates of transport-related indirect costs, for three scenarios of direct costs, in millions Euros

	Lower	Medium	Higher
Light Heatwave	**0**	**0**	**0**
Heavy Heatwave	**18**	**19**	**20**
Light Winter	**0**	**0**	**0**
Heavy Winter	**0**	**0,090**	**0,159**
Light Landslides/Alpine Hazards	**9**	**9**	**70**
Heavy Landslides/ Alpine Hazards	**25**	**28**	**28**
Light Flood	**0**	**42**	**72**
Heavy Flood	**111**	**121**	**122**
Storms	**129**	**139**	**140**
Total	**291**	**359**	**452**

7.2 Climate scenarios

7.2.1 What if" scenarios

This section gives estimation of what could be the change in terms of losses in various climate change scenarios. These scenarios are "what if scenarios" that is to say they are not grounded directly on climate model results. They propose an idea of what would be the impact in terms of losses of a change in terms of weather extremes.

Three types of change can occur:

- Extreme weather events can be more frequent
- Extreme weather events can be more extreme
- The types of extreme weather events may change, or at least the changes may not be homogenous

Our methodology allows imperfectly to account for a change in quality of event. It is done through having different change in frequency for different events. The following general rules are applied for the scenarios proposed :

- Extreme weather events are changing homogenously either in frequency or in intensity

- Except landslides/alpine hazards which do not change, because there may be less of one type but more of another which does not give a clear picture;
- Except winter extreme events which change inversely to the other events. For instance, when heatwave extreme D2 frequency increases of 10%, frequency of D4 decreases of 10%

These may be rough but are the most accurate possible for the methodology and following the general exercise framework. From this exercise, orders of magnitude are expected.

Different scenarios are estimated:

- Increase in frequencies : 1%, 5%, 10%, 100%
- Increase in intensity :10%
- Extreme scenario : combination of 10% increase in frequency and intensity, combination of 100% increase in frequency and 10% increase in intensity

The increase in frequency is obtained by increasing the probability of occurrence by 10% on all the events, with exception of winter and landslides as presented in the precedent section.

The increase in intensity is obtained by increasing the probability of occurrence of the 10% the most extreme events only, that is to say changing the proportion of heavy extreme events compared to light extreme events. Thus, it is not intensity in terms of direct costs impacts, but a disproportional increase of the 10% most extreme events of today's climate.

7.2.2 Range of results

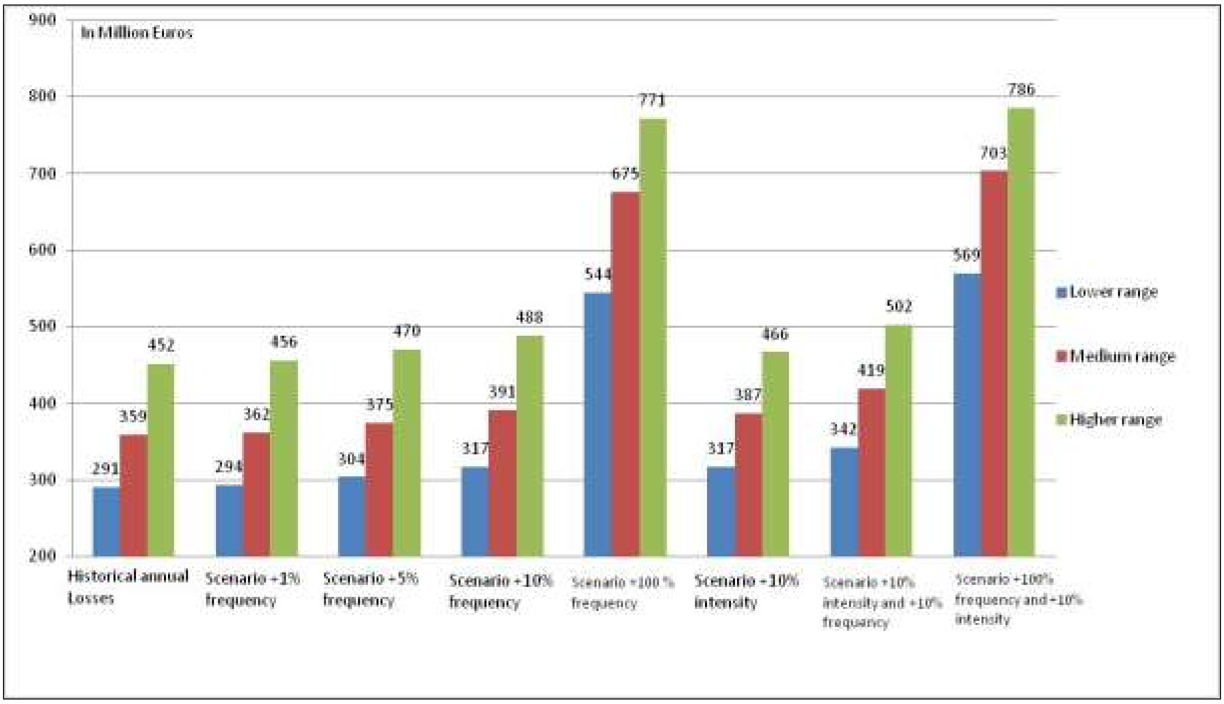


Figure 7-1: Climate change related extreme weather events scenarios and losses estimations

To start with, the main outcome of this exercise is to have an idea on the different impacts of intensity and frequency on the range of losses. Indeed, an increase in intensity of extreme events increases non-linearly the losses due to transport interruption. This can be explained by the major impacts of bottlenecks on the economic performances: indirect losses in ARIO rise non-linearly with direct losses.

Then, the importance of the frequency of events on transport related indirect costs is interesting. A change in frequency of extreme weather events on transport can be induced by a proportionally really smaller change in climate index. Indeed, risk mitigation strategies are designed for current vulnerability and protect against potential extreme events for current weather, but may not be accurate after a small change in climate conditions. For instance, if hydrological conditions change a dike gets more frequently overtopped, leading to an increase of events. The overtopping of the dike is a threshold: for a small difference it can change from no disaster to a disaster. Thus frequency of events is not exactly a proxy of climate change, but a definition of extreme events based on disruption. In this case, non linearity between climate index and impacts of extreme weather events is expected with uncertain thresholds values, which are mainly define by local conditions.

Intensity and frequency cannot be addressed exactly the same way in policy options, which make further investigation on this particularly important in future research.

The most extreme climate scenario of a rise of 10% in frequency and in intensity of extreme weather events would suggest a rise of above 10% in annual losses. Even though significant, it still remains bounded to hypothesis and methodology of calculation of these losses. An additional aspect to this is that to be a significant driver for policy now, these losses should be discounted to be compared with historical losses. With a discount rate of 2%, the scenario 10% intensity/10% frequency of losses estimate losses as in 2011 at around 336 million Euros if the conditions of the scenario are met by 2030 and 226 if they are met by 2050. This should help us to think that impacts of extreme weather events on transport in the current climate are probably the most important aspects to take into consideration in decision making related to this issue. But, as suggest the two most extremes of the scenarios, it is also important to work on potential large scale change, or ‘worst case scenario’ as they would carry significant costs.

7.3 Conclusion

Assessing economy wide impacts is often complicated as it bears the risk of scaling up natural disaster issue to the regional economy level. It is even more complicated in the case of WEATHER as it aims at disentangling causes of indirect losses and isolating transport related ones.

Therefore, results have to be taken with extreme precaution. They are more the output of an exploratory research exercise than a decision support tools. It sketches broad processes more than give precise results.

Once this taken into account, it can be said that the current annual losses due to weather related event are likely to be substantial. However, the considered climate change scenarios do not lead to an unmanageable increase in this cost.

Improving this analysis can be done through several ways. First, collecting more precise data on transport and particularly disruption processes would improve this type of analyses. What is mostly needed is not the cost of each weather event but the type of events it induces if indirect costs are to be calculated. Second, a better simulation of climate change scenario would be necessary to go beyond “what if” based on index of historical data. Third, working a stereotypical region would need a sorrow analysis and refining, especially on the up scaling of the costs to Europe. Fourth, there is no baseline in the present simulation, which means that structural changes are not taken into account. Fifth, events could be cumulative and generate adaption. So far, the model does not include any type of irreversibility.

PART III: TRANSPORT SECTOR IMPACTS

8 Assessing Transport Sector Consequences

8.1 Levels of impact assessment

In the previous sections wider economic impacts caused by the disruption in the transport sector have been derived for a stereotypical region. In contrast, the direct losses of the transport sector were derived in WEATHER deliverable 2. The results are not directly comparable due to differences in system delimitation and the theoretical approaches taken.

To get a better idea of the linkages and possibly of methodological differences of the two analyses, the following section reviews the methodology applied by the WEATHER Vulnerability Assessment (D2) and reviews the results retrieved.

The methodological foundation of accounting for transport-sector related losses were formulated in a project internal note on the “General Assessment Framework” (GAF). The subsequent elaboration emerges from this work and from the findings in WEATHER deliverable 2.

8.2 Structure of the Assessment Framework

The impacts of natural or man-made hazards on the economy are manifold. Extreme events will affect different actors, social groups or markets in different ways, involving long- and short-term impacts caused by the deterioration of physical assets, the disruption of operations and the availability of services. Further, when leaving the assessment level of single events and turning attention towards quantifying risks, local conditions start to play a major role. The probability of extreme events occurring, as well as the density and value of endangered assets and activities, will differ from region to region. Finally, the time dimension is of high importance, as the probability and severity of events may change, which is certainly the case for natural catastrophes impacted by climate change, and the density and value of assets and activities is subject to steady evolution.

8.2.1 Dimensions of the assessment framework

These manifold dimensions make quantifying the spectrum of economic impacts of climate change on the economy very challenging. Although we restrict the assessment here to the transport sector and weather extremes, i.e. we exclude the long-term impacts associated with constant temperature changes and rises in sea level, numerous dimensions still remain to be considered. In detail, we treat the main dimensions as follows.

Weather extremes: The WEATHER project considers 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. The resulting basic types of extremes and their consequences are elaborated in Table 8-1 starting from the 11 categories listed by WEATHER Deliverable 2. As not all of these extremes could be considered in detail across all modes and for reasons of simplicity and clearness of the results, they have been categorised into four major impact types. Table 8-1 presents the grouping and the consideration of events and consequences by the modal analysis in Deliverable 2.

A 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, or which are reported in supra-regional media.

Table 8-1: Categories of weather extremes and consideration by mode

Categories of events		Short description	Covered by modal analysis			
maj.	**detailed**		**Road**	**Rail**	**Air**	**Water**
Ice&Snow	Frost	Consecutive days with Tmax < 0°C	+	-	+	-
	Snow	Consecutive days with snow > 5cm	+	-	+	-
	Winter storms	Storms with snow during frost periods	+	+	+	+
	Avalanches	Event with noticeable damage	-	+	:	:
Rain&Flöods	Convective rain-falls	Single rainfall > 200 mm / day	+	+	-	-
	Permanent rain-falls	Consecutive days of rainfall	+	+	+	-
	General floods	Floods covering a wider area	+	+	:	+
	Flash floods	Flooding in less than 6 hours	+	+	:	:
	Landslides	Mass movements after rain or flood	+	+	:	:
Storms	Extratropical cyclones	Storms with notice-able damage	+	+	+	+
	Storm surges	Storm with flooding of coastal areas	-	-	-	-
	Hail	Hail with bigger hail-stones				
Heat&Drought	Heat	Heat period with noticeable damage	+	-	-	-
	Drought	Several consecutive dry weeks	-	-	-	-
	Wild fires	Non man made large fires	-	-	-	-
Others	Fog	Longer periods with sight < 10 m	-	-	+	-
	Atmosphere	Ash or dust clouds over large areas	-	-	-	-

Source: Fraunhofer-ISI.
Symbols: "+" = considered, "-" = not considered, ":" = not relevant.

Geographical scope: WEATHER research considers the impact of weather extremes across the entire European Union after the extension to Romania and Bulgaria in 2007, plus Switzerland and Norway. The assessment thus covers 29 countries, reaching from the North Pole to the Mediterranean, comprising islands, coastal regions, mountain areas and continental zones. Following the recommendations of the

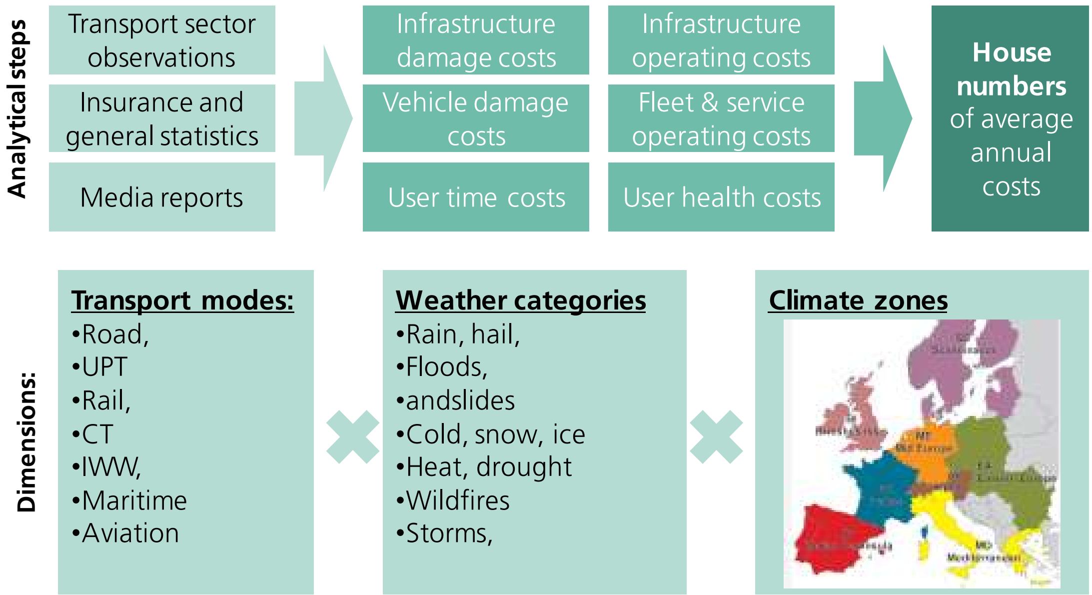
PRUDENCE project (Christensen and Christensen, 2007), we have subdivided Europe into eight climate zones: Scandinavia (SC), the British Islands (BE), France (FR), Mid Europe (ME), Eastern Europe (EA), the Alps (AL), the Iberian Peninsula (IP), and the Mediterranean Area (ME).

Transport markets: All transport modes with a focus on inter-regional services are addressed. Urban transport is touched on only briefly, as the study takes the pan-European view. Cost assessments are carried out for road, rail, aviation, maritime shipping, inland navigation and combined road-rail transport. Passenger and freight transport are considered, but without explicitly separating the two segments.

Actors and cost categories: The study takes the actor view via the various assets and activities in the transport market that can be affected by weather extremes. First, these are infrastructure assets and infrastructure operations, which are run either by private or public operators. Second, assets and operations of transport-operating companies are mainly attributable to public authorities in the case of collective passenger services, while individual passenger and freight transport may largely be a private matter. Finally, the user perspective is taken, by assessing the economic consequences of transport fatalities and injuries as well as the monetary value of travel delays.

Time dimension: The project starts with the analysis of current impacts and related economic costs along the dimensions listed above. In this assessment step, which is presented in this contribution, we relate the weather phenomena which took place in Europe during the past decade. We calculate life cycle costs for all related damages to long-life assets, i.e. reinvestment expenses plus related interest costs. But apart from this we restrict the assessment to short-term effects. Long-term changes in travel patterns, which could arise from temperature changes in southern areas or from modal shifts due to the constant deterioration of specific transport chains are excluded. In the later stages of the research we will then make rough quantitative forecasts until 2050 ??? and provide a qualitative outlook until 2100.

Figure 8-1 provides an overview of the assessment dimensions for quantifying current impacts of weather extremes on transport systems. The input data and quantification methodology differs from mode to mode, and is described in more detail below. The results of the assessment process finally are very coarse “house numbers” or orders of magnitude of the additional entrepreneurial and private costs caused by weather extremes in the past decade.



Source: Fraunhofer-ISI

Figure 8-1: Dimensions of the WEATHER transport sector assessment scheme

8.2.2 Application to road transport

The recording of the physical impacts of weather extremes, comprising damages to assets, additional operations, safety and delays, strongly differs by mode. For road transport, a hybrid approach combining the impact elasticity values with respect to weather parameters found in literature (extremes elasticity model EEM) with a media and transport operator database on actual events (incident database IDB) was applied. From information in the literature on the propagation of accidents and delays during heavy precipitation, crash rates with heat days and infrastructure costs under winter conditions could be derived. These were then applied to average annual ice, snow, heat and heavy precipitation days provided by the ECA&D database (ECA&D, 2011).

The incident database is again composed of two elements: a media review containing around 950 entries for six countries from 2000 to 2010, and recorded damage data provided by network operators in Austria (ASFINAG) and the Czech Republic. These roughly 1,000 datasets were transformed into standard events which may be related to only one specific, or to several out of the six cost categories. Examples of simple standard events are reports on delays or fatalities. Complex events are, for instance, the destruction of a road, entailing capital costs for repair and rehabilitation, police and traffic management and vehicle operation due to detouring during repair. For each standard event, default parameters for duration, extension and costs of the six basic cost categories have been pre-defined, but the database allows these to be modified by event-specific adjustment parameters.

Finally, a simple value transfer model consisting of key meteorological indicators of extremes from ECA&D (2011), plus transport network lengths, passenger and ton kilometres (EC 2011a) for each of the eight climate zones was applied, in order to obtain an idea of cost levels across Europe. We finally arrived at €1.8 billion of annual costs for the 29 countries. Table 8-2 gives an overview of the two approaches contributing to the overall estimate of specific annual costs to road transport by actor and type of extreme.. The overview reveals that still some considerable gaps remain, in particular concerning storms, storm surges and wild fires.

Table 8-2: Data availability for cost generalisation

Overview of the availability of cost estimates in road transport due to extreme weather conditions: EEM: Extremes elasticity model IDG: Incident database generalisation	Rainfalls	Floods / flash floods	Mass movements	Extra-trop. cyclones	Storm surges	Hail and hail storms	Frost periods	Snow	Winter storms	Heat periods	Droughts
Infrastructure assets	Irrelevant	IDB	IDB	No data	No data	No data	Both	EEM	No data	Irrelevant	Irrelevant
Infrastructure operations	No data	IDB	IDB	No data	No data	No data	EEM	Both	No data	Irrelevant	Irrelevant
Vehicle assets	Irrelevant	IDB	IDB	No data	No data	No data	IDB	IDB	No data	Irrelevant	Irrelevant
Transport service operations	No data	IDB	IDB	IDB		No data	IDB	IDB	IDB	No data	No data
Safety issues	EEM	No data	No data	IDB		No data	Both	Both	IDB	EEM	Irrelevant
Congestion and delays		IDB	IDB	IDB		No data	Both	Both	IDB	Irrelevant	Irrelevant
Data sources:	EEM		IDB		Both		No data		Irrelevant		

Source: Fraunhofer-ISI

8.2.3 Application to rail and intermodal freight transport

In the case of rail transport, media and transport operator data have been compiled for selected extreme events. Considered are heavy and permanent rainfall with ensuing floods and mass land movements, thunderstorms, winter storms and avalanches. Although there is detailed information on heat impacts on delays and train operating costs from the FUTURE-NET project (Baker, 2010), these are considered specific to UK networks and thus are not taken into account in the WEATHER project.

Distinguished are capital, operating and user costs, which are expressed as minimum, maximum, average and median values. Considered too are the replacement or repair of tracks, increased service operation due to detours, replacing bus services or revenue losses due to cancelled trips, cleaning and re-opening of tracks and user time losses. Safety impacts are omitted as there is a strong tendency in Europe to put safety in first place and thus to accept operation costs and delays rather than to increase accident risks.

With some extrapolation, annual total costs of €305 million are derived for Europe. Combined rail-road freight transport was studied in a separate analysis. With the hypothesis of +10 to +20 increases in operating costs due to rain, floods, storms and snow, additional annual costs of €6.8 million are derived, which leads to total costs of extreme weather events of €312 million.

8.2.4 Application to aviation and shipping

The assessment of air transport is again based on combining average risk factors, mainly from U.S. sources, with assessments of European air transport databases and literature reviews. Datasets used are the Eurocontrol customer database (Oneskyonline 2011) and accident data provided by the European Air Safety Agency. Though a large number of cost categories could be filled by this approach, problems remain in transferring US results to European conditions and concerning the identification of delays and accidents due to extremes. The €360 million overall annual costs, which extreme weather conditions are found to cost ??? air transport are considerable

The assessment of costs for the shipping sector is based on two case studies. Potential costs of extra-tropical cyclones are demonstrated by the example of Kyrill and the related damage of two vessels costing around €20 million. As inland navigation is most sensitive to water levels, excessively high levels due to floods and too low levels caused by drought periods on the Rhine (Pegel Kaub) were analysed. Total annual costs for Europe amount to roughly €5 million.

8.3 Specific Issues of Transport Sector Impacts

In the subsequent sections we go across the basic valuation principles along the six cost categories, and within each cost categories along the four main transport modes road, rail, aviation and waterborne transport. Discussed are the most relevant cost drivers and resulting indicative unit cost values.

The general principle builds on the international financial reporting system (IFRS), distinguishing between the basic types of entrepreneurial cost items. In addition we consider some elements of transport system cost analyses, namely safety and user time costs, which are close to the transport system. Table 8-3 provides an overview of the several elements considered in each of the basic transport modes.

Table 8-3: Systematic of cost categories

Functional systematic	Balance Sheet elements	Relevant for		
		Infrastructure operators	Transport service providers	Transport users
Capital costs	Depreciation	x	x	x
	Interest *	x	x	(x)
Maintenance	Personnel	x	x	
	Consumables	x	x	x
	Services	x	x	x
Administration	Personnel	x	x	
	Consumables	(x)	(x)	
	Services	x	x	
User costs	Time costs			x
	Accident costs			x

* deviating from IFRS cost categories.
Source: ISIS 2010.

8.3.1 Infrastructure operations

Whenever durable assets are damaged or destroyed and have to be replaced one needs to account for the change in life cycle capital costs of the infrastructure rather than just of the actual repair or replacement costs. Commonly infrastructure cost accounting schemes consider expenses as durable or investments when they have a life expectancy of two years or more. Capital costs consist of two components:

Depreciation is the distribution of investment costs over the life span of the asset to express its periodic loss of value due to aging and use. Usually the investment costs is expressed as the replacement value of the current period, rather than the historical purchase costs.

In its most simple form with linear depreciation and without residual values depreciation computes by dividing the investment value by the life expectancy. In ancy case, if the construction price index equals the social interest rate, the present value of the depreciation equals the investment costs.

Interest costs on capital contains three elements: financing costs, profit margin and a risk premium to balance several risks, including force mature, demand fluctuations, or funding risks. As this structure differs for public and private infrastructure or fleet operators we assign specific interest rates.

In average across the assets life span interest costs are half of the investment costs, multiplied with the interest rate. The present value can be approximated by 50% of the investment costs times interest rate times the asset's life span.

To be valued are those costs which occur in addition to the conventional maintenance cycle of the asset. In case a new infrastructure is hit, repair or replacement costs are completely additional, while the disruption of an asset which is close to the end of its life expectancy constitutes only few extra costs.

For valuing a particular infrastructure damage case caused by an extreme weather incident we thus can draw back on three parameters:

Degree of damage in terms of physical extension (network-km) and severity. In case of partial or light damages only parts of the replacement costs must be applied. Respective data is to be taken from local damage reports.

Unit costs of the infrastructure (€/network-km): standard replacement values and national price indices are available by type of infrastructure from previous research projects (Link et al. (2002), Doll and van Essen (2008), Rothengatter and Rommerskirchen (2007)).

The age of infrastructures remains as a local parameter. For simplicity an average age between 70% for high level infrastructrures and 50% for second order infrastructures may be applied. However, national specificities (e.g. the newly built TEN-T networks in the New Member States) should be considered.

Example values for road: In average the German road cost accounts deliver gross asset values for the roughly 12500 km of motorways of €164 billion and net asset costs of €112 billion. These values correspond to an age structure of 68% and €13 million unit replacement costs per motorway kilometre.

Table 8-4: Example: motorway infrastructure costs Germany, 2005

Construction element	Gross asset bn. €	Net asset bn. €	Mean age %	Depr. costs bn. €	Interest costs bn. €	Mean lifespan a	Capital costs bn. €	Capital costs €/km
Right of way	17,69	17,69	100%	0	0,71		0,71	59'167
Earthworks 1)	45,6	26,59	58%	0,99	1,06	46	2,05	88'333
Main course	11,79	7,36	62%	0,16	0,29	74	0,45	24'167
Pavement	8,86	5,22	59%	0,32	0,21	28	0,53	17'500
Equipment	18,09	9,01	50%	0,81	0,36	22	1,17	30'000
Intersections	18,58	17,4	94%	0,18	0,7	103	0,88	58'333
Tunnels 2)	3,66	3,08	84%	0,01	0,12	366	0,13	10'000
Bridges 2)	30,8	19,67	64%	0,27	0,79	114	1,06	65'833
Administr. 3)	0,63	0,44	70%	0,01	0,02	63	0,03	1'667
Rest areas	8,26	5,07	61%	0,07	0,2	118	0,27	16'667
TOTAL	163,96	111,53	702%	2,82	4,46	52	7,28	371'667

1) incl. planning, 2) running costs incl. capitalised maintenance, 3) incl. public administration, traffic police, small repair measures and routine maintenance

Across all German federal roads the age structure is 69% with unit replacement costs of €3.6 mill. per road-km. For the German rail network the figures are similar: 67% age structure with €3.9 million for the construction of new tracks. Of course these figures differ widely when considering different type of infrastructures and specific regional conditions. Unit replacement costs by track type are reported WEATHER Deliverable 2:

Table 8-5: Unit costs for calculation of impacts

WEATHER Unit costs for calculation of impacts			
average replacement costs per affected network-km	average replacement capital costs per affected network-km	average additional service costs and revenue loss per day and affected network section	average additional user costs per day and affected network section
Mio EUR/km	Mio EUR/km	EUR/day/section	EUR/day/section
2,55	0,13	43.600	27.700

For inland waterways and airports damages of infrastructures by weather extremes are rare and all event are unique. We thus do not provide default figures for the economic assessment.

8.3.2 Infrastructure operation

The costs for operating infrastructures under severe weather conditions comprise missions of traffic police or fire brigades to survey and control traffic, maintain traffic safety or to remove obstacles. Cost drivers are the severity of the event, its duration and physical extent, determining the personnel, and the equipment required.

Standard cost values are difficult to provide. But, with reference to media reports, values between €500 and €2000 for local event with limited duration seem reasonable. More precise cost values, however, need to be determined on the local level.

Both, infrastructure asset and operation related costs are commonly borne by public entities. In most cases this will be directly as transport infrastructure are owed and operated by public bodies, or indirectly via force mature provisions in concession or public-private partnership contractual arrangements.

8.3.3 Damages to rolling stock

Rolling stock may be damaged by weather extremes directly or accidents inflicted by them. In road transport accident rates may increase under all types of weather, including winter conditions, heat, rain and storm, while direct vehicle damages are mainly due to heavy precipitation with flooding, landslides, avalanches or storms. In scheduled transport modes, which are characterised by commonly high safety standards, direct weather-inflicted damages dominate the picture.

As for infrastructures the severity of damage and the age of the affected vehicles needs to be taken into consideration in order to isolate the weather inflicted economic loss from that already occurred by the vehicles' depreciation. In case no other information is provided, we can assume 50% of the damaged vehicles' purchase value is due to weather, implying total losses in all cases.

For passenger cars and trucks insurance statistics provide average losses of €5000 and €18000 Euros for fatal crashes (see table below).

Table 8-6: Vehicle damage cost values

Type of accident	**P. car**	**Lorry**	**Average**
Direct damage by weather event	5000	18000	
slight accident, only material damage	€2'811	€12'660	
Severe accident with casualties	€5*621	€13*330	€7'169

Source: WEATHER Deliverable 2

In urban public transport, rail, and shipping damage costs are very specific. E.g. aircraft purchase costs vary between one million euros for small business units used in general aviation to above €300 million for intercontinental jets (B747, A340). Due to the low probability of crashes in scheduled transport modes average damage figures are not provided here.

8.3.4 System operating and servicing costs

In the event of severe weather system operators may face increasing costs due to the delay of services, the non-availability of rolling stock or the engagement of crises management forces. In terms of delays these costs may be quantified via the personnel and the capital costs of operators. Specific studies in air transport arrive at costs around €72 per passenger-hour or €5000 per aircraft-hour. In commercial road goods transport the respective values is at around one euro per truck-hour. Similar costs need to be considered for increased travel distances for detouring closed or dangerous areas.

8.3.5 User time costs

Transport users include drivers and passengers of cars, passengers of public transport and goods shipped. In first order they are affected by variations in travel time, travel costs and transport safety. Besides in individual transport, travel costs are included in the running costs of transport companies and thus must not be computed twice.

Travel time values: User time costs are computed by applying a standard value of travel time to the time spent by users in traffic. Commonly this value of time is differentiated by travel purpose and mode. For reasons of simplicity we propose a single value per mode according to the IMPACT handbook on external costs.

$C_{TIME} = VOT / v * OccR$

- C_{TIME} : User time costs in € per vehicle-km
- VOT: Value of travel time in € per hour and passenger or ton
- v: Travel speed (in kph)
- OccR: vehicle occupancy rate (passengers or tons)

Table 8-7: Recommended values of Time in passenger and freight transport (EU-25 average)

Sector/purpose	Unit	Car/HGV	Rail	Bus/Coach	Air
Passenger transport					
Work (business)	€2002/passenger, hour	23.82		19.11	32.80
Commuting, short distance		8.48		6.10	*
Commuting, long distance		10.89		7.83	16.25
Other, short distance		7.11		5.11	*
Other, long distance		9.13		6.56	13.62
Freight transport	€2002/ton, hour	2.98	1.22	/	n. a.

* Values presented by HEATCO (70% of long distance values) have been removed, because short distance air transport (below 50 km) does not happen.

Source: HEATCO, Deliverable 5: Tables 0-6 to 0-8.

Remark: The VOT in commercial transport contains all components of a full cost calculation including vehicle provision, personnel, fuel and second-order effects on customers.

Source: IMPACT

An adaptation to European countries by PPP-adjusted income per capital is recommended. Respective statistics are available at Eurostat and will be provided in the annex to the GAF.

Besides the instant delay costs in the emergency case, the unavailability period, i.e. the time during with infrastructures or services are not available due to construction or other servicing works, is to be discussed. For road transport these can be assumed between several hours for non-destructive evens like flooding, storms or hail to several weeks for minor repairs up to six months for major repair and renewal activities. In rail transport the closure phases in case of infrastructure damages are expected to be longer.

A third component for computing user costs are detour lengths in terms of the non-availability of infrastructures. These depend very much on local conditions, i.e. network densities, and on the specific origin-destination relation.

8.3.6 User safety costs

The economic costs of traffic accidents compose of

The statistical value of life, i.e. the “value of safety per se” which society attaches to an avoided death casualty or severe injury and direct and indirect economic effects on production, the insurance sector or the health care system.

With around 1.5 Mio. € per avoided death casualty the value of statistical life (VSL) plays by far the bigger role. Other costs range only around 10% of the VSL. On the basis of European crash rates IMPACT D1 provides accident cost rates by road category and for other modes.

As for other cost categories, not all implications of a traffic accident under severe weather conditions can be attributed to these conditions alone. In particular in case of light accidents on the road a combination of drivers’ misbehaviour and the weather influences can be suspected. This mix of causes in particular holds for air traffic. The figures given in the following table illustrate the assumptions taken for road transport.

Table 8-8: Parameters for safety costs in road transport

Accident category	**Value of life**	**Allocation to weather**	**Final value used**
slight injury	16300	100%	16'300
Severe injury	211900	70%	148'330
Fatality	1630000	30%	489'000

Source: Fraunhofer-ISI, WEATHER Deliverable 2, Annex 3

In scheduled modes there is a trade-off between user time and safety costs. In particular in rail and urban public transport safety is maximised by accepting lower travel speeds and less infrastructure capacity. Both, time and safety costs, are carried by the final users.

9 Review and generalisation of European cost estimates 2000-2010

9.1 Review of present damage costs

9.1.1 Total costs 2000 to 2010

The analysis across all modes, weather categories and European regions as described in the previous section leads to overall annual costs of €2.5 billion. Considering that this value constitutes an annual average, including mild years with only few extreme weather situations, this number is significant. When interpreting it we should recall that these costs do not express the full costs of all winter or heat periods, but of their extension beyond the 90 percentile snow and ice or heat period. Moreover, we must determine a certain level of under-reporting, as our analyses are incomplete, not encompassing all modes and weather categories. Table 9-1 presents the results found by the modal analyses by weather category and mode and, as far as possible, by cost category per year during the period 2000 to 2010.

Table 9-1: Generalisation of the costs of extreme weather events for the European transport system (annual data in € m)

Extreme weather event		Infrastructure Assets (m€)	Infrastructure Operations (m€)	Vehicle Assets (m€)	Vehicle Operations (m€)	User Time (m€)	Health & Life (m€)	Total (m€)
Storm	Road (1)	76,10	22,60	5,10	1,40	63,00	5,90	174,10
	Rail (2)	0,07		12,05		6,28		18,39
	Maritime (5)			2,10	17,98			20,08
	Intermodal (6) (7)	0,53					0,72	1,25
	Air (8)			53,80	34,30	38,40	28,30	154,80
Winter	Road (1)	248,80	126,30	81,30	12,50	125,50	164,90	759,30
	Rail (2) (3)	0,04		3,38		1,60		5,02
	Intermodal (6) (7)	0,21					0,21	0,42
	Air (8)		11,20	12,00	57,70	64,60	1,90	147,40
Flood	Road (1)	630,10	21,90	24,40	30,01	93,70	21,50	821,61
	IWW (4)					4,87		4,87
	Rail (2)	103,66		111,60		67,30		282,55
	Air (8)			3,20	26,50	29,60	0,20	59,50
	Intermodal (6) (7)	0,32					0,10	0,42
Heat&drought	Road (1)						46,90	46,90
Total		1059,82	182,00	308,92	180,39	494,84	270,63	2496,60

Source: WEATH'ER Deliverable 2 (Enei et al. (2011)

Remarks:

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

Not surprisingly, the vast majority of costs are calculated for road transport. But rail, including intermodal transport (13 %), and aviation (19 %) also account for a considerable share in total costs related to weather extremes with respect to the past decade (Table 9-1). No generalisation of the case study related results for the waterway sector has been carried out for Europe so far. But we can also expect considerable costs here.

When comparing the modal situation in a more qualitative way, the analyses indicate that much of the infrastructure-related damage is subject to proper maintenance. Thus there is a trade-off between damage costs and increased network servicing activities. In the case of network and fleet operations and consequent impacts on user delays and safety, damage costs in many cases are driven by the preparedness of the transport sector. This is particularly evident in the case of winter impacts in western and central Europe. In comparison to the winter-proof Scandinavian countries, the UK, France, the Benelux countries and Germany were hit extremely hard by the conditions of the past winter seasons, which occurred after some decades of rather mild winters.

9.1.2 Average costs 2000 – 2010

As total figures are difficult to interpret in the following tables they are broken down per performance unit for road, rail and air transport. Performance units are defined as passenger kilometre equivalents, which compute as passenger kilometres (pkm) plus ton kilometres (tkm) times a mode specific ton-passenger equivalency factor. Considering the average occupancy (passengers) and load (tons) per vehicle and the vehicle-specific capacity use this factor is set to 0.3 for road and rail, and to 1.0 for air transport. The respective transport volume figures have been retrieved from EC (2011).

Table 9-2 shows the results for road transport, including passenger car, bus, coach, urban public transport, light- and heavy goods vehicle travel. The shading of the cells indicates the level of costs per pkm-equivalent. These are highest for infrastructure damages due to rain and floods in Scandinavia, the Alpine countries and France. Further significant hot spots are winter consequences to infrastructure operations and rain and winter impacts for user time losses. Surprisingly, safety aspects to not play a significant role for road transport.

Table 9-2: Average costs road transport 2010 (€/1000 pkm)

Sector element	**Weather extreme**	**Average costs by climate region (€/1000 pkm-eq.**								**TOTAL**
		AL	**BI**	**EA**	**FR**	**IP**	**MD**	**ME**	**SC**	**EUR29**
Infra assets	Ice&snow	0.08	0.02	0.15	0.03	0.00	0.00	0.03	0.19	0.04
	Rain&flood	0.22	0.07	0.06	0.16	0.10	0.05	0.05	0.41	0.11
	Storm	0.03	0.01	0.08	0.01	0.01	0.00		0.01	0.01
	Heat&drought									
Infra operation	Ice&snow	0.27	0.01	0.02	0.05	0.01	0.01	0.00		0.02
	Rain&flood	0.01	0.00	0.01		0.01	0.00	0.00	0.01	0.00
	Storm		0.00	0.02	0.00	0.00		0.00	0.00	0.00
	Heat&drought									
Fleet operation	Ice&snow	0.01		0.01	0.01	0.00	0.01	0.02	0.05	0.01
	Rain&flood	0.05	0.00	0.00		0.00	0.00	0.00	0.00	0.00
	Storm			0.00	0.00		0.00	0.00		0.00
	Heat&drought									
Fleet assets	Ice&snow	0.01	0.00	0.00				0.00	0.00	0.00
	Rain&flood	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.02	0.01
	Storm			0.00						0.00
	Heat&drought									
User time	Ice&snow	0.05	0.02	0.04	0.00		0.00	0.04	0.03	0.02
	Rain&flood	0.15	0.01	0.02	0.00	0.02	0.00	0.02	0.01	0.02
	Storm		0.00	0.05	0.01	0.00		0.02	0.01	0.01
	Heat&drought									
User safety	Ice&snow	0.06	0.02	0.06	0.04		0.00	0.06		0.03
	Rain&flood	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
	Storm			0.00	0.00					0.00
	Heat&drought									
TOTAL		0.95	0.17	0.54	0.32	0.16	0.10	0.26	0.74	**0.29**

Data source: WEATHER D2 and EC (2011)

Rail transport shows a higher number of hot spots than does road (Table 9-3). These concern infrastructure damages due to rain and floods, concentrating in Mid and Eastern Europe. These geographical differences to road transport with its clear indication of highest damages in Alpine and Scandinavian countries, appear surprising. Further significant average cost values are found for fleet operating and user time costs. With 0.57 € / 1000 pkm rail damage costs are found to be twice as high as the costs entailed by weather extremes in road travel. This is the case even though winter impacts as one of the most important problems for the railways, have only considered partly in the assessment carried out in WEATHER D2.

Table 9-3: Average costs rail transport 2010 (€/1000 pkm)

Sector element	**Weather extreme**	**Average costs by climate region (€/1000 pkm-eq.**								**TOTAL**
		AL	**BI**	**EA**	**FR**	**IP**	**MD**	**ME**	**SC**	**EUR29**
Infra assets	Ice&snow	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Rain&flood	0.27	0.17	0.76	0.05	0.02	0.41	0.13	0.06	0.19
	Storm	0.00	0.00	0.00	0.00			0.00	0.00	0.00
	Heat&drought									
Infra operation	Ice&snow									
	Rain&flood									
	Storm									
	Heat&drought									
Fleet operation	Ice&snow	0.02	0.00	0.01	0.01	0.00	0.00	0.01	0.01	0.01
	Rain&flood	0.35	0.17	0.74	0.04	0.05	0.30	0.14	0.27	0.21
	Storm	0.06	0.01	0.08	0.01			0.03	0.03	0.02
	Heat&drought									
Fleet assets	Ice&snow									
	Rain&flood									
	Storm									
	Heat&drought									
User time	Ice&snow	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Rain&flood	0.15	0.16	0.13	0.01	0.11	0.08	0.03	0.64	0.12
	Storm	0.03	0.01	0.04	0.00			0.01	0.02	0.01
	Heat&drought									
User safety	Ice&snow									
	Rain&flood									
	Storm									
	Heat&drought									
TOTAL		0.89	0.52	1.75	0.12	0.18	0.80	0.36	1.03	**0.57**

Data source: WEATHER D2 and EC (2011)

The distribution of hot spots found in aviation (Table 9-4) appears even more expressed as in the case of rail. The average value of 0.66 €/1000 pkm-equivalents are slightly above the rail value, but given the huge uncertainties of the cost estimation and value transfer procedures applied to estimate these figures, these numerical differences should not be over-interpreted. Rail and air thus seem to be similarly affected by weather extremes, but the structure differs. For aviation safety aspects in the form of vehicle damages seem to play a significant role, while this is not the case for road and rail. But, as for rail, fleet operation costs seem to be highly sensitive to adverse weather conditions.

Table 9-4: Average costs air transport 2010 (€/1000 pkm)

Sector element	**Weather extreme**	**Average costs by climate region (€/1000 pkm-eq.**								**TOTAL**
		AL	**BI**	**EA**	**FR**	**IP**	**MD**	**ME**	**SC**	**EUR29**
Infra assets	Ice&snow									
	Rain&flood									
	Storm									
	Heat&drought									
Infra operation	Ice&snow	0.03	0.01	0.04	0.03		0.00	0.04	0.04	0.02
	Rain&flood									
	Storm									
	Heat&drought									
Fleet operation	Ice&snow	0.17	0.07	0.21	0.13	0.00	0.01	0.19	0.19	0.11
	Rain&flood	0.05	0.05	0.05	0.05	0.03	0.04	0.06	0.06	0.05
	Storm	0.04	0.09	0.05	0.07	0.05	0.03	0.07	0.07	0.06
	Heat&drought									
Fleet assets	Ice&snow	0.02	0.01	0.03	0.11	0.01		0.00	0.05	0.02
	Rain&flood		0.00		0.05				0.00	0.01
	Storm	0.02	0.03	0.02	0.37	0.20	0.14	0.00	0.01	0.10
	Heat&drought									
User time	Ice&snow	0.19	0.08	0.24	0.15	0.00	0.02	0.21	0.21	0.12
	Rain&flood	0.06	0.06	0.05	0.05	0.03	0.04	0.07	0.06	0.05
	Storm	0.05	0.10	0.05	0.08	0.06	0.03	0.08	0.08	0.07
	Heat&drought									
User safety	Ice&snow	0.03	0.00	0.00	0.00	0.00		0.00	0.01	0.00
	Rain&flood				0.00					0.00
	Storm	0.06			0.10	0.01	0.25	0.02	0.01	0.05
	Heat&drought									
TOTAL		0.73	0.51	0.75	1.20	0.39	0.55	0.74	0.77	**0.66**

Data source: WEATHER D2 and EC (2011)

Due to the low number of cases considered a generalisation of inland waterway and maritime shipping costs is not possible with data from Deliverable 2. Here, a cooperation with the parallel project ECCONET should bring about more detailed information.

9.2 Forecasts of damage cost indicators

9.2.1 Forecasting total damage costs to 2050

Based on these results of the economic transport-sector assessment framework and its application in WEATHER Deliverable 2 (Enei et al., 2011), forecasts of vulnerability measures are generated using EWENT Project forecasts of extremes (FMI, 2011) in conjunction with transport sector projections from the GHG-TransPoRD and iT-REN-2030 projects (Schade et al., 2011). These indicators are provided by mode and region and are linked by assumptions on average cost elasticities with respect to the frequency of extremes and the density of transport demand.

For projecting the intensity of weather extremes in the coming four decades results derived from six RCM models, run done by the ENSEMBLES project and described by the EWENT project and used. The values provided Table 9-5 denote the number of days incresing or decreasing per type and intensity of extreme.

Forecasts in the same format have been derived for the period 2041 – 2071. These values have been related to the current intensity and frequency of weather extremes derived from the ECA&D Database (ECA&D 2012) to arrive at relative changes of frequencies of weather extremes.

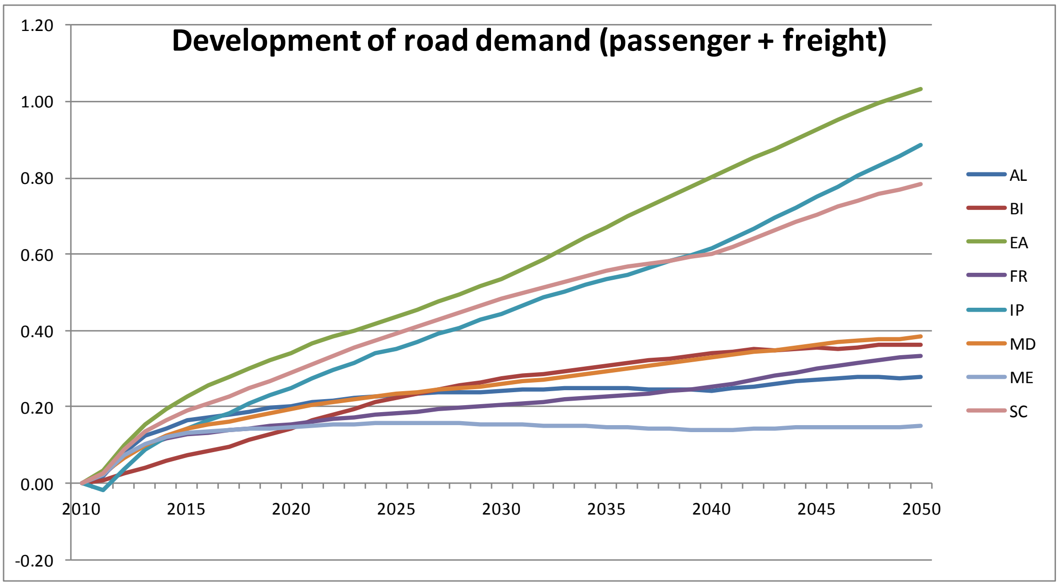
Table 9-5: Frequency (number of days/year) from 1971-2000 to 2011-2040;

Category	AL	BI	EA	FR	IP	MD	ME	SC
Absolute changes in Frequencies 2010 to 2050								
Snow&Ice								
Tmax <0°C	-10	-5.5	-8	-5	-1	-3	-8	-12
Tmax <-7°C	-1	-0.5	-2	-1	0	0	-2	-4
Tmax <-20°C	0	0	-0.2	0	0	0	0	-0.3
Snow >1 cm	-5	-2	-2	-1	-0.1	-1	-2	-5
Snow >10 cm	0	0	-0.1	-0.5	0	-0.1	0	-0.2
Snow >20 cm	0	0	0	0	0	0	0.2	0
Rain&Flood								
>30 mm	2	0.5	0.5	1	-0.5	0	2.5	2.5
>100 mm	0.1	0.1	0	0.1	0.1	0.1	0	0.1
> 150 mm	0.1	0.1	0	0.1	0.1	0.1	0.1	0.1
Storm								
>17 m/s	0	0.3	-0.2	0.18	0.5	0.1	0.4	0.3
>25 m/s	0.5	0.1	0	-0.2	0	0.1	0	0
>35 m/s	0.1	0	0	0	0	0	0	0.1
Heat								
Tmin >25°C	5	1	10	8	15	15	5	0.3
Tmin >32°C	1	0	5	1	6	9	1	0
Realtive changes in Frequencies 2010 to 2050								
Ice&Snow	-12%	-20%	-4%	-20%	-50%	-50%	-12%	-5%
Rain&Floods	44%	45%	8%	194%	-48%	0%	39%	33%
Storms	5%	7%	-2%	0%	13%	20%	3%	2%
Heat&Drought	72%	100%	104%	400%	39%	15%	167%	30%

Source ARPA-ER and Fraunhofer-ISI based on EWENT results

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. The values have been generated by the European System Dynamics Model ASTRA developed and operated by Fraunhofer-ISI. For indication, the development of road transport volumes by climate region related to 2010 levels is presented by Figure 9-1. 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.

Figure 9-1: Road transport volumes by climate regions 2010 to 2050



Source: Fraunhofer-ISI

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. As appropriate statistical data was not available, the following assumptions were made:

1. Winter impacts prove to cause massive costs only at their onset. This implies that a simple prolongation of winter periods will cause under-proportional economic costs as people and transport professionals get used to the conditions. Thus we use an elasticity of 0.5.

2. Rain, flood and storm events are, in particular floods and storms, commonly singular events for particular regions. An increase of rain and wind days thus may in many cases imply to spread the occurrence of floods and storms across the country. Accommodation effects are thus less likely. We thus use an elasticity of 0.8.
3. The cost relevance of heat periods is the contrary to winter impacts. In particular long heat periods start causing costs to operators and users. Thus we here use an elasticity of 1.5.

Table 9-6 presents the summary of the total costs forecast 2010 to 2050. Most expressed will be the additional costs in rail transport, followed by air and road. The most suffering user groups are, against intuition, not infrastructure operators but train operators and passengers. In total they face nearly double the damage costs they bear in 2010.

Table 9-6: Summary of forecast results for total transport sector costs due to weather extremes 2010 to 2050

Sector	AL	BI	EA	FR	IP	MD	ME	SC	EUR29
Road	-6%	5%	10%	72%	-32%	-18%	-24%	22%	7%
Infrastructure	*-18%*	*12%*	*-1%*	*95%*	*-36%*	*-11%*	*-9%*	*22%*	*16%*
Services	*28%*	*41%*	*34%*	*9%*	*-30%*	*-28%*	*-36%*	*14%*	*-4%*
Users	*10%*	*-18%*	*26%*	*-8%*	*-8%*	*-34%*	*-32%*	*22%*	*-10%*
Rail	72%	151%	55%	187%	-29%	25%	55%	101%	72%
Infrastructure	*37%*	*62%*	*13%*	*171%*	*-50%*	*-2%*	*29%*	*32%*	*27%*
Services	*88%*	*193%*	*89%*	*213%*	*-27%*	*53%*	*71%*	*101%*	*94%*
Users	*86%*	*197%*	*86%*	*133%*	*-26%*	*53%*	*63%*	*108%*	*96%*
Aviation	23%	50%	12%	56%	52%	67%	16%	15%	38%
Infrastructure	*-36%*	*-41%*	*-29%*		*0%*	*-64%*	*-38%*	*-34%*	*-38%*
Services	*24%*	*53%*	*15%*	*58%*	*57%*	*66%*	*18%*	*16%*	*42%*
Users	*27%*	*53%*	*14%*	*60%*	*38%*	*70%*	*19%*	*19%*	*39%*

Source: Fraunhofer-ISI

From the meteorological side the most relevant cost driver are rain and floods. The regions with the highest cost increase are France for road transport and the British Islands for rail. Aviation will face cost increases more evenly spread accross the Community.

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 condition. 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.

The approach applied for this forecasting exercise is rather simplistic and might be questioned for a number of reasons. The database of present weather extremes, which has been established around the idea of additional burdens above average weather variability, is not in all respects compatible with the forecast indicators provided by the EWENT project and we had to replace uncertainty ranges by average values. Second, the cost elasticities applied are based on expert judgement rather than on econometric analyses. Finally, transport activity and infrastructure asset forecast highly depend on economic prosperity both in Europe and worldwide, on population developments and migration flows. But nevertheless the model results demonstrate were the bigger issues of weather inflicted transportation cost increases could be located.

9.2.2 Average damage cost indicators by 2050

Average cost increases are primarily determined by the increase of weather intensities in the particular regions and the cost elasticities applied to weather category and mode. By eliminating the transport growth element from the relative cost changes we receive the impact per transport unit. The results in Table 9-7 indicate that this change of perspective does not alter the hot spots identified above to a large extent. Still, rail operations in France and the UK appear to be most vulnerable in future terms to changes in weather and climate patterns.

Table 9-7: Summary of forecast results for average transport sector costs due to weather extremes 2010 to 2050

Sector	**AL**	**BI**	**EA**	**FR**	**IP**	**MD**	**ME**	**SC**	**EUR29**
Road	-5%	3%	5%	54%	-17%	-13%	-21%	12%	5%
Infrastructure	-14%	9%	-1%	71%	-19%	-8%	-7%	13%	11%
Services	22%	30%	17%	7%	-16%	-20%	-31%	8%	-3%
Users	7%	-13%	13%	-6%	-4%	-24%	-28%	12%	-7%
Rail	41%	58%	25%	116%	-16%	13%	33%	52%	39%
Infrastructure	21%	24%	6%	106%	-28%	-1%	18%	16%	15%
Services	50%	75%	40%	132%	-15%	28%	43%	52%	50%
Users	49%	76%	39%	83%	-14%	28%	38%	55%	52%
Aviation	12%	26%	6%	31%	28%	36%	9%	8%	20%
Infrastructure	-19%	-21%	-15%	0%	0%	-34%	-21%	-19%	-20%
Services	13%	27%	8%	31%	30%	35%	10%	9%	22%
Users	14%	27%	7%	33%	20%	37%	11%	10%	21%

Source: Fraunhofer-ISI

Comparing total to average cost developments projected for 2050 reveals that roughly 50 % of total cost increases is due to rises in transport volumes. This effect is rather unique across all modes.

9.2.3 Look beyond 2050

Current climate models run to the year 2100. As indicated in Part A of this report, this is when the big changes in weather patterns are expected to take place. But for such a distance time horizon forecasts of transport activities, assets and technologies gets more than vague. We can only anticipate that the costs attached to storm, flood and heat events will amplify and that in this case even in the European transport sector cross critical thresholds.

For this period the impacts of sea level rise and the thawing of Scandinavia's permafrost soil are matters of utmost importance. Here a reconfiguration of the infrastructure locations, in particular port structures and Nordic roads and rail tracks, will move on the political agenda. The efforts taken by the Netherlands to protect urban and port areas from seawater serve as a first indicator how expensive corresponding response strategies in the long term may get.

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PART IV: ACHIEVEMENTS AGAINST OBJECTIVES

The technical annex to the WEATHER project formulates three objectives for Work Package 1: Weather Trends and Economy-Wide Impacts. In the following these objectives and the way they have been addressed by the present report are briefly reviewed.

Objective 1: Contribute to better understand the drivers and the dynamics of extreme weather events by zooming into a selected focus region

In order to achieve the first objective, the climate change projections of Regional Climate Models (RCMs) produced by the Ensembles project, over Europe, have been analysed. The patterns of changes of mean and extreme temperature and precipitation over Europe have been presented in the deliverables such as to describe the dynamics of changes over two periods of time: 2021-2050 and 2071-2099, with respect to 1961-1990. The results are presented at seasonal level for mean and extreme events, extreme defined based on percentile of the distribution (10th and 90th). The emission scenario take into account is the IPCC A1B scenario.

Objective 2: Provide scenarios of the severity and frequency of extreme weather events for the WEATHER case studies

As concerns the second objective, climate change scenarios of temperature and precipitation over N-Italy, case study area, have been produced through a statistical downscaling model implemented at ARPA-SIMC. The scenarios are produced at local scale (stations) and the results are presented in the deliverables as probabilistic projections over N-Italy(PDFs, mean over the stations).The projections have been constructed at seasonal level and for to the same periods as in the first objective. Climate change scenarios of extreme events such as frost days and ice days have been also constructed and presented in the report. In both cases, European level and local scale, a multi-model approach has been taken into account, such as to try to reduce the uncertainties in the projections.

Objective 3: Develop a dynamic model explaining the causal relations between the severity and frequency of extreme weather events, the functionality of transport systems and related sectors, economic performance and social welfare

The CIRED contribution relating to objective 3 is based around the development of the ARIO-T model and its use for a modeling and scenario exercise. The model has been developed fully addressing the specificity of transport system to the best of our collective knowledge in the WEATHER project.

The modeling exercise is a study of the causality put forward in the objective even though some aspects of it remain exogenous to the model. Indeed, ARIO-T model has as input extreme weather events and as output value added losses, or welfare loss. Thus, the model explicitly focuses for each event on linking extreme weather event and transport disruption to economy wide losses.

However, the scenario analysis and focus on multiple repetitive events with different severity levels and changing frequency is only done through historical statistical analysis, and using "what if" scenarios. This is a limit of the current exercise, which reflects also the current state of knowledge on this issue and the range of certainty of the results proposed this kind of exercise can aim at.

Additional output: Formulate a General Assessment Framework for transport sector impacts of severe weather events

The Technical Annex to Work Package 1 in addition formulates the task to provide guidance for the analytical work packages how and in what detail to assess the impacts on transport systems caused by weather extremes. Within the project this task was fulfilled by drafting and circulating a General Assessment Framework (GAF) among the project partners. Although the related work has been already published with Deliverable 2, the corresponding guidelines and findings have been summarised in this report.

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