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</table>
Contents

0  Basic concepts and delineations .......................................................... 6
  0.1  Weather, climate and climate change .................................................. 6
  0.2  Impacts and valuation ........................................................................ 6
  0.3  Definitions of the sectors relevant to ToPDAd .................................... 8
    0.3.1  Energy sector ................................................................................ 8
    0.3.2  Transport sector .......................................................................... 9
    0.3.3  Tourism sector ............................................................................ 10
  0.4  Relevant projects for ToPDAd .............................................................. 12

1  Climate scenarios, downscaling, weather monitoring and services in the EU .......... 15
  1.1  Representative Concentration Path (RCP) and downscaling for climate zones .......... 15
    1.1.1  Major GCM Experiments ............................................................ 15
    1.1.2  ClimGen: Climate scenario production via pattern scaling ................. 16
    1.1.3  Major RCM Experiments ............................................................. 17
    1.1.4  Challenges/options relevant to the ToPDAd project .......................... 18
  1.2  Weather and climate monitoring systems and service development .................. 19
    1.2.1  Introduction .................................................................................. 20
    1.2.2  The supply structure of weather and climate services ...................... 21
    1.2.3  Prospects and needs with respect to weather and climate services .... 23

2  Adaptation challenges for the Energy sector ................................................. 25
  2.1  Strategic challenges for avoiding major disturbances in the Energy sector ............ 25
    2.1.1  Introduction .................................................................................. 25
    2.1.2  Significance of climate change and weather variability for energy systems ... 26
    2.1.3  Foreseen major relevant changes in supply and use technology .......... 29
    2.1.4  Foreseen major relevant changes in societal factors .......................... 29
  2.2  Climate Zones of Europe relevant for the Energy sector .......................... 30
    2.2.1  Zones that have outstanding significance for the sector .................... 30
    2.2.2  Changes in weather phenomena with hazard implications for the Energy sector ... 30
  2.3  Energy sector level adaptation challenges in climatic zones in the EU ................ 31
    2.3.1  The most vulnerable systems of the Energy sector for specific climate hazards ... 31
    2.3.2  The most important impacts on the Energy sector across climate zones .... 33
    2.3.3  Decision criteria that drive adaptation needs in the Energy sector ......... 33
    2.3.4  Uncertainties that need to be taken into account for sound adaptation decision making ... 34
  2.4  Long-term adaptation challenges of the Energy sector in the EU .................... 35
    2.4.1  Long-term vulnerability of the Energy sector ................................... 35
    2.4.2  Long-term impacts across climate zones ........................................ 36
    2.4.3  Decision criteria that drive the adaptation needs in the energy sector in the long-term ... 36
    2.4.4  Uncertainties that need to be taken into account .............................. 36

3  Adaptation challenges for the Transport sector .............................................. 37
  3.1  Strategic challenges for avoiding major disturbances in the Transport sector ......... 37
  3.2  Climate regions of Europe relevant for the transport sector ............................ 39
  3.3  Transport sector level adaptation challenges in climatic zones in the EU ............ 42
    3.3.1  The impacts of climate change on Tourism ....................................... 42
    3.3.2  Adaptation measures for the transport sector .................................... 45

4  Adaptation challenges for the Tourism sector ................................................ 49
4.1 Key strategic challenges for avoiding major disturbances in the Tourism sector ...........................................49
  4.1.1 Climate change induced changes in the demand of tourism activities and destinations ........................49
  4.1.2 Climate change induced changes in the supply of tourism services .......................................................51
  4.1.3 Main strategic challenges .......................................................................................................................51
4.2 Climate Zones of Europe relevant for the Tourism sector .............................................................................52
  4.2.1 Zones that have outstanding significance for Tourism ........................................................................52
  4.2.2 Changes in weather phenomena with allegedly hazard implications for Tourism ............................55
4.3 Tourism sector level adaptation challenges in climatic zones in the EU .....................................................58
  4.3.1 The most vulnerable systems of the Tourism sector for specific climate hazards ..................................58
  4.3.2 Impacts of specific importance in the climate zones .............................................................................59
  4.3.3 Decision criteria that drive the adaptation needs within the Tourism sector .........................................62
  4.3.4 Uncertainties that need to be taken into account for sound adaptation ..................................................62

5 Integrated assessment and policy-development challenges ........................................................................63
  5.1 Economic impact assessment ....................................................................................................................63
  5.2 Environmental impact assessment ............................................................................................................64
  5.3 Social/health impact assessment .................................................................................................................64
  5.4 Policy development challenges at different levels ....................................................................................65

6 References ..................................................................................................................................................67

7 Appendix ..................................................................................................................................................76
  7.1 Brief description of European meteorological organisations ....................................................................76
List of figures

Figure 1: CMIP3 multi-model mean global temperature change (compared to simulated 1961-1990 mean) in three key SRES emission profiles: B1 (blue); A1B (green); A2 (red) (IPCC 2007b). ........................................15
Figure 2: The European (black) and African (red) ENSEMBLE sub-domains (domains for other non-European RCM projects are also shown). After Jones and Giorgi (2012). ..........................................18
Figure 3: Principal stages in the provision of meteorological services and the related generation of value added by stage; VA = value added (by service stage 1, 2, 3). ..................................................22
Figure 4: Energy and climate zones in the EU. ..................................................................................................30
Figure 5: The European climate regions based on the frequency and probability analysis of the selected climatic extremes (Molarius et al.2012) ..................................................................................40
Figure 6: Nights spent in hotels and campsites, by NUTS 2 regions (Eurostat). ...........................................53
Figure 7: Share of winter overnight stays, Ø 2001-2011, in % total overnight stays in the tourism years 2001-2011 (Eurostat) ..............................................................................................................54
Figure 8: The average number of months with very good conditions for non-winter tourism, on the left the situation in the 1970s and on the right in the 2080s, according to RCAO -model and A2 -scenario (Amelung et al. 2009). .................................................................................................56
Figure 9: Mean amount of snow-cover days (1.8°C increase in the temperature) at 1500 meters in the Alps (SEATM 2004). .........................................................................................................................57
Figure 10: 11-model mean changes, March mean snow water equivalent, from the left 2010-2039, 2040-2069 and 2070-2099 (Räisänen & Eklund 2011) .........................................................................................58

List of tables

Table 1: Damage classification scheme (from Perrels et al. 2010 (table 5.1) – adapted from Messner 2007). ..............................................................................................................................................7
Table 2: Summary characteristics of the IPCC Representative Concentration Pathways used to force the CMIP5 climate change experiments (after Moss et al. 2010). ..........................................................16
Table 3. Components of the power system at greatest risk of climate change over the next 50-100 years and relative likelihood of different climate-related damages to the power system. Adapted from (OFGEM 2011). .........................................................................................................................27
Table 4: Overview of climate changes impacts on transport infrastructure (EEA 2012) .................................................39
Table 5: Summary of predicted changes in weather phenomena from 2011 to 2040 and 2040 to 2070 (Mühlhausen et al. 2011). .........................................................................................................................41
Table 6: Summary of predicted impacts on transport from 2011 to 2040 and 2040 to 2070 p.101 (Mühlhausen et al. 2011). .................................................................................................................................42
Table 7: Scenario description: yearly reduction (%) in maritime imports/exports for the different countries (Delhaye et al. 2011). .........................................................................................................................44
Table 8: Effect on GDP (%) for each winter scenario and each country (Delhaye et al. 2011). ..........................44
Table 9: Mitigation strategies for weather phenomena for various transport modes. (Nokkala and Leviääkangas 2012). .................................................................................................................................45
Table 10: Strategic options for land transport network emphasis in resilience enhancement p.104 (Leviääkangas et al. 2011). ............................................................................................................................45
Table 11: Adaptation cost estimates for the 3 scenarios and their average at national level period 2040-2070 (Nemry and Demirel 2012). .................................................................................................................47
Table 12: Impacts of climate change and tourism adaptation challenges (based on Becken and Hay 2007). .........................................................................................................................................................58
Table 13: Impacts of climate change and most affected regions of Europe (based on Becken and Hay 2007). .........................................................................................................................................................59
0 Basic concepts and delineations

For the mapping of challenges in Task 1.1, at first some key concepts are defined. Some concepts may have different definitions in different circumstances; the idea of this chapter is to provide concise definitions as understood and used in ToPDAd project. This deliverable specifies the State-of-the-Art for the project.

0.1 Weather, climate and climate change

Weather

Weather is the momentary state of the atmosphere, to the degree that it is hot or cold, wet or dry, calm or stormy, clear or cloudy. Weather generally refers to day-to-day temperature and precipitation activity, whereas climate is the term for the average atmospheric conditions over longer periods of time. Weather forecasts – as presented to the public - usually project one to five days ahead. Explorative longer term (multi-week) weather forecasts are produced, but mainly for internal use in weather and climate service production. Seasonal projections are usually expressed in terms of expected deviations from period (monthly) averages and get therefore more climatic than weather characteristics.

Climate and climate change

ToPDAd uses the WMO and IPCC definitions of climate and climate change, which define climate as the statistical description of the mean and variability of relevant quantities of weather parameters over a period of time. Climate change is defined as a change in the state of the climate that can be identified (e.g. by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use.

Climate change projections show that the changes in mean climate will be different in different parts of Europe. The warming is greatest over Eastern Europe in winter and over Western and Southern Europe in summer. Generally for all climate scenarios, mean annual precipitation increases in Northern Europe and decreases further south, whilst the change in seasonal precipitation varies substantially from season to season and across regions in response to changes in large-scale circulation and water vapour loading. Change in mean wind speed is highly sensitive to the differences in large-scale circulation that can result between different global models (Alcamo et. al 2007).

Climate extreme

Climate extreme (extreme weather or climate event) is the occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable (IPCC 2012).

0.2 Impacts and valuation

A quantitative formulation of the risk of climate-change impacts links it to the quantitative definitions of Hazard, Vulnerability and Exposure:

\[ \text{Risk} = \text{Hazard} \times \text{Vulnerability} \times \text{Exposure} \]

Natural hazard is defined as the potential occurrence of a natural physical event, preferably measured with statistical frequency that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources (IPCC 2012).

Vulnerability is defined as the propensity or predisposition to be adversely affected by a changing climate or climate-related disaster. Such predisposition constitutes an internal characteristic of the affected element. This includes the characteristics of a person or a group of people and their situation that influences their capacity to anticipate, cope with, resist and recover from the adverse effects of physical events. Vulnerability highlights the social factors in the constitution of risks, moving away from purely physical explanations of loss and damage (IPCC 2012).
**Exposure** is a quantitative and qualitative estimation of the element at risk studied in a given system and geographic area. Having defined a proper classification of the exposed assets with the purpose of performing vulnerability analysis, exposure analysis starts from the “counting” or quantification of the number of elements within each vulnerability class. In addition, assigning a proper value to each asset (e.g. cost of repairing/rebuilding each type of structure), it allows the estimation of the total potential loss due to an adverse event in a given area, measuring the total amount of ‘values’ at risk, and eventually the quantification of the amount of losses and indirect losses given the damage scenarios (IPCC 2012).

**The coping range** of climate describes the capacity of systems to accommodate variations in climatic conditions, and thus serves as a suitable template for understanding the relationship between changing climate hazards and society (IPCC 2007).

**Coping capacity** is defined as the ability of people, organizations, and systems, using available skills, resources, and opportunities, to address, manage, and overcome adverse conditions (IPCC 2012).

**Resilience** is the ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions (IPCC 2012).

**Recovery capacity** is measured during the recovery phase after a natural hazard, when physical infrastructure has to be rebuilt and can be improved, and behavioural patterns and habits can be contemplated. Capacity to recover is not only dependent on the extent of a physical impact, but also on the extent to which society has been affected, including the ability to resume livelihood activities. This capacity is driven by numerous factors, including mental and physical ability to recover, financial and environmental viability, and political will. Having the capacity to change is a requirement in order to adapt to climate change (IPCC 2012).

Depending on the previously defined characteristics, climate-change impacts cause welfare effects to societies, which are usually measured in monetary terms. Climate change will affect both market and non-market services. The distinction between different types of effects is shown in Table 1. Although the terminology may differ occasionally, effects may be generally classified firstly in direct and indirect effects and secondly in tangible and intangible effects.

**Table 1: Damage classification scheme (from Perrels et al. 2010 (table 5.1) – adapted from Messner 2007).**

<table>
<thead>
<tr>
<th>Tangible</th>
<th>Intangible</th>
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<td><strong>Direct</strong></td>
<td><strong>Indirect (1st and higher order)</strong></td>
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<tr>
<td>- infrastructure (e.g. damage to wind turbines, erosion of roads)</td>
<td>- loss of life</td>
</tr>
<tr>
<td>- traffic accidents and material damage</td>
<td>- loss of ecosystem services*</td>
</tr>
<tr>
<td>- equipment</td>
<td>- health effects*</td>
</tr>
<tr>
<td><strong>Indirect (1st and higher order)</strong></td>
<td><strong>Indirect (1st and higher order)</strong></td>
</tr>
<tr>
<td>- changes in demand structure (e.g. spatial shift of tourism demand, inter-annual shift of energy demand)</td>
<td>- changes in consumer preferences (e.g. familiarity effect in activities)</td>
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<td>- logistic costs</td>
<td>- increased vulnerability of ecosystems of increasingly popular destinations (e.g. Baltic Sea region)</td>
</tr>
<tr>
<td>- emergency costs</td>
<td>- political conflicts (e.g. decisions of holiday seasons, questions of financial aid to those countries most affected)</td>
</tr>
<tr>
<td>- modal shift of transport</td>
<td>- degraded coping capacity to extreme winter weather events (lack of training, equipment etc.)</td>
</tr>
<tr>
<td>- hydro power shortages (owing to drought)</td>
<td></td>
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<tr>
<td>- higher preparedness costs on the coastal region</td>
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<td>- congestion</td>
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*) Both ecosystem services and health effects have tangible and intangible aspects, e.g. medical costs and loss of production hours are tangible, ecosystem services do not usually bear a direct market price but methods have been developed for the valuation (e.g. de Groot et al. 2002).
Direct effects cover all varieties of harm related to the immediate physical action on humans, property and the environment, while indirect effects are effects caused by disruption of physical and economic linkages of the economy, and the costs of actions taken to prevent damage and other losses. These damages are tangible when they can be easily specified in monetary terms, such as damages on assets, loss of production etc. All kind of goods and services which are not traded in a market are far more difficult to assess in monetary terms (e.g. casualties or damages to ecological goods) and the damages they could sustain are therefore indicated as intangible. Indirect intangible damages are most difficult to classify and quantify. They include different inconveniences and changes in societal positions.

**Welfare effects** are in this study understood as monetized changes in the net attributable purchasing power of households in current and/or future periods while accounting for tertiary distribution effects (income transfers and free or subsidized consumption of public goods). So, either a household’s disposable income has changed or for a given disposable income the quality and quantity of the available package of goods and services has changed. Monetized refers in this case to effects that were priced right from the start as well as originally non-priced effects (e.g. air quality) which eventually lead to monetized effects (e.g. extra health care costs). Effects that are hard to monetize and/or concern a potential change (e.g. related to willingness to pay for more safety) are not included in the calculation of welfare effects, but may still have arguably an effect on well-being or life satisfaction.

**Well-being** encompasses more than only the economic condition of an individual or household. Usually it also includes indications for personal health (e.g. healthy life years) and for quality of the (immediate) living environment (e.g. pollution levels and crime exposure risk). Historically seen, development of welfare and well-being at macro level showed high levels of correspondence (positive correlation) for Europe. However, within the last two decades the correspondence has become less stringent, in particular when distinguishing between groups in society (elderly, migrants, high educated, rural areas, etc.) (Layard 2005; Veenhoven 2009). Impacts of climate change and adaptation efforts might contribute to both widening and shrinking disparities between trends in welfare and well-being.

Supposedly in ToPDAAd both effects on welfare and on well-being are contained in the output of the involved models, with many models producing only part-indicators for effects on welfare and well-being. This calls for a careful declaration of what the welfare effect indicators actually represent in each model.

### 0.3 Definitions of the sectors relevant to ToPDAAd

The sectors relevant to ToPDAAd project are the energy sector, transport sector, and tourism sector. These sectors are important for the economy and people in Europe, providing necessary infrastructure and income to support lives and livelihoods. Climate change is expected to cause serious impacts on the sectors, and therefore the need to start adapting to the impacts is urgent. The European Union White Paper ‘Adapting to climate change: Towards a European framework for action’ addresses the effects and adaptation challenges of the ToPDAAd sectors. For the energy sector, climate change will have a direct effect on both the supply and demand of energy, whereas for transport, extreme events will cause huge economic and social impacts especially in densely populated areas. Tourism is likely to be subjected to asymmetric impacts across Europe, e.g. the snow cover in Alpine areas is decreasing and the temperatures in Mediterranean regions are increasing. This chapter provides the definitions of the key sectors, as understood in the ToPDAAd project.

#### 0.3.1 Energy sector

IPCC defines the energy sector to mainly comprise the following:

- **exploration and exploitation** of primary energy sources – in practice this means mining of fossil fuels and of uranium, and peat extraction;
- **conversion of primary energy sources** into more usable energy forms in refineries (from crude oil and natural oils & fats to all types of distillates) and power plants (from fossil fuels, uranium, biomass, waste, geothermal, water(flow), wind, and solar radiation to electricity and/or district heat);
- **transmission and distribution of energy carriers** either via networks/pipelines (electricity, natural gas, district heat, oil products) or in batches via road, rail or water (coal, oil products, wood pallets/chips, peat);
- **final energy use of delivered energy** in stationary and mobile applications (Garg et. al 2006).
The above description lack a concrete categorisation, such as used in the International Standard Industrial Classification of All Economic Activities (ISIC) adopted by the United Nations for classifying economic data of national accounts (United Nations Statistics Division). Economic activities are classified into 21 sections (from A to U) which are divided into divisions (from 01 to 99). The divisions are elaborated into groups (e.g. the division 01 has 7 groups 011-017). The ISIC is typically the basis for any sector categorisation in economic models, including those used in ToPDAd. Note that some sub-categories may be mentioned under more than one of the three sectors studied in ToPDAd.

Two main clusters of economic activities are distinguished. The first cluster concerns sectors which are directly related to the considered sector (energy/transport/tourism) and for which the considered sectors are also very significant or even dominant domain of activity. The second cluster concerns activities which, among others, are indirectly related to the considered sectors and would also be affected if the performance level of the considered sector would change. This also ties with how sector structure and linkages are implemented in the models used in ToPDAd.

Based on the ISIC and The United Kingdom Standard Industrial Classification of Economic Activities (SIC)\(^1\), which goes into more detail in their definitions, the following activities can be viewed as being part of the energy sector:

**Activities directly related to the energy sector:**

- B – 05 (coal mining), 06 (oil and gas exploration), 07210 (uranium mining), 08920 (peat extraction)
- C – 191 (cokes), 192 (oil refining), 161 (saw mills / wood pallets), 10410 (biobased oils)
- D – 35 electricity, gas, steam and air conditioning supply
- H – 492 transport via pipeline

**Activities indirectly related to the energy sector:**

- E – 38 waste collection, treatment and disposal activities; material recovery (e.g. waste as an energy source)
- F – 41 construction of buildings (e.g. power plants); 42 civil engineering (e.g. construction of electric lines etc.); 432 electrical, plumbing and other construction installation activities
- H – 491 transport via railways; 50 water transport

Delineating the energy sector according to the international and UK standard economic sector classifications ISIC and SIC works quite well and largely represents the above division in four main types of activities. There are nevertheless three sources of inaccuracy and confusion, being (1) the use of energy carriers for non-energy purposes (e.g. natural gas for fertilizer), (2) industrial establishments outside the energy sector with significant self-generation (conversion) activity (like in some paper and chemical mills), and (3) micro-generation in Small and Medium-sized Enterprises and the residential sector. The national energy statistics should have no trouble to deal with the first two sources. The third source, micro-generation – a growing phenomenon, may need more attention, not the least in ToPDAd scenario exercises.

### 0.3.2 Transport sector

The transport sector encompasses all activities necessary for the planning, preparation, realization, billing and protection of the movement of people, animals and goods between distinct locations. This definition is meant to include warehousing as well, but usually does not include internal transport within the same plant location. Modes of transport include air, rail, road, sea, inland waterways, cable, pipeline, and space. The field can be divided into infrastructure, vehicles, operations, and supporting services.

Delineating the transport sector according to the ISIC works quite well and largely represents the above division of activities and modes. The most notable exception is transport of people by their own private means of transport (notably cars), which is registered as a consumption activity in economic statistics (in as

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far as not for business purposes). This distinguishes from the above defined transport sector, in which activities are registered as production. On the other hand, in statistics on transport performance (i.e. passenger kilometres per year) commercially produced passenger kilometres and private-car-based passenger kilometres are counted together. A second source of confusion is work trips in passenger cars and vans outside the transport sector (e.g. sales representatives and repair men). According to Southworth and Wigan (2008) this (growing) section of the transport field is not adequately captured in neither economic nor transport statistics.

The term ‘transport’ is often confused with the term ‘traffic’. The latter denotes not a sector but more specifically the flows of vehicles, persons and goods over a certain network or a section thereof per unit of time.

Based on the ISIC, the following activities can be viewed as being part of the transport sector:

**Activities directly related to the transport sector:**

H – 49-53 transportation and storage

**Activities indirectly related to the transport sector:**

C – 29 manufacture of motor vehicles, trailers and semi-trailers; 30 manufacture of other transport equipment

F – 42 civil engineering

G – 45 whole sale and retail trade and repair of motor vehicles and motorcycles

N – 771 renting and leasing of motor vehicles

### 0.3.3 Tourism sector

Demand-side definition of the tourism sector is as follows:

“Any person travelling to a place other than his/her usual environment for less than twelve months and whose main purpose of trip is other than the exercise of an activity remunerated from within the place visited.” (Vanhoove 2011) Hence, tourism is a social, cultural and economic phenomenon which entails the movement of people to countries or places outside their usual environment for personal or business/professional purposes for a definite period of time.

Supply-side definition of the tourism sector is as follows:

From the supply-side (tourism industry), the tourism sector is defined as the cluster of production units in different industries that provide consumption goods and services demanded by visitors. They are called tourism industries because visitor acquisition represents such a significant share of their supply that, in the absence of visitors, their production would cease to exist in meaningful quantity. These sectors are accommodation, food and beverage serving activities, different transport modes, travel agencies and other reservation services, cultural activities, sports and recreational activities, retail trade of country-specific tourism characteristic goods and other country-specific tourism characteristic services (UNWTO 2008).

Some of the ISIC activities (e.g. I561 – restaurant and mobile food service activities) can be viewed as a part of the tourism sector in some locations (e.g. based on the level of tourism activity), while in locations with less tourism they are mainly related to sectors serving local inhabitants.

Based on the ISIC, at least the following economic activities can be viewed as being part of the tourism sector:

**Activities directly related to the tourism sector:**

G – 476 retail sale of cultural and recreation goods in specialized stores

I – 55-56 accommodation and food service activities
N – 771 renting and leasing of motor vehicles; 79 travel agency, tour operator, reservation service and related activities

R – 90 creative, arts and entertainment activities; 91 Libraries, archives, museums and other cultural activities; 92 gambling and betting activities; 93 sports activities and amusement and recreation activities

H - 491 transport via railways, 492 other land transport; 50 water transport; 511 passenger air transport

Q – 86 human health activities

**Activities indirectly related to the tourism sector:**

D - 353 steam and air conditioning supply

E – water supply; sewerage, waste management and remediation activities (if tourism causes significant extra residential spaces on top of local population needs)

F – 410 construction of buildings (e.g. accommodation in tourism destinations); 421 construction of roads and railways

H – 522 support activities for transportation
0.4 Relevant projects for ToPDAd

Apart from individual regional and sectoral assessments of climate change on the basis of specific sector models, ToPDAd will also carry out overall macro-economic impact assessments for the European economy at EU and Member State level. These simulation studies will be implemented by means of the two general top-down models GINFORS (Global Interindustry Forecasting System) and GRACE (Model for Global Responses to Anthropogenic Changes in the Environment). Whereas the dynamic Input-Output model GINFORS will be applied for medium-term projections until 2050, the more aggregated computable equilibrium model GRACE will be used for long-term projections until 2100.

The following references indicate the comprehensive abilities of the GINFORS model as well as the related expert knowledge of the GWS research team.

CECILIA2050 – The FP7 project CECILIA2050 (Choosing Efficient Combinations of Policy Instruments for Low-carbon development and Innovation to Achieve Europe's 2050 climate targets – ongoing project) analyses the performance of existing climate policy instruments and their interaction, and maps pathways for the evolution of the instrument mix in Europe. It describes ways to improve the economic efficiency and environmental effectiveness of the instrument mix, and to address constraints that limit their performance or feasibility. These include public acceptance, availability of finance and the physical infrastructure, but also the administrative and legal framework. Due to the fact that economic instruments are in the focus of the analysis within CECILIA the Institute of Economic Structures Research GWS mbH will be responsible for all the coordination of modelling related quantitative activities and will provide extended scenario based results using the GINFORS (Global Interindustry Forecasting System) model. (http://www.ecologic.eu/7305)

POLFREE – The FP7 project POLFREE (Policy Options for a Resource-Efficient Economy – ongoing project) is a research project about policies to improve resource efficiency. From its new vision for a resource-efficient Europe, the project will propose new policy mixes, business models and mechanisms of global governance through which resource-efficient economies may be promoted. The focus of the work of GWS will be in scenario development and modelling of policy implementation using the GINFORSmodel. (http://www.bartlett.ucl.ac.uk/sustainable/research/project_directory/current_projects/polfree)


econCCadapt – The overarching research objective of the project “Economics of Climate Change Adaptation” (ongoing project) for German Ministry of Education and Research is to provide essential support for the continuing development of the German Strategy for Adaptation to Climate Change and to help to fill the gap regarding high quality economic policy studies and expertise concerning the economics of climate change. The project brings together different economic disciplines and scale levels: Institutional economics, economic modelling at different scale levels using complementary methods of macroeconomic modelling and regionalized Input-Output models, cost benefit assessment and applied ethics. Results of long-term climate scenario analyses will serve as a driver for regional impacts. Macroeconomic modelling, as the highest aggregation level of an interlinked and dynamic multilevel approach, will put the results of the more detailed levels into a national economic perspective. This is the specific responsibility of GWS. Its German 3E-model PANTA RHEI will be upgraded to give answers to the relevant questions. (http://www.ioew.de/en/project-single/OEkonomie_der_Anpassung_an_den_Klimawandel_Integration_oekonomischer_Modellierungen_und_institut/)

In European Commission’s FP7 Transport program there were carried out three projects which focused on weather impacts on transportation system in Europe in 2008 - 2012; EWENT, ECCONET and WEATHER. Between these projects, there was cooperation and exchange of information as a matter of course.
The goal of EWENT project (Extreme weather impacts on European networks of transport – completed project) was to assess the impacts of extreme weather events on EU transport system. These impacts were monetised. EWENT also evaluated the efficiency, applicability and finance needs for adaptation and mitigation measures which will dampen and reduce the costs of weather impacts. The methodological approach was based on IEC 60300-3-9 risk management standard framework starting from the identification of hazardous extreme weather phenomena, followed by impact assessment and concluded by mitigation and risk control measures. EWENT identified and defined the hazards on EU transportation systems caused by extreme weather phenomena and developed relevant scenarios and estimated the probabilities of harmful scenarios caused by extreme weather. It also estimated the consequences of extreme weather events based on developed scenarios. Finally EWENT monetised the harmful consequences of weather for each transport modes. (http://ewent.vtt.fi/)

The objective of the ECCONET-project (Effects of Climate Change On the inland waterway and other transport NETworks – completed project) was to gather the expertise of partners from different fields related to meteorology, hydrology, infrastructure operation, transportation and economics to assess the effect of climate change on the transport network, taking the inland waterway network (IWT) as a case-study. The project evaluated recent climate change scenarios, leading to predictions on the weather conditions in the future which may result in changes of the hydrological balance of the inland waterway network. These were either associated with less ice formation and more balanced waterway conditions over the year or extreme situations such as prolonged low water periods or floods, depending on the region considered. The project also evaluated the effect of these changes on the costs and reliability associated with inland waterway transport and other transport, which might lead to changes in transport flows. The project provides essential information for decision makers and guidelines for future research on climate change and IWT. (http://www.ecconet.eu/)

WEATHER – FP7 project (Weather Extremes: Assessment of impacts on Transport Systems and Hazards for European Regions) aimed at analysing the economic costs of more frequent and more extreme weather events on transport and on the wider economy and explores adaptation strategies for reducing them in the context of sustainable policy design. Economic growth models were applied to study the impacts on economy and society and the inter-relations between transport and other sectors. The vulnerability of transport is assessed mode by mode including infrastructures, operations and intermodal issues. Its core objective is to determine the physical impacts and the economic costs of climate change on transport systems and identify the costs and benefits of suitable adaptation and emergency management strategies. (http://www.weather-project.eu/weather/index.php)

CRISMA – Large FP7 project CRISMA (Modelling crisis management for improved action and preparedness – ongoing project) develops integrated planning and decision support tool sets for crises response to potentially disastrous events with immediate, extensive, and lasting consequences for population and society. Both structural preparedness and operational efficiency are considered. The project includes five elaborate pilots, which function as testing ground for the models and concepts (further) developed in CRISMA. Two of these pilots concern Nordic winter storms and Western European coastal flooding respectively

MOWE-IT – FP7 project MOWE-IT (Management of weather events for transport systems – ongoing project) will assess factors that prerequisite cross-modal transferability between the air and surface-based European transport systems in order to protect the passengers, shippers, European institutions and citizens against travel delays, cancellations and/or stoppages in freight transfer caused by extreme weather and/or other natural disasters. The project will assess how the companies in passenger and freight transport comply with the European users rights protection legislation shielding theses parties against travel delays, cancellations and/or disruptions, and in case of gaps in conformity, propose new guidelines for cross-modal alignment of decision-making, capacity planning and reserve-building models at transport service and infrastructure providers in addition to incentive structures and policy instruments for more effective legislation enforcement. Such an assessment will also draw from the possibilities to use weather and other information technologies to aid the transport system and operators.

CLAVIER – The nations in Central and Eastern Europe (CEE) face triple challenges of the ongoing economic and political transition, continuing vulnerability to environmental hazards, and longer term impacts of global climate change. The overall aim of the EU FP6 project CLAVIER (CLimate ChAnge and Variability: Impact on Central and Eastern EuRope – completed project) is to make a contribution to successfully cope with these challenges. Three representative CEE countries are studied in detail: Hungary, Romania, and
Bulgaria. In the framework of CLAVIER, ongoing and future climate changes are analysed based on existing data and on climate projections with very high detail to fulfill the need of local and regional impact assessment. Researchers from six countries and different disciplines investigate linkages between climate change and its impact on weather patterns, air pollution, extreme events, and on water resources. Furthermore, an evaluation of the economic impact on agriculture, tourism, energy supply and the public sector is conducted. (http://www.clavier-eu.org/)

IMPACT2C - Political discussions on the European goal to limit global warming to 2°C demands that discussions are informed by the best available science on projected impacts and possible benefits (ongoing project). IMPACT2C enhances knowledge, quantifies climate change impacts, and adopts a clear and logical structure, with climate and impacts modeling, vulnerabilities, risks and economic costs, as well as potential responses, within a pan-European sector based analysis. IMPACT2C utilises a range of models within a multi-disciplinary international expert team and assesses effects on water, energy, infrastructure, coasts, tourism, forestry, agriculture, ecosystems services, and health and air quality-climate interactions. IMPACT2C introduces key innovations. First, harmonised socio-economic assumptions/scenarios will be used, to ensure that both individual and cross-sector assessments are aligned to the 2°C (1.5°C) scenario for both impacts and adaptation, e.g. in relation to land-use pressures between agriculture and forestry. Second, it has a core theme of uncertainty, and will develop a methodological framework integrating the uncertainties within and across the different sectors, in a consistent way. In so doing, analysis of adaptation responses under uncertainty will be enhanced. Finally, a cross-sectoral perspective is adopted to complement the sector analysis. A number of case studies will be developed for particularly vulnerable areas, subject to multiple impacts (e.g. the Mediterranean), with the focus being on cross-sectoral interactions (e.g. land use competition) and cross-cutting themes (e.g. cities). The project also assesses climate change impacts in some of the world’s most vulnerable regions: Bangladesh, Africa (Nile and Niger basins), and the Maldives. IMPACT2C integrates and synthesises project findings suitable for awareness raising and are readily communicable to a wide audience, and relevant for policy negotiations. (http://www.hzg.de/science_and_industrie/eu_projects/fp7/climate/012508/index_0012508.html.en)
Climate scenarios, downscaling, weather monitoring and services in the EU

1.1 Representative Concentration Path (RCP) and downscaling for climate zones

This section summarises the key sets of climate projection data which are available for potential use within ToPDA. These can be described in terms of data derived from coarser, global-scale general circulation model (GCM) experiments, and data sets from finer-scale regional climate models (RCMs) which are nested within GCMs and produce scenarios for a sub-domain. A climate scenario generator, ClimGen, is also summarised, which allows the combination of various GCM climate change responses with a variety of different greenhouse gas emission scenarios, thus encompassing both model and emission-related uncertainty. A final section identifies some immediate challenges within the field.

1.1.1 Major GCM Experiments

i: CMIP3

The Coupled Model Inter-comparison Project (CMIP) 3 experiment (Meehl et al. 2007) provided the cornerstone of climate change projections for the IPCC Fourth Assessment Report (IPCC 2007b). 23 GCMs participated in the experiment, each forced with historical greenhouse gas and \( \text{SO}_2 \) concentrations between 1860 and 2000 and estimated emissions beyond (to 2100). The CMIP3 experiment used the so-called ‘Special Report on Emissions Scenarios’ (SRES) emission profiles (Nakicenovic et al. 2000) representing a variety of potential global socio-economic ‘story lines’ for the 21st century (Figure 1). For the future climate change simulations the CMIP3 experiment principally used the B1, A1B and A2 scenarios. For the majority of GCMs output of primary atmospheric variables are provided at both the monthly and daily time resolution on native GCM grids though the daily data are limited in most cases to restricted time periods, simulations or variables. Data are accessible at a number of portals (e.g. Lawrence Livermore National Laboratory, USA http://esg.llnl.gov:8080/index.jsp).

![Figure 1: CMIP3 multi-model mean global temperature change (compared to simulated 1961-1990 mean) in three key SRES emission profiles: B1 (blue); A1B (green); A2 (red) (IPCC 2007b).](image)

ii: CMIP5

The CMIP5 experiment serves as the CMIP3 analogue for the imminent IPCC Fifth Assessment Report (Taylor et al. 2012). The experiment includes an expanded population of GCMs, many of which are updated versions of the CMIP3 models, as well as Earth System Models (ESMs) which include interactive schemes of earth system features beyond the circulation of the atmosphere and ocean (e.g. land vegetation; atmospheric chemistry; ocean bio-geochemical cycling).

The experiment also includes, for the first time, near-term predictive simulations (1960 - 2035) in addition to the standard long-term type integrations (1860 - 2300). The near-term experiments involve GCMs only and attempt to predict the evolution of the full climate state (combining internal climatic variability with the underlying climate change response to external forcing factors) by using observed initial conditions. The long-term experiments use pre-industrial simulations as an initial condition: thus the evolution of the climate
state in these experiments may be confounded by internally-generated processes which are not in phase with their equivalent in the actual ‘real-world’ climate system.

Future concentrations of greenhouse gases and aerosols for the CMIP5 simulations are derived from the new Representative Concentration Pathways (Table 2 and Moss et al. 2010). A primary ‘tier’ of CMIP5 experiments has been agreed using future forcings from the RCP4.5 and RCP8.5 pathways, although many modelling centres have also repeated experiments using the additional RCP3-PD and RCP6 concentration pathways.

Table 2: Summary characteristics of the IPCC Representative Concentration Pathways used to force the CMIP5 climate change experiments (after Moss et al. 2010).

<table>
<thead>
<tr>
<th>RCP Name</th>
<th>wm-2 at 2100</th>
<th>ppm CO₂ eq at 2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCP 3</td>
<td>3 wm -2</td>
<td>490ppm (peak mid C)</td>
</tr>
<tr>
<td>RCP 4.5</td>
<td>4.5 wm -2</td>
<td>~650ppm</td>
</tr>
<tr>
<td>RCP 6</td>
<td>6 wm -2</td>
<td>~850ppm</td>
</tr>
<tr>
<td>RCP 8.5</td>
<td>8.5 wm -2</td>
<td>1370ppm</td>
</tr>
</tbody>
</table>

Data from the CMIP5 experiments are available via the project home data portal (http://pcmdi3.llnl.gov/esgcet/home/htm). An expanded set of ocean, atmosphere, chemistry and land surface variables are available with key fields for many experiments available at daily in addition to monthly resolution (Taylor et al. 2012).

1.1.2 ClimGen: Climate scenario production via pattern scaling

Pattern scaling provides a method to combine spatial climate change responses from a transient GCM or ESM experiment, with a library of differing forcing scenarios. The technique allows a suite of climate scenarios to be generated which represents uncertainty from a choice of both GCM/ESM and emission profile. The statistical nature of the technique means that the range of possible couplings is large due to the quick calculation time, compared to GCM/ESM simulations. The main limitations of this approach are that (i) it assumes that localised climate change is a linear function of global mean temperature change, and (ii) it is not directly applicable to daily timescale scenarios and short-term weather extremes.

Forcing scenarios are represented by a time series of scaling indices with which to scale the spatial response patterns. The most common index, as applied in ClimGen, is global mean temperature. Within ClimGen global mean temperatures for a given GCM/ESM are usually obtained from a one-dimensional energy balance model (MAGICC e.g. see Meinhausen et al. 2011) tuned to the given GCM/ESM and forced with the prescribed chemistry and atmospheric concentrations relevant to the desired scenario.

Each GCM/ESM response pattern is calculated as the change of a given variable, per degree of global warming that has occurred in the transient simulation. For example for the mean temperature variable, Tm, at each grid cell, i.e. the response coefficient $PTm$ is given by:

$PTm(i,j) = \frac{\Delta Tm(i,j)}{\Delta global T}$
where delta is the change in both variables during a transient simulation compared with a baseline period (the 1961 - 1990 period in ClimGen). Twelve maps of coefficients are calculated per variable so that seasonal differences in the responses can be represented. The spatial coefficients are interpolated to a 0.5 by 0.5 degree grid from their native GCM/ESM grid. The coefficients can then be applied to a new delta global T series for a given scenario, s. Scenarios can either be presented as absolute values, in which case the scaled anomalies are combined with the observed CRU TS 2.1 or 3.0 1961 - 1990 climatology (Harris et al., submitted), or simply as the anomaly time series:

e.g. for \( T_m \) for future year \( f \):

\[
T_{m(i,j,f,s)} = \Delta \text{globalt}_{(i,j)} + T_{mCRU,TS_{(i,j)}s}
\]

A description of the pattern scaling method used by ClimGen is provided by Osborn (2009) (http://www.cru.uea.ac.uk/~timo/climgen/ClimGen_v1-02_userguide_2feb2009.pdf) who also outlined modifications to the linear approach described above which refines the technique when producing scenarios for precipitation and cloud.

The present version of ClimGen (v1.2) can produce scenario data for the following variables: Mean, minimum and maximum temperature; cloud cover; total precipitation; wet day frequency; vapour pressure; sea-surface temperature; diurnal temperature range. The standard output time resolution is monthly, with 23 GCM response patterns derived from the CMIP3 experiments. A disaggregation module, ‘CRU_DDS’ can transform ClimGen output to provide a daily time series of precipitation satisfying the total monthly precipitation values and wet-day count.

The library of scenario global temperature series in v1.2 includes both SRES emission time series together with new MAGICC time series representing RCP time series for each of the 23 GCMs. Therefore, whilst the response patterns themselves in ClimGen are derived from the CMIP3/SRES experiments, it is now possible to produce some scenarios indicative of the behaviour of these GCMs under RCP forcing. ClimGen has recently been used in this manner to provide driving climate scenario data for the EU FP7 project ‘ERMITAGE’ (http://ermitage.cs.man.ac.uk).

1.1.3 Major RCM Experiments

Compared to GCMs, RCMs hold the advantage of increased spatial resolution across the subdomain for which they are run. Therefore a more realistic representation of the regional climate may be possible via the resolution of finer-scale features (e.g. topography) which GCMs are unable to resolve. There are three major RCM experiments providing RCM data for the European domain:

i: PRUDENCE

The PRUDENCE project (http://prudence.dmi.dk/) 2001 - 2004) involved eight leading RCMs nested within four high-resolution atmospheric circulation models, driven with boundary conditions from four CMIP3 GCM simulations. The driving GCM simulations represented two SRES A2 simulations (HadCM3; ECHAM4/OPYC) and two SRES B2 simulations (HadCM3; AREPGE/OPA) each.

Transient simulations for the European domain were conducted to focus upon the end of the 21st century. Output data, whilst available at both the daily and monthly time resolution, are therefore only available for the 2071 - 2100 period. 21 key surface fields are provided. A common grid resolution of 0.5 by 0.5 degrees on which to perform the RCM simulations was agreed, although some RCM data is also provided on finer grids (e.g. ~0.22 deg or in some cases finer) (Christensen et al. 2005).

ii: ENSEMBLES

The EU ENSEMBLES project (http://www.ensembles-eu.org) 2005 - 2009) provided a follow on to the PRUDENCE experiments, repeating RCM simulations for the European, and an additional African, domain (Figure 2). A key advancement in ENSEMBLES was the provision of RCM simulations upon a 0.25 by 0.25 degree grid, using the latest incarnation of leading modelling centre’s RCMs. The project also expanded the number of driving GCMs (a total of six: HadCM3; NERSC; CNRM; MPI-METI; CGCM3) in order to better represent projection uncertainty, which has been shown to be dominated by the choice of GCM (rather than
emission scenario) for the near-term climate (e.g. Hawkins and Sutton 2009). Again, the driving GCM simulations are derived from the CMIP3 experiments and here the SRES A1B medium emission scenario was selected.

Figure 2: The European (black) and African (red) ENSEMBLE sub-domains (domains for other non-European RCM projects are also shown). After Jones and Giorgi (2012).

Although 16 RCMs were involved in the project, only seven completed the fully transient 21st century simulations (1951 - 2100) due to the available time and computing resources. A full description of the GCM: RCM coupling can be found in van der Linden and Mitchell (2009). For the RCMs participating in the 21st century simulations, monthly and daily data for an expanded set of variables (compared to the PRUDENCE experiments) are provided for the full integration time period (1951 - 2100). These data can be accessed via the ENSEMBLES data archive at http://ensemblesrt3.dmi.dk/.

iii: CORDEX

The CORDEX project (http://wcrp.ipsl.jussieu.fr/cordex/about.html) is an ongoing programme involving repetition of the ENSEMBLES RCM European and African sub-domain experiments but with driving GCM conditions obtained from the new CMIP5 simulations.

At present (December, 2012), the European RCM simulations have not been completed, with priority given to the African domain experiments, in order to meet IPCC deadlines for the Fifth Assessment Report. Therefore, precise details of the European experiments are unknown, although some details are provided upon the European-domain CORDEX website 'Eurocordex' http://euro-cordex.net. The design of the African experiments selected nine of the CMIP5 GCMs to use as boundary conditions and focused upon the medium RCP4.5 and high RCP8.5 concentration pathways. About 10 RCMs were involved in the initial regional projections for Africa, although it is understood that ~6 RCM centres will conduct the European domain projections where the spatial resolution will be ~0.11 by 0.11 degrees (Jones and Giorgi 2012).

1.1.4 Challenges/options relevant to the ToPDAd project

In view of the available data sets and tools described above, a number of options exist for the provision of regional climate data for the ToPDAd project. We are exploring a number of methodologies and the final choice will ultimately depend on feasibility, timescale and the specific requirements of the ToPDAd partners.

The pattern-scaling scenario generator, ClimGen, can already generate scenarios combining CMIP3 GCM response patterns with either SRES emissions profiles or the more recent RCP concentration pathways. However, it is possible that the updated GCMs used in the CMIP5 experiments may have a different response pattern to those used for CMIP3. Thus, one immediate challenge is to investigate how the CMIP5 response patterns for each GCM differ to its CMIP3 analogue. If noticeable differences are evident, per GCM, and per variable, then a revised set of CMIP5 patterns can be diagnosed and applied within an updated ClimGen library. A further refinement to ClimGen may also be possible within the ToPDAd time frame by investigating the inclusion of a second scaling index to supplement global mean temperature as used in 1.1.2 (ii). For instance, recent work (Joshi et al., in press) has indicated the improved resemblance of spatial pattern-scaled fields to the actual transient GCM field when the global land-sea warming ratio is
applied as a second scaling index with its own independent set of coefficients (i.e. a second pattern). This would partly address the main limitation of the pattern-scaling approach, viz. the assumption that local changes are linear functions of global temperature change. In particular, it would improve the emulation of GCM results under stabilisation scenarios.

Pattern-scaled scenarios can be provided on a European 0.5 by 0.5 degree grid by interpolating the native GCM data and superimposing GCM-derived anomalies on the CRU observed climatology (thus removing any GCM bias in the mean state). Whilst precipitation can be disaggregated to the daily scale using the ‘CRU_DDS’ module, the remaining variables are provided at the monthly time resolution. An immediate challenge, then, for the ToPDAd community concerns the identification of which climate variables, or indices, are required and at what time resolution.

The acquisition of suitably-fine spatial-scale data at the daily resolution is possible via the ENSEMBLES or PRUDENCE data portals. However, neither ENSEMBLES nor PRUDENCE provide scenarios produced under RCP driving conditions, thus the scenarios may not be viewed as truly ‘state-of-the-art’. The CORDEX simulations will provide comparable daily data but driven by the RCP scenarios, however the time scale for completion of these simulations is unknown. Time resolution aside, applying direct RCM scenarios holds some advantage over the pattern-scaling method in that the evolution of the climate scenario is not bound, per variable, by a linear (or approximating) function. However, the versatility of the GCM: scenario combinations, possible via pattern-scaling, enable the production of scenarios which are able to encompass both greenhouse gas and GCM-related sources of uncertainty beyond the extent possible by limited RCM: GCM couplings driven by just one or two emission profiles.

One possible, though work intensive, solution to that the uncertainty range is properly explored whilst also providing daily resolved data, could be achieved by coupling a statistical weather generator to pattern-scaled output. The UKCP09 weather generator, for example, is able to provide stochastically-generated daily series of climate variables by perturbing observed statistical characteristics of weather (and inter-variable correlations) with measures of future mean and variance for key variables (Jones et al. 2009). In total, twelve future indices calculated from monthly-mean and daily variables are required. This perturbation technique was applied recently (Murphy et al. 2009) using future values derived from RCM simulations for the UK domain, applying these changes to a gridded data set of observed variables. In the same way that the present version of ClimGen produces standard change coefficients for regular monthly climate variables, the technique could be extended to analyse PRUDENCE/ENSEMBLES RCM data to derive patterns of how each of the twelve required weather generator indices changes per degree of global warming evident in the driving GCM. Change coefficients for each of the RCM sets, and twelve indices, could then be pattern scaled by RCP global temperature time series (as described in 1.1.2). Providing a suitable gridded observed data set is supplied for the European domain with which to calibrate the weather generator, any number of pattern-scaled change indices would then allow the production of daily data. A particular limitation of this approach, besides the concern over the time needed to implement it, is that the weather generator output would have no spatial coherence of daily weather events; the series of weather generated at a point would be stochastically independent of its neighbours (in terms of the sequence of weather events). Whether this is a limitation in practice depends on the type of impact sector being considered within the ToPDAd project.

1.2 Weather and climate monitoring systems and service development

Whereas the weather sensitivity of many economic sectors is studied elaborately (see chapters 2-4 of this Deliverable) peer reviewed literature on economic implications of weather and climate services is scarce, with (tropical) agriculture and to a lesser extent hydro power planning as notable exceptions. Furthermore, the available – scattered – literature provides at best a piecemeal overview. To our knowledge only Katz and Murphy (1997) and Gunaskera (2004) are wider scoped publications. However, Katz and Murphy (op. cit.) provide an analytical framework (‘cost-loss analysis’) which presupposes complete and costless weather information distribution and uptake as well as fully informed and optimal decision making economic agents. Probably civil aviation and (large scale) electricity production are the only two sectors which approximate these assumptions, whereas naval shipping partly fulfils these assumptions. For road, rail, energy distribution and tourism the situation is very mixed. On the other hand the report by Gunaskera (2004) deals mainly with how to perform a social cost-benefit analysis of weather services, but includes few actual analytical applications. As a consequence of the above mentioned limitations the overview below leans to a significant extent on material from the EWENT study (Vajda et al. 2011; Nokkala et al. 2012; and
notably Nurmi et al. 2012) and on work by the WMO Task Team Social-Economic Benefits (Perrels et al. 2013) and some dispersed other material (referenced where appropriate).

1.2.1 Introduction

Virtually any economic activity, consumer activities included, is sensitive to weather conditions and climatic variations. For most parts of Europe the daily and weekly variation in weather conditions is significant in all seasons, whereas inter-annual variation of climatic conditions per season can be considerable in many parts of Europe. As this variability is so obviously present, all sectors have developed a coping range, within which the sector usually manages to function at least fairly satisfactorily. In concrete terms the coping range of a sector and of its constituent producers is created by structural and operational measures while assuming a given set of climatic conditions.

Structural measures encompass construction norms (so as to sustain specified elevated physical stress levels related to weather conditions), requirements for redundancy (e.g. in networks), and decisions about seasonal schedules. For the decision about the appropriate character, size and timing of a structural measure information from climate services is needed.

Operational measures aim to minimise the disturbances and/or maximise the opportunities brought about by variations in the daily weather conditions. Operational measures are either taken at the moment that the change in weather condition becomes apparent or are based on the ability to anticipate, notably by using weather information. Operational measures can take many forms, such as covering a terrace against rain, changing clothes, changing travel route and/or travel mode, preparing equipment for salting roads given a snowfall forecast, activating switch-off contracts with large power consumers to avoid system overload during anticipated weather related peak-load, ordering a different composition of perishable foodstuffs for the next day(s) in the supermarket, etc. Better anticipation will generally improve the possibilities to avoid or reduce negative effects and to better exploit positive opportunities.

Over time there will be also interaction between the levels of operational and structural measures. Innovations in structural measures may require changes in the operational decision making and vice versa experiences with operational measures can feed back in upcoming structural measures. Similarly, evolution in structural and operational measures will interact with the provision of climate and weather services. A consequence of these structural and operational level interactions with the coping range is that the eventually observed economic sensitivity of a sector for weather conditions can be smaller than one would expect. For example, Lazo et al. (2011) found that the US transport sector is relatively insensitive to weather variation as compared to many other sectors in the US economy. Apart from having excluded extreme events this result can be partly explained by the fact that costs of delays are largely transferred to clients of transport services. Nevertheless, the results of Lazo et al. (op. cit.) show that the transport sector as a whole is – relatively spoken - not very damage prone, which supposedly can be largely attributed to long-term systematic development of its coping range.

From the above description it can be inferred that weather and climate services play into a wider set of measure options that affect the coping range of an economic agent or sector. Weather services relate primarily to operational measures and climate services primarily to structural measures. The economic impact (social value added) of weather and climate services depends on their differential effect on the realized value added in a sector (or on experienced welfare of households/individuals) as compared to a situation without or with less weather information.

In the context of ToPDA an distinction should be made between

- Weather observation and forecasting systems;
- Weather services provision based on the infrastructure mentioned under (1);
- Climate services provision based on the archived weather observations and forecasts mentioned under (1 and 2);
- Climate change adaption oriented services based on climate modelling, climate impact observation systems, and climate services as meant under (3).

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2 Lazo et al. (2011) operationalized economic sensitivity as the contributions of heating degree days (HDD), cooling degree days (CDD), annual precipitation, and variation in annual precipitation in the explanation of annual variations in 50 US states’ GDP over the period 1977-2006 estimated in a translog function in which the aforementioned variables were added to the default variables capital stock, labour volume, and energy consumption. Extreme events, such as tornados and hurricanes, were not included.
1.2.2 The supply structure of weather and climate services

The backbone of the meteorological services in Europe (European Meteorological Infrastructure – EMI) is based on closely cooperating national meteorological (and hydrological) agencies (NMHS). The NMHSs have their national observation networks as well as common infrastructure for (satellite) observation (EUMETSAT, EUMETNET), medium range and seasonal weather forecasting (ECMWF), (observation) data exchange (EUMETNET), joint weather model development (EUMETNET), etc. (see Appendix for more information). In addition, also within the context of the World Meteorological Organisation (WMO) European co-operation exists, though it may involve sometimes also non-European NHMSs and/or other UN bodies. The aforementioned organisations are typically concerned with provision of input for producing the services mentioned under (1), (2) and (3) at the end of the previous section. New types of climate services (4) are provided by NMHSs, but also by other organisations.

Within the framework of the European Community also various co-operative bodies exist which are relevant for the emerging new market for climate services related to adaptation and hazard management. Notably the long-term programme Global Monitoring for Environment and Security (GMES) gains importance. GMES is governed by the European Commission in co-operation with the European Space Agency (ESA) and the European Environmental Agency (EEA). For example, the Climate Adaptation Platform (CLIMATE-ADAPT; http://climate-adapt.eea.europa.eu/) operated by the EEA will also be supplied by GMES based information.

Last but not least the Global Framework for Climate Services (GFCS) should be mentioned. This framework, promoted by the WMO, aims to build up a global coverage of climate services with special emphasis on augmenting these services in developing countries (for details: http://www.wmo.int/gfcs). GFCS also aims to promote standardisation among ‘new’ (adaptation oriented) climate services. To date there is no widely agreed broad base of common standards, owing to the recent emergence of this field of application and to the still large R&D element in the output produced.

On the basis of the above sketched international infrastructure national and regional weather and climate services are provided, in the first place by NMHS, but in most countries also by commercial weather service providers. Some infrastructure companies, such as power companies, airports, and seaports have their own observation system as well, which may or may not pool information with the NMHS network (depending on a country’s regulation). Furthermore, there are all kinds of private weather stations without any official (validated) status, e.g. in tourist locations.

In summary, the creation of value added in the supply chain of weather services occurs in three phases (Figure 3), being: (VA1) when combining data, models and expertise to generate weather forecasts and adjacent services, (VA2) when editing and distributing weather information through media channels and enabling the combination of information, and (VA3) when end-users interpret weather information and use it in decision making (to avoid damages and exploit weather related opportunities). The first phase of value added creation (VA1) represents the services of NMHSs and commercial weather service providers (‘re-users’). VA2 represents the media channels (TV, radio, newspapers, websites, mobile, etc.), which convey weather information alongside other information. The phase, in which the end-users use weather information, represents by far the largest amount of benefits (value added), i.e. VA3 >> VA1 + VA2.
In some countries, e.g. the Netherlands, the role of NMHS is limited to basic services and service provision for a few designated sectors (like civil aviation). In that case the share of ‘re-users’ (commercial service providers) gets larger in VA1. In other countries, for example Finland, the NMHS is serving many customer groups directly and via various media alongside commercial service providers. A higher share of commercial service providers in VA1 does not automatically imply larger or smaller amounts of generated value added in VA2 and VA3. The value generation in later stages (VA2, VA3) depends on access to data, pricing of services and data, effective information chains, end-user decision making skills, and quality of the basic (hydro-)meteorological services.

In various countries, e.g. UK, Norway and the Netherlands, a rigorous free public data policy is applied to weather and climate data. In various other European countries such far reaching changes can be foreseen as well. For example, in 2013 the Finnish meteorological agency (FMI) will make large amounts of observation and archived weather and climate data available for third parties against zero and low (marginal cost) charges. The INSPIRE and PSI directives of the EU promote affordable third party access to publicly funded basic data and information with the purpose of maximizing the benefit potential of these basic data and information. The different EU member countries implemented or are implementing these directives to different extents and in different ways. Other countries may follow suit in their own way. The resulting variations in weather market organization greatly affect the achievable benefit potential as well as the distribution of value added over different parties (e.g. De Vries et al. 2011; Perrels et al. 2013).

In practice, supply of weather information, both mass market and tailored, shifts ever more towards internet and mobile based services, with increasingly also interaction and feedback options for the end-users. All-in-all the recent developments hint at growing diversification of weather information suppliers (mediators), growing diversification (personalization) of weather services (‘beach weather’; ‘runner’s weather’; ‘small wind turbine weather’; etc.), increasing number of observation locations – mainly outside the (original) NMHS observation network due to decreasing unit-cost of observations, and increasing European as well as wider international co-operation with respect to observation (notably by satellites) and large scale modelling.
1.2.3 Prospects and needs with respect to weather and climate services

Skill development due to scientific and technical progress

Regarding short term (2 ~ 5 days forecasts) the forecast accuracy of temperature and precipitation shows a rather steady increase over the past 30 years (see also Nurmi et al. 2012). For at least the next two decades this trend may be expected to continue, even though for temperatures a levelling off of the improvements could be expected beyond some point due to asymptotic behaviour.

Unit-cost reductions in automated electronic observation enable the proliferation of such devices and the integration with other ambient environment observation technology. This may have for example significant consequences for so-called ‘road weather services’ (Smeding et al. 2012; Sukuvaara et al. 2012), as well as all kinds of localized weather services such as in tourist centres. Intelligent road systems would enable direct communication between road vehicle, driver and road side weather stations, whereas these localized weather stations – possibly in conjunction with road surface sensors – could provide precise information on driving conditions in the next kilometre road stretch. Similar developments could also emerge for electricity distribution and transmission network monitoring (e.g. regarding snow load and icing). When sufficiently widely penetrated these innovations could significantly reduce road accident numbers as well as power cuts. Yet, if these innovations can create such noticeable differences in risk levels between subsets of the involved networks, the traffic density may be redistributed over the network.

Ongoing improvements in radar technology make it possible to better distinguish the types of precipitation to be expected in terms of physical state (rain, hail, icy rain, wet snow, snow). This is relevant for large parts of Europe, notably in periods of mild wintery conditions, as it enables to give more precise warnings about slipperiness and accumulating snow and ice loads on overhead infrastructure (power lines, catenary above rail lines). This information can also be effectively combined with localized weather service provision and intelligent road weather services.

The reduction of unit-cost of observation and local prediction generation (by combining local observations and user feedback with an available national/regional forecast) also means that the availability of (truly) localized weather services can improve remarkably (Elevant 2010; Elevant & Turppeinen 2011). This would be particularly beneficial for tourist areas and specific tourist services (Wilson 2011). Similarly, localized weather observation and prediction may be beneficial for localized energy solutions. The emission reduction policies in Europe imply an increased emphasis on renewable energy use and increased energy efficiency. In practice this means a rising need for building block and neighbourhood scale integrated optimisation of local renewable energy use, local energy storage, and purchased energy from (and to) a network (IPCC 2011).

The EU programme Global Monitoring for Environment and Security (GMES) can develop into an important service platform for impact assessment both as ex-ante simulations and as monitoring of realized effects (including impacts of natural hazards).

Effects of climate change on predictability

Climate modelling has experienced major progress thanks to the increased modelling efforts in the past two decades (National Academy of Sciences 2012). Future improvements in global climate models relevant for strategic economic decision making will be mainly concerned with better understanding of various crucial tipping points (e.g. regarding the pace of change in sea level rise and changes in the THC). On the other hand improvement in general ‘skill’ regarding temperature and precipitation may not represent an essential difference from an economic point of view (Millner 2012). Advances in downscaling and linkages to local models (with extensions to hydrology, land use, etc.) may entail better perspectives for economic decision making which is often regional or at least has regional components.

A new branch in climate modelling is the so-called ‘decadal prediction’. At the moment this is mainly an exploratory research activity. Decadal climate predictions are trying to exploit predictability of natural internal variability arising from long-term processes in the oceans by assimilating ocean observations. Initialization of climate models has been suggested to significantly increase decadal prediction skill over the North Atlantic. There are several multi-annual and decadal cycles in the variability of climate variables. For

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3 This section on decadal prediction is based on a private communication from Teija Seilola (FMI), who is preparing a dissertation on this topic.
Europe the North Atlantic Oscillation (NAO) and the Atlantic Meridional Overturning Circulation (AMOC) are of direct importance, but also other major cycles such as ENSO are relevant due to their global effects. Monitoring of NAO is used in seasonal predictions, e.g. regarding precipitation and hydropower. Reanalysis studies showed some skill for AMOC regarding temperature in Europe. There are some preliminary indications in the literature referring to the risk that global warming may induce a general decrease in decadal potential predictability for temperature and precipitation, which is already modest to start with (Boer 2009).

Also at the level of seasonal prediction (2 ~ 12 months ahead) climate change may entail a deterioration in predictability (e.g. related to lower indicative power of NAO) as precipitation and temperature patterns may become less 'typical' for the season. Yet, on the other hand modelling research efforts may wholly or partly compensate for these setbacks.
2 Adaptation challenges for the Energy sector

2.1 Strategic challenges for avoiding major disturbances in the Energy sector

2.1.1 Introduction

This section explores the co-dependencies between energy and climate change within Europe using the technique of horizon scanning. The co-evolution of energy and climate systems is examined to identify any outstanding, unintended or significant factors that may have an impact on adaptation strategies of the future, including possibilities of mal-adaptation in which short-term solutions cause lock-in of the energy system into configurations with longer term problems for either mitigation or adaptation.

The EU has now endorsed a target to reach at least 80% reductions in GHG emissions by 2050 based on 1990 levels. Meeting this target will require Europe's grid-level energy system to be essentially carbon free by 2050. While the EU Energy Roadmap 2050 (CEC 2011b) explains that this is both technically and economically feasible through a combination of energy efficiency (demand reduction) and low carbon generation, it does not strongly consider the impact of a changing climate on the vulnerabilities of the resulting energy system, and hence the likely strategies that will be adopted by energy providers to ensure stability and reliability of supply in the face of a changing climate or the attendant uncertainties. The following summary of research therefore scrutinizes the co-evolution of energy and climate systems and identifies the potential of adaptation strategies over the next 40-100 years to reduce energy risks.

While reducing GHG emissions from the energy sector is a fundamental component of the EU's overall mitigation strategy, the EU commission also recognises the need for an effective adaptation strategy (CEC 2009; CEC 2011a) for reducing the EU's vulnerability to the future impacts of climate change within the technical framework of a decarbonised energy system (Adger et al. 2007). Adaptation strategies are particularly important because the effects of climate change are likely to occur even if future global mitigation targets are met (Swart et al. 2009). Shifts in climate patterns are an ongoing slow process likely to result in irreversible changes in weather patterns that the existing energy infrastructure and systems may not operate effectively in but which might not be recognised as a threat until it is too late to make sufficient adaptations in major infrastructure to avoid disruptions in supply. If infrastructure planning fails to recognise or address the probability or severity of future extreme weather events or climate shifts within the lifespan of the infrastructure then systems will be highly vulnerable to failure during extreme weather events or from longer term shifts in weather patterns such as a changes in precipitation significantly reducing availability of water for cooling power stations.

Within the EU's overall adaptation framework, priority is given to measures that generate overall net social or economic benefits irrespective of uncertainty in future forecasts (also known as no-regret measures). This places particular attention on the evolution of the energy sector within Europe which is set to undergo the most significant structural and technological transformation between now and 2050 (and then to 2100 beyond) when compared against other sectors (CEC 2011a).

The transmission and distribution of low carbon electricity lies at the heart of any low carbon energy future. Each country within the EU will face its own set of climate related challenges based on its geography, economic situation, current state of energy sector infrastructure and ability to utilise natural resources such as wind, hydropower and solar energy in renewable energy generation over the next 40 to 100 years. It is highly likely that renewable generation from resource rich areas such as wind in coastal areas and solar energy from the Mediterranean will need to be transmitted to areas of high energy demand density, such as Europe's urban and industrial capitals. More efficient and flexible networks to promote the use of more decentralised energy generation such as local/regional (5MW-200MW), community based (2MW-5MW) and dwelling level (<2MW) technologies will improve security of supply and minimize risk of disruption. A more interconnected electricity system with a larger number of nodes for supplying and consuming electricity will allow electricity to flow from where it is generated to where it is finally consumed along paths of least resistance offering improved efficiency and resilience.

Once decarbonisation of the energy sector within the EU is complete, billions of Euros will have been spent on the construction of new infrastructure and supporting services and systems. Legacy infrastructure left behind from the fossil fuel based systems will need to be dealt with. Very little research has looked at the impacts and implications these stranded assets will have on the economy, society and the environment, or
the implications in regard to embodied carbon. It is likely that some of these assets will be integrated into the newly decarbonised energy sector (e.g. gas networks that can be converted into transporting biogas or coal power stations fitted with CCS); some assets will be mothballed while others will be dismantled, recycled and discarded. It is unclear what proportion of these assets can be effectively incorporated into the low-carbon energy system to minimize risks, costs and impacts on the environment. It is also unclear how lock-in of existing and transition energy systems may cause some of the anticipated decarbonisation to be slowed.

Energy and climate systems also form complex relationships with social and economic systems. On-going research aims to uncover the co-dependency between these complex systems as they will co-evolve over the next 100 years to uncover any unintended consequences or unusual behaviour emerging from the system as a whole. A great deal of research has been completed on how the global climate will react to a changing energy system but what impact a changing climate will have on a decarbonised energy system – one that is largely powered by renewables – is still uncertain. Some of the questions this research hopes to answer include: What are the vulnerabilities of the energy system in a changing climate? How will these changes vary by different energy and climate regions across Europe? What will an increase in the frequency and/or severity of natural hazard events have on the energy system? Are there any pinch-points in Europe’s energy system where effective adaptation strategies can effectively be implemented to reduce risks and vulnerabilities?

The 100 years’ time-frame, adopted here in considering adaptation strategies for the energy sector, was selected for several reasons (OFGEM 2011):

- This is the outer edge of climate projections available
- Production, transmission and distribution assets can last as long as 50 years, and hence decisions taken on investments in these can be quite long-term orientated
- Significant changes in the energy system are expected in the next several decades as old capacities are retired and a lower carbon infrastructure put in place
- Regulatory mechanisms can take a decade or longer to have the desired effect, and in any event these regulatory changes will need to be coordinated with longer-term repair, replacement and new capital investment cycles.

### 2.1.2 Significance of climate change and weather variability for energy systems

Individual nations have developed plans for considering climate change adaptation strategies in their medium and long-term planning for energy security (Swart et al. 2009). A review of these reports indicates they all consider approximately the same mix of broad climate impacts to be of similar importance, so the report by the UK Office of the Gas and Electricity Markets (OFGEM) is used here as a representative example of such studies (OFGEM 2011). Several primary challenges to the energy system under a changing climate are identified, some of which are technological and some socio-economic.

Key issues for the power network throughout the EU from foreseen climate changes are:

- Temperature increases in summer, leading to increased power demand as air conditioning becomes more prevalent, as well as decreased ability of network lines to carry power (which is a function of ambient air temperature due to the need for shedding of heat by wires).
- Temperature increase in winter, leading to decreased heating demand, which at present reduces demand for natural gas (although this will change as electrification of a greater proportion of the energy system proceeds).
- Increased variability in precipitation, likely to cause increased precipitation during winter months and decreased rainfall during summer months. Substations are at threat of flooding during periods of increased rainfall, increased snowfall damages power transmission cables and droughts can damage underground cables – reducing their ability to shed heat (again reducing their ability to carry power at precisely the summer period when power demand is likely to be highest due to air conditioning loads) – and subsidence causing damage to the foundations of substations.
- Precipitation changes will alter river basin levels impacting on hydropower production and storage as well as increasing risks of drought in summer reducing the availability of water for cooling power stations.
- Sea level rise will have implications for coastal power generation capacity.
• Storm surges, again will have implications for coastal power generation as well as generation capacity located within or near flood plains.
• Changes in weather patterns are uncertain and will have as yet unknown implications for all renewable energy sources which are weather dependent for continuity and level of supply.

These changes are likely to be modest through 2050, remaining within the range of variability already incorporated into systems management, but move outside this range by 2100, requiring significant adaptation strategies to be in place at some point between 2050 and 2100. Again, the long lag in time between decisions, investments and delivery mean that the necessary adaptation strategies for the energy sector will require design and decisions prior to 2050.

OFGEM assessed the various climate impacts for the degree of damage to the power supply and worked with the UK Met Office to produce subjective estimates of the likelihoods of these different events over the next 50-100 years, summarised in Table 3. In this table the different climate risks effect on those components or functions likely to be completely disabled for some period, or those with significant reduction in function for some period are shown; Text in red denotes those components likely to have high impact on the power system from their loss of function, blue text, those with medium impact. (OFGEM 2011).

Table 3. Components of the power system at greatest risk of climate change over the next 50-100 years and relative likelihood of different climate-related damages to the power system. Adapted from (OFGEM 2011).

<table>
<thead>
<tr>
<th>Climate Change Risks</th>
<th>Function/Component completely disabled</th>
<th>Significant reduction in function</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Extreme Events</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flooding (Fluvial)</td>
<td>Substations, affected by probable sea level rise &amp; tidal surges</td>
<td>Transformers, Circuit Breakers, Logistics, Spares, Communications, Operations Centre</td>
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<tr>
<td></td>
<td>Protection, Resources, Customer Service</td>
<td></td>
</tr>
<tr>
<td>Flooding (Pluvial)/ Heavy Rain</td>
<td>Substations, affected by highly probable winter rains and possible winter rainfall</td>
<td>Transformers, Circuit Breakers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Substations, affected by highly probable winter rains and possible winter rainfall</td>
</tr>
<tr>
<td>Flooding (sea breach inc erosion risk)</td>
<td>Substations, Transformers, Circuit breakers, Overhead lines</td>
<td>Transformers, Circuit Breakers</td>
</tr>
<tr>
<td>Dam inundation</td>
<td>Substations, Transformers, Circuit Breakers, Overhead lines</td>
<td>Transformers, Circuit Breakers</td>
</tr>
<tr>
<td></td>
<td>Resources, Communications, Customer Service</td>
<td></td>
</tr>
<tr>
<td>Extreme prolonged temperature periods</td>
<td>Overhead Lines, possibly affected by increasing activity</td>
<td>Transformers and Switch Gear, possibility of suffering reduced ratings</td>
</tr>
<tr>
<td>Lightning</td>
<td>Overhead Lines, possibly affected by increasing activity</td>
<td>Transformers and Switch Gear, possibility of suffering reduced ratings</td>
</tr>
<tr>
<td>Gradual Warming</td>
<td>Overhead Lines, possibly affected by increasing activity</td>
<td>Transformers and Switch Gear, possibility of suffering reduced ratings</td>
</tr>
<tr>
<td>Temperature Increase</td>
<td>Vegetation management, prolonged growth almost certain</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Overhead line conductivity, possibly affected reducing rating and ground clearance</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Underground cable systems, rise in soil temperature possibly reducing ratings</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Resources, Communications</td>
<td></td>
</tr>
<tr>
<td>Drought (Soil drying and movement)</td>
<td>Transformers, possibly affected by urban heat islands and HVAC overload in summer</td>
<td>Substations &amp; Earthing possibly affected, reducing effectiveness</td>
</tr>
<tr>
<td>Demand increase due to mitigation and HVAC</td>
<td>Overhead lines, Cables</td>
<td>Substations &amp; Earthing possibly affected, reducing effectiveness</td>
</tr>
</tbody>
</table>

Thermoelectric power will be particularly vulnerable to and restricted by cooling water quantity and quality. Increasing temperatures will impact on the cooling efficiency and turbine operating efficiency of plants. Fossil fuel supply to these are vulnerable to increasing disruption as droughts and floods will impact on erosion in surface mining impacting on coal extraction and weather variability is likely to result in disruption in offshore extraction.
Risks and vulnerabilities for the gas network are dominated by:

- Increased coastal and river erosion, with the potential for gas leaks and reduction in local supply security.
- Increased temperature, in part due to the inability of compressor stations to function well at high ambient temperatures, and in part due to increased demand for natural gas in summers if air conditioning becomes dominated by gas-fired absorption chillers or tri-gen facilities.
- Increased flooding, leading to damage to both compressor stations and piping.
- Oil and gas supplies are vulnerable to the impact on frequency and scope of disruption in offshore and onshore extraction and disruption of production transfer and transport caused by weather events. Weather events are likely to impact on import operations and on the frequency and scope of shutdowns and reduced capacity of refineries. Changing weather patterns will impact on cooling water availability and quality in refineries.

The linkage between power and gas systems is strong, as power losses due to climate change may affect the ability to operate compressor stations and pump gas through the distribution system. In addition, an increase in the number of cold snaps and heat waves, both increasing demand, may leave energy systems vulnerable due to insufficient lead time to prepare the energy system to shed spare capacity when demand is reduced, ramp up supply in sufficient time when demand rises rapidly, or switch from one energy supply to another. It is highly likely that low carbon, renewable power technologies such as solar or wind will be backed up by gas-fired turbines, increasing interdependencies of the power and gas sectors.

Adaptation strategies will need to consider the impact of gas disruption to generating capacity, the availability of back-up supply, the delivery of energy resources within the supply chain and energy security, as well as the economic impacts (both direct costs and macroeconomic indirect costs) of supply disruption. At present, the indirect macroeconomic impacts of disruption are poorly characterised, although research programmes such as the Infrastructure Transition Research Consortium (ITRC) are beginning to develop the methodologies to allow such assessments.

EU energy systems (both power and gas) also will experience some advantages under a changing climate, specifically:

- An expected decline in snow and ice throughout most of the EU, leading to decreased winterisation costs and damage although this might be mitigated by an increase in freeze thaw cycles damaging infrastructure.
- Reduced heating demand in winter but increased cooling demand in summer may level the demand profile, leading to greater utilisation factors for energy generators as well as demand being higher during times when fuel prices have traditionally been lowest (although the pricing system is also likely to evolve). This could make district-level combined heat, cooling and power systems more attractive.
- A possibility of enhanced biomass-fuelled energy generation if feedstock yields increase under a changing climate particularly in northern European and Nordic countries (in part off-set by the possibility of drought decreasing this yield).

Finally, Schaeffer et al. (2012) reviewed the available literature to produce a summary of the most significant vulnerabilities of both energy generation and demand up to 2100. Reducing these vulnerabilities in the most cost-effective fashion, while retaining or improving security of energy supply at reasonable rates for consumers, forms the set of decision criteria that can be applied in choosing strategies for adaptation. These decision criteria for renewable energy are summarised here:

- Biomass: impact on availability and distribution of land with suitable conditions for growth; impact on rates of desertification; impact on bioenergy crop yield.
- Hydropower: impact on total and seasonal water availability; impact on frequency and duration of droughts; impact on changes in hydropower system operation; impact on rates of evaporation from water reservoirs.
- Demand: impact on demand for air conditioning in summer; impact on demand for warming during winter; impact on energy demand for irrigation.
- Wind: impact on wind resource; impact on wind shearing causing damage; impact of other extreme weather events.
Solar: insolation changes due to cloud cover; impact on efficiency of panels due to decrease in insolation; impact on efficiency of panels due to temperature rise.

Geothermal: impact on cooling efficiency.

Wave energy: impact of changes in wave resource due to shifting currents.

2.1.3 Foreseen major relevant changes in supply and use technology

Non-climate change driven primary changes that will impact on the energy sector are likely to be as follows:

- Significantly improved energy efficiency of buildings, white goods and other plug load devices, industry and transport which may reduce the pressure on creating new generation capacity, although the rebound effect (Sorrell 2007) suggests this reduction may not take place as anticipated. This change is likely to be driven primarily by improved standards. Improved efficiency may reduce demand, but that will in part be offset by changes in population and the rising demand for plug load.

- Smart meters will provide consumers with significantly more information on their energy use and associated costs with preliminary evidence that introduction of these meters produces a decrease in energy demand by 10-20%, although that reduction becomes less over time as consumers adapt to the improved information and shift behaviours back to energy-intensive lifestyles (Sorrell 2007).

- Smart appliances and buildings will allow for greater control of grids, improving the efficiency of energy generation, transmission and distribution, and reducing reliance on quick start-up systems needed to provide for peak demand when this greatly exceeds baseload. Since these quick start-up systems (e.g. diesel engines) at present tend to be higher carbon, the result will be reduced carbon intensity of the energy system (the exception is use of hydropower to supply peak load, assuming this power source is not already fully utilised in baseload). The primary social limitation is the acceptance of consumers to have their energy consumption monitored and controlled to optimise system performance. The shift to gas-fired backup will reduce the carbon intensity of peak demand, but not to levels of the renewable being backed-up.

- Smart grids will also allow for increased load levelling and hence reduced carbon intensity, as well as greater reliance on renewables many of which are more intermittent than would be acceptable in ensuring energy quality under the current energy transmission and distribution system.

- Greater introduction of air conditioning in buildings, perhaps approaching levels found in the US. Where this is supplied by electricity, the result will be greater power demand. Where this is supplied by absorption chillers, the result will be a mixture of increased power and gas demand, with high dependence on the coefficient of performance of such systems. Significant research and development is underway globally to improve this coefficient to above 4, which is necessary to make these truly lower carbon systems. Even if ground source systems are used, there will be some increase in power consumption to operate such systems, with this power demand again dependent on the coefficient of performance.

2.1.4 Foreseen major relevant changes in societal factors

Primary changes in societal factors that impact on the energy sector are likely to be as follows:

- Increased per capita energy demand due to rising plug load, although this can be offset significantly by increased energy efficiency of devices and processes and by decarbonisation of grid power (York 2007).

- Ageing of the population, leading to increased health vulnerability associated with heat waves and cold snaps. This in turn will lead to increased reliance on air conditioning in summer and heating in winter for dwellings of the most vulnerable population (primarily the elderly).

- Potential decline in EU population, leading to reduced energy demand.

- Increased urbanisation, accompanied by a rise in per capita energy consumption throughout society, concentrating areas of high energy demand (York 2007).

- Increased integration of the energy markets between EU nations, which should both stabilise price fluctuations at national level and make energy provision less vulnerable to climate impacts in any specific nation or climate region (CEC 2011a).

- Continuing off-shoring of production capacity for goods, reducing energy demand by industry, although at the expense of increased carbon leakage globally.
• Adapted energy systems will probably lead to increased levelised costs of energy, raising energy bills for consumers that is likely to be in a context of reduced purchasing power of households as structural changes in the global economy take place in response to the recent financial crisis.

2.2 Climate Zones of Europe relevant for the Energy sector

2.2.1 Zones that have outstanding significance for the sector

Geographically, energy systems within all regions within Europe will experience adverse impacts from climate change (IPCC 2007c). Within the EU the severity of energy-related impacts varies by region with the most vulnerable regions being the Mediterranean, Outermost regions and the Arctic. Other specific areas such as the Alps, islands, urban areas and densely populated flood plains are also facing unique sets of problems due to climate change. The current report considers four climate zones within Europe: Mediterranean, Atlantic, Continental and Nordic zones. These zones roughly follow the vegetative regions that correspond closely with regional climates. Although energy systems are country-specific, climate zones within Europe do not follow political borders exactly. Therefore, climate zones are assigned based on the dominant climate within a country’s borders (Figure 4). In subsequent analysis, it might be necessary to specifically look at the evolution and role of energy systems and the impact they have on isolated specific geographic areas and points of concern (e.g. sensitive alpine areas, small islands, flood plains etc.).

![Figure 4: Energy and climate zones in the EU.](image)

2.2.2 Changes in weather phenomena with hazard implications for the Energy sector

Wind energy, both onshore and offshore - but particularly offshore, has significant potential for meeting a large proportion of Europe’s renewable energy generation targets (IPCC 2011). A changing climate is expected to bring an increase in average wind velocities which will improve the overall performance of wind turbines; however, under the expected increase in extreme conditions due to climate change wind turbines may be shut down more frequently to prevent damage. In addition, the frequency and duration of Atlantic low pressure zones that decrease wind speed for significant periods of time may take place. It is expected the overall effect of a changing climate on wind power in Europe is within +/- 25 % (CEC 2009) of existing availability. Super grids that connect offshore wind-farms and neighbouring countries together will enable wind to be effectively integrated into the wider EU electricity network. This will provide a larger market for electricity being produced and minimise inefficient curtailment of wind generation when there is insufficient demand.
Changing weather patterns, such as shifts in precipitation and heat waves, often accompanied by droughts, will change hydrological cycles creating marked shifts in supply and demand for water across regions of Europe and for local climates. Hydropower has been an important historical resource for low carbon electricity both globally and in Europe, contributing a significant share of renewable electricity production (16% of total global electricity production in 2008). Around 47% of Europe’s hydropower capacity remains undeveloped amounting to around 283 GW or 1174 TWh/year (CEC 2009). Between now and the 2070s increased precipitation in Northern and Eastern Europe coupled with increased run-off from melting glaciers may increase the potential for hydroelectricity generation in this region by between 15% and 30% (Lehner et al. 2005), although the latter will diminish in the long-term as glaciers disappear. In the Mediterranean and Black Sea, precipitation is likely to be less, reducing hydroelectricity production by between 20% and 50%. Hydroelectricity production for Western and Central Europe is expected to remain relatively stable. Overall, hydroelectricity potential within Europe is predicted to decrease by up to 6% by 2070 (Lehner et al. 2005). Dam safety may also be adversely affected due to higher frequency of extreme flows and natural hazards (CEC 2009).

Higher temperatures within the Nordic, Continental and Atlantic zones may allow increased production of biomass for heating and electricity generation though will be balanced against a decrease in the availability of water which will affect crop yields (CEC 2009). Increased production of biofuels for use in decarbonising transport and electricity generation will also compete with agricultural land for food production and possibly encroach on areas set aside for national parks, wilderness, protection of eco-systems and endangered species, and land for housing and industrial development. Growing mono-crops for biofuel production will also have an unknown effect on different microclimates and ecosystems across Europe. Energy from waste biomass offers some potential to meet future carbon targets, but as new low-waste and recycling laws are enacted across Europe, the potential of this resource to meet growing energy needs will diminish.

Even though future CO₂ projections indicate that the EU will be almost entirely decarbonised by 2050 if mitigation strategies are as intended, fossil fuels, particularly in thermal power stations as a legacy of existing infrastructure, will remain an important energy source for meeting demand during the transition to a low carbon energy system. As temperatures change and inlet cooling temperatures exceed threshold levels, thermal power stations may need to be shut down. Rising temperatures and the accompanying increasing scarcity of water particularly in summer will likely have an impact on the efficiency of thermal power stations that require an increase in energy demand to maintain the power station within its operating limits as well as their operation capacity in times when water for cooling is rationed.

2.3 Energy sector level adaptation challenges in climatic zones in the EU

The challenges to energy systems in both the mid-term (today to 2050) and long-term (out to 2100) are the same with two exceptions:

- The mid-term will involve a gradual transition to a low carbon energy system, and hence will have much greater reliance on fossil fuels – especially natural gas – than does the long-term projection.

- The degree of climate change, including both the intensity and frequency of extreme weather events, will be higher in the long-term.

However, apart from these differences, the issues raised in regard to vulnerability of the energy system, and adaptation strategies to reduce this vulnerability, are not significantly different between the two periods. Hence, most of the issues are described in this sub-section, with sub-section 2.4. describing further complications unique to – or made worse during – the 2050 - 2100 period.

2.3.1 The most vulnerable systems of the Energy sector for specific climate hazards

In the mid-term the EU power sector has to meet the multiple challenges from climate change of withstanding external shocks from extreme weather events, coping with ongoing changes in local water availability and temperature, changing energy demands and decarbonising the power generation sector. If current import and energy demand trends continue, the EU’s dependency on fossil fuel imports will steeply increase, particularly if gas becomes a bridging technology as a more efficient and lower carbon intensity energy source than coal. The vulnerability of the gas network is discussed in section 2.1.2. The reliance on fossil fuel supply for the transport sector in particular is easily disrupted leading to loss of vital functions such as food production, medical care, transport of the workforce and internal security.
Climate change is predicted to cause changes in weather variability and extreme weather events. The cost of these events is rising due both to increased frequency and intensity of weather events, and to increasing urbanisation and centralisation of infrastructure, particularly those sited on coasts and rivers. In the mid-term it is expected that the increase in global temperature will result in an increase in floods, storms, droughts and heavy waves and ice storms. It is highly uncertain what the frequency and severity of these events will be as the effects of climate change on weather systems are considered beyond 2050.

The EU is committed to decarbonising its power sector and it is predicted that the share of renewable power of total primary energy generation in the EU will be 17% in 2020, increasing to 18.3% in 2030 (JRC 2009). This increase in low carbon energy will affect the region’s ability to meet normal variations in energy demand and will require a variety of complementary variable and dispatchable renewable electricity generation to ensure a continuous power supply and the proportion of each type in the energy generation mix needs to be considered during infrastructure planning to ensure a continuous supply during varying weather conditions. Variable renewables such as wind and solar can produce high levels of power with the right weather conditions, but generation can drop to zero under the wrong conditions and so these cannot at present be relied upon to meet baseload demand. Dispatchable renewables such as hydropower and biomass can be deployed when required to meet increases in demand, even allowing for seasonal variations (e.g. hydropower generation is higher when there is more rain, and biomass can be harvested in the early stages of a drought – or left to die and dry out, increasing the energy density of the biomass as fuel - and used to generate electricity). Adaptation strategies must therefore consider the likely required proportions of both dispatchable and non-dispatchable energy sources in the mix.

Currently the energy transmission system is uni-directional with flow from the concentrations of generation source to user, and is vulnerable to any disruption of supply from major generation centres. There is growing recognition that high degrees of geographic and economic concentration increases vulnerability to shocks if a vital component is damaged and no alternative is readily available (OECD 2003). The power supply system of each region is becoming more dependent on each other’s availability and vulnerable to large scale disruptions across borders in the event of damage to one region (Rübbelke and Vögele 2011). Transmission lines can stretch for thousands of kilometres and are exposed and vulnerable to a number of extreme weather conditions from high winds, snow and ice storms and floods and landslides which can cause damage and disrupt supply. Heatwaves and droughts are often accompanied by fires which can also destroy generation and transmission infrastructure (Watkiss et al. 2005). A secure continental energy system enabling a single energy market throughout Europe allowing for regional variability in supply and demand due to climate change effects is recognised as a way of reducing the strain on electricity transmission systems through better demand management (Clastres 2011). The governance structures for such international energy supply, transmission and distribution systems however are lagging behind technological capabilities.

Warming and rainfall trends are predicted to vary across the EU regions leading to sustained changes in regional hydrological cycles as well as more frequent extreme weather events such as droughts that will reduce fresh water availability. Reduction in snow melt and the eventual decline in glacier melt as glaciers reduce, with resulting lack of water in river basins made worse by drought and increased evaporation during heatwaves will lead to reduced hydropower capacity, disrupting electricity generation and storage (Rübbelke and Vögele 2011). Increased precipitation (notably in winter) is likely to increase hydropower production potential in Nordic countries of 30 TWh or more (Bye et al. 2006; Gabrielsen et al. 2005); yet at the same time the variability of the hydropower availability may increase (Bye et al. 2006).

Droughts often coincide with heatwaves which increase demand for water and power for cooling by air conditioning. About 43% of the EU’s water demand is for cooling water by power authorities for cooling thermal fossil fuel and nuclear plants and these are severely hit by any reduction in water availability when they have to be operated at reduced capacity (JRC 2009). Water is required to grow biomass energy crops as well as food crops, and a lack of water for irrigation will constrain both crop growth and selection of the type of crop and favour biomass energy from wastes. Water availability and temperature changes are predicted to affect the amount of land available for crop production as well as regional soil conditions with varying effects on crop productivity across the region, some regions with increasing crop productivity and others with a decrease. It is expected that areas with hotter temperatures will have accelerated reproduction and increased incidences of crop pests that would significantly reduce yields (Rübbelke and Vögele 2011).

In summary the climate hazard vulnerable sectors likely to have most impact on the energy sector:
Transmission infrastructure both above and below ground is very vulnerable to many types of extreme weather events which can disrupt supply affecting several connected regions if transmission is uni-directional and cannot easily be rerouted or alternative supply used.

Lack of water for cooling fossil fuel and nuclear power stations results in their operation at reduced capacity often during periods of increased demand such as heatwaves when extra power is required for cooling by air conditioning.

Renewable energy sources vary in their availability and capacity to generate power under different weather conditions so a variety of sources are required to ensure supply matches demand under the variety of weather conditions likely to occur over the next 100 years.

2.3.2 The most important impacts on the Energy sector across climate zones

To double the electricity generated from renewables from 2007 - 2020 the EU regions for the optimum location of different type of renewable generation have been identified: The Northern Seas for offshore wind generation, Southern Europe for Solar and Central and Eastern Europe for Biomass production. This will be supported by increased hydropower storage in Nordic and Alpine regions (CEC 2010). All of these regions are expected to suffer different extreme weather events which could decrease the availability of these natural resources for energy generation.

The planned European Supergrid, to be deployed 2015 - 2030, will link major centres of energy generation with consumption centres in Northern and Central Europe, as well as the hydrostorage capacity in Alpine and Nordic Regions (CEC 2010) enabling the integration of regional renewable electricity generation and storage as well as the introduction of electric vehicles to reduce the reliance on fossil fuel based transport.

A smart monitoring system and adaptable electricity supply is anticipated to allow better preventative and emergency control, to mitigate any reduction in electricity supply from areas hit by extreme events.

Wind energy generation in the Northern Seas will be affected by changes in wind patterns due to climate change; these effects in either the medium or long-term are difficult to predict. Wind power generation sites are selected due to the direction, availability and reliability of the wind. If local wind patterns change this could result in a reduction of average wind speeds reducing a site’s capacity or in a higher incidence of very high wind speeds which activate the cut-out speed control, stopping production. Changing wind patterns in the Northern Seas might decrease the potential levels of wind energy generation. However wind production sites have a short lifetime compared to traditional power stations and so are adaptable as they can be re-sited when they need to be replaced (CEC 2009), especially if there is a movement towards the more cost effective floating turbines.

It is anticipated that warmer winters across Europe, particularly in Nordic countries and Northern Europe, and hotter summers, particularly in Southern Europe, will shift peak demand for power from winter where demand for heating is reduced, to summer where cooling is required particularly in periods of extreme heat in the hotter Southern European region. Water availability is highly likely to become a serious issue in Southern Europe during drought and heatwaves with their increased threat of forest fires which require water to put out and rescue infrastructure and populations. Increasing droughts often coinciding with heat waves will reduce power, especially nuclear, generation at times of higher demand for air cooling, particularly in Southern Europe where nuclear generation capacity is sited mainly on rivers where water flow is likely to be lower during summers. Central Europe also contains a high proportion of hydropower capacity which will be significantly reduced during drought. As a result these areas will need to import energy to meet the increasing demand required for air cooling during these hotter summers (JRC 2009; IIASA 2012).

Warmer winters and increased rainfall in Northern Europe is anticipated to increase biomass growth, while hotter drier summers in Southern Europe will decrease biomass growth due to lack of water for irrigation and reduction of land suitable for high yield crop growth. Hotter drier summers will also extend the fire season in Southern Europe, potentially damaging biomass crops and other energy generation technologies, as well as transmission infrastructure (IIASA 2012). However biomass can be harvested during the initial stages of a drought and stored dry to act as a dispatchable energy source.

2.3.3 Decision criteria that drive adaptation needs in the Energy sector

Energy security is enhanced by energy supply diversity and resilience. Adaptation goals should focus on diversification of generation sources and technologies and ensuring supplies are spread over diverse geographical regions, while the energy transmission system needs to be highly interconnected and flexible.
in order to reroute energy in the case that local generation and supplies are disrupted (OECD 2003; UKERC 2011). How cross border energy transmission is securely maintained and how promotion of competition and investment in the EU energy market is stimulated are important issues.

The specific decision criteria for investments in adaptation (either capital investments or institutional changes) focus on bringing about this diversity and resilience in regard to a number of the key vulnerabilities identified in earlier sections (see Section 2.1.2). Drawing on the summary of vulnerabilities by URS (2010), the key decision criteria for adaptation strategies include improving the following:

- Reduction in the vulnerability of fuel supply infrastructure through reduction in the probability of disruption due to storms and sea level rises and sea surges, especially along coastal areas.
- Reduction in the vulnerability of power plants and substations to flooding.
- Improvements in the technology of energy generation, transmission and distribution to reduce the current decrease in efficiency with rising ambient temperature.
- Reduction in the vulnerability of renewable energy sources to climate.
- Improvements in the routing of energy through interconnected systems such as an EU-wide transmission grid.
- Reduction in the risks of cascade failures through improved redundancy in the infrastructure and the incorporation of smart grid features.
- Avoiding regional concentration of infrastructure that could provide “pinch points” for disruption.
- Improvements in the institutional capacity to reflect concerns for long-term climate impacts in siting and investment decisions.
- Improvements in the interconnections between energy systems and the IT and transport infrastructure related to them.
- Increased fuel storage capacity.
- Increased flexibility in the routing of supply lines.
- Better matching of siting of energy centres and businesses, industry and residences.
- Reduction in energy demand, and matching of the temporal profile of remaining energy demand to potential fluctuations in energy provision.
- Increased dry-cooling capacity for power plants.
- Improvements in public understanding of the need for, and ways to address, demand reduction.
- Improvements in finance models to allow for longer term Capex payback periods.

Cutting across these specific decision criteria related to performance on key metrics are four encompassing criteria against which each of the performance criteria are to be judged (Adger et al. 2005):

- Effectiveness: the degree to which a given strategy can deliver on the improvements noted above, reducing vulnerabilities through both the severity and probability of major disruptions.
- Efficiency: the degree of improvement per unit capital expenditure, both in the sense of initial Capex and in the macroeconomic implications (including the multiplier effect).
- Equity: the degree to which the risks and benefits of energy infrastructure investment and demand reduction are spread equally across nations in the EU and subpopulations within those nations.
- Legitimacy: the degree to which the major actors in adaptation decisions support the proposed changes and are willing to create the institutional capacity to deliver on them.
- Robustness: the degree to which a given adaptation strategy is desirable under a range of possible climate, resource and energy demand scenarios.

2.3.4 Uncertainties that need to be taken into account for sound adaption decision making

There are five primary categories of uncertainty:

- Scientific. Climate science is evolving, as are the predictions of climate change events and their impacts. Significant uncertainties exist in the relationship between GHG emissions and global mean temperature; between global mean temperature and regional climates (see Section 2.2); between regional climate and the probability and severity of specific climate events; between specific climate events and damage to the energy system; between climate and energy demand; and in the response of actors in the energy system to damage that occurs.
Regulatory. There is significant uncertainty in both the political will to implement stringent mitigation and adaptation policies, the efficacy of such policies and the assessment of this efficacy to drive adjustments within an adaptive management framework.

Political. Policies have tended to be piecemeal and instable, creating investment risks. Strategies of adaptation are on time scales much longer than political cycles, reducing the political will to introduce requirements for potentially costly measures.

Economic. Investors at the moment are uncertain as to the market and political drivers for mitigation and adaptation strategies, and hence the response of the financial sector to provide capital required for such strategies. There is significant uncertainty in estimates of the indirect economic effects of energy disruption, and in the effect of adaptation strategies on mitigation targets (leading to the potential for unanticipated mal-adaptation measures). Especially significant is uncertainty in long-term projections of the cost-supply curves for energy fuels and systems, as the available resource bases for many of the energy systems is characterised by large uncertainties in precisely the parts of the curves of most significance: the marginal availability and costs of extraction as reserves are drawn down (Mercure and Salas 2012).

Organisational. Energy systems involve a myriad of actors or agents, each with unique incentives, responsibilities, resources, etc. The energy markets are currently undergoing reform across the EU and globally, and it may be decades before institutions are created to properly manage this market.

2.4 Long-term adaptation challenges of the Energy sector in the EU

2.4.1 Long-term vulnerability of the Energy sector

The energy generation and distribution systems are vulnerable to extreme weather events in a number of ways (OFGEM, 2012; Schaeffer et al, 2011). Most types of power generation are vulnerable in one way or another; hydropower, wind, thermal (nuclear, coal, gas, biomass) and solar are expected to be affected by changes in climate patterns. These vulnerabilities are identical to those in sub-section 2.3, although increasing during the 2050 - 2100 period.

Model studies on hydropower potentials suggest a decrease in generation capacity in the latter half of the 21st century as water from glacier melt declines:

- Total gross hydropower potential of Europe to decrease by about 6 % by the 2070s [method B, HadCM3] (Lehner et al. 2005), with individual countries’ gross hydropower potential being modelled as decreasing by around 40 % or more for Albania, Bulgaria, Cyprus, Malta, Greece.
- Developed hydropower potential in Portugal to decrease by 22.1 % by the 2070s (Costa et al. 2012).
- Pasicko et al (2012) suggest a 10 % decrease in hydropower in Croatia
- Schaeffer et al (2011) discuss potential impacts without estimating potential reductions in ‘firm power’.
- By contrast, annual growth in capacity of EU hydropower may increase by up to 3.1 % per year due to investment in currently unexploited hydropower (cited in Hamududu and Killingtveit 2012), with significant variation between countries, dependent on the extent to which available hydropower resources are already exploited.

Model studies on the future potential of wind power have generated mixed results, suggesting changes in the (seasonal) wind power potential:

- Summer power decreases of 5-14 %, winter increases of 4-10 % over Ireland for the period 2021 - 2060 [using ECHAM downscaled using RCA3] (Nolan et al. 2011).
- Summer power decreases of 10-20 %, winter increases of 3-12 % over the UK, with a worst case summer decrease of 24 % for the 2081 - 2100 or 2070 - 2099 period [result depends on whether GCM used was ECHAM5 or HadCM3] (Cradden et al. 2012).
- Summer power decreases of 5-15 %, winter increases of 5-15 %, dependent on UK region in 2080 [using HadAM3, HadCM3 and HadRM3] (Harrison et al. 2008).
- More than double the current production (up to 2070) over Croatia [using ECHAM5-MPIOM downscaled using RegCM] (Pasciko et al. 2012).
Averaged over the year, the results tend to show only slight overall increases in available wind power. The model studies have used a range of Global Climate Models (GCMs) and Regional Climate Models (RCMs).

Model studies on impacts on thermal power plants:

From van Vliet et al. (2012):

- 78% of European total electricity is produced by thermoelectric plants.
- Summer average decrease in European power plant capacity of 6.3% - 19% for 2031 - 2060 (simulations done for 2071 - 2100, but not reported).

Rübbelke and Vögele (2011) looked at the ways in which international energy flows have been, and may in the future be, affected by drought-induced scarcity of cooling waters for thermal power plants, focusing in particular on nuclear power plants.

- International flows of energy are affected when nuclear power base load plants are operating at reduced output due to reduced cooling availability.

Fossil fuel extraction may also be affected by changes in storm frequency and strength (offshore oil and gas fields) (Burkett 2011). Biomass production may be affected by changes in precipitation and temperature patterns, and consequent changes in use of land from biomass production to food production.

2.4.2 Long-term impacts across climate zones

The climate models used in preparing long-term forecasts (RCA3, ECHAM5-MPI-OM) have been run out to 2100 (Kjellstrom et al. 2005).

The RCA3 results show:

- Temperature increases in the range of 1-6°C from 2050 to 2100, relative to 1990, with North-eastern Europe having warmer winters and Southern Europe having warmer summers.
- A general reduction in precipitation for the Mediterranean and South-Central Europe, with Northern and Atlantic regions experiencing an increase in winter rains (Dec, Jan, Feb).
- Increased winter wind speeds; decreased summer wind speeds for northern and Atlantic regions; generally decreased wind speeds for the Mediterranean and South-Central Europe.

Taken together, the seasonal variations in power generation and regional changes in rainfall and summer temperatures, and the changes in international power flows resulting from reduced cooling of thermal plant suggest that power supplies will be limiting across the southern region in times of summer heat.

2.4.3 Decision criteria that drive the adaptation needs in the energy sector in the long-term

These are the same as in 2.3.3.

2.4.4 Uncertainties that need to be taken into account

These are the same as in 2.3.4. However, there are significantly fewer model runs out to 2100, and so the sample is less representative of all models and variants of these. Resolving these uncertainties requires a wider array of models employed, with a rolling reestimation, resimulation and reevaluation programme.
3 Adaptation challenges for the Transport sector

3.1 Strategic challenges for avoiding major disturbances in the Transport sector

It is well known that transport, with its substantial contribution to global carbon emissions, is one of the responsible sectors for climate change. The question of how climate change will impact the transport sector has attracted relatively little attention until a few years ago (Mills and Andrey 2003, Koetse and Rietveld 2009). This can perhaps be explained with the fact that climate change does not have such an obvious impact for transport as it has for other sectors – i.e. agriculture, water or health – especially if we see climate change as a relatively smooth process in which some climatic indicators (temperature, rainfall, etc.) are moving from previous averages to new ones. However, climate change sometimes implies adverse and extreme weather conditions that, quite obviously, negatively influences transport systems’ performance. Densely populated areas, in particular in coastal zones, are especially sensitive to many of the weather phenomena, winds, rainfall etc. One single event may lead to a chain of reactions that influence large parts of the transport system (Koetse and Rietveld 2009). Traditionally, transport planning has not accounted for climate change but the longevity of transportation infrastructure, the long-term nature of climate change, and the potential impacts identified by recent studies suggest that it should be taken into account from the beginning of the planning stage for new transport infrastructure (Hooper and Chapman 2012). This would mean taking into account both structural and operational measures. Structural measures encompass construction norms so as to sustain specified elevated physical stress levels related to weather conditions. These relate to the planning of size and timing of services. Operational measures are either taken at the moment that the change in weather condition becomes apparent. Examples of such are changing travel route and/or travel mode, preparing equipment for salting roads given a snowfall forecast. However, there have been positive findings on the interaction of the measures, which in fact can decrease the economic sensitivity of transport sector for weather conditions to lower level than expected (Lazo et al. 2011).

Weather patterns that are driven by the dynamics in the ocean troposphere and stratosphere are on their way to change according to some recent scientific studies. Therefore the weather situations that we know from the history may no longer be reliable and lead to the situation that the weather that we know may no longer be reliable for predictions. The fact that historical weather patterns are no longer reliable predictors for future climate conditions, calls for the identification of possible future patterns and their specific impacts. The transport sector is also facing major changes, not only related to the weather conditions, but on natural resources affected by the climate change. This means that there is pressure of finding cleaner energy sources. European Commission has set targets on energy saving and new electric engine technology for vehicles. Simultaneously, the new emerging technologies need to be configured to the extreme weather conditions.

Transport sector is by no means a holistic entity in the face of climate change. Not only each transport mode (aviation, maritime, inland waterways, road, rail and light traffic) has its own challenges resulting from the extreme weather, in addition the climate zones pose a challenge that is location-specific also in terms of slower changes of the climate. Climate change is making the prediction of future more challenging, as there are impacts which at present are at margins but will change their character and occurrence over the time. Similarly, some of the present challenges will become less frequent in the future and which may or may not make it easier to deal with them. For instance, as the global warming is reducing the frequency of cold spells, the corresponding preparedness to mitigate the impacts in areas where this trend is taking place is likely to reduce. This would mean that operators’ and transport system users resilience would not improve between now and the future in such cases.

Whilst it is evident that climate change will increase or decrease the frequency of occurrence of extreme weather events, this can also have unanticipated consequences. Typically the change will affect a climate zone as a whole where certain key characteristics will change. Heat waves will become more frequent in areas where they have not been appearing before and this will put stress to infrastructure, for instance in road and rail transport. At the same time, when other events become rarer the resilience of system will weaken over the time as expertise and readiness needed to deal with the phenomena disappears. Another example is as winter temperatures become warmer the corresponding impact on snow and flooding increases, even in regions where these have not be typical before.
The UK Climate Projections (UKCP09) include the following predicted climate changes and associated potential impacts (Hooper and Chapman 2012) which hold for whole Europe:

- **Increased number of hot days will lead to:**
  - Increased thermal loading on road pavements
  - Increased rail track buckling
  - Expansion/buckling of railway bridges
  - Increased heat exhaustion of maintenance and operation staff
  - Reduced engine combustion efficiency of airplanes
  - Increased required runway lengths
- **Decreased number of cold days will lead to:**
  - Reduced winter maintenance costs for road and rail
  - Improved working conditions for personnel in cold environments
  - Permafrost problems
  - Positive effects on marine transportation
  - Reduction in icing problems for electric rail systems
- **Increased heavy precipitation will lead to:**
  - Road and rail submersion and underpass flooding
  - Increased landslides and undercutting
  - Poor visibility
  - Exceedance of existing 100 year flood
- **Seasonal changes will lead to:**
  - Longer summer/shorter winters will mean changes in timing of e.g. winter maintenance regimes
  - Reduction in frozen precipitation will improve road safety
- **Drought will lead to:**
  - Navigation problems on inland waterways
  - Possibly increased failure of earthworks due to changes in the water table
- **Sea-level rise will lead to:**
  - Locations of ports or airports may be inappropriate
  - Localised problems, e.g. storm surges
  - Possible increases in coastal erosion causing problems for coastal transport routes
- **Extreme events will lead to:**
  - Possibly increased numbers of tropical storms
  - Increased lightning effects on aviation
  - Disruptions for all modes of transportation
- **Wind changes:**
  - There are no clear projections available

The European Environment Agency has compiled a large review of research, where transport is also featured. The results of this study are shown in table below, where an overview of climate change impacts on transport infrastructure is provided.
Table 4: Overview of climate changes impacts on transport infrastructure (EEA 2012).

<table>
<thead>
<tr>
<th>Factor</th>
<th>Effect</th>
<th>Impact on infrastructure/services</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Temperature</td>
<td>Change of distribution patterns, higher average and maximum temperature</td>
<td></td>
</tr>
<tr>
<td>1.1 High temperatures and heat waves</td>
<td>Overheating</td>
<td>Infrastructure equipment, lifetime reduction, reliability of the electronic and the electric components (i.e. rail rolling stock equipment); slope instabilities due to the thawing of permafrost in alpine regions</td>
</tr>
<tr>
<td>1.2 Sudden temperature changes</td>
<td>Tension, overheating</td>
<td>Rail track buckling, slope fires, signalling problems</td>
</tr>
<tr>
<td>1.3 Intense sunlight</td>
<td>Soil erosion</td>
<td>Damage to embankments, earthwork</td>
</tr>
</tbody>
</table>

2. Precipitation | Change of distribution patterns, more extreme events |
| 2.1 Intense rainfall | Soil erosion, landslides, flooding | Damage to embankments, earthwork; Road traffic safety: risk of collisions as a result of bad weather conditions; Risk of weather-related delays in all modes of services |
| 2.2 Extended rain periods | Slower drainage, soil erosion | Rail infrastructure assets, operation |
| 2.3 Flooding: coastal, surface water, fluvial | Landslides | Drainage systems, tunnels, increased scour of bridges; Risk of weather-related delays in all modes of services |
| 2.4 Drought | Desiccation | Earthworks desiccation; Road traffic safety: risk of collisions as a result of dust on road and consequent decrease of wheel grid; Increased abrasion of mechanical components; Potential change of water levels on navigable rivers (very low levels during summer and high levels in rain periods) |
| 2.5 Snow and ice | Heavy snowfall, avalanches | Restrictions/disruption of train operations; Road traffic safety: risk of collisions as a result of bad weather conditions; Risk of weather-related delays in all modes of services |

3. Wind | Change of distribution patterns, more extreme events |
| 3.1 Storm/gale (inland) | Higher wind forces | Damage to rail installations, catenary; All modes potential traffic disruptions and safety concern |
| | Uprooting of trees | Restrictions/disruption of train operation; Road traffic safety |
| 3.2 Coastal storms and sea-level rise | Coastal flooding | Embankments, earthwork, operation |
| 4. Lightning strikes and thunderstorms | Overvoltage | Catenary, traffic control and communications systems |
| 5. Vegetation | Faster plant growth, new plants | Vegetation management |

Source: Adapted from Notte et al., 2011 to incorporate main impacts on all modes of transport.

From Table 4 we can compile the three main climatic drivers for weather impacts in the transport sector:

1. Temperature,
2. Precipitation and
3. Wind.

There is a complex relationship between these different drivers, which need to be adequately modeled. This will be treated in the next section.

### 3.2 Climate regions of Europe relevant for the transport sector

In the recently completed FP7 project EWENT, the climate regions for Europe were analysed and according to this, Europe was divided into six climate regions that are practical in illustrating the various conditions in relation to transport sector (Figure 5) (Vajda et al. 2011):

1. Northern region (Nordic)
2. Temperate eastern region
3. Temperate western region
4. Mountainous regions (Alpine)
5. Mediterranean region
6. Oceanic region (Maritime)
It is notable that these climate regions have their own fundamental features which have various impacts on different transportation modes. Hence, in one climate region the same weather phenomena can have positive or negative impacts depending on the transportation mode in question. Overall as the figure shows some events such as strong winds in the Atlantic region will impact the Oceanic region, whereas sandstorms can affect the Mediterranean region etc.

The climate agenda for future was analysed for each of these climate zones in Europe, using simulations based on Regional Climate Models (RCM’s) from the ENSEMBLES project. A total of 6 RCM’s were used, driven by a Global Climate Model (GCM) based on the A1B (medium, non-mitigation) emission scenario of the IPCC (van der Linden and Mitchell 2009). The analyses compared the near-future (2011 - 2040) and far-future (2041 - 2070) time horizons with the present climate (1971 - 2000). Uncertainty due to emissions was neglected and the focus was on the A1B emission scenario, because the uncertainty in emission scenarios rivals model uncertainty only in the latter half of the 21st century (see Table 5 below).

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4 SMHIRCA-ECHAM5-r3, SMHIRCA-BCM, SMHIRCA-HadCM3Q3, KNMI-RACMO2-ECHAM5-r3, MPI-M-REMO-ECHAM5-r3, C4RCA3-HadCM3Q16.
Table 5: Summary of predicted changes in weather phenomena from 2011 to 2040 and 2040 to 2070 (Mühlhausen et al. 2011).

<table>
<thead>
<tr>
<th>Forecast per region</th>
<th>Nordic</th>
<th>Temperate</th>
<th>Alpine</th>
<th>Mediterranean</th>
<th>Maritime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Windgusts</td>
<td>-1.5% to 0.3%</td>
<td>-2.1% to -0.2%</td>
<td>-0.4% to 1.5%</td>
<td>-1.3% to 0.5%</td>
<td>-1.1% to 0.8%</td>
</tr>
<tr>
<td>Snowfall</td>
<td>-7.7% to -2.6%</td>
<td>-14.2% to -7.2%</td>
<td>-3.1% to -0.8%</td>
<td>-7.4% to -1.2%</td>
<td>-4.5% to -0.9%</td>
</tr>
<tr>
<td>Heat Waves</td>
<td>0% to 4.0%</td>
<td>0.1% to 6.5%</td>
<td>0.1% to 7.0%</td>
<td>2.8% to 18%</td>
<td>6.2% to 14.6%</td>
</tr>
<tr>
<td>Cold Waves</td>
<td>-16% to -7.8%</td>
<td>-41% to -22%</td>
<td>-8.8% to -0.5%</td>
<td>-25% to -5.3%</td>
<td>-15% to -5.1%</td>
</tr>
</tbody>
</table>

Changes in wind extremes are difficult to assess, since the multi-mean indicates a decrease over the Atlantic and Mediterranean Sea but a slight decrease or no significant change in either direction over the continent.

The frequency of snowfalls is projected to decrease all over Europe (see Table 5). The multi-model means show 1-5 fewer days of snow in Southern Europe, with changes in the frequency of snow days increasing progressively northward, to 10-20 days in Scandinavia compared to 1971-2000. The sign of change is consistent among all six RCMs, except in the Mediterranean and the western part of the continent. Contrary to the general decrease in snow days, the probability of extreme snowfall (> 10 cm) increases over large areas of Scandinavia and north-eastern Russia (1-5 days/year). This increase is partly due to the anticipated increase of total precipitation in the future but also due to warmer temperatures, since heavy snowfall tends to occur close to near-zero degrees Celsius. When snowfall become rarer, the alertness of the transport system become vulnerable as expertise become also rarer. On the other hand, the extreme snowdays in the North will put all transport modes in stress.

Warm days (mean temperature above 25°C) will become more prevalent by the 2050s. Scandinavia will experience 5 more warm days/year and Southern Europe 30-40 more days/year. In western and central parts of the continent, the projections suggest warm days will become more frequent by 20-30 days/year. The spatial variation of hot days (maximum temperature above 32°C) suggests a substantial increase for the southern part of the continent, up to 40 days/year, and an increase of 5-20 days/year in the mid-latitudes. This change implies that mid-latitudeal regions may experience as many days with heat waves by 2070 as the Mediterranean countries do in the present climate (see Table 5). This will increase the probability of congestion problems of road transport in the Mediterranean.

The simulated cold extremes decline in occurrence substantially by 2070 over the whole continent, most strongly over Northern Europe. The decrease in the frequency of frost days (0°C) varies between 20-30 days/year in Northern Europe and decreases gradually towards Southern Europe, with a decrease of 1-5 days/year. Most of the six models agree on the amplitude of change over land. This implies that Finland, Sweden and Norway are likely to experience as many frost days in the 2050s as some mid-latitude countries (such as the Baltic countries, Poland and Ukraine) do in the current climate.
Considering the magnitude of changes in precipitation extremes, a somewhat less clear change for the applied threshold indices are present than in earlier studies; an increase of 1-5 days/year over Europe except the Mediterranean, where no significant change or a sporadic decrease is expected.

The changes in the Baltic Sea maximum ice cover extent and the average maximum fast ice thickness were assessed based on the output of 19 global climate models; the results suggest that maximum ice cover extent and the probability of severe ice winters will decrease. Severe ice winters will become rare after 2030 also in the Nordic region where they are at present common phenomena with a corresponding increase in probability for mild and extremely mild ice winters. Eventually the icebreaker expertise may also decrease. Colder winters may cause severe difficulties after that.

3.3 Transport sector level adaptation challenges in climatic zones in the EU

3.3.1 The impacts of climate change on Tourism

Table 6 summarizes the effects of climate change by transport mode for each transport mode, based on the same climate scenarios used by EWENT, presented above.

Table 6: Summary of predicted impacts on transport from 2011 to 2040 and 2040 to 2070 p.101 (Mühlhausen et al. 2011).

<table>
<thead>
<tr>
<th>Impact by mode</th>
<th>Nordic</th>
<th>Temperate</th>
<th>Alpine</th>
<th>Mediterranean</th>
<th>Maritime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road Delay</td>
<td>&gt; &gt; &gt; &gt; &gt;</td>
<td>&gt; &gt; &gt; &gt; &gt;</td>
<td>&gt; &gt; &gt; &gt; &gt;</td>
<td>&gt; &gt; &gt; &gt; &gt;</td>
<td>&gt; &gt; &gt; &gt; &gt;</td>
</tr>
<tr>
<td>Road Accidents</td>
<td>&lt; &lt; &lt; &lt; &lt;</td>
<td>&lt; &lt; &lt; &lt; &lt;</td>
<td>&lt; &lt; &lt; &lt; &lt;</td>
<td>&lt; &lt; &lt; &lt; &lt;</td>
<td>&lt; &lt; &lt; &lt; &lt;</td>
</tr>
<tr>
<td>Rail Delay</td>
<td>&lt;&gt; &lt;&gt; &lt;&gt; &lt;&gt; &lt;&gt;</td>
<td>&lt;&gt; &lt;&gt; &lt;&gt; &lt;&gt; &lt;&gt;</td>
<td>&lt;&gt; &lt;&gt; &lt;&gt; &lt;&gt; &lt;&gt;</td>
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<td>&lt;&gt; &lt;&gt; &lt;&gt; &lt;&gt; &lt;&gt;</td>
</tr>
<tr>
<td>Rail Accidents</td>
<td>&lt; &lt; &lt; &lt; &lt;</td>
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<td>&lt; &lt; &lt; &lt; &lt;</td>
<td>&lt; &lt; &lt; &lt; &lt;</td>
<td>&lt; &lt; &lt; &lt; &lt;</td>
</tr>
<tr>
<td>Aviation Delay</td>
<td>$ $ $ $ $ $ $ $ $ $</td>
<td>$ $ $ $ $ $ $ $ $ $</td>
<td>$ $ $ $ $ $ $ $ $ $</td>
<td>$ $ $ $ $ $ $ $ $ $</td>
<td>$ $ $ $ $ $ $ $ $ $</td>
</tr>
<tr>
<td>Aviation Accidents</td>
<td>= = = = = = = = = =</td>
<td>= = = = = = = = = =</td>
<td>= = = = = = = = = =</td>
<td>= = = = = = = = = =</td>
<td>= = = = = = = = = =</td>
</tr>
<tr>
<td>Inland waterways Transport</td>
<td>Delay</td>
<td>&lt; &lt; &lt; = &gt;</td>
<td>&lt; &lt; &lt; = &gt;</td>
<td>N/A N/A</td>
<td>N/A N/A</td>
</tr>
<tr>
<td>Inland waterways Transport</td>
<td>Accidents</td>
<td>= = = = = = = = = =</td>
<td>= = = = = = = = = =</td>
<td>= = = = = = = = = =</td>
<td>= = = = = = = = = =</td>
</tr>
<tr>
<td>Coast Delay</td>
<td>&lt; &lt; &lt; = = N/A N/A = = &lt; &lt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coast Accidents</td>
<td>= = = = = = = = = =</td>
<td>= = = = = = = = = =</td>
<td>= = = = = = = = = =</td>
<td>= = = = = = = = = =</td>
<td></td>
</tr>
</tbody>
</table>

Road transport

For road transport most studies focus on traffic safety and congestion. Rainfall is the most important variable, whereas it increases accident frequency, but decreases accident severity because average speed is reduced (Koetse and Rietveld 2009). The disruptions of the network as a consequence of extreme events are the most important expected impact on the infrastructural level. This means that the regulation for the construction of road infrastructure should take climate resilience into account. The foreseeable impacts on the rail infrastructure are similar and call for a similar action (Hooper and Chapman 2012).

The anticipated decrease in snowfall and frozen precipitation would have a positive impact on road, rail and air transportation reducing the cost of maintenance in many European countries; however in the Nordic

5 The approximate assessment is based on the assumption that the waterway infrastructure is not going to be changed and the transport volumes are approximately the same as today. Accidents are expected to remain unchanged or to decrease due to improved fairway information and technological developments. Considering the current technology level and assuming no further development, an increase of accidents related to grounding may be expected in areas vulnerable to low-water occurrence.
countries, where heavy snowfall is already one of the most common disruption factors, it seems to become a more severe phenomenon. The phenomenon should gain more attention in research with the better climate models and improving parameterization of cloud processes since the increase in intensity would have a very high impact like in Canada.

**Rail transport**

For rail transport three major shifts in weather conditions can be important. An increase in hot and dry summers lead to increased buckling of rain tracks, desiccation of tracks and ventilation problems for underground railway systems. Due to wetter climate increases in precipitation can lead to more flooding of railway tracks. In addition strong wind can cut trees and blow leaves and sticks on rails. The trees can fall on electricity cables especially in wooden areas. The clearing will cause delays

**Aviation sector**

The aviation sector is particularly complex. Budd and Riley (2012) find that the aviation is seriously challenged by climate change both directly and indirectly. During the arrival and departure procedures, aviation is much more sensitive against even slight weather phenomena. However, it has a short recovery time even from strong phenomena (Mühlhausen et al 2011).

Direct impacts come from changes in the frequency, spatial distribution, duration and intensity of wind, rain and snow. In addition fog causes low visibility why the separation of aircraft has to be increased. All these phenomena may cause major trouble with large cost implications, for both airlines and travelers.

On the legislation side, the EU emissions trading system (EU ETS) is aimed to make the polluter pay by creating a market for emissions. On the long-term this might reorient demand to shorter distances and/or to other modes.

**Walk and Cycling**

Walk and Cycling are widely considered as modes which might help reducing emission if they would be to substitute some trip with other modes of transport, especially car on shorter distances. Their modal share, however, will be probably also influenced by climate change, with the rise in temperatures being expected to have positive impacts in Northern Europe and negative impacts in Southern Europe.

**Water Transport**

**Icebreaking**

The ice cover of the Baltic Sea Motorway varies considerably from year to year. The northern parts of the Motorway freeze every winter. In a hard ice winter, the Motorway freezes completely. Traffic conditions were difficult in terms of the ice in winters 2002 - 03, 2009 - 2010 and 2010 - 2011. In the worst case, merchant vessels bound for Russian ports but stuck in the ice had to wait for icebreaker assistance for as long as two weeks. Despite climate change, hard ice winters occasionally occur in the Baltic Sea, especially in the Gulf of Finland and the Gulf of Bothnia.

In a report of the European Commission (EC 2007) export forecasts have been introduced. The export will grow in Russia 2.4 fold in 2007 - 2030 as they do also in Baltic countries (Estonia, Latvia, and Lithuania). The growth of export has a significant effect particularly on sea transports, and icebreaking interruptions would hinder both the imports and exports, affecting the economies of the countries around the Baltic Sea.

Even the current icebreaker fleet available in the Baltic Sea is incapable of providing a satisfactory level of service in a hard ice winter. The combination of growing traffic volumes and the hard ice winter will mean serious difficulties for industrial and commercial transports, affecting both the competitiveness and the economies of countries located around the Baltic Sea.

In the IceWin project, an assessment was made of the economic effects of interruptions in icebreaking. A general equilibrium model EDIP was used to evaluate three scenarios: a mild winter, an average winter and a severe winter. The table below shows the reduction in yearly maritime transport over the Baltic Sea for the different countries which will be discussed. For example, in a year with a mild winter, there is a reduction of 25 % in the Finnish yearly imports and exports via the Baltic Sea. Note that for Sweden we take into account the accessibility of the three main harbours (see Table 7).
Table 7: Scenario description: yearly reduction (%) in maritime imports/exports for the different countries (Delhaye et al. 2011).

<table>
<thead>
<tr>
<th>Country</th>
<th>Mild</th>
<th>Average</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finland</td>
<td>0.25</td>
<td>0.417</td>
<td>0.417</td>
</tr>
<tr>
<td>Estonia</td>
<td>0.167</td>
<td>0.333</td>
<td>0.417</td>
</tr>
<tr>
<td>Latvia</td>
<td>0.083</td>
<td>0.167</td>
<td>0.25</td>
</tr>
<tr>
<td>Lithuania</td>
<td>0</td>
<td>0</td>
<td>0.25</td>
</tr>
<tr>
<td>Poland</td>
<td>0</td>
<td>0</td>
<td>0.25</td>
</tr>
<tr>
<td>Sweden</td>
<td>0/0/0.5</td>
<td>0/0.167/0.5</td>
<td>0.25/0.25/0.5</td>
</tr>
</tbody>
</table>

Table 8 shows both the relative effects on GDP and social welfare for the six countries. Both in absolute as well as in relative terms, the effect on GDP is, as expected, the largest for Finland. If icebreaking services are interrupted, GDP would decrease with about 2.9 % in mild winters up to 6.8 % during average and severe winters. Remember that for Finland the scenario average is the same as the severe scenario. Imports and exports to and from Poland and Lithuania are assumed only to be stopped during severe winters and even then, the effect on GDP is rather limited (around 0.5 %).

Table 8: Effect on GDP (%) for each winter scenario and each country (Delhaye et al. 2011).

<table>
<thead>
<tr>
<th>GDP</th>
<th>EE</th>
<th>FI</th>
<th>LV</th>
<th>SE</th>
<th>LT</th>
<th>PL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild</td>
<td>0.52</td>
<td>-2.86</td>
<td>-0.35</td>
<td>-0.09</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>1.22</td>
<td>-6.78</td>
<td>-0.71</td>
<td>-0.47</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Severe</td>
<td>1.75</td>
<td>-6.78</td>
<td>-1.07</td>
<td>-1.54</td>
<td>-0.41</td>
<td>-0.51</td>
</tr>
</tbody>
</table>

Inland waterway transport

Generally, inland waterway transport (IWT) is characterised by a high degree of reliability and safety compared to other transport modes. It is also known for its low environmental impact, compared to the more polluting road transport. To some extent IWT has always been dependent on climate conditions. River basins are expected to be sensitive to climate change aspects, e.g. in terms of water level fluctuations and resulting effects on costs and reliability. Several project and studies address this topic. Examples are CLAVIER, KLIWAS and ECCONET. Changing climate conditions and a rise of extreme weather periods could trigger an impact chain with the result that navigation conditions for inland vessels change, cost advantage and reliability of waterborne transports decrease, thus impairing competitiveness of in particular those sectors which rely on cost-effective transport of especially bulk and containerized cargo.

Model results of ECCONET show no significant effects on low flow conditions for the Rhine canal and the Rhine Main Danube canal until 2050. The upper Danube would experience a moderate increase in low flow conditions. In the period from 2050 - 2100 the trend towards drier summers and more wet winters is confirmed by our models and will gain in importance towards the end of the century. Statistical evidence points out that the disposition for ice formation on both Rhine and Danube will most likely reduce over the whole 21st century. Fog is a hard to track problem as there is a large anthropogenic influence, however the current trend points to a decrease in the occurrence of fog.

In the ECCONET project geographic multimodal transport model NODUS was used to simulate the impacts of climate change on the inland navigation transport on the Rhine over the period 1977 - 2050. The main conclusion was that the possible climate changes from 2005 - 2050 and their impact on the Rhine hydrology, as modelled by the two long term dry and wet scenarios, are not likely to be strong enough to
induce any significant shift in modal shares. However, we should note that a drier scenario would justify maintaining more small vessels in operation despite the planned improvements in waterway infrastructure.

### 3.3.2 Adaptation measures for the transport sector

In the EWENT project and the recently started MOWE-IT project the potential for measures as well as cross-modality opportunities have been discussed. Table 9 shows both short-term and long-term alternatives and also addresses the feasibility of measures, in terms of costs associated (Nokkala and Leviäkangas 2012).

Table 9: Mitigation strategies for weather phenomena for various transport modes. (Nokkala and Leviäkangas 2012).

<table>
<thead>
<tr>
<th>Transport mode</th>
<th>Weather phenomena</th>
<th>Short-term</th>
<th>Long-term</th>
<th>Feasibility (costs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road</td>
<td>Wind gusts</td>
<td>Improve road-side information areas of strong winds</td>
<td>Design shields at critical areas to prevent wind for disturbing traffic</td>
<td>Location-specific, in areas with high occurrence, most likely high costs as well</td>
</tr>
<tr>
<td></td>
<td>Low temperatures</td>
<td>Improve road-side information and use variable speed limits</td>
<td>Design new ways to reduce impacts (vehicle technologies, maintenance equipment etc.)</td>
<td>Short-term relatively low cost, long-term high cost</td>
</tr>
<tr>
<td>Rail</td>
<td>Wind gusts</td>
<td>Improve information systems to alert of incidents or damage to infrastructure; clearing of vegetation (trees) in rail corridors</td>
<td>Design new routes with resilience to wind gusts; investigate possibilities for sub-surface electricity and communications systems</td>
<td>Some are relatively low cost measures, easily to adopt, some require substantial investments</td>
</tr>
<tr>
<td></td>
<td>Low temperatures</td>
<td>Increase maintenance staff at critical times; equip switches with efficient heating systems</td>
<td>Design equipment and maintenance with better resilience against cold temperatures</td>
<td>Depending on frequency and development needs costs can be minor or more significant</td>
</tr>
<tr>
<td>Aviation</td>
<td>Fog (visibility)</td>
<td>Improve forecasts on conditions resulting in poor visibility</td>
<td>Design and locate new airports in ways to reduce fog</td>
<td>Significant but related to building of the entire infrastructure</td>
</tr>
<tr>
<td></td>
<td>Low temperatures</td>
<td>Improve de-icing operations and maintenance at vulnerable airports</td>
<td>Improve equipment that can faster and cost-effectively provide needed maintenance</td>
<td>Compared to problems the costs of technologies are relatively low</td>
</tr>
<tr>
<td>Waterborne transport</td>
<td>Wind gusts</td>
<td>Improve weather information provision</td>
<td>Design port entrances and handling equipment with better resilience against wind</td>
<td>Relatively low costs</td>
</tr>
<tr>
<td></td>
<td>Drought</td>
<td>Provide information to ships in advance</td>
<td>Design inland waterways with greater resilience to drought, including ports</td>
<td>Relatively low costs</td>
</tr>
</tbody>
</table>

At the systems level, Leviäkangas et al. (2011) present a summary analysis of the land transport and the network resilience. In principle, the cost factor is the challenge as most measures to be taken are costly. On road use, costs can be borne by users as charging of services is possible. In rail and aviation the fact that systems are centralised and concentrated provides opportunity to better manage the measures needed. (Table 10).

Table 10: Strategic options for land transport network emphasis in resilience enhancement p.104 (Leviäkangas et al. 2011).
<table>
<thead>
<tr>
<th>Strategic emphasis</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road system resilience</td>
<td>Much of the cost can be borne directly by the users, because users pay for in-vehicle safety systems and possibly also partly for information services. The road system is the most “connecting” mode of transport – its reliability also serves the other modes best.</td>
<td>Investing in maintenance equipment and more comprehensive traffic management is expensive and possibly not a very cost-efficient strategy. The road system is a scattered system that is complex to manage and control.</td>
</tr>
<tr>
<td>Rail and aviation system reliance</td>
<td>Rail and aviation systems are concentrated and centralised and manageable. Mitigation and adaptation strategies are more easily implemented in centralised systems. Aviation infrastructure owners and the aviation industry are obliged to bear much of the cost (which are then passed on to the consumer).</td>
<td>Both industries are in an economic pinch and introducing more obligations might further aggravate their situation. For the rail sector some measures might require large public investments, which could be difficult to justify for a sector that already enjoys some public financial support. Both rail and air travel chains almost without exception include stretches on roads and streets.</td>
</tr>
</tbody>
</table>

A recent study by Nemry and Demirel (2012) addressed the adaptation challenge in road and rail transport.

A process-based approach, combining projected climate data with geographical transport information with technical and economic information, was applied to assess future vulnerability to heat stress, heavy rainfalls and sea level rise. Adaptation measures were studied to mitigate the risk or weather induced stresses:

1. Rail buckling
2. Road pavement damage
3. Bridge scour

One of the areas studied was the cost of road pavement adaptation to higher temperature due to climate change. Road Asphalt binder adaptation is the least costly measure and, given the relatively short life cycle (~7 years), it is not expected to represent a major challenge for infrastructure planners. This is shown in Table 11 for the three scenarios created in the study.
Protection of river bridges may be needed over the next decades for about 20% of the stock in order to mitigate scour risk associated with increasing river flood. Given that bridges are designed for long life spans (>100 years) and that their maintenance and repairing activities have to be planned long in advance, future climate-related risk should be included in corresponding prior cost-benefit studies. It has to be noted that in this study, only one particular climate scenario was considered, which may significantly underestimate the uncertainty about both the vulnerable bridge stock and adaptation costs.

Regarding heat-induced rail buckling risk, the most commonly applied adaptation measure (speed limits) results in trip delays. These were assessed to be currently negligible (~0.01% of total current trips time) and could be doubled or multiplied by four depending on the climate scenario (A1B or RCP8.5) over the period 2070 - 2100. Changing the track anchoring conditions (adapting stress-free temperature to higher summer temperatures) could help reducing these delays, but a detailed assessment would be needed to validate such an option and assess its costs.

It was assumed that, long distance and highway lines of EU railway network are always under good quality conditions (~20%). For the short and medium distance traffic, it was considered that 5% of rail tracks in the network are sustained by inadequate ballast. Also, speed limits are assumed to be applied...
during 50 % of the daily traffic period (~from 12:00 to 20:00). Unfortunately, the absence of a clear definition for inadequate ballast, and the lack of statistical data on heat related delays in Europe make impossible to validate this percentage for the European Union as a whole.

Several country-specific conditions could justify using higher or lower values. For instance, in case of countries / regions with mild winters, inter-seasonal maintenance may be less stringent and ballast is potentially deficient. Other country-specific conditions may also be considered, such as the number of tunnels (e.g. Austria) under which rail buckling is much lower weather stressed. This needs to be taken into account when interpreting the results.

In the ECCONET project a more detailed study was made on adaptation in the inland waterway sector. The project distinguishes 4 classes of adaptation measures. In the class of ship and operation related measures, the most promising measures involve weight reducing technologies, flat hulls (for push boat technology) and the use of coupling convoys (especially on the Rhine river). As an important side note, we need to mention that a substantial rise in fuel cost has a significantly larger effect on the transport cost than any climate and discharge change scenario (KLIWAS).

In terms of infrastructure measures we can conclude that large infrastructural works are not justified with respect to climate change. This is caused by the large investment costs and the limited benefit of such projects until 2050. There is however, even under current conditions, a strong need for improved maintenance of the waterways.

Improved forecasting are very hard to make and any development in this class has an unknown R&D cost. Nevertheless any improvement in this type of forecasting is considered very valuable to the sector.

As for the change of production processes and stock keeping, the cheapest solution in the short term is usually waiting or using already available storage capacity. Only when problems continue, the shipper will consider using another transport mode, usually railway freight, which is generally a more costly and inflexible solution. Investments in stock keeping and relocation are very costly and are only taken as a final option.
4 Adaptation challenges for the Tourism sector

According to the Commission of the European Communities (CEC 2009), the tourism sector may be able to respond to market signals or environmental changes brought about by climate change. Nevertheless, this autonomous adaptation is unlikely to be optimal because of uncertainty and imperfect information or financial constraints. Hence, adaptation efforts cannot be left solely to individuals and businesses.

The tourism sector is growing in importance, numerically and economically, and the current and anticipated changes in climate highlight the urgent and immediate needs for strong and effective responses to the threats and opportunities climate change represents for the tourism sector. The consequences of climate change for tourist destinations are far-reaching, as they affect the resource base of tourism, both directly and indirectly (Becken and Hay 2012).

It is obvious that there will be winners and losers, since climate change alters the comparative advantage of holiday destinations, creating opportunities for some and challenges for others. So, when focusing on the challenge of avoiding major disturbances in the sector, we should keep in mind that one of the key challenges may well be not to miss opportunities that may serve as a means to reduce the overall negative impacts for the sector.

4.1 Key strategic challenges for avoiding major disturbances in the Tourism sector

The tourism sector is a climate sensitive economic sector in which both supply and demand are affected by climate directly but also indirectly, as the overall development of the travel industry heavily depends on social aspects and the prevailing economic situation. The demand is directly affected by climate by altering the consumption and travel choices (the demand for tourism, the demand for different activities and the demand for a given destination) of an individual and supply is affected directly by altering the suitability of production costs and indirectly by the changes in demand. The travel preferences of individuals are often called push factors in the tourism-related literature. They include social-psychological factors that motivate the individuals to travel and choose among activities or among totally different kinds of products and services. Push factors determine individuals’ demand functions for tourism and different tourism activities and thus determine the aggregate demand for tourism. Pull factors are qualities of destinations that define the attractiveness of a destination (Becken and Hay 2007). Most often-used climate-related pull factors are thermal comfort, water availability and snow cover reliability. Pull factors divide the aggregate demand of different types of tourism activities between different destinations.

The key strategic challenges in the tourism sector therefore can be categorized in the following way:

- **Changes in demand**
  - Changing demand of different types of tourism (e.g. winter sports) (push factors)
  - Changing demand of tourism destinations, (e.g. trips to Crete) (pull factors)
  - Changing volatility of demand (weather dependence)
  - Demographic change

- **Changes in supply**
  - Transportation
  - Adaptation measures, e.g.
    - Snow making
    - Building heating/cooling systems
    - Insurance coverage

4.1.1 Climate change induced changes in the demand of tourism activities and destinations

Recreational activities and tourism are defined as those activities that people choose to do in their spare time. Even though some consumer subgroups may have less leeway for adaptation, overall demand for recreation and tourism tends to be quite flexible. Thus, the demand for tourism can – in principle – be adapted to climate conditions or climate-induced-impacts by behavioural adaptation, e.g. choosing a
different holiday destination, a different timing for the same destination or by switching to a different activity altogether and/or technical adaptation (range of specialized equipment) (Scott et al. 2009).

In particular technical adaptation implies the continuation of a preferred activity in the originally intended location and timeframe (month; season), but under changed conditions. This adaptation approach gets more likely the stronger the push factors are. Conversely, a change of location or timing means that a consumer seeks (approximately) the same experience with the same convenience level, thus implying a change on the distribution of demand for holiday destinations. This is an example of pull-factor driven adaptation. If no reasonably similar experience can be found with a minimum acceptable experience level, the probability increases that the consumer changes activity/type of experience altogether, which in turn may entail also locational changes. This last type of adaptation involves both push- and pull-factors.

The literature on the effects of climate change is mainly concentrated on changes in pull factors, while much less literature can be found on changes in push factors. A limited number of studies have explored the impacts of climate change on tourists and their preferences. Lohmann and Kaim (1999) conducted a survey among German citizens and found that weather was the third most important and climate the eight most important factor explaining the destination choice. A study in Switzerland reported that 58 % of skiers indicated they would continue to ski under poor conditions at the same frequency, whereas almost 32 % would ski less often and 4 % would not ski at all. Push-factors might also have some unpredicted impacts on destinations that are likely to disappear or to be spoiled in the near future. “Last minute” tourism market trend is already being observed in some parts of the world (Scott et al. 2009).

The aggregate demand for tourism is expected to keep on growing in the next couple of decades. Tourism in the European Union increased by 7.2 % overall from 2000 to 2009, meaning an average annual change rate of 0.8 % (Eurostat 2012). Climate change will probably have little effect on overall demand, but may have considerable effects on distribution by location, season and (perhaps) by type of holiday (Amelung 2009; Scott et al. 2009).

As aggregate demand for tourism is expected to keep on growing in the future, the relevant question is, to which destinations and activities will demand be oriented, or in other words, how well the qualities of destinations match the preferences of tourists. One must note that the climate factor is only one of the pull factors affecting the (subjective) quality of a destination (next to cultural factors, shopping possibilities, price level etc.) of which some are inherently directly part of the supply of tourism sector). However, the climate-change-induced changes in demand can be at least to some extent projected by studying the climate-change-induced changes in the pull factors and by comparing them to the predicted push-factors. It is not enough to study the absolute changes in the attractiveness of a particular destination. To be able to draw estimates on the future tourism, the attractiveness of different destinations need to be studied relative to competing destinations and activities (Hamilton et al. 2005).

Therefore, demand variability as a key challenge needs to be analysed by looking into three topics:

- Analysing the push factors (i.e. what are the main trends in consumer behaviour concerning tourism?)
- Analysing the pull factors (i.e. how will climate change alter the properties of tourist destinations?)
- How will the qualities of holiday destinations (that are affected by climate change) meet the consumer’s projected future preferences?

Hence, there is a simultaneous process of changing tastes and changing destinations that is explaining current and future sales in the tourism industry. For some regions this will mean a decreasing demand, for others an increasing demand. Both are challenges for the sector, but volatile sales are a challenge for the vivid tourism sector, that is quite used to. But there is a third, second order challenge: what if the change in demand is also altered by climate change? Given, that weather and climate are constitutive properties of touristic experiences, this is very likely to be the case. In other words: If the weather dependency of tourism demand is also affected by climate change, this (i.e. changing volatility) is a challenge that may in some circumstances surpass the mere down- or upturn of regions and is a new management challenge to the industry, that should be supported by adequate tools.

Other socioeconomic factors, like demographic change have a more direct but nonetheless important impact on the sector.
In the European context it is also important to realise that population structure is changing significantly. The share and absolute number of aged people (65+) will increase significantly (from 17% in 2008 to 23% in 2030, Eurostat 2012). This will affect the structure of the tourism market and may thereby either attenuate or increase climate change effects for different tourist regions.

4.1.2 Climate change induced changes in the supply of tourism services

By its very nature the supply of tourist services encompasses different sectors such as transportation, water supply, energy, hospitality services, holiday resorts, tour operators and so on. Climate change has an effect on all of those and each of the sectors needs to be studied first separately.

Transportation

For the future of the tourism sector the transportation sector is of particular importance. The effects of climate change on transportation have been studied already in the EU-projects EWENT and WEATHER, and will be further studied in this study and in another ongoing FP7 project MOWE-IT (with special emphasis on intermodal substitution).

The price of transportation (gasoline, plane tickets etc.) is an important determinant of the movement of people. For example Berrittella et al. (2006) assumed that the price of transportation will decrease in the future making long distance travelling cheaper and distant locations more accessible. The picture is not quite that clear, as increased frequency of extreme weather events and climate mitigation policies (emission reduction targets) will tend to raise the travel costs. Furthermore, on-going consolidation in the civil aviation sector may eventually lead to less competitive markets. Currently about 75% of the emissions attributable to tourism stem from transportation (UNWTO 2008) and quite contrary to Berrittella et al. (2006), it has been argued that climate change mitigation policies are likely to lead to an increase in transport costs. An example is the (attempted) inclusion of civil aviation in the EU ETS. This would make tourists change their travel patterns (e.g., shift transport mode or destination choices) and thus decrease the share of long-haul travelling (UNWTO 2008).

Adaptation of supply to changes in the demand of tourism activities and destinations

However, one of the most dramatic climate-change-induced changes for the suppliers will come indirectly through the changes in demand. Climate change will have an enormous effect on the pull factors of destinations. The suppliers can have an influence on some of them (at the same time increasing their production costs) for example by substituting the decreased level of natural snow by artificial snow or by building heating/cooling systems. Besides technical adaptation measures, tourism providers can adapt by more business-like measures, e.g. by pricing, buying insurance coverage, marketing, diversification or by relocating their businesses (Scott et al. 2009). Different kinds of innovations might arise, making room for new activities to attract tourists.

Of course, destinations with increased level of tourism demand will have to adapt too: e.g. new hotels must be built, environmental issues must be handled, and the issues with increased demand for energy, food and water must be solved. Adaptation literature is usually focused more on the adaptation to deteriorating conditions, but for example the coastal region of Baltic Sea is predicted to attract more visitors in the future provided that the Baltic Sea will not get too polluted. The increased amount of tourism adds another burden to the environment. If the protection of the Sea is neglected, the increased income from tourism may be short-lived.

4.1.3 Main strategic challenges

Overall, some preliminary main results and key strategic challenges were spotted from the literature: (e.g. EEA 2012):

- Autonomous adaptation is unlikely to be optimal because of uncertainty, imperfect information or financial constraints. Hence adaptation efforts cannot be left to individuals or businesses.
- Climate change alters the comparative advantage of holiday destinations, creating opportunities for some, and challenges for others. In the first half of the century (until 2050s), Northern Europe will gain on the climatic advance of Southern Europe to some extent. Thus, the relative competitiveness of Northern Europe will improve.
In the latter part of the century, conditions in the Mediterranean will deteriorate and more northern parts of Europe will have absolute advantage in the summer, especially conditions on the southern coast of the Baltic Sea will be optimal for outdoor tourism.

The scarcity of water resources due to overexploitation of resources and prolonged droughts in the Mediterranean may cause disturbances in the future.

Spring and autumn conditions for tourism will improve all over Europe.

Snow-related tourism will face higher risks as snow-cover days will decrease (excluding the most northern parts of Europe such as Lapland) and inter-annual variability will increase. This results in lower snow cover reliability, putting ski resorts at lower altitudes at risk.

Ski resorts in higher altitudes and further north will face the same risks in the latter part of the century.

Tourism is volatile – determinants for (e.g. price/income dependencies) destination choice and volume are largely unknown.

Weather dependency of tourism demand might in itself increase, thus increased volatility adds another key strategic challenge for tourism management.

Weather dependency is not equal though related to climate dependency of demand. So the difficulty to assess the (long-term) climate dependency of tourism of various tourist activities is per se a challenge of long-term planning in tourism (i.e. infrastructure development and investment decisions).

The importance of ‘relative attractiveness’ is unknown; e.g. the impact of poor snow conditions in one place may depend on the extent of change in conditions in competitive destinations.

### 4.2 Climate Zones of Europe relevant for the Tourism sector

#### 4.2.1 Zones that have outstanding significance for Tourism

The statistics on the tourism sector in Europe can be found from Eurostat. A commonly used indicator of performance of the tourist sector in a country or region is the number of overnight stays per year and season\(^6\). From the statistics can be inferred that in the EU, tourism is concentrated in coastal regions, the Alpine regions and in some cities (Figure 6). The top 20 regions each recorded more than 24 million nights per year (in 2010). This top 20 list includes six regions from Italy, five from Spain and France each, two from Germany, and one from Austria and the United Kingdom each.

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\(^6\) Another useful indicator for this study would be (estimated) tourist expenditures by region.
Supposedly the overnight stays indicator often also reflects daytrip based tourism activity (return trip on same day) quite well, even though the literature acknowledges the problem of adequately measuring daytrip based tourism (Vanhove 2011; Stynes and White 2006). For example in tourist areas (such as for beach tourism) with significant nearby domestic population centres the share of daytrip visitors may rise far beyond the average for popular tourist areas. Cases in point are the beach coasts of the Benelux and some stretches along the English South Coast.

As can be seen from Figure 6 (Eurostat) the coastal areas and islands (Canary Islands, Madeira, Crete, Malta, etc.) in Southern Europe are the most popular tourist destinations in Europe at the moment. Eastern Europe is trailing behind Western Europe, apart from Bulgaria. Some cities attract a lot of tourists such as Paris and London. The Alpine region is an important ski tourism location.

The zones can be divided either by activity (i.e., placing Alpine region and Lapland under the same group) to e.g. city destinations, beach destinations and ski destinations. Another way is to simply use geographical division, e.g. Mediterranean, Alpine Europe, Northern Europe, Eastern Europe and Western Europe.

The application of a particular zonal categorisation will depend on the questions to be answered in ToPDAd. For merely understanding effects of climate change a climatic-geographical zoning seems a likely candidate. On the other hand if we want to understand inter-regional competition effects of climate change and adaptation, a zonal system based on type of tourism seems more appropriate. This may mean that we need to use both types of classification (and perhaps still others as well) and thereby need GIS based linkage options to enable communication between the assessment results of the different zonal classifications. In this respect it is also important to acknowledge the large variation in size of the administrative areas used for the tourist statistics (see Figure 6) which could hamper comparability. Yet, the spatial definition basis is also an issue for the energy and transport sector as well as for the downscaled
output of the climate model ensemble, and should therefore be approached as a comprehensive solution for the entire ToPDAd study.

In the following we are applying a zoning which meets both criteria, i.e. activity based zoning which is further classified by climatic-geographical zones.

The first activity based zone considered is snow oriented winter tourism regions that are further divided by the climatic-geographic zones of Alpine Arc (AA) and Nordic Countries (NC).

**Snow oriented winter tourism regions**

- Alpine Arc (AA)
- Nordic Countries (NC)

Further on, another important activity based zone constitutes beach oriented summer tourism which is further classified by the Mediterranean Basin (MB), the Coastline of the EU 27 (CL) and the European Lakes (EL).

**Beach oriented summer tourism regions**

- Mediterranean Basin (MB)
- Coastline of the EU 27 (CL)
- European Lakes (EL)

The third activity based zone considered under ToPDAd is Urban tourism and other tourism types with the climatic-geographic zone of Cities of Europe and Unspecified Regions that will profit from diversification.

**Urban tourism and other tourism types**

- Cities of Europe (CE)
- Unspecified Regions that will profit from diversification (UR)

Figure 7 below, shows the relative importance of winter tourism in Central and Northern Europe.

![Share of winter overnight stays, 2001-2011, in % total overnight stays in the tourism years 2001-2011 (Eurostat).](figure7)
4.2.2 Changes in weather phenomena with allegedly hazard implications for Tourism

According to an IPCC assessment published in 2011, by the end of the 21st century there will likely be increases in frequency of both extreme high temperatures and heavy precipitation events, with the latter contributing to increases in local flooding in some regions. Furthermore, a pole-ward shift in mid-latitude storm tracks is anticipated. Due to reduced precipitation and/or increased evapotranspiration, droughts will intensify in the 21st century in areas such as the Mediterranean. Most glaciers will continue to retreat and extreme high sea levels will occur with increasing frequency as a result of the combination of increasing mean sea level and the likely increase in tropical cyclones maximum wind speed (Becken and Hay 2012).

As mentioned above, weather phenomena may affect the sector on either the demand or the supply side or on both. The literature analyses usually these phenomena either in a qualitative or in a quantitative way. Index based quantitative analyses (e.g. based on the TCI (Mieczkowski 1985)) can reveal that a simple weather index such as temperature that is supposed to rise under climate change conditions may first influence overnight stays positively in some region, whilst the impact turns to the negative if a certain threshold is surpassed. A qualitative description of weather phenomena likely to be expected, as stated e.g. by Becken and Hay (2007), on the other hand usually focuses on more simplistic relations. However, both approaches are valuable to grasp a broader scope of possible influences.

- Changing TCI
- Higher temperatures
  - Reduced snow cover
  - Hotter days,
  - Increased winter storms
- Higher sea level
  - Increased coastal erosion/inundation
- Rainfall variability
  - Drought
- Floods
- Extreme weather events

As can be seen from this collection of weather phenomena, the distinction between those, who influence either the demand side (the benefits of a stay) or the productions costs and therefore the supply side are not clear cut: If a region is attractive, reduced snow cover may well be substituted by higher costs due to artificial snow making and demand may not change at all. Some studies on extreme events have shown that also if the production of the touristic good per se is not affected, the perceived danger from e.g. floods may keep tourists away from a region (or attract additional ones!).

Still, for an economic analysis, it makes sense to distinguish between supply and demand side effects. Whilst extreme events are a good example of affecting both sides, the TCI and general warming related issues are more associated to the demand side, whilst snow cover certainly is affecting the industry’s supply side already now.

Extreme weather events

Extreme weather events increase operating costs (e.g. evacuation, maintenance costs) and are responsible for loss of revenue (e.g. cancellations). On the other hand, some operations experience increased demand when others are unable to operate. Hence, extreme weather events generate winners and losers (Becken and Hay 2012).

It is unclear in which regions of Europe severity or frequency of extreme weather events will increase but it is clear that extreme events have a strong impact on tourism and therefore even unchanged patterns of extreme weather events constitute a key challenge for adaptation.

However, for the tourism sector, climate change is more likely to cause economic hazards for some regions than acute natural hazards. Tourism demand is expected to grow, but as the climate related pull factors change in holiday destinations, people may reconsider their holiday destinations accordingly. A single weather parameter (such as annual mean temperature) is not enough to describe the change in the climatic
pull factors and various kinds of indicators are needed to describe the attractiveness of destinations for different activities.

**Changing TCI and warming**

Mieczkowski (1985) created a tourism climate index (TCI) which consists of five sub-indices: the highest weight is given to the daytime comfort index (maximum daily temperature and minimum daily relative humidity), whereas sunshine index (total hours of sunshine) and precipitation (mean monthly precipitation) are given the second-highest weights. These are complemented by daily comfort (mean daily temperature and mean daily relative humidity) and wind speed (average monthly wind speed). The best TCI score is 100 and the worst -30, over 70 being “very good”. For a more detailed description of TCI see Mieczkowski (1985). TCI is created to describe the climatic attractiveness of a destination for “light outdoor activities” which could include city tourism and other related activities. TCI scores for the current and future climate were modelled by using HIRHAM and RCA3 models using A2 and B2 scenarios in the PESETA-project (Amelung et al. 2009).

Between the baseline (‘1970’) and 2020 the changes are small but visible. In all three seasons (winter is excluded) there is a northward trend in TCI patterns. Changes are most significant in the Mediterranean where the area ranked “better than very good conditions” expands. Some parts of the Mediterranean already become too hot to be optimally pleasant in the summer. The water resources in the Mediterranean can become a huge risk already on a shorter term (Amelung et al. 2009).

By the end of the 21st century, the distribution of climatic attractiveness in Europe is projected to change significantly, however the estimate of the magnitude of the change depends on the model-scenario used. For the spring season all model results show a clear extension towards the north of the zone with good conditions, excellent conditions being available in the Mediterranean in all model results. In the summer the zone of good conditions also expands towards the north, whereas this zone is shrinking in the south. Depending on the model-scenario, the conditions in Northern Europe including Scandinavia become good or even excellent. Some of the most popular holiday destinations such as in Greece show a decrease of their rating, sometimes even quite dramatically. The projected changes for autumn are fairly similar to those of spring. In the winter, some parts of the Mediterranean will improve up to acceptable levels. All in all, these results can be summed in one map, where the number of months suitable for tourism (TCI over 70) is summed over a year which shows that season length will become much more evenly distributed across Europe. This is depicted in Figure 8 which is based on RCAO model and A2-scenario. More detailed results and predictions from different models can be found from the PESETA tourism report by Amelung et al. (2009) and are thus not reported here in further detail.

![Figure 8: The average number of months with very good conditions for non-winter tourism, on the left the situation in the 1970s and on the right in the 2080s, according to RCAO-model and A2-scenario (Amelung et al. 2009).](image_url)

Moreno et al. (2007) adjusted the TCI to be more suitable to assess the attractiveness of a destination for beach tourism by specifying a higher optimal temperature range. No models have been run to predict the changes in this index, but as higher temperature is more suitable for beach tourism, the Mediterranean is better off than predicted with the traditional TCI. Thus, the demand pattern for beach oriented tourism is probably going to follow the same pattern as for light outdoor tourism (Mediterranean will first gain but
eventually the optimal conditions will move towards the north) with development lags a few decades behind. The future development in the TCI or a similar index should be modelled to be able to predict the beach oriented tourism patterns in the future.

**Reduced snow cover**

Winter tourism must be studied separately from other forms of tourism since it requires very different conditions. Winter activities require snow, thus snow-cover is crucial for ski resorts. Snow can also be artificially made but it is expensive, scenery is not as attractive as with natural snow and snowmaking requires the right temperature range. However, weather should not be too cold either as extremely low temperatures have a negative effect on the attractiveness of a destination as well. If a winter tourism climate index was developed, also sunshine and wind factors should be included (Shih et al. 2009). Shih et al. (2009) ran a model with multiple weather variables to study the effects of weather on ski lift ticket sales, the only variable to consistently reach statistical significant was snow depth. In another study, the amount of snow-cover-days explained almost 90 % of the annual variance in ski lift ticket sales in southern Finland (Nurmi and Jokinen 2012). Thus, it can be argued that snow-cover is the most important climate related pull factor for winter tourism.

Alpine Europe and its ski-industry, mainly located in France, Switzerland and Austria, is of high importance for the respective countries. Austria is particularly dependent on the industry, the annual contribution of tourism to GDP is over 18 % and over half of it consists of winter tourism. By some estimates the length of the snow cover period in the most sensitive areas may be reduced by about four weeks if mean temperature rises by 1°C. As can be seen from Figure 9, the mean length of snow covered season will be significantly reduced in the future (assuming a 1.8°C increase in the temperature), approximately 40 days at an altitude of 1500 meters. The pace of the change is determined by the pace of the climate change.

![Figure 9: Mean amount of snow-cover days (1.8°C increase in the temperature) at 1500 meters in the Alps (SEATM 2004).](image)

Besides the Alps, winter tourism and recreation is important also in Northern Europe, especially in Finland, Sweden and Norway. Moen and Fredman (2007) studied the industry from the Scandinavian (mainly Swedish) perspective. Scandinavian countries compete of ski tourists among themselves but also between the Alpine Europe. Moen and Fredman estimated the current ski season at the mountain regions of Sweden to be 162 days, starting from November 24 and closing at May 4. The reduction in number of days with snowfall during the ski season for the period 2070 - 2099 is estimated at 59 % under scenario RE-A2, relative to the current climate. This converts into 96 days. In Finland, during the upcoming decades of 2040 - 2069 the greatest risk of snowless conditions in winter is in the southern parts of Finland whereas Lapland will still have plenty of snow during winters as the change in the snow-cover-days there is expected to be
small. In the last part of the century (2070 - 2099) snow-covered season is expected to decrease significantly also in Lapland.

Although winter precipitation increases, the increase is not sufficient to compensate for the increased fraction of liquid precipitation and increased snowmelt caused by higher temperatures. The multi-model mean results suggest a slight increase in March mean snow water equivalent only locally in mountains of northern Sweden in the first part of the century. The nature of the changes remains the same throughout the 21st century, but their magnitude increases with time as the greenhouse gas forcing grows larger. Figure 10 depicts the situation in March over the Scandinavia (Räisänen and Eklund 2011).

Climate change models should be run to predict the snow-cover-day period on a European scale. This would facilitate to make predictions on the changes of winter tourism patterns during the on-going century. Also the push factors are expected to change with vanishing snow conditions and less and less people have an urge for snow related activities.

4.3 Tourism sector level adaptation challenges in climatic zones in the EU

4.3.1 The most vulnerable systems of the Tourism sector for specific climate hazards

As stated above, the tourism sector is a climate sensitive economic sector in which both supply and demand are both directly and indirectly affected by climate change. The demand is directly affected by climate by altering the preferences (push factors) of and travel choices (pull factors) of consumers and supply is affected by a modified production cost structure and changes in the demand structure. Since this section deals with adaptation challenges, it will focus more on the supply side. However, we need to remember, that climate change induced demand variability and the change of weather sensitivity of demand per se are equally important adaptation challenges.

Table 12: Impacts of climate change and tourism adaptation challenges (based on Becken and Hay 2007).

<table>
<thead>
<tr>
<th>Impacts of climate change</th>
<th>Tourism adaptation challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higher temperatures</td>
<td>Artificial snow making, Extend ski operations to higher altitudes, Re-design ski slopes, Cancel ski tourism, Promote non-snow winter activities, Build attractions (ice rink, spa), Develop all year tourism (i.e. summer activities), Insurance, Open higher-elevation ski runs, Levelling out ski slopes, Closures of lower altitude ski; Subsidies for cableway operators to keep ski fields open</td>
</tr>
<tr>
<td>Reduced snow cover</td>
<td>Install air conditioners, Room fans, Hotel pools, Beach umbrellas, Develop artificial indoor beaches, Provide drinking water, Skin sun protection, Promote water-based or cool indoor activities, Plant more trees for shade &amp; cool buildings, Avoid</td>
</tr>
<tr>
<td>Hotter days</td>
<td></td>
</tr>
</tbody>
</table>
### Winter storms
- Heed storm warnings
- Protect properties
- Build to storm standards
- Trim tree branches
- Evacuate guests
- Close damaged resorts
- Disaster insurance
- Visit alternative areas

### Higher sea level
- Build coastal protection (sea/rock wall, groyne, dyke)
- Replenish beach sand (trucks, pumping)
- Close damaged beach areas
- Closure of coastal resorts
- Rebuild beach infrastructure
- Revegetate/plant soil-binding vegetation in coastal areas
- Protect and maintain coastal native vegetation communities
- Disaster insurance
- Build coastal levees
- Improve drainage & pumping systems
- Ban development in at-risk zones
- Establish building set-back limits well above mean sea-level

### Increased coastal erosion/inundation
- Build coastal protection (sea/rock wall, groyne, dyke)
- Replenish beach sand (trucks, pumping)
- Close damaged beach areas
- Closure of coastal resorts
- Rebuild beach infrastructure
- Revegetate/plant soil-binding vegetation in coastal areas
- Protect and maintain coastal native vegetation communities
- Disaster insurance
- Build coastal levees
- Improve drainage & pumping systems
- Ban development in at-risk zones
- Establish building set-back limits well above mean sea-level

### Rainfall variability
- Increased water storage
- Recycle water
- Desalination
- Encourage minimal water use by guests
- Purchase water
- Limit or set quotas on water use
- Use trickle irrigation
- Repair leaks
- Use timers on taps
- Drought-tolerant plants

### Drought
- Disaster insurance
- Enhanced flood design and site standards
- Install pumping systems
- Closure of flood-affected resorts
- Close areas prone to flooding
- Use alternative routes or areas

### Floods

#### 4.3.2 Impacts of specific importance in the climate zones

The following table tries to summarize, which tourism regions of Europe will be most affected by the above quoted impacts of climate change. Table 13 tries to give an idea of how regions of Europe identified above may be affected by impacts of climate change. Minus in brackets indicates negative anticipated effects for tourism development caused by the respective climate change impact whereas plus intuitively signals potential positive effects for a particular region. +/- denotes that the respective climate change impact might have a negative and/or positive effect on the study region.

**Table 13: Impacts of climate change and most affected regions of Europe (based on Becken and Hay 2007).**

<table>
<thead>
<tr>
<th>Impacts of climate change</th>
<th>Most affected regions of Europe</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Higher temperatures</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Reduced snow cover</strong></td>
<td>Alpine Arc (-)</td>
</tr>
<tr>
<td></td>
<td>Nordic Countries (-)</td>
</tr>
<tr>
<td><strong>Hotter days</strong></td>
<td>Alpine Arc (+)</td>
</tr>
<tr>
<td></td>
<td>Nordic Countries (+)</td>
</tr>
<tr>
<td></td>
<td>Mediterranean Basin (-)</td>
</tr>
<tr>
<td>Event</td>
<td>Impact Areas</td>
</tr>
<tr>
<td>--------------------------------------------</td>
<td>---------------------------------------------------</td>
</tr>
<tr>
<td>Decreasing heating degree days</td>
<td>Alpine Arc (+)</td>
</tr>
<tr>
<td></td>
<td>Mediterranean Basin (-)</td>
</tr>
<tr>
<td></td>
<td>Coastline of the EU 27 (-)</td>
</tr>
<tr>
<td></td>
<td>European Lakes (-)</td>
</tr>
<tr>
<td></td>
<td>Cities of Europe (-)</td>
</tr>
<tr>
<td>Increasing cooling degree days</td>
<td>Mediterranean Basin (-)</td>
</tr>
<tr>
<td></td>
<td>Coastline of the EU 27 (-)</td>
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<tr>
<td></td>
<td>European Lakes (-)</td>
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<tr>
<td></td>
<td>Cities of Europe (-)</td>
</tr>
<tr>
<td>Winter storms</td>
<td>Alpine Arc (-)</td>
</tr>
<tr>
<td></td>
<td>Nordic Countries (-)</td>
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<tr>
<td></td>
<td>Mediterranean Basin (-)</td>
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<td></td>
<td>Coastline of the EU 27 (-)</td>
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<tr>
<td></td>
<td>European Lakes (-)</td>
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<tr>
<td></td>
<td>Cities of Europe (-)</td>
</tr>
<tr>
<td>Higher sea level</td>
<td></td>
</tr>
<tr>
<td>Increased coastal erosion/inundation</td>
<td>Coastline of the EU 27 (-)</td>
</tr>
<tr>
<td>Rainfall variability</td>
<td></td>
</tr>
<tr>
<td>Drought</td>
<td>Mediterranean Basin (-)</td>
</tr>
<tr>
<td></td>
<td>Coastline of the EU 27 (-)</td>
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<tr>
<td></td>
<td>European Lakes (-)</td>
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<td></td>
<td>Cities of Europe (-)</td>
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<tr>
<td>Floods</td>
<td>Alpine Arc (-)</td>
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<tr>
<td></td>
<td>Nordic Countries (-)</td>
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<tr>
<td></td>
<td>Mediterranean Basin (-)</td>
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<td>Coastline of the EU 27 (-)</td>
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<td></td>
<td>European Lakes (-)</td>
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<td></td>
<td>Cities of Europe (-)</td>
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</tbody>
</table>
Snow oriented winter tourism regions

Mountain and winter sports, and especially skiing, are frequently identified as being highly vulnerable to climate change. Ski resorts in lower altitudes in the Alpine Europe and in the southern parts of Scandinavia (and Finland) are at risk due both to increased inter-annual variability and decreased mean snow-cover-period.

The amplification of global climate change signals in the Alpine region cause a shortening of snow season which means a reduction in the amount of precipitation that falls as snow. Agnew and Viner (2001) predict a reduction of precipitation that falls as snow of 30 % in 2020 and -50 % in 2050.

Many adaptation measures have the potential to significantly reduce the negative impacts of climate change on the ski industry. But there are limits on the ability of the ski industry to adapt due in part to economic and resource constraints. As snow making increases, issues such as water availability and costs will become more significant. Thus, in years when natural snowfalls are poor, the ski season may be curtailed (Becken and Hay 2012).

Beach oriented summer tourism regions

The Mediterranean basin is one of the most sensitive areas of the world to human-induced climate change (Calbó 2010). Heatwave frequency and duration will especially affect Southern European river basins and the Mediterranean coast. Climate change projections suggest that European summer heatwaves will become more frequent and severe during this century, consistent with observed trends in the past decades (Fischer and Schär 2010). More detailed modelling reveals that the frequency of heatwave days for the Iberian Peninsula and Mediterranean region is expected to increase from about two days per summer for 1961 - 1990, to around 13 days by 2021 - 2050, and to as many as 40 days by 2071 - 2100 (Becken and Hay 2012).

Several studies also indicate a high probability that for many major tourism destinations, water availability will be reduced due to increased temperatures and decreased and more variable precipitation. Peak demand for tourism in the Mediterranean occurs in summer and water demand peaks at the same time with agriculture, residential areas, the energy sector and nature. Water supply drop in the summer induced by climate change will deepen the water shortage problems.

In some parts of the Mediterranean, climate conditions deteriorate already in the summer as temperatures rise above optimal. At the same time the share of elderly people in European population is expected to rise, which might shift preferences toward milder temperatures.

The main climate related effects to the Mediterranean regions are (based on Nicholls 2006 and Agnew and Viner 2001):

- Increase in the number of days exceeding 40°C leaves many countries of Southern Europe simply too hot for human comfort in the summer months;
- Heat related health incidents (heat stress and mortality);
- Increased vulnerability to tropical diseases such as malaria;
- Increasing risk of water supply restrictions, forest fire and urban smogs;
- Change in periods when tourists visit countries;
- More frequent and severe droughts and flash floods;
- Sea level rise, which may lead to coastal erosion, beach degradation, the salinization of aquifers and habitat loss;

As naturally dynamic landforms, the physical conditions of a beach are highly sensitive to changes in sea level, storms and wave climates, and sediment budgets. Through these processes, climate change will impact strongly on soft shorelines such as beaches and sand dunes, leading to accelerated coastal retreat and beach loss in these areas (Becken and Hay 2012).

Further on, the European lakes, such as Lake Zurich in Switzerland and Lake Balaton in Hungary, are important tourist attractions for water based recreation activities. However, European Lakes are suffering from cumulative environmental stresses (Agnew and Viner 2001).
In the case of Lake Balaton, regression results of temperature and overnight stays by Pretenthailer and Köberl (2010) suggest weak positive effects for the periods 2016 - 2025 and 2041 - 2050 on the basis of three different climate scenarios.

**Urban tourism and other tourism types**

Destinations that rely primarily upon their natural resource base to attract visitors, such as mountains and coasts, are likely to be more at risk than those that depend upon cultural or historical attractions. However, there are also challenges for the cities of Europe.

In urban areas a heat island effect can be observed. Due to the differences in absorption and radiation of heat by buildings compared to rural areas where evaporative cooling from vegetation is much more pronounced, local heat increases in the cities of Europe and as a result air quality in urban areas decreases (especially in Central and Southern Europe) (McEvoy 2005).

Not very intensive tourism regions so far may gain in relative attractiveness if very attractive places loose out for climatic reasons. E.g. The Mediterranean has been identified as a tourism vulnerability hotspot by the World Tourism Organisation (UNTWO 2008). Besides the direct climate impacts, relatively large share of income is generated by tourism and Mediterranean countries are not as wealthy as the countries in Northern Europe. On the mid-term, Northern Europe gaining on the climate advantage will probably distribute the income from tourism more evenly across Europe. Supply of water is a key factor for adaptation in the Mediterranean as the demand of water peaks at the same time in several sectors. So the increased cost of water supply may also make other places with a more moderate climate more attractive.

**4.3.3 Decision criteria that drive the adaptation needs within the Tourism sector**

This is one of the topics we would like to clarify by the ToPDAd project.

First it is important however to clarify, what is meant by this question. Adaptation needs in the tourism sector are driven mostly by the weather/climate sensitivity of either demand or production cost. These two factors are also the main influencing factors for determining, whether an investment decision in a touristic project is economically viable or not. So the usual economic decision criteria like return on investment etc. can directly be translated into meteorological/climatic conditions that render a project profitable or not. Adaptation options most of the time will play the role of softening this dependence. Candidates of meteorological/climatic conditions that heavily influence the economic decision criteria for the main tourism regions of Europe that have to be examined in terms of their relevance include:

- Natural snow cover season length
- Cost of artificial snow cover to keep the season length at 100 days
- Number of skier days per season that can be secured by artificial snow making
- Regions/periods where humans will experience weather related discomfort

**4.3.4 Uncertainties that need to be taken into account for sound adaptation**

Apart from uncertainties from the entire modelling chain (climate models, climate impact models, and weather sensitivity models) there is one main uncertainty that is difficult to detect from past data:

The manner in which the guests will react to weather conditions that have not been experienced before at a certain location remains an open question. The changing patterns of leisure activities (since some of the current activities can no longer be exercised in proximity) can heavily influence holiday location choices. Thus, locations choices can change abruptly if some activities will no longer be part of the cultural heritage (i.e. skating in the Netherlands, skiing in Alpine areas).
5 Integrated assessment and policy-development challenges

5.1 Economic impact assessment

The vulnerability with respect to different climate change effects varies significantly across regions and sectors. Besides particular regional and sectoral assessments of climate change on the basis of specific sector models (WP2) also an over-all macro-economic impact assessment for the European economies at EU and Member State level will be carried out within the ToPDA project.

The whole analysis will be carried out on the basis of the two general top-down models represented in the consortium, GINFORS (Global Interindustry Forecasting System) and GRACE (Model for Global Responses to Anthropogenic Changes in the Environment). Both models give complementary insights to the impacts of climate change on the economies. Whereas the dynamic Input-Output model GINFORS will be applied for projections in the medium-long term, up until 2050, the more aggregated computable equilibrium model GRACE will be used for long-term projections up until 2100, when the climatic changes potentially can become large.

At the beginning of this project a big challenge will be the updating of the models with regard to currently available new economic and environmental data sources. This is especially the case for the relatively disaggregated GINFORS model (Lutz et al. 2009 & 2010). Core of this updating process will be the World Input Output Database (WIOD), calculated in an FP7-project funded by the EC, which has been published in spring 2012. Besides this the horizon of projection which is up to now restricted to the period up to the year 2030 has to be extended to the year 2050. After doing so the necessary detailed structure (input-output models) for analysing economy wide impacts will be implemented in GINFORS for 41 countries including all 27 European countries and “Rest of World”.

The use of the updated and upgraded model in scenario analysis will give an insight into the economy-wide impacts induced by climate changes and adaptation strategies. GINFORS reports the impacts on main macro-economic variables like GDP and employment as well as sector-economic variables for 59 product groups and 35 industries (production, value added, imports, intermediate demand, labour and capital demand, final demand categories [consumption, fixed capital formation, exports] as well as prices). Besides it gives a detailed insight into the development of bilateral trade differentiated for 59 product groups due to globalized production networks. The bottom up structure of the system and the bilateral trade on the sector basis allow a consistent analysis of the macro-economic impacts, including the effects on international competition.

Besides updating the economic impact assessment tools a second important challenge will be the identification of optimal linkage possibilities to the results coming from key sector models. Results from the sector studies, generated by the other models, can be represented in the two macro-economic models, either by calibration of model parameters with reference to the sector studies (“soft-link”) or by explicit and consistent aggregation of impacts and adaptation policies from the sector level. Possible feedbacks from the generalized macro level, such as impacts on prices, may be provided as further input to the sector studies.

In general GINFORS as a relatively disaggregated model principally allows results from sector studies to be implemented directly. This is especially the case of energy and transportation where a refined modelling already has been carried out whereas tourism as an economic cross-section activity has to be modelled in more detail when addressing sector specific climate change impacts.

Due to the fact, that GRACE is a more aggregated and less data demanding model, direct implementation of results from sector studies is problematic. Hence, the sector studies rather provide background for soft-linking of results. The model can to a larger extent be understood as a conceptual framework for understanding the process of growth under climate change.

The options for linking the bottom-up key sector models with the macro-economic impact models GRACE and GINFORS as well as potential feedback loops to sector models have to be analysed in greater detail within the project tasks 1.3 and 1.4 as well as work package 2 because therefore a better understanding of the relevant sector models is necessary. Only such specific knowledge allows the linking with the bottom-up models by considering how recovery resources will be allocated by governments and businesses following
a climate event and thus supports a better macro-level assessment with innovative consumption and production functions.

5.2 Environmental impact assessment

Environmental impact assessment will be addressed by the GINFORS model. The challenge of updating the GINFORS model by using the new WIOD-database has also positive effects on the environmental impact assessment within the ToPDAd project because this data base contains also environmental data on air pollution and resource use in a global coverage. This should of course be included in the process of updating the environmental modules of GINFORS.

An updated and upgraded GINFORS model allows the calculation of economy-wide impacts of climate change and adaptation strategies for all EU27 Member States at the individual country-level as well as at the common EU27 level which is based on a deep sectorial bottom up structure in a global framework integrating international competition. The environmental modules (energy, resource use) of the new GINFORS model calculate for all 41 countries CO₂-emissions, emissions of further 7 air pollutants, resource use for 12 kinds of materials, water demand and agricultural land use. This extended coverage enables quantification of the environmental stressors, and guarantees that every impact of adaptation measures back to these important environmental pressure variables will be mentioned. Environmental shocks, but also adaptation policies will in most cases have their direct impacts in certain economic sectors.

The new data base will allow a bottom up structure for all European countries. This means that an explicit and consistent aggregation of impacts of climate change and adaptation policies from the sector level to the country and to the EU level will be possible. Besides, the results at the national level can serve as a feedback input for the assessment of vulnerability for the strategic key sectors or at the regional level.

5.3 Social/health impact assessment

Most of the health impacts of climate change are likely to be existing health hazards that are amplified by global warming. The direct impacts may be increased death rates during heat waves and deaths and injuries from extreme events such as floods and landslides. In addition, a range of indirect health impact pathways are likely to exist, e.g., linked to disturbances of natural ecological systems (e.g., changing the range of vector borne diseases) or disruption to livelihoods and communities (e.g., mental health consequences of droughts and floods). Enhanced frequency of epidemics, for instance dengue fever, may affect tourism and thus retard economic development (WHO/WMO 2012). The need for analysing health impacts from climate change in the context of other drivers such as socioeconomic development and urbanisation has been pointed out by many. For instance, in regions where access to safe drinking water is already an issue, degradation of water supplies from urbanisation processes could increase the health risks. The resilience to climate change impacts are likely to be higher in well-off societies compared to poor.

The current knowledge basis, tools, and methods for assessing health risks from climate change are insufficient for informing decision-makers about the potentially broad range of health impacts at the international, national and local levels (WHO 2009). Whereas the limited available research suggests unmitigated climate change will substantially increase financial costs to health services, studies need to cover a wider range of health-impact pathways to adequately inform policy (Campell-Dendrum et al. 2009). Whereas climate related risk factors were not among the risk factors addressed in WHO’s recent comparative risk assessment (CRA) for 2010 (Lim et al. 2012), health impact assessment for climate change may build on the methods for allocating risk factors in this kind of assessment. For instance, there may be climate related factors behind identified risk factors such as ‘unimproved water source’ and ‘child and maternal undernutrition’ in the CRA. Moreover, there may be climate related risk factors behind cases of mortality and morbidity as identified in the global burden of disease estimation, e.g., such as drowning, exposures to forces of nature, diarrheal cases, and cardiovascular deaths (Lozano et al. 2012). The challenge is to identify, disentangle and allocate risk factors in a consistent way.

For some of the direct effects of climate change the knowledge basis may be sufficient for estimating isolated impacts. For instance, it is well known that extreme high or low air temperatures are associated with increased mortality rates. In the heat wave of summer 2003 in Europe more than 70 000 excess deaths were recorded (Robine et al. 2008). High temperatures cause clinical syndromes such as heat-stroke, characterized by a body temperature above 40.6°C and a breakdown of thermoregulation. Temperature attributable mortality has, however, also been demonstrated at moderate temperatures. The
epidemiological evidence is strongest for cardiovascular diseases, although respiratory diseases are also associated with heat stress. Temperature-mortality relationships are found to differ greatly by latitude and climatic zone and may be highest in warm and humid regions (McMichael et al., 2004, 2006). Heat is also shown to affect work performance. E.g., Seppänen et al. (2006) estimated an inverted U relationship for productivity in office type work. Recent studies have addressed the risk of heat stress at work and impacts on worker productivity in tropical developing countries and potential increased risk associated with global warming (Dash and Kjellstrom, 2011; Kjellstrom and Crowe, 2011; Kjellstrom et al. 2009). The economic costs for enterprises of heat stress may be small if workers can easily be replaced, for instance due to high unemployment rates and lacking work environment regulations. From a societal perspective the costs may, however, be high. Thus, to estimate the broader social costs of the physical health impacts, including impacts on productivity, detailed knowledge about the community in question is needed.

Many protective measures towards climate induced health risks are well-known, including their costs. There are, however, currently few studies attempting to assess the cost-effectiveness of implementing or expanding protective measures. Obviously, lacking tools to quantify avoided direct and indirect health impacts reduce the potential merits of cost-effectiveness analyses. There is thus a strong need to develop knowledge and tools that enable such analyses. In addition to direct and indirect health benefits related to climate change, there are health co-benefits related both to adaptation measures and GHG mitigation measures that need to be taken into the equation. These could in fact be larger than the costs of the policies themselves. A range of studies have documented large co-benefits in terms of reduced air pollution and health damage from CO$_2$ abatement (Aunan et al. 2006). Whereas the basis for estimating health effects of air pollution is solid, e.g. for important pollutants such as fine particulate matter (PM$_{2.5}$) (Pope et al. 2009) and surface ozone (Bell et al. 2004, Jerrett et al. 2009), there are other less well-known interactions between global warming and air pollution that may be of importance. For instance, rising air temperatures may increase levels of ozone and potentially also PM$_{2.5}$. Previous work has suggested that global warming may exacerbate ozone most in already-polluted areas (Jacobson 2008). Also, both air pollution and heat stress are associated with cardiovascular and respiratory diseases, thus an assessment of health impacts of climate change should take into account possible combined effects of these risk factors.

5.4 Policy development challenges at different levels

ToPDAd aims to provide a model based tool to support decision making directed towards enhancement of social and economic resilience by promoting adaptation to climate change in Europe. Adaptation is usually considered to be a “local challenge” (Schneider et al. 2007), in the sense that the way climate is expected to change, what implications it may have, and how to best deal with it may vary significantly over short distances. As a consequence, development of EU strategies, national policies and regional initiatives for adaptation have to leave a considerable space for local judgments and responsibilities. This distinguishes development of adaptation strategies from developing mitigation strategies, where policy instruments to a much larger extent can be implemented directly on national and EU levels, such as charges on carbon or prescriptions of technologies.

The importance of the local perspective for the development of adaptation strategies also put major challenges to the establishment of decision support tools. First, one has to be specific on what decision maker the tool is meant to support. Decision makers on different levels (individual, municipal, regional, national or EU level) make different decisions to facilitate adaptation, depending on their responsibilities and means and instruments available. What is regarded adequate information differs accordingly. Second, the different decision making tools, such as models, provide information of relevance for different decision makers. Combining the tools implies that one also has to reassure that the transfer of information between models is not turning the outcomes irrelevant to the decision maker who is supposed to use it. Finally, a model or research based tool can never provide information to such an extent that the decisions can be directed by the outcomes of the tool. This is particularly important to bear in mind when addressing adaptation, where local knowledge pays such an important role, while model based knowledge is in most cases derived from generalizations.

On this background, the main challenge in policy development on different levels may be stated as defining roles and responsibilities for different bodies and stakeholders within an adaptation strategy. A lack of transparency in this context provides bodies on higher levels with opportunities to shuffle responsibilities upon decision makers on lower levels, where the ability to cope is strictly limited or absent (Dellink et al.
2009, Marco 2010). The consequence, which has been observed in many cases, is that there is a high concern for adaptation on higher levels, but there is little action.

In developing decision support tools for adaptation, these issues need clarification. As knowledge based tools can provide only a share of the full information needed to make appropriate decisions, it is vital to know what purpose the information is meant for. With reference to these challenges, and with reference to the sectors addressed in ToPDA, this part of the project will be carried out by the following steps:

- Define “levels” and corresponding “decision makers”.
- What is the “space of action” on each level, and what are the implications of an action taken on one level for the “space of action” on a different level?
- What kind of information is needed to support actions on a given level?
- To what extent are there conflicts of interests, and how can they be dealt with?
- How can responsibilities be allocated across levels in order for each action to contribute maximally to a given purpose?
- How can information from different models be combined in order to support the objective put forward in 5)?

While 1) – 4) can be considered descriptive tasks, 5) and 6) imply normative studies.
6 References


Christensen, J.H. and co-authors (2005): PRUDENCE Final Report, Danish Meteorological Institute, Denmark.


EC (2007): Northern Transport Axis, Pilot for the analytical support framework to monitor the implementation of the infrastructure and “soft” measures proposed by the High Level Group, Directorate-General Energy and Transports.


KLIWAS 4.01 ‘Water Balance, Water Level and Transport Capacity’, Bundesanstalt für Gewässerkunde (BfG), DST et al., 2012 (preliminary report, under preparation).


van der Linden, P. and Mitchell, J.F.B. (eds.) (2009): ENSEMBLES: Climate change and its impacts: summary of research and results from the ENSEMBLES project, Met Office Hadley Centre, UK.


McEvoy, D. (2005): Climate change and the visitor economy: Inception report, Manchester, Centre for Urban and Regional Ecology, School of Planning and Landscape, University of Manchester.


7 Appendix

7.1 Brief description of European meteorological organisations

An important European level co-operation regarding observation is the European Organisation for the
Exploitation of Meteorological Satellites (EUMETSAT). It delivers weather and climate-related satellite data,
images and products 24 hours a day, 365 days a year. This information is supplied to the National
Meteorological Services of the organisation's Member and Cooperating States in Europe, as well as other
users world-wide. EUMETSAT is an intergovernmental organisation and was founded in 1986 (for details:
http://www.eumetsat.int/Home/index.htm).

The European Centre for Medium-Range Weather Forecasts (ECMWF) is an independent
intergovernmental organisation supported by 34, mainly European, States. ECMWF provides the results of
its forecast activities to its Member and Co-operating States, the members of the WMO and the public.
Various levels of access restrictions apply. Principal forecast products are a 10 days forecast (deterministic
and ensemble prediction) and various seasonal forecast products (for details:
http://www.ecmwf.int/about/overview/).

EIG EUMETNET is a grouping of 29 European National Meteorological Services that provides a framework
to organise co-operative programmes between its Members in the various fields of basic meteorological
activities. These activities include observing systems, data processing, basic forecasting products, research
and development and training. EUMETNET's mission statement is: “To help its Members to develop and
share their individual and joint capabilities through cooperation programmes that enable enhanced
networking, interoperability, optimisation and integration within Europe; and also to enable collective
representation with European bodies in order that these capabilities can be exploited effectively.” (for

The Global Monitoring for Environment and Security (GMES) is an ambitious Earth observation programme
is headed by the European Commission (EC) in partnership with the European Space Agency (ESA) and
the European Environment Agency (EEA). GMES provides a unified system through which vast amounts of
data, acquired from space and from a multitude of in-situ sensors, are fed into a range of thematic
information services designed to benefit the environment, the way we live, humanitarian needs, and support
effective policy-making for a more sustainable future. These services fall into six main categories: services
for land management, services for the marine environment, services relating to the atmosphere, services to
aid emergency response, services associated with security and services relating to climate change (for
details: http://www.esa.int/Our_Activities/Observing_the_Earth/GMES/Overview3).