ESPON Climate

Climate Change and Territorial Effects on Regions and Local Economies

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Scientific Report

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This report presents the final results of an Applied Research Project conducted within the framework of the ESPON 2013 Programme, partly financed by the European Regional Development Fund.

The partnership behind the ESPON Programme consists of the EU Commission and the Member States of the EU27, plus Iceland, Liechtenstein, Norway and Switzerland. Each partner is represented in the ESPON Monitoring Committee.

This report does not necessarily reflect the opinion of the members of the Monitoring Committee.

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Table of contents

Figures

Maps

Tables

1. Introduction

Territorial development is generally considered as very important for dealing with climate change. For instance, territorial development is regarded to be responsible for and capable of reducing regional vulnerability to climate change and developing climate mitigation and adaptation capacities against the impacts of climate change (Stern, 2006; IPCC, 2007a). Also, the World Bank Report „The Global Monitoring Report 2008“ which deals with climate change and the Millennium Development Goals concludes that the development of adaptive urban development strategies is a fundamental field of action for dealing with the challenges of climate change (World Bank, 2008).

The EU White Paper „Adapting to climate change: Towards a European framework for action" (European Commission, 2009a, 4) explicitly relates to spatial planning and territorial development, respectively: „A more strategic and long-term approach to spatial planning will be necessary, both on land and on marine areas, including in transport, regional development, industry, tourism and energy policies."

In the EU Territorial Agenda (BMVBS, 2007a, 7) it is stipulated under Priority 5 that "joint transregional and integrated approaches and strategies should be further developed in order to face natural hazards, reduce and mitigate greenhouse gas emissions and adapt to climate change. Further work is required to develop and intensify territorial cohesion policy, particularly with respect to the consequences of territorially differentiated adaptation strategies."

Mickwitz et al. (2009, 60) came to the following conclusion: „While the need for co-ordination and integration across sectors, scales and levels is growing, the capacities to respond are frequently shrinking […]. While it is generally recognised that the role of spatial planning for climate mitigation and adaptation should be strengthened, the practice is not very well developed as yet." Thus, there is a need for a step forward towards a clear territorial response to climate change.

However, territorially differentiated adaptation strategies call for an evidence basis. This is what the ESPON Climate project is mainly about; a pan-European vulnerability assessment as a basis for identifying regional typologies of climate change exposure, sensitivity, impact and vulnerability. On this basis, tailor-made adaptation options can be derived which are able to cope with regionally specific patterns of climate change. In the ESPON Climate project this regional specificity is addressed by seven case studies from the transnational to the very local level.

ESPON Climate's territorial perspective is somehow unique, because most of the existing vulnerability studies have a clear sectoral focus, addressing very specific potential impacts of climate change on single elements of a particular sector. The leading existing studies have so far not employed such a comprehensive methodological approach. Furthermore, most studies lack a clear territorial pan-European focus. Specialised research is sensible and necessary but the findings of specialised studies are not easily transferable between sectors or between regions. Findings may not even be comparable due to methodological differences.

This is particularly troublesome in an international policy context like the European Union, when it needs to be determined, what are the consequences of climate change on the competiveness of Europe as a whole or the territorial cohesion of European regions.

Therefore, the ESPON Climate project developed a new comprehensive vulnerability assessment methodology and applied it to all regions across Europe in order to create the evidence base needed for a climate change responsive European territorial development policy. However, any vulnerability assessment is confronted with uncertainty which is based in the models (the project made use of CCLM[1]), the emission scenario (A1B[2]) and of course, the future trends in socio-economic development. Thus, the results of ESPON Climate have to be seen as a possible vulnerability scenario which shows what Europe's future in the wake of climate change may look like and not as a clear-cut forecast. Nonetheless, it gives some evidence based hints as to what adaptation should be about in view of the identified regional typologies of climate change.

[1] CCLM is a non-hydrostatic unified weather forecast and regional climate model developed by the COnsortium for SMall scale MOdelling (COSMO) and the Climate Limited-area Modelling Community (CLM).
[2] The IPCC developed six scenarios on the development of greenhouse gas emissions (GHG) from 2000 to 2100 (SRES scenarios). A1B is used for almost all vulnerability assessments as a moderate scenario.

2. Conceptual and methodological framework

2.1 Concepts and overall methodology

The ESPON Climate project uses a conceptual framework that is widely used in the climate change and impact research community (see Figure 1). According to this framework rising anthropogenic greenhouse gas emissions contribute to global warming and thus to *climate change*. This anthropogenic contribution runs parallel to natural climate variability. The resulting climate changes differ between regions, i.e. each region has a different *exposure* to climate change. In addition, each region has distinct physical, environmental, social, cultural and economic characteristics that result in different *sensitivities* to climate change. Together exposure and sensitivity determine the possible *impact* that climatic changes may have on a region. However, a region might in the long run be able to adjust, e.g. by increasing its dikes. This *adaptive capacity* enhances or counteracts the climate change impacts and thus leads to a region's overall *vulnerability* to climate change.

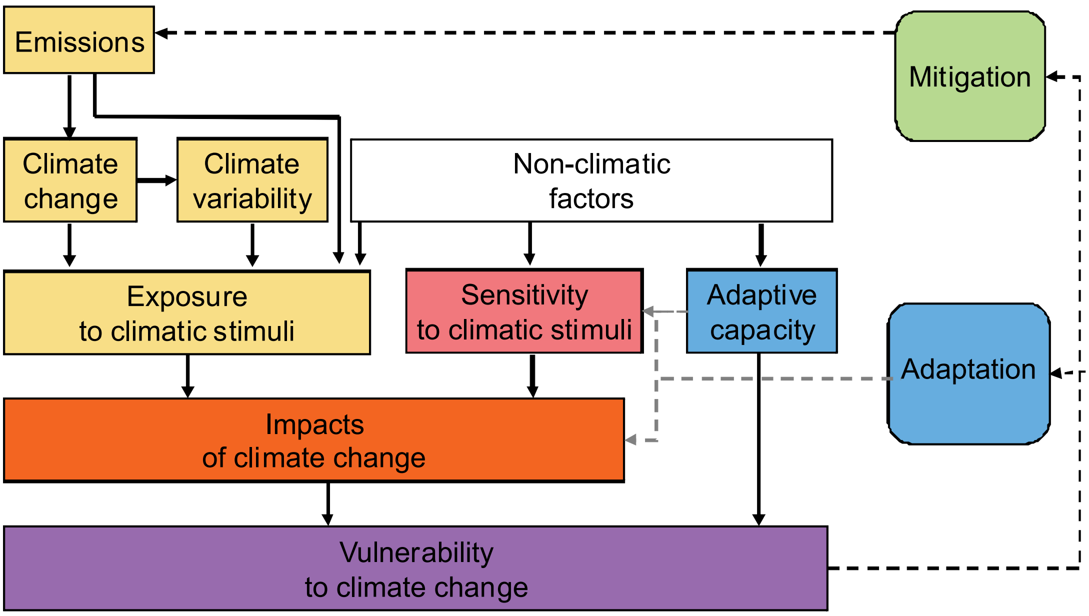

Figure 1: Climate Change research framework (adapted from Füssel & Klein, 2002, p. 54)

Following this framework the project's methodology consisted of the following main components. The *exposure analysis* focused on the climatic changes as such. It made use of existing projections on climate change and climate variability from the CCLM climate model, whose results have been used, among others, by the 4th IPCC assessment report on climate change. Using the IPCC climate scenario A1B (Nakicenovic et al. 2000) the ESPON Climate project aggregated data for two time periods (1961-1990 and 2071-2100) for eight climate stimuli. River flooding and sea level rise were added as two immediate 'triggered effects' of these climate stimuli.

Each region was then assessed in regard to its climate change *sensitivity*. For each sensitivity dimension (physical, environmental, social, economic and cultural) several sensitivity indicators were developed. Each indicator was calculated in absolute and relative terms and then combined. This integrated two equally valid perspectives on sensitivity: While relative sensitivity (e.g. density of sensitive population) is advantageous from a comparative point of view, the absolute sensitivity (e.g. absolute number of sensitive inhabitants) is more relevant from a policy/action point of view.

Exposure and sensitivity were then combined to determine the potential *impacts* of climate change. The analysis thus focused on what would be the result if climate change took place unrestrictedly and impacted on the regions without further preparation. For determining impacts each sensitivity indicator was related to one or more specific exposure indicator(s). For example, heat sensitive population (persons older than 65 years living in urban heat islands) were related to changes in the number of summer days (above 25°C), while forests sensitive to fire were related to summer days and summer precipitation. After determining the individual impacts, all impacts of one dimension were aggregated. The impact values of the five sensitivity dimensions were finally combined to one overall sensitivity value. This combination was calculated on the basis of relative weights, which were determined through a Delphi survey among the members of the ESPON Monitoring Committee.

Table 1: Definitions according to Füssel & Klein (2002) and IPCC (2007)

Exposure: The nature and degree to which a system is exposed to significant climatic variations.

Sensitivity: The degree to which a system is affected, either adversely or beneficially, by climate related stimuli. The effect may be direct or indirect.

(Climate) Impacts: Consequences of climate change on natural and human systems. Depending on the consideration of adaptation, one can distinguish between potential and residual impacts.

Adaptive capacity (or adaptability): The ability of a natural or human system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

Vulnerability: The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.

Mitigation: Climate change mitigation refers to all human attempts to mitigate the effects of climate change.

The basic rationale for conducting a Delphi survey (whose method is explained in more detail in the next section) is as follows: The integration of exposure, sensitivity and adaptive capacity and particularly in between their various dimensions raises particular issues induced by the theoretical framework. At these stages of the analysis process weighting issues occur. Even if no explicit weighting were applied, this would implicitly, but de facto constitute a weighting with equal weights. Ultimately such weighting refers to normative questions, i.e. cultural beliefs and political preferences influence the weighting of factors such as social or economic sensitivity on the aggregated regional level (e. g. value of human lives against economic damages).

The normative implications could be considered by other methods either, such as paired comparisons between each variable or a multi-criteria analysis. However, both alternative methods are more complex and would have call for much more expenditure of time by the monitoring committee members. Thus, the ESPON preferred a Delphi-based approach in order to guarantee for a sufficient return rate and consequently a representative coverage of the whole Europe.

Therefore, using a Delphi-based approach a questionnaire survey was conducted among the ESPON monitoring committee, which consists of representatives of each participating European country. These representatives were asked to propose weights for the various components of the assessment. The results provided the normative basis for the quantitative analysis of the European vulnerability assessment and reflect the collective assessment of the relative importance of each sensitivity and adaptive capacity dimension (cp. Table 2). Equal weights were applied between exposure and sensitivity as well as between impact and adaptive capacity, because the weighting results between these components was balanced.

Table 2: Weights resulting from the Delphi-based assessment

Sensitivity		*Adaptive capacity*	
Cultural sensitivity	0.1	Economic resources	0.21
Economic sensitivity	0.24	Knowledge and awareness	0.23
Environmental sensitivity	0.31	Infrastructure	0.16
Physical sensitivity	0.19	Institutions	0.17
Social sensitivity	0.16	Technology	0.23

A third major component of the project was the assessment of *adaptive capacity* in regard to climate change, i.e. the economic, socio-cultural, institutional and technological ability of a region to adapt to the impacts of a changing regional climate. This could mean preventing or moderating potential damages but also taking advantage of new opportunities. Several indicators were developed for each of the five major determinants of adaptive capacity. The individual indicators were subsequently combined for each determined and finally aggregated to an overall adaptive capacity. This aggregation was again conducted on the basis of the Delphi survey results.

To determine the overall *vulnerability* of regions to climate change the impacts and the adaptive capacity to climate change were combined for each region. The underlying rationale is that a region with a high climate change impact may still be moderately vulnerable if it is well adapted to the anticipated climate changes. On the other hand, high impacts would result in high vulnerability to climate change if a region has a low adaptive capacity.

Mitigation is also highly relevant for territorial development and cohesion since climate policy implementation and the transition to a low-carbon society will have differential effects on sectors and regions. Mitigation measures, even implemented at the regional level, will not have significant effects on regional climate but only contribute to an overall reduction of global climate change. Therefore the project's mitigation analysis could only determine the mitigation capacity of each region but cannot determine what effect this would have locally or regionally.

Figure 2 describes the individual steps of the vulnerability assessment and may serve as a general orientation. Each step is described in detail in the full scientific report. Note that all numbers shown in the diagram are only examples intended to make the various calculation procedures more transparent.

The seven case studies of the ESPON Climate project serve to cross-check and deepen the findings of the pan-European assessment of the other research actions. They provide in-depth regional analyses of climate change vulnerability (exposure, sensitivity, impact, adaptation). The studies cross-check the indicators and findings of the European-wide analysis with the results of the case study areas, but explore also territorially differentiated adaptation strategies to climate change. Section 3.7 presents further details on the rationale for selecting the seven case studies.

Reflecting on the project's methodology a number of key features and challenges are apparent. First of all the project used a generally accepted conceptual framework and on this basis was able to build a coherent vulnerability assessment methodology. Nevertheless, the selection, calculation and aggregation of the individual indicators involves not only scientific knowledge, but also normative decisions on what aspects of such concepts as climate change, sensitivity or adaptive capacity are to be captured and assessed. In addition the choices of indicators are also shaped by the availability and quality of statistical data. Therefore, care was taken to discuss for each selected indicator its relevance for climate change research, any comparable existing studies and the indicators as well as data sources they used and finally the respective indicator methodology employed in the ESPON Climate project. The latter is also necessary because most of the indicators finally used in the project are made up of several input variables. The construction of such composite indicators is especially challenging as it involves different choices on selection of data, normalisation procedures, weighting schemes and aggregation methods (Saltelli, Nardo et al. 2004).

Even though the overall 'architecture' of the project's methodology is easy to communicate, the 'nuts and bolts' of the methodology at the individual indicator level are fairly complex. Of course, researchers specializing in only of these indicators would demand more complex modelling, but ESPON Climate's main goal was rather to make existing indicators and data compatible and combine them in an overarching, coherent methodological framework. And, as shown by the project's case studies, this methodology can also be adapted to various spatial levels.

A further benefit of the project's assessment methodology is its transparency and flexibility. Underlying normative decisions have been made explicit and subjected to normative input from the ESPON Monitoring Committee. The resulting weights of the various dimensions of the methodology can easily be changed and respective result maps be created (see Chapter 3.5 for an example of this). In addition, individual indicators (or new data for a particular indicator) can easily be updated or replaced or new indicators be added without needing to change the methodology of the assessment. This applies to exposure, sensitivity and adaptive capacity indicators. Even the causal relations between particular exposure and sensitivity indicators can easily be modified on the basis of new research findings. This flexibility makes the project's methodology especially 'future-proof', i.e. capable of incorporating new findings and data from various research fields.

2.2 Methodology in detail

The following section describes in detail the individual steps that need to be performed within each component of the vulnerability assessment. Figure 2 summarises the various steps and may serve as an orientation for the textual explanations. Note that all numbers shown in the diagram are only examples intended to make the various calculation procedures more transparent.

Exposure assessment

1. Aggregation of exposure data

The exposure analysis, based on the CCLM climate model, yielded data for each NUTS 3 region for each of the eight exposure indicators (see Chapter 3). For further analysis these data were normalised, yielding values between 0 and 1. For indicators with changes in two directions, i.e. increase and decrease of intensity, the greater value range from 0 will be used for determining the highest value as reference point for the normalisation, which will then be applied for both directions. After this indicator classification the scores for all eight indicators will be averaged, yielding the overall aggregate exposure intensity of each region (see yellow box in Figure 2).

For later linking some exposure indicators to sensitivity indicators in the impact analysis it is necessary to reverse the mathematical sign of the exposure scores. For example, increased forest sensitivity has to be related to *decreased* (not increased) summer precipitation. See the summary Table 6 at the end of the sensitivity chapter for an indication which indicators this refers to.

A special type of exposure indicators need to be highlighted, which were termed ‘triggered climate effects’ as they are directly triggered by other climatic stimuli. For example, globally rising mean temperatures lead to rising mean sea levels. Or the amount of winter precipitation in a river catchment area determines the likelihood and extent of river flooding in downstream areas. These two triggered climate effects are therefore dependent on global climate changes or on the accumulated effects of climate changes in larger regions. The data for these two triggered climate effects are therefore not taken from the CCLM climate data for a particular raster cell, but are derived from global climate change projections and special hydrological models respectively.

The aggregation of the classified exposure data by region is only necessary for producing an aggregate exposure map. This map (in combination with the cluster analysis) is informative in itself, but will not be relevant for the subsequent impact and vulnerability assessment, because they are making use of individual exposure indicators and not one combined exposure indicator.

Sensitivity assessment

2. Identification of sensitivity indicators

For assessing the sensitivity of regions to climate change five sensitivity dimensions were identified, namely physical, environmental, economic, social and cultural sensitivity. For each of these dimensions indicators were identified that capture the most important regional sensitivities to the climatic changes projected in the exposure analysis.

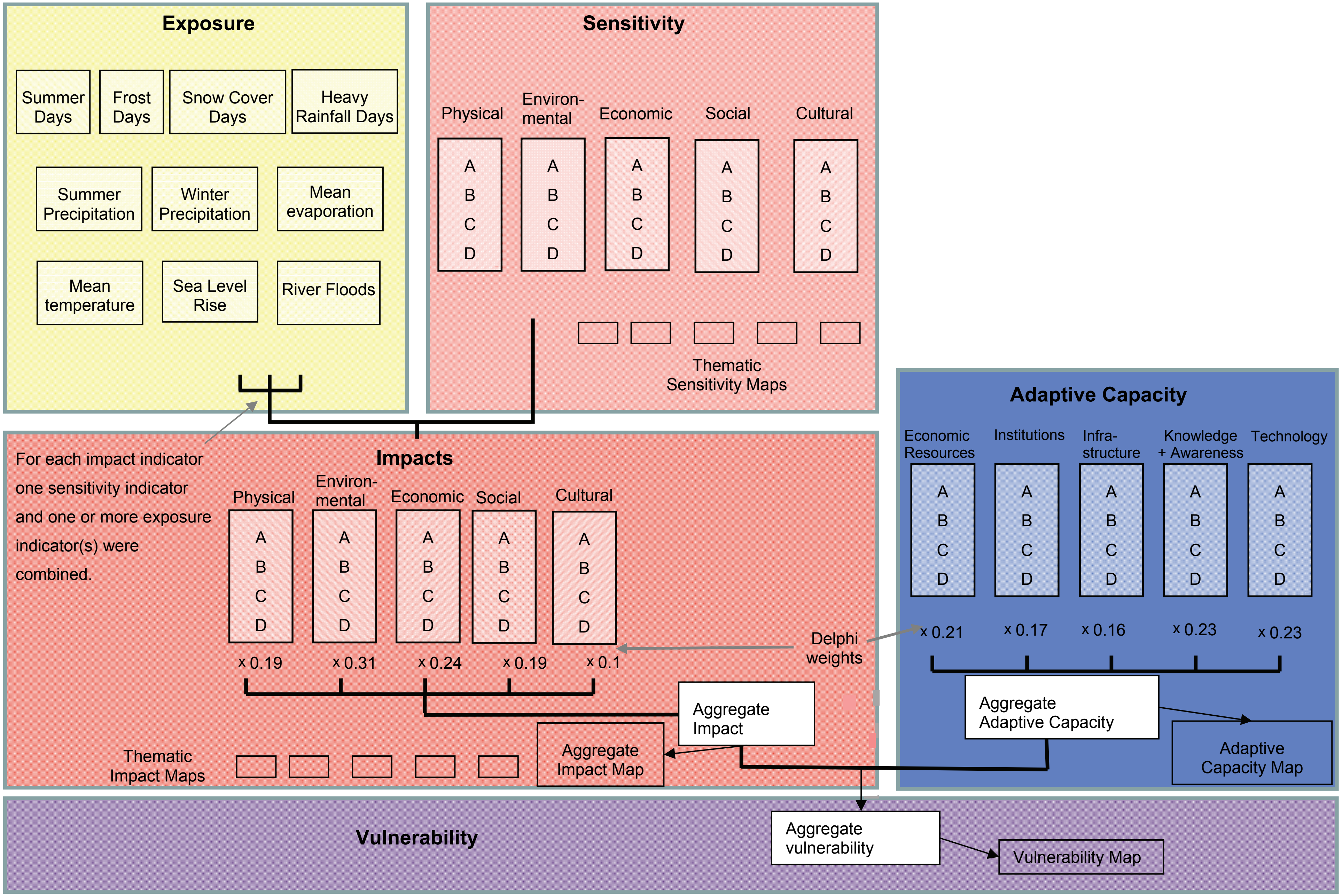

Figure 2: Overview of the ESPON Climate vulnerability assessment methodology

3. Determining individual sensitivities

Each sensitivity indicator was calculated individually, i.e. different data were used and possibly combined to arrive at a meaningful indicator. For some indicators this is relatively simple, e.g. calculating the relative share of senior citizen in a NUTS 3 region. For other indicators it is necessary to use additional data and perform more complex calculations, e.g. when determining the settlement area sensitive to heavy rainfall flash floods (see details in section 3.2).

Also, for each sensitivity indicator one absolute and one relative indicator were calculated. For example, for roads sensitive to river flooding it was calculated for each NUTS 3 region what percentage of the region's road network and what total length of roads are sensitive to river flooding. Both of these aspects are important, because a sparsely developed region might only have a few kilometres of sensitive transport infrastructure, but in relation to the total transport infrastructure of that region this is quite relevant. On the other hand, a more densely developed region might have many kilometres of sensitive transport infrastructure, which might nevertheless only account for a small fraction of the total infrastructure of that region. Thus, absolute and relative indicators have to be used in combination to yield a comprehensive measure of a region's sensitivity.

4. Normalisation and aggregation of sensitivity data

The sensitivity data for all indicators needed to be transformed to be able to aggregate and later relate them to the exposure indicators. In a first step, the absolute and the relative indicator for a particular sensitivity are normalised, using the normalisation technique already described above, yielding values from 0 to 1 (there cannot be 'negative' sensitivity, only zero sensitivity). On this basis relative and absolute sensitivity indicators were combined and then normalised again. In a second step these combined sensitivity scores were aggregated, i.e. a combined average was calculated for each sensitivity dimension, which was again normalised at the end. Thus there was one sensitivity score for each dimension (see Figure 2).

Impact assessment

5. Combination of exposure and sensitivity

Combining the exposure to climate change with the sensitivity to climate change results in the (potential) impact of climate change. This process of relating exposure to sensitivity is not performed at the aggregate level – as initially planned – but at the indicator level. This takes into account that for each sensitivity indicator there is a different combination of relevant exposure indicators. Thus for each region the score of a particular sensitivity indicator was multiplied with the averaged scores of the exposure indicators relevant for this sensitivity indicator and then normalised. The normalisation followed exactly the procedures described for the normalisation of the exposure indicators. This normalisation is different from standard normalisation techniques, because (a) not the highest value is necessarily taken as the reference point, but the value with the greatest distance from 0. This is so, because impact values can also be negative (if a negative exposure is multiplied with a sensitivity indicator). By all means the distinction between negative and positive impacts needed to be preserved, thus the slightly unconventional normalisation technique. In the end, values can range from -1 to +1, though normally only the negative or positive side will have values up to the extreme value.

6. Aggregating impact scores

In a next step the normalised scores of all indicators belonging to one dimension (e.g. environmental impacts) were combined. Sometimes all indicators were added up then averaged, in other cases they were first averaged in sub-groups before averaging the sub-group results (e.g. first combining summer and winter tourism indicators before then combining them with other economic sectors). The result for each dimension was again normalised – thus making it possible to create comparable impact maps for each of the five sensitivity dimensions.

Afterwards the dimension's scores were aggregated once again to yield one overall impact score. However, simply averaging the scores of the five dimensions would have implied that all dimensions are equally important, i.e. that the sensitivity of humans to climate change is as important as e.g. the sensitivity of cultural monuments to climate change.

In order to make such normative assumptions transparent and allow the perspectives and preferences from various ESPON countries to enter into the assessment, an internet-based Delphi survey was conducted. The Delphi Method is based on a structured process for collecting and synthesizing knowledge from a group of experts generating a maximum level of agreement through iterative and anonymous investigation of opinions by means of questionnaires accompanied by controlled opinion feedback (Helmer 1966; Linstone/Turoff 1975; Cooke 1991). The principle advantages of this approach are that it (a) avoids key persons taking influence on responses, (b) overcomes the geographical constraints and costs of bringing together a group of experts and (c) allows Delphi participants to express their personal views freely due to the anonymity of answers.

Furthermore, the Delphi-method due to its design is particularly useful for a subject with strong differences of opinion or high levels of uncertainty like given in the study at hand. Therefore, the method has already been applied for a definition of successful adaptation to climate change (Doria et al 2009).

As participants of the Delphi survey the members of the ESPON Monitoring Committee were chosen. This committee was conceived as the relevant community to be surveyed as it represent the various member states and also accounts for the final ESPON policy recommendations to the EU institutions and member states respectively. Out of the 47 members of the Monitoring Committee 25participated in the first round and 27 in the second round of weighting (see below). Care was taken (through detailed explanations on the Delphi survey website and follow-up phone calls) to ensure a correct understanding of the concepts and methods used in the survey.

The survey itself was conducted in two rounds:

1. In a first round, all members of the ESPON Monitoring Committee were asked for their initial opinion. Using a specially designed website they had to allocate on percentages for each sensitivity dimension as well as for each component of the two 'pairs' exposure/ sensitivity and impacts/adaptive capacity. Each of these three estimations added up to a sum of 100%.
2. Before the second round all participants were informed about the results of the first round and were then asked to again distribute percentage scores. Usually, those participants, whose opinions differed significantly from the average scores of the first round, often allocate more moderate scores in the second round.

Typically a third round would be conducted in a Delphi survey. However, after the second round the scores of the participants had already converged to such a degree that it was considered unnecessary to conduct yet another round of weighting. Hence the weights, a.k.a preferences expressed by the participants after the second round were used as the relative weights for the various components of the vulnerability assessment.

Thus, for the impact analysis these weights were multiplied with the impact score of each dimension in order to arrive at one aggregate impact score for a region (see Figure 2). On this basis a map could be produced that shows the regional climate change impacts across Europe.

Thus the impact incorporates three 'dimensions': a relative, dynamic dimension (exposure measured as projected *changes* of climate), an absolute, static dimension (sensitivity measured as relevant regional *conditions* vis-à-vis climate change) and a normative dimension (relative importance of exposure and sensitivity on the basis of expressed *preferences* of survey participants).

Adaptive capacity assessment

7. Adaptive capacity calculation and aggregation

The assessment of the adaptive capacity to climate change was also divided into five dimensions: Economic resources, institutions, infrastructure, knowledge and awareness as well as technology were considered the most relevant assets a region has for adapting to climate change. For each dimension several indicators were identified and then classified into five classes as described above. On this basis an average score was calculated for each dimension. Using the results from the Delphi survey the weighted scores of the five dimensions were added up, resulting in an aggregate adaptive capacity score for each NUTS 3 region, which was again normalised at the end. Maps of both the dimension's average and the overall adaptive capacity score were produced for better pan-European comparison.

Vulnerability assessment

9. Vulnerability calculation

Finally, the results from the impact assessment were multiplied with the aggregate adaptive capacity score and then normalised. Thus an aggregate vulnerability score was calculated for each region. A final vulnerability map concluded the pan-European assessment.

A final *word of caution* regards the various mathematical procedures, like calculating averages, multiplying different values and normalising them. While the sequence and logic of these operations are straightforward and serve the purpose of combining a great number of very different indicators, any sense of 'dimension' is necessarily lost. In other words, because scores of different indicators needed to be made compatible by means of normalising their values before calculating averages or multiplying them, it is not possible to retain the magnitude of the individual indicators: the extreme value of each indicator is by definition set to 1. This also means that all aggregated values are inherently relative. A regional impact or vulnerability score is only 'high' or 'low' in relation to all other European regions.

3. Climate change and Europe's regions: Key findings

3.1 Patterns of climatic changes across Europe

Climate change exposure refers to the nature and degree to which a system is exposed to climatic variations. This exposure depends on global trends of climate change and - due to spatial variations - on the system's location (cp. Füssel/Klein 2006, 313). The exposure analysis of the ESPON climate change project is based on the results of the regional climate model CCLM (see below). Taken together with sensitivity[3] to climate change as well as adaptive capacity, exposure becomes a component of impacts of climate change (potential as well as residual).

The climate exposure values used in the ESPON climate project are based on the Intergovernmental Panel on Climate Change (IPCC) scenarios published in 2000 (IPCC 2000) and employed within the fourth IPCC assessment report in 2007. Based on these scenarios the CCLM model has been run simulating future climate change for almost the whole European territory (Lautenschlager et al. 2009). Besides CCLM also other model projections have been published within the past years. Thus in the subsequent chapters, the IPCC scenarios and the CCLM projections as well as other model projections will be elaborated with the overall aim to provide an overview on the issue of exposure to climate stimuli which is of central importance within the research framework of the ESPON Climate project. Subsequently, the results from the analysis of different climatic parameters derived from CCLM data will be presented followed by an analysis on the regional distribution for the European territory.

3.1.1 Future Climate projections: The CCLM model

The impacts of climate change will be analysed based on the latest outputs of the COSMO-CLM (or CCLM) model, a non-hydrostatic unified weather forecast and regional climate model developed by the COnsortium for SMall scale MOdelling (COSMO) and the Climate Limited-area Modelling Community (CLM). The model CCLM was selected due to its fine spatial resolution (~20km), an extended and transient simulations period until 2100, spatial coverage of Europe, and its state-of the art climate module, its availability and large output of climate variables. In contrast to the ENSEMBLES[4] database of regional models, CCLM provides aggregated information on variables representing extremes events such as days with heavy rainfall, frost days, summer days and days with snow cover, which are of particular importance within the case studies of this project (see Table 3:). Moreover, at the starting time of this project, the simulation runs of CCLM were the most up to date (December 2008), whereas in the ENSEMBLES database of regional models older versions of climate models are used.

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[3] „The distinction between changes in sensitivity and changes in exposure is not always straightforward for processes that affect the extent or spatial structure of the exposure unit. Consider the vulnerability to flooding of a country that experiences significant internal migration from the highlands into the flood plains. This migration changes the exposure of certain population groups to flooding events. Aggregated to the country level, however, the effects of migration represent changes in the sensitivity of the population to flooding events" (Füssel and Klein 2006, p. 317).

[4] van der Linden P., and J.F.B. Mitchell (eds.) 2009: ENSEMBLES: Climate Change and its Impacts: Summary of research and results from the ENSEMBLES project. Met Office Hadley Centre, 160pp.)

We are aware of the shortcomings associated with the use of a single climate model, which will be communicated together with the results. However, projections of the CCLM model are compared to other models within the case studies of the project. Further projects should aim at comparing the European wide results of this project to a larger range of global and regional climate models and scenarios.

To produce future climate projections this model leans on the emission scenarios as defined by the Intergovernmental Panel on Climate Change (IPCC) in its 2000 report on emissions scenarios (IPCC 2000). Here, IPCC has presented six scenarios on the development of greenhouse gas emissions (GHG) from 2000 to 2100 (SRES scenarios). These scenarios presume the absence of additional climate policies which may affect GHG emissions. These scenarios cover a wide range of GHG emission drivers in the fields of demography, economy and technology. Divided into four scenario families (A1, A2, B1, and B2) they explore alternative development pathways with respect to the evolution of future GHG emissions.[5]

The A1 scenario presumes “business as usual”, i.e. a continuous increase of human CO_2 emissions. It based on

- a global population that reaches 9 billion in 2050 and then gradually declines, the quick spread of new and efficient technologies.
- a convergent world - income and way of life converge between regions.
- extensive social and cultural interactions worldwide.

There are subsets to the A1 scenario family based on their technological emphasis: The chosen A1B subset is based on a balanced use of all energy sources.

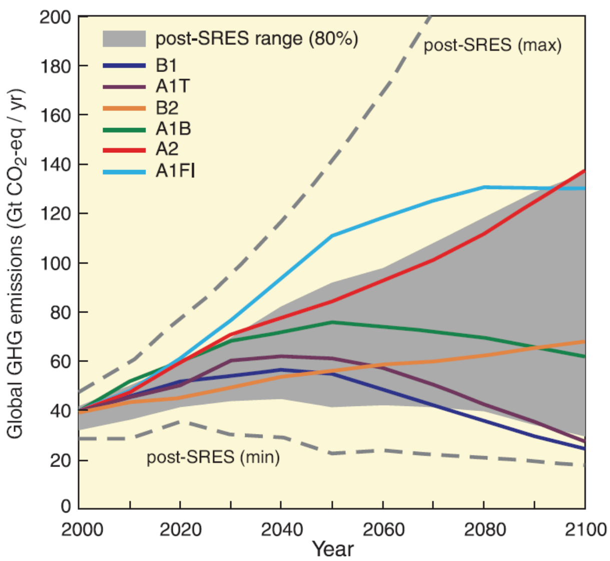


Figure 3: IPCC scenarios of global greenhouse-gas (GHG) emissions until 2100 (source: IPCC 2007, 44)

[5] “The A1 storyline assumes a world of very rapid economic growth, a global population that peaks in mid-century and rapid introduction of new and more efficient technologies. A1 is divided into three groups that describe alternative directions of technological change: fossil intensive (A1FI), non-fossil energy resources (A1T) and a balance across all sources (A1B). B1 describes a convergent world, with the same global population as A1, but with more rapid changes in economic structures toward a service and information economy. B2 describes a world with intermediate population and economic growth, emphasising local solutions to economic, social, and environmental sustainability. A2 describes a very heterogeneous world with high population growth, slow economic development and slow technological change” (IPCC 2007, p. 44).

Since their release these scenarios have been the basis for different studies on climate change and climate change projections. In 2007 the IPCC scenarios have been adopted for running the CCLM climate model. Based on the scenarios A1B and B1 several model runs for the past decades as well as for the coming years until 2100 have been conducted. Exposure to climate stimuli will be analysed based on the latest outputs of the CCLM model.

Scenario B 1 is not realistic anymore as annual growth rate of global emissions after 2000 has been about 3%, while growth rates under the emissions scenarios is between 1.4% and 3.4% (see e.g. the Global Carbon Project's latest results in Quere et al. 2009).. It became obvious that the B1 calculations are futile due to the fact that human GHG emissions have already reached the high-end of the IPCC scenarios, i.e. A1FI. It was thus decided to only continue with the A1B scenario as it displays a reasonable average (in case emissions would in fact decrease). A1B assumes a balanced use of resources (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end-use technologies). A1B is used for almost all vulnerability assessments as a moderate scenario. The worst-case scenario A1F may become more and more likely due the recently observed CO^2 emissions which were in 2010 the highest in history, according to the latest estimates by the International Energy Agency (see http://www.iea.org/index_info.asp?id=1959). However, A1F is not considered yet by several relevant input variables such as LISFLOOD. Therefore, it was not possible to make use of this scenario for the exposure assessment.

3.1.2 Indicators on exposure to climate stimuli

The CCLM model has been adopted for climate change runs with three realisations for the time period 1961-1990 and two realisations for each scenario for the time frame 2001 – 2100 based on two of the IPCC climate scenarios (A1B and B1). Generally, regional models can be assumed to be more accurate with respect to the spatial reference of model projections not least since they usually offer higher spatial resolution outputs. In order for regional models to operate they are normally 'driven' by global models. The results presented here have been conducted in conjunction with the globally coupled atmosphere ocean model ECHAM5/MPI-OM. For European-wide data the spatial resolution available is approximately 18 km. Based on these model projections different climate-change indicators have been calculated constituting the basis for the current analysis of exposure to climate stimuli.[6, 7]

In principle, the CCLM model delivers a wide range of climate-related output parameters (cp. Wunram 2007). These parameters relate to many different fields relevant within meteorology

[6] Besides the CCLM model outputs a range of other projections exists for the area of Europe which originate from both global climate models as well as regional climate models. For a more detailed elaboration see Annex 2.

[7] The relevant climate parameters frequently discussed in reports with respect to future climate change impacts relate to temperature and precipitation as well as wind speed (cp. IPCC 2007, pp. 872-879). Analyses focus mostly on changes in mean values as well as in extremes which has been the base for the choice of CCLM parameters as utilized within the exposure to climatic stimuli analysis to be carried out within the present research. Likewise these fields are focussed on in current report of the European Environmental Agency (EEA) (cp. EEA 2008, pp. 39-59). Here, indicators are based on IPCC scenarios A1B and A2 and B2. Indicators in the field of atmosphere and climate include global and European temperature, European precipitation, temperature extremes in Europe and Precipitation extremes in Europe as well as storms and storm surges and air pollution by ozone.

and climate research. For almost all output parameters, data is provided on an hourly to daily basis. Thus, for the purpose of this research, selected parameters have originally been aggregated by PIK for the time frames 1961-1990 and 2071-2100 for both scenarios (A1B and B1) in order to attain mean values exhibiting projected mean changes for the European territory (see Figure 4 as an example).

The focus on central climate parameters is crucial since the CCLM model delivers a broad range of parameters (also varying by data stream) which is hardly useful for applied research outside the meteorological domain. A larger range of output data is available for data stream 3 of the model, compared to data stream 2. This includes aggregated data on “extreme” events, such as days with heavy rainfall, summer days or frost days. To represent these events within the study, climate information from data stream 3 was used covering a large area of Europe, but excluding counties like Iceland (see Figure 4) which are part of the ESPON space.

The derived exposure indicators will be discussed in more detail within the subsequent sections. Generally, the change indicators always relate the climate conditions in the reference time period (1961-1990) to the climate conditions in the time period 2071-2100. The absolute or relative difference between these two periods constitutes the projected change for each climate parameter.

The selected climatic variables listed below reflect on a wide range of climatic conditions, from temperature to hydrologic variables. Variables of pressure and heat fluxes have been disregarded due to lacking direct relations with the preliminary sensitivity indicators. Data on storm events area subjected to large uncertainties on the European level. Mean wind speeds exhibits regional and large scale biases especially in Eastern Europe, at the west coast of Scandinavia, in France, parts of the Iberian Peninsula and parts of North Africa.[8]

For hydrologic variables, relative changes have been considered to best account for the regional varying climatic conditions. This accounts for the fact that small changes in summer precipitation can have much larger impacts in the Mediterranean area (with little absolute precipitation in summer), than a reduction of the same amount in Scandinavia, with considerably higher precipitation levels.

[8] Heinz-Dieter Hollweg, Uwe Böhm, Irina Fast, Barbara Hennemuth, Klaus Keuler,Elke Keup-Thiel, Michael Lautenschlager, Stephanie Legutke, Kai Radtke, Burkhardt Rockel, Martina Schubert, Andreas Will, Michael Woldt, Claudia Wunram (2008): Ensemble Simulations over Europe with the Regional Climate Model CLM forced with IPCC AR4 Global Scenarios, M&D Technical Report No.3, Hamburg.

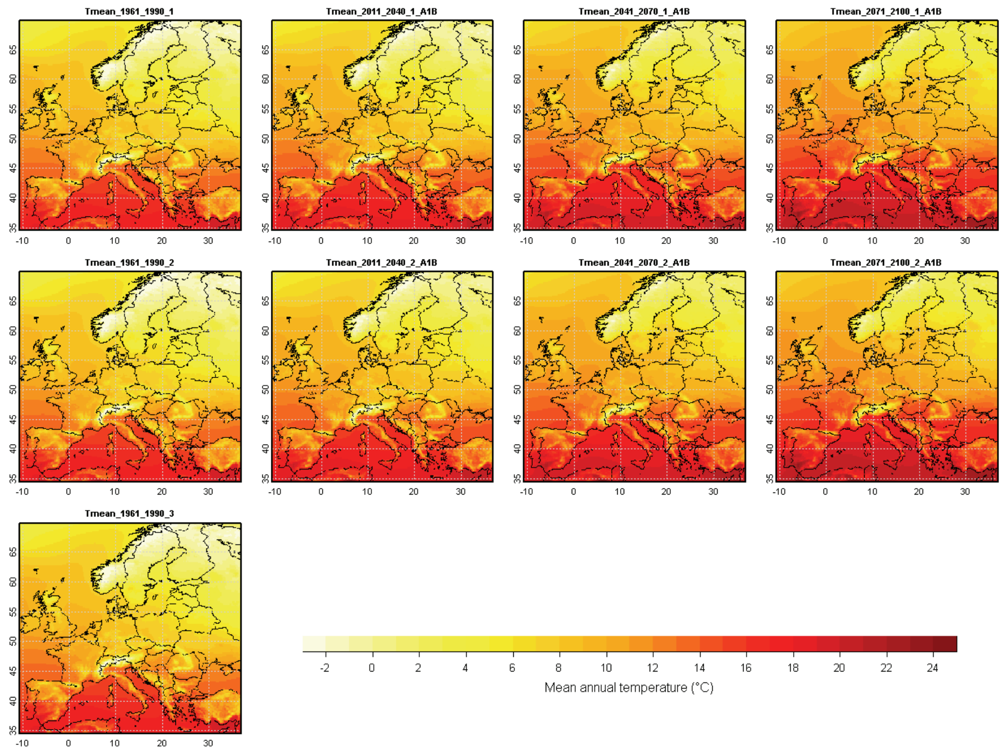


Figure 4: CCLM output on mean annual temperature (T_2M_AV), averaged for different timeframes (1961-1990, 2011-2040, 2041-2070, 2071-2100), for different model runs and scenario A1B. (source: Lautenschlager et al. 2009, preparation by PIK)

Change in annual mean temperature

Based on the CCLM parameter 'air temperature in 2 metres above surface' (T_2M_AV, yearly) average annual temperatures in degrees Celsius for the selected time frames have been calculated. This indicator serves to indicate regional variation of changes in temperature, as the main indicator for climate change.

Change in annual mean number of frost days

Based on the CCLM parameter 'frost days' (FD, yearly) average annual number of frost days (days with minimum temperatures below *0°C*) for the selected time frames have been calculated. This indicator serves to indicate changes in regional climate extremes with respect to cold temperatures, which is from a territorial perspective especially relevant for natural and agricultural systems.

Change in annual mean number of summer days

Based on the CCLM parameter 'summer days' (SU, yearly) average annual number of summer days (days with maximum temperatures above *25°C*) for the selected time frames have been calculated. This indicator serves to indicate changes in regional climate extremes with respect to summer temperatures. This has from a territorial perspective relevance for the tourism sector as well as for human wellbeing. .

Relative change in annual mean precipitation in winter months

Based on the CCLM parameter 'total precipitation' (PRECIP_TOT, monthly) average precipitation in kg/sqm for the selected time frames has been summed up for the meteorological winter months (December, January and February). This indicator accounts for changes in winter precipitation. Seasonal averages have been calculated to account for the strong intra-annual variation of this variable. Together with precipitation in summer months, conclusions about water availability can be drawn.

Relative change in annual mean precipitation in summer months

Based on the CCLM parameter 'total precipitation' (PRECIP_TOT, monthly) average precipitation in kg/sqm for the selected time frames has been summed up for the meteorological summer months (June, July and August). This indicator represents regional exposure to changes in summer precipitation. Seasonal averages have been calculated to account for the strong intra-annual variation of this variable. From a territorial perspective changes in summer precipitation are especially relevant for vegetation.

Change in annual mean number of days with heavy rainfall

Based on the CCLM parameter 'rainfall' (RAIN_TOT, yearly) average annual number of days with heavy rainfall (above 20kg/sqm) for the selected time frames has been calculated. This indicator will illustrate regional exposure to changes in heavy rainfall events and thus indicate hydrologic extremes. This variable has strong relevance for local heavy rainfall event, especially when occurring over highly sealed surface area.

Relative change in annual mean evaporation

Based on the CCLM parameter 'surface evaporation' (AEVAP_S, yearly) the average annual amount of water evaporating in a distinct area has been calculated. This indicator represents the changes in evaporation, and is from a territorial perspective thus of relevance especially for the natural systems, combining information on temperature and hydrologic conditions.

Change in annual mean number of days with snow cover

Based on the CCLM parameter 'snow cover' (SNOW_COV) the average annual number of days with snow covering the surface of the reference area has been calculated. This indicator serves to indicate the change in the number of days with snow cover and indicates changes in the snow condition, from a territorial perspective for example for the winter tourism sector.

In addition two 'triggered effects', which constitute a culmination of several of the above variables, were also included:

Change of inundation through river flooding

Some extreme whether events may be triggered by climate stimuli related with precipitation, such as river flooding and mass movements (IPCC 2007, Prudhomme, C., Reynard, N. 2009). The impact of climate change on flooding is covered by JRC's LISFLOOD model. LISFLOOD is a GIS-based hydrological rainfall-runoff-routing model that is capable of simulating the hydrological processes that occur in a river catchment area (Van Der Knijff, J. M., Younis, J. and De Roo, A. P. J. 2008). However, like is the case with any other pan-European model on highly complex and dynamic systems like rivers, LISFLOOD's simulation outputs contain some degree of uncertainty. Besides the fact that in the case of ESPON Climate LISFLOOD data were only based on one climate model (CCLM), one may mention difficulties to account for effects of snowmelt, river regulation or dykes (for more detailed discussions see Dankers and Feyen 2009, but also this project's case studies on the Netherlands and NRW). Nevertheless, for the purpose of a pan-European, comparative assessment the LISFLOOD simulations currently provides the best available dataset.

Within ESPON Climate change in exposure to river flooding was therefore calculated based on data provided by JRC's LISFLOOD model (cp. van der Knijff and de Roo 2008). In particular the outputs of LISFLOOD were used that are based on the climate projections of the CCLM model on the basis of the A1B scenario. The outputs are inundation heights on 100 x 100 metre grids along major European rivers. Using the outputs for the 1961-1990 and 2071-2100 time periods the ESPON Climate project calculated the changes in inundation heights of a 100 year return flood event for each grid cell and subsequently for each NUTS 3 region.

Change of inundation through coastal storm surge based on projected sea level rise

Sea level rise is not a climate change exposure indicator in the CCLM model, because it is rather a first level effect triggered by changes in global temperatures and regionally also by land up- and downlift. Most sea-level rise vulnerability assessments have so far focused mainly on identifying land located below elevations that would be affected by a given sea-level rise scenario (Schneider and Chen, 1980; Rowley et al., 2007). This requires use of elevation data from digital elevation models (DEMs) to identify low-lying land in coastal regions. However, sea level rise during normal tides may not be the greatest challenge for these regions, because the most recent projections range only between 0.3 and 1.8 metres (see Rahmstorf 2007, Vermeer, Rahmstorf 2009, Grinsted, Moore 2009). But during severe coastal storms such additions to storm surge heights may pose a great threat. It is not clear, though, how exactly coastal storms and sea level rise interact. Furthermore, even though differences in sea level rise exist between coastal regions in Europe (as measured by altimetry data since 1992), oceanologists have so far not been able to estimate how these differences would develop until e.g. the year 2100. Therefore the ESPON Climate project decided to take a 'middle of the road' approach and base its coastal storm surge indicator on a uniform one metre sea level rise. This value lies in the middle range of the above cited projections (see also Nicholls 2010) and also corresponds to the lowest vertical resolution of the European-wide available Hydro1K digital elevation model (USGS 2010).

Thus, one metre was added to the fine-grained regional DIVA projections of storm surge heights of a 100-year return event (cp. Vafeidis et al. 2005). Using the digital elevation model it was calculated which areas would then be inundated by coastal flooding in comparison to storm surge flooding without any accounting for sea level rise.

This choice of climate stimuli is additionally justified by the needs of the different case studies which are characterised by specific climatic conditions, as shown in Table 3:

Table 3: Climate stimuli considered on case study level

	Mean tempera-ture	Frost days	Summer days	Winter precipita-tion	Summer precipita-tion	Heavy rainfall days	Evapo-ration	Snow cover days	Sea level rise	River flooding
Coastal Aquifers	x	x		x	x		x		x	x
NRW	x	x	x	x	x	x	x	x		x
Bergen	x			x	x	x			x	x
Tisza	x			x	x					x
Spain	x	x	x	x	x	x	x	x		
Netherlands	x			x		x			x	x
Alpine space	x	x	x	x	x	x		x		x

3.1.3 Mapping climate change indicators

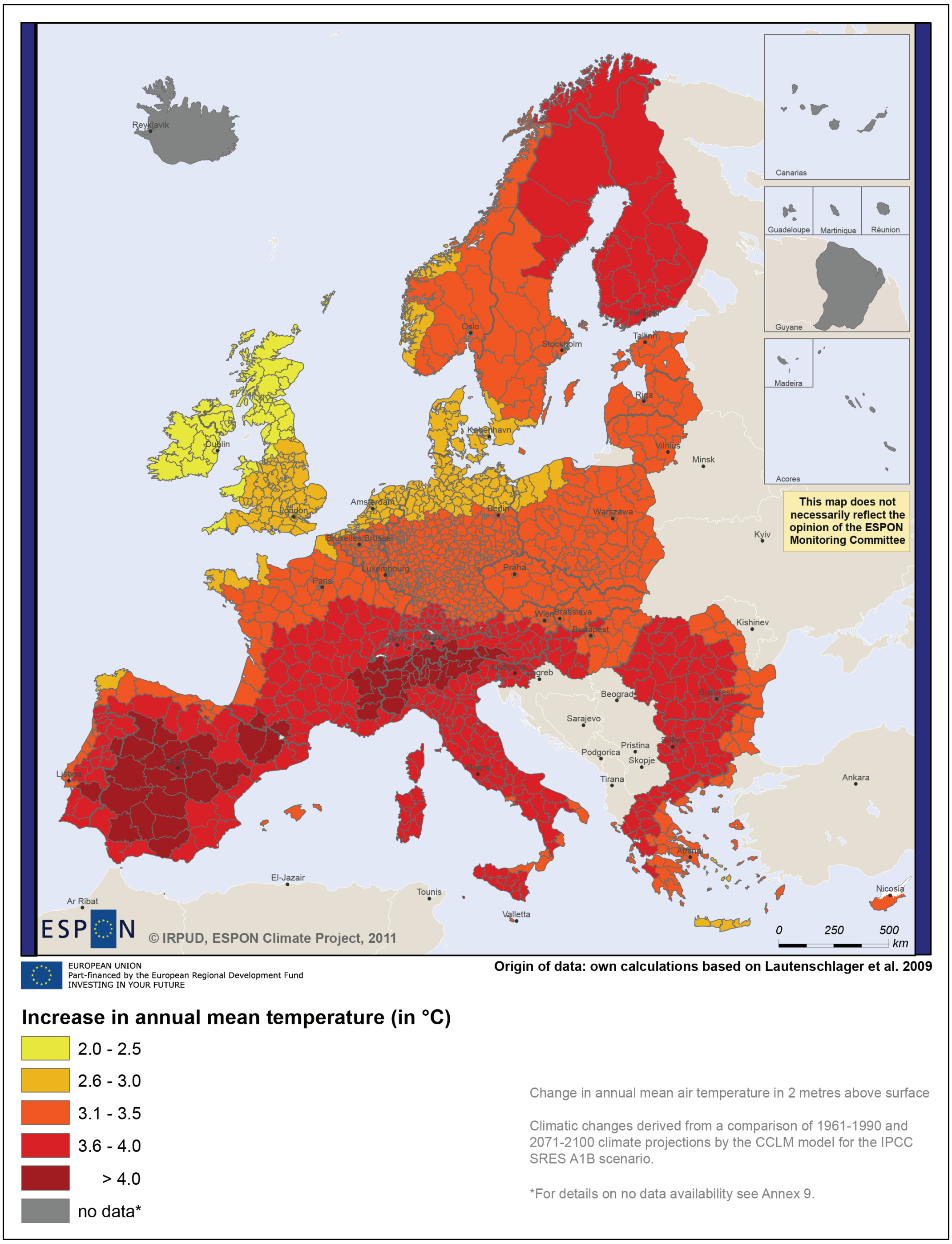
The exposure indicators listed in the preceding section have all been calculated based on the outputs of the respective parameters from the CCLM model runs and LISFLOOD.
The averaged CCLM projections for the four time-slices 1961-1990 and 2071-2100 have been calculated based on the model outputs for the respective parameters. For each of the future projections two climate model runs are available, for the reference period (1961-1990) three respectively. In order to consider all available runs the results from different runs have been averaged prior to further calculations of change indicators for each period of 30 years. The baseline change indicators presented in this chapter compare the future period 2071-2100 to the reference period 1961-1990 for the scenario A1B. The changes are calculated either as absolute changes subtracting the averaged present value from the respective value for the simulated future period or as relative changes in per cent relating the absolute change value to the value for the reference period.

In order to approximate the climate data to the European regions the individual cell values have to be aggregated to the NUTS3 level. To accomplish this task, different approaches may be taken. In order to ensure consistency throughout the whole ESPON space with its strong heterogeneity concerning the area of the NUTS3 regions the approach chosen by the project is based on an intersection of the administrative units with the CCLM cells. This approach enables to determine the regional values by considering the single cell values by their aerial shares for each NUTS3 region when calculating the aggregate regional value. All of the results presented in the following maps have been subject to the methodological procedures described above.

For Iceland and the French outermost territories the CCLM model runs that were used to calculate the exposure indicators do not cover these countries and due to methodological reasons could not be substituted with other model runs. Furthermore, data on river flooding were derived from the outputs of the LISFLOOD model which in addition to the afore-mentioned countries also lacks data on Cyprus. The lack of exposure data in turn also meant that no impact and vulnerability indicators could be calculated for these cases. See Annex 9 for a more detailed overview of data availability.

Change in annual mean temperature

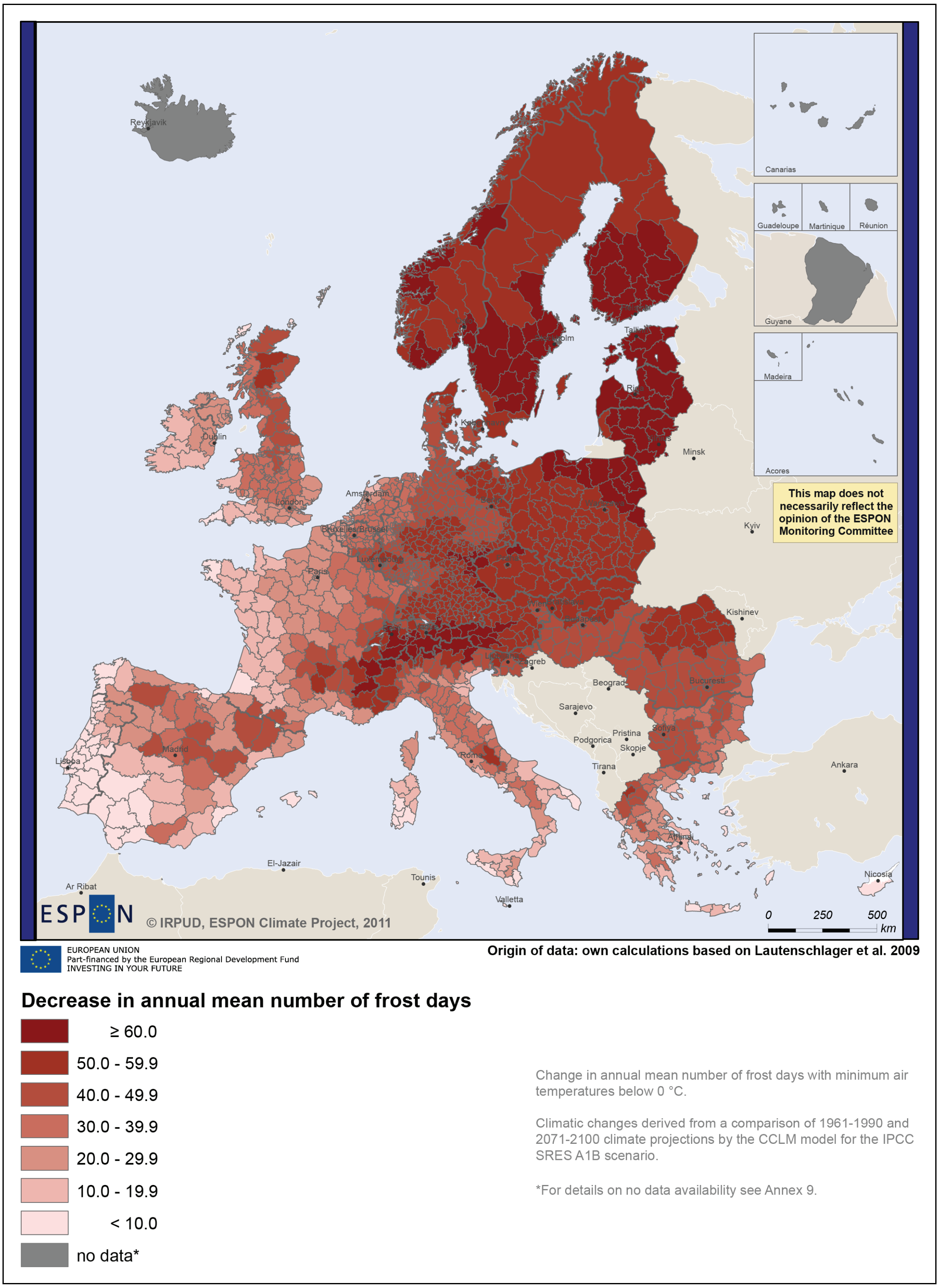
Annual mean temperatures are projected to increase between 2 and over 4.1 °C in the ESPON territory (see Map 1). The UK, Ireland, Denmark, parts of the Netherlands and Germany exhibit the lowest temperature changes of up to 3 °C. Western and northern parts of France, Belgium, most parts of Germany, Poland, the Czech Republic, Slovakia and parts of Sweden and Norway and the Baltic states will be subject to temperature increases between 3 and 3.5 °C. Southern and South-Eastern Europe as well as northern Scandinavia and Finland are projected to experience the highest temperature changes with absolute changes of more than 3.5 °C. Spain, parts of Portugal and the Alpine region will even experience temperature changes of more than 4 °C.



Map 1: Change in annual mean temperature

Change in annual mean number of frost days

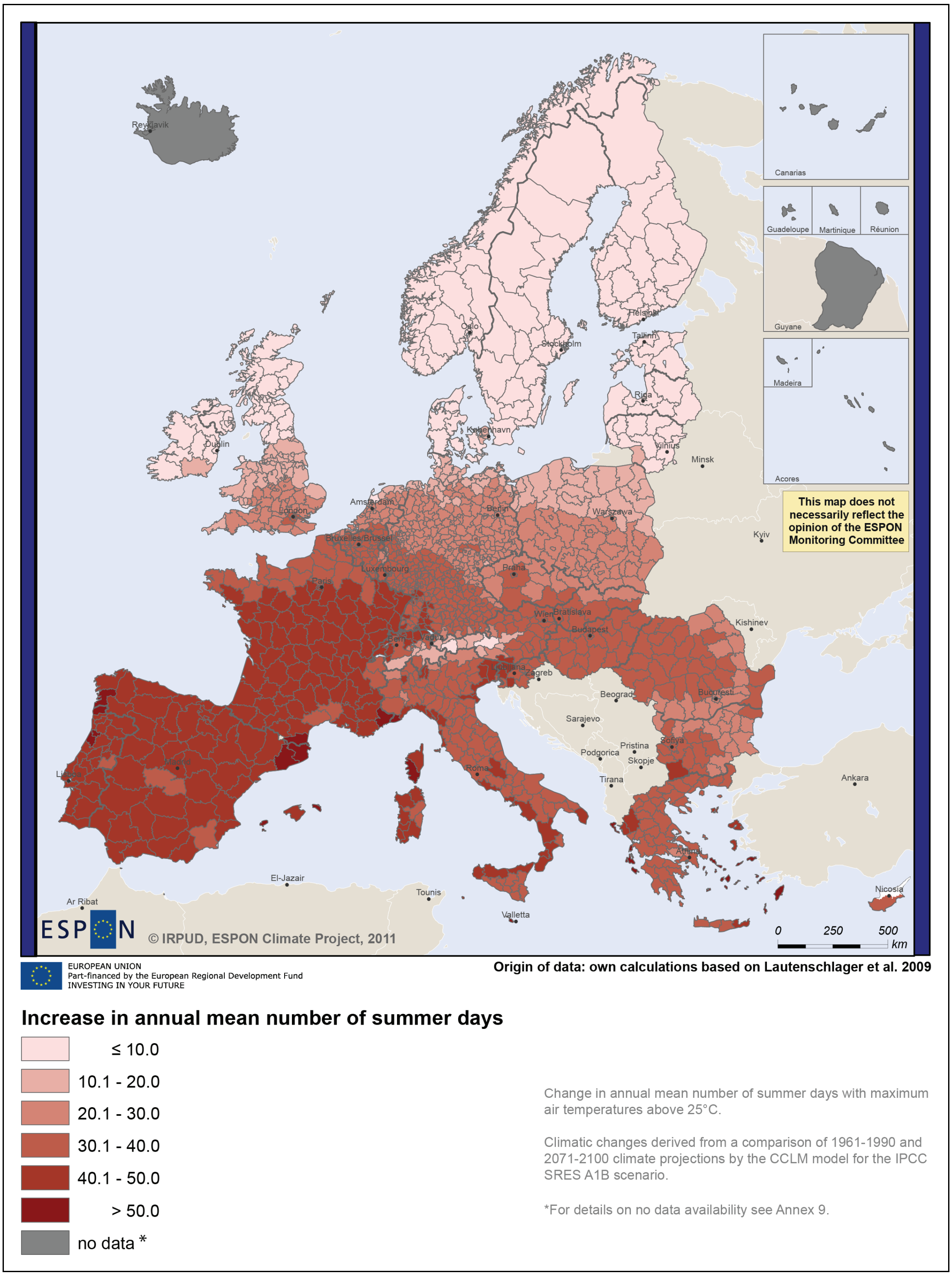
The averaged model outputs on number of frost days indicate roughly a South-West to North-East stretched pattern considering the whole of Europe (see Map 2Map 3). While Spain, most parts of France and Italy and also Ireland exhibit comparatively slight decrease in number of frost days particularly the alpine countries, most parts of Germany, Eastern Europe as well as the Baltic states, Scandinavia and Finland are projected to experience more severe decrease in the number of frost days with regional peaks of 60 days and more.



Map 2: Change in annual mean number of frost days

Change in annual mean number of summer days

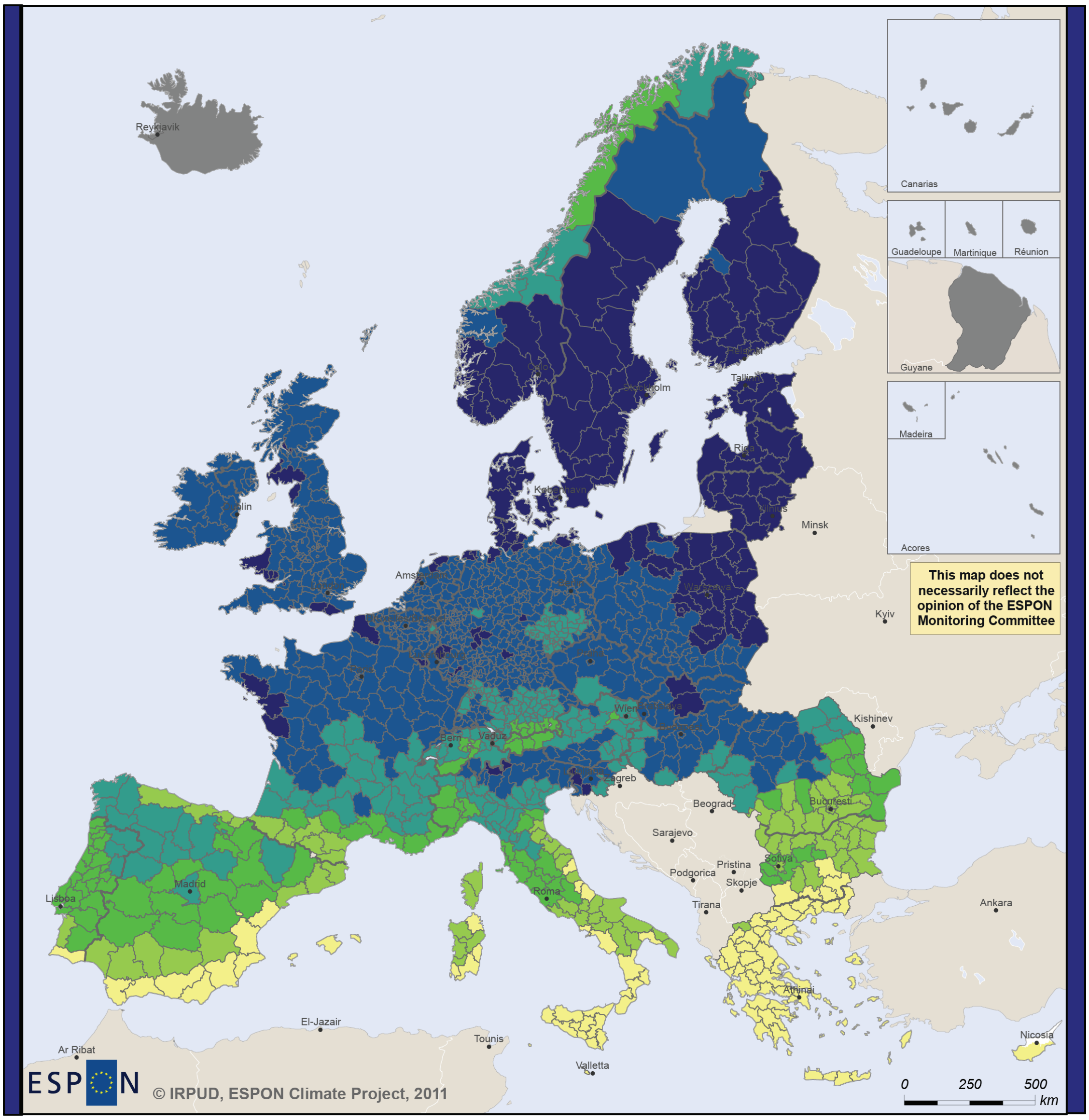
The patterns on the projected changes of the annual mean number of summer days show almost the inverse picture compared to the change in annual mean number of frost days (see Map 3). Here, increases between less than 10 and more than 50 days per year in average have been calculated by the model. The comparatively slightest increases are predicted for the North of Europe including Scandinavia, Finland, the Baltic States as well as parts of Denmark, UK and Ireland while predominantly France, Spain and Portugal exhibit increases of more and 40 days per year on average.



Map 3: Change in annual mean number of summer days

Relative change in annual mean precipitation in winter months

For the European patterns of change in winter precipitation exhibit the CCLM model projects twofold developments (see Map 4). While in most parts of Northern and Central Europe winter precipitation is projected to increase Southern Europe and particularly most parts of the Mediterranean area will experience decreases in winter precipitation of 10% and more. Regions in Greece and Bulgaria as well as Cyprus show the highest relative decreases.



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Origin of data: own calculations based on Lautenschlager et al. 2009

Change in annual mean precipitation in winter months (in %)

- ≤ -20.0
- -19.9 - -10.0
- -9.9 - 0.0
- 0.1 - 10.0
- 10.1 - 20.0
- > 20.0
- no data*

Relative change in annual mean precipitation in metereological winter months (December - February).

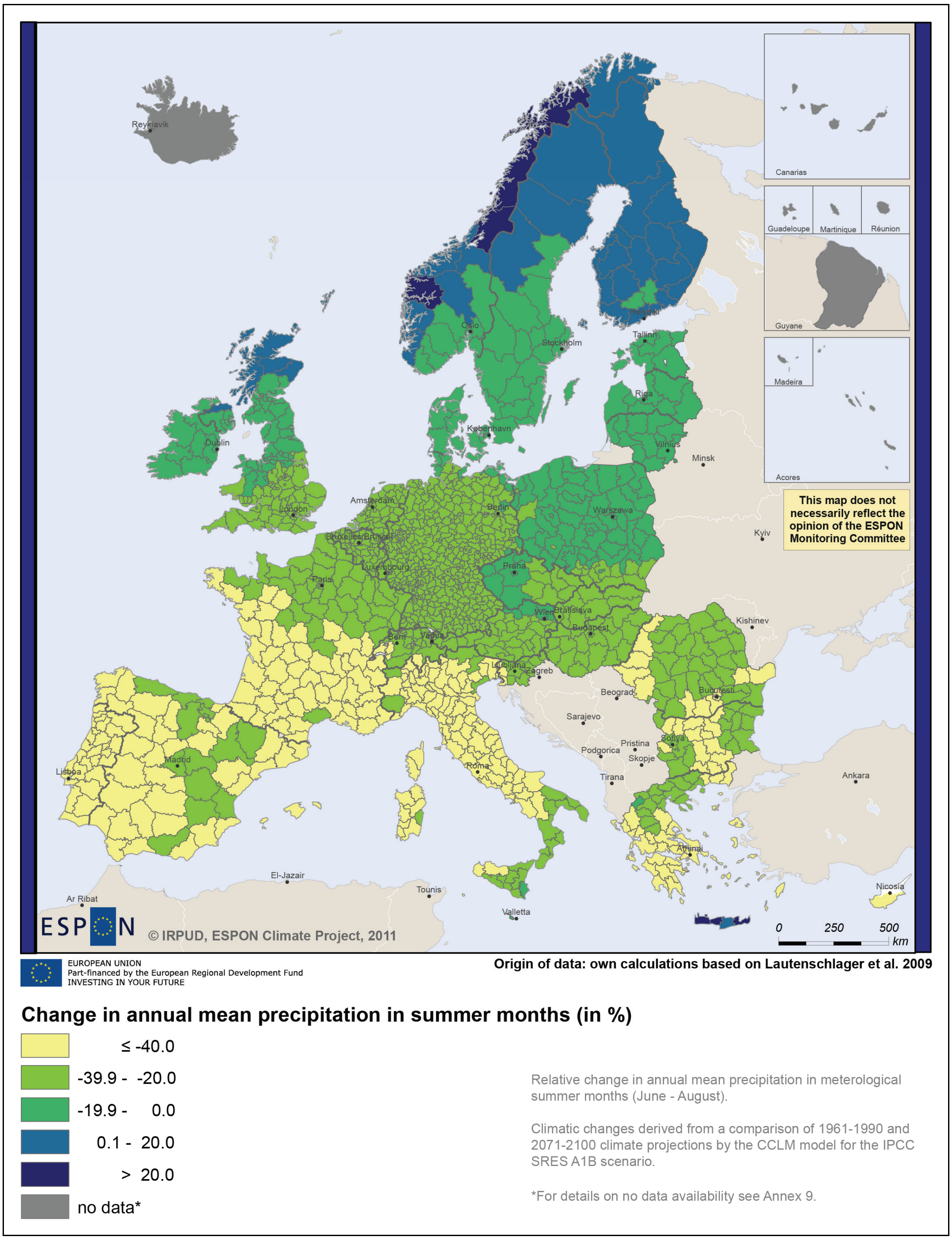
Climatic changes derived from a comparison of 1961-1990 and 2071-2100 climate projections by the CCLM model for the IPCC SRES A1B scenario.

*For details on no data availability see Annex 9.

Map 4: Relative change in annual mean precipitation in winter months

Relative change in annual mean precipitation in summer months

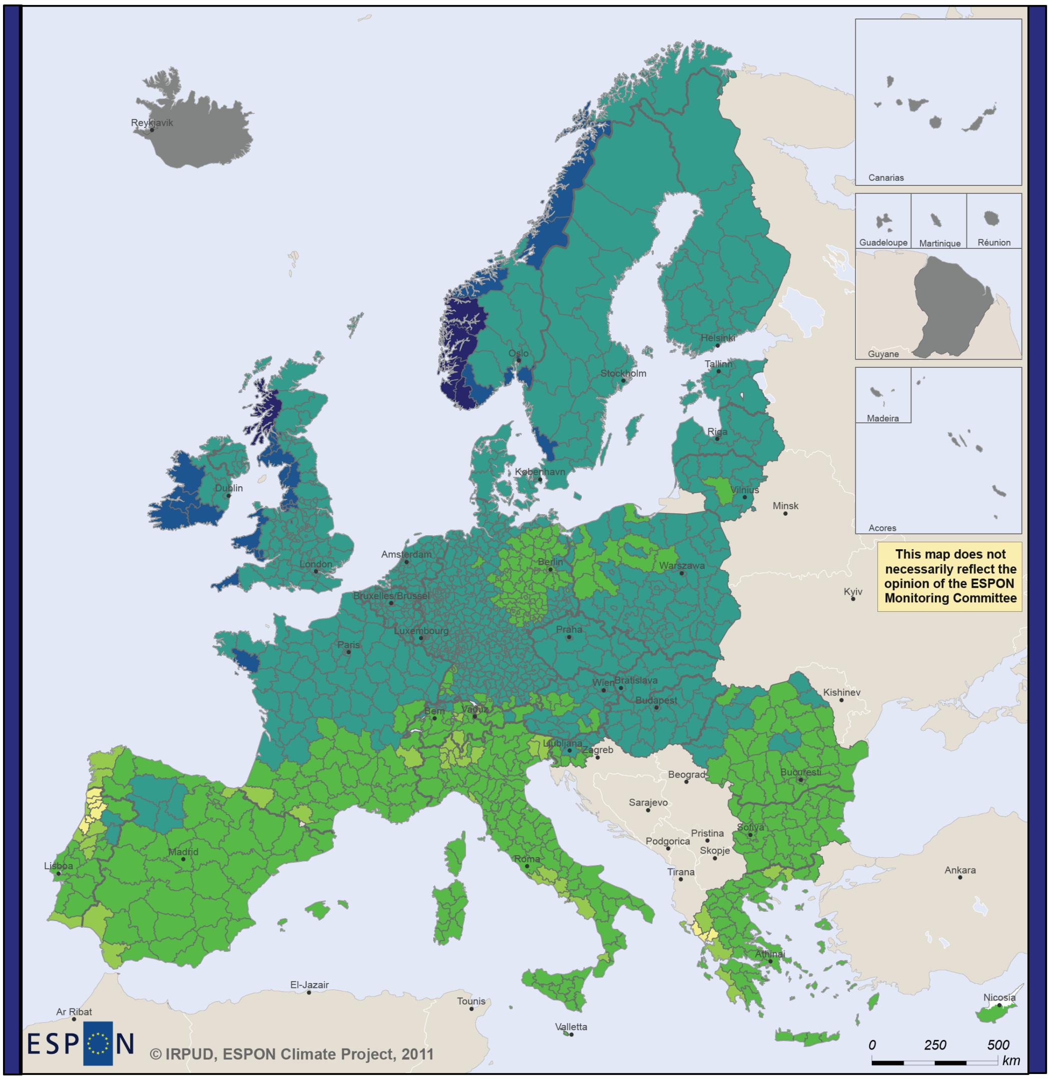
The CCLM outputs on precipitation in summer month again are twofold considering the changes within the European territory (see Map 5). While parts of Scandinavia and Finland as well as Northern UK will experience increases up to 40 % most of the ESPON space will experience decrease in summer precipitation up to 40 % and more. For parts of Scandinavia, the Baltic states, Poland, parts of the Czech Republic, Denmark, Ireland and parts of the UK those decreases are projected to range up to 20 % while the rest of Europe and here particularly France, Portugal, Spain, Italy, Greece are projected to experience the strongest relative decreases in annual summer precipitation considering the overall patterns for the European territory.



Map 5: Relative change in annual mean precipitation in summer months

Change in annual mean number of days with heavy rainfall

As the previous precipitation-related indicators also the change in annual number of days with heavy rainfall reveals a twofold pattern over the whole of Europe. Roughly a North-South divide with a division at alpine latitudes becomes evident (see Map 6). Most of the territory at lower latitudes is projected to experience average decreases in annual heavy rainfall of up to 5 days and more whereas for the territory north of this division line is projected to gain in average number of days with heavy rainfall. For most of these regions increases will amount up to 3 % but along the coastline of Norway as well as Western UK and Ireland and some parts of the Atlantic coast of France increases between 4 and 13 days have been calculated by the CCLM model.



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Origin of data: own calculations based on Lautenschlager et al. 2009

Change in annual number of days with heavy rainfall

- ≤ -6.0
- -5.9 - -3.0
- -2.9 - 0.0
- 0.1 - 3.0
- 3.1 - 6.0
- > 6.0
- no data*

Change in annual mean number of days with more than 20mm/sqm of rainfall.

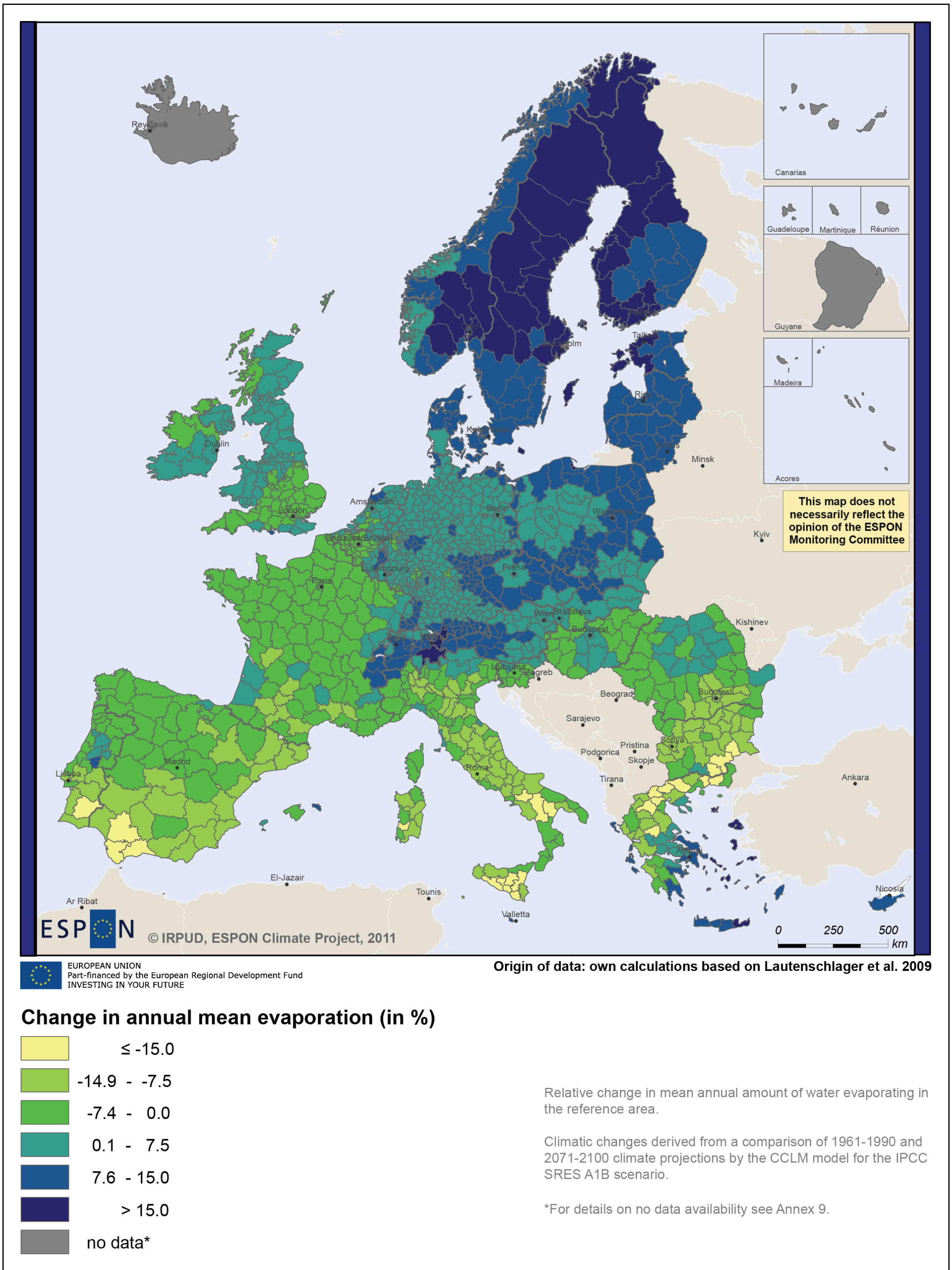
Climatic changes derived from a comparison of 1961-1990 and 2071-2100 climate projections by the CCLM model for the IPCC SRES A1B scenario.

*For details on no data availability see Annex 9.

Map 6: Change in annual mean number of days with heavy rainfall

Relative *change in annual mean evaporation*

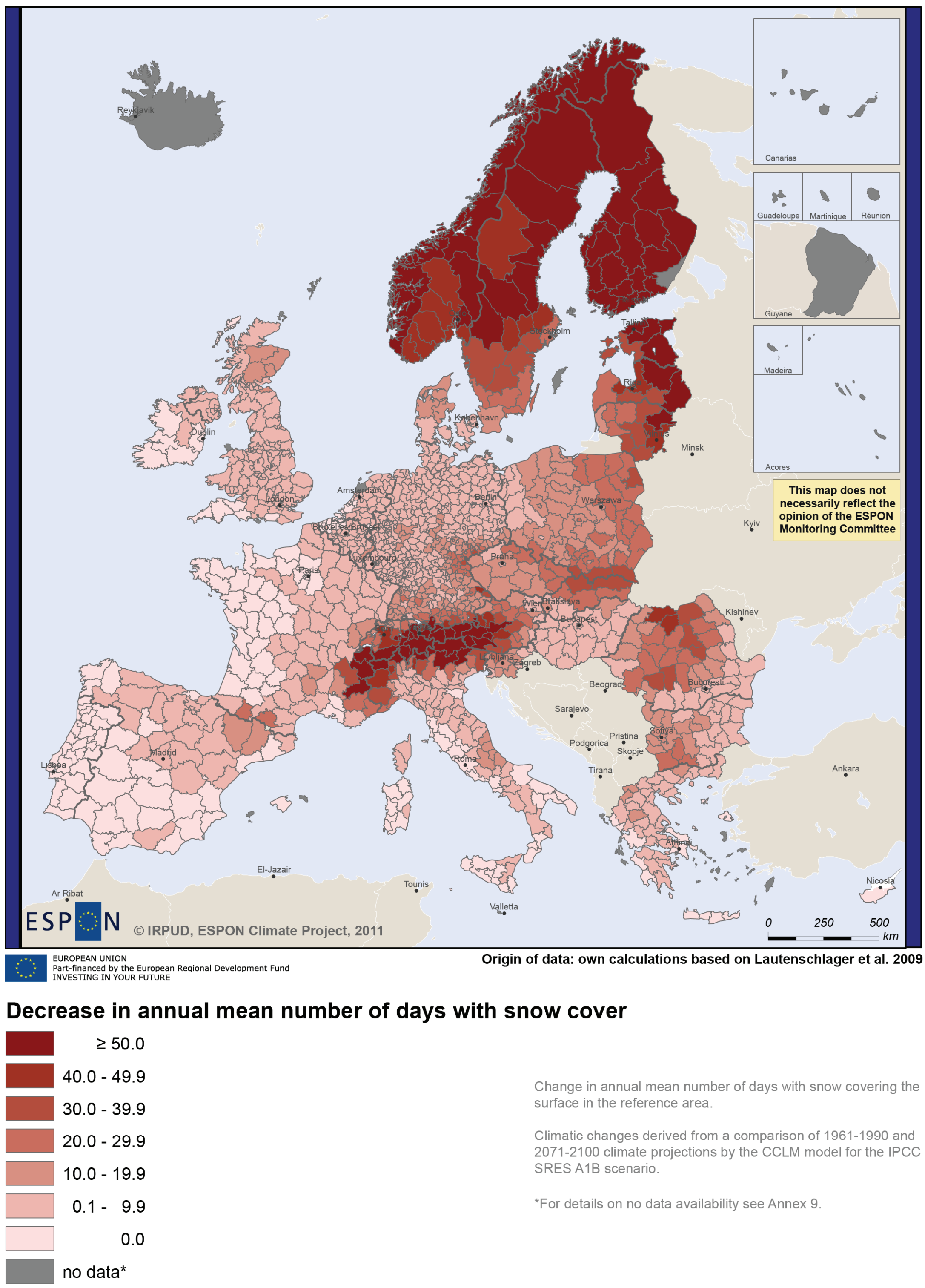
European patterns on change in annual mean evaporation range from decrease of more than 15 % to increases up to 22 % (see Map 7). Most of the higher decreases are found in Southern Europe, particularly in the Mediterranean and Romania. Strong increases on the other hand are predominant projected for Scandinavia, Finland and the Baltic States as well as parts of Poland but also the Alpine space and parts of Czech Republic.



Map 7: Relative change in annual mean evaporation

Change in annual mean number of days with snow cover

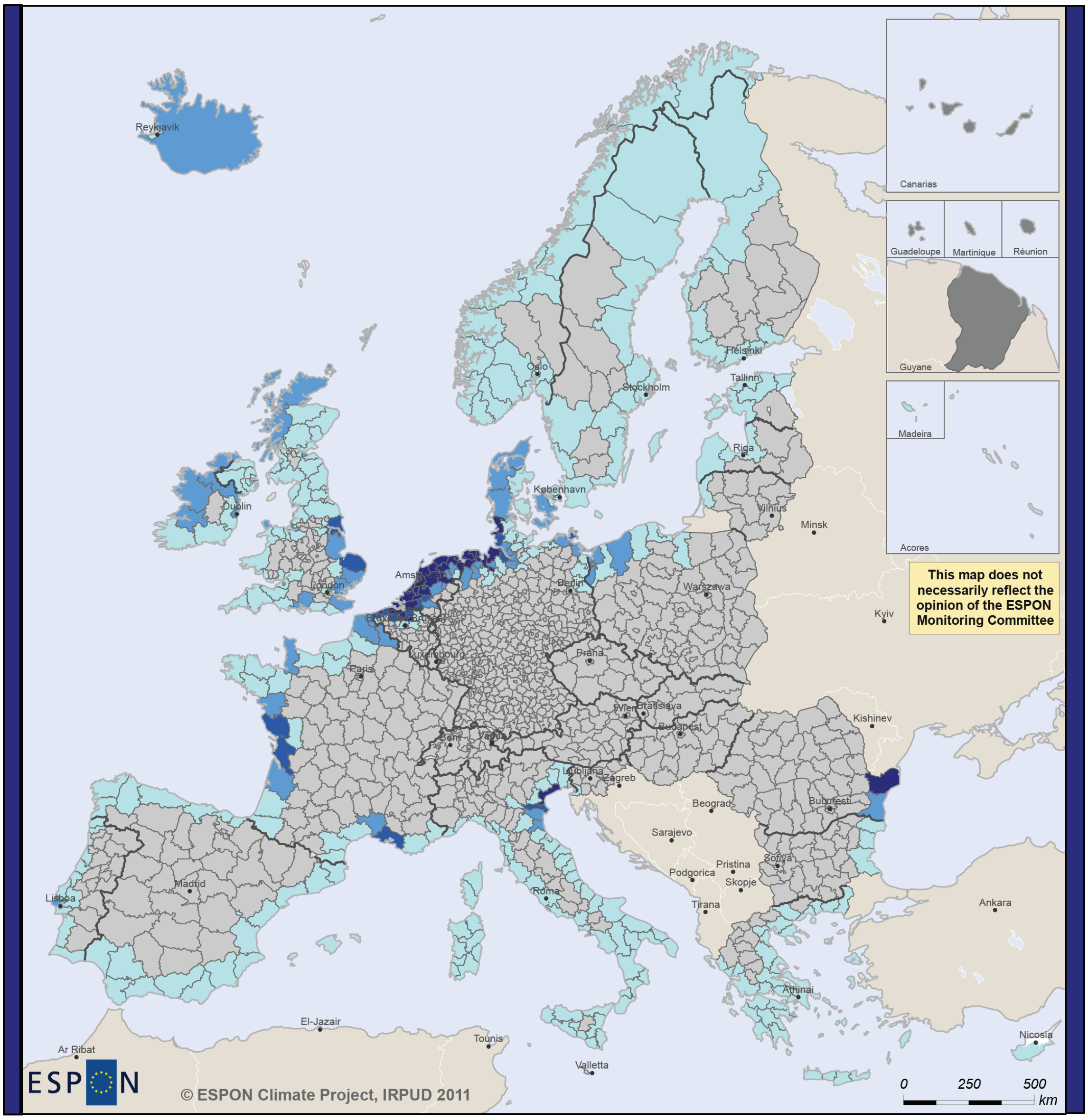
Snow cover is projected to decrease most significantly in Scandinavia, Finland, the Baltic States and the Alpine countries (see Map 8). Furthermore, some of the parts of Eastern Europe are also projected to experience a comparatively strong decrease in the number of days with snow cover. The rest of the European territory will mostly experience decreases of up to 20 days.



Map 8: Change in annual mean number of days with snow cover

Change in inundation through coastal storm surges

The inundation effects of sea level rise adjusted coastal storm are rather marginal for most coastal regions. However, for some regions more severe changes can be expected. This affects primarily regions at the Dutch and German coastlines but also in Denmark and France. Equally severe changes, however, can be projected for some regions in north-eastern Italy and the Danube delta in Romania.



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Origin of data: own calculations based on DIVA 2004 and USGS Hydro1k Europe

Change in regional exposure to coastal storm surge events

- highest negative impact (0.5 - 1.0)
- medium negative impact (0.3 - <0.5)
- low negative impact (0.1 - <0.3)
- no/marginal impact (>-0.1 - <0.1)
- no exposure
- no data*

Inundation depth changes due to a sea level rise adjusted coastal storm surge event.

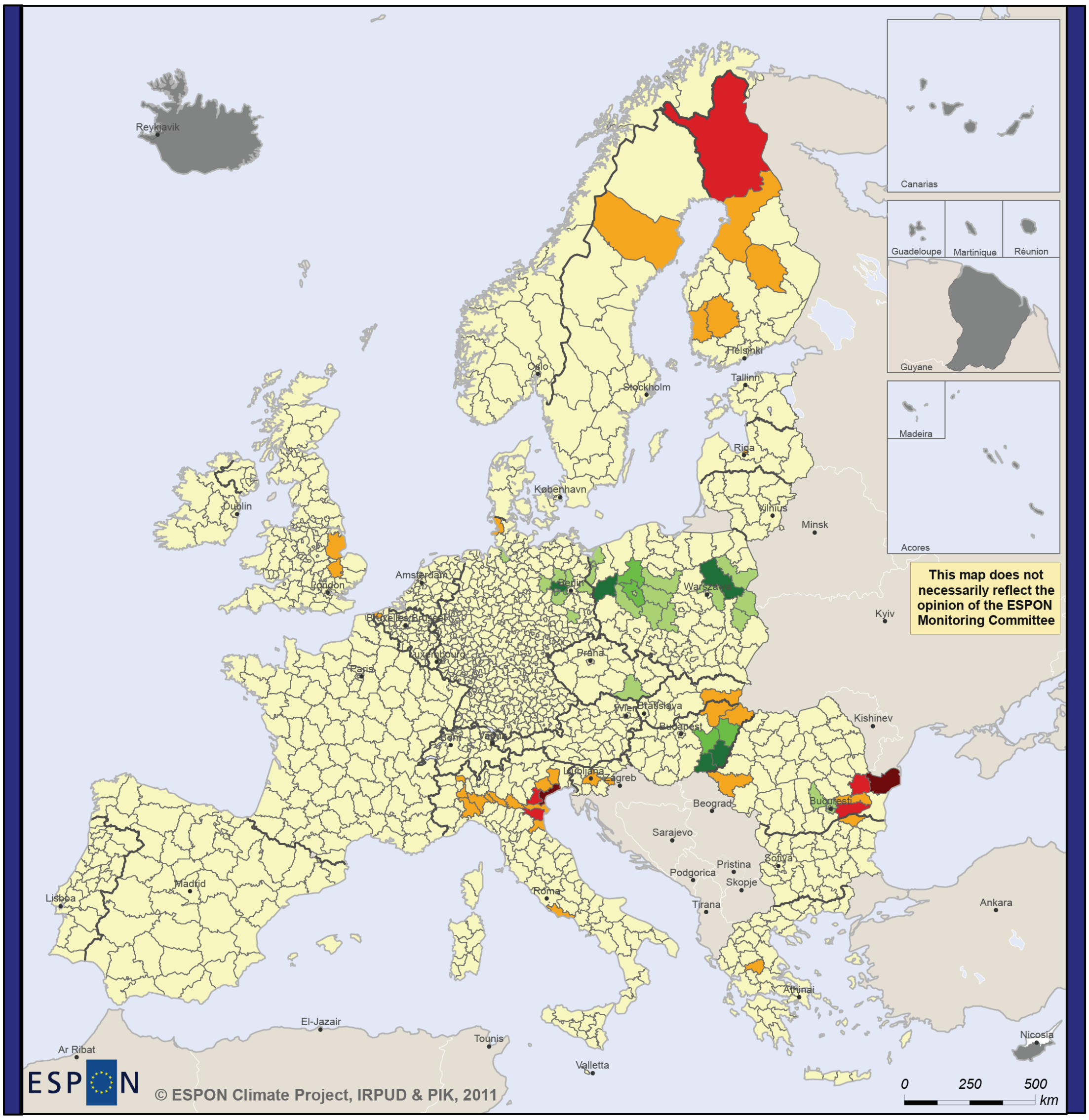
Calculated on the basis of regional coastal storm surge heights projected by the DIVA model for a 100 year return event and heightened by a 1 m sea level rise.

*For details on no data availability see Annex 9.

Map 9: Change in regional exposure to coastal storm surge events

Change in inundation through river flooding

Also river flooding affects most European regions only marginally, but some regions exhibit considerable changes. Among the areas characterised by considerable increases in river flooding are regions located in Northern Scandinavia and Northern Italy. Also some regions in Romania are quite severely affected. Corresponding to the precipitation patterns there are also some regions projected to experience decreases in exposure to river flooding, predominantly in eastern parts of Germany, in Poland and Hungary.



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Origin of data: own calculations based on JRC LISFLOOD 2010

Change in regional exposure to river flooding

- highest negative impact (0.5 - 1.0)
- medium negative impact (0.3 - <0.5)
- low negative impact (0.1 - <0.3)
- no/marginal impact (>-0.1 - <0.1)
- low positive impact (-0.1 - >-0.3)
- medium positive impact (-0.3 - >-0.5)
- high positive impact (-0.5 - -0.86)
- no data*

Inundation depth changes due to climate induced changes in river flooding.

Calculated by comparing the LISFLOOD model's 1961-1990 and 2071-2100 projections for a 100 year return event based on climate projections by the CCLM model for the IPCC SRES A1B scenario.

*For details on reduced or no data availability see Annex 9.

Map 10: Change in regional exposure to river flooding

3.1.4 Typology of climate change regions

Typologies of climate change regions were developed by means of a cluster analysis, based on the projected changes in the eight climate variables from the CCLM model between the time periods 1961-1990 to 2071-2100 under the A1B scenario (averaged model runs). It has been carried out for those cells, which contain values for all indicators (i.e. land cells, 2271 cells in total). The African part was excluded from the analysis as it is characterised by large model uncertainties and is not in focus of this project. The spatial distribution of the projected changes in climate variables within the raster cells is summarised below.

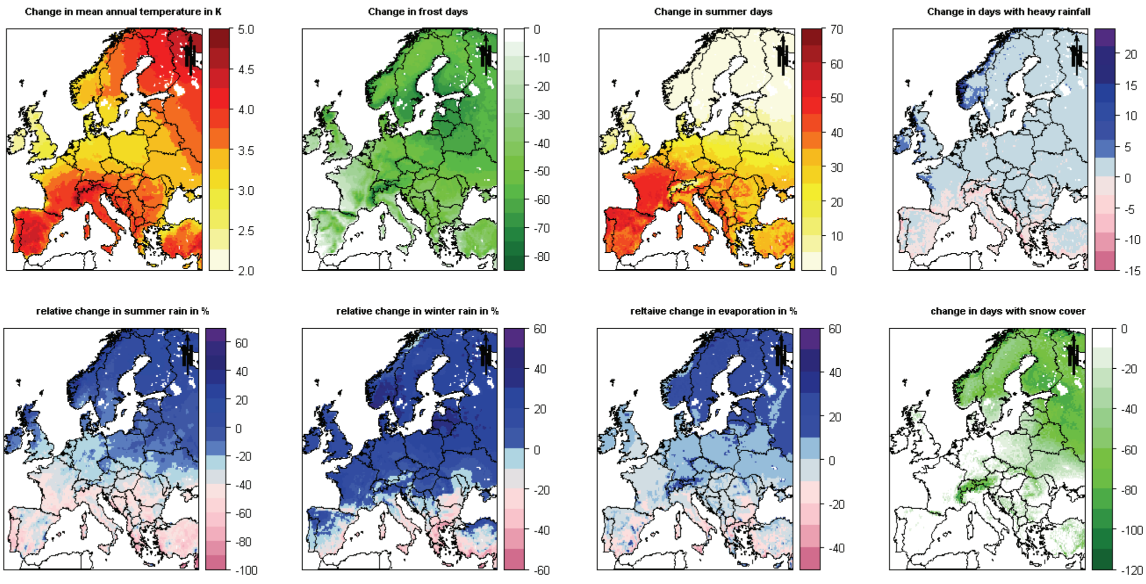


Figure 5: Changes of the eight considered climate variables of the model CCLM between the time periods 1961-1990 to 2071-2100 (Africa is marked with white cells). Note that evaporation values are indicated with negative values (opposed to precipitation).

Fehler! Verweisquelle konnte nicht gefunden werden. Figure 6 gives an overview on the frequency distribution of the values of the climate variables for the considered cells. The variables “change in frost days” and “change in days with snow cover” show negative values (thus decreasing number of days) for all cells, whereas the variables “temperature change” and “relative change in summer days” show positive values (and thus increasing temperature or days). For the other variables, both increases and decreases are projected for Europe.

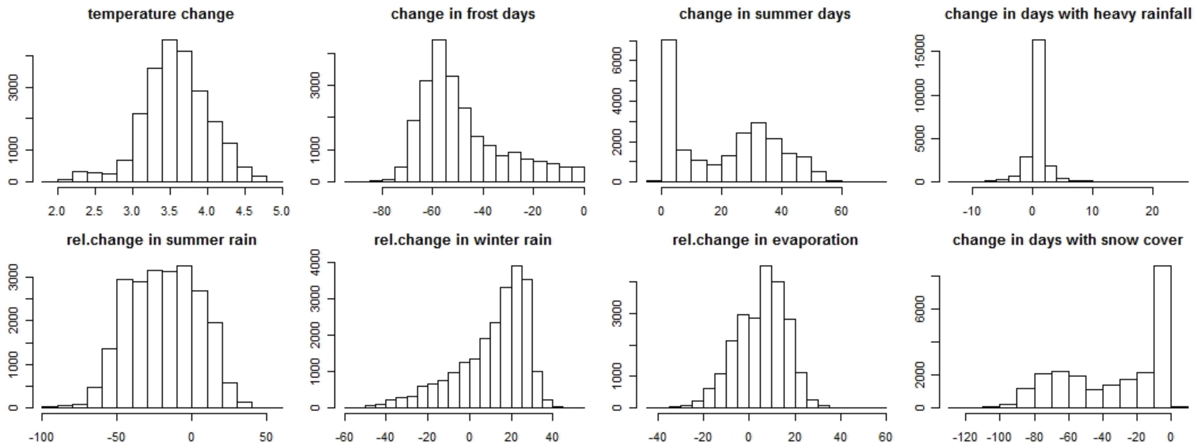


Figure 6: Frequency distribution of the climate variables for the considered cells (n=22771). Note that evaporation values are indicated with negative values (opposed to precipitation).

The variable „change in days with heavy rainfall" was treated in a particular way due to the fact that for most of the cells only slight changes are projected and strong changes are projected for only a small number of cells. These extreme values narrow the main part of the data set, so cluster centres would be restricted to a small value range. Thus, the values of this indicator were "trimmed" at the lower and upper end. In effect, this means that all pixels with a projected increase in days with heavy rainfall of more than seven days were set to the value seven, while those with decreases of more than five days were set to the value of five. The standardised distributions for the original as well as the trimmed variable are shown in Figure 7.

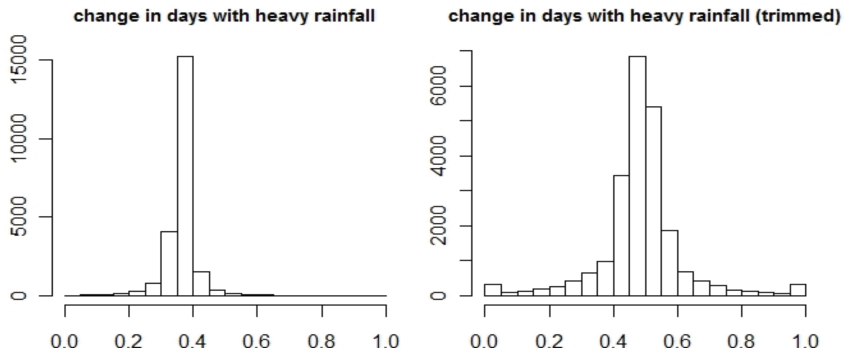


Figure 7: Standardised distributions of the changes in days with heavy rainfall without trimming (left) and with trimming (right).

Furthermore, the whole data set was standardised by its range to values between 0 and 1 (Milligan and Cooper, 1988). The standardised distributions of all remaining variables are shown in Figure 8.

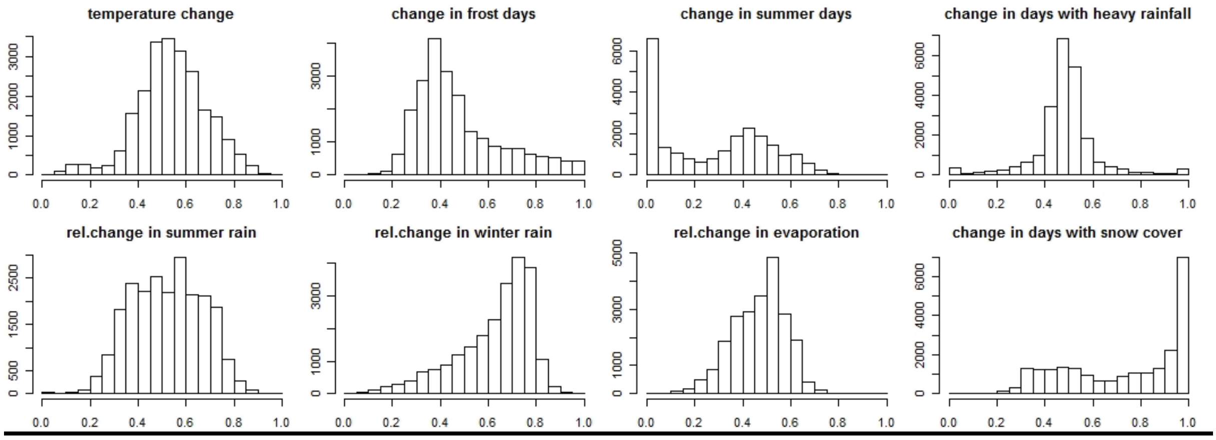


Figure 8: Standardised distributions of the climate variables for the considered cells (n=2277), trimmed values of changes in days with heavy rainfall. Note that evaporation values are given by negative values (opposed to precipitation).

Technique of the cluster analysis

A cluster analysis categorizes the dimensions of a data set by allocating the objects into groups in such a way, that the objects within these groups are more similar to each other than to objects in different groups. The cluster mechanisms can be distinguished in hierarchical, partitioning and density-based methods (Handl et al., 2005). In our analysis the first two methods are being combined.

In a hierarchical clustering the data set is transformed into a distance matrix containing all pair wise distances between the objects in the data set. Using specific amalgamation rules, at first the objects and further the accumulated groups were merged. The “ward”-method has been applied which merges that pair of groups that contributes least to the within-cluster-variance of the whole partition (Ward, 1963).

Hierarchical clustering is used to cluster a small subset of objects to create a starting partition for the subsequent partitioning method. For discovering the structure in the data set the widely known partitioning method of K-means has been applied (MacQueens, 1967). This algorithm minimizes the total within-cluster sum-of-squares (TSS) criterion. If the data set consists of P variables and the number of groups was chosen to K, the criterion is defined by (Steinley, 2006):

$$TSS = \sum_{j=1}^{P} \sum_{k=1}^{K} \sum_{i \in C_k} (x_{ij} - \bar{x}_j^{(k)})^2$$

The objects are assigned to the k given initial cluster centres. Than the new centre is calculated as the average off all objects within the cluster and again all objects are assigned to their nearest cluster centre. This procedure is repeated until a break-up criterion is reached (e.g. points no longer change position or maximum number of loops). The largest advantages of K-means are the calculation speed and the applicability for very large datasets. On the other hand there is a risk of local minima in the optimization process and the user has to choose in advance the number of cluster which is expecting.

Determination of the number of clusters

For identifying the most robust and therefore most representative number of clusters a consistency measure is used, which belongs to the groups of stability based methods (see also Ben-Hur et al. (2002), Roth et al. (2002)). It is based on the idea that if the pre-given number of clusters does not fit the underlying structure of the data, a stochastically initialised cluster algorithm will generate indefinite and different results.

The procedure of the chosen method is to generate pairs of maps, i.e. run K-means twice, for a pre-given cluster number k. Out of these pairs of maps the size of their overlap is assigned as a measure for the consistency, showing how much the two cluster results vary (see Figure 9). A lower variety and a higher value for the consistency measure imply a higher similarity between the pre-given number of clusters and the underlying structure in the analysed data. This pair wise matching will be repeated several times (~200) to achieve a certain mean value for the consistency measure. The overall procedure will be repeated for different cluster numbers k whereby we can identify the k which maximises the consistency measure.

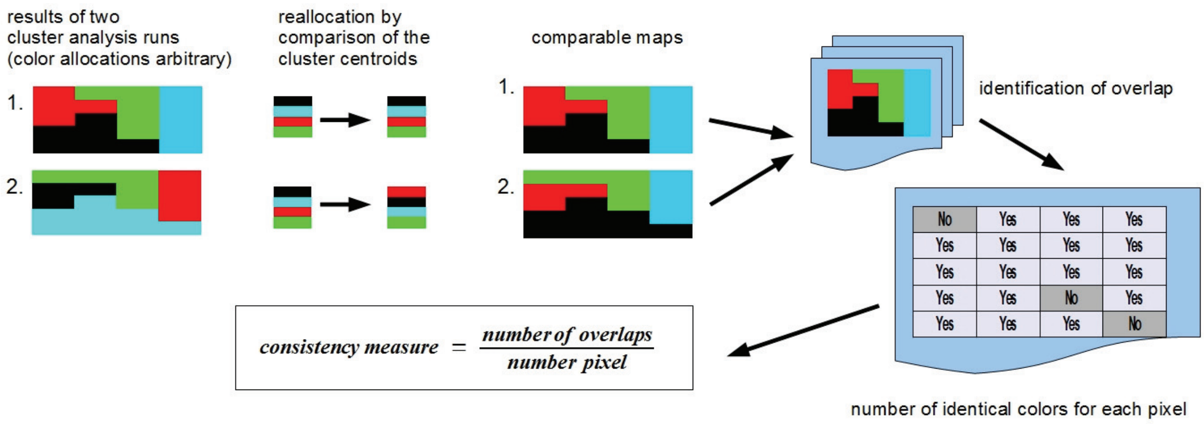


Figure 9: Determination of the number of cluster by means of measuring their consistency (Sietz, in review)

This method provides clearer results than the traditional approach of elbow criterion, as can be seen in Figure 10. In the elbow-criterion, a similarity measure (like the inner-cluster-variance) is applied and the optimal number of clusters can be discerned by a clear “elbow” of the curve. Yet, with an increasing number of clusters, the clusters fit the data-set increasingly better and the detection of “elbows” becomes difficult.

The developed consistency measure gives a clearer picture: The cluster numbers 2, 3 and 5 have the highest consistency values for this data set. Lower numbers of clusters tend to have higher values of consistency but a separation of the data into two and three clusters would not provide a sufficient representation of typologies. Thus, the 5 cluster solution has been selected.

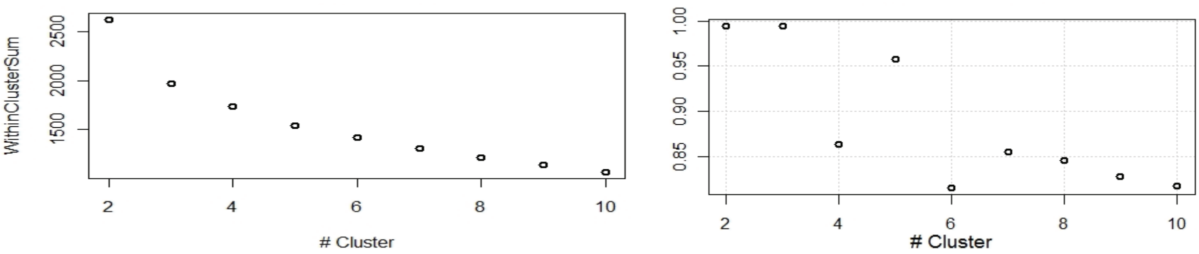


Figure 10: Comparison of the traditional elbow-criterion (left) and the consistency measure (right)

The characteristics of each cluster concerning the mean value of the eight climatic variables can be seen in Figure 11. Some variables show large variations over the cluster, e.g. change in summer days, whereas others are characterised by relatively small variations, e.g. change in evaporation.

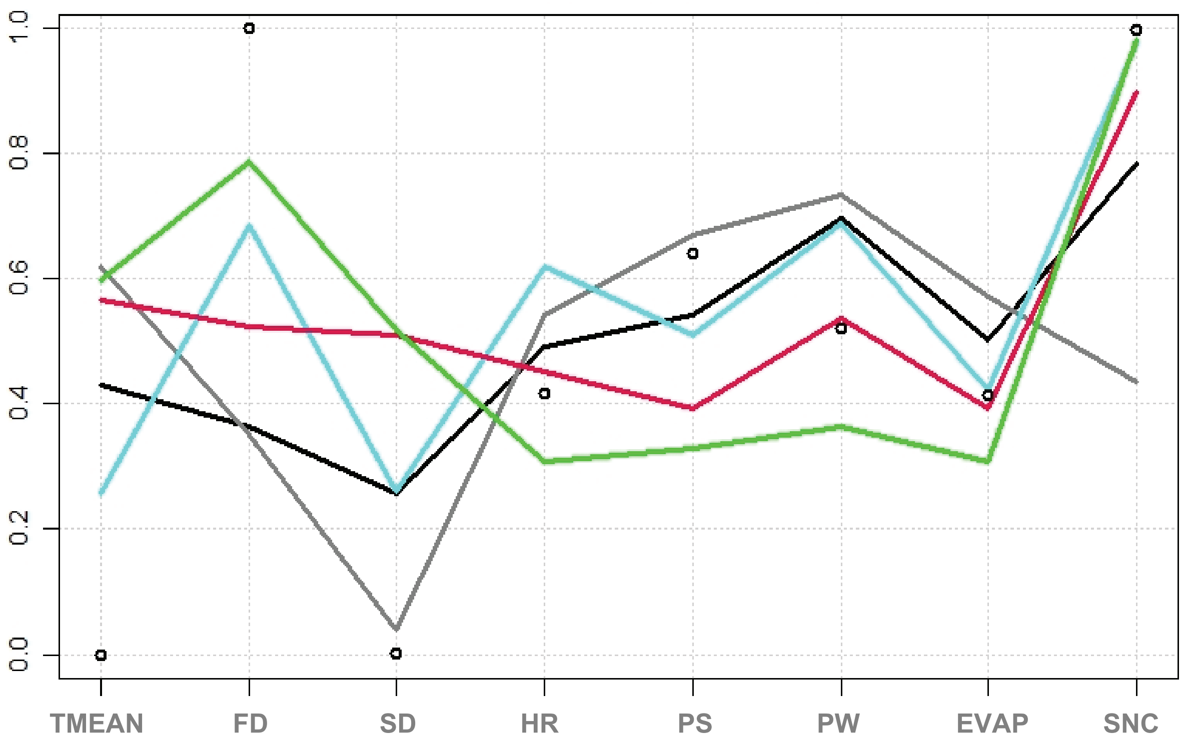


Figure 11: Cluster feature graph for detailed information about the cluster characteristics for the eight climate variables (mean values). Additionally the black circles show the location of the value of zero.

The quality of the cluster representation of each cell (expressed by the distance between the datapoint and the cluster centre) is shown in Figure 12. The red pixels are well represented by their cluster centre, in contrast to the violet pixels: the alpine region, the Norwegian coast, the Atlantic coast are not well represented. A good representation by the cluster can be seen for Eastern Europe.

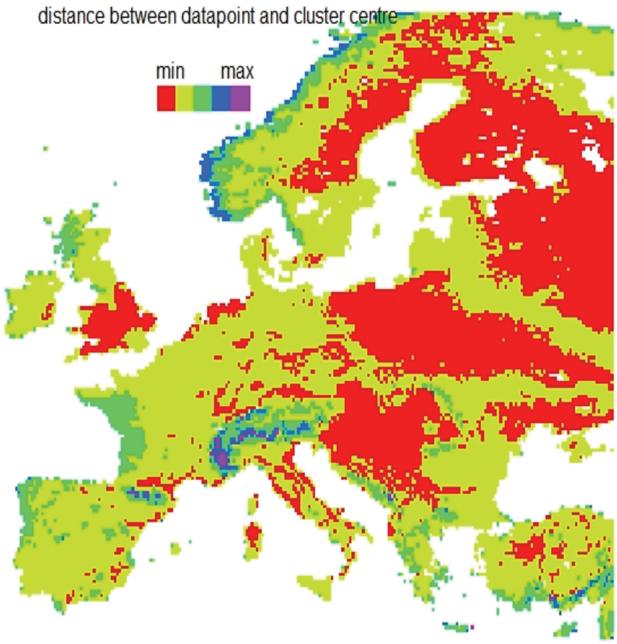


Figure 12: Spatial distribution of the distance of the properties of each data point to the corresponding cluster centre for 5 clusters.

Typologies of climate change regions

The analysis of European patterns of climate change has led to a typology of climate change regions derived from a cluster analysis.9 Based on the exposure indicators 5 different types of regions according to their climate change profile have been identified. The most prominent climate change characteristics in each of these regions are summarised in Table 4. This table shows on the one hand that every chosen stimulus is important for describing the main characteristics of a least one type of region.

Table 4: Different types of regions characterised by climate change based on cluster analysis

Cluster/Stimuli	Northern-central Europe	Northern-western Europe	Northern Europe	Southern-central Europe	Mediter-ranean region
Change in annual mean temperature	+	+	++	++	++
Decrease in number of frost days	--	-	--	--	-
Change in annual mean number of summer days	+	+	o	++	++
Relative change in annual mean precipitation in winter months	+	+	++	o	-

[9] Originally it was planned to carry out a factor analysis prior to derive this typology. However, due to partly implausible and rarely useful results it was decided to made use of a cluster analysis. See annex 2 for a more detailed discussion.

(table continued)

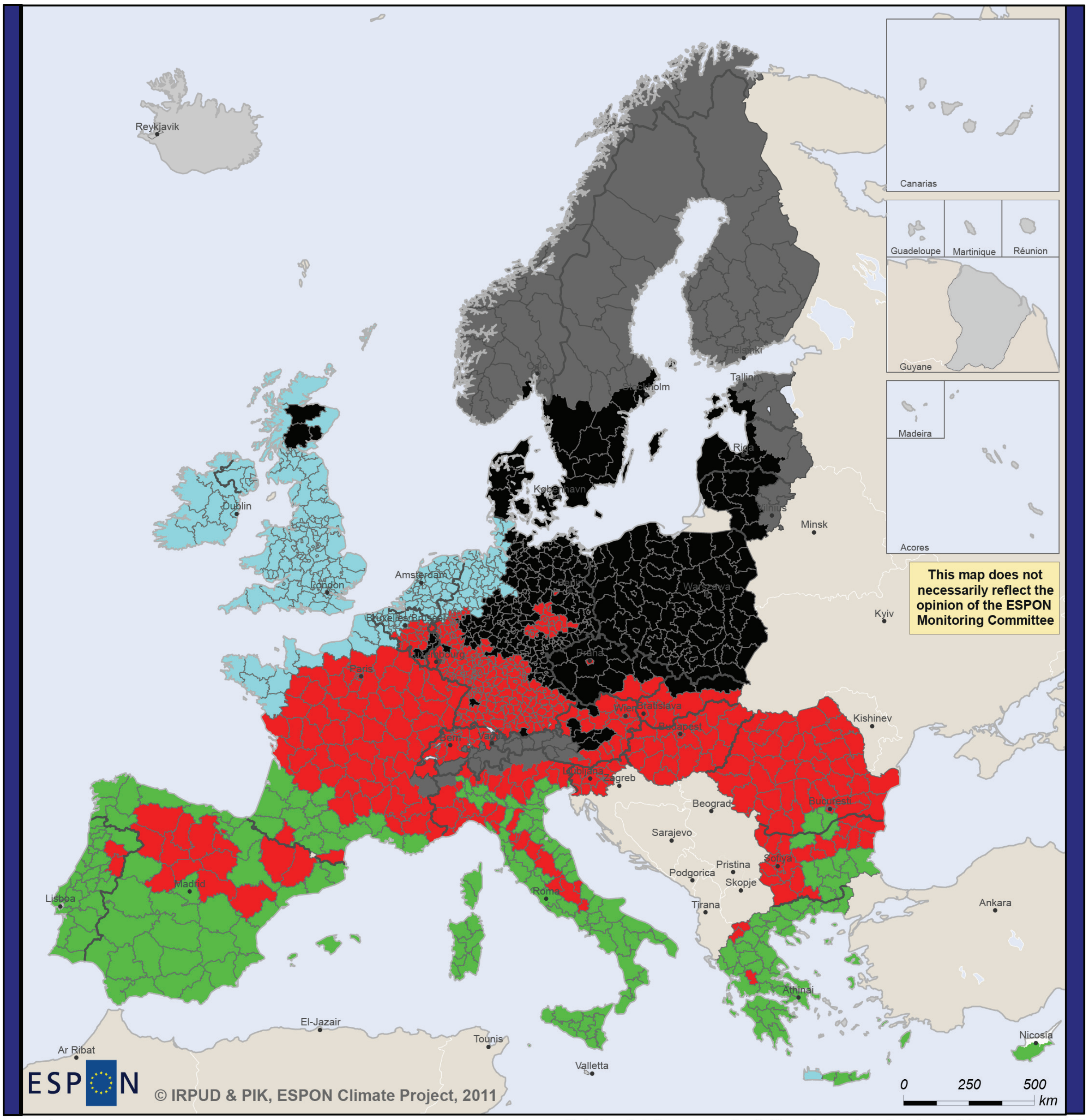
Relative change in annual mean precipitation in summer months	-	-	o	--	--
Change in annual mean number of days with heavy rainfall	o	+	+	o	-
Relative change in annual mean evaporation	+	o	+	o	-
Change in annual mean number of days with snow cover CDSC	-	o	--	o	o

Key:
++ Strong increase
+ Increase
o insignificant stimulus for the characterisation of the cluster
- Decrease
-- Strong decrease

A strong increase in annual mean temperature is observable for three clusters, namely 'Northern Europe', 'Southern central Europe and 'Mediterranean region'. Strong decreases in number of frost days predominantly characterise the clusters of 'Northern central Europe, 'Northern Europe' and 'Southern central Europe' whereas strong increases in annual mean number of summer days is projected for the clusters of 'Southern central Europe' and 'Mediterranean region'. Concerning change in precipitation in winter months the 'Northern Europe' cluster shows particularly strong increases while for summer months most significant changes in terms of strong decrease can be observed in 'Southern central Europe' and 'Mediterranean region' clusters. The variables heavy rainfall and evaporation do not show very strong changes for any of the clusters while days snow cover are projected to decrease strongly in the 'Northern central Europe' cluster.

The resulting spatial patterns (see Map 11) divide the ESPON territory into 5 regions. The results seem plausible as main topographic characteristics are well covered (such as Alps, Carpathians, Balkan, Pyrenees, Apennines) and underline the validity of the derived typology at least from a pan-European perspective. On the regional level the case studies conducted within this research project will contribute further to local variations of climate change providing more insights to the validity of the developed typology.

It has to be emphasised that these clusters do not constitute 'climate clusters', but 'climate change clusters', i.e. each cluster consists of regions that are similar in regard to the *changes* of the climatic stimuli as presented in the previous pages. Furthermore, the names of these clusters only serve the heuristic purpose of providing easy to understand and easily distinguishable labels. As such they should not be considered as completely accurate in a geographical sense.



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Origin of data: own calculations based on Lautenschlager et al. 2009

European climate change regions

- Southern-central Europe
- Northern Europe
- Northern-central Europe
- Mediterranean region
- Northern-western Europe
- no data*

Regions with similar climate *change* characteristics.

Climate change regions derived from a cluster analysis of eight climate change variables (change in annual mean temperature, summer days, frost days, snow cover days, winter precipitation, summer precipitation, heavy rainfall days and annual mean evaporation).

Climatic changes calculated on the basis of a comparison of 1961-1990 and 2071-2100 climate projections from the CCLM model for the IPCC SRES A1B scenario.

*For details on reduced or no data availability see Annex 9.

Map 11: European climate change regions

3.2 Europe's regions and their different sensitivities to climatic changes

According to the IPCC, sensitivity is defined as "the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. The effect may be direct (e.g. a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g. damages caused by an increase in the frequency of coastal flooding due to sea-level rise)" (IPCC 2007c).

However, not every element of the system is sensitive to every climate-related stimulus. Thus, it has to be clarified, based on literature, which stimulus exactly affects which element of the system. Moreover, the same stimulus may affect the system territorially differently: For example, the same change in summer temperature may affect the tourist sector positively or negatively depending on the existing climatic conditions, the agricultural sector may benefit from an in increase in precipitation or not depending on various local factors.

The table below gives an overview of all sensitivity indicators used in the ESPON Climate project and to which exposure indicators they were (at first only conceptually) related. These exposure-sensitivity linkages were later applied when calculating the individual impacts of climate change (see section 3.3).

ESPON Climate defined five dimensions of sensitivity and identified several indicators for each dimension. However, (as was the case for the exposure analysis) for some countries or some regions no data were available for certain indicators. Usually this only had minor effects, but in some instances it made subsequent assessments impossible. For instance, sensitivity indicators that are based on CORINE land-use data do not cover Switzerland as well as the French outermost territories. Sensitivity indicators based on data from the Eurosoil database do not cover Cyprus, Iceland and the French outermost territories. Since the CORINE and Eurosoil based indicators constitute a significant part of the overall sensitivity analysis, no overall sensitivity, no impacts and no vulnerability could be calculated for these cases. A detailed overview on data sources and data availability is provided in Annex 9.

The sensitivity indicators of each of the five sensitivity dimensions are described in detail in the sections below, before results of the aggregated sensitivity analysis are presented.

Table 5: Overview of sensitivity indicators in relation to exposure indicators

									Triggered climate effects	
	Change in annual **mean temperature**	Decrease in number of **frost days**	Change in number of **summer days**	Change in mean **winter precipitation**	Change in mean **summer precipitation**	Change in number of **heavy rainfall days**	Change in annual **mean evaporation**	Change in number of **days with snow cover**	Change in occurrence of **river flooding**	Change of **mean sea level**
Physical sensitivity										
Settlements sensitive to flash floods						●				
Roads and railways sensitive to flash floods						●				
Settlements sensitive to river flooding									●	
Roads and railways sensitive to river flooding									●	
Airports and harbours sensitive to river flooding									●	
Thermal power plants and refineries sensitive to river flooding									●	
Settlements sensitive to coastal flooding										●
Roads and railways sensitive to coastal flooding										●
Airports and harbours sensitive to coastal flooding										●
Thermal power plants and refineries sensitive to coastal flooding										●
Environmental sensitivity										
Forests sensitive to forest fires			●		●*					
Protected natural areas	●	●	●	●	●	●	●	●		
Areas prone to soil erosion						●				
Soil organic carbon	●			●*	●*		●			

●* = reversed relationship, i.e. sensitivity increases when there is a decrease in the exposure indicator .

	Change of annual **mean temperature**	Decrease of number of **frost days**	Change of number of **summer days**	Change of mean **winter precipitation**	Change of mean **summer precipitation**	Change of number of **heavy rainfall days**	Change of annual **mean evaporation**	Change of number of **days with snow cover**	Change in occurrence of **river flooding**	Change of **mean sea level**
Social sensitivity										
Population sensitive to summer heat			•							
Population sensitive to coastal flooding										•
Population sensitive to river flooding									•	
Population sensitive to flash floods						•				
Cultural sensitivity										
UNESCO Cultural World Heritage Sites sensitive to river flooding									•	
UNESCO Cultural World Heritage Sites sensitive to coastal flooding										•
Museums sensitive to river flooding									•	
Museums sensitive to sea level rise										•
Economic sensitivity										
Agriculture sensitive to water availability							•			
Forestry sensitive to water availability							•			
Summer tourism sensitive to summer temperatures					•					
Winter tourism sensitive to snow cover changes								•		
Energy demand sensitive to summer heat			•							
Energy demand sensitive to winter frost		•								
Energy supply sensitive to changing river water levels					•*					

3.2.1 Physical sensitivity

Physical sensitivity relates to all human artefacts that are important for territorial development and are potentially affected by climate change. This includes settlements (homes, public buildings, industrial facilities) and infrastructure (e.g. transport and energy infrastructure). These physical assets of a region are typically adapted to normal regional weather conditions and can thus withstand smaller climatic changes. However, buildings and infrastructure are sensitive to more extreme weather events like flash floods, large-scale river floods and coastal storm surges.

Settlements prone to river flooding

Relevance: Human settlements are concentrations of dwellings but also of industrial and commercial buildings. A large proportion of a country's or region's population lives and most social and economic activities take place in settlements. Even though settlements have usually been adapted to their specific geophysical environment, they are nevertheless sensitive to extreme weather events which can severely damage buildings, endanger the population and disrupt businesses.

One of these extreme weather events are river floods, which in Europe are mainly linked to prolonged or heavy precipitation in the winter months and subsequent snowmelt, culminating in high river flows in early spring. These hydrological parameters in combination with temperature parameters are predicted to be affected by climate change. However, climatic changes in all regions of a river basin have to be taken into consideration, because the river flood occurring in one region is the result of climate changes in the upstream regions. River floods often lead to catastrophic situations and high damages because of the high concentrations of population and physical assets in river valleys.

Existing studies: While there is ample evidence that the number and frequency of river floods in Europe has significantly increased since 1960, there is no *general* trend with respect to climate change (Becker and Grunewald 2003, Mudelsee et al. 2003, Kundzewicz et al. 2005, Hisdal et al. 2007). Instead, regionally differentiated studies attribute changes e.g. in the frequency and seasonality of river flood events to changes in snowmelt patterns in central Europe and Nordic countries as well as changed precipitation patterns in the Mediterranean (Brazdil et al. 2006, Cyberski et al. 2006, Hisdal et al. 2007, Ramos and Reis 2002). On the other hand, the occurrence and magnitude of river floods has also been shown to be significantly affected by human activity, e.g. deforestation in river catchment areas, urbanisation in river valleys, loss of natural floodplain storage as well as river and flood management (Barnolas and Llasat 2007). Consequently, research on river flood projections related to climate change has yielded complex results. The most comprehensive and sophisticated hydrological model on European river systems, LISFLOOD, predicts an increase in river floods in western and eastern Europe, while warmer winters and shorter snow seasons reduce flood hazards in central and north-eastern Europe (Dankers and Feyen 2008 and 2009).

Indicator methodology: As outlined above, linking flood events to climate change requires consideration (and modelling) of hydrological processes in entire river basins. Such complex modelling is clearly beyond the scope of the ESPON Climate project, which instead has to rely on existing research – in this case the LISFLOOD project. Fortunately, in 2010 the EU Joint Research Centre (JRC), who had previously only used other climate scenarios for their model runs, re-calculated inundated areas by river flooding on the basis of the A1B scenarios using the CCLM climate model. The ESPON Climate project compared the inundation heights of a 100 year return event for the time periods 1961-1990 and 2071-2100 and thus determined changes in inundation (see section 3.1). The results were overlaid with CORINE Land Cover data, which use the same 100 by 100 metre grid cell raster. The changes in inundation height were multiplied with the respective area size of inundated land and then added up for each NUTS 3 region (absolute sensitivity). The aggregated values were then also related to the total settlement area of each NUTS 3 region (relative sensitivity).

Transport and energy infrastructure prone to river flooding

Relevance: Transport and energy infrastructures are of great importance for regional development. Roads, railways, airports, harbours and also power stations and refineries are the technical backbone of today's social and commercial life. Any disruption, damage or destruction of these infrastructures has severe economic and social consequences. Given the vast expanse of these infrastructure systems they are very sensitive to extreme weather events that have the potential to physically impact upon them.

Like for settlements, river floods constitute such extreme weather events which may adversely affect transport infrastructures. Therefore the above discussion on changing hydrological patters in river basins and their linkage to climate change equally applies here.

Existing studies: As already noted under 'infrastructure prone to flash floods' most studies concentrate more on overall economic and human damages of flood events. A differentiated analysis of sensitivities and damages of settlements (concentrated areas) versus infrastructures (mostly linear) are usually not included. Nevertheless, since the same climatic phenomena are involved for settlements as well as infrastructures, the cited studies – especially the LISFLOOD research project – provide the most up-to-date and comprehensive analysis of river flooding in Europe.

Indicator methodology: Thus for calculating a sensitivity indicator for transport infrastructure in relation to river floods the same indicator construction approach was adopted as described for settlement sensitivity, namely using LISFLOOD results calculated for the A1B climate forcing scenario (see above). On this basis and using geographical data on the various infrastructures the area size or length of potentially affected portions of infrastructures was calculated, multiplied with the respective inundation height changes and finally related to the overall area or length of infrastructure in a NUTS 3 region. This was done for each infrastructure individually.

Settlements prone to coastal storm surges

Relevance: Human settlements have already been defined and conceptually related to climate change in regard to flash floods and river floods. In addition to these two extreme weather events that typically occur inland, sea level rise and resulting coastal flooding would affect coastal towns and villages. In fact, coastal areas have always been the site of many major cities and urban agglomerations due to the importance of international maritime transport. Therefore, damage to buildings and settlements in coastal area due to rising mean sea levels or more severe storm surges would possibly affect a large proportion of a country's urban centres.

Existing studies: Global sea level rise is being studied by many research groups worldwide, whose findings were summarized and integrated into model projections by the IPCC's (see IPCC 2001 and 2007). According to the IPCC thermal expansion of sea waters is responsible for 70-75% of the sea level rise projected by the various climate change scenarios. However, Rahmstorf et al. (2007) have shown that observed sea-level rise from 1990 onwards is close to the upper limit of the projected global ranges. As regards Europe various studies have validated that past sea level changes range from (depending on the region) -0.3 mm to 2.8 mm per year during the 20th century (e.g. Guinehut, Larnical 2008, Novotny/Groh 2007, Church et al. 2006, Cazenave 2006, Demirov, Pinardi 2002). Sea level rise projections for Europe indicate the greatest increases for the Baltic and Arctic coasts and northern Mediterranean coasts (Johansson et al. 2004, Meier et al. 2006, Nichols 2004). The latest projections on sea level rise on the basis of the A1B scenario indicate values for the year 2100 that are between 0.97 and 1.56 metres above the 1990 annual mean sea level (Vermeer, Rahmstorf 2009). Interestingly their projections for the other scenarios are also very close to this range, which was explained by the fact that air temperature increases projected by the various scenarios for the first half of the 21st century are very similar, and these air temperatures slowly translate into higher water temperatures in the second half of the century. And lastly, implications of sea level rise for 13 European countries were discussed in separate articles and summarized by Nichols and de la Vega-Leinert (2008), concluding among others that Mediterranean river deltas are expected to be 'hot spots' of sea level rise impacts.

Indicator methodology: For determining settlements particularly sensitive to sea level rise it was decided to be relatively irrelevant to calculate areas below one metre above mean sea level (which is the projected level of sea level rise for Europe, see section 3.1). It can safely be assumed that every coastal settlement is prepared for such a sea level rise – even at the present. It makes more sense to consider what effect this one metre sea level rise would have in the event of a major costal storm. Therefore, using the renowned DIVA model and the HYDRO1K digital elevation model, the area of land was determined that would be inundated after adding one metre to the storm surge height projected by DIVA. Subsequently these areas were overlaid with the CORINE Land Cover data in order to determine the settlement areas located in these inundated areas. Finally both the total size of these settlement areas and their ratio in relation to the total settlement area of each NUTS 3 region were calculated and then combined to reach the final coastal flooding settlement sensitivity indicator.

Transport and energy infrastructure prone to coastal storm surges

Relevance: Coastal areas not only exhibit a high concentration of human settlements, but correspondingly also of transport infrastructure systems. Thus streets, railways, airports, harbours, thermal power stations and refineries in coastal areas are likewise prone to the effects of sea level rise. And as explained before, the disruption or destruction of these infrastructures would have great effects on the coastal population but also on industrial development, trade and tourism in coastal areas.

Existing studies: The most important studies regarding sea level rise in Europe have been discussed in the previous section and equally apply to infrastructure systems

Indicator methodology: For measuring the sensitivity of transport and energy infrastructure in coastal areas to sea level rise the same procedures as for settlements were applied. The projected inundated areas and the corresponding changes in inundation heights were overlaid with a map of the infrastructure networks and facility locations. Absolute and relative sensitivity indicators were calculated for each type of infrastructure separately.

Settlements prone to flash floods

Relevance: As discussed above human settlements are home to a large proportion of a country's or region's population and businesses. Settlements are also sensitive to extreme weather events which can severely damage buildings, endanger the population and disrupt economic activities.

One of these extreme weather events are flash floods that can be defined as "a local flood of great volume and short duration resulting from heavy rainfall in the immediate vicinity" (Merriam-Webster Dictionary). Over natural watersheds they typically occur in case of more than 200 mm of rain during less than six hours, while in built-up areas even precipitation of 50 mm within one hour can produce a local flash flood. Even though the ESPON Climate project does not have such detailed hourly climate projections, it will be assumed in the following that there is a linear relationship between 'days with heavy rainfall' (one of the project's exposure indicators) and the occurrence of such even more extreme, short-term heavy rainfall events. What makes these flash floods especially damaging and dangerous are the short warning time and great water speeds.

Climate change affects the occurrence of flash floods through altering local precipitation patterns. Of particular importance are changes in the number of days with heavy rainfall and the intensity of heavy rainfall. In addition there are other factors, such as the topography of an area (e.g. steep slopes or narrow valleys), soil conditions and the coverage of the terrain (e.g. sealed surfaces or no vegetation cover) that facilitate or intensify flash floods.

Existing studies: Most studies on flash floods deal with specific flash flood events, the damages they caused and potential flood management measures. Large-scale or even pan-European studies and data on flash floods are rare and also more practice- and policy oriented than data-driven and analytical (e.g. APFM 2007). However, a series of studies have been conducted within the framework of the Floodsite programme, which focussed on flash flood occurrence in the Mediterranean region. The studies analysed historical data and modelled past and future flash flood events in the Mediterranean (Thielen et al. 2000, Wobrock et al. 2000, Real 2003). A more large-scale project that is currently on-going is compiling and analysing flash flood data from seven European hydrometereological regions (Gaume et al. 2009). Initial findings of all these studies show that flash floods are more severe in Mediterranean countries than in inner continental countries and that there is a strong seasonality for flash flood occurrence. However, flash floods are also a very regionally or even locally specific phenomenon with different climatic forcing mechanisms in each locale (ibid., see also Dankers and Feyen 2008, Christensen and Christensen 2003, Kundezewicz et al. 2006). The URBAS project (2008) deals with such micro-scale parameters of flash floods in urban areas of Germany. Their methodology takes into account various climatic, topographical, infrastructural, land-use and building-related data that allow a fairly detailed analysis and forecasting of urban flash flood events.

Indicator methodology: Ideally one would determine flash flood sensitive settlements by performing a GIS analysis that takes into account flow accumulation (water running down slopes and channelled into valleys) as well as water accumulation in sinks. However, after cross-checking results of such a detailed analysis the project team had to conclude that the currently available digital elevation models do not have a sufficiently accurate vertical resolution. Consequently flow accumulation would, for example, suddenly stop somewhere in a river valley, because the elevation model indicated a one meter jump in elevation.

Therefore the flash flood risk had to be calculated as a general flash flood potential of a NUTS 3 region. Using the HYDRO1K digital elevation model the mean and standard deviation of sloop steepness were calculated for each NUTS 3 region. Furthermore, using the EUROSOIL database the average hydro-geological class was calculated for each NUTS 3 region. The hydro-geological classification takes into account several relevant soil characteristics, such as the coarseness and water permeability of the topsoil and substratum material and the depth to an impermeable layer. In essence this indicator reflects how much and how easily the soil in a given location can absorb precipitation. As another component of flash flood sensitivity the land cover was taken into account. Since the effects of heavy rainfall are generally mediated by natural vegetation, the share of area without forests, grass- or bushland was calculated, i.e. the remaining areas included especially highly sealed areas like settlements as well as agricultural areas (that are seasonally without any vegetation) (see also SWIM 2000). The overall flash flood potential was calculated by adding the normalised slope steepness (weighted with 0.33), normalised standard deviation of slope steepness (0.33), the mean hydrogeological soil group (0.17) and non-natural land cover (0.17) (see also Lutz 2010, Kwak, Kondoh 2008 for similar methodologies). Finally the absolute area and relative share of settlements areas in a NUTS 3 region was calculated and multiplied with the flash flood potential.

Transport and energy infrastructure prone to flash floods

Relevance: As discussed further above, transport infrastructures such as streets, railways, but also airports and harbours are vital for a society's social and economic functioning. At the same time they are very sensitive to extreme weather events that have the potential to damage, disrupt or destroy them.

Flash floods, as defined above, are one of these extreme weather events that have the capacity to seriously impact the facilities and the operation of transport infrastructure systems. Again, the short warning lead-time and great intensity of flash floods are the most damaging and dangerous aspects of flash floods. And as discussed above, climate change is affecting the occurrence and intensity of flash floods due to altering local precipitation patters, in particular heavy rainfall patterns.

Existing studies: Research on flash floods in Europe has already been discussed under 'settlements prone to heavy rainfall flash floods'. It can be noted that these studies concentrate more on the climatic phenomenon of flash floods as such and the overall economic and human damages. A differentiated analysis of sensitivities and damages of settlements (concentrated areas) versus infrastructures (mostly linear) are usually not included. Nevertheless, the cited studies are the most relevant and up-to-date investigations into flash flood events in Europe – or rather particular regions within Europe as pan-European data and analyses are so far missing.

Indicator methodology: The same methodological considerations and procedures as discussed in the previous section applied to determining the regional flash flood potential of transport and energy infrastructures. The regional flash flood potential was then calculated for the facility areas or network lengths individually by multiplying the flash flood potential with the absolute kilometres or square metres located in a region and then the corresponding densities in relation to the total NUTS 3 area.

3.2.2 Environmental sensitivity

Climate is an integrated part of nature. Thus any changes to climate will directly or indirectly affect all parts of the natural environment. However, some environmental entities are more sensitive to climatic changes than others. The aim of this section is to identify these more sensitive elements and describe indicators measuring them.

By definition the natural environment consists of all natural physical entities and biological life within the earth's biosphere. Relevant environmental impacts relate primarily to soils and species. In regard to species one may differentiate between distributional and phenological changes.

Phenological changes comprise changes to periodic plant and animal life cycle events, e.g. the date of the first blossoming of a flower species, the onset of leaf colouring and fall in certain tree species or the first appearance of migratory birds in an area. There is clear evidence of such phenological changes in Europe in recent decades (Parmesan and Yohe 2003, Root et al. 2003, Menzel at al. 2006). Many of these life cycle changes have been studied in detail and can be precisely measured (e.g. Menzel et al. 2006, DEFRA 2007, Hoye et al. 2007) and most of them can even be reliably explained by climatic changes (van Vliet 2008). However, reviewing the available scientific literature on the nexus between climate change to phonological change a recent report by the European Environmental Agency (EEA 2008) comes to the conclusion: "While advancing trends in seasonal events will continue as climate warming increases in the years and decades to come, it is uncertain how different species will respond when temperature thresholds are reached and whether linear relationships between temperature and growing season will be realised in the future" (ibid. 115). For this reason the scientific community has so far not made projections on future phenological changes, thus making it difficult to include life cycle event changes of species in the environmental assessment of the ESPON Climate project.

Distributional changes of plant and animal species are likewise highly related to climate change. Some species benefit from changing climatic parameters and are able to increase their populations and/or enlarge their habitats, while other species' habitats are shrinking and their populations are nearing extinction levels. Thus climate change has facilitated (in combination with other factors) completely new biodiversity patterns that will continue to change in the future. In particular the gradually warmer winters have led to and are projected to continue to extend the distribution areas of many species northwards and to higher altitudes (c.f. Parmesan and Yohe 2003, Walther et al. 2005). Of interest to a comprehensive and pan-European assessment are of course not distributional changes of individual species but aggregate changes. In regard to plant distributions such an aggregate analysis has been undertaken by Thuiller et al. (2005) and Bakkenes et al. (2002 and 2006). They were able to model distributional changes for almost 1400 plant species across Europe until 2050 and 2080 respectively. Both models projected the greatest changes to occur in Mediterranean, Euro-Siberian and mountain regions and suggest up to 60% loss of plant species in some areas. However, both studies base their projections on other climate models than the CCLM model used by the ESPON Climate project and, more importantly, on more extreme climate forcing scenarios.

Therefore the indicators described below are mostly soil and ecosystem-based. Soils are made up of mineral and organic material which serves as the natural medium for the growth of plants. Soils evolve over long time periods through complex interactions between the underlying rock formation, below surface micro-organisms, above surface plants and animals – and climatic factors like moisture and temperature. Soils are therefore relatively stable environmental entities that are nevertheless climate sensitive e.g. to extreme weather events like flash floods. Soils also form the basis for ecosystems, which may be defined as relatively stable systems characterized by particular functional relationships between plants, animals, microorganisms and their physical environment in a particular area.

Forests sensitive to forest fires

Relevance: Forests are areas with a high concentration of trees. Due to this density and the size of trees forests account for most of the earth's vegetation biomass. But forests also contain other plant species and are the habitat of many micro-organisms and animals. Through the complex interaction of these forest species with the underlying soils and the local climate, forests play an important role for soil and water conservation. In addition to these natural functions forests are also an economic asset, as a large proportion of European woodlands are used for forestry.

As regards climate change, it first needs to be noted that forests' biomass are the earth's major carbon pool. Thus forests (and changes of forests) have a significant effect on global CO_2 levels, which is one of the drivers of climate change. On the other hand, climate change affects forests in various and complex ways: In general, higher CO_2 levels have a 'fertilizer effect' on tree growth. Higher temperatures and thus longer growing seasons promote tree growth in some areas, but decreasing precipitation reduces tree growth in other areas. Changing local climate conditions may even enable or reduce the survival of certain tree species in particular locations – thus changing the geographical distribution of the various types of forests. Furthermore, other plant and animal species (in particular pests – but also pollinators) are likewise affected by climate change, leading to increasing or decreasing forest growth or damage. Many forest damages are typically caused by (winter) storms, whose patterns and intensity are also expected to change due to climate change. Finally, changing temperature and moisture conditions affect forests' sensitivity to fires. Forest fires are most often human induced (and this human influence also differs between countries), but in any case they can more easily spread in warmer and drier conditions.

Existing studies: The climate change effects on forests outlined above are actually very complex and affect different types of trees and forests in different ways (see Kropp et al. 2009 for a systematic overview). It is therefore very difficult to reliably predict these effects – and even more to predict them for all territories across Europe. Historic studies have shown, however, that after centuries of forest exploitation growth rates of forest biomass have been recovering in Europe since the middle of the 20th century – in part due to better forest management (Spieker et al. 1996). Also, a north-east shift in the distribution of certain tree species has been observed (Bakkenes et al 2002, Harrison et al. 2006). This shift is expected to continue under the further influence of climate change, as a complex modelling project undertaken by the European Commission's Joint Research Centre (JRC) indicates. Incorporating a wide range of tree, soil, geo-morphological and climate data the project simulated geographical distributional changes of habitats suitable for various types of forests (Casalegno et al. 2007 and 2009). Using the IPCC A1B climate scenario the simulation shows a general south-west to north-east shift in suitable forest habitat categories. Focusing on forest fire dangers in Europe (but using the IPCC A2 scenario) a modelling project by Flannigan et al. (2005) projects a significant increase of fire potentials, an enlargement of the fire-prone area and a lengthening of the fire season (see also Camia et al. 2008). Further results can be derived from the LPJ Dynamic Global Vegetation Model which is run on a global scale and also projects changes in functional forest types and carbon cycles.

Many of the possible climate change effects on forests are too complex or are so far not fully understood and have therefore not been modelled quantitatively yet. The two modelling projects referred to above are notable exceptions and have produced scenarios covering the entire European territory. However, the forest fire model is based on a different climate scenario than the ESPON Climate project and is thus not usable for the ESPON project. The other modelling project only predicts changes of forest habitat suitability (i.e. where certain types of forest could or could not exist). However, given the fact that most land in Europe is in one way or another under intensive human use it seems unlikely that the overall coverage of forests will increase, i.e. that forests will in the future cover all areas that are environmentally suitable habitats for forests. It is more reasonable to expect that any changes in the distribution of forest types will take place more or less within the boundaries of existing forests. A further problem not addressed in the above studies is the fact that anthropogenic factors often play an important role for the occurrence of forest fires. While new studies are beginning to model these factors by determining the proximity of forests to human infrastructures (Reineking et al. 2010), a full-fledged and tested model of forest fire occurrence that consistently incorporates anthropogenic factors has still not been developed yet.

Indicator methodology: Therefore, given the methodological shortcomings described above, the ESPON Climate project decided to refrain from any unwarranted and highly uncertain modelling and instead take the past occurrence of forest fires as a starting point for determining the forest fire sensitivity. Using the detailed data of the ATSR World Fire Atlas and the CORINE Land Cover data the number of fires that occurred in forest areas of each NUTS 3 regions was determined. Without trying to disentangle which exact natural or anthropogenic factors caused these fires, it was assumed that where fires occurred in the past there is a likelihood that fires might occur in the future. The impact analysis would then determine where climate conditions are changing in a way that would increase this likelihood. So, for calculating the forest fire sensitivity indicator the number of forest fires and the ratio of these fires in relation to the total forest area of a NUTS 3 region were calculated and then combined.

Protected natural areas

Relevance: Protected natural areas are clearly delineated geographical areas with legal protection status that aim to protect and conserve the most threatened plant and animal species and their habitats. With this general purpose the Natura 2000 network was set up by the European Union, creating a network of protected areas across Europe that conform to common selection and management criteria. Two types of areas are distinguished, namely Special Protection Areas for Birds and Special Areas of Conservation (designated for other species and habitats). Currently there are a total of 27,661 protected areas covering about one sixth of the European Union's landmass that are part of the Natura 2000 network (EEA 2009).

Each of these protected areas is equally important for protecting rare species and habitats, but they are not equally sensitive to climate change. Given the special characteristics and biological requirements of the endangered species and habitats experts regard those habitats as most sensitive to the projected climate changes that rely on a certain amount of moisture (e.g. wetlands, humid grasslands). If precipitation and evaporation levels change, these habitats' uniquely adapted plants and animals would decline in numbers or even become locally extinct.

Existing studies: For assessing the sensitivity of protected areas and their habitats some studies have applied complex modelling approaches (e.g. Berry et al. 2003, Normand 2007). Other studies opted for a simpler – but perhaps more robust – indicator approach, classifying the various habitat types on the basis of special habitat characteristics and especially temperature and moisture sensitive species (Kropp et al. 2009, Holsten 2007, Petermann et al. 2007). This assumes that these habitats have to be conserved exactly as they are today and does not take into consideration possible natural adaptation mechanisms. So far only regional and national analyses have been conducted with the indicator-driven approach, but their methodologies make them in principle suitable for large-scale, pan-European studies using the Natura 2000 statistical data. However, while national studies have developed and successfully implemented a methodology of classifying the climate change sensitivity of the habitat classes relevant for their country (e.g. Petermann et al. 2007), such a classification does not yet exist for the over 230 European habitat classes of NATURA 2000.

Indicator methodology: Given the current state of research outlined above the ESPON Climate project could not revert to a comprehensive classification of the individual NATURA 2000 habitat types in regard to climate change. One can argue, however, that NATURA 2000 protected habitats are protected as they are today. Thus, even if some habitats are better able to adjust to climatic changes, this would nevertheless mean that these habitats have indeed changed. Even this would run counter to the conservation intended by NATURA 2000. Therefore, for the purpose of this research project all NATURA 2000 areas were classified as generally sensitive to climate change. Hence the absolute size of NATURA 2000 areas and their ratio to the total NUTS 3 area of each region was calculated and then combined.

Areas sensitive to soil erosion

Relevance: Soil erosion may be defined as the wearing away of the land surface by natural or anthropogenic forces that ‘detach and remove soil from one point on the earth’s surface to be deposited elsewhere’ (Thompson 2007). Soil erosion is a natural, continuously occurring process, but its occurrence and intensity can dramatically increase if some of its driving forces change. At its worst soil erosion can virtually strip the topsoil from the underlying land and severely reduce the environmental (and thus also agricultural) function of an affected land area.

Several factors can be distinguished which determine the rate of soil erosion: Geological factors include primarily the soil and rock type (particularly its porosity and permeability) and the slope of the land. Biological factors include vegetation cover, the organisms living in and on the soil and the land use. For example, forested areas provide ground cover thus ameliorating the effect of rain and the forest plants and other organisms also make forest soils more porous and permeable to rain water. Human land uses, such as agricultural use (cropland, grazing) reduce the vegetation ground cover permanently or seasonally and also decrease the water permeability due to soil compaction. Finally, climatic factors include the amount and intensity of precipitation, temperature, wind speed and storm frequency. All of these climatic factors are subject to processes of climate change, but wind speed and storm frequencies are more difficult to predict and have thus not been included in the exposure analysis of the ESPON Climate project. Therefore this indicator will more specifically relate only to soil erosion caused by rainfall.

Existing studies: At the European level (but often also at the national level) there are insufficient and non-comprehensive field data on soil erosion. Therefore most soil erosion assessments at European scale have reverted to mathematical models of soil erosion (most notably the PESERA project). These models are not only used for predictive purposes but also for gauging the current state of soil erosion in Europe. According to JRC, using model results from several research projects, an estimated 115 million hectares or 12% of the total EU land area was (in the year 2000) subject to rainfall-based soil erosion (EEA 2008, 130). As to regional differentiation across Europe, the soil erosion focal point at JRC concluded: “The Mediterranean region is particularly prone to soil erosion, because it is subject to long dry periods followed by heavy bursts of erosive rain, falling on steep slopes with fragile soils. This contrasts with northwestern Europe where soil erosion is less because rain falling on mainly gentle slopes is evenly distributed throughout the year and consequently, the area affected by erosion is less extensive than in southern Europe" (JRC 2010). There are also several projects attempting to model the effects of future climate change on soil erosion, e.g. at the European level PESERA 2004, MESALES and Kirkby et al 2004. Generally erosion is projected to increase with increases in precipitation amount and intensity (heavy rainfall events) and further losses of vegetation cover. However, the models also "show a non-linear spatial and temporal response of soil erosion to climate change" and are known to not adequately represent the increase of different types of storms (EEA 2008, 131).

Indicator methodology: The soil erosion sensitivity indicator was calculated taking into account three main components: slope steepness, land cover and soil characteristics. The slope steepness component was calculated as a combination of mean and standard deviation of slope steepness in each NUTS 3 region using the HYDRO1K digital elevation model. The land cover component used the CORINE Land Cover database and concentrated on land *not* covered by forests and natural grass- and bushlands, because these vegetations are known to mediate heavy rainfall precipitation. Lastly, for the soil component the NUTS 3 average was calculated the erodibility variable of the European Soil Database. This variable already combines several soil characteristics relevant for soil erosion. The three components were equally weighted when calculating the overall soil erosion sensitivity indicator of each NUTS 3 region.

Soil organic carbon

Relevance: Soil consists of small rock particles (from the underlying rock layer), organic matter and living soil organisms. The major component of soil organic matter is soil organic carbon, which is derived from residual plant and animal material that is decomposed through complex biological and chemical processes. Organic carbon and organic matter more generally are a source of food for soil organisms (e.g. bacteria, fungi, microbes but also invertebrates like worms, ants and termites) and thus supports soil biodiversity. Soil organic matter also contains various nutrients (e.g. nitrogen, phosphorus, sulphur) that contribute to soil fertility. Furthermore, organic matter absorbs six times its weight in water and thus constitutes an important water reservoir for plants. Finally, soil organic carbon improves the physical structure of soil, increasing water permeability and reducing compaction – which both reduces the risk of soil erosion (JRC 2009, EEA 2008).

Soil organic carbon is both affected by and affecting climate change. Organic carbon is essentially a net carbon sink and thus mitigates climate change: Plants are building organic material using atmospheric CO_2, which then becomes encapsulated in the soil when the plants decay and are decomposed into soil organic carbon. In other words, the formation of soil organic carbon reduces CO_2 concentrations in the atmosphere and thus mitigates climate change. On the other hand climate change has a significant effect on soil organic carbon: Basically organic matter decays more quickly at higher temperatures (leading to less organic carbon in warmer climates) and decays more slowly under more moist conditions (leading to more organic carbon accumulation in cooler climates). Both of these climatic variables are predicted to change significantly in the various climate change scenarios, leading to organic carbon gains or losses in different parts of Europe.

Existing studies: In the past the main driving force for the reduction of soil organic content has not been climate change but rather land conversion to cropland in combination with unsustainable agricultural land management practices (e.g. Sleutel et al. 2003, Dersch/Boehm 1997). Another factor has been the irrigation of peat land, which is of special importance because peat land is estimated to account for 60% of the entire carbon content in European soils (Byrne et al. 2004, Lappalainen 1996). Overall, research on European soil carbon content estimates that the organic content in European soils equals nearly 10% of the carbon accumulated in the atmosphere (EEA 2008, Hiederer 2009). As regards future changes, a study by Smith et al. (2005) projected for the year 2080 losses in soil organic carbon across Europe due to climate change, that could, however, in many areas be reversed through improved agricultural technology and practices (see also Jones et al. 2009).

Indicator methodology: There are no empirical pan-European data on soil organic content. However, the JRC soil focal point has combined comprehensive data from the European Soil Database with other databases on land cover, climate and topography and has thus been able to calculate data for the organic carbon content in the surface horizon of soils in Europe. On this basis the average soil organic carbon content was calculated for each NUTS 3 region. This indicator will later be related to exposure indicators: higher temperatures leading to a reduction of soil organic content and more precipitation leading to an increase in soil organic content.

3.2.3 Social sensitivity

The term ‘social’ encompasses a wide spectrum of meanings, but in general refers to qualities of a human collective, e.g. its composition or interactions. In a more narrow sense the term is also used in regard to socio-economic differences within a population and corresponding redistributive policies.

Within the scope of this project social sensitivity relates to human populations that may be adversely or positively affected by climate change. In particular, this includes climate-related sensitivities in regard to public health and personal mobility. Many of these sensitivities relate only to certain social groups, e.g. senior citizens or spatially defined communities, e.g. urban populations.

With the above general definitions in mind one might also expect to find certain socio-economic groups under this heading such as poor households, but biologically they are equally sensitive to climate changes as other groups. However, poor households have a reduced economic capacity to cope with or adapt to climate changes, i.e. they might not be able to afford better heating or air conditioning. Therefore, according to the ESPON Climate methodology such socio-economic population groups are covered in the adaptive capacity component of the assessment. Likewise, especially relevant social institutions like hospitals are also dealt with in the adaptive capacity section of this report. Changes in the degree of accessibility of these and other institutions (like schools, universities, municipal administrations etc.) are reflected in the respective indicators on roads and railways.

For future projections of social sensitivities to climate change it would also be necessary to account for demographic changes. This includes regional population growth or loss as well as structural changes e.g. in the age composition of populations. For both types of demographic changes the ESPON Climate project was able to draw on population projections up to the year 2100 developed by the ESPON DEMIFER project that deals precisely with such issues. See the section on demographic changes for a discussion and first results of such a dynamic analysis.

Population especially sensitive to heat

Relevance: Humans are in general sensitive to high temperatures – especially when occurring over an extended period of time. Prolonged periods of high temperatures during the summer are a particular health issue for urban populations and in particular for senior citizens.

Of special importance in terms of heat sensitivity are senior citizens, which may be defined as persons above the retirement age (usually at the age of 65 years). This population group currently constitutes about one eighth of the total population of Europe, but is expected to grow by an additional 58 million persons until the year 2050 (DG Regio 2008). This growing population group is characterized, among others, by frequent and severe health problems and with age increasing mortality risk – even without any climate change.

Senior citizens living in urban areas are especially sensitive to heat. Urban environments are in general characterized by different climatic conditions compared to rural environments. In rural areas hot temperatures are usually mediated by wind and vegetation, but in urban areas higher densities of buildings and infrastructure create a hotter and drier micro-climate. At night there is also less cooling down of temperatures in urban areas. Thus, by default urban environments are more problematic for human health than rural environments.

The projected climate changes will most likely exacerbate these urban conditions. For example, increasing number of days with maximum temperatures above 25° C are already taxing conditions for human health, in particular for certain population groups (see senior citizen below). In densely built up areas with a high proportion of sealed surfaces this problem can become even more severe when so called heat islands develop that drive up temperatures even further and keep them up over longer periods than in other areas. A higher incidence of heat-related fatigue, illnesses and deaths can therefore be expected.

Existing studies: There are many studies on the relationship between heat phenomena and human health. They show, for example, that urban populations of different cities have different temperature thresholds above which the daily mortality rate rises significantly, i.e. residents of Athens have different heat sensitivities than residents of Stockholm (e.g. Baccini et al. 2008, Kovats et al. 2006). During extended or repeated heat waves the mortality rate increases even further, as studies on the 2003 heat waves in Europe proved (Robine et al. 2007). Under the expected climate change with generally warmer temperatures the number of heat-related deaths is projected to rise by up to 20% until the year 2050 in Germany and four- to fiftyfold in Portugal (Koppe et al. 2003 and Dessai 2003 respectively). The PESETA study projected almost 86,000 net extra deaths per year in 2071-2100 in the EU-27 member states compared to the 1961-1990 EU-25 average – albeit under a severe climate change scenario (EEA 2008, 153).

Especially the relationship between old age and high temperatures is well researched. Old people are often not able to adequately regulate their body temperature during hot summer days and might also dehydrate due to not drinking enough fluids. In addition, the human cardiovascular system, which is typically already weakened in old persons, is under special stress during hot days. For these reasons senior citizens are more prone to heat-related illnesses and death (Koppe et al. 2004, Havenith 2005). Increasing numbers of old adults (see above) will therefore increase the proportion of population at risk (Confoalonieri et al. 2007).

Indicator methodology: The indicator for measuring the above described sensitivities is the absolute number and the share of urban residents older than 65 years living in high density urban areas. For identifying such urban heat islands CORINE Land Cover data were used. The land cover type 'urban continuous' represents mostly inner-city areas with almost complete surface sealing. This analysis was conducted on a 100 by 100 metre grid level. In order to rule out individual cells or small clusters of urban continuous cells, which might e.g. be located in small settlements where urban heat island effects clearly cannot develop, only those cells were retained in further calculations whose size was not smaller than the average of urban continuous clusters (about 90 ha) and that possessed a population density of above the European average of urban settlements (3.000 inhabitants per square kilometre). For this determination the CORINE Land Cover data and the disaggregated (also 100 by 100 metre grid cells) population data developed by Gallego et al. (2009/2011) were used. These data also allowed calculating the absolute number of inhabitants in each urban heat island. In a final step, applying Eurostat data on age composition, the absolute number of inhabitants above 65 years living in the identified urban heat islands and their share in relation to the total population of each NUTS 3 region was calculated, normalised and then combined.

Population sensitive to sea level rise adjusted costal storm surges

Relevance: Coastal populations may be preliminarily defined as the total of all persons living within short distance from a coastal shoreline. Such populations are generally more sensitive to climate than populations of many other areas, because they are directly affected by frequent weather changes, high winds and full-blown coastal storms. These factors do not impose higher health risks as such; in fact coastal climates are often more healthy for humans than many inland climates. However, coastal populations are at least potentially threatened in their livelihood and survival if they live in low-lying areas close enough to the ocean to be possibly reached by coastal storm surges.

Climate change is projected to lead to rising mean sea levels (see 'settlements prone to coastal storm surges' for more detail). This would – without further adaptive measures – result in low-lying coastal areas to be permanently flooded or temporarily flooded during coastal storm surges. Of course current, new or improved dikes and other storm defences would mitigate or even prevent such flooding to occur. However, according to ESPON Climate's overall methodology such measures are covered in the adaptive capacity component of the project and will not be incorporated here.

Existing studies: Research on climate-related risks for coastal populations has been carried out for centuries in efforts to better determine risks and protect human lives. The outlook of drastic climate changes over the next decades has further intensified coastal research. The DINAS-COAST research consortium and the PESETA project have attempted to model the likely effects of sea-level rise and storm flooding – however, based on the high A2 IPCC climate change scenario (not used by the ESPON Climate project). According to PESETA, by the year 2080 up to 1.3 million people on Europe's coasts would experience coastal flooding each year if no adaptation measures are implemented (EEA 2008, 176).

Indicator methodology: For calculating this sensitivity indicator the same methodology was applied as for settlements sensitive to coastal storm surges. The areas projected to be inundated by a 100 year return event of costal storm surge flooding and the corresponding changes in inundation heights were identified. Then, using the population disaggregation by Gallego et al. (2009/2011) the number of people living in these areas were determined and multiplied with the respective inundation height changes. In a final step these values were related to the total population of each NUTS 3 region.

Population sensitive to river flooding

Relevance: River valley populations may be defined as populations living in low-lying areas in close proximity to a river. In Europe as in most other parts of the world one can find a high concentration of population in river valleys – due to the fact that rivers have historically been and continue to be important transport routes. Consequently most of Europe's large cities and conurbations are located along major rivers.

People living in river valleys are one of the most sensitive population groups in regard to climate change. This is because climatic and resulting hydrological changes taking place in entire river basins accumulate and are 'channeled' through the rivers. In a way rivers can thus be considered amplifiers and transporters of climate change effects. The projected changes in precipitation patterns and volumes are therefore projected to especially affect persons living in river valleys.

Existing studies: The most relevant studies on river flooding in Europe have already been discussed in the indicator description related to settlements prone to river flooding. The LISFLOOD and PESETA projects are the most advanced research projects to date that model river flooding changes in Europe up to the year 2100. They not only project the likelihood of occurrence of flood events but also model the exact geographic areas potentially affected by river water inundation. Lately LISFLOOD has been applied to climate data using the IPCC A1B forcing scenario. In particular the input of several climate models have been used, among them the CCLM model that is also the basis of the ESPON Climate project.

Indicator methodology: The methodology for this indicator resembles the procedures used for the respective indicators for settlements and infrastructures. For determining the number of people living in flood prone river valleys the spatially disaggregated population data (Gallego et al. 2009/2011) based on the CORINE database was used overlaid with the changes in inundation heights of a 100-year flood event projected by the LISFLOOD model. The resulting absolute indicator was then also related to the total population of each NUTS 3 region.

Population sensitive to flash floods

Relevance: Populations especially sensitive to flash floods are those that live in areas with climatic, biological and geological characteristics favourable to the occurrence of flash floods. These conditions (and flash floods as such) have already been defined in the indicator description for settlements prone to flash floods. In contrast or complementary to analysing effects on the built environment, this indicator focuses on the people possibly affected by flash floods.

Climate change most of all affects the frequency of occurrence of heavy rainfall and the amount of water that precipitates in a short period of time.[10] The special danger of flash floods for humans are the short warning time and great water speeds that are typical for flash floods. It is therefore not uncommon that persons are washed off their feet and drown - even in relatively small, local flash flood events.

Existing studies: The most relevant studies regarding flash floods have already been discussed in the respective settlement indicator section and need not be repeated here. It should be emphasized, however, that flash floods are a very locally specific phenomenon. It may be an issue that may lend itself to a more thorough investigation in the case studies of the ESPON Climate project.

Indicator methodology: The methodology for this indicator again runs parallel to the equivalent indicator for settlements and infrastructures. First a flash flood potential was calculated for each NUTS 3 region on the basis of topographical, soil and land cover data. This was then related to the absolute number of inhabitants and the population density of each NUTS 3 region.

[10] Climate change also affects another factor responsible for flash floods, namely the vegetation cover of flash flood prone areas.

3.2.4 Cultural sensitivity

The terms culture and cultural heritage refer to a wide range of tangible artefacts and intangible attributes. Tangible artefacts include – among others - buildings, other built structures (e.g. bridges of historic value), monuments, works of art, books but also special landscapes that have been shaped by human use over centuries and have thus acquired certain cultural or historical qualities. Intangible aspects of culture encompass music, folklore, language, literature but also shared attitudes, values and practices of a group, organisation or community.

In principle, all of these cultural assets and intangibles can be sensitive to climate change. For example, monuments, churches and castles are sensitive to all types of flooding, but also to precipitation and temperature changes. The same applies even more to landscapes and open archaeological sites. Similarly one can investigate the sensitivity and geographical locations or clusters of public and private institutions 'delivering' culture, e.g. art workshops, galleries, museums, theatres, operas, musical halls, and all the people working in the production, maintenance and dissemination of various forms of art and culture. Thus one may also be able to assess the climate change sensitivity of the 'cultural economy'.

However, for conceptual as well as practical reasons only a small subset of the above aspects could be included in the project's sensitivity analysis:

Firstly, on a conceptual level all intangible cultural aspects of a region were defined as part of that region's adaptive capacity: Norms and values are not primarily *affected by* climate change, but are important cultural assets that influence how well or quickly a society can *adjust to* climate change. Thus these aspects are taken up in the adaptive capacity module (see Chapter 3.4).

Secondly, on a more practical level, for many of the above cultural assets there are no or only insufficient databases for the kind of analysis carried out by the ESPON Climate project. One has to keep in mind that several assessments are performed on a very fine-grained geographical level (e.g. 100x100 metre raster cells for flooding events) that require exact geographical locations of institutions and places of work (and respective employment data). Thus it is not sufficient to know that 'the town of Firenze is a cultural cluster', but one needs exact positions of the respective public and private cultural institutions or firms. Furthermore, in order to later link certain climate change variables to particular cultural assets and thus determine the cultural impact, one also needs information on the quality of the various cultural assets. Such qualities would be, for example for a historic building, the age, architectural structure, outer building materials, underground sealing and underground materials. Without such basic data as well as coherent definitions and datasets on a pan-European level one cannot determine sensitivities to climatic changes of such cultural assets.

Thirdly, at a more rudimentary level, for many cultural assets referred to above there is not even complete and coherent European or even national *listings*. And even where such national listings exist, they are often not compatible with each other and require crude 'rule of thumb' adjustments, as the ESPON Cultural Heritage project found out for national listings of historic monuments, which reflected more the differences in national preservation legislation and bureaucracy than the actual existence and distribution of historic monuments. But attempts to collect data from various sources and create integrated directories oneself quickly run into conceptual and semantic problems (e.g. there are many different types and corresponding names for 'castles' – not just in English but in every other European language).

In the end only two types of cultural assets that are sensitive to two types of climatic stimuli remained, which could be adequately assessed by the ESPON Climate project. A detailed database including geographical positions of all World Heritage Sites is compiled and maintained by the UNECO's World Heritage Commission. This list is based on a coherent and systematic assessment that is applied to all submitted nominations worldwide. In addition, a list of all museums in Europe was compiled by the project team on the basis of national telephone directories and Google Earth for exact geographical positioning of postal addresses. Only institutions that bear the term 'museum' (in the respective national or regional language) in their name were admitted. Both museums and World Heritage Sites were only analysed in regard to river flooding and coastal flooding, because the available data on each site/building did not allow to analyse sensitivities in regard to other climate change aspects, e.g. temperature or precipitation changes.

UNESCO Cultural World Heritage Sites sensitive to river flooding

Relevance: Cultural World Heritage Sites are monuments, buildings or (parts of) cities that are listed by UNESCO as of global cultural importance. According to the official nomination criteria these sites have to either (a) represent a masterpiece of human creativity, (b) give testimony to a past or present cultural tradition or civilization, (c) exemplify a type of building, architectural ensemble or settlement that illustrates an important stage in human history or (d) be directly associated with traditions, ideas, artistic and literary works of global importance. Within Europe (including Turkey and European parts of Russia) there are currently 354 sites that meet at least one of these criteria and have been officially listed as Cultural World Heritage Sites. Disruption, damage or destruction of these sites has to be considered a significant loss to human culture and history.

Cultural World Heritage Sites are especially sensitive to climate change. For example, historic buildings are often built of organic building materials that are sensitive to temperature and moisture changes. Furthermore, walls and floors are often directly grounded on the underlying soil and react to soil moisture changes. In both cases cosmetic and even structural damage can occur to the sites. More intense or frequent river or coastal flooding brought about by climate change can damage archaeological sites and historic buildings through water erosion. Also, building materials of monuments and historic buildings are often not designed to withstand prolonged immersion in water. And even after a flood event there can be damages caused by micro-organisms like mould.

Existing studies: In general Sabbioni et al. (2006), summarizing the results of the Noah's Ark project, evaluated the impacts of climate change on historic building materials and the biodeterioration of built heritage. Accordingly sensitivity to climate change induced temperature and moisture changes depends to a large degree on the specific building materials and the soil types upon which the historic buildings were built. In regard to World

Heritage Sites there are very few publications on the effects of climate change, both globally and in Europe. Studies on individual sites or sites in a particular country exist as well as UNESCO reactions e.g. to severe river floods in Europe (UNESCO 2002). The most comprehensive report on climate change effects and World Heritage Sites was published by the World Heritage Committee itself (WHC 2006). However, the report only provided a kind of conceptual overview that served as the basis for recommendations on how the WHC and member states should react to expected climate change effects. The empirical basis of the report consisted of a simple survey among the states that signed the World Heritage Convention. According to the survey 125 World Heritage sites were mentioned as threatened by climate change. Of these threatened sites 42 are Cultural World Heritage Sites like archaeological ruins, churches, temples, and historic city centres etc. The most relevant climatic threats identified for these sites were (in order of importance): (a) hurricanes, storms and lightening, (b) sea level rise, (c) wind and water driven erosion, (d) flooding, (e) rainfall increase, (f) drought, (g) desertification and (h) temperature rise (ibid. 33). Unfortunately, however, the results were not disaggregated by continent or country. More detailed and pan-European data can finally be expected from an EU research project called ‘Climate for Culture’ that will investigate the impacts of climate change on World Heritage Sites in Europe and North Africa. The project was officially launched in November 2009.

Indicator methodology: Temperature and moisture sensitivity of World Heritage sites is difficult to determine without detailed data on the specific building materials and soil conditions. However, it can be more easily assessed which sites are sensitive to climate change due to their location in areas likely to be affected by river flooding and coastal flooding. The specific calculation method runs parallel to the respective indicators for sensitive settlements. Geographical data for each World Heritage site was obtained from the World Heritage Commission and buffered according to the type of heritage site (building, historic city centre, historic park, landscape). These areas were then overlaid with the map containing the changes in inundation heights due to changes in river flooding and the respective values multiplied with each other. This absolute indicator was calculated then also related to the total area of World Heritage sites in each NUTS 3 region in order to also have a relative indicator.

Museums sensitive to river flooding

Relevance: Museums are cultural institutions that accommodate collections of artefacts of artistic, historical or scientific importance. The mandate of museums is to make their artefacts available for public display. Any damage or destruction of museum buildings inhibits public access to poses a potential threat its unique contents.

Thus the sensitivity of museums to climate change relates primarily to the physical structure of the buildings in which they are accommodated. One can assume that the level of moisture and temperature changes projected until the year 2100 does not pose any major threats to these buildings. However, as has often happened in the past large-scale river flooding and coastal storm floods have the potential to cause serious damage to museums, thus incapacitating their operation and endangering their contents.

Existing studies: Research and publications on the topic of past or future weather related impacts on museums are so far rare. Most scientific literature on the topic consists of special reports written in the aftermath of a catastrophic flood event that also affected cultural institutions. For example there are reports on the great river flood in Florence (1966) in which millions of art works were damaged or destroyed or on the Elbe river flood of 2002 which affected art collections of state museums. However, pan-European studies on such climate related events and damages and much less on future projections seem not to exist. Nevertheless, the ESPON 2006 project on cultural heritage provides a first basis for further analysis, as it includes an overview, data and geographical analysis of the distribution of museums, galleries, libraries and theatres – both separately and combined. Unsurprisingly the study shows that these cultural institutions are generally concentrated in cities and that there are significant differences between countries: some countries have a tradition of a dense network of museums, while others may have much less museums. It can thus be expected that there are clearly distinguishable patterns of museums' sensitivity to climate change.

Indicator methodology: For determining the sensitivity of museums to river flooding a similar methodology was used as for settlements and infrastructures. Based on the LISFLOOD model areas were identified with inundation changes when comparing past and future model results. Afterwards it was determined which museums are located in the relevant 100 by 100 metre raster cells. For the necessary geographical database of the museums' location the project made use of OpenStreetMap data. The indicator combined the absolute number of sensitive museums and their ratio to the total number of museums in each NUTS 3 region. While this allowed a first and partly satisfactory analysis, it was determined that it would be necessary to have a more comprehensive database of European museums. Unfortunately this does not exist. The project therefore generated its own database on the basis of postal addresses of museums listed in the national yellow pages (or their equivalents). Using the internet-based Google Earth software and 'harvesting' the yellow page data on a 50 by 50 km raster grid it was possible to create a pan-European GIS database with exact geographic locations of 20.000 museums in Europe. For purposes of further analysis each data point was buffered with 25 metres. Afterwards these areas were overlaid with the map containing the changes in inundation heights due to changes in river flooding. The absolute sensitivity indicator was calculated by multiplying the affected museum area with the respective change in inundation heights. This value was then related to the total area of museums in each NUTS 3 region; this ration constitutes the relative sensitivity indicator.

UNESCO Cultural World Heritage Sites sensitive to coastal flooding

Relevance: The relevance of World Heritage Sites within the framework of this project was already described in the indicator on World Heritage Sites sensitive to river flooding.

Existing studies: As discussed above, the only relevant literature on the topic of World Heritage sites and their relation to climate change is only very general and does analyse individual sites or sites located in one specific country. It seems that the analysis undertaken und to be updated by the ESPON Climate project is the first attempt to systematically and at the pan-European level assess World Heritage site's linkage to climate change adjusted coastal flooding.

Indicator methodology: For measuring the sensitivity of World Heritage Sites in coastal areas to sea level rise the same procedures as for settlements were applied. The projected changes of inundated area were overlaid with a map of all (buffered) World Heritage Sites. Then affected sites were aggregated to the NUTS 3 level and also related to all WHC sites in each region.

Museums sensitive to coastal flooding

Relevance: Again, the relevance of museums within the framework of this project was already described in the equivalent indicator regarding river flooding.

Existing studies: As indicated above, literature on the sensitivity of museums to extreme weather events is extremely rare and usually focused on (a) specific museums and/or (b) specific catastrophes. ESPON Climate's analysis seems to be the first effort at the pan-European level to assess European museums' sensitivities to costal storm surges.

Indicator methodology: For measuring the sensitivity of museums in coastal areas to sea level rise the same procedures as for settlements were applied. The inundated areas according to DIVA and adjusted by a one metre sea level rise were then overlaid with the geographical information on museums' location. Then the affected museum area in these inundated areas was summed up and subsequently also calculated as ratio in relation to the museum area of each NUTS 3 region.

3.2.5 Economic sensitivity

Climate change can potentially impact on a wide range of economic activities and sectors, and economic sensitivity relates to all economic activities that are potentially affected. This can for example be changes in profitability in agriculture or forestry, changes in tourist demand or supply, loss of production due to flooding, costs of rebuilding infrastructure after extreme weather events.

Some of the economic sectors, such as the primary sector, are directly affected by changes in the environment due to climatic variables such as changes in the level of precipitation and heat. Other sectors, such as manufacturing industries, are affected indirectly through the supply and demand chains. A third category, such as infrastructure, will primarily be affected as a result of extreme weather events such as flooding but may also be affected by gradual long-term changes in temperature and precipitation.

There is a fundamental difference between the economic sensitivity dimension and the other dimensions of sensitivity in the model used in the project. The economic sensitivity of a region will – in principle – be largely dependent on differences in the region's physical, environmental, social, and cultural characteristics. Therefore, the economic effects can to a large extent be thought of as second order effects of the other dimensions of sensitivity. A region which is physically sensitive to climate change will also be economically sensitive to climate change. For example; if a region's infrastructure is sensitive to flooding, it will have effects on its economy as well. Damages to for instance transport systems will require repairing costs but may also hamper, at least temporarily, regional economic development by reducing the accessibility of the region which again may have negative impacts on firms profitability in that region. So, a region's physical sensitivity to flooding will be highly correlated to its economic sensitivity to flooding. Therefore, indicators for economic sensitivity of extreme events would be closely correlated to indicators for the physical or social sensitivity. In many cases one would use exactly the same indicator as proxy for the economic sensitivity, as one would use as an indicator for physical or social sensitivity.

This chapter concentrates on the economic production sectors, but the economic effects are derived of the physical and social sensitivity of extreme events which are dealt in other parts of this technical paper.

Indicators for the sensitivity of economic sectors will be calculated based on the regional dependency on different economic sectors, and on assumptions about sensitivity to climate change in a given economic sector based on the literature review. The regional dependency can, for some economic sectors, be measured by the relative share of employment, or GVA, in that sector in the region. For example – a region with a large share of its GVA and/ or employment coming from agriculture sector can be seen as largely dependent on (specialised in) this sector. If the climate changes, and affects agriculture (for example through changes in the growing season, lack of water or other environmental effects) in a negative or positive way in this region, that region can be labelled as economically sensitive (either in negative or positive terms).

Based on a comprehensive review of scientific literature, the key sectors of the economy which are likely to be directly affected by climate change are: the primary sectors (agriculture, forestry, fishery and aquaculture), the tourist sector, the energy sector and infrastructure. Others sectors will be affected indirectly through the supply and demand chains. Effects also include direct impacts to biophysical environment such as direct damages to infrastructure and built environment as a result of extreme weather events such as flooding. All in all, due to complex supply chains a significant part of the economy can be affected by climate change. However, the quantification of the indirect climate change impacts especially at a European scale, with all the different and diverse regional economies, is a difficult task to undertake (Hallegatte et al., 2008b, Hallegatte et al., 2008a). Our analysis, therefore, will be limited to the economic sensitivity of the sectors which will be directly affected by climate change, and includes agriculture and forestry, tourism and energy.

The main objective here is to map sensitivity of economic sectors of European NUTS 3 regions to climate change. The first –introductory – step in this process is to explore the economic importance and relevance of these sectors in the European economy. The next step is to identify sensitivity indicators for the different sectors based on available literature, and thereby identify the impacts these sectors may experience because of climate change.

Primary sector

Relevance: Agriculture is a climate sensitive sector, and will be affected by climate change, both in positive and negative ways (CEC, 2009a). In general, crops respond to both increased temperatures and increased CO2. Higher CO2 levels are leading to higher productivity for all crop growth. Higher temperatures and longer growing seasons will benefit crop growth in some regions; whereas increased temperature combined with decreased precipitation will limit growth in other regions. Climate variability might also be of concern, as crops are especially sensitive for climate factors in some specific stages of growth. The IPCC Fourth Assessment Report (AR4) summarises the geographical impacts of climate change on agriculture in the following way: "Agriculture will have to cope with increasing water demand for irrigation in Southern Europe, and with additional restrictions due to increases in crop-related nitrate leaching" (Alcamo et al 2007:543).

With a fraction of only approximately 2 % of total gross domestic production (GDP), which decreases over time (0.8% during the period 1998-2008 and 4 % of total employment (Eurostat, 2010a), agriculture accounts for a small fraction of the European economy. But between countries the agriculture fraction of total domestic production differs considerably.

Agriculture accounts for a larger part of GDP in the south and east of Europe. The sector accounted in 2008 for 3,4 % in Spain, 3,7 % in Greece and 4,5 % in Poland, but only 0,9 % in Germany and 1,3 % in UK. This uneven distribution of agriculture activity goes hand in hand with the uneven distribution of climatic impacts on this sector, as the southern and eastern parts of Europe are – according to most climate scenarios - precisely the ones to be most affected by climate change. However, apart from the obvious contribution of agriculture in the national economies, primary sector performs other important geographical and sectoral roles as well including the provision of a support framework for people living in remote areas: "With over 56 % of the population in the 27 Member States of the European Union (EU) living in rural areas, which cover 91 % of the territory […] farming and forestry remain crucial for land use and the management of natural resources in the EU's rural areas, and as a platform for economic diversification in rural communities (Directorate-General for Agriculture and Rural Development, 2010).

The multifunctional role of agriculture is also emphasised in the EU Common Agricultural Policy (CAP). Because of the importance of the above mentioned 'agricultural services' there is a need to firstly understand the magnitude of the climate change impacts in agriculture and, secondly to design mechanisms to increase the resilience of the European regions by building their adaptive capacity. Following the aims of rural development policy such climate change adaptation will improve the competitiveness, the environment and the quality of life in rural areas (CEC, 2009b).

Forestry in Europe is also a small sector in terms of its share of GDP. In 2003, only 1.4 million workers were employed in the sector, measured in full-time equivalents (Blombäck et al 2003), but the importance of the sector varies substantially between European regions. Forest ecosystems in Europe are very likely to be strongly affected by climate change (Alcamo et al, 2007; Shaver et al 2000; Blennow and Sallnäs 2002; Askeev et al 2005; Kellomäki and Leinonen 2005; Maracchi et al 2005). Forests may be particularly sensitive to climate change because of the long growth time of trees. Trees planted today will grow under future climate conditions for several decades, which may vary substantially. High temperatures and drought will increase the risk of forest fires and this may lead to substantial damages in the Mediterranean forests. Increased frequency and intensity of storm might also harm the forestry sector.

As regards the fishing sector, its share of the GDP in Europe is generally less than 1%. But, its economic impact is highly significant in terms of employment in those regions (particularly in rural areas) where there are few alternative sources of employment.

Increasing sea temperature will change maritime species distribution, increase production in the northern parts of the North Sea and decrease production in the southern parts of current ranges. The vulnerability of the north-east Atlantic marine eco-region is assessed and reported in the IPCC Fourth Assessment Report (AR4). The report concludes that “climate change is very likely to produce significant impacts on selected marine fish and shellfish” (Alcamo et al 2007: 555; citing Baker, 2005). Brander (2005) also points out that high fishing pressure is expected to aggravate the risk to fisheries such as the Northern cod (Alcamo et al 2007:555). Minor historical sea-surface temperature changes - as low as 0.9°C over the 45 years to 2002 – may lead to growth for some species and reductions for others. The result of temperature rise may then be an unbalance and mismatch between species.

As pointed out by Beaugrand et al. (2002) and Edwards et al (2006) “warmer sea temperatures have increased growing seasons, growth rates, feed conversion and primary productivity in the marine and freshwater fish and shellfish aquaculture, all of which will benefit shellfish production extended the growth season” (Alcamo et al 2007:555). According to Beaugrand and Reid (2003) expanded geographic distribution and range will create opportunities for new species. However, increased temperatures will also “increase stress and susceptibility to pathogens” (Alcamo et al 2007:555, citing Anadón et al, 2005), and changes in the ecosystem which result in new invasive or non-native species will increase operation costs. In addition, damages on equipment and facilities due to more storms will lead to higher capital costs (Alcamo et al 2007:556). Increased water temperature in the sea may also increase the problems with salmon louse and thereby represent a danger to salmon fish farming in several European countries.

According to Maracchi et al (2005) agriculture and forestry are especially sensitive to climate change in northern and southern regions of Europe. Agriculture in the Northern areas may be positively affected by climate change. This is due to the introduction of new crop species and varieties, increased crop productivity, extension of appropriate areas for crop growing, longer growth periods and increased temperatures. The southern regions will experience limited benefits and large disadvantages. Some of the negative effects of increasing water limitation may be compensated by increased water use efficiency caused by increasing CO_2. However, in general “lower harvestable yields, higher yield variability and reduction in suitable areas of traditional crops are expected for these areas” (ibid: 117).

Accordingly, the negative effects of climate change on the agriculture sector in southern Europe, combined with the relative greater importance of the sector, is expected to lead to larger income loss in these regions than in the rest Europe. The agricultural systems in

Western Europe are assumed to be less sensitive to climate change, and model-based predictions indicate better opportunities with regard to yield increases and wider agricultural crops for northern Europe (EEA 2008).

Existing studies: The climate change effects on agriculture are complex and affect livestock and different types of crops, in different regions, in different ways, see Maracchi et al (2005) for a recent overview over expected effects of climate change on European agriculture.

There are several methods developed to study the response of agriculture to climate change. The following table from Iglesias et al (2009, 17) summarizes some characteristics of the different methodological approaches:

Table 6: Approaches for studying the response of agriculture to climate change (Iglesias 2009, 17)

Type of methodological approach	Description and use	Strengths	Weaknesses
Process-based crop models/agro-climatic model	Calculate crop responses to factors that affect growth and yield (i.e. climate, soils, and management).	Process based, widely calibrated, and validated. Available for most major crops.	Require detailed weather and management data for best results.
Empirical statistical models	Based on the empirical relationship between observed climate and crop responses.	Present day crop and climatic variables are well described.	Do not explain casual mechanisms. May not capture future climate crop relationship or CO2 fertilization.
Production functions derived from crop models and validated with empirical data	Based on the statistical relationship between simulated crop responses to a range of climate and manage options. Used in climatic change impact analyses.	Allow to expand the results over large areas. Include conditions that are without the range of historical observations.	Casual mechanisms are only partially explained. Spatial validation is limited due to limitations in the database.

The process-based crop model is basically controlled experiments, where crops are grown in laboratory or fields, under controlled different possible climates. This will give information about how crop growth are affected of different environmental factors – like different soil quality, climate, topographic differences, and management (i.e. sawing date/growth period), i.e. Porter and Seminov 2005, and Ferrera et al, 2010. As the process-based models links exposure directly to production and yields we summarizes some results from the existing literature under.

Maracchci et al (2005) refer to agro-climatic studies (Harrison and Butterfield 2000; Nonhebel 1996) which show that for a major cereal as wheat increased temperature will only cause a small reduction in yield. On the other hand, more CO2 will lead to a big yield increase. The net effect of both temperature increase and CO_2 for a modest change in climate is a large yield increase. Type of soil, or topographic environment may also have effects on yields (Popova and Kercheva, 2005; Ferrara et al, 2010). Maracchi at al. (2005) summarizes climate change effects for Europe with possible large increases in yield in southern Europe, particularly in northern Spain, southern France, Italy and Greece, and Fenno-Scandinavia. In the rest of Europe, yields may show small increases except some small areas where yields are predicted to decrease, such as in southern Portugal, southern Spain and the Ukraine.

For other types of crops, like maize, simulation of future climate scenarios for selected sites in different agriculture zones in EU suggest increases in yield for northern areas (up to Denmark, the Boral region was not included in this study) and decreases in southern areas (Wolf and van Diepen, 1995). According to Maracchi et al (2005:125) "[t]his is due to a small effect of increased CO_2 concentration on growth...and a negative effect of temperature on the duration of growing season".

Vegetables are also sensitive to changes in temperature and CO_2. However, the effects of a changing climate on different types of vegetables vary a lot according to the kind of yield and the response of "phenological development" (Maracchi et al, 2005:125) to temperature change. For crops such as onions, temperature increase will reduce the period of crop growth and accordingly the yield, while growth and yield for crops such as carrots will be improved by an increase in temperature. According to Farrar (1996) and Komor et al (1996), cited in Maracchi et al, (2005:127) "root and tuber crops are expected to show a large response to rising atmospheric CO_2 due to their large underground sinks for carbon and apoplastic mechanisms of phloem loading". However, increased temperature may lead to a shortening of the growth season and increase the need for water. Results from climate change scenario studies based on crop models indicates that potato yields in northern Europe will increase while there will be a decreases or no change in the rest of Europe (Wolf 2000, cited in Maracchi et al, 2005:127). Other crop groups may react differently on climate change. Vegetables are a main crop group which includes a wide range of species that will be differently affected by for example temperature and changes in growing season (short or long-time). Some vegetables will benefit from increased temperatures, leading to earlier sawing, faster growing or harvesting before the risk of drought in summer, whereas species that need a longer growing season will be in risk of drought in the summer period.

According to Maracchi et al (2005:128) "Livestock systems may be influenced by climate change directly by means of effects on animal health, growth, and reproduction, and indirectly through impacts on productivity of pastures and forage crops." Heat stress affects animal production negatively by reducing reproduction and the production of milk in dairy cows and also leads to lower fertility in pigs (Furquay, 1989).This may have negative impacts on livestock production during the summer period in existing high-temperature regions of Europe. On the other hand increased temperature in cold periods for cooler regions will probably be positive since it will lower the feed requirements and energy costs for heating, and also contribute to increased livestock survival.

In the recent PESETA-Agriculture study, the methodology used was to give an assessment of the potential effects of climate change on agricultural crop production in Europe through derived crop production functions from process-based calibrated and validated models for

Europe (Iglesias et al, 2009). They operate with 9 sites – or agro-economic zones – in Europe. The crop models include information about irrigation, technology and management (i.e. sawing date) on the site level. Crops simulated were winter wheat, spring wheat, rice, grassland, maize and soybeans. As the PESETAS study use different climate change scenarios than the ESPON Climate Project, the IIPC's A2 and B2 climate change scenarios respectively, we cannot directly use their results.

The PESETAS projections on agricultural impacts conclude that for the period 2071-2100, southern Europe would experience large decreases in yields. In Nordic countries increasing yields are expected mainly due to a longer growing season and higher minimum temperatures in winter. As reported in the IPCC Fourth Assessment Report (AR4) agriculture in southern Europe will also have to deal with rising demand for water for irrigation. Increases in crop-related nitrate leaching will impose additional restrictions on agriculture in these areas (Alcamo et al 2007:543).This will even worsen the projections for the south, and this is not fully built into the PESETA model.

Indicator methodology: The literature indicates that the growth processes and simulation in the agriculture sector is complex. One type of possible sensitivity indicators for agricultural production could be the regions dependency of different types of crops. The problem with this methodology is that it requires detailed weather and management data for all regions, and in the ESPON CC-project we do not have access to a model handling this complexity and combining it with the exposure – and crop-specific thresholds - on each type of crop.

In order to approach agriculture's sensitivity to climatic changes, we utilize data for the soil quality of the NUTS3 regions as a proxy variable for the sensitivity of drought in agriculture crop production. In order to approach soil quality, data from the European Soil Data Centre (ESDC) was utilised. The used indicator represents the available water capacity and is expressed in mm/m. In combination with the CORINE Land Cover database the average value of this indicator for both land used for agriculture and forestry was calculated.

In order to compute the sensitivity indicator, economic regional data was utilised to relate the above with the size of the agriculture sector in each region. The use of two different variables was initially explored: (a) the percentage of employment in the primary sector (NACE A-B) at NUTS3 level, and (b) the share of the primary sector' Gross Value Added (GVA) at NUTS3 level. The main data source for the calculation of these shares is Eurostat. Both of these variables could potentially provide insights for the dependency of regional economies on the primary sector. However, they are expected to perform differently across regions due to the diverse structure of the regional economies: while the share of employment is expected to highlight regions with more labour-intensive primary sector, the share of GVA is expected to highlight regions with high outcome and potentially regions with high productivity in the primary sector. Most importantly though, both of these variables are related with the overall primary sector and are introduced here as proxies for agriculture and forestry production given the lack of economic variables at NUTS3 level directly related only to agriculture.

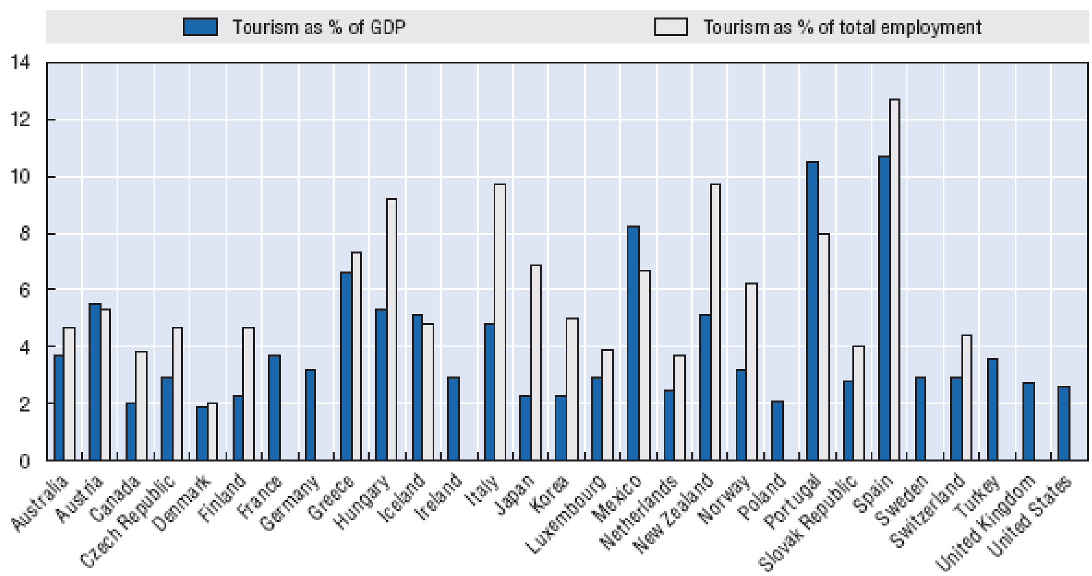
Since both variables highlight different elements of the regional primary sector profiles, a decision was taken to use both of them. In order to do so, the average of both variables was calculated, which represents the economic dependency of a region to the primary sector.

Such a methodological choice enabled the project to capture the special characteristics of both variables. Regions with a high share of employment in the primary sector will face broader social effects (positive or negative) due to climate change because the larger workforce, which is dependent on the primary sector, will be directly affected. In addition, regions with high share of primary sector GVA could experience a decrease or an increase of the overall regional economic output.

Tourism

Relevance: Tourism is one of the most dynamic segments of the service sector, and it plays a significant role in many countries economic growth and development. In Spain and Portugal tourism makes up more than 10 % of GDP, and also large share of employment. In Spain tourism employment constitutes almost 13 of total employment, in Italy app. 10 %, in Hungary more than 9 % and in Portugal 8 % (OECD 2010). Although these figures clearly illustrate the differences in importance of tourism between different countries, the variations would be vastly larger if the figures were regionalised. In popular tourist regions in Spain, Portugal Greece etc., both the share of GDP and employment is far above the national average. Hence, such regions are more sensitive to climate changes which affect tourism.

The OECD area plays a predominant role in international tourism and in the past two decades international tourism has been growing faster than the world economy. However, domestic tourism is far more important than international tourism. Domestic tourism, i.e. travel by residents in their own country, accounts for 75 % of tourism consumption (OECD 2010). This is related to factors such as country size, geographical location, accommodation capacity, points of attractions and so forth. Tourism also shows a strong seasonality in most countries. In most OECD countries tourism activity is highest in the summer season (July-September), and lowest in the winter season (October-March). In Europe the volume of tourism might be twice as high in the summer as in the winter season.



Sources: Country data, OECD data processing.

Figure 13: Tourism in OECD economies

The 1.8 million businesses – mostly small and medium-sized enterprises (SME) – which are active in this sector employ approximately 5.2 % of the total workforce in Europe (approximately 9.7 million jobs).Interestingly enough a significant proportion of people employed in this sector is young people. In total, the European tourism industry generates more than 5% of EU GDP, and this figure has been steadily rising (ECORYS SCS Group, 2009). In comparative terms, tourism is the third largest economic activity in the EU after the trade and distribution and the construction sectors. However, because of its nature, tourism is strongly linked with other sectors such as distribution, construction, transport companies in general (air, rail, maritime, bus/coach, etc.) and the cultural sector (including cultural and creative industries). Considering these links, tourism's contribution to EU27 GDP is probably much bigger than shown in the formal tourism statistics. It has been estimated to generate more than 10% of Europe's GDP and 12% of all jobs (CEC, 2010).

Tourism is a very complex phenomenon and definitions are numerous. It is not a clearly defined industrial sector but more an activity which necessarily has to be analysed both from a supply and demand side perspective. The current UNWTO definition of tourism is: "Activities of persons travelling to and staying in places outside their usual environment for not more than one consecutive year for leisure, business and other purposes not related to the exercise of an activity remunerated from within the place visited" (ESPON 2006).

This definition can be associated with the three following factors or concepts; (1) the movement of persons, (2) an economic sector or industry, and (3) a broad systems of interacting relationship of people, their needs to travel outside their communities and the services that attempt to meet these needs by providing products (Gunn 2002, Page 2003, Chadwick 1994, ESPON 2006). The complexity of tourism also makes it very difficult to map and analyse tourism activities, and particularly to undertake comparative studies. Not only may adequate data be hard to get at but it may also be difficult to know exactly what to measure and how to measure it since definitions often vary between countries.

Existing studies: A region's attractiveness for potential tourists depends heavily on the local weather and climate for most types of touristic activities, and future changes in climate have a strong potential to affect the tourism sector. Climate stimuli primarily affect tourism indirectly by changing the attractiveness of an area such as by "loss of biodiversity, impacts on the natural and built environment, and on tourism-related infrastructure" (OECD 2010).

Impacts will vary between regions, with coral reefs, ski resorts, and island beach and dive resorts being particularly vulnerable (op cit., see also the Alpine case study). Changes in attractiveness due to climate change may lead to changes in consumer behaviour and use of "tourism-related infrastructure" such as hotels, restaurants, transport system etc., and these changes can be used to measure the sensitivity of the tourism sector. Although it is not explicitly stated it seems that the Alpine case study is using "overnight stays" as a sensitivity indicator. In the Spanish case study "regional income" operationalised as "jobs in the tourist sector" seems to make up the indicator for economic sensitivity.

The ESPON project 1.4.4 “Preparatory Study of Spatially Relevant Aspects of Tourism” suggests three main areas of study to be in focus, and the two first areas seem to be of particular interest:

- Travel and flows. To which places in Europe do people go and when? The types of flows – who is going where, for how long, and why? The carriers/movers of flows – how do people move?
- Economic effects and employment. Tourist expenditures and consumption – how much is spent on a daily basis by visitors, on what and where? Supply of services (accommodation, transportation, services, attractions). Job creation and economic development (employment structure, business structure).
- Environmental and social effects. Physical environment (infrastructure for transportation, accommodation, facilities), natural environment (fuel emissions, water resources, energy resources, land use), social environment (cultural heritage etc.).

In the last 10-20 years there has been a growing literature on the relation between tourism and climate change. Firstly, some studies relate particular tourist destinations to climate change (e.g. Scott el al, 2004). These studies focus at large on the exposure of the tourism sector to climatic change. Secondly, there are studies that build statistical models of behaviour focusing on the tourism demand of certain types or groups of tourists as a function on weather and climate (Maddison, 2001; Lise and Tol, 2002, Bigano et al, 2006), which can be thought of as sensitivity analyses (Perch-Nielsen, 2010). Changes in tourism demand have also been addressed by simulation of projected changes in tourism flows depending on how climate change affects the attractiveness of that place relative to its competitors (Hamilton et al, 2005).

In a recent paper Perch-Nielsen (2010) has developed a vulnerability framework for the tourism sector. She explicitly defines indicators for exposure and sensitivity for beach tourism, and uses a transparent index approach that yields an assessment of the overall relative vulnerability of the beach tourism sector in 51 countries. She then analyses the vulnerability of the beach tourism sector of climate change at the country level. Beach tourism is chosen because the associated activities of sunbathing and swimming are more linked to specific weather conditions than other tourism activities like e.g. sightseeing. Our proposed summer indicator is based on this approach.

In many of the existing analyses of tourism the “The tourism climate index” (TCI) is used as a composite measure of systematically assessing the climatic elements most relevant to the quality of the tourism experience for the ‘average’ summer tourist (Amelung and Moreno, 2009; Mieczkowski, 1985). The original TCI developed by Mieczkowski was based on previous research related to climate classifications for tourism and recreation, and on theoretical considerations from the literature related to human comfort, particularly with reference to tourism activities. Meteorological data limitations reduced the number of climate variables that were integrated into the TCI to seven (monthly means for maximum daily temperature, mean daily temperature, minimum daily relative humidity, mean daily relative humidity, total precipitation, total hours of sunshine, and average wind speed). These seven climate variables were combined into five sub-indices that comprised the TCI. A standardized rating system, ranging from 5 (optional) to -3 (extremely unfavourable), was devised to provide a common basis of measurement for each of the sub-indices. Although devised on the basis of available literature, the rating systems of the five sub-indices and their relative weightings within the TCI are subjective, and the single most important variable in the index is temperature. Changes in the TCI is used as exposure variable in several new studies of climate change effects on tourism (Amelung and Moreno, 2009; Perch-Nielsen et al 2010).

The direct impacts of some aspects of climate change can be expected to bring tourism winners and losers. Global warming may make some destinations more attractive to visitors by making what were previously less hospitable climates more attractive. However, the widespread nature of the projected impacts suggests that many destinations could also suffer serious and costly impacts.

Tourism is very sensitive to climate both with regard to climatic changes in the origin and the destination of the tourists' countries. It is also sensitive to climate seasonality, and according to Viner (2006) it is "the seasonal contrasts that drive the demand for summer vacations in Europe". Hamilton et al (2005) point out that a climate change scenario of 1°C increase in mean temperature would imply a gradual move of tourist destinations further north and to more mountainous areas. This would influence the preferences of sun and beach lovers from western and northern Europe. As a result the relative coolness of high-lying and mountainous areas of France, Italy and Spain could gain increased popularity. Accordingly, some studies predict a possible shift towards a higher level of domestic tourism (Ceron and Dubois 2002).

Climate change may result in seasonal changes and extended tourist seasons in the Mediterranean. Tourism may decrease in summer due to increased temperature during this period of the year whereas tourism in spring and perhaps autumn may increase (Ciscar at al 2009). Alcamo et al (2007, 556-57) states, referring to Amelung and Viner (2006), that: "Occupancy rates associated with a longer tourism season in the Mediterranean will spread demand evenly and thus alleviate the pressure on summer water supply and energy demand". Thus climate change may even be beneficial for the Mediterranean tourist industry if it levels-out demand and reduces the summer peak, while increasing occupancy in the shoulder seasons (EEA 2008). However, in the absence of such adjustments the Mediterranean tourist industry will be among the main losers.

Winter tourism will also be affected by climate change. In winter time significant reductions in natural snow cover is expected to shorten the season and thereby hit the ski industry in central Europe very hard. Skiing will have to start later and finish earlier in the season (Elsasser and Burki 2002). According to Hantel et al (2000) an increase of one degree Celsius in the most sensitive elevation in the Austrian Alps will reduce skiing days in winter time with four weeks, and with six weeks in spring. An estimate from Beniston et al (2003) indicates that a temperature increase of 2°C and no change in precipitation would cut down the seasonal snow cover at a Swiss Alpine site by 50 days per year.

However, the economic effects of climate change on tourism depend very much on the question whether holiday seasons remain fixed or if shifts in the holiday season will occur.

For example a more flexible timing of holidays among a large proportion of the population would alter projected impacts significantly. These effects may be offset.

Summer tourism in the Nordic Countries is likely to benefit from improved conditions. Increased temperatures are expected to make this region more attractive to international tourists during the summer. The effect on winter tourism is more uncertain. The effect will be dependent on days with snow at the winter sports centres. One of the projected effects of climate change is higher temperatures and less snow, and this may have a negative effect on winter tourism in some areas (Aaheim et al. 2008). At country, or even NUTS3 level, the positive effect on tourism in summer is expected to outweigh the potential negative effects on winter tourism, so the total effects are considered to be positive. For the Atlantic north region (United Kingdom and Ireland) it is expected that climate change will lead to a small decrease in international arrivals of tourists. But the negative effect of less international tourists is assumed to be outweighed by the expected increase in domestic tourists (Hamilton et al. 2005). Total effect is therefore considered to be slightly positive.

According to Hamilton et al (2005) domestic tourism will increase, too, leading to an increase in the tourism industry in the Baltic States. Southern Europe and Iberian Peninsula are the European regions with the largest share of international tourists (Hamilton et al 2005). In Malta and Cyprus the shares of international arrivals are 90% and 79%, respectively. The temperatures are already high in this area, and climate change with even higher temperatures is expected to make these regions less attractive to international tourism, leading to decreases in international arrivals. Domestic tourism is expected to increase but, is not expected to outweigh the decrease in international tourism, so the net effect for the region is considered to be a decrease in the tourism industry.

According to Hamilton et al (2005) an increase in international tourism is expected in Austria and Switzerland in the Central Europe North region (Austria, Germany, and Switzerland). This is because of the assumption that localities at higher altitudes will become more attractive (Hamilton & Tol, 2007). In Germany a decrease in international tourism is expected but all countries in the region are expected to become more attractive as tourist destinations for the domestic population. This is assumed to outweigh the negative effect from decreased international tourists in Germany. The effect on winter tourism in Austria and Switzerland is more uncertain as the ski industry in central Europe is likely to be disrupted by significant reductions in natural snow cover. This will primarily be a problem at the beginning and the end of the ski season.

Indicator methodology: Unfortunately, the data needed in order to get a comprehensive overview of tourism is only available to a small extent at NUTS 3 level, and accordingly it is very difficult to estimate the sensitivity of this sector or activities. According to the ESPON-report data at NUTS 2 and NUTS 3 level is available from Eurostat for the following categories only (ibid.: 12-13):

(a) The capacity of collective tourism accommodation (hotels, campsites etc.), for which data is required annually at NUTS 3 level.

(b) Guest flows at these collective accommodation establishments, showing arrivals and nights spent in different broad types of accommodation.

Most information is again required annually, with data down to NUTS 2. Some information, on arrivals, nights spent and occupancy rates, is required monthly for the country as a whole. However, not all countries provide these data and, likewise important there are differences in definitions which make comparative analyses both very difficult and inaccurate.

The ESPON report cited above also discusses the possibility of using the Tourism Satellite Account (TSA) which is the main internationally recognised standard to measure tourism in the economy (OECD 2009). Even though it is a useful tool and a number of countries have adopted this, there are many problems associated with the TSA's use. The main one is the considerable cost involved in order to acquire the necessary data on tourism demand and supply. Also, because the TSA is tied to a country's Input-Output matrices, (which is one of the strengths of the tool) a major limitation is that these I/Os are updated infrequently since enormous amounts of data are required for such an update. This means the data of a TSA can sometimes be old, thus limiting their use in terms of effective policy-making. The ESPON-report (1.4.5), therefore, concludes that TSA are only partly developed, and that only a few countries have enough data to perform statistical analyses at the regional level.

On the basis of the different available sources mentioned above the following indicators for estimating sensitivity of tourism could be relevant: (a) Employment; but this indicator is not available on NUTS 3. The problem is also how to measure tourism since definitions vary a lot between countries and so do data availability. (b) Economic figures; for tourism, comparable data on GVA and employment are aggregated with a long list of other sub-sectors such as retail, restaurants, etc. and they not available at NUTS 3 level. The Tourism Satellite Account (TSA) which shows the economic significance of tourism cannot be used either due to its data gaps and low coverage of many countries. (c) Number of overnight stays (d) Number of beds which indicate whether a region is dependent on, or specialised in tourism, and accordingly may be sensitive to climate change which affects tourism. If tourism is sensitive for various climate stimuli this will also affect the number of beds over time, if for instance overnight stays increase/decrease due to climate change so will number of beds also probably increase/decrease. When this information is regionalised one can see how the dependency varies between regions, i.e. which regions are most sensitive to climate change with regard to tourism.

As mentioned above, the statistics do not separate between the different types of tourism relevant for the ESPON Climate project. Data available is number of beds in hotel and similar accommodations at NUTS 3 level, and these can be used as a proxy indicator for estimating the significance of this sector as a hole in the regional economy. Number of beds should be measured both in absolute and relative numbers. To relate the sector to the climate change model we therefore assume that the tourism sector in the region is related to either summer or winter tourism, and not to both.

Sensitivity indicator for winter tourism: In order to select which regions are winter tourism regions, DG Regio's typology of mountain regions was used. The project included all four types of regions of the methodology. Subsequently those NUTS 3 regions were identified which according to the CCLM data used in the project include areas that have at least 100 days of snow cover, as this is considered a crucial threshold for profitable winter sports tourism (Elsasser and Bürki 2002). Number of beds in these regions will then represent the tourism intensity concerning winter sports, and represent our winter tourism sensitivity.

Sensitivity indicator for summer tourism: In principle all regions in Europe can be and are destinations for summer tourism, notwithstanding major concentrations of summer tourism in the warmer, Mediterranean climate zones. Also, coasts with sandy beaches are prime summer tourism destinations. But not all tourists are attracted by water. There is also significant summer tourism in mountain regions – and in regions with otherwise attractive landscape and/or historic cities. Nevertheless, a major factor for the suitability and attractiveness of a region as a summer tourism destination clearly is 'pleasant summer weather'. As described above, the Tourism Comfort Index (TCI) has defined and quantitatively modelled what weather conditions are preferred by summer tourists. Therefore the future TCI score of each NUTS 3 region during the summer season was modelled based on the CCLM projections for 2071-2100. The second component of the tourism sensitivity indicator consisted again of the number of beds available for tourists in each region.

Some may argue that the focus on summer months is not justified. Accordingly an increase of temperatures may not only lead to hotter climate in the summer but also extend the tourism season before and after the summer period. Thus negative effects during the summer months would be offset by positive effects before and after the summer. However, the absolute quantity of accommodations, the highest occupancy rates, the highest prices and thus the main revenue generation in a tourism region is determined by the tourism peak in the summer months when most tourists want and can (e.g. due to school breaks) spend their main vacation away from home. Therefore the effects on the summer climate of a region are far more crucial than the effects of an extended tourism season.

Energy

Relevance: While in 2009 only 2.4% of EU27 GVA was due to energy, gas and water supply sector (Eurostat, 2010c), the importance of this sector is much greater in the overall economy as a production factor. However, the overall trend show that the energy intensity of EU's economy (gross inland energy consumption divided by GDP) steadily decreases. The separation of increasing economic activity from increasing energy consumption is of course a goal for sustainable development.

On the energy production side hydropower is the main renewable energy source today, and it is highly dependent on water. Climate change with changing precipitation patterns might have regional effects on the hydroelectric production potential (Lehner et al, 2005). The generation of electric power in thermal power stations (in particular coal-fired and nuclear facilities) relies on large volumes of water for cooling (e.g. Förster and Lillenstam, 2009). The use of cooling water may be restricted if limit values for temperature are exceeded during heat waves or drought periods, and this may force plant operators to reduce capacity - or even temporarily close down plants.

In general, primary energy production decreased by 4.7% during the period 2008-2009, following the downward trend of the previous decade. The decrease concerns both natural gas (-10.1%) and hard coal (-9.2%). On the contrary, renewable energy recorded a substantial increase of +8.3% and accounted for 18.4% of total EU-27 primary energy production, with natural gas lagging behind with 19.3%. Nuclear energy continues to be the main energy production source with 28% of total EU-27 primary production. In regards to the net energy imports, a decrease of 5. 7% took place during 2008-2009. The EU-27 total energy dependence rate (EDR) slightly decreased, going from 54.8% in 2008 to 54.7% in 2009 (Eurostat, 2010b).

Energy demand is dependent on climatic conditions (e.g. outside temperature), particularly in the domestic sector, but potentially also in the service and industry sectors. Because of an increase in mean average temperature in Europe, predictions indicate fewer days with heating but an increase in days with cooling. However, in the short-medium term, changes in energy and economic costs taken as a whole are estimated to be modest. This is due to aggregated effects of reduced demand in winter heating and increased demand for summer cooling (EEA 2008).

But when looking at regional patterns across Europe it becomes apparent that there will be increasing electricity demand due to cooling in the summer in southern Europe and reduced heating energy demand due to more moderate winters in northern Europe (EEA 2008). This translates into a likely net benefit to northern Europe and net losses for southern Europe. According to Alcamo et al (2007:556) estimates from Giannalopoulos et al (2005) indicates that: “Around the Mediterranean, two to three fewer weeks a year will require heating but an additional two to three (along the coast) to five weeks (inland areas) will need cooling by 2050.” Peak electricity demand is likely to shift in some locations from winter to summer.

Existing studies: Since the electricity sector’s demand and supply side have physical assets in the landscape, the sector will be affected by the physical impacts of climate change (Eskeland and Mideksa, 2009). The regional effects will vary depending on regional-specific climatic variables, infrastructure, socioeconomic variables and energy use profiles (Amato et al. 2005).

On the supply side there are concerns on the potential climate change effects on production of thermoelectric power. Water availability represents a growing concern, as energy consumption patterns and demand from competing water use sectors increase the pressure on power generators to reduce water use. Feeley et al (2008) analyses how projected energy demand patterns affect the freshwater withdrawal and consumption rates for various cooling systems. Changing precipitation patterns and higher temperatures might also have impacts on the cooling capacity for power plants. Förster and Lillenstam (2009) models how thermal power plants with once-through cooling could be affected by changing river temperatures and steam flows. They report that even if climate change may not have severe effects on power production in fall, winter and spring, the effects on power generation could be severely constrained in the summer months due to a changing climate.

On the demand side, the demand for heating and cooling is closely connected to temperature (even variables like household income, household size, electricity price etc. also plays a role). Energy demand depends on temperatures in a u-shaped fashion, and an approach in the literature to link the energy demand with outdoor temperatures is through the concept of heating degree days (HDD) and cooling degree days (CDD) (Isaac and van

Vuuren, 2009; Hekkenberg et al, 2009). HDD and CDD describe the departure of daily temperature from some threshold representing the human comfort zone. The threshold is often defined as 18 degrees by default.

In rural areas hot temperatures are usually mediated by wind and vegetation, but in urban areas temperatures can even be higher due to the high proportion of sealed surface (Santamouris et al, 2001). The problem can be especially severe when so called “heat islands” develop in densely built-up areas. These heat related phenomena affect the urban population and also have economic effects, e.g. costs for in-house cooling systems.

We have not found any literature documenting that industries energy demand in general will be directly affected by climate change (defined as affected directly by the exposure variables used in ESPON CC project). In a study on the effect of climate change on energy demand Bigano et al (2006) actually found that an increase in temperature affects the demand in households and in production sectors differently. They report that households demand for cooling and heating responds to temperature changes, and that the magnitude of the response in energy demand to changes in temperature depends on the temperature level in the region. For service and industry sectors they reports in general small and not statistically significant effects.

Indicator methodology: The ESPON ReRisk project has developed several indicators for a region’s risk of energy poverty. The observation that Europe had rising energy prices, increased imports and increasing dependency on fossil fuel was taking as the starting point in the project was. Considering this, the ESPON ReRisk project focused on the implications of energy poverty in EU regions for economic competitiveness and social cohesion (ReRisk Final draft, 2009). They did not analyse the mechanisms behind the rising energy prices, they were simply are taken as premises for their analyses. Changes in prices were also not regionalized. This means that the indicators from ReRisk cannot be used as sensitivity indicators in the ESPON Climate project.

The first group of energy related indicators focuses on the demand side of energy sector. To analyse in detail this sector, the following sensitivity indicators have been calculated:

Changes in demand for cooling, overall population

The number of summer days (number of days with temperature over 25 degrees) was used as a proxy indicator for changes in cooling demand. The starting point for the sensitivity indicator is the population at NUTS3 regions and the number of summer days in the present climate period. The latter has been derived as the average summer days during the period 1961-1990. The sensitivity indicator is the product of the multiplication of the normalised values of these two variables.

Changes in demand for cooling – heat island effect

The same methodology was applied for this indicator as well with the only exception that instead of using the overall population, only the population living in urban heat islands (see definition and identification method under ‘physical sensitivity’ was determined for each NUTS 3 region.

Changes in demand for heating, overall population

The focus here is not demand for cooling but rather demand for heating. Thus, instead of using the number of summer days, the number of frost days as an average during the period 1961-1990 was utilised. Apart from this, the methodology and the used data is the same with the other sensitivity indicators for the overall population.

Changes in demand for cooling, service sector

The focus here turns from the overall population to the service sector. Service sector together with residential users are the main occupiers of urban built space and responsible for a great proportion of the overall demand for cooling and heating. The sensitivity and expected impact indicators are calculated using the same methodology and data used for the same indicator for the overall population, but instead of using population the average GVA and employment in service sector is utilised here.

Changes in demand for in heating, service sector

The methodology of this indicator is basically the same as for heating demand from the overall population of a region. The only difference is that instead of inhabitants of a region, the number of employees in the service sector was used.

Changes in conditions for energy supply

This indicator captures the sensitivity of energy production against the projected climatic changes as well as the potential impacts given a set of assumptions. As a first step, the location of thermal power stations plants is utilised here as the main sensitivity indicator. The location of power plants provides some insights for the sensitivity of the energy production as energy production is highly related with physical resources located in specific areas. In more details, water availability is a crucial factor for thermal power station as water is necessary for cooling purposes. Lack of water recourses could easily lead to failure of a power plant.

In order to further approach the potential impacts on energy production due to the projected climatic changes, river basin data was utilized. Because energy production can be affected by the availability of water resources, the most appropriate spatial unit for our analysis is the river basin as power plants located in the same basin will face similar water availability problems (Förster and Lillenstam, 2009). Based on this argument, the climatic exposure indicators were calculated for the river basins. Two climatic stimuli are used here: decrease in summer precipitation and increase in summer days. And underlying assumption is that the river temperatures increases when summer days (days with temperatures over 25 degrees in summer) increases. Both exposure variables provide insights for the availability of water resources during summer, when the scarcity of water resources is more intensive. In simple words, the higher the increase in summer days and the higher the decrease in summer precipitation, the higher the impact could be for the energy supply. After calculating the above at the river basin level, the data was disaggregated to the NUTS3 level. Then the overall exposure was calculated as the average of the normalised versions of the two exposure indicators[11]. This average exposure for these NUTS3 regions which host power plants represents the potential impact on the supply side of the energy production. Figure 14

[11] It needs to be highlighted that in order to address the negative impact of the precipitation (decrease in precipitation leads to increase in exposure) the normalised version was multiplied by -1.

presents the expected impacts on energy supply based on the above framework and the projected climatic changes.

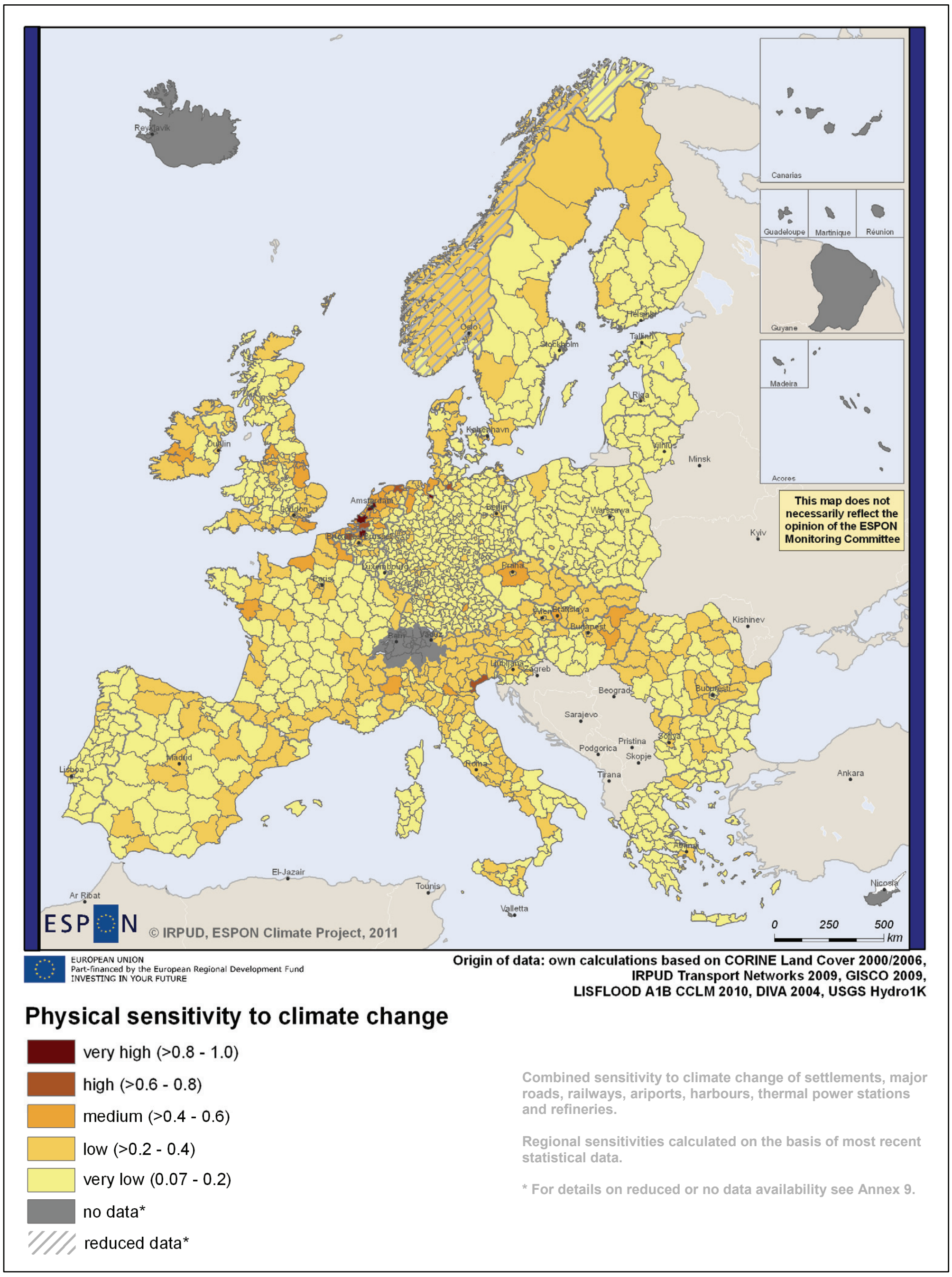
In addition, power plants also face the risk of coastal and river flooding. In order to address this issue, the portion of power plants per NUTS3 regions which will be newly affected by a 100 year river and coastal flooding event were calculated.

3.2.6 Aggregation of sensitivities to climate change

The sensitivity analysis is only an intermediate step within the ESPON Climate methodology. The results of the subsequent impact analysis, which are based on both the exposure and sensitivity analyses, are much more important. Therefore in the following pages only the combined sensitivities for each of the five dimensions of sensitivity are displayed as maps and briefly commented upon.

Combined physical sensitivity

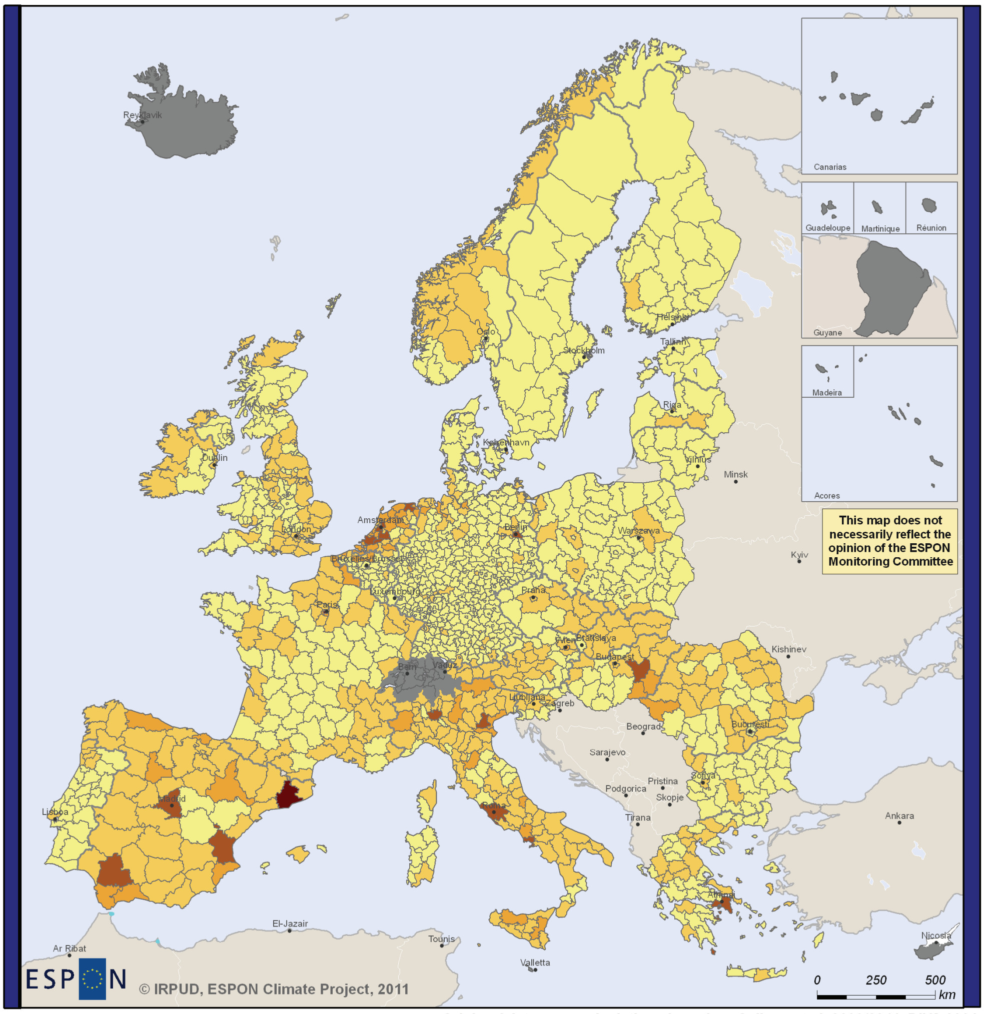
Physical sensitivity relates to all human artefacts that are important for territorial development and which are potentially affected by climate change. This includes settlements, roads, railways, airports, harbours, thermal power stations and refineries. These physical assets of a region are typically adapted to normal regional weather conditions and can withstand smaller climatic changes. However, buildings and infrastructure are sensitive to extreme weather events like flash floods, large-scale river floods and coastal storm surges, because their frequency and magnitude may change due to climate change. The map shows that in Europe the physical assets that are sensitive to these extreme weather events are mainly concentrated along the coastline.



Map 12: Combined physical sensitivity to climate change

Combined social sensitivity

Social sensitivity relates to human populations that may be adversely or positively affected by climate change. In particular, this encompasses climate-related sensitivities in regard to public health and personal mobility. In particular this dimension includes populations sensitive to river flooding, coastal flooding, flash floods and heat (i.e. senior citizen in urban heat islands). Map 13 shows that these populations are mainly concentrated in Southern European agglomerations and along the coastline. In fact, the most sensitive regions are coastal agglomerations in the Mediterranean with the exception of the Netherlands. This may in part reflect the higher population densities of these cities compared to northern European cities.



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Origin of data: own calculations based on Gallego et al. 2009/2011, DIVA 2004, Hydro1K, LISFLOOD A1B CCLM 2010, CORINE Land Cover 2000/2006.

Social sensitivity to climate change

- very high (>0.8 - 1.0)
- high (>0.6 - 0.8)
- medium (>0.4 - 0.6)
- low (>0.2 - 0.4)
- very low (0.03 - 0.2)
- no data*

Combined sensitivity to climate change of population in river flooding prone areas, in coastal storm surge prone areas, population prone to flash floods and heat sensitive population in urban heat islands.

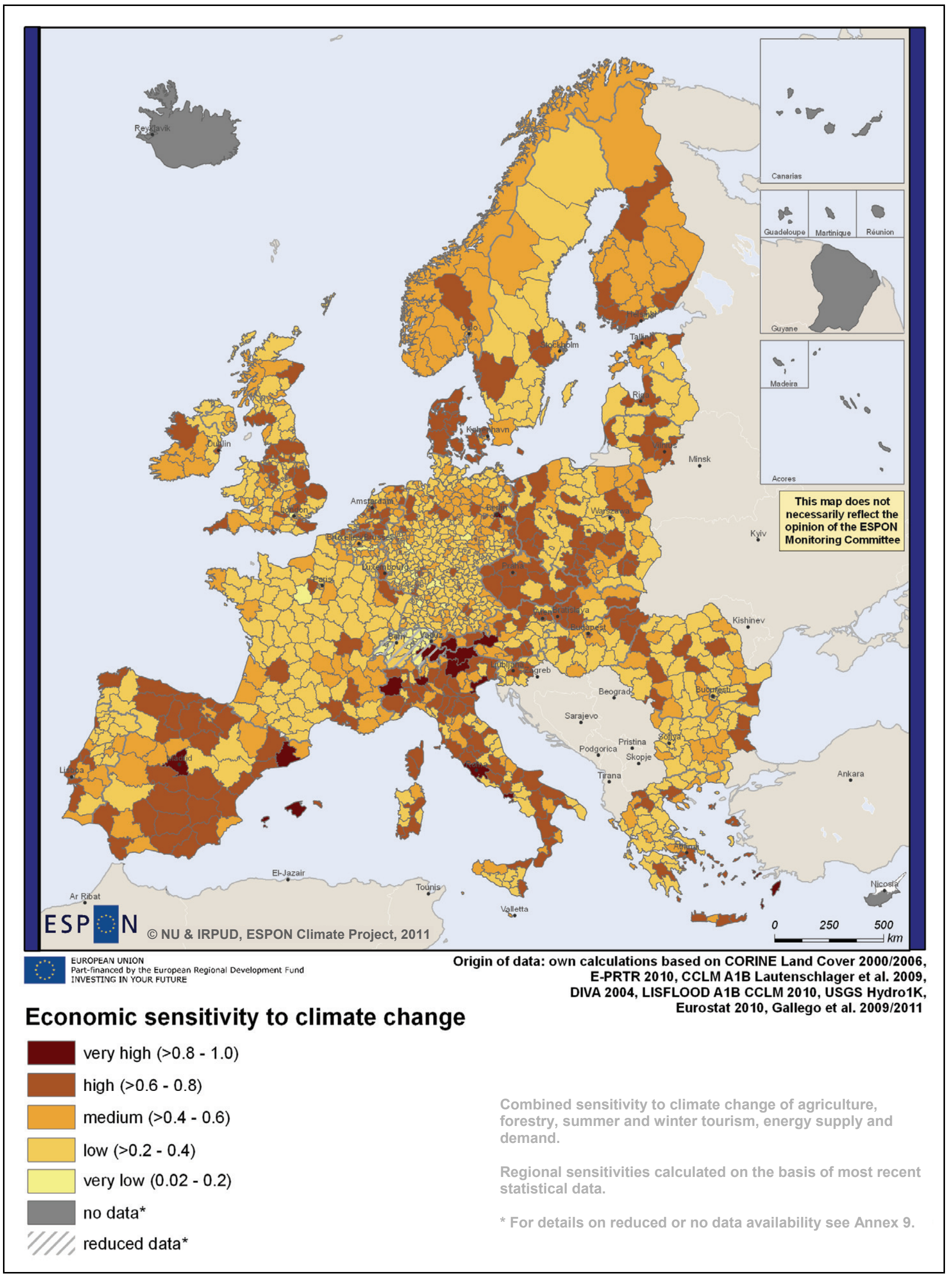
Regional sensitivities calculated on the basis of most recent statistical data.

* For details on reduced or no data availability see Annex 9.

Map 13: Combined social sensitivity to climate change

Combined economic sensitivity

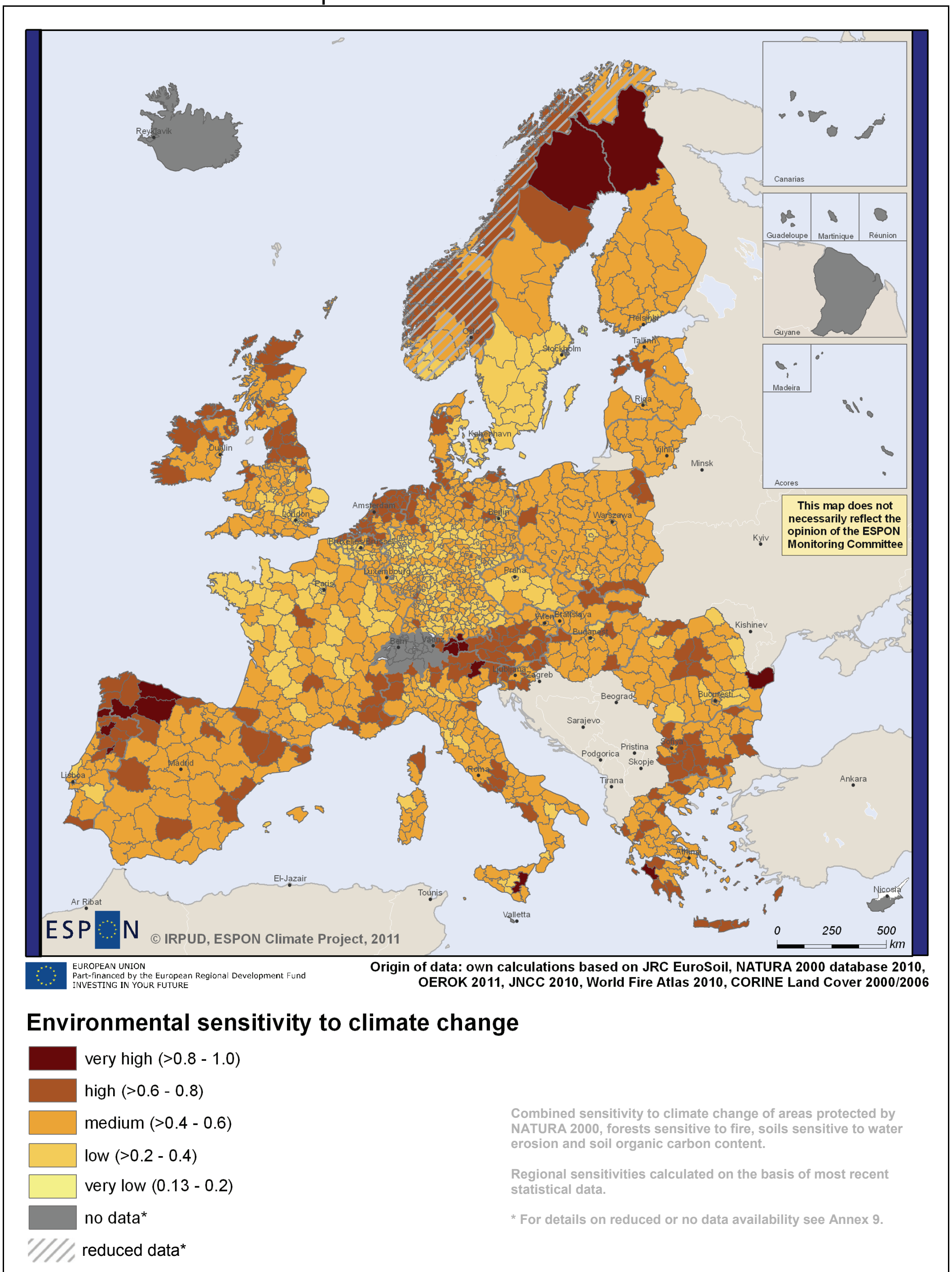
Economic sensitivity related to economic activities or sectors that are especially sensitive to climatic changes. This includes agriculture and forestry whose economic goods are highly dependent on suitable climate. Tourism, both summer and winter tourism, capitalises on specific climatic conditions. The energy sector is also very sensitive: Power plants need water for cooling and are sensitive to flooding. Private households and the service sector require heating and/or cooling and thus demand more or less energy. Consequently Map 14 highlights particularly those local economies which are dependent on tourism, agriculture and forestry: the Mediterranean region, the Alps, large parts of Eastern Europe, but also Scandinavia (energy demand for heating!).



Map 14: Combined economic sensitivity to climate change

Combined environmental sensitivity

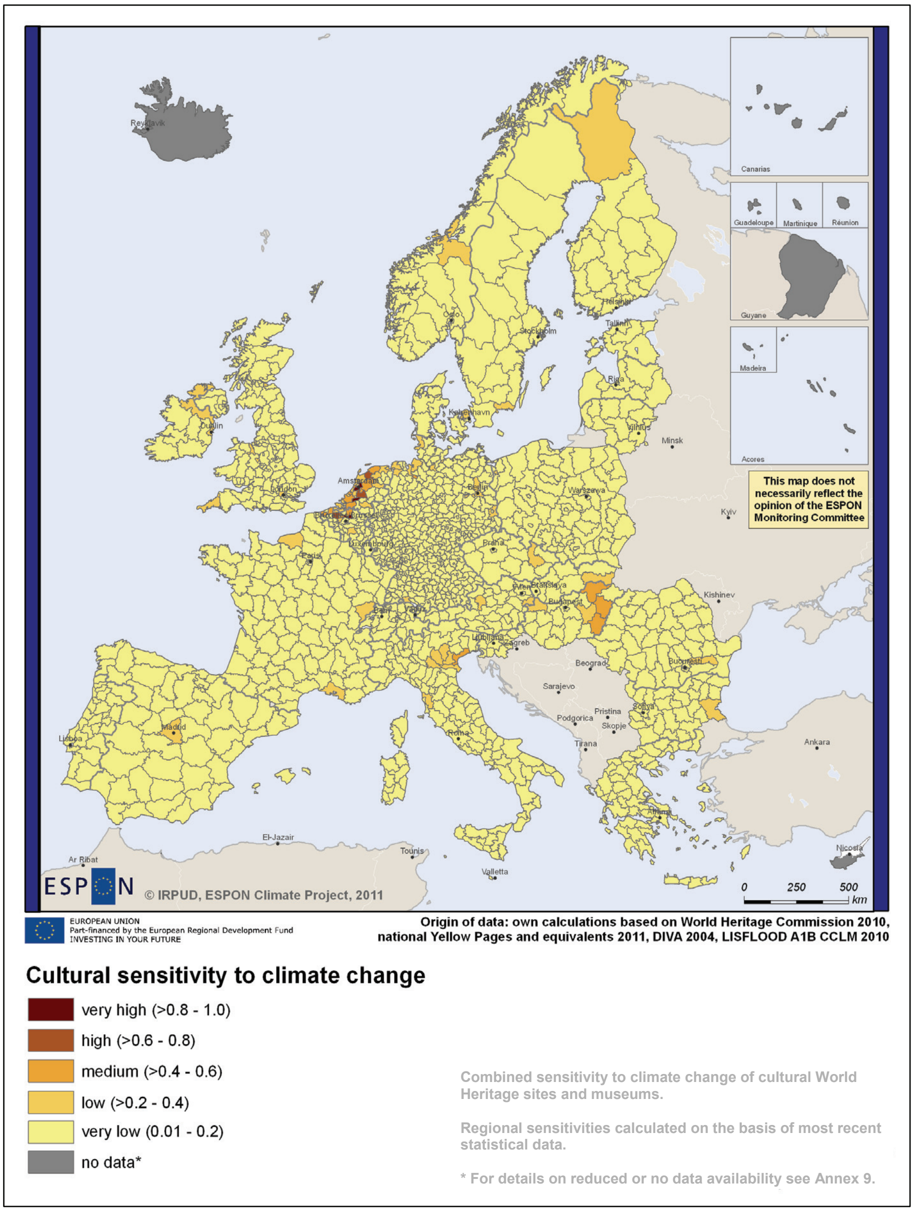
Climate is an integrated part of nature and thus directly or indirectly affects all other parts of nature. However, many plants and animals are able to cope with climatic changes, e.g. by migration or genetic adaptation. Thus the environmental sensitivity dimension focuses on natural entities that are highly sensitive (like protected natural areas or especially fire prone forests) and relatively stable entities like soils, that have only limited capacities to adapt and at the same constitute the basis for animal and plant ecosystems. Map 15 shows that especially mountain and river delta regions have protected natural areas and/or possess sensitive soils and forests. Moreover, the north of Scandinavia was identified as particularly sensitive due to the size of protected areas in the wilderness.



Map 15: Combined environmental sensitivity to climate change

Combined cultural sensitivity

Cultural sensitivity encompasses cultural assets like museums and internationally recognised historic sites that may potentially be damaged or destroyed due to climate change. While this may to a minor degree be true for all temperature and moisture changes, the highest and most sure sensitivity relates to extreme weather events like river flooding and coastal flooding. Map 16 therefore shows concentrations of sensitive cultural assets in regions along the coasts and along major rivers. Coastal cities like Amsterdam and Venice with their outstanding cultural heritage can easily be distinguished. But also some inland regions exhibit high cultural sensitivity values, owing to the fact that many old cities and historic sites are deliberately located along major rivers.



Map 16: Combined cultural sensitivity to climate change

3.3 The impacts of climate change on Europe's regions

According to the methodological framework of ESPON Climate and in line with the climate change research community impact was defined as the combination of exposure and sensitivity to climate change. For example, a region that is highly exposed to climatic changes may not exhibit severe impacts because it is sparsely populated. In contrast, an only moderately exposed region may be densely populated and thus have a higher climate change impact than the former region.

The pattern of impacts of climate change on Europe's regions can also be seen as evidence basis for adaptation needs: the more the potential impacts increase, the more important is adaptation in order to avoid negative consequences on the economy, population, physical assets, cultural heritage and the environment.

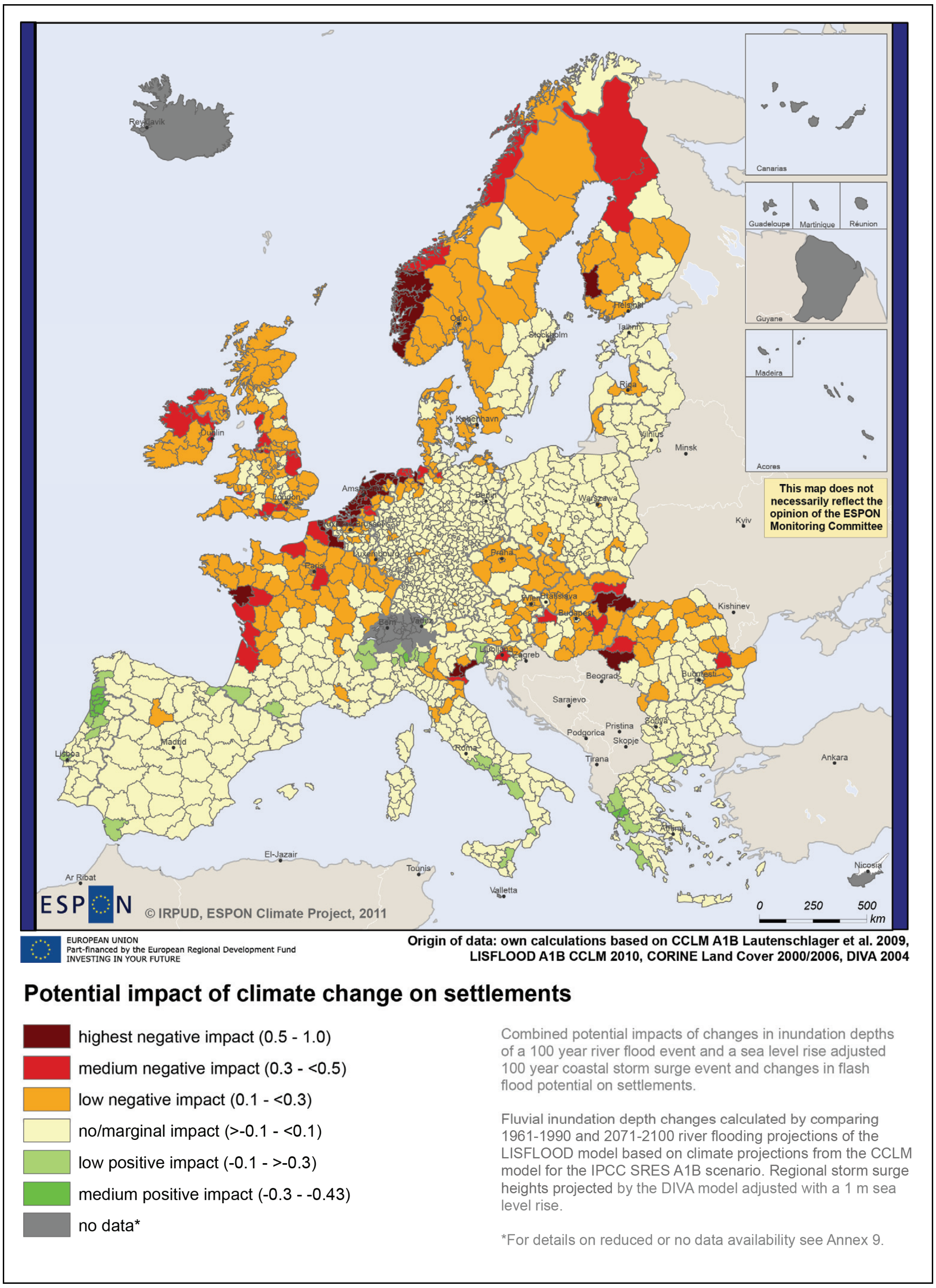
Before presenting the results of the impact analysis it should be noted again that each sensitivity indicator was related to one or several different exposure indicator(s). These linkages already formed the basis for the selection and definition of the sensitivity indicators and were applied when calculating the impact values for each region (see introduction to section 3.2).

In the following sections the results of ESPON Climate's impact analysis are presented. First maps on the individual indicator level are presented and briefly explained. Some indicators were combined for the sake of greater readability of the report (e.g. all settlement related impacts instead of separately for flash floods, river flooding and coastal flooding). Finally the combined impact for all indicators of one impact dimension is shown and commented upon.

3.3.1 Potential physical impacts of climate change

Potential impact of climate change on settlements

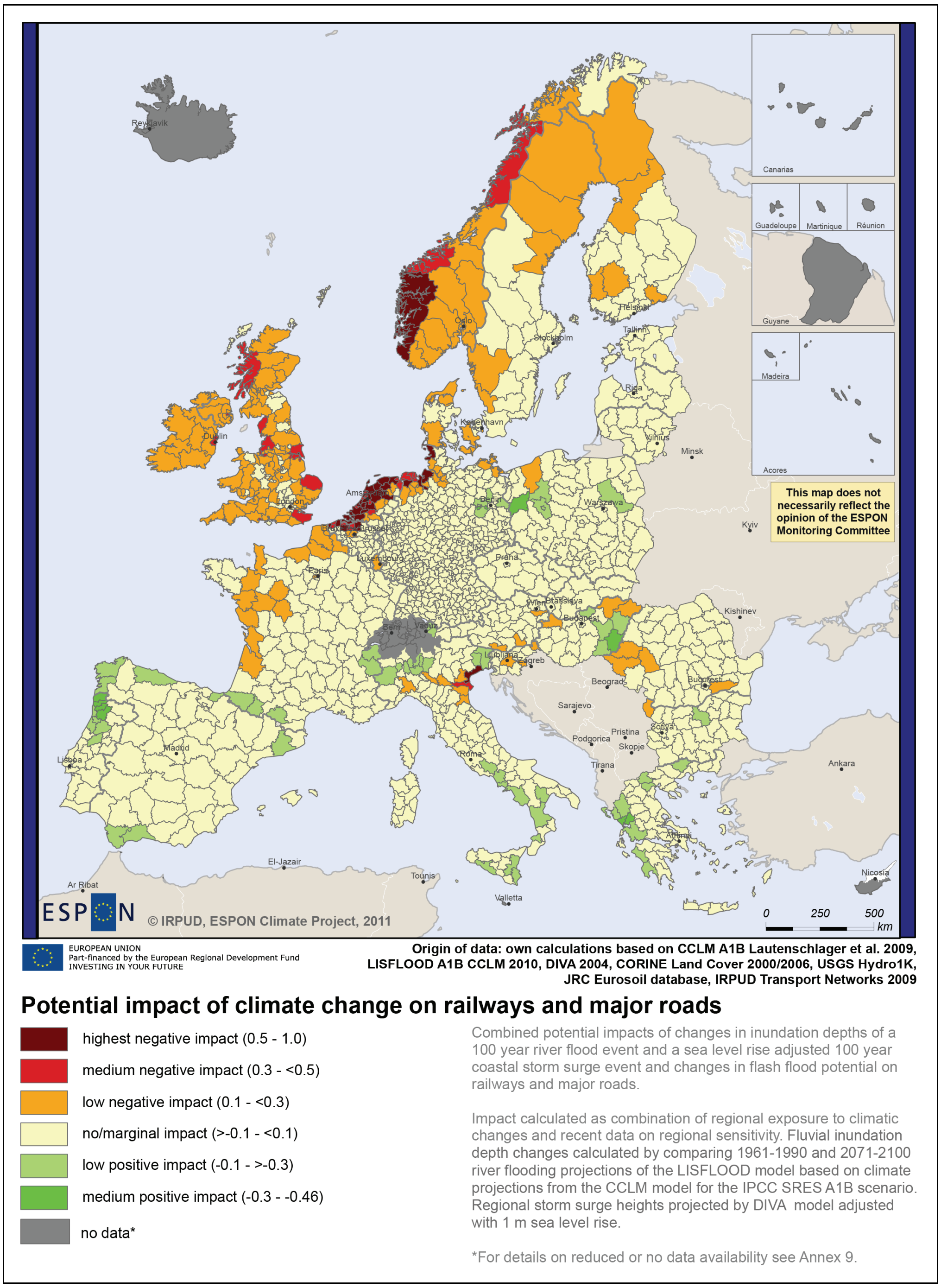
The map below indicates that settlements in coastal regions are projected to have high negative impacts. In Belgium, the Netherlands and Germany this even applies to cities in the 'second' row that would be newly affected by coastal storm surges due to sea level rise. Impacts from river flooding are also clearly discernible throughout Europe. The highest negative impacts are often due to a combination of exposures: River and coastal flooding in northern Italy and western France and flash floods and coastal flooding in Norway. But positive impacts are evident in Southern, Eastern and South-eastern Europe due to generally decreasing precipitation in these regions which may lead to a decrease in river flooding.



Map 17: Potential impact of climate change on settlements

Potential impact of climate change on railways and major roads

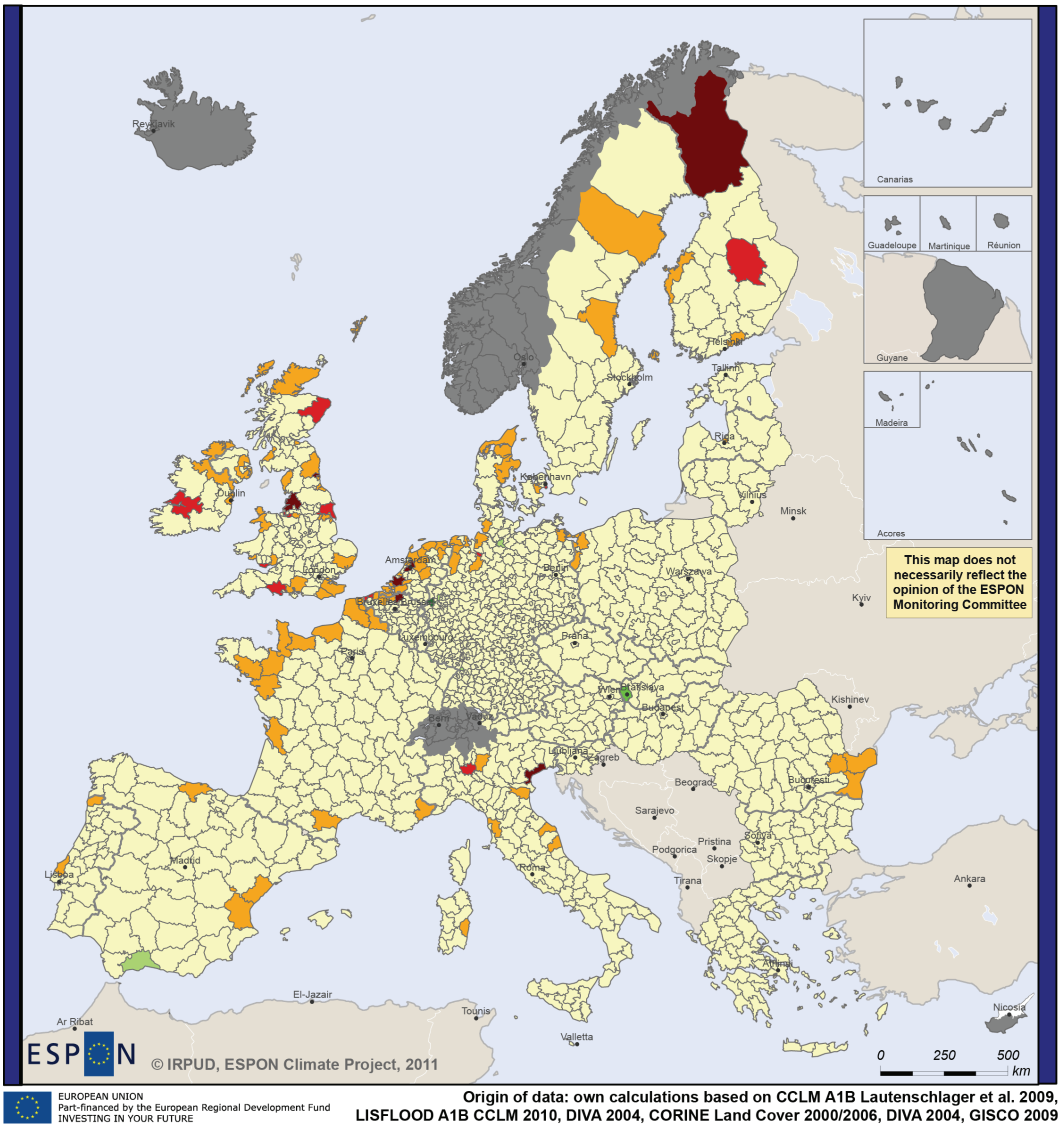
A very similar pattern of climate change impacts is evident in regard to railways and major roads. Apart from the highly impacted Italian regions on the Adriatic Sea, where coastal flooding and major river flooding from the river Po combine, most South-European regions' road and rail infrastructure is projected to be only marginally affected or would even be less subject to flooding events than in the past. Moderate and high negative impacts are mostly to be found in North-western Europe, with 'hot spots' primarily where several types of flooding converge. Transport infrastructure in Eastern and South-eastern Europe would be expected to be less affected by flooding than in the past.



Map 18: Potential impacts of climate change on railways and major roads

Potential impact of climate change on airports and harbours

As one would expect, European airports and harbours seem to be generally located in areas that are not likely to be flooded. Almost across Europe the impacts of climate change on these point infrastructures are only marginal. This makes the few affected airports and harbours stand out even more in the map below (i.e. Venice, Lapland and Dutch coastline).



Potential impact of climate change on airports and harbours

- highest negative impact (>0.5)
- medium negative impact (0.3 - <0.5)
- low negative impact (0.1 - <0.3)
- no/marginal impact (>-0.1 - <0.1)
- low positive impact (-0.1 - >-0.3)
- medium positive impact (-0.3 - -0.46)
- highest positive impact (-0.5 - -0.76)
- no data*

Combined potential impacts of changes in inundation depths of a 100 year river flood event and a sea level rise adjusted 100 year coastal storm surge event on airports and harbours.

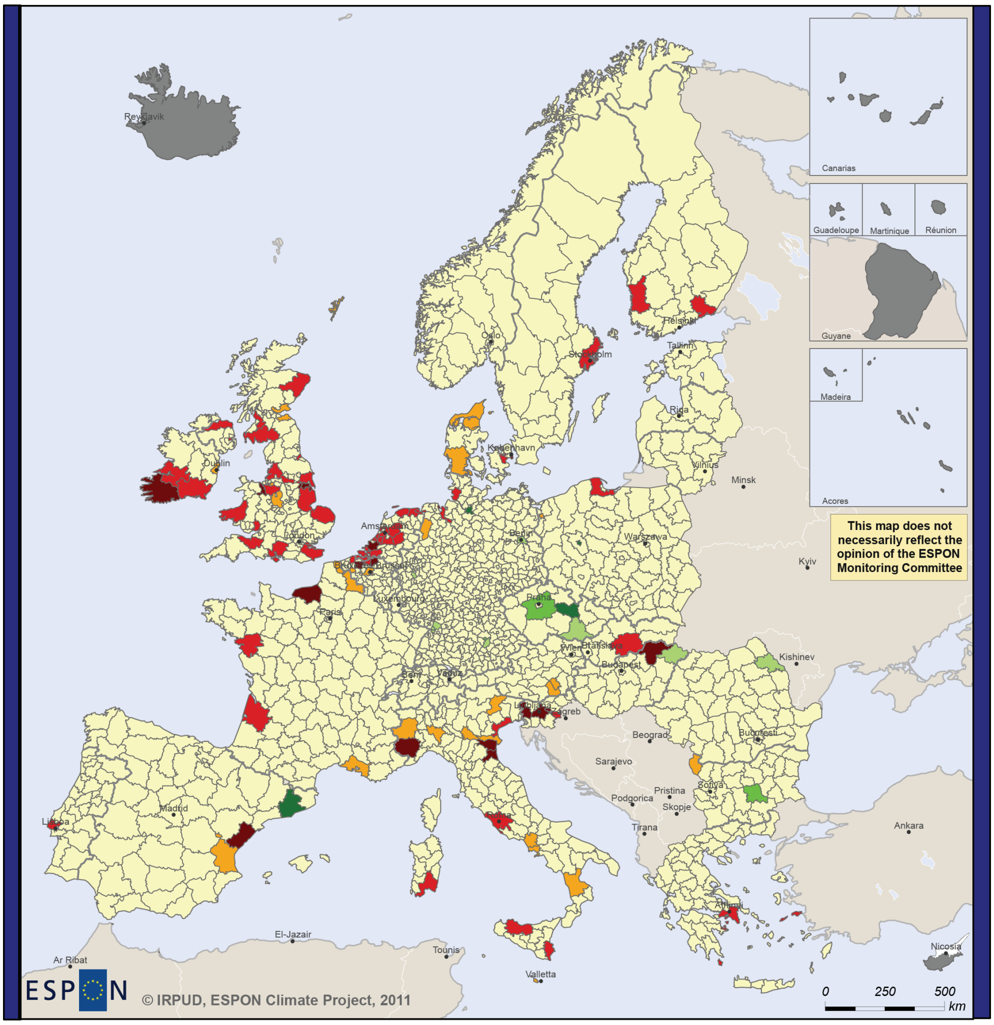
Impact calculated as combination of regional exposure to climatic changes and recent data on regional sensitivity. Fluvial inundation depth changes calculated by comparing 1961-1990 and 2071-2100 river flooding projections of the LISFLOOD model based on climate projections from the CCLM model for the IPCC SRES A1B scenario. Regional storm surge heights projected by DIVA model were adjusted with a 1m metre sea level rise.

*For details on reduced or no data availability see Annex 9.

Map 19: Potential impact of climate change on airports and harbours

Potential impact of climate change on thermal power stations and refineries

This map shows a pattern of impact which is determined by the projected increase in sea level rise adjusted storm surges and inundation caused by river flooding. In consequence, mainly power stations and refineries in North-western Europe on the coastline of the Atlantic Ocean and the North Sea may expect a medium to high negative impact. A similarly negative impact is projected for those facilities which are located along rivers (like Po and Tisza) for which the inundated heights for the 100-year flood are projected to increase. In contrast, a positive impact is projected for facilities located in Barcelona and parts of Poland and the Czech Republic where a decrease in inundations heights is projected.



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Origin of data: own calculations based on CCLM A1B Lautenschlager et al. 2009, LISFLOOD A1B CCLM 2010, DIVA 2004, CORINE Land Cover 2000/2006, E-PRTR 2010

Potential impact of climate change on thermal power stations and refineries

- high negative impact (>0.5)
- medium negative impact (0.3 - <0.5)
- low negative impact (0.1 - <0.3)
- no/marginal impact (>-0.1 - <0.1)
- low positive impact (-0.1 - >-0.3)
- medium positive impact (-0.3 - -0.46)
- highest positive impact (-0.5 - -0.95)
- no data*

Combined potential impacts of changes in inundation depths of a 100 year river flood event and a sea level rise adjusted 100 year coastal storm surge event on thermal power stations and refineries.

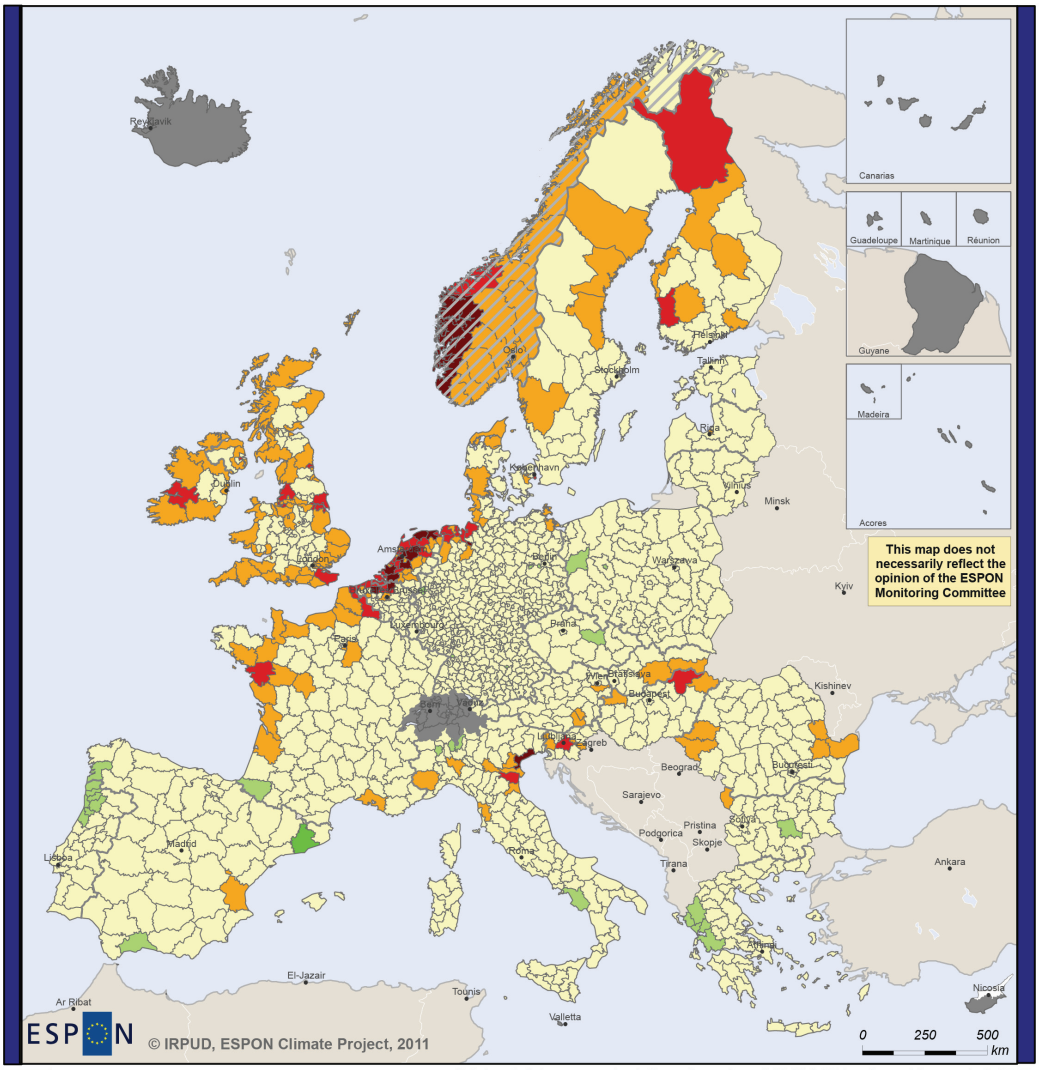
Impact calculated as combination of regional exposure to climatic changes and recent data on regional sensitivity. Fluvial inundation depth changes calculated by comparing 1961-1990 and 2071-2100 river flooding projections of the LISFLOOD model based on climate projections from the CCLM model for the IPCC SRES A1B scenario. Regional coastal storm surge heights projected by DIVA were adjusted with 1 metre sea level rise.

*For details on reduced or no data availability see Annex 9.

Map 20: Potential impact of climate change on thermal power stations and refineries

Combined physical impact of climate change

Given the almost homogenously low marginal impacts on airports and harbours it is not surprising to find the impact patterns seen for settlements and roads and rails prevail in the combined physical impact map. The overall hot spots are almost all located on or in close proximity to coasts, and especially at river mouths and are located in the North of Europe. In contrast, practically all regions projected to benefit from climate change in regard to settlements and infrastructures are inland regions that will benefit from decreasing river floods due to declining precipitation.



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Origin of data: own calculations based on CCLM A1B Lautenschlager et al. 2009, LISFLOOD A1B CCLM 2010, CORINE Land Cover 2000/2006, IRPUD Transport Networks 2009, GISCO 2009, E-PRTR 2010, USGS Hydro1k Europe, JRC EuroSoil database, DIVA 2004

Potential physical impact of climate change

- highest negative impact (0.5 - 1.0)
- medium negative impact (0.3 - <0.5)
- low negative impact (0.1 - <0.3)
- no/marginal impact (>-0.1 - <0.1)
- low positive impact (-0.1 - >-0.3)
- medium positive impact (-0.3 - -0.33)
- no data*
- reduced data*

Combined potential impacts of changes in inundation depths of a 100 year river flood event and a sea level rise adjusted 100 year coastal storm surge event and changes in flash flood potential on settlements, major roads, railways, airports, harbours, thermal power stations and refineries.

Impact calculated as combination of regional exposure to climatic changes and recent data on regional sensitivity. Climatic changes derived from comparison of 1961-1990 and 2071-2100 projections from CCLM model for IPCC A1B scenario. Fluvial inundation depth changes based on LISFLOOD projections. Regional coastal storm surge heights projected by DIVA adjusted with 1 m sea level rise.

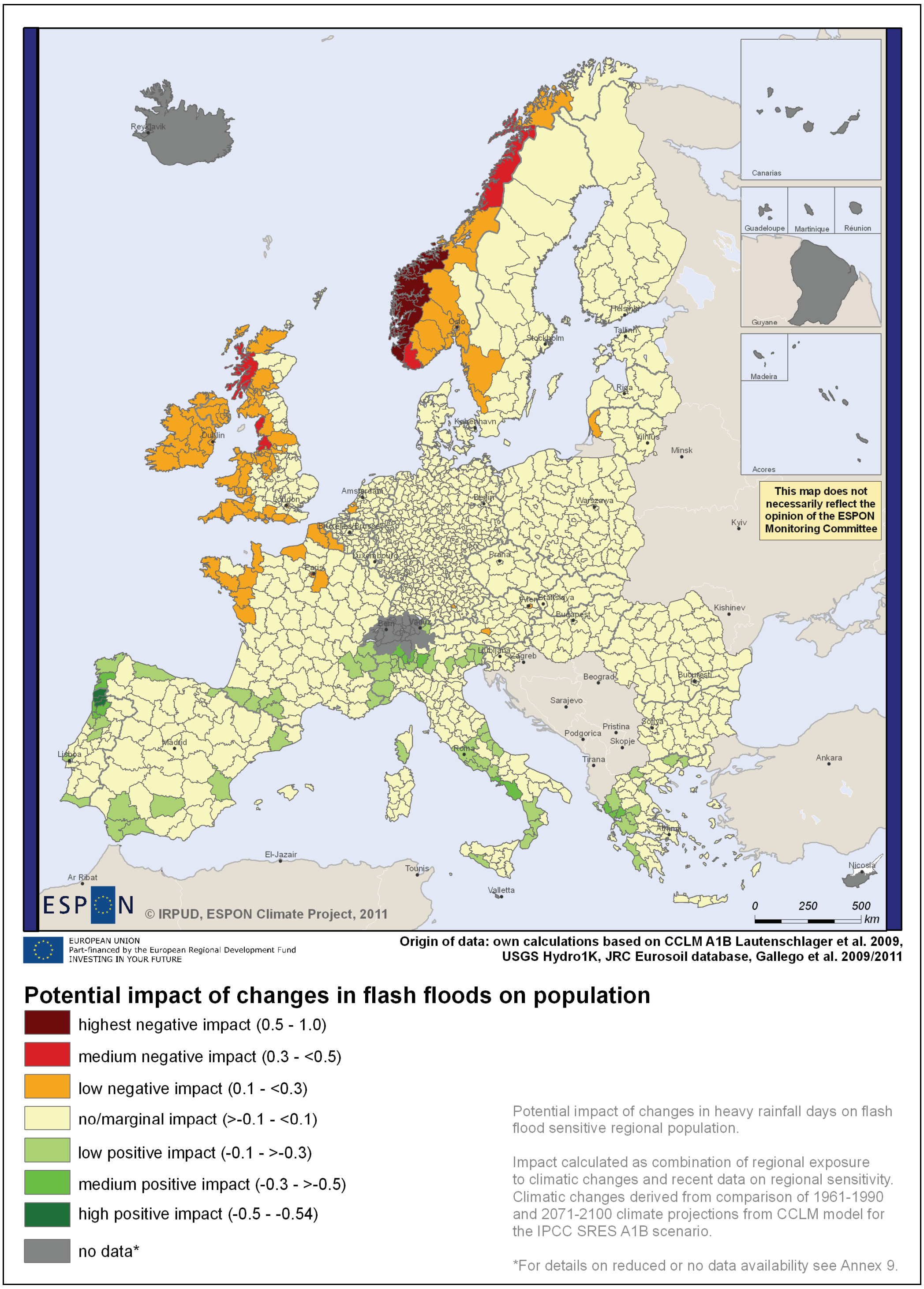
*For details on reduced or no data availability see Annex 9.

Map 21: Potential physical impact of climate change

3.3.2 Potential social impacts of climate change

Potential impact of flash floods on population

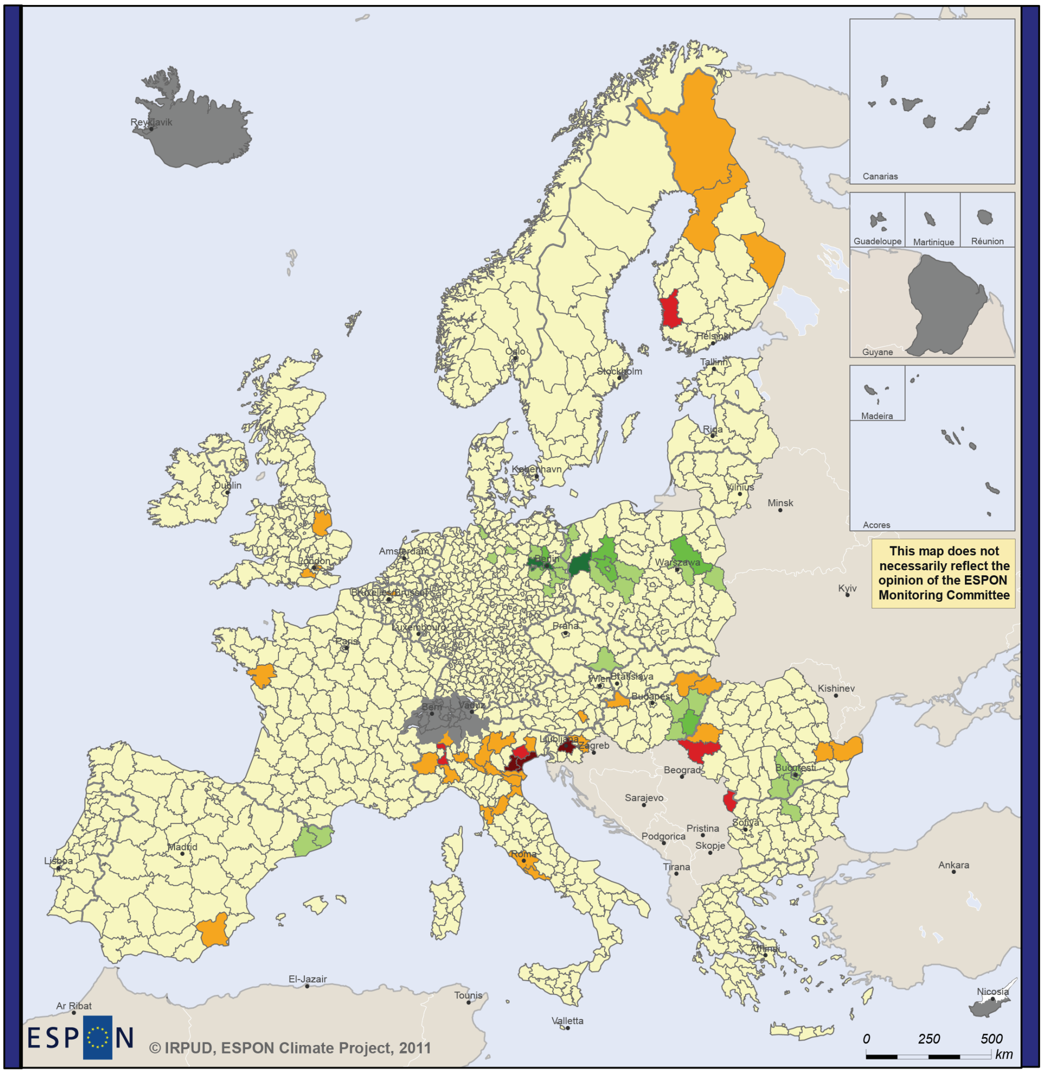
The impact patterns regarding flash flood and population reflect the generally decreasing number of days with heavy rainfall in Southern Europe and its major population concentrations. In northern Europe populations will be especially affected in Ireland and western UK and France. The highest negative impacts of flash floods are projected for Norway with its mountainous and especially flash-flood prone regions at the North Sea coastline.



Map 22: Potential impact of changes in flash floods on population

Potential impact of river floods on population

Increased river flooding, as already seen in regard to settlements, will severely affect regions in northern Italy, where climate changes in the Alps converge. Since these are also densely populated regions the negative impacts are projected to be very high. In contrast, some population centres in Spain and many populous regions in South-eastern and Eastern Europe are expected to benefit from less river flooding – with the city region of Berlin as a clear 'winner' of climate change in this regard.



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Origin of data: own calculations based on CCLM A1B Lautenschlager et al. 2009, Gallego et al. 2009/2011, LISFLOOD A1B CCLM 2010

Potential impact of changes in river flooding on population

- high negative impact (0.5 - 0.93)
- medium negative impact (0.3 - <0.5)
- low negative impact (0.1 - <0.3)
- no/marginal impact (>-0.1 - <0.1)
- low positive impact (-0.1 - >-0.3)
- medium positive impact (-0.3 - >-0.5)
- highest positive impact (-0.5 - -1.00)
- no data*

Potential impact of changes in inundated depths of a 100 year return river flood event on population.

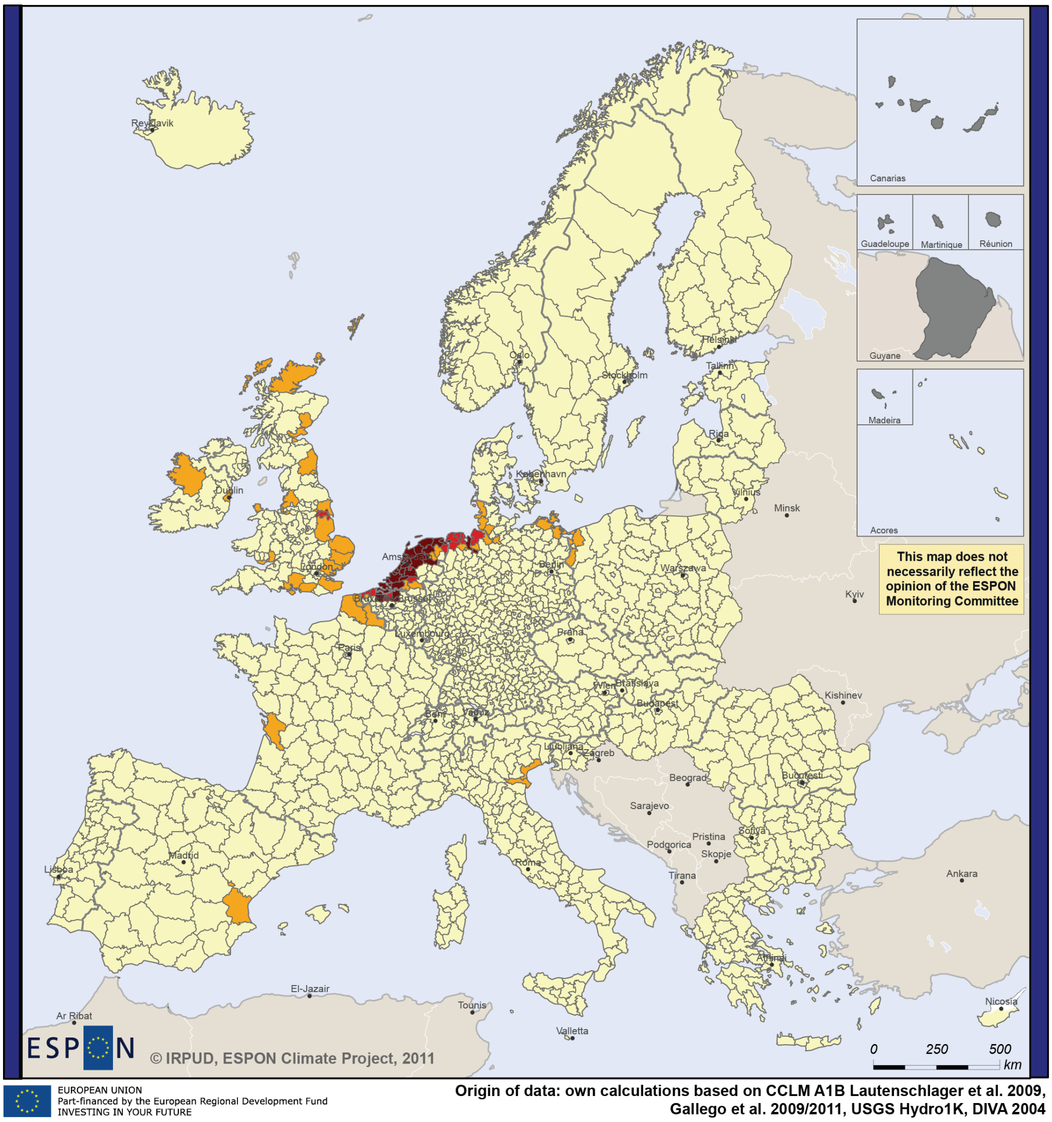
Impact calculated as combination of regional exposure to climatic changes and recent data on regional sensitivity. Inundation depth changes calculated by comparing 1961-1990 and 2071-2100 river flooding projections of the LISFLOOD model based on CCLM A1B climate projections.

* For details on reduced or no data availability see Annex 9.

Map 23: Potential impact of changes in river flooding on population

Potential impact of sea level rise on population

As discussed in the previous sections, sea level rise will affect European coastal regions primarily in the event of coastal storm surges. Overall, the coastal regions with only marginal impacts prevail. But along the Adriatic coast, the French Atlantic coast and especially the Belgium and Dutch coastal lowlands with their major population centres will be highly affected.



Origin of data: own calculations based on CCLM A1B Lautenschlager et al. 2009, Gallego et al. 2009/2011, USGS Hydro1K, DIVA 2004

Potential impact of sea level rise on population

- highest negative impact (0.5 - 1.0)
- medium negative impact (0.3 - <0.5)
- low negative impact (0.1 - <0.3)
- no/marginal impact (>-0.1 - <0.1)
- no data*

Potential impact of changes in inundation depths of a sea level rise adjusted 100 year coastal storm surge event on population.

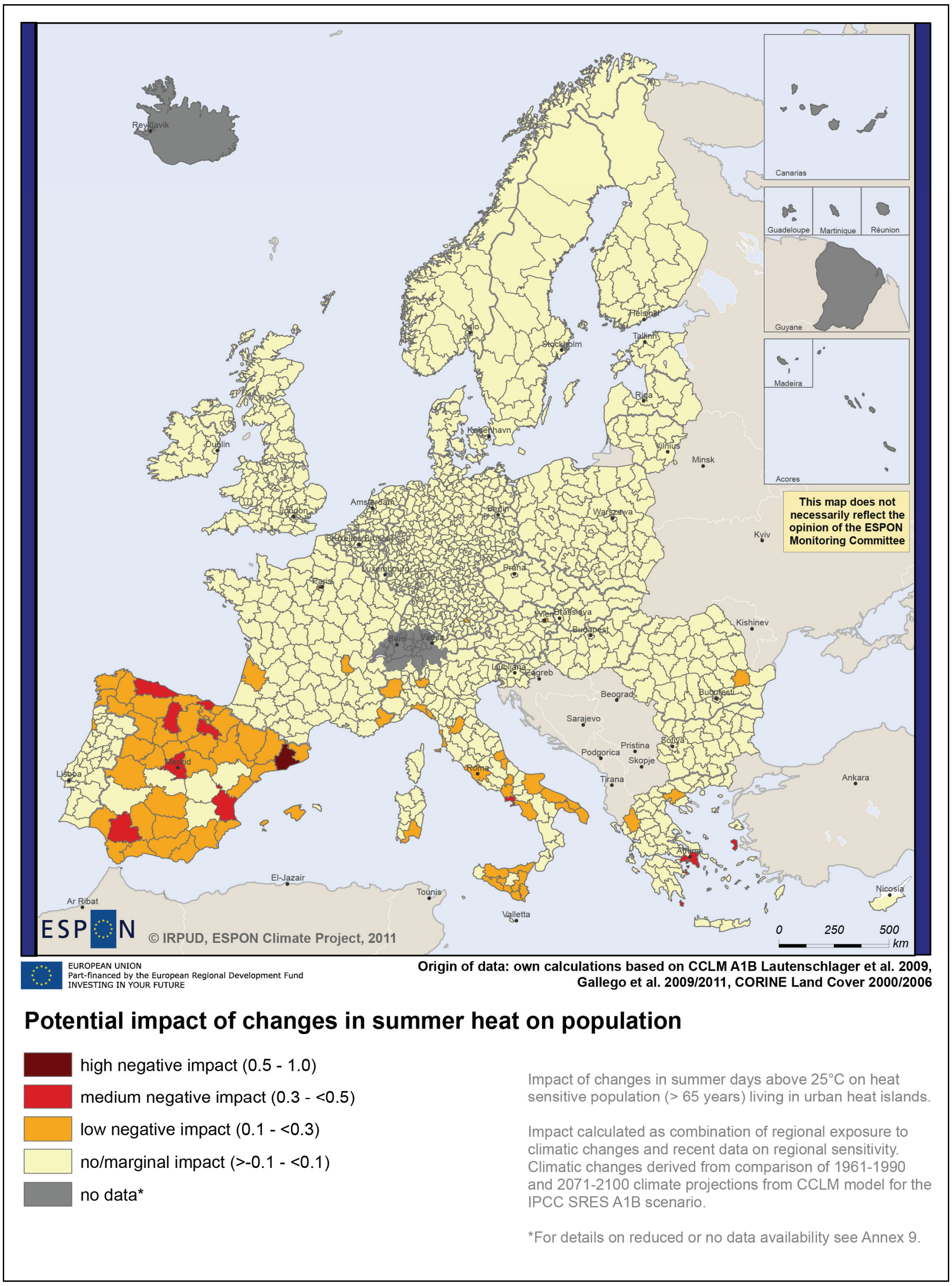
Impact calculated as combination of regional exposure to climatic changes and recent data on regional sensitivity. Climatic changes derived from comparison of 1961-1990 and 2071-2100 climate projections from CCLM model for the IPCC SRES A1B scenario. Regional coastal storm surge heights projected by the DIVA model and adjusted with 1 m sea level rise.

*For details on reduced or no data availability see Annex 9.

Map 24: Potential impact of sea level rise on population

Potential impact of changes in summer heat on population

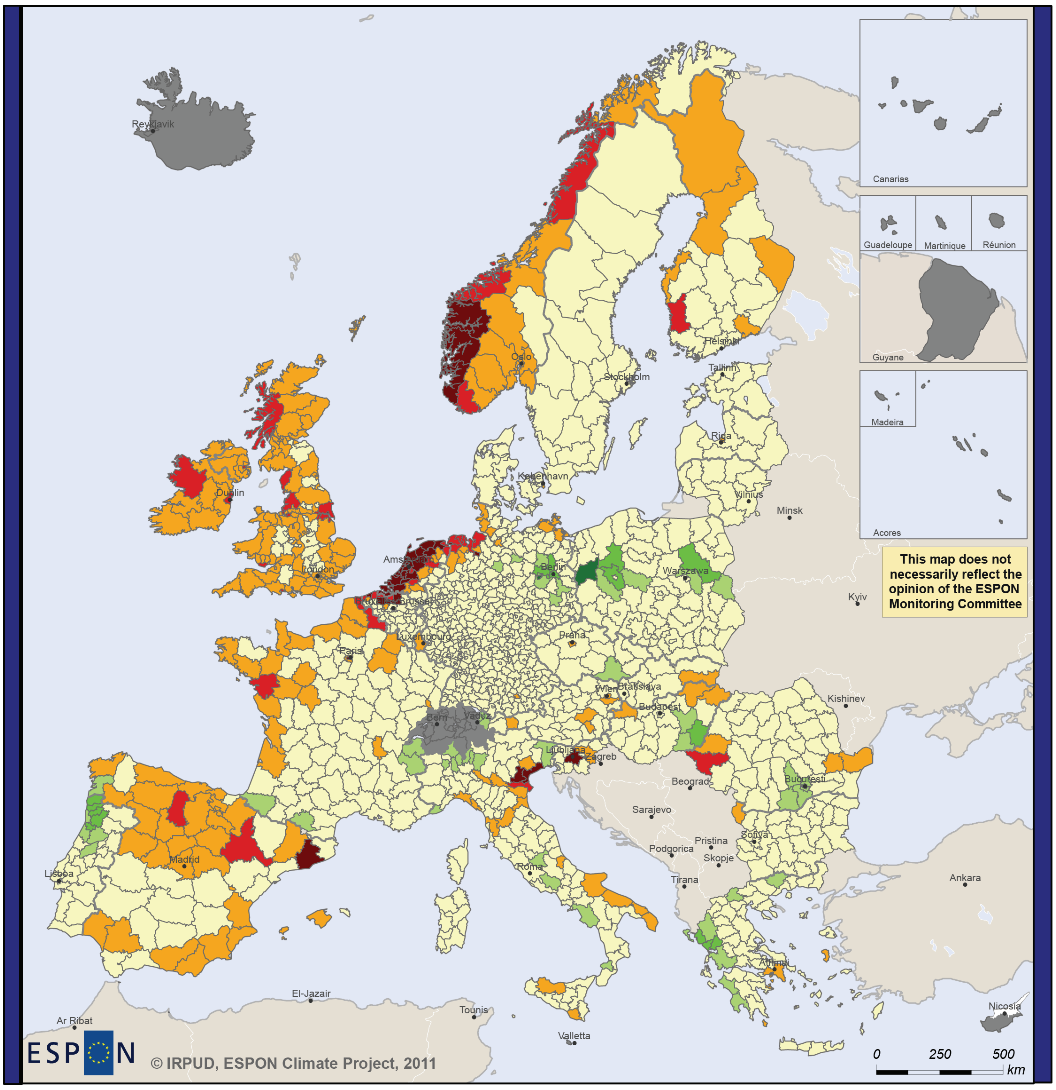
People older than 65 years living in urban heat islands are especially sensitive to increases in hot summer days. According to ESPON Climate's projections these impacts are concentrated in southern Europe, where local climate is generally getting hotter by 2071-2100. In addition, most Mediterranean cities are much more compact than their northern counterparts, thus accounting for more urban heat islands. The most severely impacted country, according to the map below, is Spain – both as a whole and all their urban centres in particular.



Map 25: Potential impacts of changes in summer heat on population

Combined social impact of climate change

In combination the various climate change impacts on population yield an already familiar picture. Coastal regions in North-western Europe in general and coastal cities in particular are projected to be highly impacted. Inhabitants in most inland regions, except in Spain, would only be marginally affected, some even enjoying positive impacts due to generally drier climates resulting in decreasing river flood risks.



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Origin of data: own calculations based on CCLM A1B Lautenschlager et al. 2009, Gallego et al. 2009/2011, DIVA 2004, USGS Hydro1K, JRC Eurosoil database, LISFLOOD A1B CCLM 2010, CORINE Land Cover 2000/2006.

Potential social impact of climate change

- highest negative impact (0.5 - 1.0)
- medium negative impact (0.3 - <0.5)
- low negative impact (0.1 - <0.3)
- no/marginal impact (>-0.1 - <0.1)
- low positive impact (-0.1 - >-0.3)
- medium positive impact (-0.3 - >-0.5)
- high positive impact (-0.5 - -0.86)
- no data*

Combined potential impacts of changes in inundation depths of a 100 year river flood event and a sea level rise adjusted 100 year coastal storm surge event as well as changes in flash flood potential and summer heat on population.

Impact calculated as combination of regional exposure to climatic changes and recent data on regional sensitivity. Climatic changes derived from comparison of 1961-1990 and 2071-2100 climate projections from CCLM model for the IPCC SRES A1B scenario. Fluvial inundation depth changes based on LISFLOOD projections. Regional coastal storm surge heights projected by DIVA model were adjusted with 1 m sea level rise.

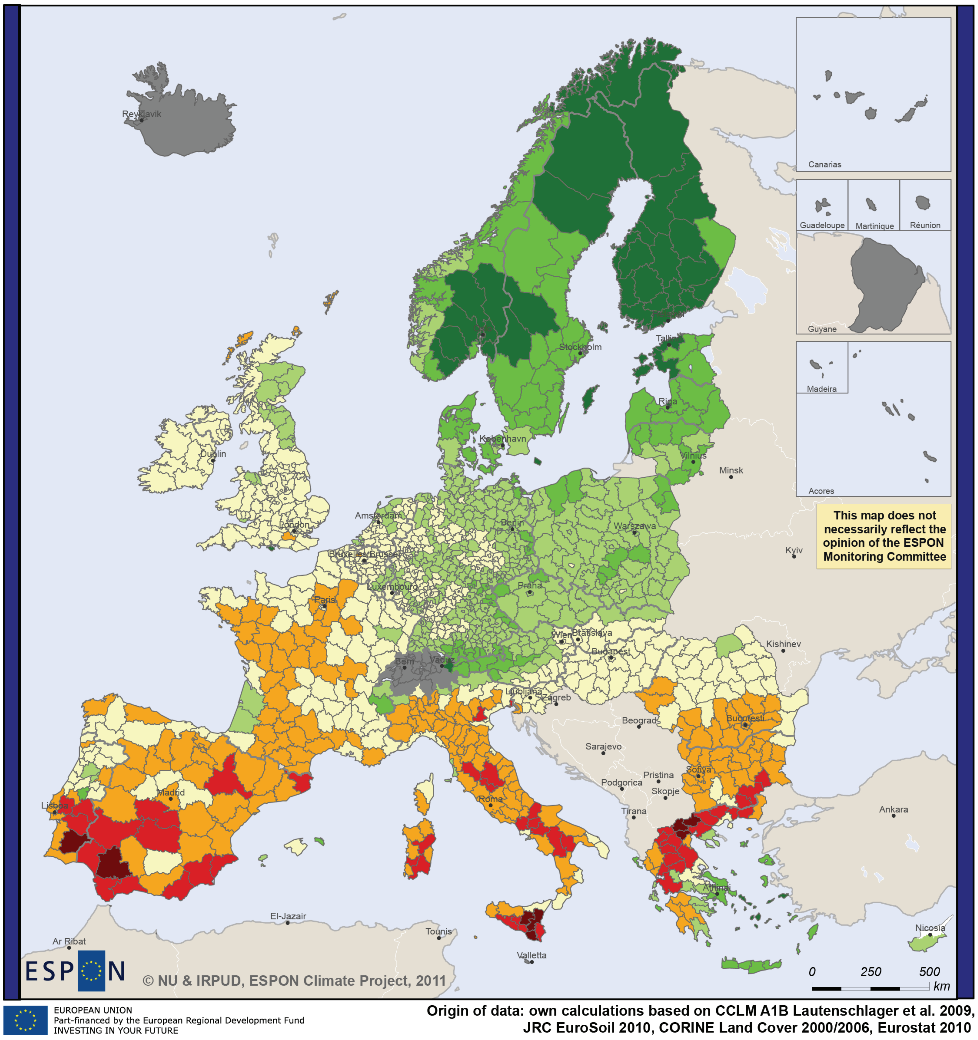
*For details on reduced or no data availability see Annex 9.

Map 26: Potential social impact of climate change

3.3.3 Potential economic impacts of climate change

Potential impact of climate change on agriculture and forestry

Agriculture and forestry are of course very climate dependent economic sectors. Temperature and moisture conditions are of utmost importance. Not surprisingly then, agriculture and forestry in many Southern European regions are projected to suffer from hotter and especially drier climate in the future. South-eastern Europe seems to be especially hard hit, not least because of the great importance these sectors have for their local economies. Much of Eastern and Northern Europe, however, will benefit from warmer and wetter climate there, with agricultural gains playing a major role in Poland and gains especially for forestry in many Scandinavian regions.



Potential impact of climate change on agriculture and forestry

- high negative impact (0.5 - 0.69)
- medium negative impact (0.3 - <0.5)
- low negative impact (0.1 - <0.3)
- no/marginal impact (>-0.1 - <0.1)
- low positive impact (-0.1 - >-0.3)
- medium positive impact (-0.3 - >-0.5)
- highest positive impact (-0.5 - -1.0)
- no data*

Combined potential impacts of changes in annual mean evaporation on agriculture and forestry.

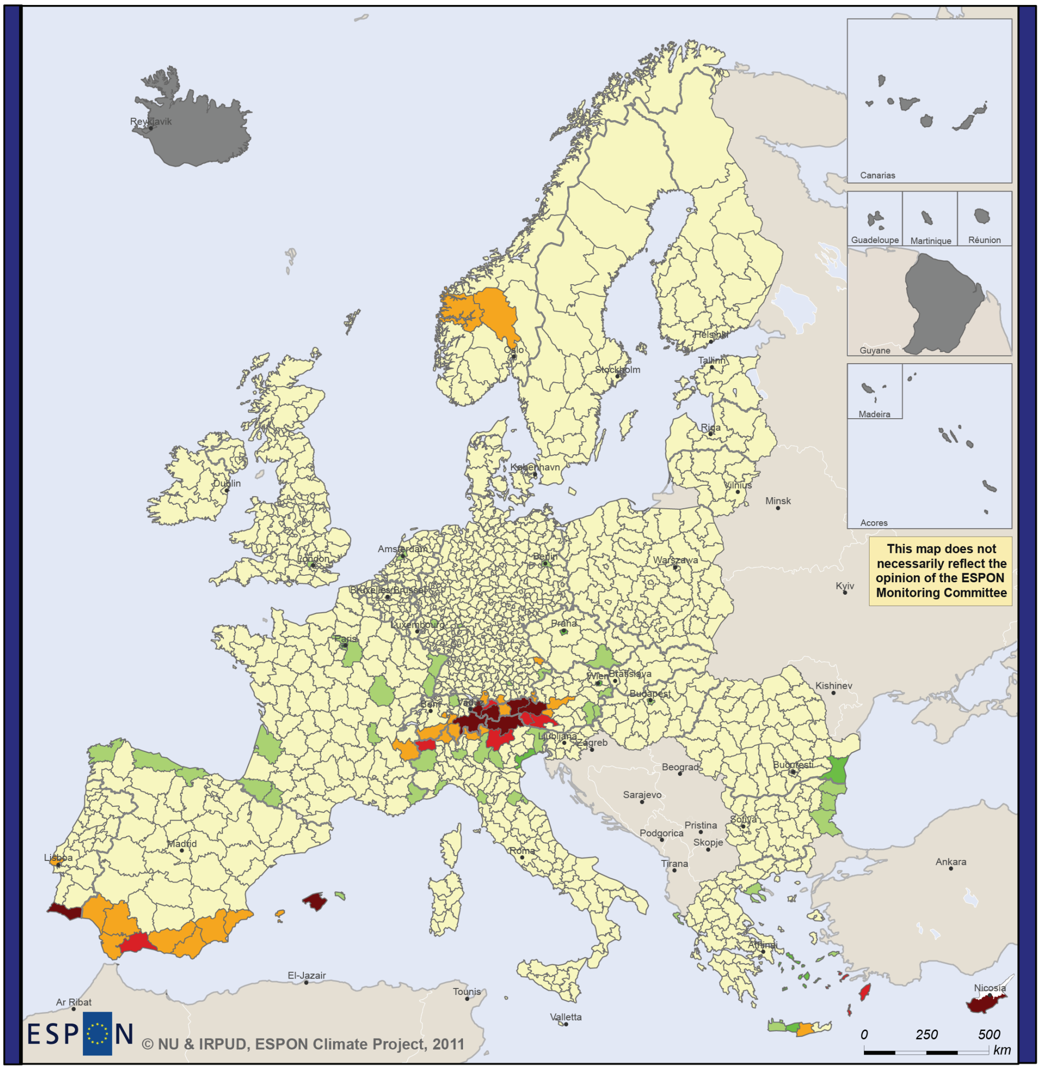
Impact calculated as combination of regional exposure to climatic changes and recent data on regional sensitivity. Climatic changes derived from comparison of 1961-1990 and 2071-2100 climate projections from CCLM model for the IPCC SRES A1B scenario.

*For details on reduced or no data availability see Annex 9. Values for economic indicators at NUTS 3 level include fisheries.

Map 27: Potential impact of climate change on agriculture and forestry

Potential impact of climate change on tourism

For another very climate dependent economic sector, tourism, the projections show highly concentrated negative impacts. They are to be found on Cyprus, Mallorca, in Southern Spain and Portugal and in the Alps. For the Southern European regions increasing temperatures in the summer months are projected to decrease the Tourism Comfort Index. Alpine regions are especially impacted because of declining snow cover days with adverse effects on winter tourism. Otherwise, most European regions' tourism sectors are expected to benefit slightly from warmer climate.



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Origin of data: own calculations based on CCLM A1B Lautenschlager et al. 2009, TCI 2010, USGS Hydro1K, Eurostat 2010

Potential impact of climate change on tourism

- highest negative impact (0.5 - 1.0)
- medium negative impact (0.3 - <0.5)
- low negative impact (0.1 - <0.3)
- no/marginal impact (>-0.1 - <0.1)
- low positive impact (-0.1 - >-0.3)
- medium positive impact (-0.3 - >-0.5)
- high positive impact (-0.5 - -0.98)
- no data*

Combined potential impacts of changes in summer days and snow cover days on summer and winter tourism.

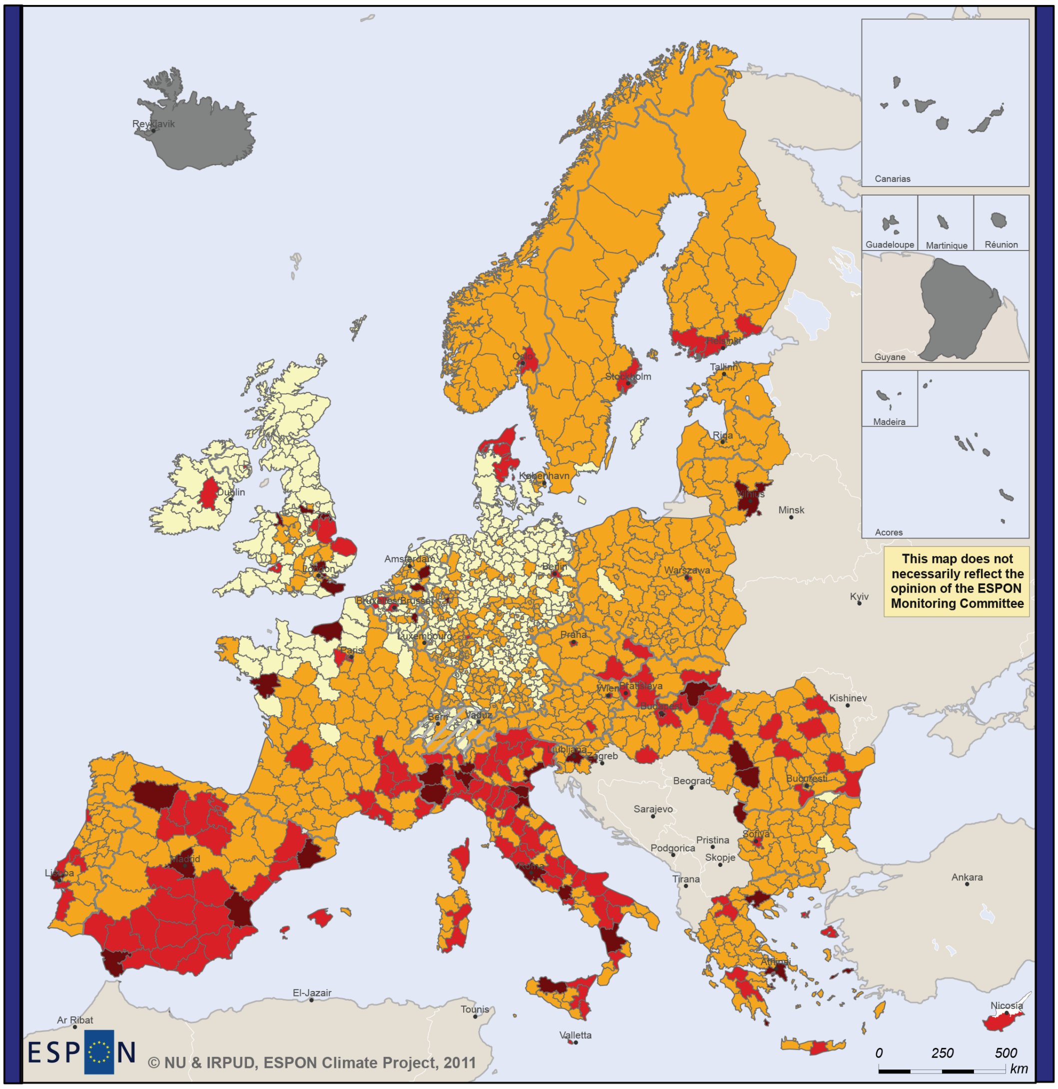
Impact calculated as combination of regional exposure to climatic changes and recent data on regional sensitivity. Climatic changes derived from comparison of 1961-1990 and 2071-2100 climate projections from the CCLM model for the IPCC SRES A1B scenario.

*For details on reduced or no data availability see Annex 9.

Map 28: Potential impact of climate change on tourism

Potential impact of climate change on the energy sector

Europe's energy sector is projected to be heavily affected by climate change. While heating demand will generally decline, the warmer temperatures across Europe and especially in the South will drive up energy demands for cooling. Therefore urban agglomerations in Mediterranean and South-Eastern European countries are expected to be impacted the most. In central and northern Europe declining water levels in major rivers could also impact on power stations, which require water for cooling their combustion facilities.



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Origin of data: own calculations based on CCLM A1B Lautenschlager et al. 2009, DIVA 2004, LISFLOOD A1B CCLM 2010, E-PRTR 2010, CORINE Land Cover 2000/2006, Gallego et al. 2009/2011, Eurostat 2010

Potential impact of climate change on the energy sector

- highest increase (0.5 - 1.0)
- medium increase (0.3 - <0.5)
- low increase (0.1 - <0.3)
- no/marginal impact (0.01 - <0.1)
- no data*
- reduced data*

Combined potential impacts of changes in summer precipitation, summer days, frost days, changes in inundation depths of a 100 year river flood event and a sea level rise adjusted 100 year coastal storm surge event on energy supply and demand.

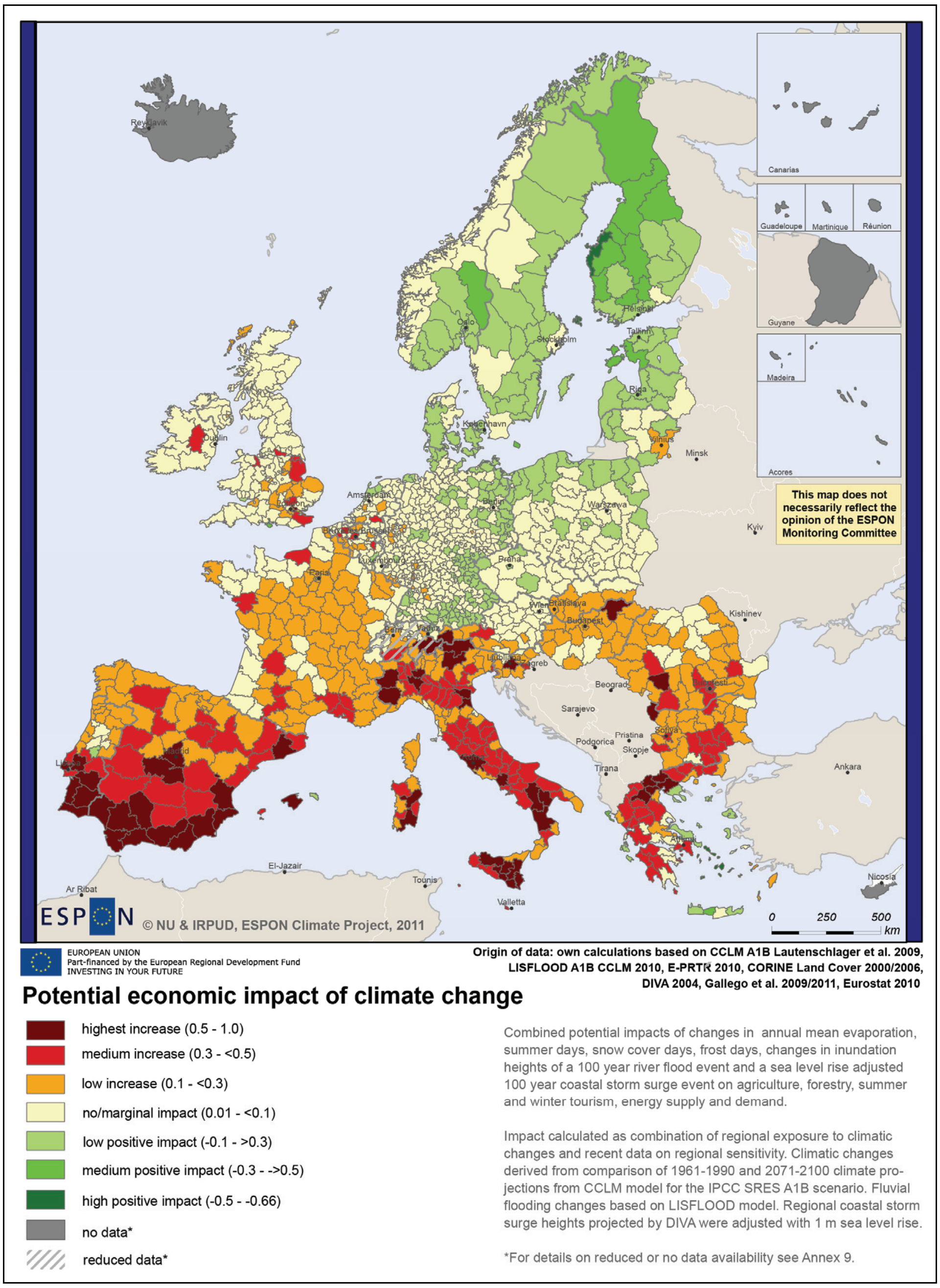
Impact calculated as combination of regional exposure to climatic changes and recent data on regional sensitivity. Climatic changes derived from comparison of 1961-1990 and 2071-2100 projections from CCLM model for IPCC SRES A1B scenario. Fluvial inundation depth changes based on LISFLOOD model. Regional coastal storm surge heights projected by DIVA adjusted with 1 m sea level rise.

*For details on reduced or no data availability see Annex 9.

Map 29: Potential impact of climate change on the energy sector

Combined economic impact of climate change

Overall the economic impacts of climate change show a clear south-north gradient: many economically important countries like large parts of the U.K. may expect only a low to marginal negative impact on their economy or even a positive impact which particularly the case for wide parts of Germany Poland almost the whole Scandinavia. However, large parts of Southern Europe are dependent on (summer) tourism, but also agriculture. Both are projected to be negatively impacted due to the increase in temperature and decrease in precipitation while the environmental conditions for agriculture in North-Eastern Europe tend to be improved. Moreover, energy demands come into play through the increased need for cooling. The Alps as a premier tourist depended region are also identified as hotspot which mainly results from the projected decrease in snow cover. The economic impact in South Eastern Europe is a consequence of the impact on agriculture – which is still important there.

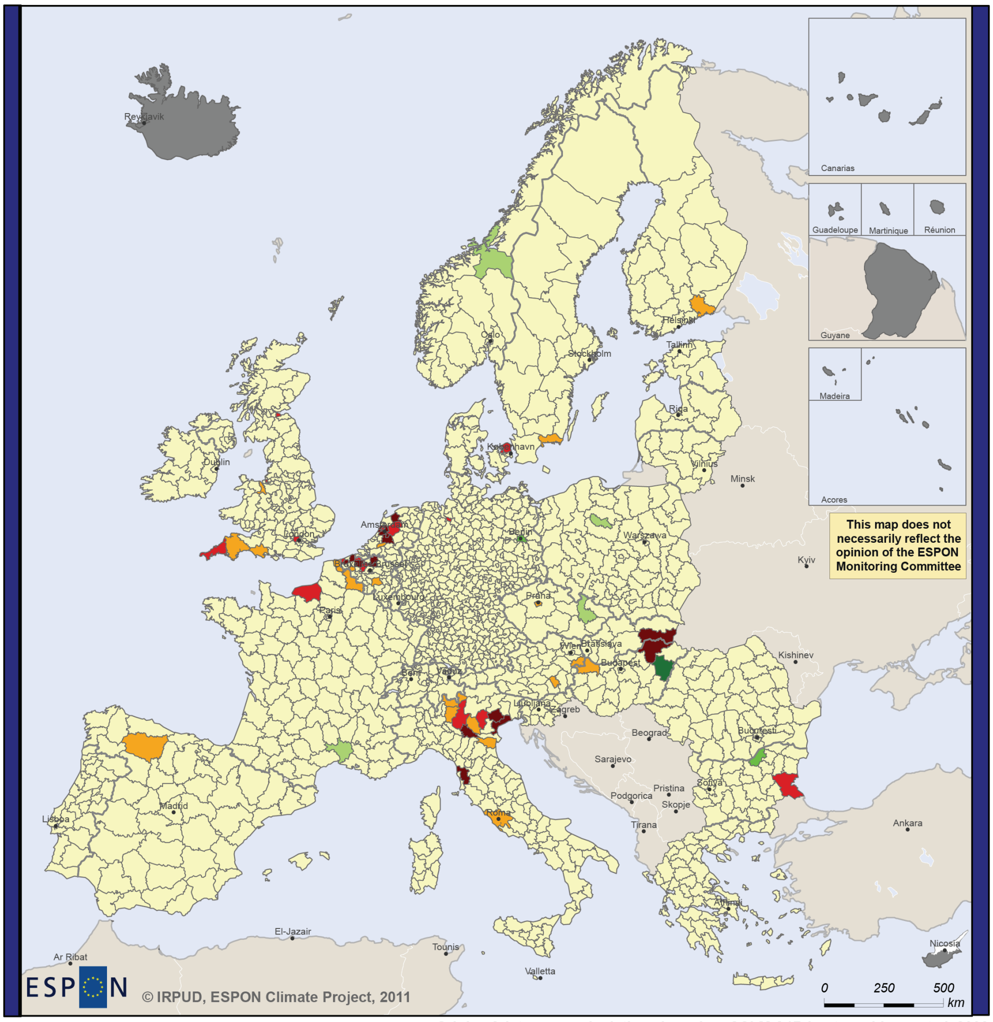


Map 30: Potential economic impact of climate change

3.3.4 Potential cultural impacts of climate change

Potential impact of climate change on Cultural World Heritage sites

Historic sites registered by the World Heritage Commission are not found in every European region. Hence it is not surprising to only find scattered impacts across Europe. However, the 'hot spots' in some way coincide with the patterns found in regard to settlements and population, because most major urban centres have long historical roots and thus possess historic sites of high value. This applies especially to many Italian regions, but also parts of the Netherlands and border regions between Slovakia and Hungary that are also subject to major increases in river and coastal flooding.



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Origin of data: own calculations based on CCLM A1B Lautenschlager et al. 2009, DIVA 2004, LISFLOOD A1B CCLM 2010, USGS Hydro1K, World Heritage Commission 2010

Potential impact of climate change on World Heritage sites

- highest negative impact (0.5 - 1.0)
- medium negative impact (0.3 - <0.5)
- low negative impact (0.1 - <0.3)
- no/marginal impact (>-0.1 - <0.1)
- low positive impact (-0.1 - >-0.3)
- medium positive impact (-0.3 - >-0.5)
- high positive impact (-0.5 - -0.87)
- no data*

Combined potential impacts of changes in inundation depths of a 100 year river flood event and a sea level rise adjusted 100 year coastal storm surge event on registered World Heritage sites.

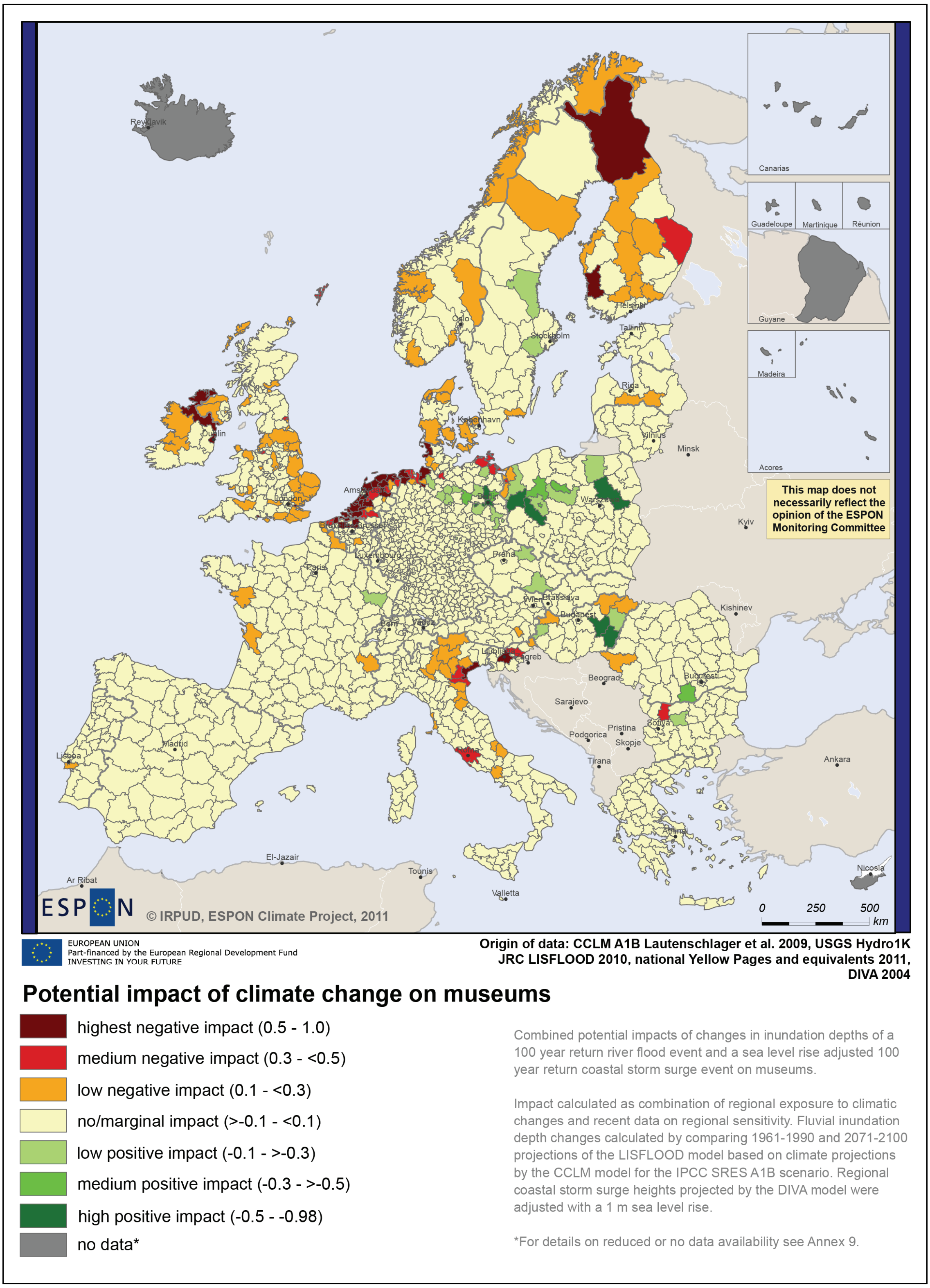
Impact calculated as combination of regional exposure to climatic changes and recent data on regional sensitivity. Fluvial inundation depth changes calculated by comparing 1961-1990 and 2071-2100 projections of the LISFLOOD model based on climate projections from the CCLM model for the IPCC SRES A1B scenario. Regional coastal storm surge heights projected by DIVA model were adjusted with 1m metre sea level rise.

*For details on reduced or no data availability see Annex 9.

Map 31: Potential impact of climate change on World Heritage Sites

Potential impact of climate change on museums

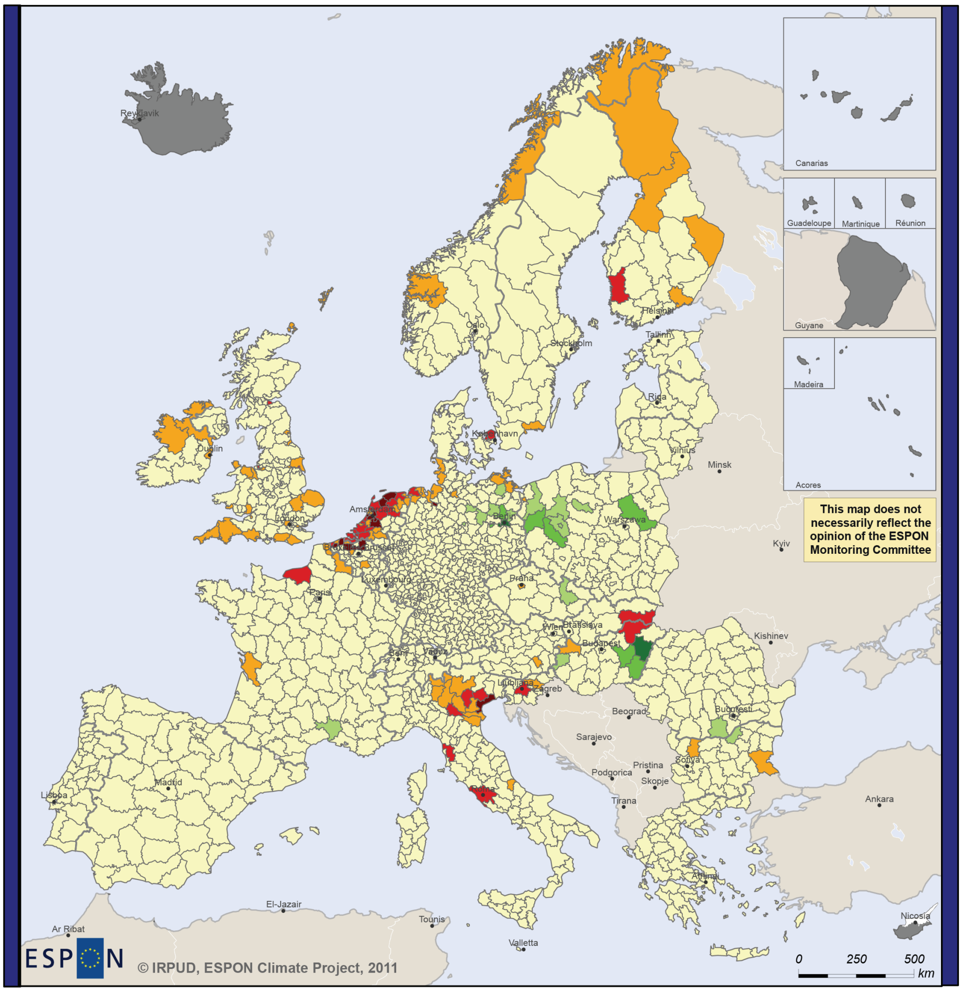
In comparison museums are found across Europe, resulting in more differentiated impact patterns. Again the Italian high impact regions stand out, but – due to river flooding – also some Slovenian, Finnish, Irish and German regions are highly affected. In contrast some regions in Central and Northern Europe have high impacts mainly due to changes in coastal flooding, while many Eastern European regions benefit from decreasing river flooding levels.



Map 32: Potential impact of climate change on museums

Combined cultural impact of climate change

The potential impact of climate change on cultural assets is obviously an issue for a minority of European regions such as the Dutch coastline and the Po valley, while most regions may expect no or just a marginal impact. This result mainly comes from the change of frequency and magnitude of extreme events, to which cultural heritage sites and museums are sensitive. Creeping changes in temperature and precipitation play hardly a considerable role for cultural heritage. Thus, the hotspots in Italy are a consequence of the projected increase of flood hazard on the one hand and the density of cultural heritage sites in this country. Other remarkably impacted regions in the north of Europe are those which encompass some cultural sites and museums, and are most affected by an extreme increase in flooding.



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Origin of data: own calculations based on CCLM A1B Lautenschlager et al. 2009, DIVA 2004, LISFLOOD A1B CCLM 2010, USGS Hydro1K, World Heritage Commission 2010, national Yellow Pages and equivalents 2011

Potential cultural impact of climate change

- highest negative impact (0.5 - 1.0)
- medium negative impact (0.3 - <0.5)
- low negative impact (0.1 - <0.3)
- no/marginal impact (>-0.1 - <0.1)
- low positive impact (-0.1 - >-0.3)
- medium positive impact (-0.3 - >-0.5)
- high positive impact (-0.5 - -0.62)
- no data*

Combined potential impacts of changes in inundation depths of a 100 year river flood event and a sea level rise adjusted 100 year coastal storm surge event on registered World Heritage sites and museums.

Impact calculated as combination of regional exposure to climatic changes and recent data on regional sensitivity. Fluvial inundation depth changes calculated by comparing 1961-1990 and 2071-2100 projections of the LISFLOOD model based on climate projections from the CCLM model for the IPCC SRES A1B scenario. Regional coastal storm surge heights projected by DIVA model were adjusted with 1 m metre sea level rise.

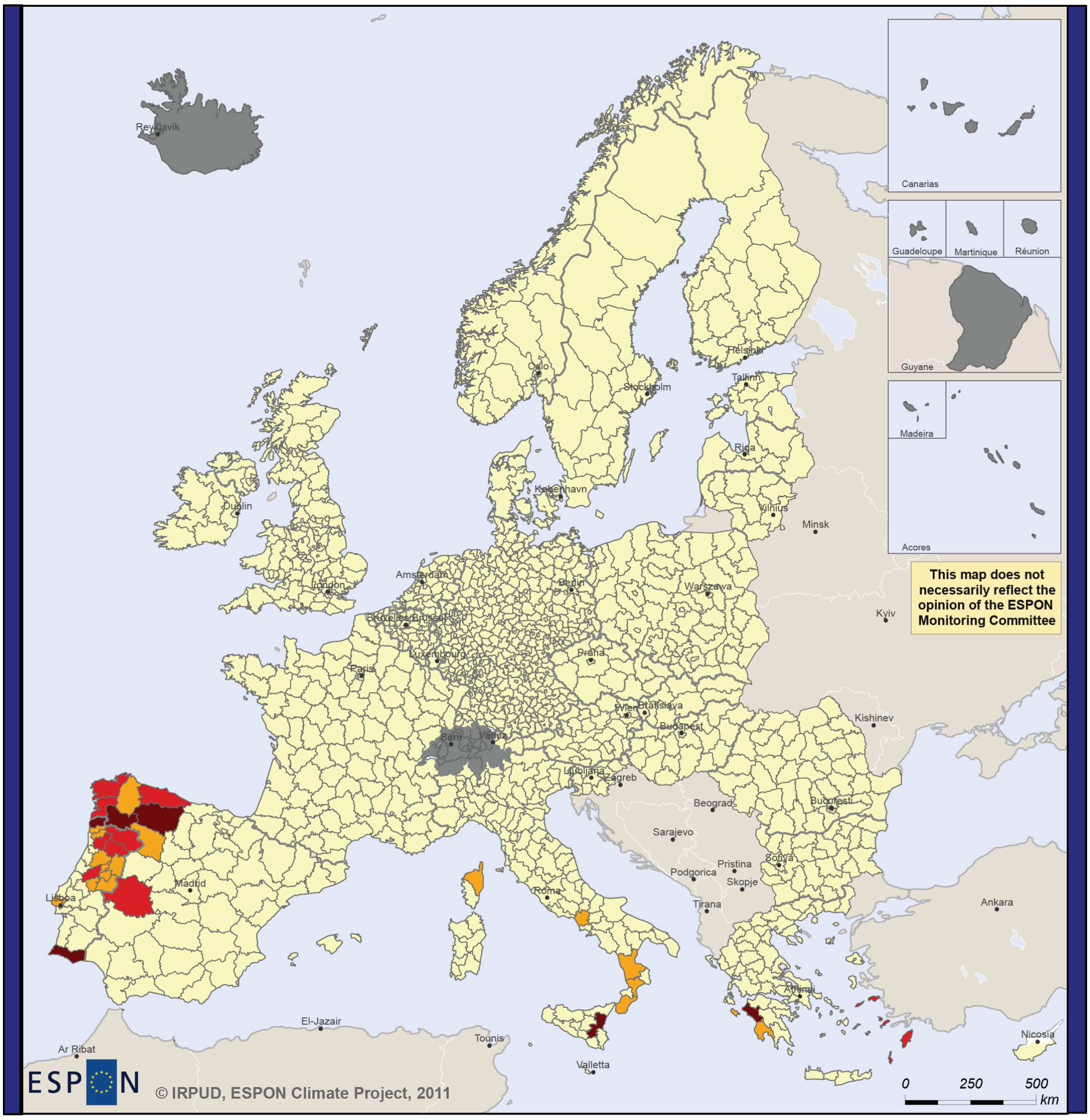
*For details on reduced or no data availability see Annex 9.

Map 33: Potential cultural impact of climate change

3.3.5 Potential environmental impacts of climate change

Potential impact of climate change on forest fires

Forest fires, while highly 'visible' in the media every summer, are only increasingly problematic in the future in South-European countries. Here already dry conditions are exacerbated by increasing summer temperatures and declining precipitation – again especially in the summer. North-western Spain, Portugal and some regions in southern Italy and Greece are projected to be most severely impacted by forest fires in 2071-2100.



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Origin of data: own calculations based on CCLM A1B Lautenschlager et al. 2009, JRC EuroSoil, World Fire Atlas 2010, CORINE Land Cover 2000/2006

Potential impact of climate change on forest fires

- highest negative impact (0.5 - 1.0)
- medium negative impact (0.3 - <0.5)
- low negative impact (0.1 - <0.3)
- no/marginal impact (-0.01 - <0.1)
- no data*

Potential impact of changes in summer days and summer precipitation on forests prone to fire.

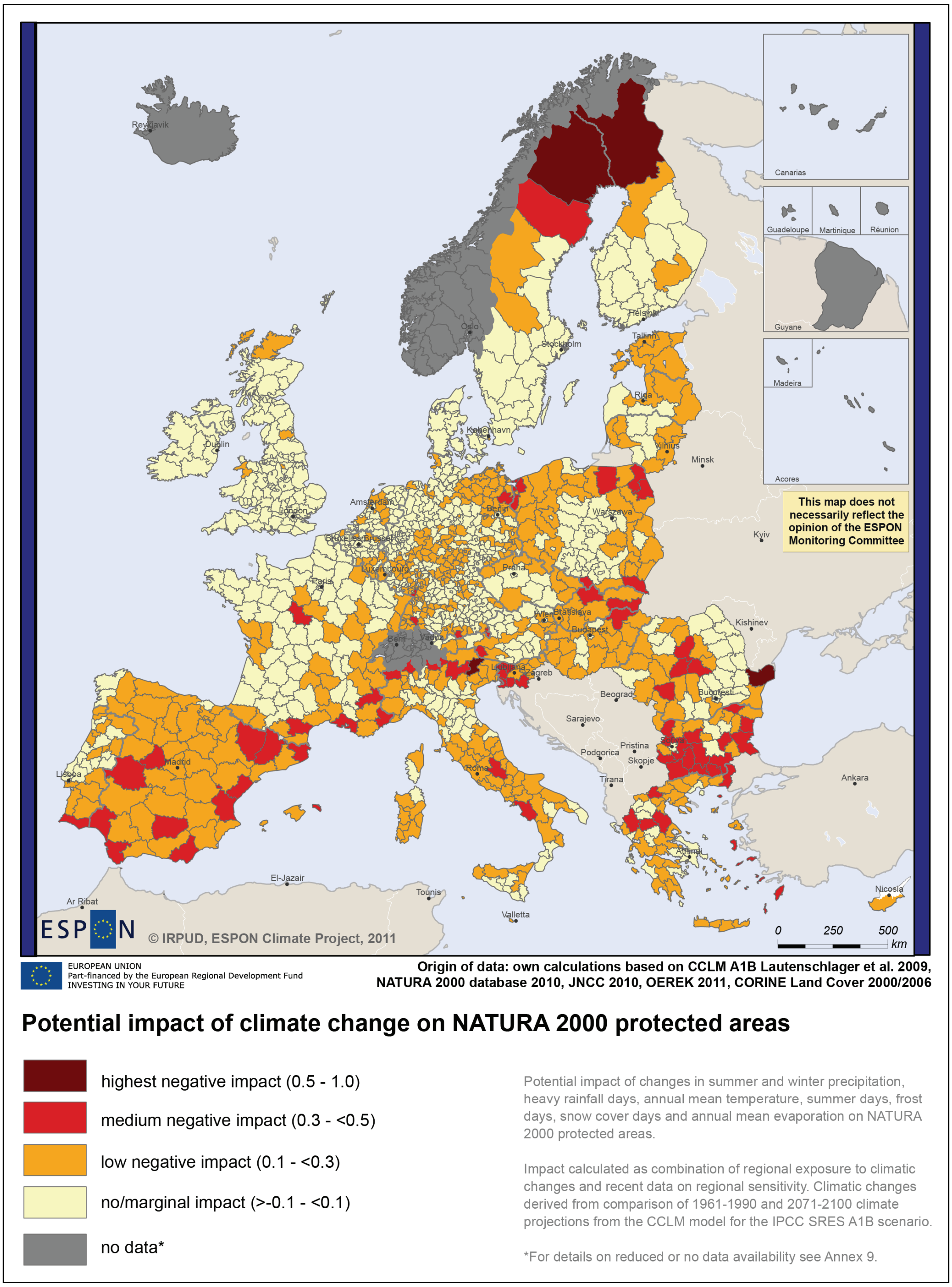
Impact calculated as combination of regional exposure to climatic changes and recent data on regional sensitivity. Climatic changes derived from comparison of 1961-1990 and 2071-2100 climate projections from the CCLM model for the IPCC SRES A1B scenario.

*For details on reduced or no data availability see Annex 9.

Map 34: Potential impact of climate change on forest fires

Potential impact of climate change on NATURA 2000 protected areas

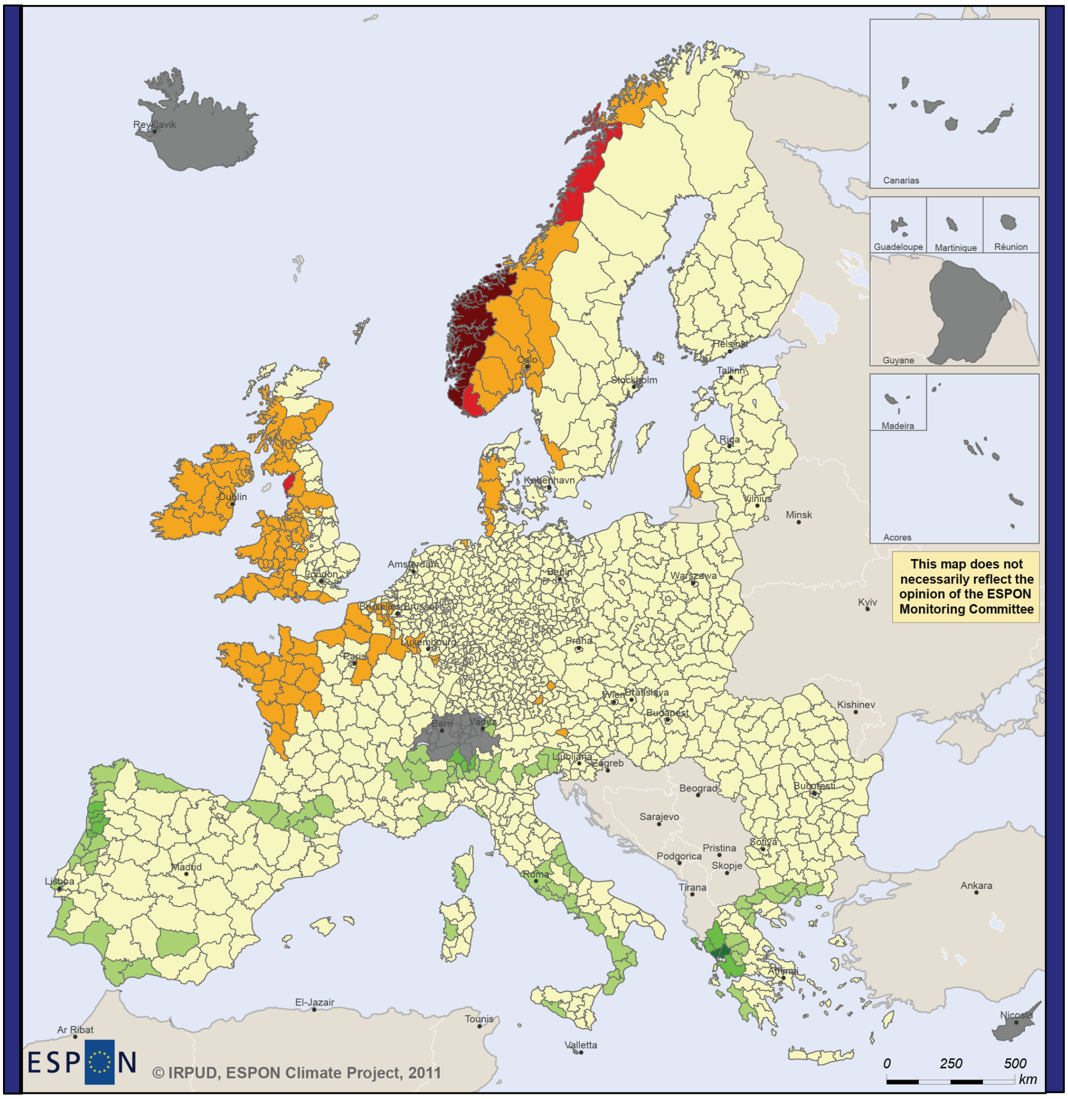
Natural areas of high environmental value that are protected under the EU NATURA 2000 directive can be found all across Europe. The highest impacts of climate change on these habitats are generally located in regions with the highest exposure changes. In the South of Europe this relates particularly to higher temperatures and less rain, in the North to less frost and snow cover days, which equally changes living conditions for species drastically. The high impacts in Sweden and Finland (Lapland) are in part also due to their very large protection areas.



Map 35: Potential impact of climate change on NATURA 2000 protected areas

Potential impact of climate change on soil erosion

Soil erosion is of course highly influenced by heavy rainfall. Since precipitation levels are projected to be generally declining in the South of Europe, the soil erosion potential will decline there as well. Regions expected to be adversely affected are located in western France, UK and Ireland and, most of all, in Norway. Here strong increases in precipitation, highly erodible soils and steep mountains converge to result in the highest soil erosion impacts in Europe.



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Origin of data: own calculations based on CCLM A1B Lautenschlager et al. 2009, JRC EuroSoil, CORINE Land Cover 2000/2006

Potential impact of changes in heavy rainfall on soil erosion

- highest negative impact (0.5 - 1.0)
- medium negative impact (0.3 - <0.5)
- low negative impact (0.1 - <0.3)
- no/marginal impact (>-0.1 - <0.1)
- low positive impact (-0.1 - >-0.3)
- medium positive impact (-0.3 - >-0.5)
- highest positive impact (-0.5 - -0.54)
- no data*

Potential impact of changes in heavy rainfall days on soil erosion sensitive areas.

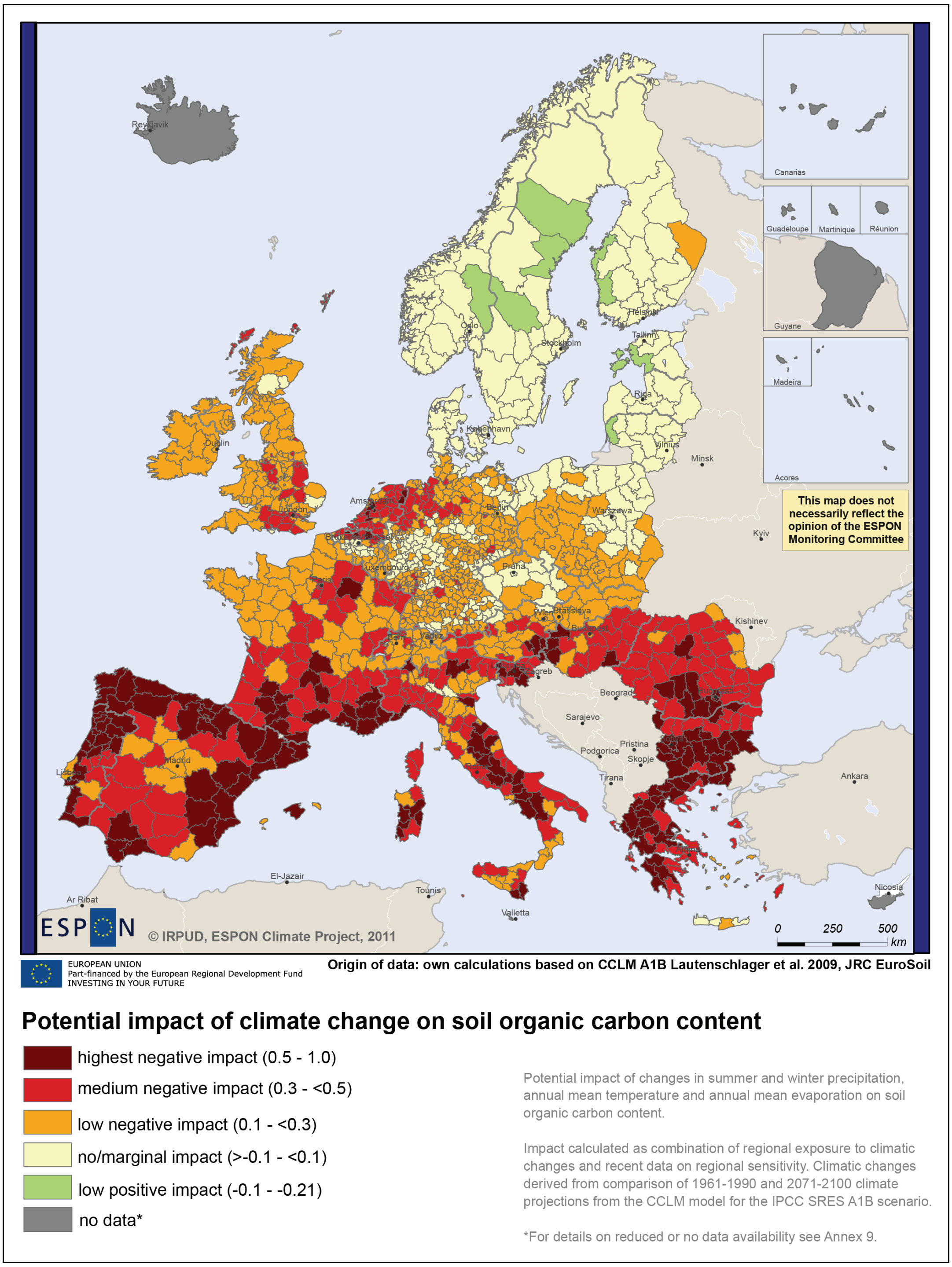
Impact calculated as combination of regional exposure to climatic changes and recent data on regional sensitivity. Climatic changes derived from comparison of 1961-1990 and 2071-2100 climate projections from the CCLM model for the IPCC SRES A1B scenario.

*For details on reduced or no data availability see Annex 9.

Map 36: Potential impact of changes in heavy rainfall on soil erosion

Potential impact of climate change on soil organic carbon content

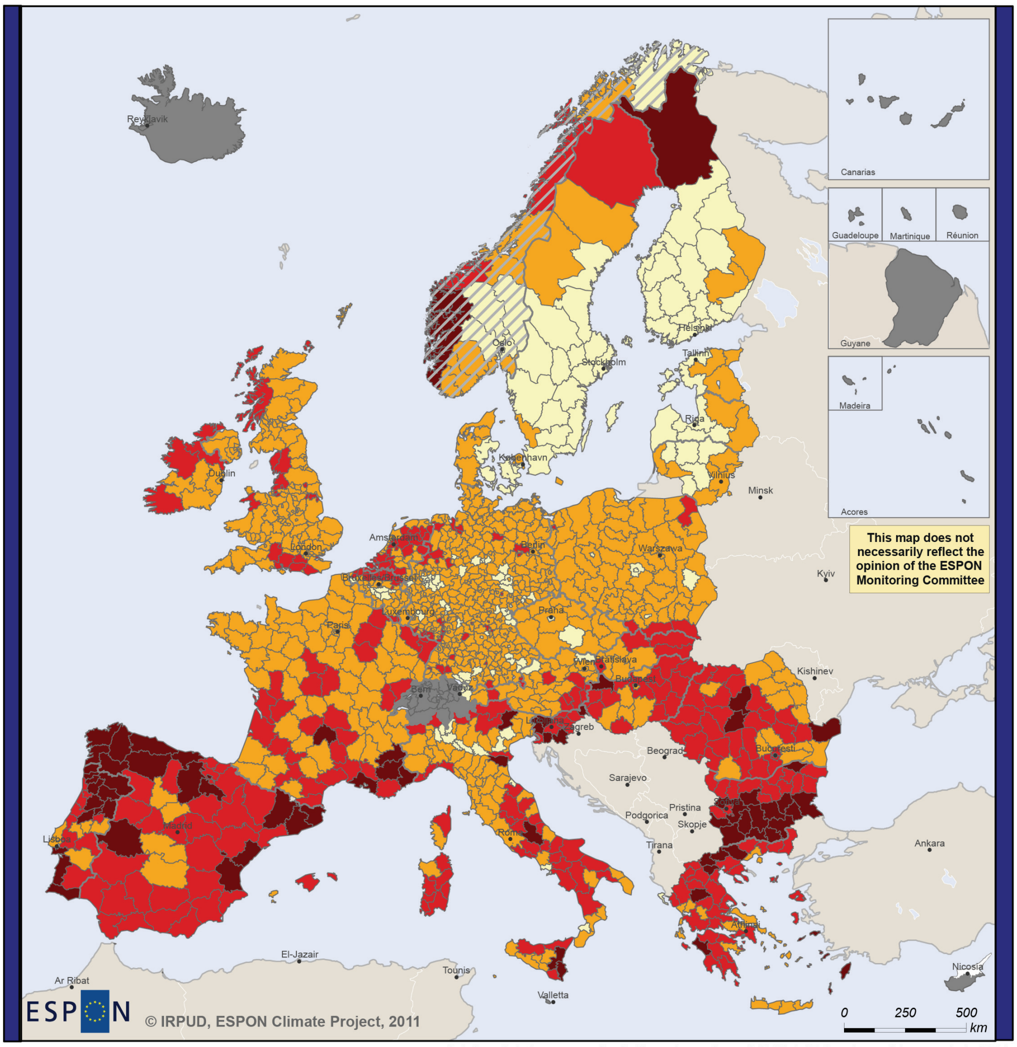
Soil organic carbon is a major component of soils and plays a crucial role for plants, microorganisms and animals – and thus for biodiversity. Since soil organic carbon consists of (decaying) organic matter, hotter and drier conditions accelerate its decomposition. Not surprisingly then, the soil's content of organic carbon is projected to decrease in the future in Southern and South-eastern Europe. But even in some lowlands in central Europe warmer climatic conditions and the particular soil characteristics in these regions can create significant impacts on soil organic carbon. In the north, however, where the climate gets even wetter, soil organic carbon will accumulate even further and create positive overall effects.



Map 37: Potential impact of climate change on soil organic carbon content

Combined environmental impact of climate change

The map below shows that climate change is expected to have the highest environmental impacts in the south and north of Europe – in particular in mountainous regions. Important factors are the high slopes and specific soil characteristics that facilitate soil erosion there. In the Mediterranean the drier and hotter climate also increase the likelihood of forest fire occurrence. Soils in river deltas or along coasts seem to also be negatively impacted by climate change. The severe impacts in northern Scandinavia are in part also due to their very large protected areas where *any* climatic change (in this case warmer and wetter climate) is considered as negatively affecting the specific ecosystems under environmental protection.



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Origin of data: own calculations based on CCLM A1B Lautenschlager et al. 2009, JRC EuroSoil, NATURA 2000 database 2010, JNCC 2010, OEROK 2011 World Fire Atlas 2010, CORINE Land Cover 2000/2006

Potential environmental impact of climate change

- highest negative impact (0.5 - 1.0)
- medium negative impact (0.3 - <0.5)
- low negative impact (0.1 - <0.3)
- no/marginal impact (-0.08 - <0.1)
- no data*
- reduced data*

Combined potential impacts of changes in summer and winter precipitation, heavy rainfall days, annual mean temperature, summer days, frost days, snow cover days and annual mean evaporation on soil erosion, soil organic carbon content, NATURA 2000 protected areas and forest fire sensitivity.

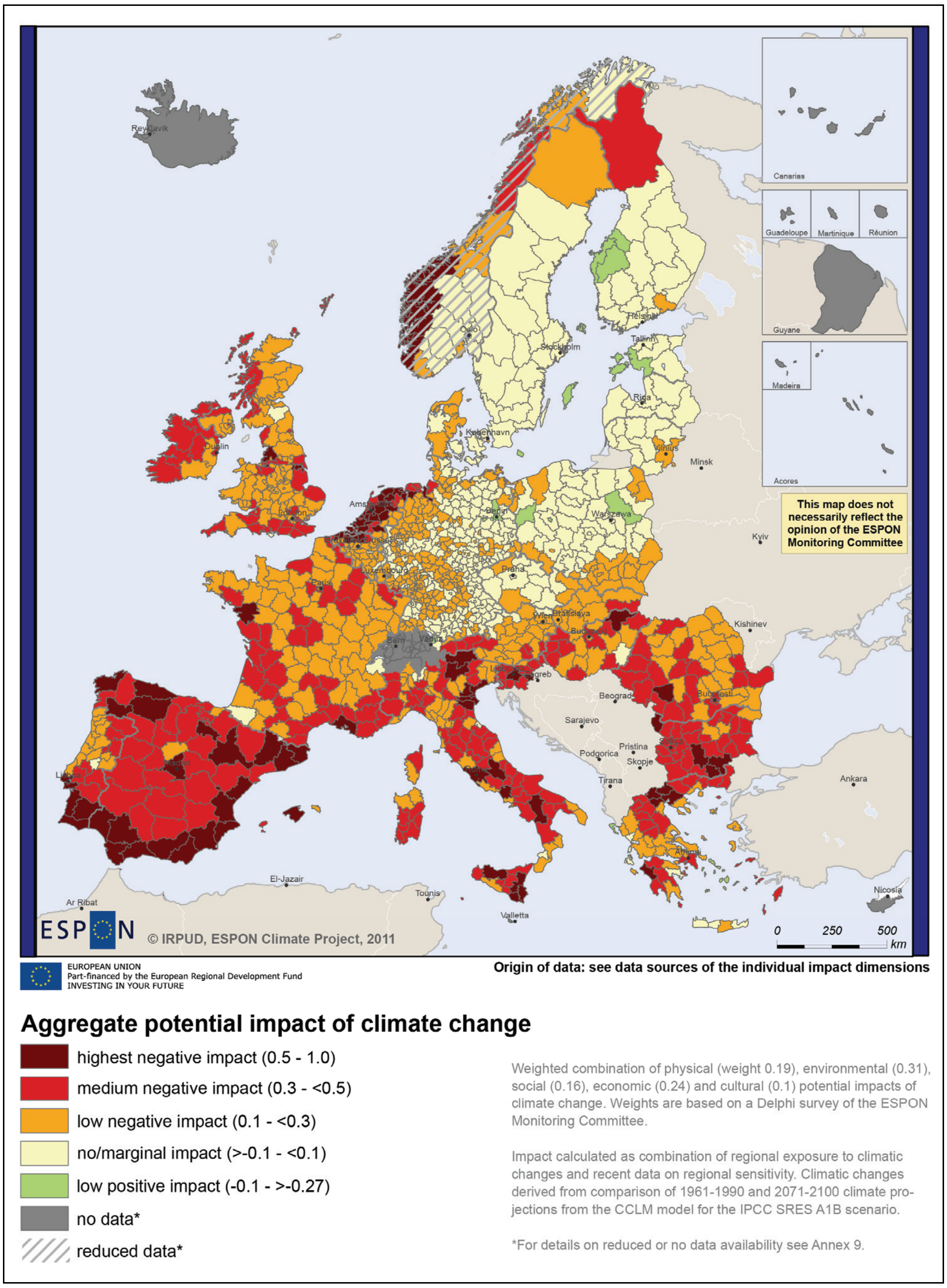
Impact calculated as combination of regional exposure to climatic changes and recent data on regional sensitivity. Climatic changes derived from comparison of 1961-1990 and 2071-2100 climate projections from the CCLM model for the IPCC SRES A1B scenario.

*For details on reduced or no data availability see Annex 9.

Map 38: Potential environmental impact of climate change

3.3.6 Aggregate impact of climate change on Europe's regions

Using the weights derived from the Delphi survey the combined impacts of each dimension were aggregated to an overall impact for each region. The resulting potential impacts of climate change on Europe's regions differ considerably: hot spots are mostly in the South of Europe – i.e. the big agglomerations and summer tourist resorts along the coast. However, other specific types of regions (e.g. mountains, i.e. in Norway, but also the densely populated Dutch coastline) are particularly impacted, but partly for other reasons (sea level rise, economic dependency on summer and/or winter tourism). While generally marginally affected, there are some Scandinavian regions with a moderate or even high negative impact which results mainly from the sensitivity of the environment and flood prone infrastructure. All in all, two of the five climate change regions identified in the exposure analysis are clearly discernible in this map: North-western Europe and the Mediterranean region.



Map 39: Aggregate impact of climate change on Europe's regions

3.4 Regional capacities to adapt to climate change

Adaptation is considered to be an important societal response to global climate change (IPCC 2007). The ability of a society to respond to the challenge of climate change, to adapt to the impacts, is depended on the adaptive capacity of the society. This section explores the concepts of adaptive capacity that underlie the action on climate change. This report reviews the literature on adaptive capacity, and develops indicators in order to measure these capacities in the context of European regions. Firstly, literature on adaptive capacity and its determinants are reviewed, and indicators for measuring adaptive capacity are presented. Finally, this section presents the map of adaptive capacity in terms of European regions and discusses these findings.

3.4.1 Adaptation and adaptive capacity

The inertia of the earth's climate system means that there is a need to adapt, irrespective of the mitigation measures undertaken to reduce the emission of greenhouse gases (IPCC 2007b). Majority of the European countries have now begun the process of drafting national adaptation strategies and there is a trend towards regional and local strategies of adaptation. Adaptive capacity as a concept has been used in order to explore and understand how adaptation processes take place and what kinds of resources and processes enable adaptation to take place and what processes and structures hinder it. Adaptive capacity, therefore, consists of determinants that underlie the ability to adapt. There is thus an increasing need to understand adaptive capacity of different regions in order to understand the ways in which they can adapt to climate change. The ability and the capacity of a region to adapt are dependent on the adaptive capacity of that region and this can vary significantly across different regions.

Adaptation is seen as a response strategy to climate change, involving the adjustments to reduce vulnerability of communities, regions, or activities to climate change. Adaptation refers to the processes, practices, or structures to moderate or offset potential damages or to take advantage of opportunities associated with the changing climate (Smit, Pilifosova 2001). The Intergovernmental Panel on Climate Change (IPCC) defines adaptation as 'adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities' (IPCC 2007). Adaptation is a crucial component of impact and vulnerability assessments as systems vulnerability is based on not only the exposure of the system to changes but also the ability of the system to adapt to changes experienced or projected. Furthermore, adaptation can be seen as an important policy response option to climate change.

Adaptation to climate change has been characterised as a process that can take place through different ways. Adaptation can occur either as anticipatory and reactive responses to the changes that occur as a result of climate change. Alternatively, adaptation can take place through planned adaptation actions and measures that are undertaken by different actors, i.e. private actors or public interests. Private actors are generally considered to undertake autonomous adaptations without interventions from the government (Leary 1999). Hence, autonomous adaptation has been termed as private and planned adaptation as public adaptation in the Third Assessment Report of the IPCC (Smit, Pilifosova 2001).

Adaptive capacity is crucial to the process of adaptation as it enables action. Although it is necessary to note the importance of the role that adaptive capacity plays in the process of adapting to climate change, it has been argued that it is not enough on its own for adaptation to take place (Smith, Vogel & Cromwell III 2009). There have been recent efforts to produce a list of general outlines required for planned adaptation (Füssel 2007), and the role of institutions is also advocated by some (Gupta et al. 2010). Furthermore, it should be noted high capacity at the national level is not necessarily reflected as high capacity at the lower levels of governance (O'Brien et al. 2006), which is of particular relevance to this project.

It should also be noted that whilst the existence of adaptive capacity can contribute to adaptation, it can also contribute towards maladaptation. Maladaptation as a term has recently emerged into the theoretical discussion in relation to the adaptation of societies to climate change and the choices that are available for that society to adapt. Maladaptation is defined as 'action taken ostensibly to avoid or reduce vulnerability to avoid climate change that impacts adversely on, or increases the vulnerability of other systems, sectors or social groups' (Barnett, O'Neill 2010, 211). As examples of maladaptation Barnett and O'Neill provide five examples of pathways, which lead to unfavourable outcomes in relation to adaptation. These are measures that lead to increases in emissions of greenhouse gases, measures that disproportionately burden the most vulnerable in society, measures that have high opportunity costs, measures that reduce incentives to adapt or finally those that lead to path dependency thus closing out options for future adaptation potential. Although discussion on maladaptation is beyond the scope of this particular project, it is worthwhile keeping in mind that adaptive capacity can also contribute to maladaptation.

Adaptive capacity

Adaptation of a society is dependent on the adaptive capacity of that particular society, irrespective of whether adaptation is autonomous or planned. The existence of adaptive capacity has been shown to be a necessary prerequisite for the design and implementation of adaption strategies that effectively reduce the likelihood of adverse effects from climate change (Brooks, Adger & Kelly 2005). Adaptive capacity also enables society to take advantages of the opportunities that are created through changes in the climate. Adaptive capacity is defined as the ability or potential of a system to respond successfully to climate variability and change, and includes adjustments in both behaviour and in resources and technologies (IPCC 2007). Defined in this manner, adaptive capacity has a distinctly context or a place specific flavour. Thus, a system's adaptive capacity is fore mostly determined by a locally determined set of resources and conditions that constrain or facilitate the ability of the system to successfully adapt to the changes in climate (Adger, Arnell & Tompkins 2005, Smit, Wandel 2006).

The IPCC's Fourth Assessment report also outlines adaptive capacity to have two dimensions, a generic one and a specific one (IPCC 2007). Generic adaptive capacity refers to the general ability and capacity of a system to respond to climate change, reflecting its socio-economic status. Whereas specific capacity relates to a specific climate change impact, such as a drought or a flood that poses a threat to the system. This is closely related to the idea that adaptive capacity refers not only to the ability of a system to plan for hazards and opportunities in advance (anticipatory adaptation) but also its ability to respond or cope with the effects (reactive adaptation) (Smit, Pilifosova 2001).

Determinants of adaptive capacity

As adaptive capacity refers to the characteristics contributing to adjustments in natural or human systems in response to actual or expected environmental change and external stress, much research effort has been placed on understanding what the characteristics of a system are that affect its ability or propensity to act. Researchers have put forward and stressed the economic aspects (Williamson, Hesseln & Johnston) or institutional aspects (Gupta et al. 2010) of adaptive capacity. It has been argued that adaptive capacity, first and foremost, is context specific and varies from country to country and region to region and within social groups and individuals, as well as over time (Smit, Wandel 2006). Furthermore, adaptive capacity varies according to its value, but also in terms of its nature in that the scales of adaptive capacity are not independent or separate (Ibid.). This means for example that capacities of regions are tied to the capacity of countries in terms of enabling or constraining environments for adaptation (Ibid.).

A system's adaptive capacity is a not static but changes over time, responding to society's economic, institutional, political and social conditions over time. Adaptive capacities also vary according to the scales of governance in question (Westerhoff, Keskitalo & Juhola In press). A recent study of four different European countries outlined that different capacities were important at the national level whereas others at the regional and local levels. Most importantly, the lower the scale of governance, the more intertwined and depended on each other the capacities became. For example, climate information and networks were considered to be good and enabling adaptation but the lack of human capital hindered the use of those. Furthermore, the lack of human capital to access networks meant that local authorities were unable to access the networks for financial and social capital that could have enabled them to increase their human capital in the first place.

Irrespective of its complex nature of the concept, identifying the dimensions of adaptive capacity has been of interest to many, e.g. (Williamson, Hesseln & Johnston). Although it is acknowledged that adaptive capacity is a dynamic concept, it is possible to identify a set of determinants that affect a region's ability to adapt (Smit, Pilifosova 2001), see Table 7. Economic resources are considered to be important as it is recognised that societies with greater economic resources are likely to be more able to adapt to climate change, and conversely lack of economic means limits the ability to adapt. Secondly, it is argued that technological resources enable the design, development and implementation adaptation measures whereas lack of them limits these opportunities. Thirdly, a skilled and informed personnel is considered enhance adaptive capacity whilst the opposite situation is considered to reduce the capacity to adapt to changes. In terms of considering infrastructure, it is argued that a greater variety leads to greater variety of options for pursuing adaptation. Fifthly, well-developed and functioning institutions do not only manage current climate risks in a satisfactory way but also enable for future planning in terms of changes. Finally, it is argued that the availability and access to resources for adaptation in an equitable manner is crucial for adaptive capacity. It is further argued that the determinants are not independent of each other nor are they mutually exclusive. Rather it should be interpreted as a combination of determinants that varies between regions and countries.

Table 7: Determinants of adaptive capacity (Smit, Pilifosova 2001)

Economic resources	Economic assets, capital resources, financial means and wealth
Technology	Technological resources enable adaptation options
Information and skills	Skilled, informed and trained personnel enhances adaptive capacity and access to information is likely to lead to timely and appropriate adaptation
Infrastructure	Greater variety of infrastructure enhances adaptive capacity
Institutions	Existing and well-functioning institutions enable adaptation and help to reduce the impacts of climate-related risks
Equity	Equitable distribution of resources contributes to adaptive capacity

Since the publication of the IPCC's Third Assessment Report in 2001, there have been several further studies that have focused on further identifying the determinants of adaptive capacity. There have been assessments of adaptive capacity at the national level (Adger, Arnell & Tompkins 2005, Haddad 2005, Yohe, Tol 2002, Moss, Brenkert & Malone 2001), at the local level (Posey 2009)and across all levels of governance (Westerhoff, Keskitalo & Juhola In press).

National level determinants of adaptive capacity have been linked to levels of national development, political stability, economic wellbeing, and human and social capital (IPCC 2007). In addition, proxy indicators have been used for human and civic resources and environmental capacity (Ibid.). An attempt to operationalise a working definition of adaptive capacity at the national level utilises the IPCC TAR list of determinants, also detailed above in Table 1 (Yohe, Tol 2002). The study applies them to national level data and discusses the capacities in terms of two examples of flooding. The authors also note that it is difficult to estimate the relative strength of the different capacities and how that affects possible adaptation.

Brooks et al. explore the possibilities of developing a set of indicators for vulnerability and capacity to adapt at the national level (Brooks, Adger & Kelly 2005). The paper outlines 46 potential proxies for vulnerability and adaptive capacity at the national level, see Table 8.

Table 8: Potential variables for national level vulnerability (Brooks, Adger & Kelly 2005).

Category	Variable	Proxy
Economy	National wealth	GDP per capita (US$ PPP)
	Inequality	GINI coefficient
	Economic autonomy	Debt repayments (% GNI, averaged over decadal periods)
	National wealth	GNI (total, PPP)
Health and nutrition	State support for health	Health expenditure per capita (US$ PPP)
	State support for health	Public health expenditure (% of GDP)
	Burden of ill health	Disability adjusted life expectancy
	General health	Life expectancy at birth
	Healthcare availability	Maternal mortality per 100,000
	Removal of economically active population	AIDS/HIV infection (% of adults)
	Nutritional status	Calorie intake per capita
	General food availability	Food production index (annual change averaged over 1981–90 and 1991–99)
	Access to nutrition	Food price index (annual change averaged over 1981–90 and 1991–99)
Education	Educational commitment	Education expenditure as % of GNP
	Educational commitment	Education expenditure as % of government expenditure
	Entitlement to information	Literacy rate (% of population over 15)
	Entitlement to information	Literacy rate (% of 15–24 year olds)
	Entitlement to information	Literacy ratio (female to male)
Infrastructure	Isolation of rural communities	Roads (km, scaled by land area with 99% of population)
	Commitment to rural communities	Rural population without access to safe water (%)
	Quality of basic infrastructure	Population with access to sanitation (%)
Governance	Conflict	Internal refugees (1000s) scale by population
	Effectiveness of policies	Control of corruption
	Ability to deliver services	Government effectiveness
	Willingness to invest in adaptation	Political stability
	Barriers to adaptation	Regulatory quality
	Willingness to invest in adaptation	Rule of law
	Participatory decision making	Voice and accountability
	Influence on political process	Civil liberties
	Influence on political process	Political rights
Geography and demography	Coastal risk	km of coastline (scale by land area)
	Coastal risk	Population within 100 km of coastline (%)
	Resource pressure	Population density
Agriculture	Dependence on agriculture	Agricultural employees (% of total population)
	Dependence on agriculture	Rural population (% of total)
	Dependence on agriculture	Agricultural employees (% of male population)
	Dependence on agriculture	Agricultural employees (% of female population)
	Agricultural self-sufficiency	Agricultural production index (1985, 1995)
Ecology	Environmental stress	Protected land area (%)
	Environmental stress	Forest change rate (% per year)
	Environmental stress	% Forest cover
	Environmental stress	Unpopulated land area
	Sustainability of water resources	Groundwater recharge per capita
	Sustainability of water resources	Water resources per capita
Technology	Commitment to and resources for research	R&D investment (% GNP)
	Capacity to undertake research and understand issues	Scientists and engineers in R&D per million population

Although these variables are mainly used for assessing vulnerability, the paper acknowledges that adaptive capacity is a component of vulnerability. However, the authors do not explicitly make a difference between variables for adaptive capacity and vulnerability, and this is a concern highlighted in the last section of this report. Brooks et al. also highlight an interesting methodological issue in terms of choosing the determinants of adaptive capacity for a specific study. The authors state that the choice of indicators in vulnerability and adaptive capacity indicators is often based on assumptions about the factors and processes that lead to vulnerability, informed literature reviews and intuitive understandings of the human-environment relationship, thus to some extent based on a subjective choice of the authors (Brooks, Adger & Kelly 2005).

Haddad analyses the adaptive capacity of nations to fulfil their given national aspirations (Haddad 2005). National aspirations are defined as a set of defensible principles by which choices can be made between policies that focus on climate change adaptation. Haddad then calculates the adaptive capacity of nations to fulfil those aspirations based on data that cover economic, political, social and biogeophysical aspects, see Table 9 for more detail on the determinants selected.

Table 9: Selected criteria for assessing adaptive capacity (Haddad 2005)

Criteria	Data source selected
Economic	Sovereign debt rating
	Ranking according to income (low-to-middle income)
	Purchasing power parity-adjusted per capita GDP
Political	Civil freedom
Sociological	GINI Index (a measure of equity in individual income)
Biogeophysical	Water-stressed countries
	Percentage of land in a shared water basin

There have also been studies that look at the adaptive capacity at the national level to a specific threat posed by climate change. A study by Alberini et al. used an expert judgement to assess adaptive capacity at the national level (Alberini, Chiabai & Muehlenbachs 2005). Focusing on human health, the study utilised conjoint choice questions from a group of public health and climate change experts in order to investigate the adaptive capacity of two hypothetical countries. The study selected seven attributes of adaptive capacity, namely per capita income, inequality of distribution of income, measures of the health status of the population, the health care system, and access to information. The selection of these determinants was based on a review of literature and consultations with public health and climate change researchers. In addition, the questionnaire based on the selected determinants was tested prior to actual study in two meetings consisting of professionals within climate change and public health field.

In addition to the national level studies, there have been some local case studies that have analysed the adaptive capacity of a particular region or a community. These studies argue for the need to assess and measure adaptive capacity at the regional or local level because the decisions to adapt are made at that level. The lessons from these are important but they always represent context specific issues from which extrapolation of findings can be difficult. The lessons that have been drawn from the local level stress the importance of relationships within community members through social networks as the ability to participate in decision-making (Tompkins, Adger & Brown 2002). Engle and Carmen Lemos analysed the adaptive capacity of river basin management in Brazil (Engle, Lemos 2010). They base their study on nine broad categories of determinants, see Table 10.

Table 10: Determinants of adaptive capacity.

Determinant	Encompasses
Human capital	Knowledge (scientific, 'local', technical, political), education levels, health, individual risk perception, labour)
Information and technology	Communication networks, freedom of expression, technology transfer and data exchange, innovation capacity, early warning systems, technological relevance
Material resources and infrastructure	Transport, water infrastructure, buildings, sanitation, energy supply and management, environmental quality
Organisation and social capital	State-civil society relations, local coping networks, social mobilization, density of institutional relationships
Political capital	Modes of governance, leadership legitimacy, participation, decentralization, decision and management capacity, sovereignty
Wealth and financial capital	Income and wealth distribution, economic marginalization, accessibility and availability of financial instruments (insurance, credit), fiscal incentives for risk management
Institutions and entitlements	Informal and formal rules for resource conservation, risk management, regional planning, participation, information dissemination, technological innovation, property rights, risk sharing mechanisms

In the European regional and local context in a four-country case study, the determinants that were considered relied on the IPCC definition of capacities (Westerhoff, Keskitalo & Juhola; in press). The importance of each capacity was discussed by 94 respondents across governance levels, including policy makers, scientists and practitioners. Determinants that were considered important included issues such as human capital, the ability to access regional networks and political support. This and other local case studies also note that adaptive capacity within communities is also extremely heterogeneous by locality but that it is also distinguished by age, gender, health and social status at the individual level.

The complexity of adaptive capacity and its measurement should not be underestimated. It has been noted that there have been only a few studies that have been globally comprehensive, and that 'the literature lacks consensus on the usefulness of indicators of generic adaptive capacity and the robustness of the results' (IPCC 2007, 728). An assessment of five vulnerability studies demonstrates that the 20 countries ranked "most vulnerable" show little consistency across studies (Eriksen, Kelly 2007). Haddad also points out this problem, whereby an exhaustive ranking of countries in terms of adaptive capacity is depended on the objectives of their adaption policies (Haddad 2005). This study demonstrates the fact that nation's ability to adapt is altered when their aspirations in terms of adaptation are changed, leading to different outcomes in the ranking of countries in terms of their adaptive capacity.

Although interesting in terms of the theoretical development of adaptive capacity, it is not surprising that different capacities are needed for different aspirations in terms of adaptation, thus leading to changing rankings. In any case, it is necessary to acknowledge that the specific national level determinants of adaptive capacity remain a contested issue (IPCC 2007). Although Haddad's study demonstrates the difficulties of using adaptive capacity to rank or compare countries in terms of their adaptive capacity, it does not automatically mean that indicators for adaptive capacity are rendered obsolete. In fact, it rather highlights the complexity and context dependency of adaptive capacity.

3.4.2 Review of indicators for adaptive capacity

As discussed above, the complexity of adaptive capacity and its determinants has not deterred attempts to develop indicators for measuring it. Many of the studies that have selected a set of determinants for adaptive capacity have also developed indicators for them. The importance of indicators is recognised as they can be used to identify regions or nations that are particularly vulnerable or have low adaptive capacity to deal with climate change (Adger et al. 2004). One study of national indicators focused on coping ranges and the ability to handle external stress (Yohe, Tol 2002). Brooks et al. defined 46 variables (mostly related to vulnerability) and also developed proxies for each variable already presented in Table 10. This study provides the most comprehensive look at vulnerability/adaptive capacity at the national level, drawing a large number of indicators.

The most obvious difficulty in developing and designing an indicator for adaptive capacity below national level is the existence and availability of data. This has also been recognised by Yohe and Tol, who acknowledge that adaptive capacity is essentially a local characteristic but admit that availability of data does not allow analysis below the national level (Yohe, Tol 2002). Therefore it is not surprising that there are case studies of adaptive capacity that have tried to get a more detailed understanding of what constitutes adaptive capacity.

These local studies have analysed adaptive capacity of governance systems at the local level, most notably of river basin management in Brazil and at the municipal level in terms of flood plain management in the United States (Posey 2009). Posey argues that the municipal level is the appropriate level to assess adaptive capacity, considering that decisions concerning adaptation to climate change are likely to be made at this level (Posey 2009). Posey adopts the IPCC definition of adaptive capacity discussed above and provides a quantitative test of the relationship between adaptive capacity and socio-economic statuses at the municipal level. The study uses local participation in a flood plain management programme as an indicator for adaptive capacity. The findings indicate that socio-economic characteristics of a municipality's population are associated with the capacity of municipal leaders to effect collective action in response to the environment challenges, including climate change. Engle and Lemos consider how each indicator might contribute to adaptive capacity (see Table 11 for their selection of determinants for adaptive capacity). The governance and institutional index were derived from a survey sent to the council members of river basin councils (Engle, Lemos 2010).

Table 11: Indicators selected to assess governance influences on adaptive capacity (Engle, Lemos 2010)

River basin governance indicator	Indicator description
Representation (*R*)	The level of representation and the established accountability and legitimacy of institutional arrangements serve to measure this variable within each river basin. Therefore, the more representative the river basin council is of its constituents, the greater the adaptive capacity.
Participation (*P*)	The processes and types of participation vary between river basin basins, and thus serve to measure different levels of participation. Therefore, the more participatory the council members, the greater the adaptive capacity.
Knowledge and information use (*K*)	The basins use scientific knowledge and information in different manners and to varying extents. Therefore, the more knowledge and information use within the basin council, the greater the adaptive capacity.
Equality of decision making and knowledge availability (*E*)	The power distribution among stakeholders, access to technical knowledge (e.g., climate and hydrologic models), and the ability to express oneself freely are very different within and between river basins. Therefore, the greater the equality of decisions and equality of knowledge use within the river basin council, the greater the adaptive capacity.
Flexibility (*F*)	The ability of the institution to bend, but not break, and to learn through experience, speaks to its ability to manage crises effectively and efficiently. Therefore, the greater the flexibility of the river basin council, the greater the adaptive capacity.
Commitment (*C*)	Believing that the institution and governance structure can be successful in managing resources, speaks to the level of commitment that the stakeholders have to the management model. Assuming that the new Brazilian model has the potential to be more effective and efficient than the previous model, then the greater the commitment/buy-in, the greater the adaptive capacity.
Networks (*N*)	Networks capture the various institutional levels and relationships involved with river basin management. Therefore, the greater the networking and connectivity between groups and stakeholders involved in management processes, the greater the adaptive capacity.
Experience (*X*)	More experience suggests a greater ability to deal with everyday events, as well as crisis situations, effectively and efficiently. Experience in water issues, and policy-related processes vary greatly between river basins. Therefore, the greater the experience, the greater the adaptive capacity.
Resources (*S*)	The levels of financial and human capital are critical for the overall success of an organization or governance structure. Specifically, education and wealth can vary greatly within and between river basin councils. Therefore, the greater the resources, the greater the adaptive capacity.

3.4.3 Adaptive capacity indicators for ESPON Climate

The objective of this work package is to develop a combined adaptive capacity index for the regions within ESPON space, based on a selection of available indicators that measure the generic adaptive capacity of each region. Based on the review of literature above, adaptive capacity is defined as the ability or potential of a region to respond successfully to climate variability and change, and includes adjustments in both behaviour and in resources and technologies. Within this project, region is considered to consist of a NUTS3 region. A regional focus, according to the emerging literature, is favourable as more information of the regional level is necessary. This claim is based on the notion that many of the decisions related to adaptation are likely to be taken at the sub-national level.

This study, along the lines of previous research of the A-team (Schröter et al. 2004) considers adaptive capacity to consist of three parts: awareness, ability and action, which are further comprised of dimensions of adaptive capacity as defined by the IPCC and others, see Figure 14. Knowledge and awareness as a dimension of adaptive capacity play an important role in terms of identifying vulnerabilities in relation to climate change and enable the identification of adaptation measures. In order to move from awareness to action, ability is necessary, which consists of technology and infrastructure within a given society. Finally, the ability to achieve action is supported by economic resources and institutions that enable a society to carry out the adaptation measures that have been defined. Equity, the sixth IPCC dimension is not considered as its own dimension. The IPCC considers that equity in relation gender, socio-economic status and political institutions and other aspects is crucial (IPCC 2001). These are considered within the other dimensions.

In this project, the focus is on generic dimensions of adaptive capacity that can be measured across the regions in Europe. It is accepted that some dimensions are generic in that they enable adaptation across the localities and countries irrespective of their location and climate impacts, whilst others are more specific to particular climate change impacts, such as heavy precipitation and drought (IPCC 2007a). On the one hand, factors such as education, income and health are considered to be contributing towards higher adaptive capacity in general of any given society. On the other hand, there are particular climate change impacts, such as droughts or floods, solutions of which require specialised technical knowledge or technological capacity, which may not be reflected in this study. However, focus is also placed on coping capacity to sudden impacts of climate change, such as extreme weather events to which coping measures needed are generic, i.e. number of hospital beds or similar.

Within the scope of this project, the focus is on generic dimensions, and this enables the project to relate adaptive capacity data on the likely impacts of climate change (already encompassing exposure and sensitivity) in order to arrive at results on the vulnerability of European regions to climate change. In addition to this cross-European assessment it should be noted, however, that the adaptive capacity of a region to specific climate hazards could and will be explored in the case studies within the ESPON Climate project. The following five sections focus on the groups of generic dimensions of adaptive capacity chosen here, i.e. knowledge and awareness, technology, infrastructure, institutions and economic resources.

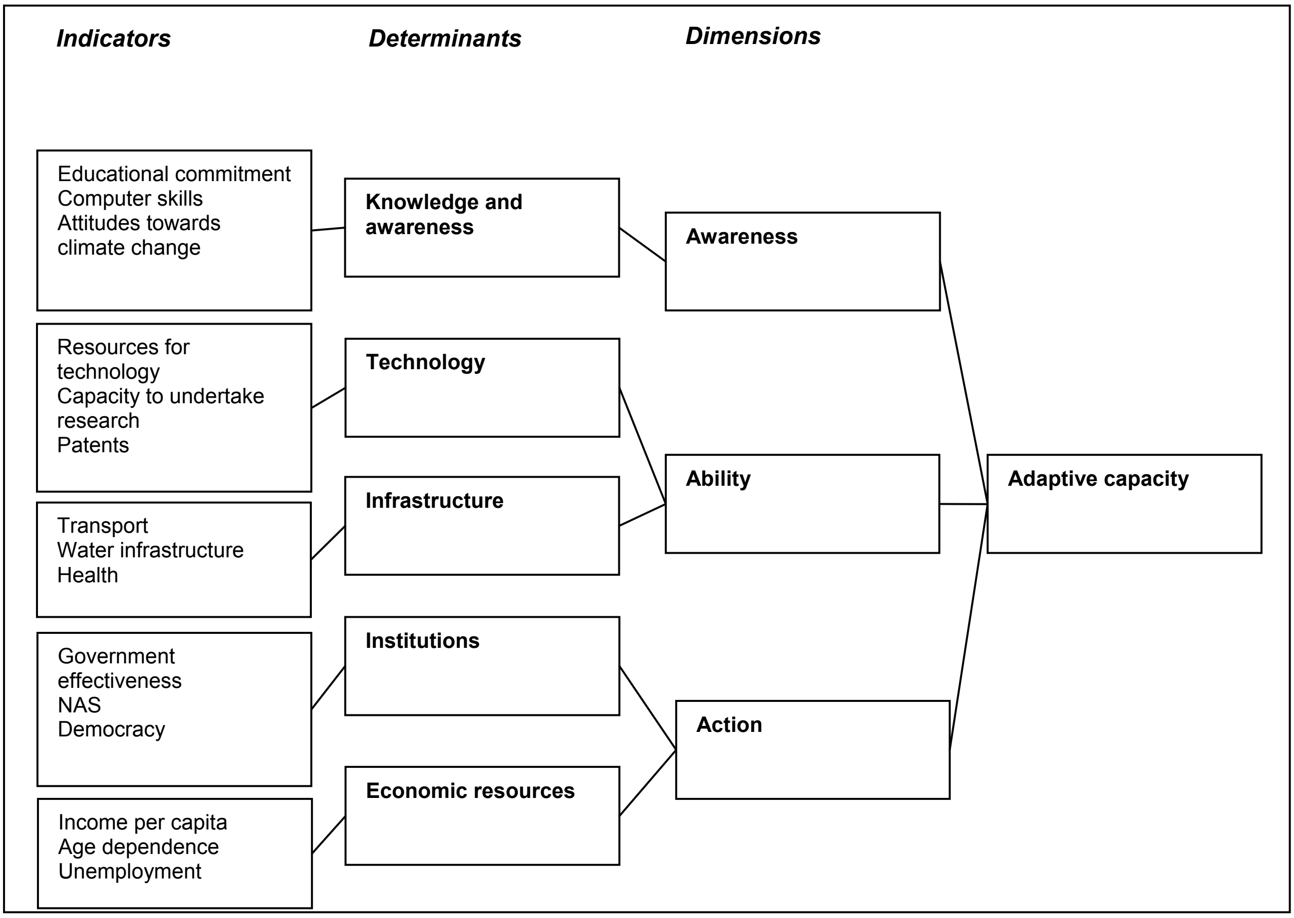


Figure 14: Dimensions, determinants and indicators of adaptive capacity (Schröter et al 2004)

Methodology of ESPON adaptive capacity indicators

One aim of ESPON Climate is to develop a vulnerability index on NUTS 3 level for the entire ESPON space. The index is formed as a combination of adaptive capacity and impact indices.

As discussed in chapters 2 and 3, a wide variety of determinants and indicators have been developed and used to measure adaptive capacity. However, not many of these studies have been conducted on regional level and even fewer on a total area as large as the ESPON space. In fact the study of Schröter et al. (2004), from which the methodology of this study is mostly derived, seems to be the only one that has had such a focus. Also apparent from the discussion of earlier chapters is that the issue of adaptive capacity itself is complex and can be measured in many ways. The general methodology of the adaptive capacity index of ESPON Climate Change and indicators behind it are explained in the following chapters.

In order to capture the variety that is thought to form adaptive capacity in societies the five determinants adopted from IPCC and Schröter et al. (2004) must also have a broad focus, looking into many different sectors of activities. Thus, the selected indicators (Figure 14) will also form a very heterogenic set of variables. The indicators are not all on the same numerical scale, nor are their geographical scales alike. This situation is not ideal for the overall analysis but due to lack of data on the regional level some generalisation has to be performed.

In order to create an index the indicators were transformed to mutually comparable scale by normalising the values of each indicator. The values for the five ESPON Climate adaptive capacity dimensions (what Schröter et al. call determinants) are calculated as averages of the normalised values of the respective indicators according to Figure 14. The results are then normalised again. The adaptive capacity index is then calculated as weighted average of the five dimensions. The weights for the dimensions are drawn from a Delphi survey conducted in ESPON Climate and are presented Table 12. The three aggregate dimensions (what Schröter et al. simply call dimensions) (see Figure 1) are also calculated as weighted averages of five ESPON dimensions using the same weights as for the overall adaptive capacity index.

Table 12: Adaptive capacity dimension weights from Delphi survey

Dimension	Knowledge and awareness	Technology	Infrastructure	Institutions	Economic resources	**Total**
Weight	23	23	16	17	21	**100**

Data is not available for all regions even on the geographical scales used and some gaps remained in the data set. The missing values are approximated as the mean of all other indicator values for the given region. A precise description of these modifications for all indicators can be found in the annex. Also referred in the annex are the data years for the original data on each indicator and region. The data has been acquired as close to year 2006 as possible.

Knowledge and awareness

Recognition of the necessity to adapt, gathering knowledge of available options, and the ability to asses and implement the adaptation measures are crucial for adaptive capacity (IPCC 2001). Skilled, informed and trained personnel enhances adaptive capacity and access to information is likely to lead to development of adaptation options that are timely and appropriate, whilst lack of trained and unskilled personnel can lower a nation's adaptive capacity. Despite this, there are studies that highlight that social capital and networks, values and perceptions can play an important component in compensating for lack of official training and skills (IPCC 2007a). Within the European context, awareness also plays an important part as it can be argued that awareness and the willingness to act on climate change rather than just being educated are more important in the European context.

Educational commitment

Relevance: Skilled and trained personnel and population in general can increase the adaptive capacity of a society because of the contribution of trained personnel towards assessing and implementation measures required to adapt to climate change.

Existing studies: Majority of the existing studies cite educational levels as one of the core component of the capacity to adapt to climate change (IPCC 2007, Brooks, Adger, Kelly

2005). A region that has an educated population is likely to become concerned about climate change, as well as strive towards developing adaptation options and measures in the short and in the long term.

Indicator methodology: The level of a regions educational commitment can be assessed with the education expenditure per capita within a region. Data is available from Eurostat at NUTS0 level for the entire ESPON space.

Computer skills

Relevance: Education levels, as the indicator above, is based on the assumption that skilled and trained personnel contribute to higher adaptive capacity. Within the European context, computer skills play an important part in the education systems of different countries with an increasing number systems relying on information and computer technology.

Existing studies: No existing studies have analysed computer skills as part of a region's capacity to adapt but it is argued here that ICT based approaches will play an important role in coping and adapting to climate change within Europe, perhaps more than elsewhere in the world. Having a population that has a high level of ICT skills is likely to have a higher capacity to adapt to climate change.

Indicator methodology: Computer skills as part of knowledge and awareness can be assessed by using an indicator that details the percentage of people who have never used a computer. The data is available from Eurostat at NUTS 2 level for ESPON space excluding Switzerland and Liechtenstein

Attitudes towards climate change

Relevance: Apart from knowing about climate change, regional adaptive capacity depends on the attitudes that individuals of region have towards climate change. In the end these attitudes determine whether climate change related public actions will be undertaken and necessary institutional changes be made.

Existing studies: Existing studies of adaptive capacity have not used attitudes towards climate change as an indicator of adaptive capacity but have rather focused on rates of literacy to reflect information and skills of a population (Brooks, Adger & Kelly 2005). However, it can be argued that within European regions literacy plays no significant factor in adaptive capacity. Instead attitudes toward climate change are likely to influence the adaptive capacity of a region and are ability to adapt to climate change.

Indicator methodology: The data availability in this regard is similar to the public information indicators described above. The relevant Eurobarometer questions surveyed in 2008 relate to attitudes in regards to (a) the perceived seriousness of climate change, (b) the (in)ability to influence climate change, (c) personal actions to fight climate change and (d) the actions of private and public institutions to fight climate change. Of these questions (a) is most suitable for the purposes of this analysis. The question surveys perceptions on a scale of 1 to 10, where 1 equals "Not a serious problem at all" and 10 equals "An extremely serious problem".

Data is provided GESIS (Leibniz Institute for the Social Sciences) on NUTS 2 level for most countries and on level 1 or 3 for others. Data for Cyprus and Luxembourg are on municipal level. Data is provided for EU 27 countries. Switzerland, Iceland, Liechtenstein and Norway are not included in Eurobarometer survey. The total number of respondents in the study is 30,170 of which 26,661 are within ESPON space.

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Technology

Technological resources enable adaptation options, and consequently lack of access and development of technology can lead to lower adaptive capacity as many of the strategies identified in response to climate change involve technology (IPCC 2001). Development of technologies can be undertaken by both the public and the private sector, and innovation is considered an important factor in this. However, it is necessary to keep in mind the distinction between general technological capacity versus a particular technological response that can be developed for a specific climate change impact (IPCC 2007a). The focus here is on general aspects of technology without a specific focus on particular climate change impacts.

Resources for technology

Relevance: The ability to develop new technologies for adaptation is an important element of adaptive capacity. Climate change is likely to represent challenges for which technological solutions are required in order to either alleviate the impacts of climate change or take advantage of the new conditions brought on the by the changes. The development of new technologies is very much dependent on the resources available for research and development.

Existing studies: Technology is considered an important part of adaptive capacity, and as a part of reducing vulnerability to climate change (Brooks, Adger & Kelly 2005). Technology that can prove useful include, for example, efficient cooling systems, improved seeds, desalinisation plants can increase the coping capacity in the short term and also pave the way for more longer term solutions (IPCC 2007a).

Indicator methodology:

Resources for technology can be measured by the percentage (% of GDP) in R&D investment. Reliable data is available from Eurostat on NUTS 2 regions for the entire ESPON space excluding Liechtenstein.

Capacity to undertake research

Relevance: In addition to the availability of resources, the capacity to undertake research is important for technological capacity for adaptation. The impacts of climate change will vary across Europe, and will be felt very differently across different regions. Thus, adaptation to climate change needs to take place according to specific local vulnerabilities and these regional solutions require research efforts. Therefore, it is important that regions have the capacity to undertake research that enables the development of technologies that increase the adaptive capacity of the region. Research can also further improve the coping capacity of a region to climate change impacts that can be very specific to a particular region.

Existing studies: It has been shown that areas that have been advanced on adaptation in Europe have been involved in research activities, not only relating to adaptation (Keskitalo 2010). Similarly, a case study of community resilience and adaptive capacity in the US cited the importance of using the County's world class scientists in order to improve adaptive capacity of the community (Saavedra, Budd 2009).

Indicator methodology: A suitable indicator for measuring this is the number of scientists and engineers in R&D per million labour force. Data for this is available at NUTS 2 level for the entire ESPON space excluding Liechtenstein. Data for Switzerland provided on national level. Original data provided on NUTS 1 level for Belgium and French overseas departments. Details on the disaggregation of data are presented in the annex.

Patents

Relevance: The number of patents applied for in a given region is also an indication of the technological capacity of that region. It indicates that there is research taking place within a region, and furthermore that this research is utilised for further purposes to develop products and services.

Existing studies: There are no existing studies that utilise patents to measure but the number of patents does reflect the utilisation of research and development efforts by the government and the private sector (IPCC 2007b).

Indicator methodology: A suitable indicator is to measure the number of patent applications per million inhabitants. Data is available for this from Eurostat on NUTS 2 level for the entire ESPON space, excluding the Spanish islands of Ceuta and Melilla, for which data was acquired from the Instituto Nacional de Estadística.

Infrastructure

Greater variety of infrastructure is considered to enhance adaptive capacity (IPCC 2001). Existence and development of infrastructure can form the basis for the development of adaptation options and measures. Different types of infrastructure can also be vulnerable to particular impacts of climate change, and a greater variety can help to buffer the impacts the climate change in both short and long term. Infrastructure is vital also in terms of the coping capacity of a region in terms of sudden impacts of climate change, such as extreme weather events.

Transport

Relevance: One aspect of the infrastructure that supports adaptive capacity and most importantly coping capacity of a region is how easily its population can be reached by emergency services or how easily the population can leave an emergency area on their own. This is particularly relevant in cases of extreme weather events of which projected increases are still uncertain but possible in Europe.

Existing studies: Transport structure is important for longer term adaptation (IPCC 2007b, Brooks, Adger & Kelly 2005) but also for shorter term coping and preparedness for climate change impacts (Saavedra, Budd 2009).

Indicator methodology: A generally suitable indicator for these aspects can be the density of road networks measured as kilometres of road per surface area of a region. Reliable statistical data on the road network of NUTS 2 regions are available across the ESPON space from Eurostat, excluding Greece and Portugal, except for the region Norte. Data on IS acquired from Statistics Iceland. Data on areas of NUTS regions are also available from Eurostat.

Water infrastructure and availability of water

Relevance: The existence and well-functioning of water infrastructure is important for adaptive capacity because climate change is likely to impact the conditions for water supply and waste water treatment. It is likely that the impacts of climate change will vary from positive to negative within regions but the assumption is that improvements on existing water infrastructure can increase adaptive capacity.

Existing studies: Climate change will have a profound effect on water infrastructure thus affecting the availability of the water within European regions. An efficient and well-functioning water infrastructure is important for adaptive capacity. Thus far, there have been no studies that focus on availability of water as way of measuring adaptive capacity.

Indicator methodology: A water exploitation index (WEI) by European Environment Agency can be used to measure the adaptive capacity of the water sector. The index is calculated as the mean annual total abstraction of freshwater divided by the mean annual total renewable freshwater resource. The index shows available water resources in a region compared to the water used with a higher index, over 20 %, indicating water scarcity. Data provided on national level for the entire ESPON space excluding Liechtenstein.

Hospital beds and doctors

Relevance: Climate change may reduce or increase the occurrence of extreme weather events, which can cause emergency situations (e.g. river floods, forest fires etc.). For any such emergencies that effect on human health, the number of hospital beds and the number of doctors are important indicators for the coping capacity and the ability to deal with climate change impacts, of a NUTS 3 region, and reflect the coping capacity of the region.

Existing studies: Existing studies cite health as an important in underlying a society's capacity to adapt (Brooks, Adger, Kelly 2005, IPCC 2001, Schröter et al. 2004) and by focusing on the number of hospital beds and the number of doctors reflects the longer term adaptive capacity as well as the short terms coping capacity of the region.

Indicator methodology: Number of hospital beds per 100 000 inhabitants is used here. NUTS 2 level data are available from Eurostat for the entire ESPON space. Data for Iceland acquired from Statistics Iceland and data for Ceuta and Melilla acquired from the Instituto Nacional de Estadística.

Institutions

Institutions, defined as a means of holding society together, are considered to play an important part of adaptive capacity, and it is argued that existing and well-functioning institutions enable adaptation and help to reduce the impacts of climate-related risks (IPCC 2001). Countries that have well developed and functioning institutions are considered to have higher adaptive capacity in relation to developing or transition countries. Well-developed institutions and governance structures not only have the capacity to deal with present day challenges but also enable to plan for future. Equity considerations are also important in terms of institutions with recent studies showing that the distribution of adaptive capacity is the result of social and economic processes that affect not only the society as a whole, but also individuals based on their age, gender, health and social status, for example (IPCC 2007b). The following indicators are used to reflect the role of institutions in adaptive capacity. All original data on institutions is provided on national level.

Government effectiveness

Relevance: Although responses to climate change increasingly take place outside the sphere of the Government, the Government and its decision-making remain important as they set legislative background within which action on adaptation is taken. The efficiency of government is an important factor overall in decision-making, and is likely to impact positively the adaptive capacity of a region. If decision-making is effective and carried out in that manner, it is likely also that decisions related to adaptation are taken when necessary.

Existing studies: Studies of regional level adaptation so far show that adaptation is taking place in regions that are forerunners in many aspects of regional development, and are part of countries that have been active on adaptation policy at the national level (Westerhoff, Keskitalo & Juhola In press, Ribeiro et al. 2009).

Indicator methodology: Data on government effectiveness is available from the World Bank database. Reliable data is provided on national level for 215 countries, including the whole ESPON space.

National adaptation strategies

Relevance: The existence of a national adaptation strategy (NAS) is likely to increase adaptive capacity of a region. Majority, although not all, NAS have some relevance for the regional level and can thus act as an encouraging factor and spur on political processes at the regional level. Some NAS also have measures for building adaptive capacity at different levels of governance.

Existing studies: Studies analysing the emerging NAS are beginning come forward (Keskitalo 2010, Swart et al. 2009, Massey, Bergsma 2008, Gagnon-Lebrun, Agarwala 2007, Gagnon-Lebrun, Agarwala 2006). These studies analyse the different forms that strategies take as there is very little direction from the supra-national level in the EU in terms of adaptation. Building of adaptive capacity is an explicit aim in some strategies, though not in all, but it is assumed that an existence of a national strategy is likely to build up the institutional capacity of the regional level. A recent study of adaptation strategies has analysed 29 existing NAS in Europe according to whether the emphasis is on concerns of climate adaptation, recommendations for action, or measures that lead to concrete actions (Massey & Bergsma 2009).

Indicator methodology: The study by Massey and Bergsma (2009) divides adaptation level into concerns, recommendations and measures, suggesting that countries with most measures are likely to have advanced most on adaptation. It is assumed here that the further a country has advanced on adaptation the higher the institutional adaptive capacity are they likely to have[12]. The numbers of concerns, recommendations and measures are not necessarily directly linked or related to each other, therefore adding them together does not provide useful results for the purposes of this analysis. To get around the problem the countries are ranked and classified into quintiles on each of the three categories and the indicator value is formed as the mean of these quintile values.

Democracy

Relevance: Adaptive capacity, it is argued, will be greater if resources and power in governing resources for adaptation are equitably allocated (IPCC 2001). Equity highlights the fact that both availability of capacity and access to it are both crucial in taking advantage of adaptive capacity for climate change adaptation. More recent local level studies have shown that adaptive capacity is uneven within nations, and that the distribution of adaptive capacity is the result of social and economic processes that affect not only the society as a whole, but also individuals based on their age, gender, health and social status, for example

[12] The data for the indicator that measures the national adaptation strategies in Europe was obtained from Eric Massey, Department of Environmental Policy Analysis, Institute for Environmental Studies (IVM) of the Vrije Universiteit Amsterdam.

Existing studies: The A-team used an indicator to describe female activity in their assessment of adaptive capacity in Europe (Schröter et al. 2004).

Indicator methodology: Democracy is measured here by the female participation in political life, using the gender weighted democratisation index (Vanhanen, 2010). Data for this is available from FSD (The Finnish Social Science Data Archive) and is provided on national level for all independent states with over 40 000 inhabitants.

Economic resources

It is widely accepted that economic assets, capital resources, financial means and wealth play an important role in adaptive capacity (Smit, Pilifosova 2001). Wealthy nations are more likely to be in a better position to adapt to changes in the climate, by being able to bear the costs of adaptation. However, it should be noted that adaptation is not an exclusive concern for areas with lower economic development, and a high income per capita is neither a necessary nor a sufficient indicator of the capacity to adapt (IPCC 2001). Economic resources can also be distributed unequally, resulting in a lower adaptive capacity. It is argued that adaptive capacity will be greater if resources and power in governing resources for adaptation are equitably allocated either within a community, nation or at the global level (IPCC 2001). The following indicators are used to measure the economic capacity to adapt.

Income per capita (GNP)

Relevance: Economic assets play an important role in adaptive capacity as they can be used to fund and support adaptation measures and strategies. They can also to further increase adaptive capacity by investing in other capacities, such as information dissemination, education amongst others.

Existing studies: Existing studies have shown that economic resources play an important role in a region’s adaptive capacity (Yohe and Tol 2002, IPCC 2007a). Although economic resources are considered important, the literature also highlights that a region’s low economic activity does not necessarily imply that it has low adaptive capacity or that a higher income automatically results in an increased adaptive capacity, c.f. (Tompkins, Adger 2005, Næss et al. 2005).

Indicator methodology: A suitable indicator for measuring economic performance is GDP per capita (€ PPP) of a region. Statistical data is available for entire ESPON space from the ESPON Database. Data for Iceland was acquired from Eurostat.

Age dependency ratio

Relevance: Economic resources, as mentioned above, are important for a region’s adaptive capacity. The extent to which a part of a region’s population is dependent on other members within the region reflects the availability of resources for adaptation.

Existing studies: A study that analysed the adaptive capacity of European regions used the dependency ratio as an indicator to measure the economic resources adaptation (Schröter et al. 2004).

Indicator methodology: Age dependency ratio. The old-age dependency ratio is the ratio of the number of elderly persons (aged 65 or more) divided by the number of persons of working age (aged 15-64 years). The population data are available from Eurostat at NUTS 3 level. Data for Liechtenstein and Luxembourg were acquired from national statistical institutes.

Unemployment

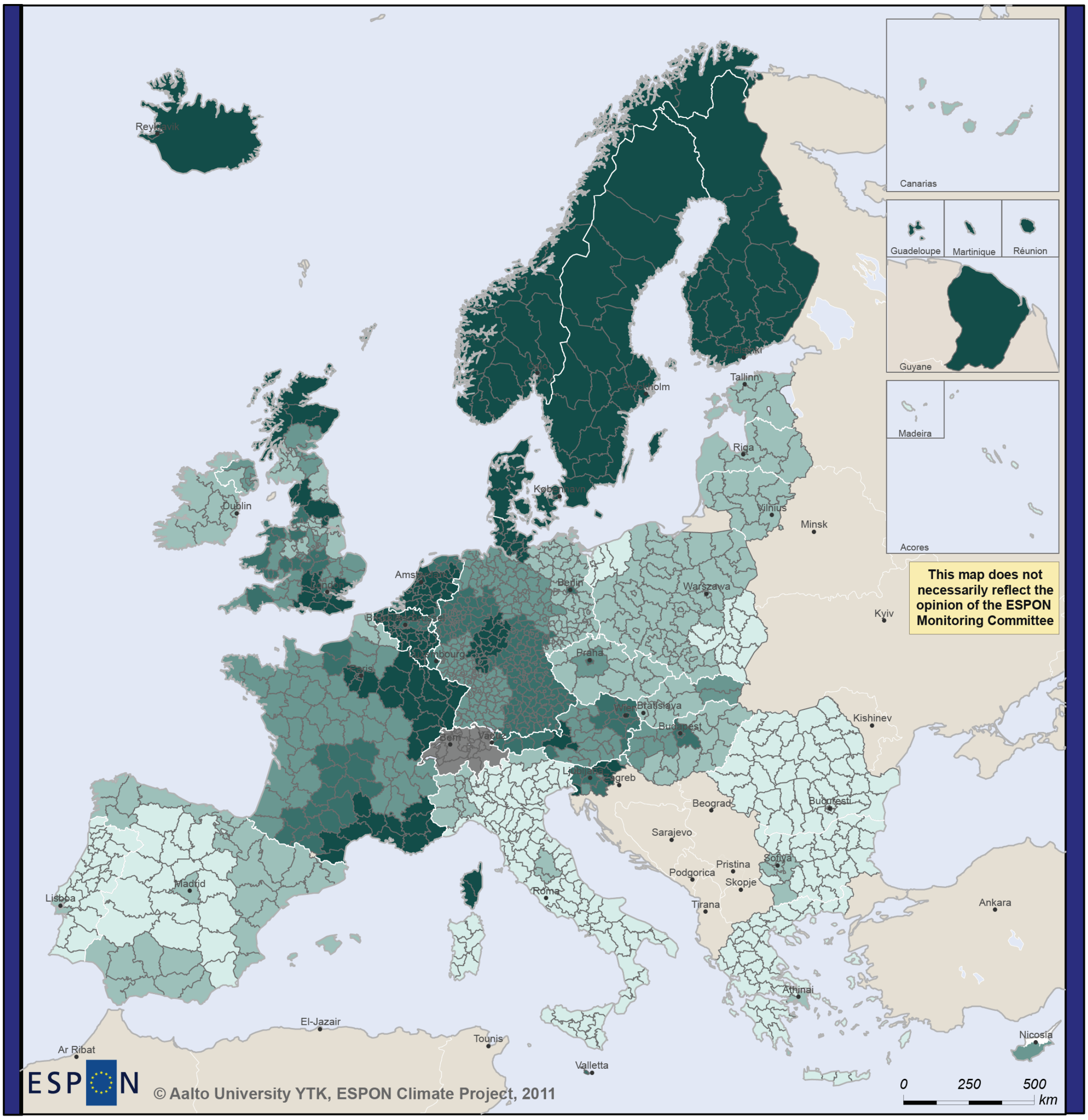
Relevance: Adaptive capacity will be greater if resources and power in governing resources for adaptation are equitably allocated either within a community, nation or at the global level (IPCC 2001). Equity highlights the fact that both availability of capacity and access to it are both crucial in taking advantage of adaptive capacity for climate change adaptation. More recent local level studies have shown that adaptive capacity is uneven within nations, and that the distribution of adaptive capacity is the result of social and economic processes that affect not only the society as a whole, but also individuals based on their age, gender, health and social status, for example (IPCC 2007b). Long-term unemployment can also lead to inequities within a society.

Existing studies: Thus far there have been no studies that use statistics of long-term unemployment to reflect the issue of equity in adaptive capacity.

Indicator methodology: The NUTS 2 level data is available from Eurostat for the ESPON space excluding Liechtenstein.

3.4.4 Mapping the adaptive capacity of European regions

The maps of adaptive capacity for European regions in presented in this section. In addition to the map that compiles all indicators, this section presents maps for each dimension of adaptive capacity (knowledge and awareness, infrastructure, technology, economic resources, institutions, as well as maps for the three aggregate dimensions (awareness, ability, action).



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Origin of data: Eurostat 2010, ESPON Database 2006, GESIS 2008, NSIs 2010

Adaptive capacity: Knowledge and awareness

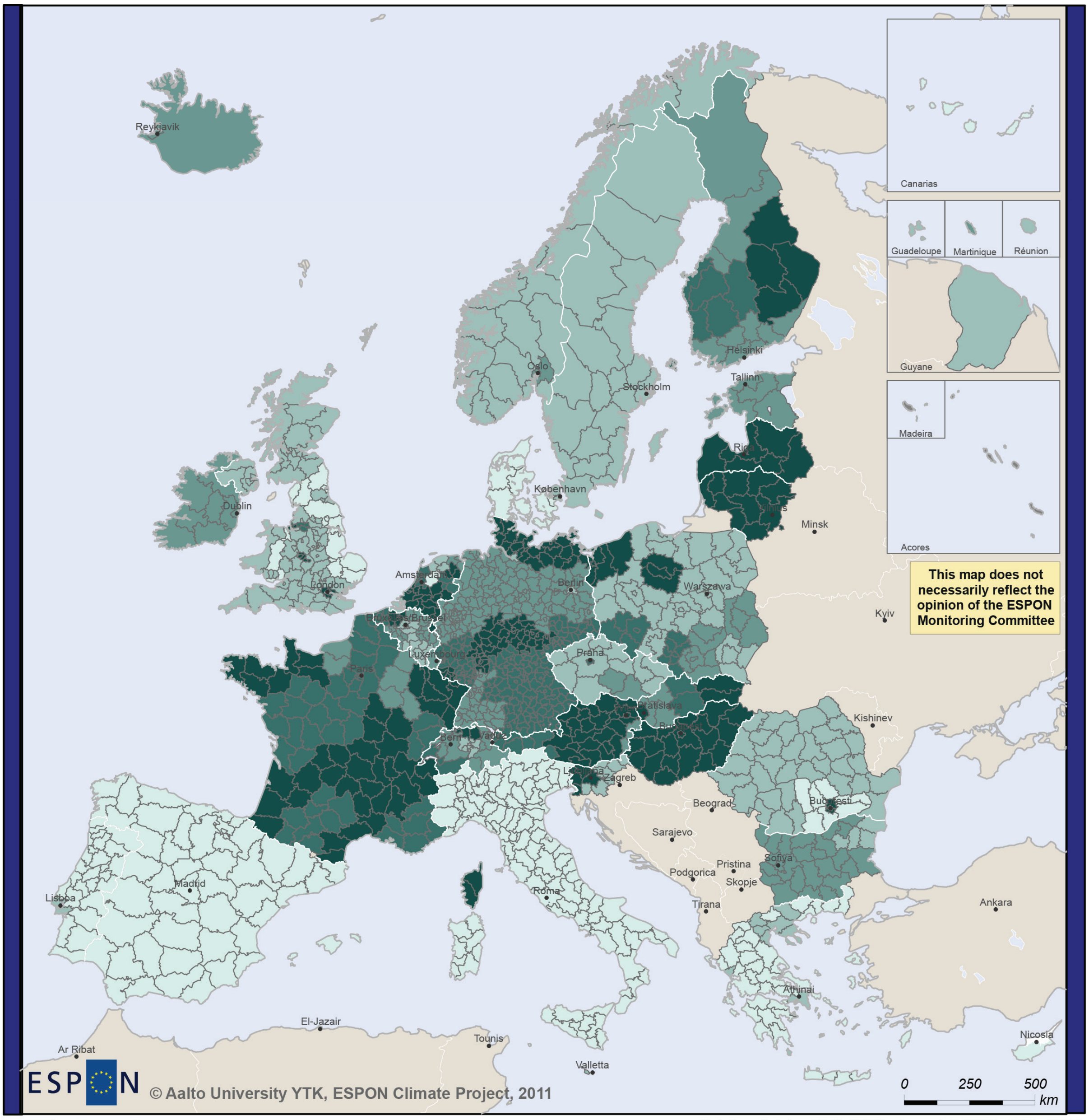
- highest capacity
- high capacity
- medium capacity
- low capacity
- lowest capacity
- no data*

Knowledge and awareness of climate change classified by quintiles.

The knowledge and awareness dimension of climate change adaptive capacity combines indicators on people's attitudes towards climate change, people's ability to use computers and access information and on investments in education.

*For details on reduced or no data availability see Annex 9.

Map 40: Adaptive capacity: Knowledge and awareness



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Origin of data: EEA 2006, Eurostat 2010, NSIs 2010

Adaptive capacity: Infrastructure

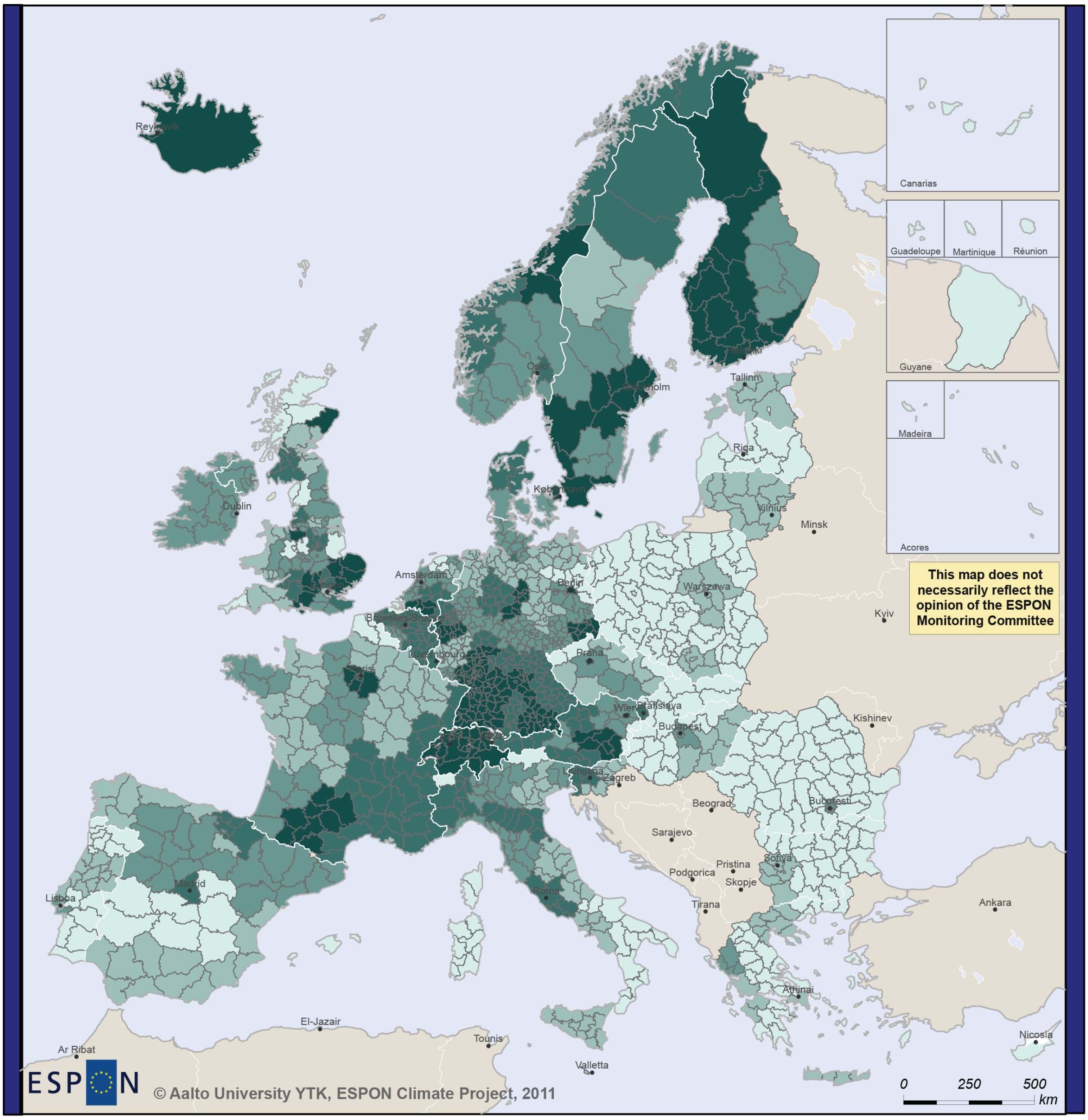
- highest capacity
- high capacity
- medium capacity
- low capacity
- lowest capacity
- no data*

Infrastructural capacity to adapt to climate change classified by quintiles.

The infrastructural dimension of adaptive capacity towards climate change combines indicators on the road network density, hospital beds and sustainable water use.

*For details on reduced or no data availability see Annex 9.

Map 41: Adaptive capacity: Infrastructure



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Origin of data: ESPON Database 2006, Eurostat 2010, NSIs 2010

Adaptive capacity: Technology

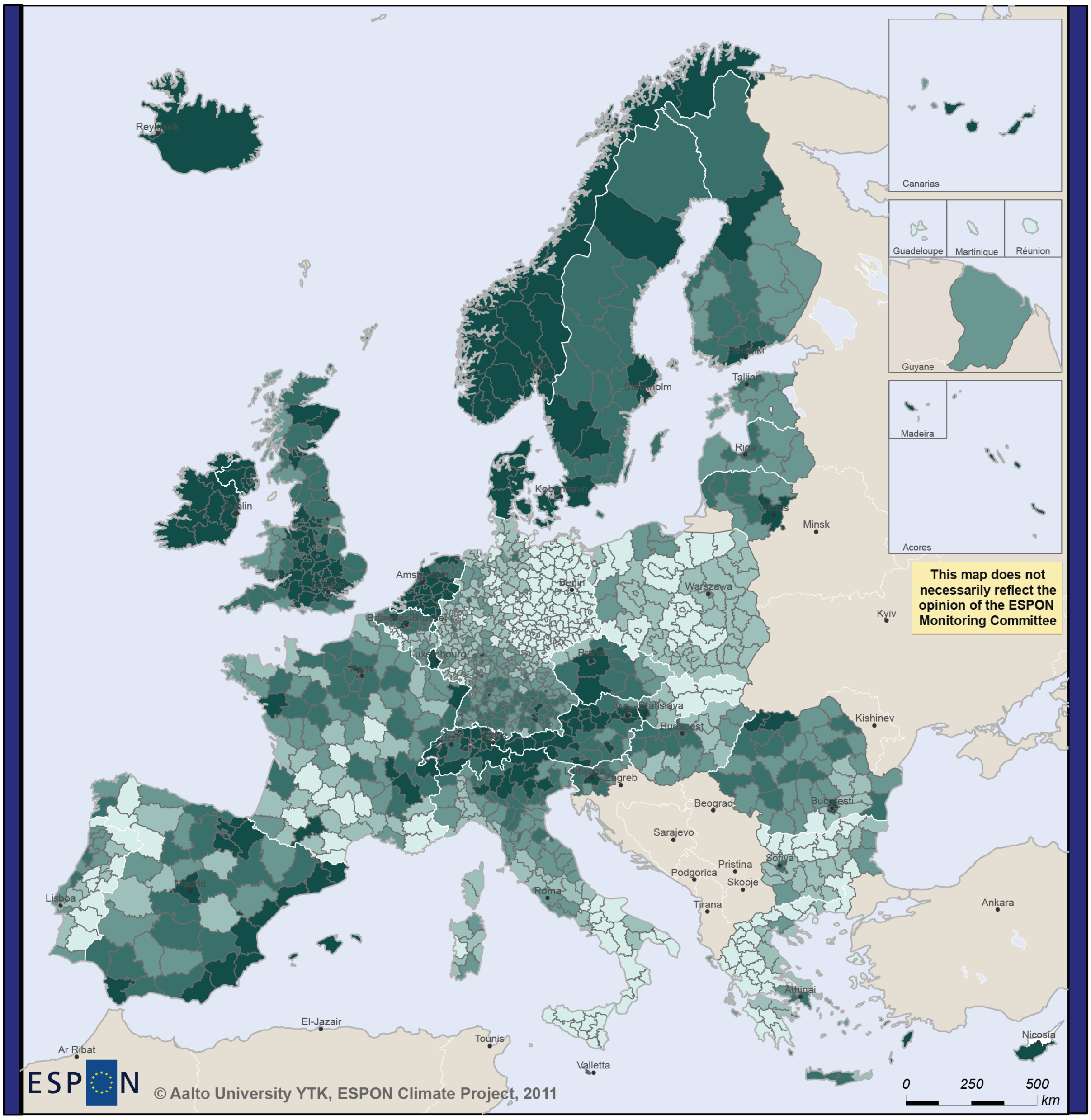
- highest capacity
- high capacity
- medium capacity
- low capacity
- lowest capacity
- no data*

Technological capacity to adapt to climate change classified by quintiles.

The technology dimension of adaptive capacity towards climate change combines indicators on research and development expenditure, research and development personnel and patent applications.

*For details on reduced or no data availability see Annex 9.

Map 42: Adaptive capacity: Technology



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Origin of data: ESPON Database 2006, Eurostat 2010, NSIs 2010

Adaptive capacity: Economic resources

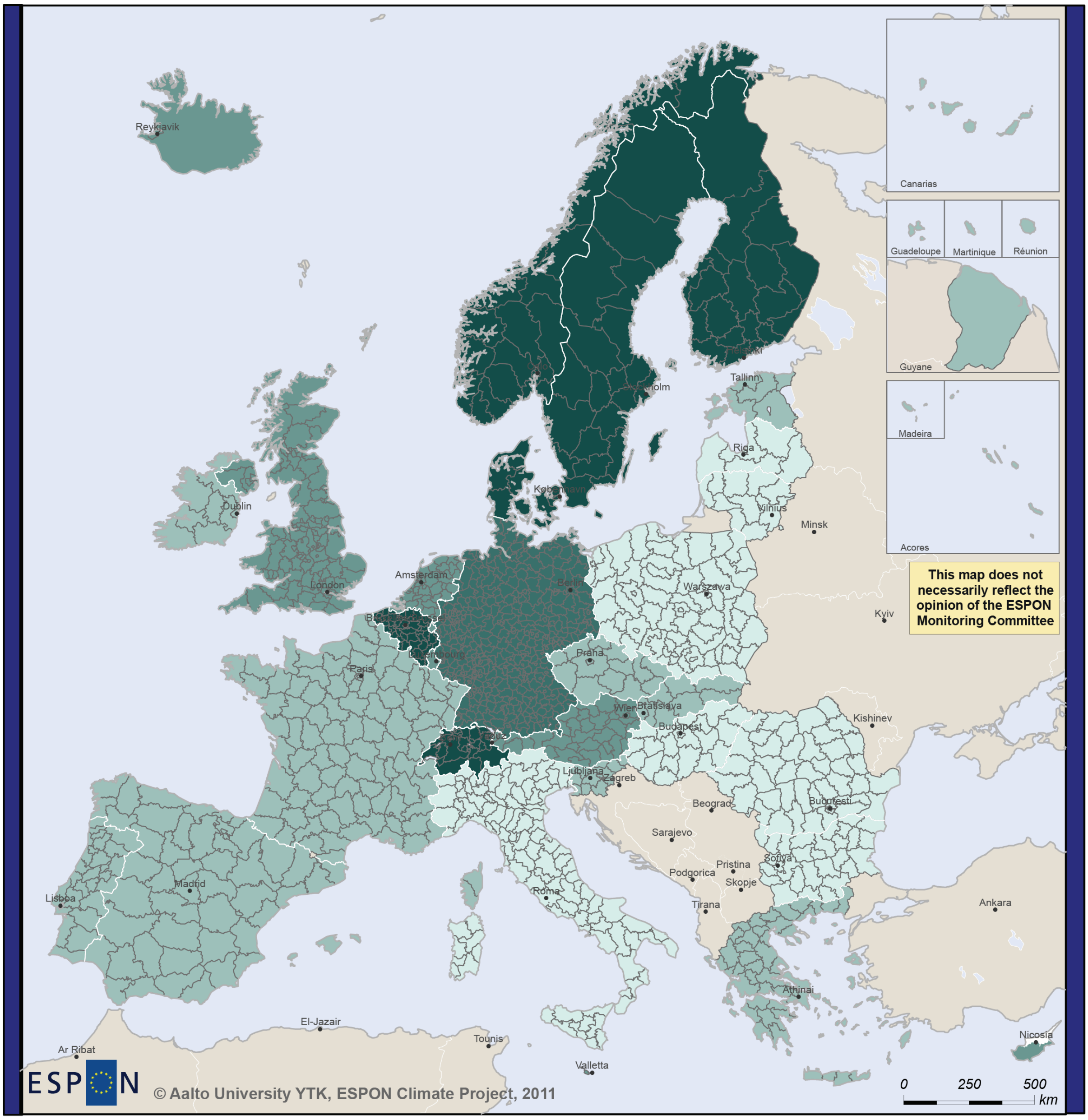
- highest capacity
- high capacity
- medium capacity
- low capacity
- lowest capacity
- no data*

Economic capacity to adapt to climate change classified by quintiles.

The economic resources dimension of adaptive capacity towards climate change combines indicators on GDP, age dependence and long-term unemployment.

*For details on reduced or no data availability see Annex 9.

Map 43: Adaptive capacity: Economic resources



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Origin of data: FSD 2010, Massey & Bergsma 2009, World Bank 2010

Adaptive capacity: Institutions

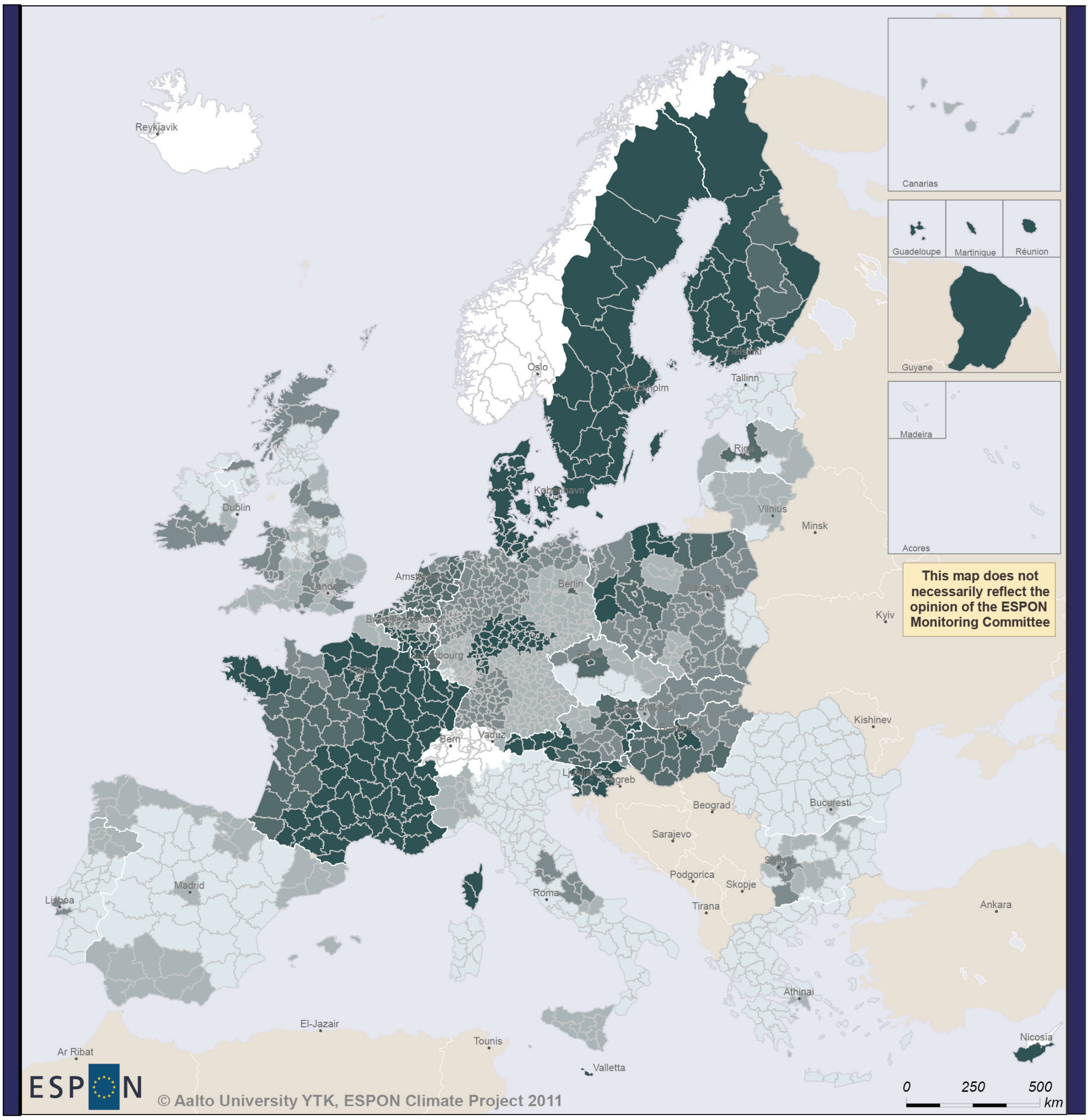
- highest capacity
- high capacity
- medium capacity
- low capacity
- lowest capacity
- no data*

Institutional capacity to adapt to climate change classified by quintiles.

The institutional dimension of adaptive capacity towards climate change combines indicators on national adaptation strategies, government effectiveness and state of democracy.

*For details on reduced or no data availability see Annex 9.

Map 44: Adaptive capacity: Institutions



Origin of data: Eurostat 2010, ESPON Database 2006, GESIS 2008, NSIs 2010

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Aggregate Dimensions of Adaptive Capacity

Awareness

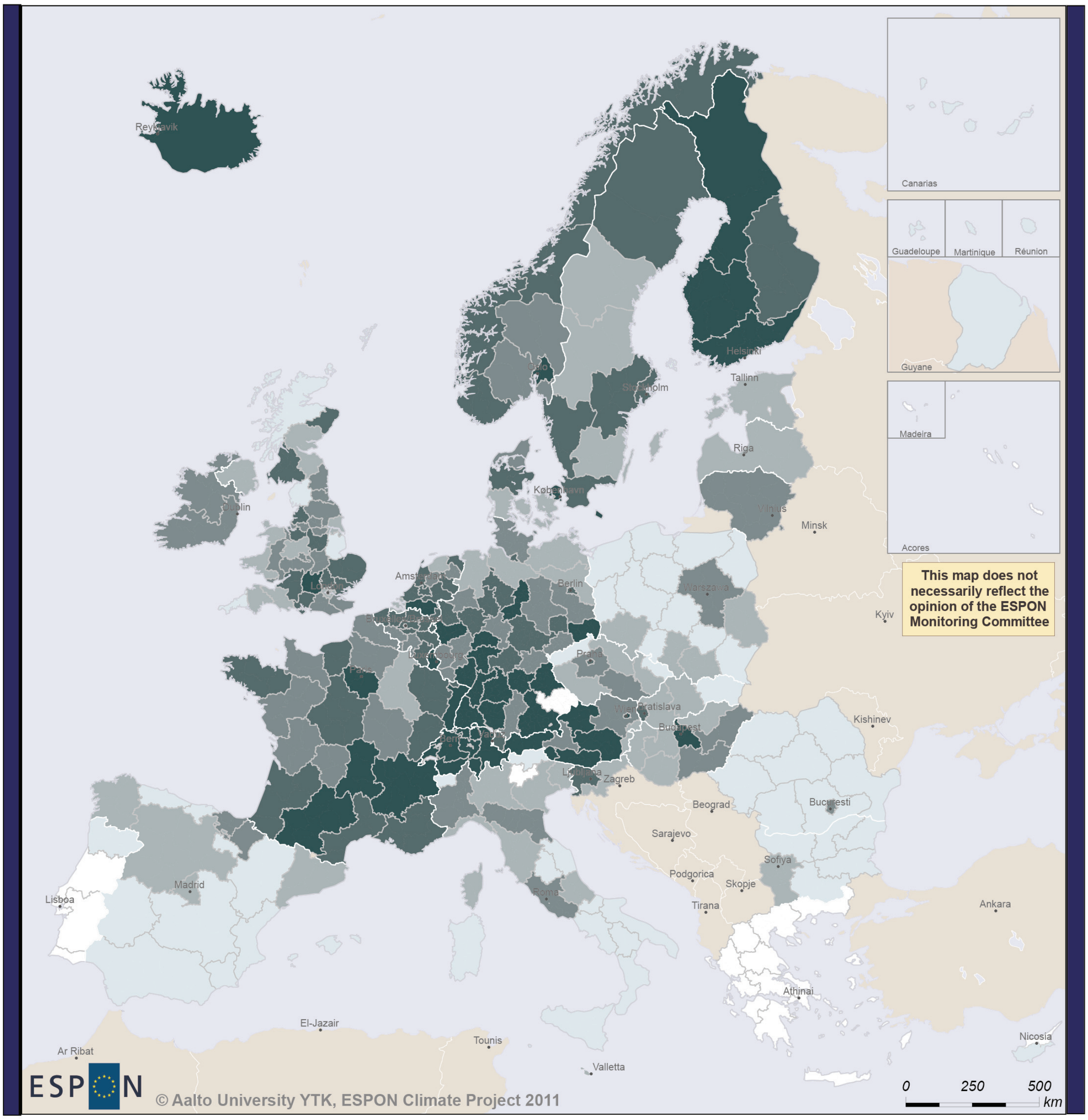
- Highest capacity
- High capacity
- Medium capacity
- Low capacity
- Lowest capacity
- No data

Aggregate dimension 'awareness' classified by quintiles.

The awareness dimension describes regions' capacities to adapt to climate change through peoples attitudes towards climate change, their ability to use computers and access information, and funds invested in education.

See Annex 9 for details on no data availability.

Map 45: Aggregate dimension of adaptive capacity: Awareness



Origin of data: EEA 2006, Eurostat 2010, NSIs 2010

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Aggregate Dimensions of Adaptive Capacity

Ability

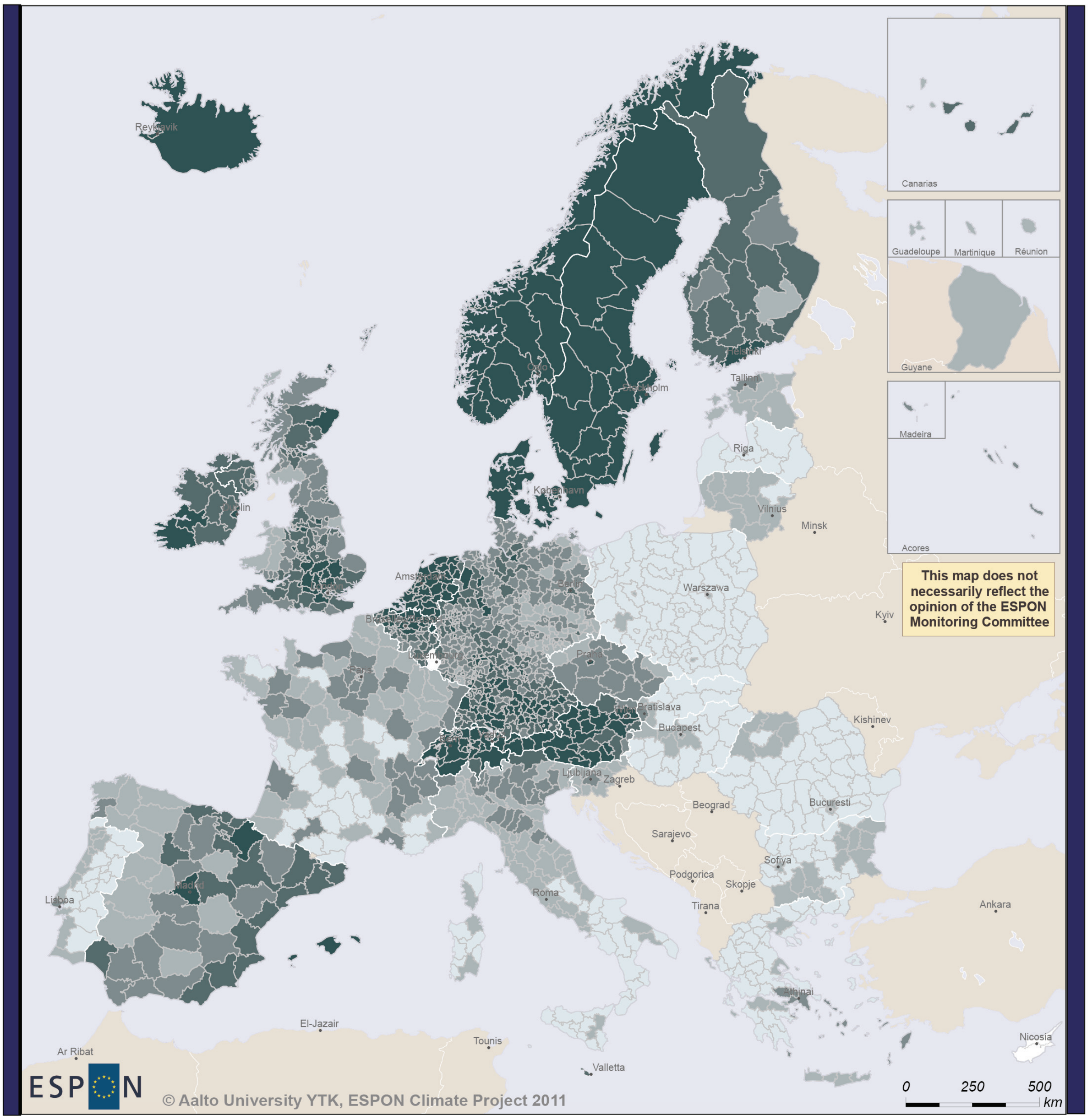
- Highest capacity
- High capacity
- Medium capacity
- Low capacity
- Lowest capacity
- No data

Aggregate dimension of 'action' classified by quintiles.

The ability dimension describes regions' capacities to adapt to climate change through six indicators: research and development expenditure, research and development personnel, patent applications, road network density, sustainability of water use and health care capacity.

See Annex 9 for details on no data availability

Map 46: Aggregate dimension of adaptive capacity: Ability



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Origin of data: ESPON Database 2006, Eurostat 2010, FSD 2010, Massey & Bergsma 2009, NSIs 2010, World Bank 2010

Aggregate Dimensions of Adaptive Capacity

Action

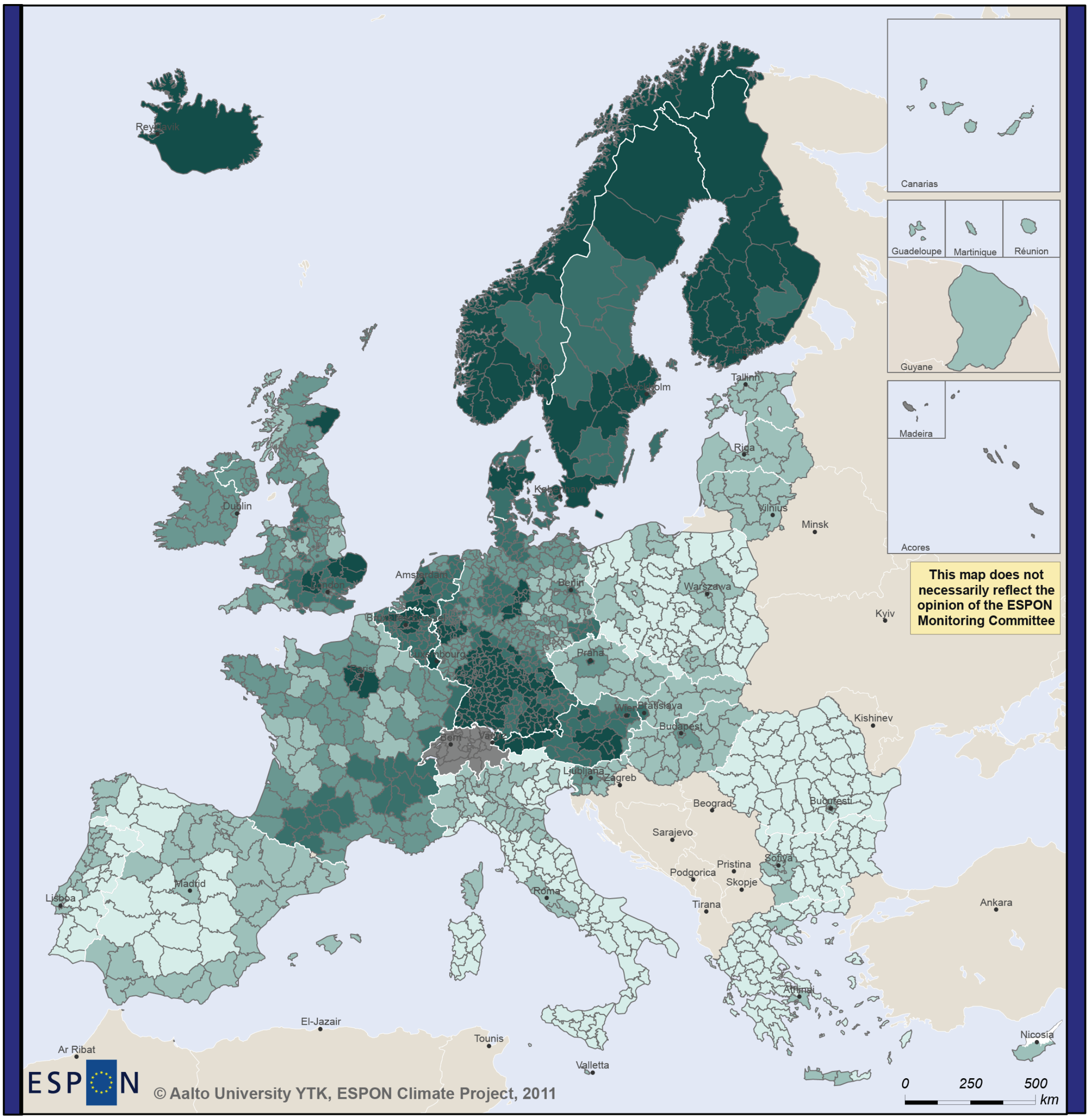
- Highest capacity
- High capacity
- Medium capacity
- Low capacity
- Lowest capacity
- No data

Aggregate dimension 'action' classified by quintiles.

The action dimension describes regions' capacities to adapt to climate change through six indicators: GDP, age dependence, long-term unemployment, government effectiveness, national adaptation strategies and level of democracy.

See Annex 9 for details on no data availability.

Map 47: Aggregate dimensions of adaptive capacity: Action



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Origin of data: GESIS 2006, ESPON Database 2006, Eurostat 2010, NSIs 2010, EEA 2006, FSD 2010, Massey & Bergsma 2009, World Bank 2010

Overall capacity to adapt to climate change

- highest capacity
- high capacity
- medium capacity
- low capacity
- lowest capacity
- no data*

Overall adaptive capacity towards climate change classified by quintiles.

The overall adaptive capacity was calculated as weighted combination of economic capacity (weight 0.21), infrastructural capacity (0.16), technological capacity (0.23), knowledge and awareness (0.23) and institutional capacity (0.17). Weights are based on a Delphi survey of the ESPON Monitoring Committee.

*For details on reduced or no data availability see Annex 9.

Map 48: Overall capacity to adapt to climate change

Adaptive capacities of European regions

The map of aggregate adaptive capacity shows the adaptive capacity that European regions possess across the continent. This map combines the scores of the five adaptive capacity dimensions, using the weights derived from the Delphi survey. Overall, one can observe variations in adaptive capacity between countries and within countries. At the European level, there are several trends that can be seen from the map. When analysing the map, there are several methodological issues that need to be kept in mind. Firstly, absence of regional level data has led to the fact that for some indicators, national level data has been used, which reduces regional variation since the data for each region is the same. Secondly, for some indicators, particularly those related to institutions are by nature national, i.e. government effectiveness and the existence and quality of a national adaptation strategy.

Firstly, in analysing the maps, a difference in adaptive capacity can be distinguished between Northern Europe and Southern Europe. Overall, the Nordic countries have higher capacity than most of the Southern European countries. Norway and Iceland have no regional variation in terms of adaptive capacity of individual regions. Most of Western and Central Europe have a relatively high capacity when one considers the European average. In comparison, Eastern European countries, on the whole, have lower capacity than Western or Northern European countries. Overall, the countries around the Mediterranean appear to have lower capacity than the countries around the Baltic Sea region.

Similar trends can also be identified at the country and regional level throughout Europe. Firstly, it can be noted that in all countries, capital city regions, overall, have higher capacity than most regions within that country. This is also true, even in cases where the country itself as a whole has lower capacity. The Baltic regions, however, are a curious exception in this regard with adaptive capacity being uniform throughout the three countries with no regional variation at all. Similarly Iceland and Norway have no regional variation at all.

The regional variation within countries also shows how within some countries, existing regional patterns are reflected in the way that adaptive capacity is spread across the countries. North-South or East-West divisions can be seen in the maps in that they reflect the overall development patterns. Those regions, which are less developed, can also be seen to have less adaptive capacity.

It is also possible to analyse the adaptive capacity of European regions in terms of the aggregate dimensions of adaptive capacity, hence focusing on awareness, ability and action. In terms of Northern Europe, where aggregated adaptive capacity is generally high, differences between regions can be seen in all three different aggregate dimensions. For example, Sweden scores high on awareness and action but has lower ability to adapt. Finland on the other hand has high ability but scores lower on awareness and action. Similar trends can be observed in Western and Central Europe also. Ability and action are high but awareness is lower in comparison to the other two dimensions.

For Eastern Europe, all three dimensions are lower than in other parts of Europe and for significant differences exist between the three different dimensions. Although indicators used for measuring action are the consistently low across the regions within Eastern Europe. The Mediterranean region overall has lower capacity than the more Northern regions in Europe. Most differences The Iberian peninsula scores low on awareness and ability but scores higher in terms of the action dimension. Mediterranean regions in France have high ability but score lower on awareness and action. Similar trends can also be observed within regions in Italy.

Capital cities also emerge as having high adaptive capacity from the aggregated map. Interestingly, there is also variation in terms of the aggregate dimensions of adaptive capacity in the capital city regions in Europe. When comparing the three aggregate dimensions in each capital city region, it appears that ability is the highest across the board. This is compared to the action dimension, which is also relatively high and appears to be higher than awareness.

It is also useful to compare the results of this analysis with results from other research efforts that have mapped adaptive capacity on a European scale. The ATEAM produced adaptive capacity maps and published them in their final report (Schröter et al. 2004) (see 15). Overall, the results of this ESPON study and the ATEAM study show similar trends. This is partially because the construction of the indicators is similar with this ESPON study utilising similar indicators as the ATEAM. Both maps show that Northern parts of Europe have higher capacity than Southern Europe. The ATEAM maps did not calculate adaptive capacity of Eastern European countries whereas this study does. The ATEAM project also projected changes of adaptive capacity into the future which was not done in this project. The ATEAM does not explain their methodology, so it is difficult to comment on how this was done.

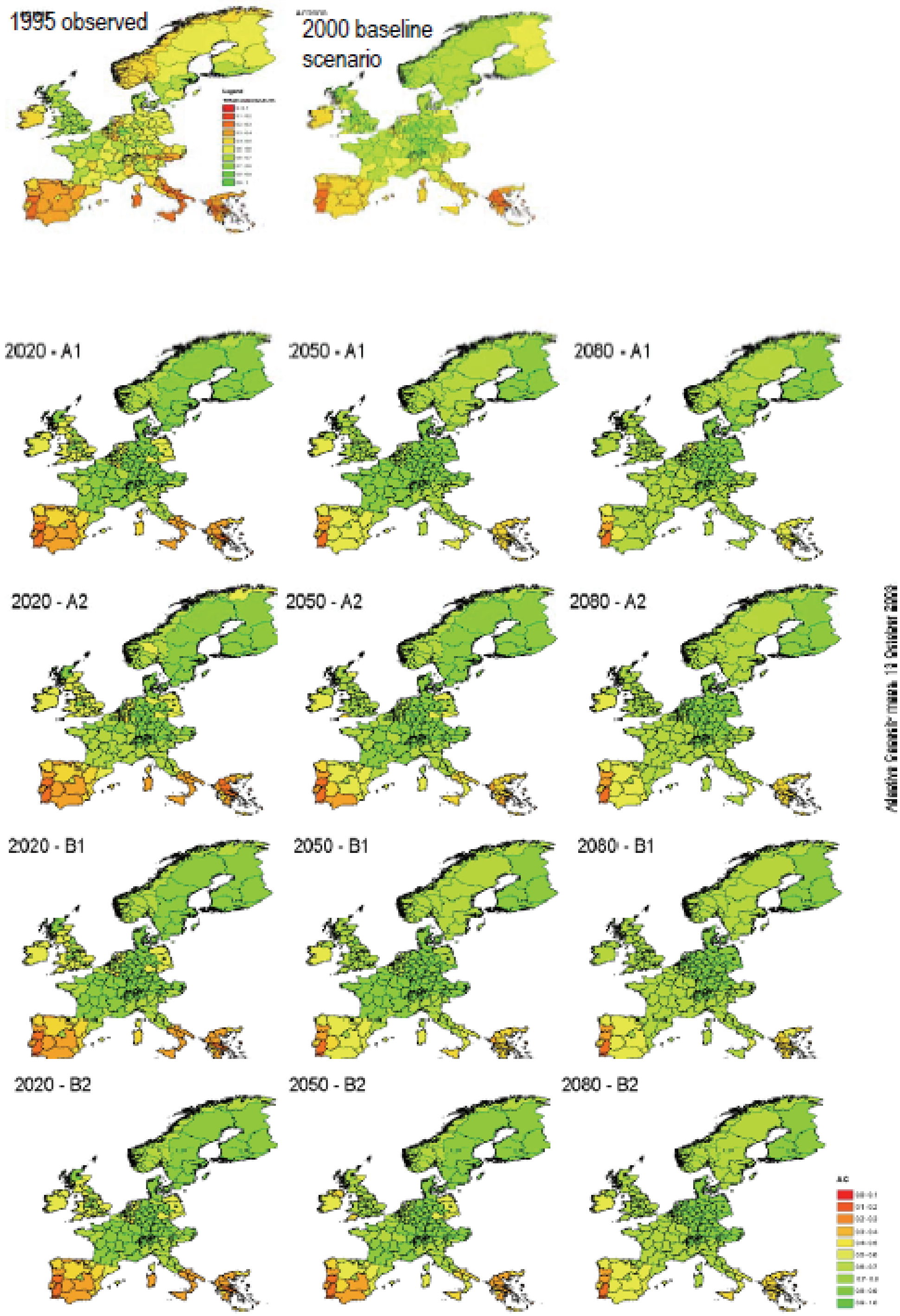


Figure 33. Preliminary maps of the adaptive capacity index (green = high adaptive capacity, red = low

Figure 15: ATEAM Adaptive capacity maps (Schröter, 2004, 119)

Enhancement of adaptive capacity

Enhancement of adaptive capacity is important for a society in order to improve its ability to adapt to climate change since it lays the foundation for actions on adaptation. Enhancing adaptive capacity has been discussed in the literature to varying degrees in the recent years, and it has been discussed in relation to development of societies in general. The IPCC's Third Assessment Report discusses adaptation mainly with regards to developing countries and as a result, enhancement of adaptive capacity is mainly discussed in relation to, and considered to be compatible with the goals of sustainable development. It is admitted that the processes needed for enhancing adaptive capacity are similar to those of sustainable development processes, including social, economic and environmentally sustainable growth. On the other hand, underdevelopment can hamper and result in a lower adaptive capacity for a society.

Although enhancement of adaptive capacity is crucial in preparing to adapt to the impacts of climate change, it is important to keep in mind that adaptive capacity, even an enhanced one, does not automatically or necessarily lead to the planning, or implementation of adaptation as discussed in the previous sections of this report. Thus, enhancement of adaptive capacity can contribute to and enable the emergence of adaptation but does not necessarily result in the adoption of adaptation measures.

The Third Assessment Report outlines several issues that contribute to the building of adaptive capacity that draw mostly on developing country context but are also relevant in the developed country context (IPCC 2001). These include reduction of poverty within the society, as well as to moderate structural inequities. Lowering of inequities in the distribution of wealth and resources among groups, as well as intergenerationally, is considered important, as well as improving access to resources in general. Overall, improved institutional capacity and efficiency also contribute to the enhancement of adaptive capacity. Improvements in technology and infrastructure naturally play a part in the enhancement in adaptive capacity, but case studies have also shown the value of local experience together with active participation to match the local resource and needs.

IPCC's Third Assessment Report considers some underlying requirements that contribute to a high adaptive capacity based on an extensive literature review of relevant material (IPCC 2001), and these relate closely to the dimensions discussed in the previous section. The authors conclude that a nation that has a stable and prosperous economy is likely to have higher adaptive capacity, and the ability to enhance it. Access to technology across scales of decision-making and sectors also enables societies to enhance their adaptive capacity. Similarly, governance systems that ensure equitable distribution of resources and power influence positively the adaptive capacity of a society. More specifically in relation to climate change, roles and responsibilities in relation adaptation actions are important, as is the dissemination of climate information across scales of decision-making.

As vulnerability to climate change will be observed across multiple levels in society, adaptive capacity is also distributed across levels of decision-making in a society. Therefore, the enhancement of adaptive capacity can also take place across several scales within a society

(IPCC 2001). The Third Assessment Report, having reviewed literature on the matter, outlines possible measures that aim to enhance adaptive capacity at different scales of social organisation, see Table 13 for more details.

Table 13: Measures to enhance adaptive capacity across several scales (IPCC 2001)

Scale of social organisation	Actions and measures to enhance adaptive capacity
Global	Greater cooperation between industrialised and developing countries to align global and local priorities by improving policy/science interactions Working toward greater public awareness of climate change and adaptation issues Inclusion of global institutions for global-level adaptation, which would include research and facilitation of policy, funding, and monitoring at all levels of social organisation Removal of barriers to international trade can lead to improving market conditions, which can reduce the exploitation of marginal land, accelerate the transfer of technology, and contribute to overall economic growth, which in turn can enhance adaptive capacity Effective global economic participation can stimulate technology transfers, technical and managerial skills transfers, and other skills transfers associated with the "learning and doing" process
National	Development of climate change policy that is specifically geared toward more vulnerable sectors in the country, particularly focusing on poverty reduction Establishment of broadly based monitoring and communication systems, i.e. drought or flood information systems Establishment of public policy that encourages and supports adaptation at local or community levels and also in the private sector Pursuit of sustainable economic growth, which can contribute to the development of sustainable technologies and infrastructure
Local	Establishment of social institutions and arrangements that discourage concentration of power in a few hands and prevent marginalization of sections of the local population Arrangements need to consider representativeness of decision-making bodies and maintenance of flexibility in the functioning of local institutions Encouragement of diversification of income sources that leads to risk-spreading particularly amongst the most vulnerable Encouragement of formal or informal arrangements for collective security Identification and prioritisation of local adaptation measures and provision of feedback to higher levels of government to be reinforced by adequate provision of knowledge, technology, policy, and financial support

The report exemplifies this division by using a case study example from Bangladesh and need to enhance capacity in relation to a specific climate impact, sea level rise. On the one hand, at the local level, reduction of vulnerability and enhancement of adaptive capacity can relate to specific measures at the individual, household or community level, and they also need to be location specific to reflect the climate change impact in question. On the other hand, at the national level, measures to enhance adaptive capacity can relate more to building up and improving technological solutions and infrastructure, whilst also focusing on developing efficient and well-functioning political institutions. Measures to enhance adaptive capacity amongst the neighbouring countries that also face similar impacts can include cross-border co-operation and strengthening of international economic and political structures.

The Third Assessment report also outlines key findings related to adaptation and adaptive capacity on different continents (IPCC 2001). For Europe, the report recognises that in general, the adaptive capacity and potential for adaptation is relatively high in comparison to other continents. This is mainly as a result of strong economic conditions and a stable population with a possibility to migrate. In addition, well-developed political, institutional and technological system can support in adaptation to the impacts of climate change. The TAR, however, does point out that it equity issues are of concern is Europe as well since more marginal and less wealthy areas less likely to adapt. Furthermore, without appropriate policies, responses to climate change can potentially lead to greater inequities.

Enhancing adaptive capacity of European regions

As already been discussed above, adaptive capacity and the enhancement of it as a whole, as well as its determinants and dimensions, enables or improves the ability of societies to adapt. It is important to note that adaptive capacity does not necessarily lead to adaptation measures being designed or implemented. Majority of the writings that deal with enhancing adaptive capacity focus either on societal development in general or on a particular dimension. Thus far not much attention has been paid to the relations between the different dimensions and how these interact with each other. For example, it is yet unclear whether it is necessary to have certain capacity to develop and improve other kinds of capacity, or whether it is necessary to improve capacity in all dimensions in order to achieve enhancement of adaptive capacity as a whole. This naturally raises the question of how the dynamics between the dimensions, if at all, affect the efforts to enhance adaptive capacity. Thus, it is acknowledged here that it is nearly impossible to discern the way in which the different dimensions of adaptive capacity relate with each other.

In this report, adaptive capacity is considered to consist of three aggregate dimensions, awareness, ability and action. Awareness here consists of one dimension, knowledge and awareness, and further measured by educational commitment, computer skills and attitudes towards climate change. Ability is made of the infrastructure and technology dimensions. Transport, water availability and hospital beds measure infrastructure as a dimension, whilst resources available for technology and the capacity to undertake research and development measure the technology dimension. Action comprises of two dimensions, institutions and economic resources. Institutional capacity is measured by government effectiveness, regional co-operation and the existence of a national strategy. Economic resources are measured by income per capita and state expenditure at the regional level as well as age dependency ratio.

Measures to enhance adaptive capacity here, naturally, relate to the development of awareness, ability or action in a broader manner than just the by focusing on the aspects that are measured here by indicators of adaptive capacity. It is acknowledged that the indicators chosen and applied in this report do not fully reflect the nature of each dimension of adaptive capacity, and that the efforts to enhance adaptive capacity solely based on factors that are described by the indicators in this report may not lead to improvements in the dimensions of adaptive capacity. Thus, improvements in one aspect of one dimension do not necessarily mean that that one dimension has a direct influence on the overall adaptive capacity. Thus far, as discussed above, examples of cases where adaptive capacity has been enhanced are still rare in the relevant literature, and much of the literature focuses on developing country cases, although some examples from municipal and regional level in the developed countries are beginning to emerge.

In terms of raising the awareness of climate change, its impacts and the possibilities for adaptation, successful cases and early movers on adaptation have generally highlighted the changes in awareness and thinking and leadership in terms of responding to the challenge of climate change (Saavedra, Budd 2009). Other examples have shown the role of climate information, and the provision of data to be crucial for building adaptive capacity (Twomlow et al. 2008). In terms of the EU, the clearing house mechanism for adaptation knowledge to be established as a result of the White paper on adaptation is a good example of steps towards increasing the knowledge of climate change. In addition, at the national level, there are several examples of national portals, i.e. Denmark and Finland, where climate change and adaptation related information is being made available for stakeholders at the sub-national level.

Ability, underlying adaptive capacity, is composed of technological solutions for adaptation, as well as existing infrastructure and new developments for solving problems posed by climate change impacts. The role that technology can play in enhancing adaptive capacity has been highlighted in some cases. For example, the use of irrigation related technologies can play a major role in agricultural areas (Pittman et al.). Similarly, new technologies in tilling the land have been shown to increase the adaptive capacity of resources users (Hagmann, Chuma 2002). However, the authors also point out that issues related to knowledge and dissemination are crucially related to the uptake of new technology, highlighting that the existence of technology does not itself mean that a society possesses a higher adaptive capacity. Infrastructure is important for adaptation, taking the form of public goods that societies provide for their citizens. These public goods, such as land use coastal defence systems and early warning systems of extreme events are important for enhancing adaptive capacity (Tompkins et al.). Infrastructure in Europe in general is quite well developed but much of this has been designed before climate change has become concern, and new developments need to take the projected climate change impacts into account.

Action in this report is composed of two dimensions, institutions and economic resources that enable a society to act on adaptation. In comparison to the other dimensions, more has been written about the role of institutions, including social capital and decision-making at different scales of social organisation (Gupta et al. 2010, Tompkins et al., Eakin, Lerner & Murtinho 2010, Spiess 2008). Collaborative learning and sharing of experiences and practices is considered to be important and can enhance adaptive capacity (Pelling, High 2005, Marshall 2010), and according to the literature this particularly important in the developing country context (Eakin, Lerner & Murtinho 2010). Institutions perhaps play a larger role in enhancing adaptive capacity in Europe where the other dimensions are considered to be quite high already. Gupta et al even outline the adaptive capacity of institutions themselves to comprise of 22 characteristics that can be used to analyse institution’s adaptive capacity (Gupta et al. 2010). For example, within the forest sector, socio-economic factors that affect the adaptive capacity of the sector relate to the management traditions and decision-making structures (Lindner et al. 2010), and measures to enhance capacity need to address these management systems. Much has not been written in terms of enhancing the economic resources for adaptation. Some examples in terms of business do exist with the focus on different sectors (Berkhout, Hertin & Arnell 2004).

In terms of the assessment conducted here, the adaptive capacity maps can give initial indication in terms of what dimension scores lowest in the indicators. For Northern Europe, both awareness and ability seem to lower than action, thus indicating that in terms of policy recommendations, measures that focus on knowledge and awareness as well technology and infrastructure can have a positive effect on adaptive capacity. In the British Isles, awareness appears to be lowest of all three dimensions, although quite significant variation between regions can be distinguished. Here policy recommendations to enhance adaptive capacity need to focus on all three dimensions. In terms of enhancing adaptive capacity in Central Europe, ability appears to be the dimension with the highest score, and therefore measures can be targeted towards enhancing the awareness and action dimensions of adaptive capacity. Regions around the Mediterranean appear to have lowest scores in terms of awareness and to some extent ability. However, given that on a European scale, the regions score lower on average, policy measures should target each of the three dimensions. Similarly, regions within Eastern Europe have lower capacities all around, but specific policy measures can be targeted on action, since this appears to have the lowest capacity of the three dimensions.

3.5 A regional typology of climate change vulnerability

The IPCC defines vulnerability as "[t]he degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity" (IPCC 2007c). Within the ESPON Climate project the first two elements (climate variation and sensitivity) were first combined to arrive at the impact of climate change and then related to the adaptive capacity. On this basis this chapter presents the pan-European vulnerability results of the project (section 3.5.1) and some alternative scenarios (section 3.5.2).

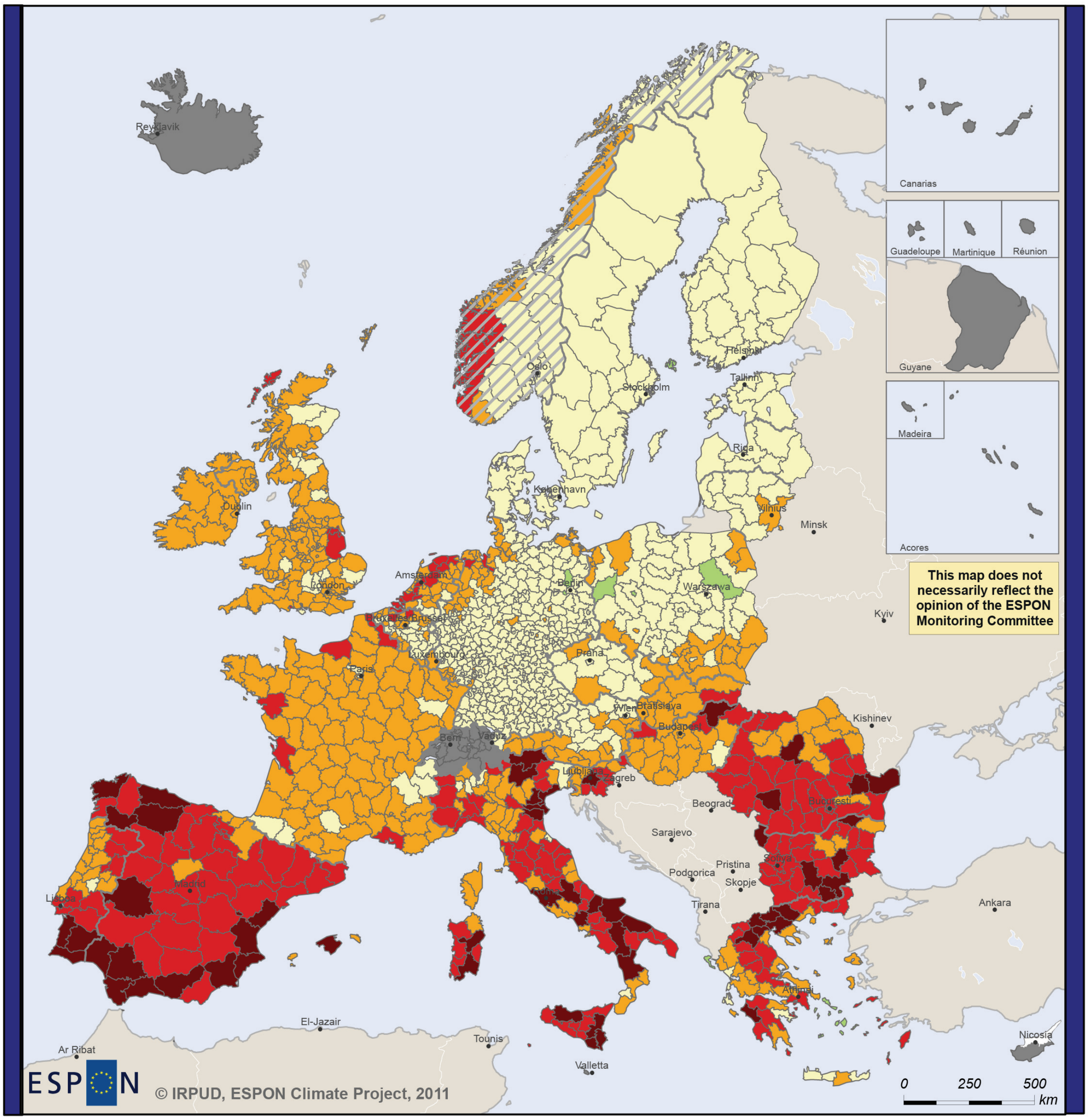
3.5.1 The ESPON climate change vulnerability typology

The potential vulnerability of Europe's regions to climate change (see Figure 70) looks slightly different compared with the map on aggregate impact: the south-north gradient which was already visible on the aggregate impact map is now even more obvious. This is due to the considerable adaptive capacity of Scandinavia and Western European countries which lowers the potential impact projected for these regions. However, this is somehow astonishing: particularly those countries which may expect a medium to high negative impact seem to be less able to adapt than others for which the severity of the problem is less visible. In consequence, a medium to high vulnerability may be expected in the Mediterranean region, but also in South-East Europe.

This scenario for the future runs counter to territorial cohesion. Climate change would trigger a deepening of the existing socio-economic imbalances between the core of Europe and its Southern and South-eastern periphery. Particularly the East of Europe is also affected by demographic changes (in particular outmigration and ageing; see scenarios in the Scientific Report), which may lead to an additional increase in sensitivity and therefore impact. At the same time these demographic changes would also decrease Eastern Europe's adaptive capacity, since an ageing of population makes the population more sensitive (i.e. to heat) and less capable to adapt.

These problematic patterns of vulnerability call for additional efforts in balancing and harmonising spatial differences to ensure a balanced and sustainable territorial development of the EU as whole, strengthening its economic competitiveness and capacity for growth while respecting the need to preserve its natural assets and ensuring social cohesion as stated by the Green Paper on Territorial Cohesion (EC 2008).

Apart from this remarkable result, territorially differentiated adaptation strategies seem to be important primarily for tourist resorts in the Mediterranean region, but also in the Alps, because both types of regions are identified as particularly vulnerable. Such differentiated strategies are discussed by two ESPON Climate case studies. Moreover, agglomerations - mainly in the South - have to be mentioned. They are vulnerable for several reasons, of which urban heat might be the most relevant one from a long-term perspective as this poses not only risk for human health, but also leads to additional energy demand for cooling and as a second order effect possibly to frequent power failures.



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Origin of data: see data sources of the individual impact and adaptive capacity dimensions

Potential vulnerability to climate change

- highest negative impact (0.5 - 1.0)
- medium negative impact (0.3 - <0.5)
- low negative impact (0.1 - <0.3)
- no/marginal impact (>-0.1 - <0.1)
- low positive impact (-0.1 - -0.25)
- no data*
- reduced data*

Vulnerability calculated as the combination of regional potential impacts of climate change and regional capacity to adapt to climate change.

The potential impacts were calculated as a combination of regional exposure to climate change (difference between 1961-1990 and 2071-2100 climate projections of eight climatic variables of the CCLM model for the IPCC SRES A1B scenario as well as resulting inundation depth changes for a 100 year return flood event based on river flooding projections of the LISFLOOD model and coastal storm surge height projections of the DIVA model adjusted with a 1 m sea level rise) and most recent data on the weighted dimensions of physical, economic, social, environmental and cultural sensitivity to climate change. Adaptive capacity was calculated as a weighted combination of most recent data on economic, infrastructural, technological and institutional capacity as well as knowledge and awareness of climate change.

* For details on reduced or no data availability see Annex 9.

Map 49: Potential vulnerability to climate change

3.5.2 Alternative vulnerability scenarios

Alternative demographic scenario

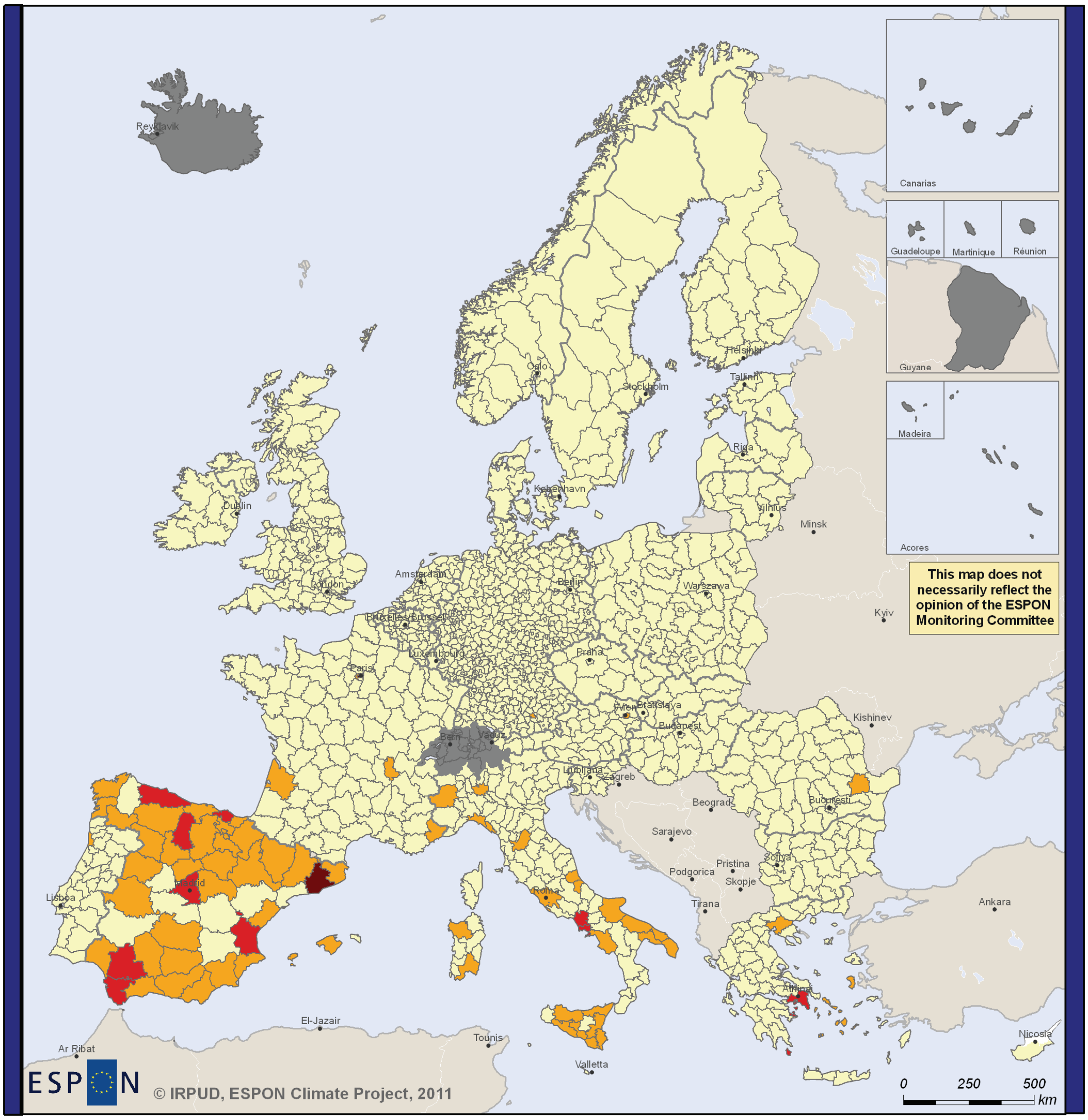
Climate change will affect future regional development and vice versa. Thus, an analysis of the effects of climate change should take into account not only future projections on exposure to climatic stimuli but also future sensitivity. However, such sensitivity projections would also raise considerable problems since, as already stated, both variables affect each other. Furthermore, economic, physical or social projections until the year 2100 are seldom, if at all, attempted. In any case such projections would be extremely uncertain given the complex hard to predict change mechanisms. On the other hand it is clear that solely considering future projections on climate change and comparing them with recent data on sensitivity neglects part of the story.

In light of these considerations the ESPON Climate project decided it was impossible or dubious to attempt fully-fledged alternative scenarios, but to rather address the issue of future alternatives as an excursus. Since for most indicators future projections are generally not available the following analysis focuses on demographic trends, because long-term projections on demographic development are at least more common than projections on other socio-economic processes and because the ESPON DEMIFER project could supply compatible demographic data up to the year 2100.

Based on the DEMIFER data the indicators relating to social sensitivity have been recalculated to represent climate change impacts on 2100 population. For instance the potential impact of summer heat on sensitive population in the year 2100 was calculated based on the analysis of recent sensitive population in urban heat islands (i.e. senior people over 65 years old). In doing so, future population in urban heat islands was derived and combined with projections on increases in the number of summer days. Of course this approach still holds considerable limitations, e.g. recent (and not future) data on urban heat islands could be used which, again, illustrates the bottlenecks of such analysis. This holds for almost all indicators since the location of future population is uncertain and will most likely differ to a good extent from the spatial data on recent settlement patterns used within these analyses. Accordingly, for this analysis only the magnitude (and not the extent) of regional impacts may vary since most indicators in this field are derived from analysis of high resolution raster data which itself remains static in terms of settlements patterns. However, further urbanisation i.e. in areas which are already prone to the urban heat island effects would definitely worsen the given situation.

The results indicate some variations as compared to the reference scenario which focuses on recent population. Although the maps are not immediately comparable one can depict varying patterns on the European level by comparing the results from this analysis to the reference scenario.

For the analysis of impact of climate change on future heat-sensitive population the results appear to be quite plausible: impacts increase most significantly in Southern European regions with a particular focus on Spain as a whole. This is on the one hand of course a function of the increase in the number of summer days but also a result from an increasing number of old people rendering the situation even worse whereas most of the other regions do not show significant changes. The overall pattern looks almost similar to the analysis results building upon recent population data (see chapter 3.3.2),



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Origin of data: own calculations based on CCLM A1B Lautenschlager et al. 2009, Gallego et al. 2009/2011, CORINE Land Cover 2000/2006, ESPON DEMIFER Project.

Scenario: Potential impact of changes in summer heat on 2100 population

- highest negative impact (0.5 - 1.0)
- medium negative impact (0.3 - <0.5)
- low negative impact (0.1 - <0.3)
- no/marginal impact (0.0 - <0.1)
- no data*

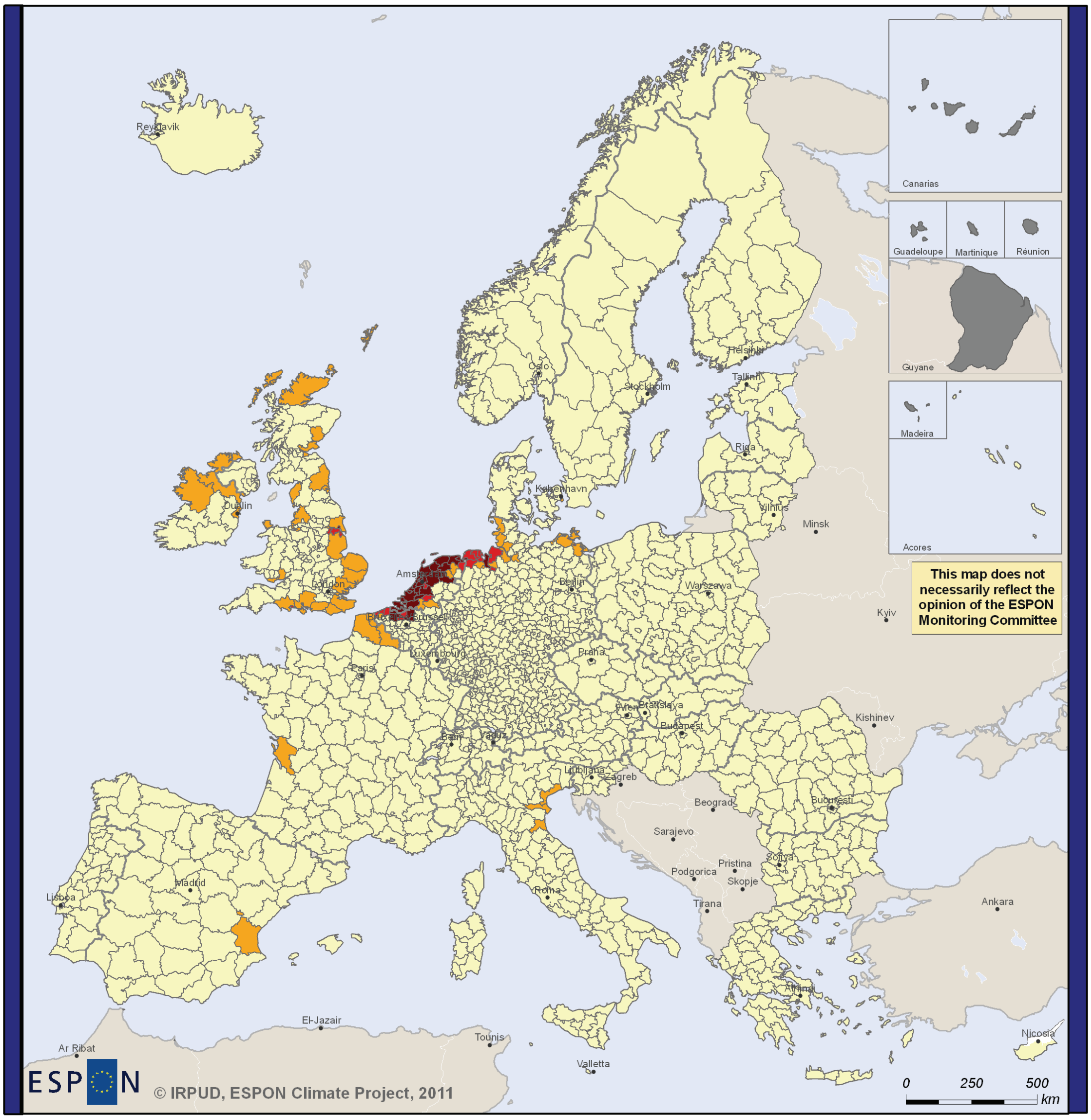
Impact of changes in summer days above 25°C on heat sensitive population in urban heat islands, using DEMIFER population projections for the year 2100.

Impact calculated as combination of regional exposure to climatic changes and recent data on regional sensitivity. Climatic changes derived from comparison of 1961-1990 and 2071-2100 climate projections from CCLM model for the IPCC SRES A1B scenario.

*For details on reduced or no data availability see Annex 9.

Map 50: Potential impact of changes in summer heat on 2100 population

The patterns emerging from the analysis of future population sensitive to coastal flooding again resemble almost completely the patterns resulting from the analysis based on recent demographic data (see Map 51). Only for a small number of regions any variations can be observed like for instance in Ireland where increases in population are projected which may lead to increased impacts from coastal flooding.



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Origin of data: own calculations based on CCLM A1B Lautenschlager et al. 2009, Gallego et al. 2009/2011, DIVA 2004, USGS Hydro1K, ESPON DEMIFER Project.

Scenario: Potential impact of changes in coastal storm surge on 2100 population

- highest negative impact (0.5 - 1.0)
- medium negative impact (0.3 - <0.5)
- low negative impact (0.1 - <0.3)
- no/marginal impact (0.0 - <0.1)
- no data*

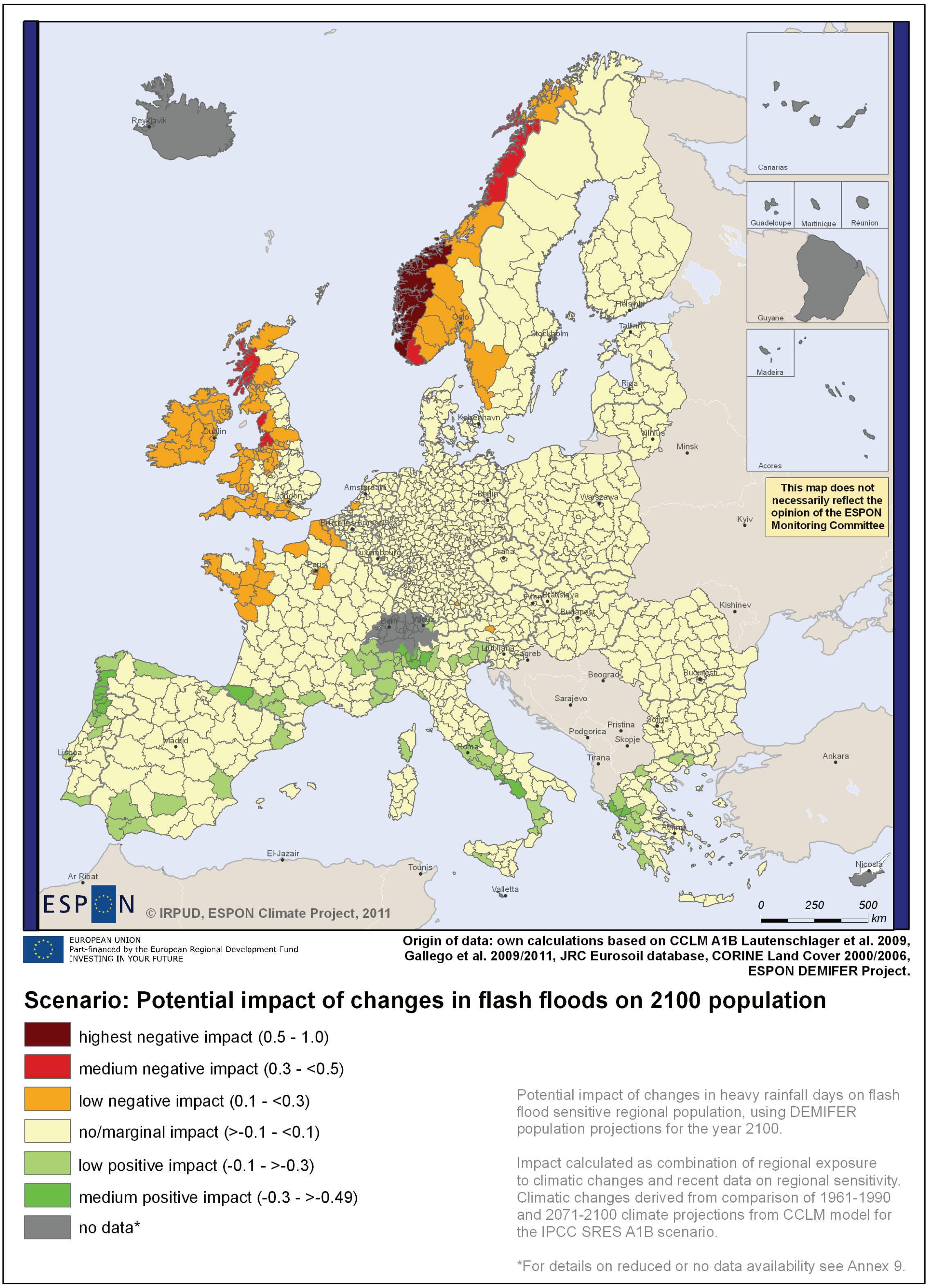
Impact of changes in inundated heights of a sea level rise adjusted 100 year coastal storm surge event on sensitive population, using DEMIFER population projections for the year 2100.

Impact calculated as combination of regional exposure to climatic changes and recent data on regional sensitivity. Climatic changes derived from comparison of 1961-1990 and 2071-2100 climate projections from CCLM model for the IPCC SRES A1B scenario. Regional coastal storm surge heights were calculated on the basis of a one metre sea level rise.

*For details on reduced or no data availability see Annex 9.

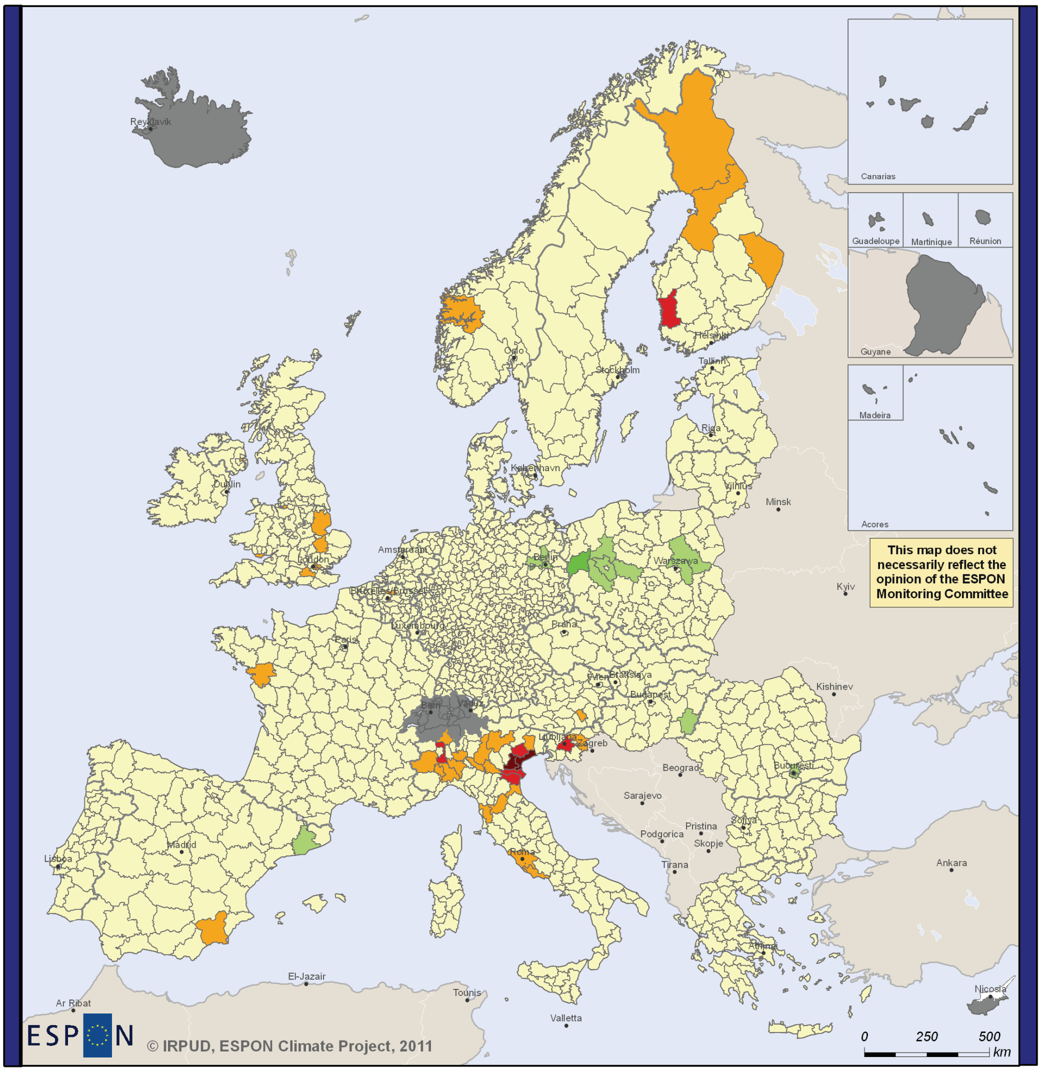
Map 51: Potential impact of changes in coastal storm surges on 2100 population

The analysis building upon projected future population and the impacts of changed flash floods due to climate change likewise exhibits almost the same patterns as the corresponding analysis based on recent population figures (see Map 52). Some cases are observable where a gain in positive impact emerges due to decrease in exposure and increases in population. However, an extension of built-up areas in these regions would lead to an increased impact.



Map 52: Potential impact of changes in flash floods on 2100 population

In contrast to the other indicators of the social dimension of climate change the indicator on future population impacted by changes in inundation through river flooding shows more significant changes if compared to the analysis based on recent population data. The emerging pattern displayed in Map 53 suggests that less population will be impacted in South-Eastern Europe both positively and negatively as compared to the analysis based on recent data. Furthermore, some minor variations are observable throughout the rest of the European territory, for instance in Germany where the analysis suggests a less positive impact (which again is due to less population which could potentially affected).



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Origin of data: own calculations based on CCLM A1B Lautenschlager et al. 2009, Gallego et al. 2009/2011, LISFLOOD A1B CCLM 2010, CORINE Land Cover 2000/2006, ESPON DEMIFER Project.

Scenario: Potential impact of changes in river floods on 2100 population

- highest negative impact (0.5 - 1.0)
- medium negative impact (0.3 - <0.5)
- low negative impact (0.1 - <0.3)
- no/marginal impact (>-0.1 - <0.1)
- low positive impact (-0.1 - >-0.3)
- medium positive impact (-0.3 - >-0.46)
- no data*

Potential impacts of changes in inundation heights of a 100 year river flood event on flood sensitive regional population, using DEMIFER population projections for the year 2100.

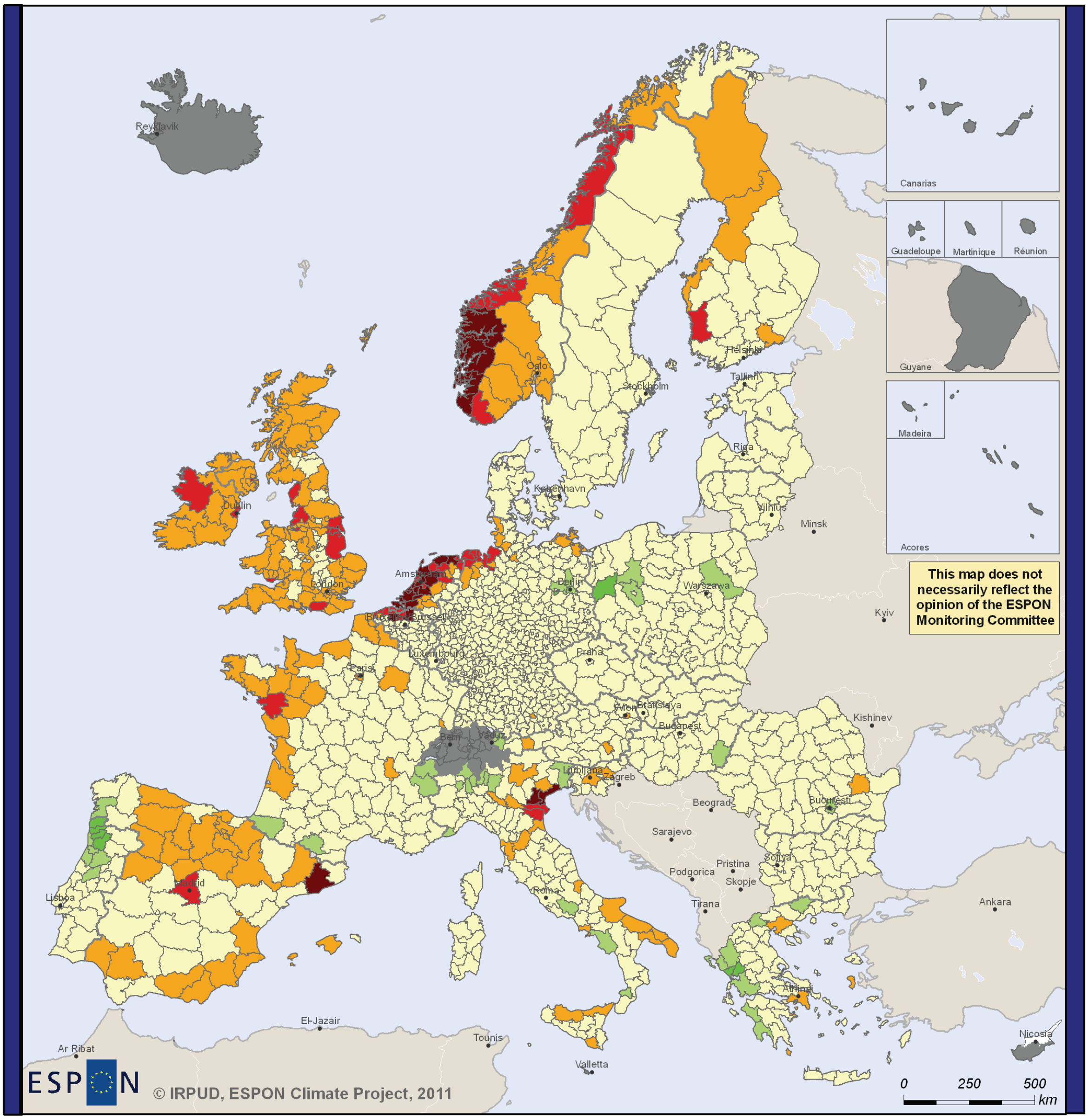
Impact calculated as combination of regional exposure to climatic changes and recent data on regional sensitivity. Climatic changes derived from comparison of 1961-1990 and 2071-2100 climate projections from CCLM model for the IPCC SRES A1B scenario.

*For details on reduced or no data availability see Annex 9.

Map 53: Potential impact of changes in river floods on 2100 population

As the final outcome of the analysis, the aggregate impact map was produced based on the four aforementioned single impact maps. For most parts of the European territory, no significant changes can be observed when comparing with the corresponding analysis results based on recent demographic data. However, The Eastern and South-Eastern parts of Europe which are generally projected to lose population display fewer impacts as compared to the reference results. Furthermore shrinking and ageing of these regional populations may also deteriorate the given capacity to adapt which is already rather limited.

On the other hand only few regions are projected to experience increases in population display significant changes. Only few exceptions can be depicted like in France or Ireland for instance where population gains lead to increases in negative impact.



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Origin of data: own calculations based on CCLM A1B Lautenschlager et al. 2009, Gallego et al. 2009/2011, DIVA 2004, USGS Hydro1K, JRC Eurosoil database, LISFLOOD A1B CCLM 2010, CORINE Land Cover 2000/2006, ESPON DEMIFER Project.

Scenario: Combined social impact to climate change in 2100

- highest negative impact (0.5 - 1.0)
- medium negative impact (0.3 - <0.5)
- low negative impact (0.1 - <0.3)
- no/marginal impact (>-0.1 - <0.1)
- low positive impact (-0.1 - >-0.3)
- medium positive impact (-0.3 - >-0.49)
- no data*

Combined potential impacts of changes in inundated heights of a 100 year river flood event and a sea level rise adjusted 100 year coastal storm surge event and changes in flash flood potential on population, using DEMIFER population projections for the year 2100.

Impact calculated as combination of regional exposure to climatic changes and recent data on regional sensitivity. Climatic changes derived from comparison of 1961-1990 and 2071-2100 climate projections from CCLM model for the IPCC SRES A1B scenario. Regional coastal storm surge heights were calculated on the basis of a one metre sea level rise.

*For details on reduced or no data availability see Annex 9.

Map 54: Combined social impact to climate change in 2100

Alternative weighting scenario

In addition to the alternative demographic scenario the project developed an alternative based on a different weighting of the impact and adaptive capacity dimensions. Thus the scenario method is used to test the future outcome of different normative assumptions. The normative assumptions underlying all the maps presented in this report were explicitly determined by the members of the ESPON Monitoring Committee by putting different weights to the impact and adaptive capacity dimensions (see below). In contrast, the maps on the following pages are based on equal weights between these dimensions.

When looking at the aggregated impact and vulnerability maps it becomes obvious that the Delphi weighting has a considerable influence on the pattern of both, impact as well as vulnerability: the general North-South gradient is still existent, but less relevant. An equal weighting of all sensitivity and adaptive capacity dimensions lower the average impact and in consequence the vulnerability. This is particularly relevant for the South of Europe.

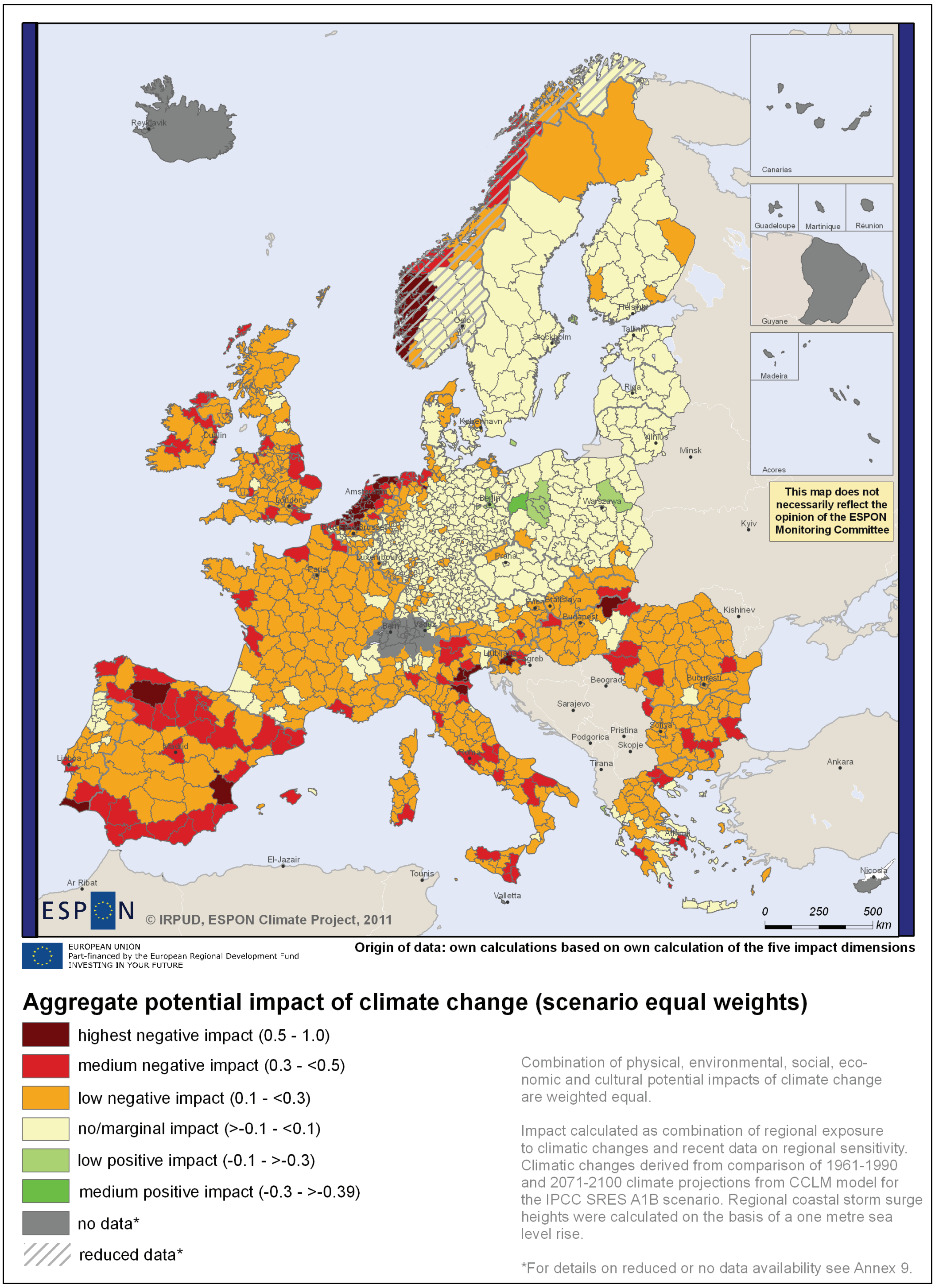
The main causing factor for the different patterns are the different weights that the Monitoring Committee put on the five sensitivity dimensions, as visible by the table below, while the influence of the weighting of the adaptive capacity components on the related map is not relevant at all.

Table 14: Dimension and weightings of sensitivity and adaptive capacity

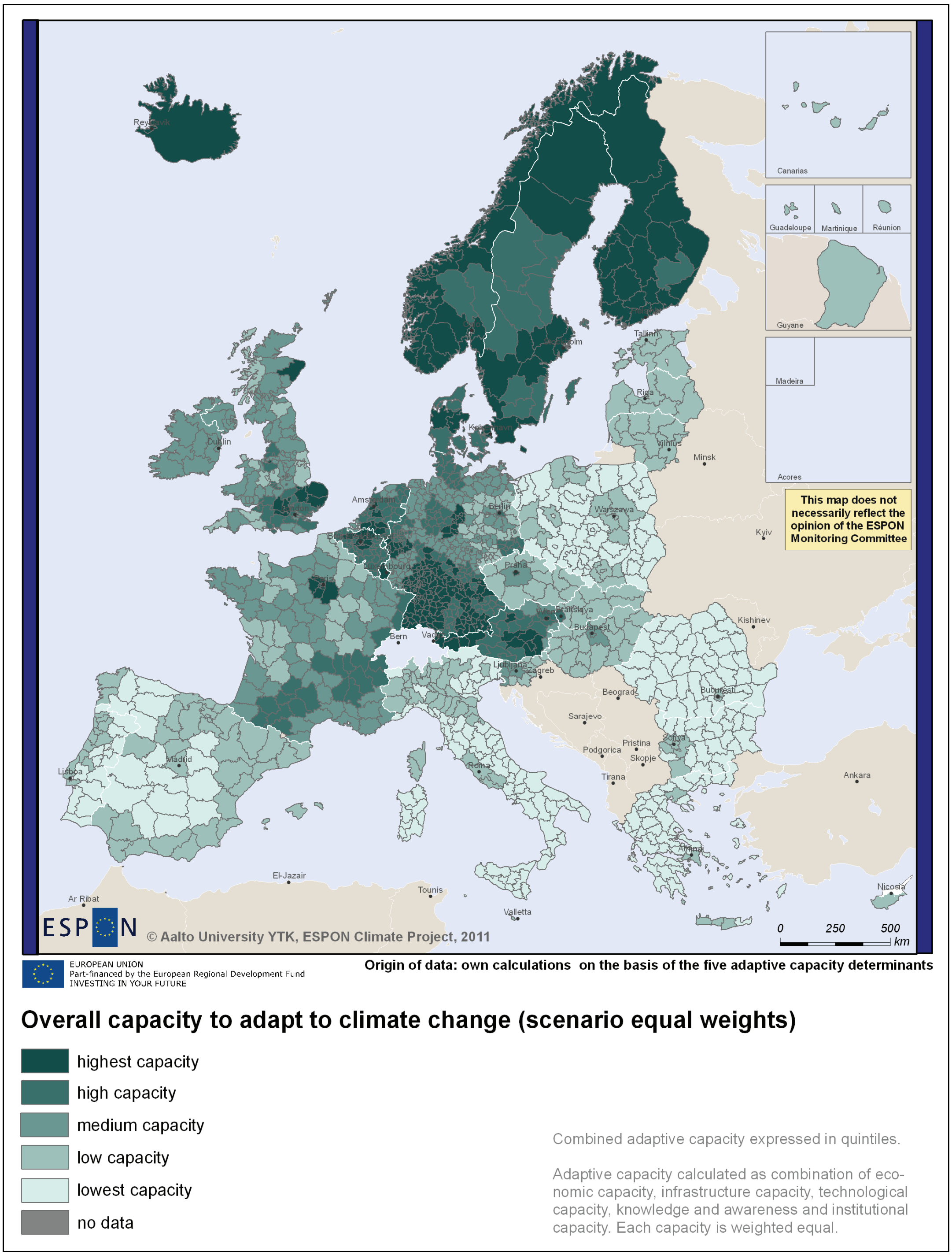
Sensitivity		*Adaptive capacity*	
Cultural sensitivity	0.1	Economic resources	0.21
Economic sensitivity	0.24	Knowledge and awareness	0.23
Environmental sensitivity	0.31	Infrastructure	0.16
Physical sensitivity	0.19	Institutions	0.17
Social sensitivity	0.16	Technology	0.23

However, this weighting makes sense and leads to much more plausible results when considering the following aspects from an ex-post perspective: Cultural sensitivity which was weighted as less important than all the other dimensions completely depends on the change in frequency and magnitude of extreme events (storm surges, river flooding and flash floods). The same applies to physical sensitivity. It should be stated that the related uncertainty in the climatic models is much higher than for the projected long-term changes in temperature. In other words: the projected impacts which determine environmental and economic sensitivity (and here the directly affected sectors tourism, energy and primary sector) are related with less uncertainty. Moreover, environmental as well as economic sensitivity are relevant for almost all NUTS 3 regions and mostly their complete territory. On the contrary, cultural sensitivity is determined by point data only (Cultural Heritage sites, museums). The monitoring committee decided to put the highest weights on environmental sensitivity. This is plausible, because all existing adaptation strategies consider biodiversity as a key vulnerable sector. Almost all species and habitats are affected by climate change which becomes also clear when looking at the aggregated environmental sensitivity map which shows that almost the whole of Europe may expect a moderate to a high negative impact on its environment due to climate change. In consequence, the high weighting of this sensitivity dimension leads to an overall increase of impact of climate change on almost all European regions. This increase is the higher the more decrease in precipitation and more increase in temperature is projected. Therefore, the relatively high environmental (as well as economic) sensitivities are causing factors for the enormous impact of climate change on Southern Europe.

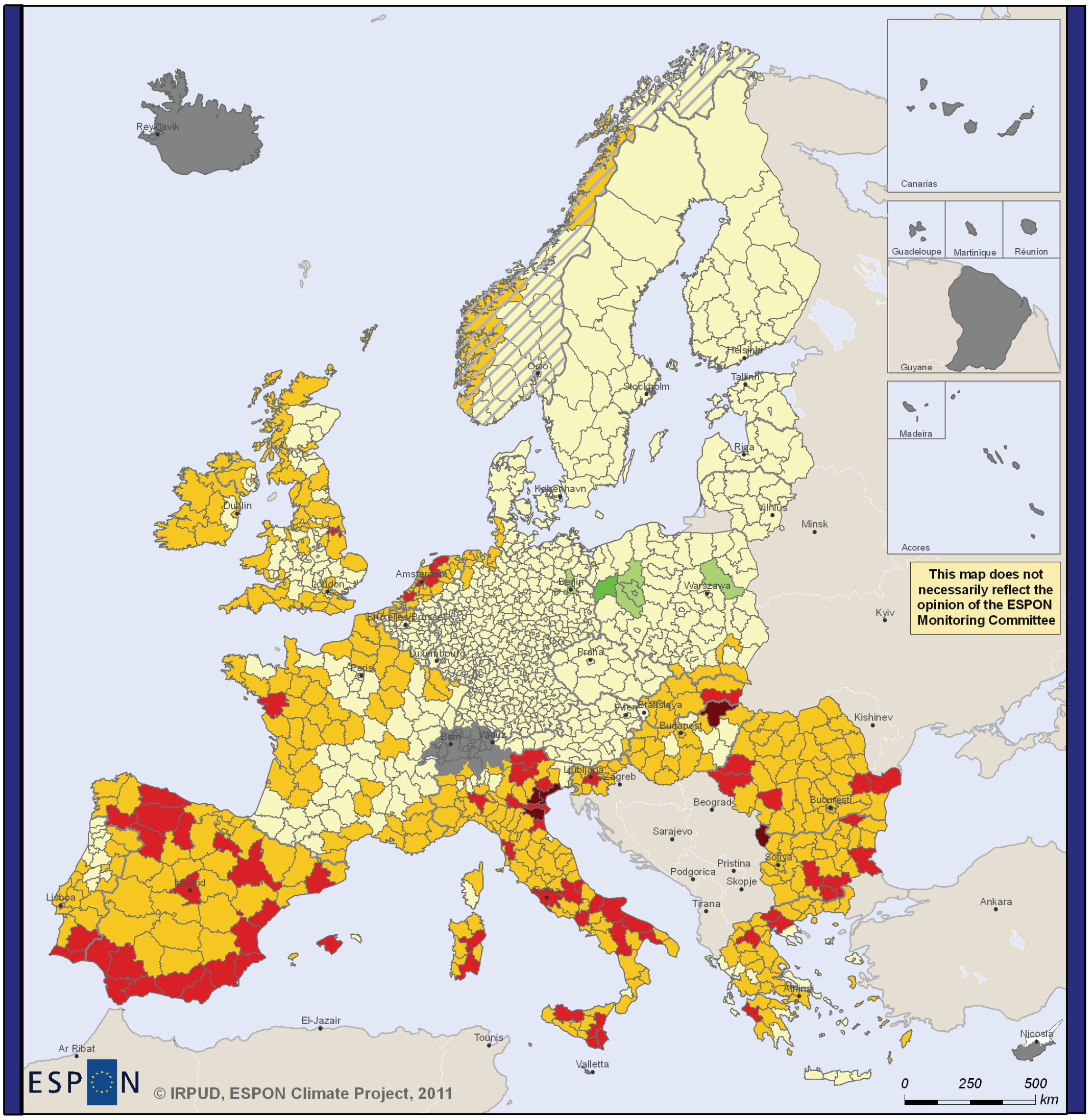
To conclude, the project decided to stick to the weighted impact, adaptive capacity and vulnerability maps. All discussions and policy recommendations are based on this set of maps.



Map 55: Aggregate potential impact of climate change (scenario equal weights)



Map 56: Aggregate adaptive capacity (scenario equal weights)



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Origin of data: own calculations based on on the aggregate impact and adaptive capacity data.

Potential vulnerability to climate change (scenario equal weights)

- highest vulnerability (0.5 - 1.0)
- medium vulnerability (0.3 - <0.5)
- low vulnerability (0.1 - <0.3)
- no/marginal effects (>-0.1 -<0.1)
- low positive effects (-0.1 - <-0.3)
- medium positive effects (-0.3 - -0.36)
- no data*
- reduced data*

Combination of regional potential impacts of climate change and regional capacity to adapt to climate change. In this scenario all impact and adaptive capacity dimensions are weighted equally.

* For details on reduced or no data availability see Annex 9.

Map 57: Potential vulnerability to climate change (scenario equal weights)

3.6 Mitigative and response capacity of European Regions

Thus far this report has focused on the vulnerability of European regions in relation to the expected climate change impacts. However, mitigation of greenhouse gas emissions is also important and alongside adaptation has been considered a crucial societal response to global climate change (IPCC 2007). The methodology and calculation of adaptive capacity for European regions as part of the pan-European vulnerability also enables to focus on the concept of mitigative capacity and response capacity. Although these two concepts do not form part of the vulnerability assessment, they enable this ESPON Climate report to discuss the response of European regions more widely.

Similarly to adaptive capacity, the ability of a society to mitigate emissions is depended on the capacity of the society to respond. Thus, this section explores the concepts of mitigation and response capacity that underlie the action on climate change. Mitigation capacity can be defined as the ability of a society to reduce the emissions of greenhouse gases (GHG), This section reviews the literature on mitigation capacity, and develops indicators for measuring mitigative capacity that mirror the adaptive capacity indicators that were developed for the pan-European vulnerability analysis. Firstly, literature on mitigative capacity and its dimensions are reviewed, and indicators are presented. In addition, this section introduces the concept of response capacity. Response capacity, in this case, refers to the ability of regions to respond to the climate challenge by combining aspects from both mitigative and adaptive capacity. Finally, this report discusses response capacity in terms of European regions.

3.6.1 Regional capacities to mitigate climate change

Climate change mitigation in general refers to all human attempts to mitigate the effects of climate change; in practice mitigation activities strongly focus on decreasing net greenhouse gas emissions into the atmosphere, stressing the preventive nature of climate policy. Due to this, current climate policy includes also adaptation to climate change, which stresses the inevitability of climate change and its undesirable effects (see 16). Here the focus is on developing an indicator from a territorial and/or regional perspective. It is important to keep in mind that climate change mitigative capacity, just like adaptive capacity, lacks a commonly agreed definition and is thus open for various kinds of interpretations. In this kind of situation, selected indicators and their data availability may more or less define or even determine the issue (cf. Rosenström 2009, 9-10).

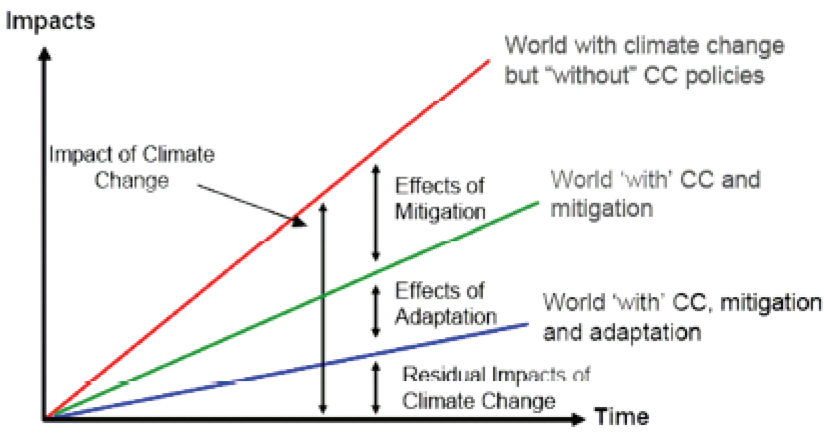
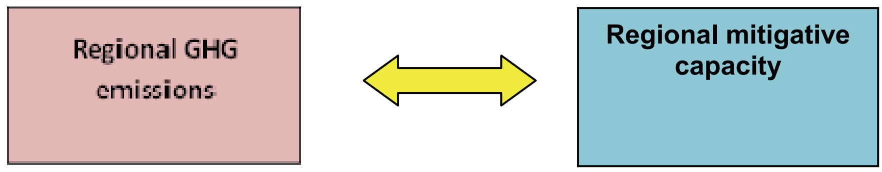


Figure 16: The impacts of climate change (Kirkinen et al 2005; modified from Rothman et al 2003).

A definition of mitigative capacity has been provided by Winkler et al (2007) and earlier and quite generic definitions have also been provided by Yohe (2001) and IPCC (2001). Winkler et al (2007) give quite a brief and clear definition to mitigative capacity, stating that '[W]e define mitigative capacity simply as a country's ability to reduce anthropogenic greenhouse gas emissions or enhance natural sinks' (Winkler et al 2007, p. 694). Winkler et al (2007) also point out that mitigative capacity is the ability to reduce GHG emissions in either absolute or relative terms. Moreover, mitigative capacity is not intended to simply explain the degree to which countries do in fact mitigate GHG emissions but it is about *how much countries could mitigate*—their theoretical possibilities to reduce emissions and enhance natural GHG sinks. The latter refers to mitigative *potential*, which could be used as a synonym for mitigative capacity. In ESPON Climate, we define mitigative capacity to include elements from awareness, ability and action, so our definition is somewhat broader than the one by Winkler et al (2007) when including also *action* which refers to what countries actually do or have done in order to mitigate GHG emissions, or to enhance natural sinks.

Regional mitigation challenge – regional GHG emissions

Regional GHG emissions inevitably have an influence to the mitigative capacity of that region (Figure 4). It can be even argued that larger the regional GHG emissions, the larger the driver for improving the regional mitigative capacity. On the other hand, climate change is a global phenomenon, and GHG emissions contribute to this problem not depending on their geographical origin. Thus, regional GHG emissions are an important element from the mitigative capacity perspective, and in ESPON Climate, it is important to have a description of them for comparison of the regional mitigative capacity and regional GHG emission in order to evaluate their relationship. The question that arises is whether the high-emission areas are different from the areas with high mitigative capacity.



Derived from UNFCCC national level data and allocated to NUTS3 areas in relation to population and value added

Measured partly with the same indicators as adaptive capacity

Figure 17: Relationship between regional GHG emissions and mitigative capacity in the region.

Relevance: Greenhouse gases (GHG) that will be dealt with when discussing climate change mitigative capacity, include those identified in the UNFCCC Kyoto Protocol (UNFCCC 1997). These GHGs are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydro-fluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6), all measured in tonnes of CO_2 equivalents.

Indicator methodology:

GHG data is available at the UNFCCC Secretariat website (see UNFCCC 2010). The data covers each GHG emission category and includes time series from 1990 onwards at the national level (up to 2007 at the moment). Because GHG emissions data at regional/local level is usually not available, the national level data can be allocated to regions in relation to other variables reflecting the size of the region, such as land area, amount of population, and regional GDP of regional value added.

Allocating all national GHG emissions to regions by using only one of these variables describing the size of the region provides a rough estimate on regional GHGs. On the other hand, in industrialised countries, such as all EU Member States, CO_2 from energy use, i.e. from fuel combustion for energy production and transport, represents 80-90 % of all GHG emissions. By assuming that final energy consumption reflects directly GHG emissions, sectoral data for different final energy consumption categories is available by International Energy Agency (IEA). This data allows a simultaneous use of different regional variables (area, population, value added) when allocating the sectoral data to regions. This gives a slightly better estimate on regional GHG emissions than the use of only one variable. Sector-based data on final energy consumption is available for all EU Member States for the time period from 1971 onwards, currently up to 2007.

The following choices have been made when allocating the national GHG data (excluding land use, land use changes and forestry): First, the shares of energy consumption in 2007 of (1) all industry, services, agriculture and non-energy use and (2) transport and residential sector in 2007 were calculated from the IEA (2009) data, and then corresponding amounts of GHG emissions excluding land use, land use changes and forestry were calculated by using the UNFCCC (2010) data. After that, GHG emissions from (1) all industry, services, agriculture and non-energy use were allocated to regions on the basis of the region's share of national value added by using Eurostat (2010) regional data, and GHG emissions from transport and residential sector were allocated to regions on the basis of region's share of the country's population, calculated from the Eurostat (2010) regional data. Finally, the two allocated GHG emission categories were summed up to the regional GHG emission estimates.

Dimensions of mitigative capacity

The literature on mitigative capacity and its dimensions is not as wide as the literature on adaptive capacity and its dimensions. Yohe was the first to attempt to define dimensions of mitigative capacity (Yohe 2001), and his work has been referred to by IPCC (2001). Yohe's list of dimensions of climate change has had influence from the work done with adaptive capacity, and this is reflected in the title of his editorial article "Mitigative capacity – the mirror image of adaptive capacity on the emissions side" (Yohe 2001) where he presents the following dimensions:

1. The range of viable technological options for reducing emissions,
2. The range of viable policy instruments with which it might affect the adoption of these options,
3. The structure of critical institutions and the derivative allocation of decision-making authority,
4. The availability and distribution or resources required to underwrite their adoption and the associated, broadly defined opportunity cost of devoting those resources to mitigation,
5. The stock of human capital, including education and personal security,
6. The stock of social capital including the definition of property rights the country's access to risk spreading processes, and the ability of decision-makers to manage information, the processes by which these decision-makers determine which information is credible, and
7. The credibility of the decision-makers, themselves.

Yohe (2001) states that this is essentially the same list of determinants that he recorded for adaptive capacity in the same article, but their application to the emissions side of the climate issue is not the same. This indicates that the indicators of mitigative capacity cannot be the same as indicators of adaptive capacity. Yohe (2001) does not give examples of actual indicators of mitigative capacity.

Winkler et al (2007) have further developed Yohe's determinants and also defined a set of indicators in relation to the factors, which influence mitigative capacity. They use the term factor instead of determinant. This may reflect the difficulty of commanding all aspects of climate change mitigation and squeezing them into a compact list of determinants. Winkler et al (2007) provide a list of determinants of mitigative capacity and related indicators (see Table 15). Some of the indicators put forward are quantitative, some qualitative.

Table 15: Determinants of mitigative capacity and related indicators (Winkler et al., 2007).

Determinant		**Indicators**
Economic factors	Ability to pay	GDP per capita
	Abatement costs	Average abatement cost of reducing GHG emissions 20 % from business as usual until the year 2030 (data from the POLES project
	Opportunity costs	The best foregone alternative use of the money. Change in production possibility frontier (PPF) which represents the trade-off between expenditure on mitigation and on other purposes. No quantitative indicators presented.
Institutional factors	Regulatory effectiveness and market rules	Ability of the Government to formulate and implement sound policies and measures such as CDM projects; effective rules for markets such as carbon tax or tradable permit system; capacity to monitor and enforce regulations; effectiveness of the court system in enforcing contracts. No quantitative indicators presented.
	Education and skills base	Adult literacy rate; Enrolment ratio (% of population of school age enrolled in education)
	Public attitudes and awareness	Influence, effectiveness and agenda of media (in relation to climate change); GHG emission targets at municipal level : reliance on science on climate change; reliance on climate-oriented NGOs
Technological factors		Number of researchers per million inhabitants; electricity consumption per capita; number of telephones per 1000 people; Internet users per 1000 people

In addition to Yohe (2001) and Winkler et al (2007), Richerzhagen and Scholz (2008) have dealt with capacities for climate change mitigation in their analysis that focused on China. However, they do not refer to the above mentioned authors but define instead "structural determinants of climate capacities":

1. economic-technological factors (i.e., the structural features of economy and society as well as the availability of climate-relevant economic, financial, and technological resources),
2. political-institutional factors (i.e., governance arrangements, administrative structures and procedures as well as climate-related policies and laws which influence participation and the coordination of policies and activities of public administration and other relevant actors), and
3. cognitive-informational factors (i.e., the existence of climate-related information and the degree of public concern about climate problems).

Mitigative capacity indicators for ESPON Climate

This report follows the idea of mirroring adaptive and mitigative capacity by using the same dimension categories. However, the same indicators are not used to measure both, as suggested by Yohe (2001) and especially by Winker et al (2007). As in the context of adaptive capacity, we use three aggregate dimensions of awareness, ability, and action. The actual individual dimensions include knowledge and awareness representing the awareness aggregate dimension; infrastructure and technology representing the ability aggregate dimension, and economic resources and institutions representing the action aggregate dimension, see Figure 5. In the following, the selected indicators under the five dimensions are presented and described.

In terms of operationalising a set of indicators for mitigative capacity at the regional level, an obvious difficulty is the availability and gathering of regional data. Climate change is a global phenomenon and a global problem, and climate policies are usually planned and implemented at national level. To some extent mathematical allocation of national data to regions may be reasonable, but obviously gathering original data at the regional level requires access to original data collected for national statistics. This is often not available, which strongly limits the possibilities to provide relevant and reliable information on regional climate change mitigation capabilities.

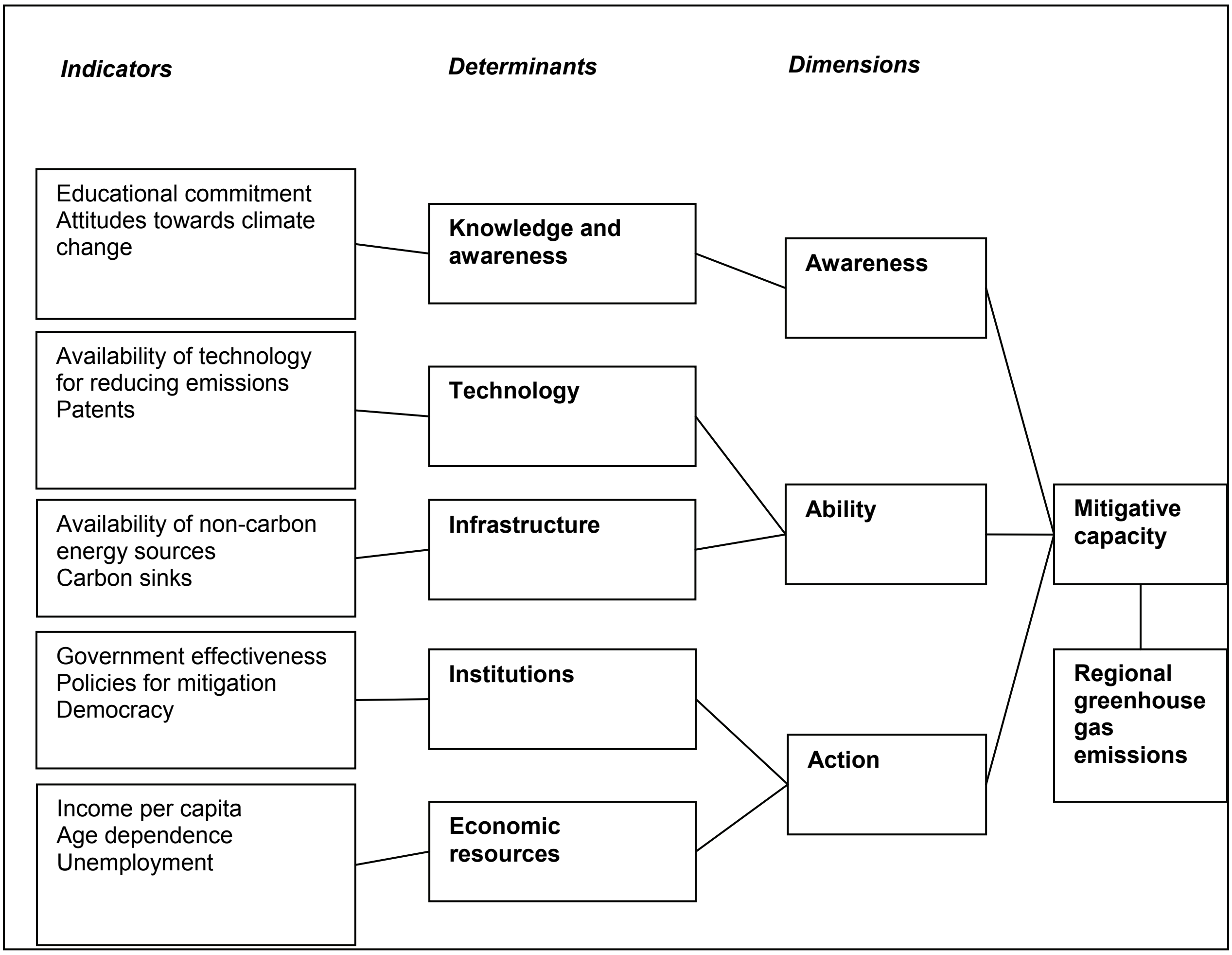


Figure 18: Dimensions, determinants and indicators of mitigative capacity (Schröter et al 2004)

Methodology of indicators

The general methodology of estimating regional mitigative capacity in ESPON Climate is identical to that of adaptive capacity described. While 15 indicators are used to calculate adaptive capacity ten (10) are used for mitigative capacity. Due to data availability issues eight of those 10 indicators are the same used in the adaptive capacity set.

The methodology for mitigate capacity follows the overall methodology of the project: For each indicator the values for the NUTS regions are normalised. Dimensions of mitigative capacity are calculated as unweighted averages of indicators specified in Figure 14. The dimensions are then normalized again. The mitigative capacity index is then calculated as the weighted average of the determinants, using the same Delphi weights as in adaptive capacity.

Knowledge and awareness

Recognition of the necessity to mitigate, gathering knowledge of available options, and the ability to asses and implement the policies and measures are crucial for mitigative capacity (IPCC 2001). Skilled, informed and trained personnel enhances mitigative capacity and access to information is likely to lead to development of mitigation options that are timely and appropriate, whilst lack of trained and unskilled personnel can lower a nation's mitigative capacity. In the European context, awareness also plays an important role as it can be argued awareness and the willingness to act on climate change rather than just being educated are more important in the European context.

Educational commitment

Relevance: Skilled and trained personnel and population in general can increase the mitigative capacity of a society because of the contribution of trained personnel towards assessing and implementation measures required to mitigate climate change.

Existing studies: Majority of the existing studies cite educational levels as one of the core component of the capacity to mitigate climate change (Yohe 2001; Winkler et al 2007). A region that has an educated population is likely to become concerned about climate change, as well as strive towards developing mitigation options and measures in the short and in the long term.

Indicator methodology: The level of a regions educational commitment can be assessed with the education expenditure per capita within a region. Data is available from Eurostat at NUTS0 level for the entire ESPON space.

Technology

Technological resources enable different mitigation options, and consequently lack of access and development of technology can lead to lower mitigative capacity as many of the strategies identified in response to climate change involve technology (IPCC 2001). Development of technologies can be undertaken by both the public and private sector, and innovation is considered an important factor in this. However, it is necessary to keep in mind the difference between general technological capacity, and specific technological response which can be developed for a specific greenhouse gas component, or specific type of carbon sink. The focus here is on general aspects of technology without a specific focus on particular GHG or sink type.

Available technologies for reducing GHG emissions in the region.

Relevance: In principle climate change mitigation is strongly dependent on available technologies in a given society. Some technologies are in close connection to issues already discussed such as non-fossil energy sources, but other technologies may become very important in the future such as carbon capture and storage (CCS) technologies.

Indicator methodology: Resources for technology can be measured by the percentage (% of GDP) in R&D investment. Reliable data is available from Eurostat on NUTS 2 regions for the entire ESPON space excluding Liechtenstein.

Patents

Relevance: The number of patents applied for in a given region is also an indication of the technological capacity of that region. It indicates that there is research taking place within a region, and furthermore that this research is utilised for further purposes to develop products and services.

Existing studies: There are no existing studies that utilise patents to measure but the number of patents does reflect the utilisation of research and development efforts by the government and the private sector (IPCC 2007b).

Indicator methodology: A suitable indicator is to measure the number of patent applications per million inhabitants. Data is available for this from Eurostat on NUTS 2 level for the entire ESPON space, excluding Ceuta and Melilla, for which data acquired from the Spanish Instituto Nacional de Estadística.

Infrastructure

Infrastructure is important for mitigative capacity as it can facilitate and enable the move to use of non-fossil fuel energy resources. Natural resources, particularly related to the production of renewable energy, available for a region are part of the energy infrastructure that underlies a region’s ability to mitigate greenhouse gases. Similarly infrastructure related to land use is important in relation to mitigative capacity.

Non-carbon energy resources available in the region

Relevance: Availability of non-fossil energy resources is an important part of climate change mitigation capacity. Non-fossil energy sources include e.g. biomass, hydro, wind, geothermal, nuclear etc. A crucial question is how centralised electricity production facilities such as nuclear or big hydro plants and imported energy, especially imported electricity, are treated from the regional perspective.

Existing studies: Energy saving potential refers to possibilities to decrease energy consumption in the region via improvements in energy efficiency, avoidance of unnecessary energy consumption, changes in the structures of energy consuming activities and shifting energy production to another location. These options are derived from the well-defined factors affecting energy consumption, i.e. activity effect, intensity effect and structural effect, identified in the literature dealing with decomposition analysis, where the relative shares of these factors are studied and calculated using different mathematical methods (cf. Ang & Zhang 2000; Ang et al 2003; Ang 2004; see also Vehmas 2009).

Indicator methodology: National data of non-fossil energy sources is available from the publications of International Energy Agency (IEA 2009a; 2009b; 2009c; 2009d).Total primary energy supply and final energy consumption are reported by energy source. Regional availability of these energy sources vary a lot, so allocating national data to regions based on population, value added or land area of the region may provide misleading results.

Data on “PV output” and “wind energy potential” for European regions at NUTS 2 level are available and used in the ReRisk project in the ESPON 2013 programme. Then ReRisk draft final report does not describe detailed methodological information about these indicators, this should be obtained from the original sources (JRC renewable energies unit for PV output and ReRisk project where own estimated have been done on wind power potential based on European Topic Centre on Air and Climate change (ETC/ACC) data of wind intensity). These indicators refer to the availability of these non-carbon energy sources in the European regions, and the data at NUTS 2 level is available in the Annex of the ReRisk draft final report and related maps are also included in the report.

Carbon sinks in the region

Relevance: From the perspective of climate change mitigation capacity, the land use perspective is the clearest in the case of forest areas, because forests are an important carbon sink in the climate system. This indicator requires an estimate of the amount of forests and the size of this regional carbon sink in terms of absorbed carbon dioxide. The bigger the carbon sink, the larger is the climate change mitigation capacity.

Indicator methodology: National estimates of carbon sinks are available at the UNFCCC database (see UNFCCC 2010). Regional data of land use types are required to provide a useful indicator for this dimension of mitigation capacity. An available indicator is the amount of carbon sinks (estimated amount of greenhouse gas absorbed by forests etc. in GHG units) at national level in the UNFCCC (2010) database.

Institutions

Institutions, defined as a social rules and norms, are considered to play an important part developing responses to climate change, and also are a determinant of mitigative capacity. Well-developed institutions enable societies to plan and execute policies related to the reduction of greenhouse gases. The following indicators are used to reflect the role of institutions in adaptive capacity.

Government effectiveness

Relevance: The efficiency of government is an important factor overall in decision-making, and is likely to impact positively the adaptive capacity of a region. If decision-making is effective and carried out in that manner, it is likely also that decisions related to mitigation are taken.

Indicator methodology: Data on government effectiveness is available from the World Bank database. Reliable data is provided on national level for 215 countries, including the whole ESPON space.

Policies and measures in use for climate change mitigation in the region

Relevance: Existing policies and measures aimed at climate change mitigation reflect apolitical willingness to mitigate climate change. Climate change related policies are designed, including the use of legally based instruments, at the national level. In addition, some regions may have their own GHG emission targets, economic instruments, voluntary agreements, and other instruments. Policies and measures are often in use at national level, so the national data availability is applicable at regional level in most of the cases. Thus, there is no specific need to provide a regional indicator on policies and measures due to the fact that policies and measures are mostly implemented at national level.

Existing studies: OECD and European Environment Agency (EEA) have established a database on environmental policy instruments (OECD and EEA 2009) which includes environmental subcategories such as climate change. However, the database does not give precise up-to-date information of each policy instruments, but gives an overview what kinds of instruments are in use in different countries. The content of the database is based on national communication, and information of different countries is not directly comparable. For example, energy tax on fossil fuels can be considered as a single instrument or several instruments when applied to different fuel types (coal, oil, gas, etc.). In the context of the UNFCCC, National Communications provided regularly by the UNFCCC and Kyoto Protocol parties include information on policies and measures is use, most of them for climate change mitigation. The reports include descriptions of existing and planned climate strategies, including relevant policies and measures.

Indicator methodology: The focus in this indicator is on the number of different instrument for this purpose. Studying the effectiveness and impacts of existing policies and measures is also important, but this goes further from the mitigation capacity to actual mitigation already taking place. As noted earlier, policies and measures are usually implemented nationally, but their impacts on different regions are also different. The capacity of a carbon tax is obviously larger in a region where large amounts of fossil fuels are used in comparison to a region where energy use is mainly based on non-fossil sources. Thus, the indicator describing the policies and measures dimension of climate change mitigation capacity is the number of policies and measures in use in the region. In practice, regional differences are difficult to find since the basic data is mostly described at national level only.

Democracy

Relevance: Mitigative capacity, it can be argued, will be greater if resources and power in governing resources for adaptation are equitably allocated. Both availability and access to capacity are important in mitigative capacity.

Indicator methodology: Equity is measured here by the female participation in political life, using the gender weighted democratisation index (Vanhanen, 2010). Data for this is available from FSD (The Finnish Social Science Data Archive) and is provided on national level for all independent states with over 40 000 inhabitants.

Economic resources

Economic assets are an important part of mitigative capacity as they enable the use of capital resources and financial means to be used in development of technologies for low carbon technologies. The following indicators are used to measure the economic aspects of mitigative capacity.

Economic resources

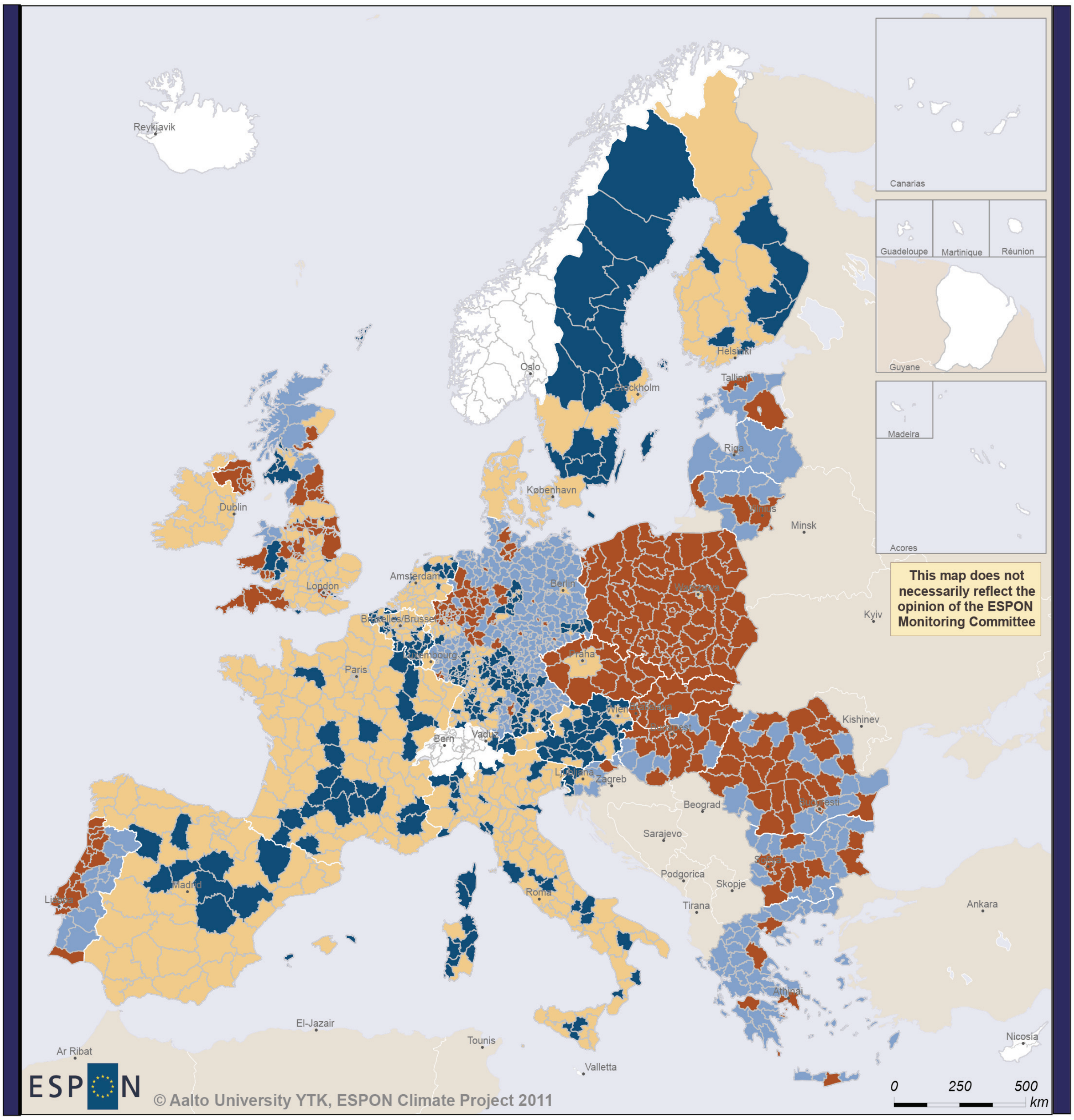
Relevance: Economic assets play an important role in mitigative capacity as they can be used to fund and support mitigation measures and strategies, and also in the development of technologies to reduce GHG emissions. They can also to further increase mitigative capacity by investing in other capacities, such as information dissemination, education amongst others.

Indicator methodology: A suitable indicator for measuring economic performance is GDP per capita (€ PPP) of a region. Statistical data is available for entire ESPON space from the ESPON Database. Data for IS (Iceland) acquired from Eurostat.

Territorial potentials for mitigation of climate change

The territorial potential for mitigation is demonstrated in Map 58 that shows the mitigative capacities of European regions. Regions can be classified into four different types, depending on whether they have high or low levels of greenhouse gas emissions and whether they simultaneously have high or low mitigative capacity. A high value is considered to be average of high and these are calculated from the case study area. Similarly, low GHG emissions mean that the rate of emissions is lower than the average of the case study areas.

Regions that have low emissions and high mitigative capacity are mostly located in Northern parts of Europe, and parts of France and the Iberian Peninsula. Regions that have high emissions and high mitigative capacity can be found in Western Europe as well as in parts of Scandinavia. Regions that have low emissions and low mitigative capacity can mostly be found in Eastern Europe as well as in Scotland and Portugal. Regions that have high emissions and low mitigative capacity are of course the most crucial in terms of reduction of greenhouse gas emissions. These regions can be found in Eastern Europe, and in the UK and Ireland. Also, some regions in Southern Italy fall into this category.



Origin of data: EEA 2010, ESPON Database 2006, Eurostat 2010, FSD 2010 GESIS 2008, IEA, NSIs 2010, UNFCCC, World Bank 2010

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Mitigative capacity and GHG emissions of European Regions

- High mitigative capacity - Low emissions
- Low mitigative capacity - Low emissions
- High mitigative capacity - High emissions
- Low mitigative capacity - High emissions
- No data

High mitigative capacity = Mitigative capcity performance higher than in 50 % of the regions
Low mitigative capacity = Mitigative capacity performance lower than in 50 % of the regions
Low emissions = GHG emissions lower than in 50 % of the regions
High emissions = GHG emissions higher than in 50 % of the regions

Regional GHG emissions estimated from national level data using population and gross value added data from Eurostat.

Map 58: Mitigative capacity and GHG emissions of European regions.

3.6.2 Regional capacities to respond to climate change

Response capacity of European regions

Mitigation of greenhouse gas emissions and adaptation to climate change impacts have generally been dealt with in separate policy domains not only at the global level but also by national governments. However, at the regional and local level, adaptation and mitigation are often dealt with together in a regional or a local climate change strategy (Ribeiro et al. 2009). These strategies, in most cases, have begun as strategies for mitigation but have then incorporated adaptation into to the strategy process. Given the above analysis of mitigative and adaptive capacity, this raises the broader question of what is the capacity of the European regions to deal with climate change.

The relationship between mitigation and adaptation has increasingly become an interest to researchers. The Fourth Assessment Report of the IPCC states that the capacities to adapt and mitigate are driven by similar sets of factors (IPCC 2007c). These factors, according to the IPCC, represent a generalised response capacity that can be mobilised both for adaptation and mitigation. A society's response capacity is closely related to the development path chosen, and it is argued that pursuing sustainable development can be a way of promoting both mitigation and adaptation. Furthermore, it is pointed out that response capacity, whilst relating to climate policy, also is closely tied to the underlying socio-economic and technological development paths of a given society.

Response capacity

Tompkins and Adger have further explored the notion of response capacity in order to highlight the unnecessary dichotomy between mitigation and adaptation, and to aid the formulation and implementation of climate policy (Tompkins, Adger 2005). Tompkins and Adger consider that creating a false dichotomy between adaptation and mitigation slows down the response to the climate challenge. Rather, it is more useful to focus on the two together as part of the management of risk and resources in a society. Response, according to the authors, is defined as any actions that are taken by any region, nation, community or an individual to tackle or manage environmental change either before the change occurs or before the change has taken place (Tompkins, Adger 2005). In defining response capacity, the authors avoid an explicit reference to climate policy in order to emphasise the fact that there are also many other drivers of decision-making and that climate issues should not be analysed in isolation from wider developments in societies.

The authors identify two factors that drive response capacity, mainly the availability and penetration of new technology and willingness and capacity to of society to change or adopt this new technology. Thus, response capacity 'describes the ability to manage both the cause of environmental change and the consequences of that change' (Tompkins, Adger 2005, 564). These two factors create a response space within which responses to climate change takes, combining the availability of new technology and willingness to change existing practices.

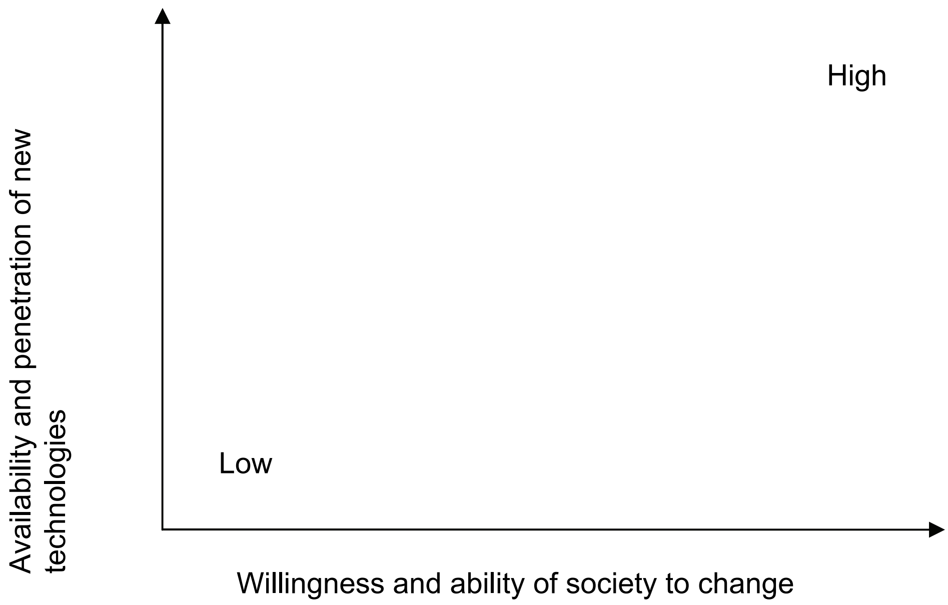


Figure 19: Response space (Tompkins, Adger 2005)

Tompkins and Adger do not explicitly address or explore the relationship between adaptive and mitigative capacity to response capacity in their paper. This report acknowledges that this relationship is most likely complex and that it may well be too simplistic to assume that adaptive and mitigative capacity equals response capacity on a conceptual level. However, response capacity denotes the capacity to deal with the causes of environmental change, i.e. mitigation, and the consequences of that change, i.e. adaptation. Furthermore, the willingness of a society to change is related to the awareness dimension of both adaptive and mitigative capacity as well by the action dimension of adaptive and mitigative capacity. In addition, availability and penetration of new technologies in a society is related to the ability dimension of adaptive and mitigative capacity.

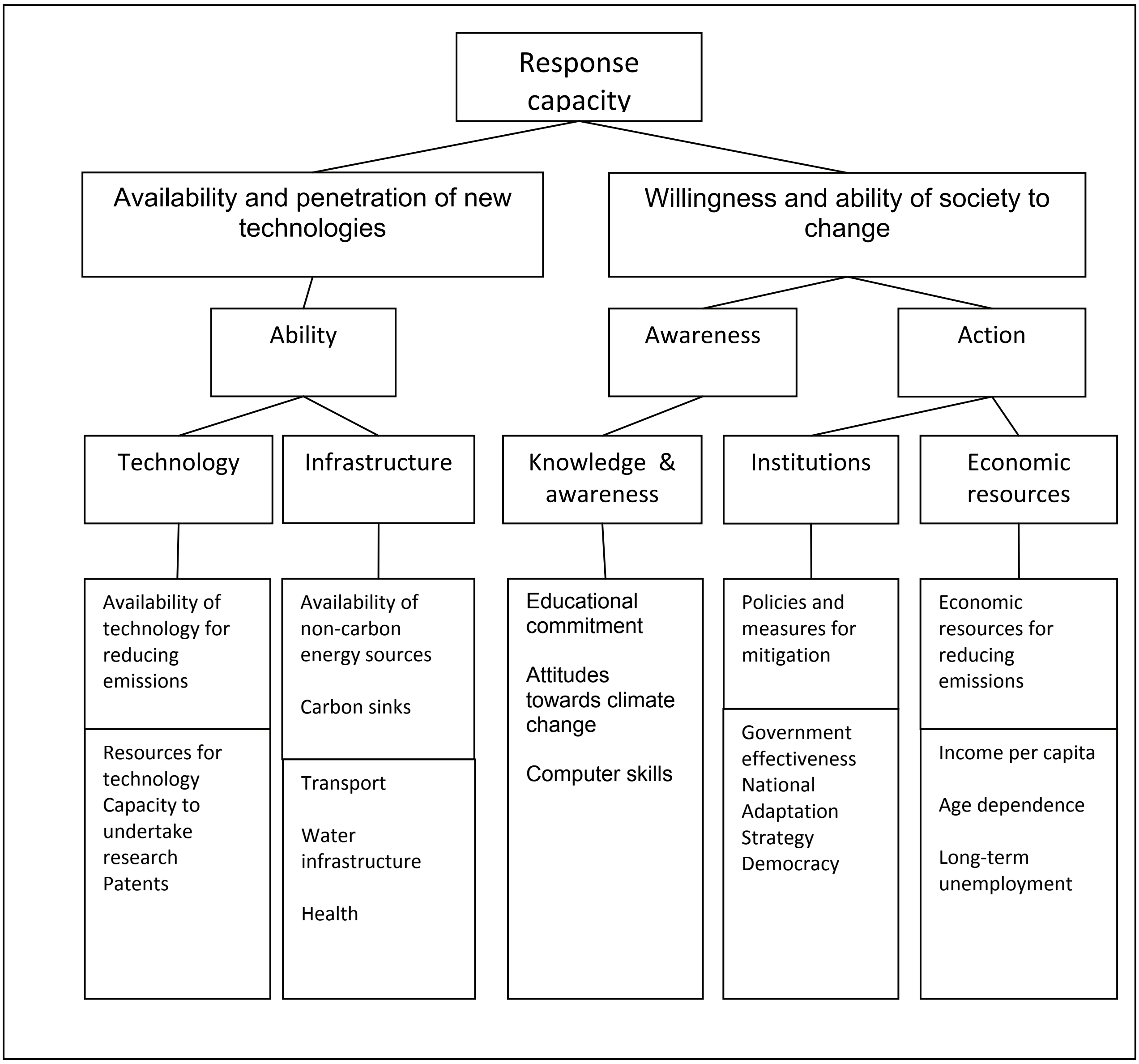


Figure 20: Response capacity combining adaptive and mitigative capacity.

Methodology

Although the response capacity could be considered to be the product of adaptive (AC) and mitigative capacities, similarities between adaptive (AC) and mitigative capacity (MC) indices present challenges for using them to assess the response capacity of regions. Combining the two mathematically into one single response capacity indicator would stress the importance of those indicators that are used in both AC and MC components. As we have no reliable information of the relative importance of individual indicators beyond the determinant level, the results would not be well-grounded.

Map of response capacity

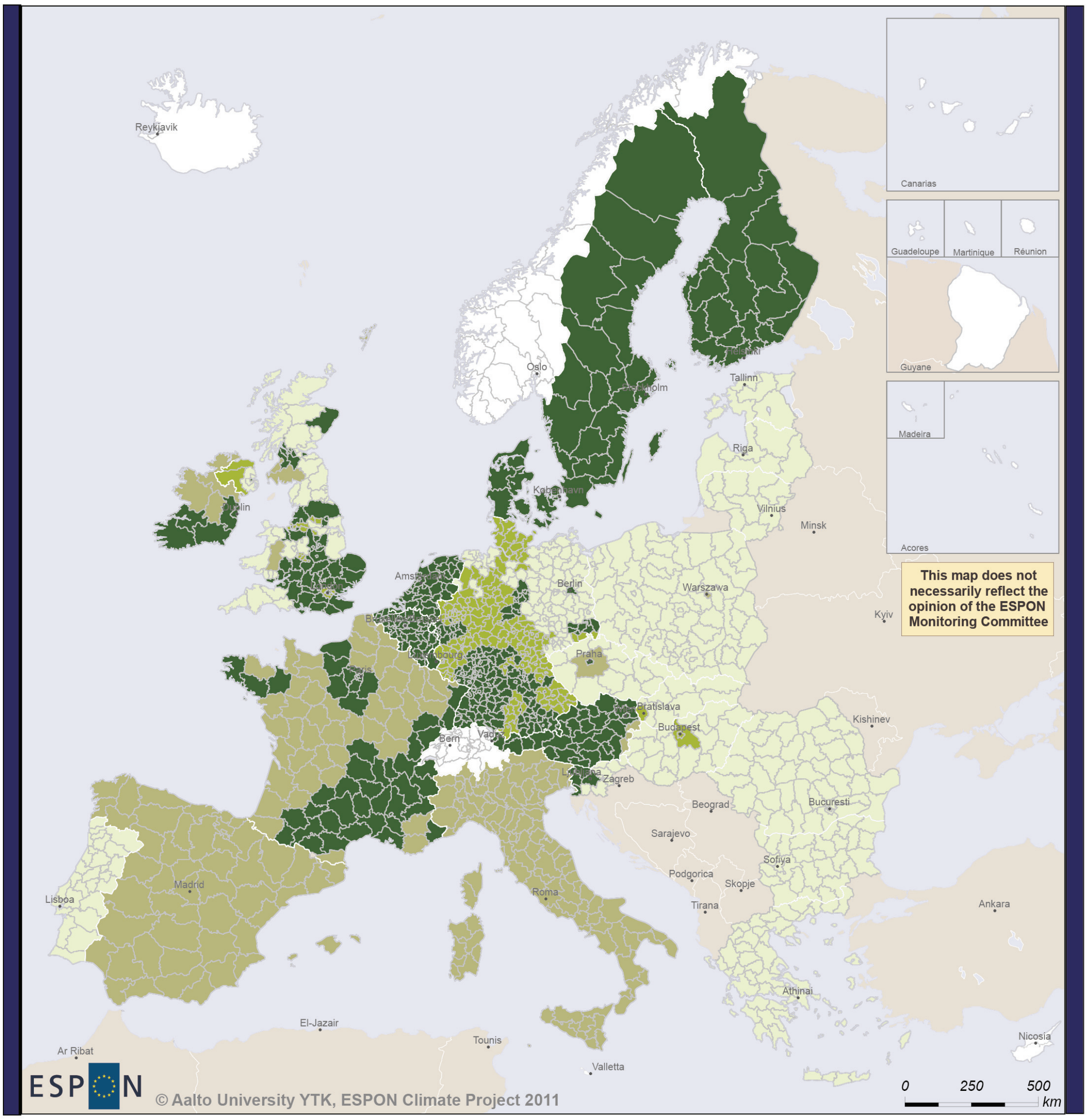
The map of response capacity of European regions integrates both adaptive and mitigative capacity (see map of response capacity). The assessment is done here by comparing adaptive and mitigative capacities through a simple 2-dimensional classification. The regions are divided into two classes by the median values of both indices. Integrating these creates four classes, high-high, high-low, low-high and low-low. This makes it possible to compare the differences between AC and MC and observe in general terms, how the response capacity of regions varies across the ESPON space. Another reason for viewing response capacity this way lies within the indices. They share some indicators and combining the indices directly would stress the importance of these shared indicators unnecessarily.

As already discussed above, both mitigative and adaptive capacity are measured to a certain extent with the same set of indicators. Differences between mitigative and adaptive capacity arise mainly from the Infrastructure dimensions. For mitigative capacity, these consist of availability of non-carbon energy sources and carbon sinks whereas for adaptive capacity, infrastructure indicators measure transport, water infrastructure and health. In addition, a different indicator is used in measuring the Institutions dimension. For mitigation, the number of policies relates directly to mitigation whilst for adaptation the respective indicator measures the levels of the NAS (concern, recommendation, and measure).

Overall, the map shows that there are regions which have high or low capacities in both adaptive and mitigative capacity, but also that there are regions within which either mitigative or adaptive capacity is lower than the other. Regions which have high capacity to both mitigate and adapt have carbon sinks and policies in place to reduce greenhouse gas emissions as well as infrastructure to deal with the impacts of climate change.

Regions which score low both on adaptive and mitigative capacity have less capacity to respond to climate change overall. Thus, these differences mainly arise from the fact that either the countries within which the regions exist, do not have national level policy measures to mitigate or adapt in place, since the policy indicators for both mitigative and adaptive capacity are measuring data on the national level. Furthermore, infrastructure in terms lower capacity means lower potential for non-carbon energy sources and smaller areas of carbon sinks, or alternatively less infrastructure to deal with the impacts of climate change.

The differences between the types of regions have also implications to policy in terms of mitigation and adaptation. There are regions which have the capacity to mitigate and adapt to the impacts climate change, whilst there are also regions which have a lower capacity to contribute to the mitigation of greenhouse gas emissions, and that also have lower capacity to adapt to the impacts. Similarly, there are regions which have a lower capacity to mitigate but higher adaptive capacity or alternatively regions which have lower capacity to adapt but higher capacity mitigate. In terms of policy implications, emphasis can be placed on increasing those dimensions that are the same for both capacities in order to improve the overall response capacity to climate change. Enhancing and increasing of mitigative and adaptive capacity is equally important, and can be in many cases complementary since it is recognised that similar capacities can underlie both actions.



Origin of data: EEA 2010, ESPON Database 2006, Eurostat 2010, FSD 2010, GESIS 2008, Massey & Bergsma 2009, NSIs 2010, UNFCCC, World Bank 2010

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Response Capacity of European Regions

Relative adaptive and mitigative capacities

- High adaptive capacity - High mitigative capacity
- High adaptive capacity - Low mitigative capacity
- Low adaptive capacity - High mitigative capacity
- Low adaptive capacity - Low mitigative capacity
- No data*

A total of 15 indicators was used to calculate the adaptive capacity index, while 10 indicators were used for the mitigative capacity index. The indices are calculated as weighted averages of normalized indicator values.

*For details on reduced or no data availability see Annex 9

Map 59: Response capacity of European regions.

Response capacity and typology of regions

ESPON Typology Compilation Final Report presents a compilation of regional typologies to use in ESPON Programme (Böhme et al. 2009). The study provides a classification of regions and the typology does not conflict with other classifications, differentiates between different categories within the classification, is methodologically robust, relies on data that is of sufficient quality and is generally availability. The study identifies eight types of regions: (1) urban regions, (2) sparsely populated regions, (3) border regions, (4) mountainous regions, (5) islands, and (6) coastal regions. This report considers the adaptive capacity maps and the maps of these eight typologies, and draws initial conclusions on the regional typologies and the adaptive capacities of different types of regions.

Urban regions

Urban regions, in the ESPON Typology, are defined by four criteria, i.e. location of enterprises, status as a national capital, city size (> 250 000) inhabitants) and OECD regional typology. When one considers the adaptive capacity of the urban regions, it can be seen that urban regions on the whole have high adaptive capacity. This is particularly the case in terms of capital cities, of which capacity tends to be the highest in each country.

Sparsely populated regions

The indicators used to identify sparsely populated regions are population density of inhabitants per square km and population development in per cent from 2000-2006. Sparsely populated regions are relatively few in Europe. Northern regions in Scandinavia have high capacity that most likely reflects high national capacity of the Nordic countries. Sparsely populated regions in Scotland, on the other hand, have relatively lower capacity compared to other regions within the UK.

Border regions

In the ESPON Typology border regions are identified by indicators that define political type of border and density of border crossings. Adaptive capacity, as measured in this study with the use of many national level indicators, highlights the importance of border regions. Border regions can be an interesting focus in terms of adaptation, given that climate change impacts occur irrespective of territorial boundaries. Simultaneously, adaptation policies and strategies are mainly developed through national processes. Thus, this can potentially lead to unequal focus and action on adaptation across the border region, and further highlights the necessity of interaction across border regions within the EU.

Mountainous regions

Mountainous regions are identified by using indicators that measure the share of regional population living in mountainous municipalities and accessibility to cities with at least 50,000 inhabitants. When one examines the adaptive capacity, it can be seen that most mountainous regions in Scandinavia and the Alpine region have high capacity. Out of the mountainous regions within Europe, regions in the Pyrenees have the lowest capacity.

Islands

Island regions within the ESPON space are identified by using share of population living in island municipalities, size of island regions, i.e. number of inhabitants. Island within the Baltic Sea Region on the whole have high adaptive capacity, and this can reflect the fact that on the whole these countries have high capacity as reflected by national level indicators. Island regions within the Mediterranean have lower capacity than island regions in Northern Europe. However, these regions' adaptive capacity is not lower than within their respective countries in general.

Coastal regions

The ESPON Typology uses the share of regional population living in coastal municipalities and coastal municipalities not further away than 10km way from the coastline as indicators to identify s coastal regions. Coastal regions are particularly vulnerable climate change impacts, particularly sea level rise. On the whole, the adaptive capacity of coastal regions reflects the adaptive capacity of those countries where the regions are located. Adaptive capacity within the coastal regions around the Baltic Sea Regions, particularly in the Northern parts, is high. Coastal regions around the North Atlantic also have high capacity. Coastal regions around the Mediterranean have lower capacity but on the whole comparative to the capacity within the respective countries.

Summary

This report discusses the response and the capacity of regions to respond to climate change. It is important to understand what adaptive and mitigative capacity consists of as a part of vulnerability of European regions. Adaptive and mitigative capacity underlies society's action and determines the response to the changing climate. Adaptive and mitigative capacity enable action on climate change, but as already discussed, having high adaptive or mitigative capacity does not necessarily mean that action on climate change takes place.

In order to understand society's response capacity, this report reviews literature on adaptive, mitigative and response capacity and constructed a list of indicators to measure these concepts. Both adaptive capacity and mitigative capacity consist of three aggregate dimensions, awareness, ability and action. Further, these aggregate dimensions are divided into five dimensions, namely knowledge and awareness, infrastructure, technology, economic resources and institutions. Several indicators are identified for these dimensions that can be used to measure these dimensions. Some of the indicators for specific dimensions are similar in both adaptive and mitigative capacity but some differ. This report also presents a map of regional greenhouse gas emissions in Europe as part of the mitigative capacity map. Furthermore, the report presents the response capacity of European regions, by combining both mitigative and adaptive indicators to reflect this.

As a result, this report presents maps of adaptive, mitigative and response capacity of European regions on NUTS3 level. The maps show how adaptive and mitigative capacity varies between countries in Europe as well as within countries. Northern, Western and Central Europe have higher adaptive capacity than Southern Europe. Eastern Europe on the whole has lower capacity than other parts of Europe. Within countries, adaptive capacity was higher in capital city regions in comparison to other regions in the countries. Only a few countries had uniform adaptive capacity across all regions. Mitigative capacity, partially being measured with same indicators as adaptive capacity, shows similar trends to adaptive capacity in Europe.

3.7 Case studies

The seven case studies of the ESPON Climate project serve to cross-check and deepen the findings of the pan-European assessment of the other research actions. They provide in-depth regional analyses of climate change vulnerability (exposure, sensitivity, impact, adaptation). The studies cross-check the indicators and findings of the European-wide analysis with the results of the case study areas, but also explore the diversity of response approaches to climate change. Finally, they develop conclusions for the implementation of measures at the European level.

Thus, the case studies needed to integrate a twofold approach:

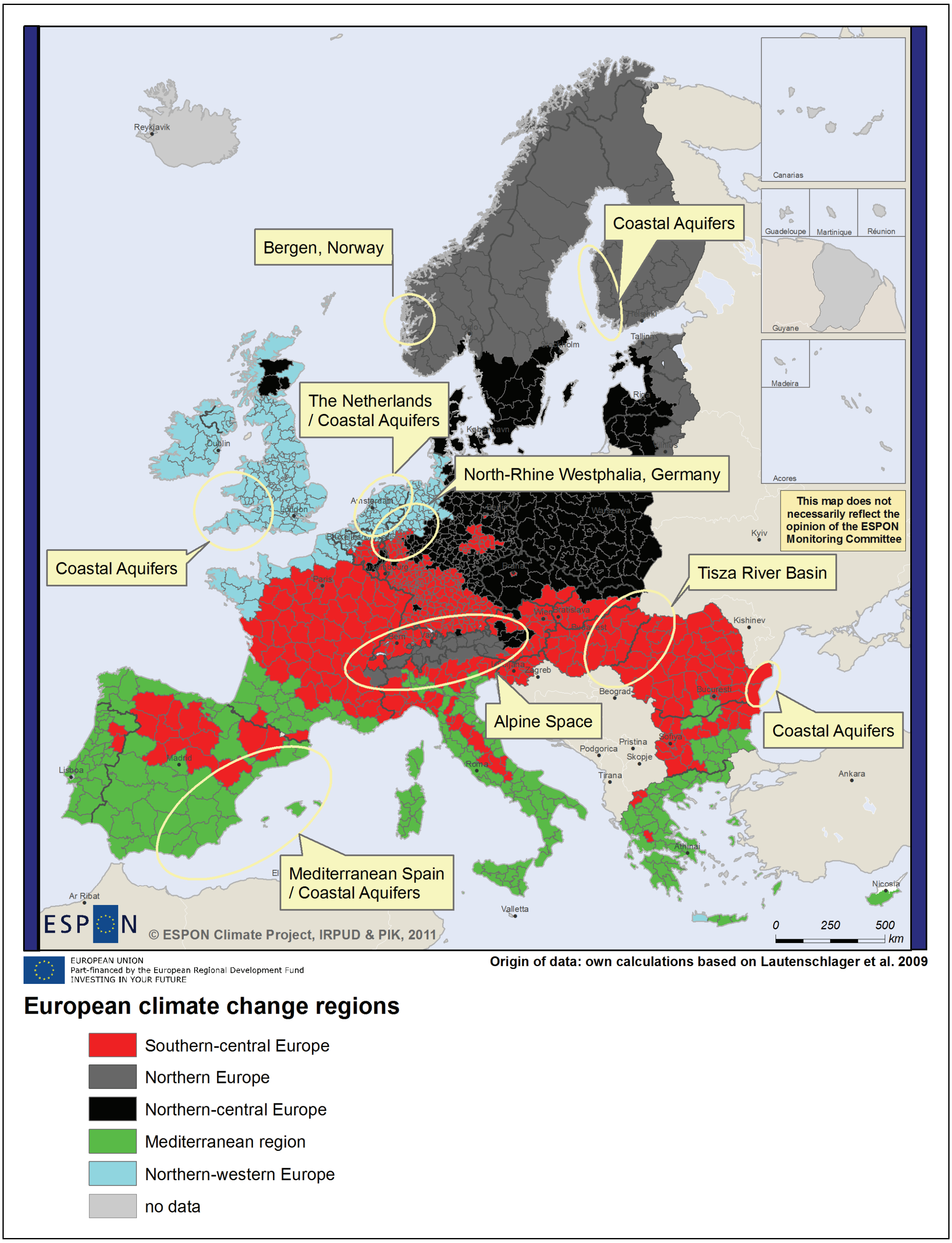
- An analytical approach coherent with the overall methodology of the project in order to ensure comparability among each other and connectibility with the overall analysis on the European scale;
- an explorative approach focusing on aspects not covered in the European-wide analysis, such as understanding the cultural and institutional factors influencing climate change effects on different European regions, and aspects peculiar to the respective case study area which can best be captured by the case study approach. In addition each case study explores certain dimensions of exposure, sensitivity and adaptation to climate change of particular relevance to it.

The legal framework and the political-administrative system significantly determine how adaptation responses are designed and by which institutions they are implemented. Although the policies of the Community shape national policies more and more, the specifics of the different Member States mainly characterise the design of national policies. In some of the EU Member States e. g., a new development is legally allowed when it is conforms to the regional plan. This so called regulatory function of spatial planning is known under the term “conforming planning” in the international discourse on planning theory (Rivolin, 2008; Larsson, 2006). In most of the EU Member States and thus also in the majority of case studies, however, the so called development function dominates at the regional planning level which is discussed under the term “performing planning”. This planning type is characterised by non-binding programmatic and/or strategic statements. Potential projects are then evaluated against the question whether they support the implementation of the programme or strategy. Furthermore, there are – if at all – only partially binding effects for the subordinated local level. The research question in this respect is if the planning system has an influence on the role of spatial planning in national adaptation strategies.

Seven case studies were identified which cover all five types of climate change regions identified in the exposure cluster analysis. As seen in the table below their coverage ranges from local and regional to national and transnational. Furthermore they cover different macro-geographic regions of Europe, represent different geomorphological types (high and low mountains, lowlands, rivers, coasts) and are located in different INTERREG cooperation areas. Thus the case studies not only provide an in-depth analysis of climate change vulnerability in Europe, but at the same time they explore a wide variation of European regions and corresponding differences in climate change exposure, sensitivity, impact and adaptive capacity.

Table 16: Case studies and selection criteria

Case study area	**ESPON three-level approach***	**Geographic coverage**			**Climate change regions**
		Macro-geographic regions	**Geomorpho-logical character**	**INTER-REG IVB cooperation areas**	
Alpine space	transnational	Central and southern Europe	mountain area	Alpine Space, Mediterranean, South Eastern Europe	Northern Europe Northern-central Europe, Southern-central Europe
Tisza river	trans-national	Central & Eastern Europe	river basin	Central Europe, South East Europe	Northern-central Europe, Southern-central Europe
North Rhine-Westphalia	regional	Germany (Western Europe)	river basin, hilly land	North West Europe	North western Europe, Northern-central Europe, Southern-central Europe
Coastal Mediterranean Spain, Balearic Islands	regional	Southern Europe	coastal area	Western Mediterranean, South West Europe	Mediterranean region
Bergen	local	Norway (Northern Europe)	coastal area, mountain area	North Sea Region	Northern Europe
The Netherlands	national	Western Europe	coastal area, river basin, lowlands	North Sea Region, North West Europe	North western Europe
Coastal Zone Aquifers	transnational	Finland, the Netherlands, United Kingdom, Spain, Romania	coastal area, lowlands	Baltic Sea Region, North West Europe, Western Mediterranean, South East Europe	All climate change types covered



Map 60: Case study locations within the major climate change regions

The above figure shows the locations of the seven ESPON Climate case studies by mapping them onto the typology of climate change regions.

The following sections give an overview of the seven case studies, whose detailed results are presented in full length in the Annex. A cross-case analysis is presented in section 3.6.8.

3.7.1 Case study 1: North Rhine-Westphalia (NRW)

The federal state of North Rhine-Westphalia (NRW) is situated in the north-west of Germany, comprising 396 municipalities (LAU2) and 53 NUTS 3 regions. Regional characteristics are diverse in terms of climate and geomorphology as well as in socio-economic structure. NRW is the most populous and the most densely populated state in Germany and contributes more than 20 % to the overall German GDP. Thus, possible adverse impacts of climate change may have severe consequences in reducing the overall economic performance of Germany.

The case study constitutes the first integrated, multi-sectoral vulnerability assessment for NRW. For some sectors, well-established methodologies have been applied to quantify the components of the vulnerability, for others new and innovative approaches have been developed. Based on the overall methodology of the pan-European assessment, the sensitivity towards climatic changes is expressed as a relative measure covering the range of values within the municipalities of NRW. It also takes into account the relevance of the respective sector for the municipality. Most adverse impacts are apparent in the Rhine valley and mountainous areas. This is mainly due to heat stress and flood danger in the valleys and increasing wind throw and forest fire danger in the higher elevated areas.

The generic adaptive capacity is expressed by the available private and public economic resources as well as the level of knowledge and awareness. This indicator shows a more heterogeneous spatial pattern with highest adaptive capacities in the upper Rhine valley and university towns and lower values in the Ruhr area and low mountain ranges.

The resulting relative vulnerability map shows less vulnerable municipalities in large parts of the lowlands. Otherwise, however, the pattern is more heterogeneous, mainly caused by the spatially distributed values of the adaptive capacity. By and large, most vulnerable municipalities are situated along the upper Rhine valley, the Ruhr area in the mountainous areas as well as at the foothill of the mountains.

The focus of current adaptation strategies of NRW on urban areas is to some extent in line with our results, which show higher potential impacts in these areas. However, adaptive capacity with regard to knowledge and awareness and economic resources is generally higher in the urban municipalities, leading to a lower vulnerability. It has also been shown, that high potential impacts occur in the mountainous regions as well as along the foothills of the mountains. These municipalities should thus be investigated further with regard to their adaptation potential. Given new scientific findings and the discrepancy in risk level concerning inundation, current adaptation to flooding should be re-evaluated in NRW.

Our results show sector-specific differences of impact and vulnerability severity and regional hot spots. However, further research is necessary on the concrete sectoral impacts and underlying cause-and-effect chains of vulnerabilities to initiate practice-oriented adaptation.

The overall methodology employed in the case study is transferable to other regions. However, the selection of impacts chains should be adapted to the specific regional relevance. Moreover, given a better data source for some sectors, absolute vulnerabilities or impacts could be determined in addition to the relative values. This has been carried out as an example for the wind throw risk in forests, where sensitivity was related to actual past damages occurring during a severe winter storm.

3.7.2 Case study 2: Climate change adaptation and Tourism in the Alpine space

Within the last 200 years both summer and winter tourism emerged as core economic sectors within the Alpine countries. After the Mediterranean region the Alps are the second most favoured holiday destination in Europe. With 60 million overnight guests tourism is the most important economic sector in most rural and alpine regions in the European Alps. At the same time tourism in the Alpine region is one of the economic sectors most affected by climate change.

The case study aimed at an in-depth analysis of impacts of the different climatic stimuli on Alpine tourism, of the specific sensitivity of Alpine tourism and the adaptive capacity of the tourism sector. The main focus was on the institutional and cultural dimension of vulnerability. For the adaptive capacity assessment of the tourism sector a specific set of indicators for assessing adaptive capacity was developed and a standardized survey was conducted among representatives of public authorities and non-state organizations in all Alpine states. The case study therefore complements the pan-European vulnerability assessment conducted in ESPON Climate with a qualitative approach by integrating qualitative data into the indicator based overall methodology.

The results of the vulnerability assessment of Alpine tourism give a better understanding of the impacts of climate change on the tourism sector and the adaptive capacity of the studied tourism regions in the European Alps. The expected effects of changing climate stimuli on the tourism industry can be differentiated along the altitude of the European Alps: for high alpine summer tourism the increase in mean temperature and the number of summer days are expected to have a positive effect due to the freshness of summer resorts whereas for high alpine winter tourism a decreasing attractiveness of snow sport activities is expected because of a decrease in days with snow cover, shortening of the touristic season and an increasing occurrence of natural hazards. Rural tourism in lower mountain areas is expected to benefit in summer as a result of an increasing attractiveness of the lake regions. In winter medium and low lying tourism destinations are expected to experience a significant decrease in snow reliability and length of season. In the lowlands of the European Alps especially city tourism will gain attractiveness due to a prolonged season and an increasing number of summer days.

Concerning the adaptive capacity of the tourism sector there are two fields of actions for enhancing the adaptation of tourism activities to climate change impacts across all Alpine regions: the informational basis available for decision-makers and the climate change awareness among tourism actors. In order to achieve well-informed decisions on adaptation activities in tourism regions and to develop consistent and long-term strategies, region specific climate data as well as impact and vulnerability assessments are needed. Additionally, this information has to be made available for decision makers in the tourism sector. The second field of action concerns the problem awareness among actors as a precondition for realizing adaptation options and reducing vulnerability. The study shows that major efforts need to be made in the field of awareness raising and capacity building within the tourism sector. This includes actors from the tourism economy as well as local providers, local populations and guests.

3.7.3 Case study 3: Tisza river basin

The river Tisza has the largest catchment area among the tributaries of the river Danube. It covers nearly 160 thousand km^2 and has about 14 million inhabitants. Extreme weather phenomena are already a serious problem in the region. According to the forecasts, the frequency of extreme weather events in the context of droughts and excess waters (floods) is expected to increase as a result of climate change.

The assessment of the impact of climate change on river discharges is confronted with several uncertainties, which are described on the basis of national and regional research in a separate chapter of this case study. For the vulnerability of the impacts of extreme weather (floods, drought and excess water) events has been assessed by using the EU level methodology of the ESPON Climate Change Project. From the COSMO CLM study the quantitative change of summer and winter precipitation have been taken as exposure indicators. Sensitivity was analysed by means of two indices in the economic dimension, while in the physical dimension the impacts were assessed directly by four indexes, where the analysis was based on the maps of the LISFLOOD model.

The results of the impact analysis in the physical dimension show the most negative impacts are to be expected on the upstream (mountainous and hilly regions) section of River Tisza and its tributaries, although most of the current potential flood prone areas are on the plain along the downstream river sections. In terms of economic impacts the picture is more diverse. The highest increase is predicted for the lowland and hills of the Tisza basin.

Indicators of adaptive capacity characterise the social and economic as well as infrastructure conditions, showing how they are capable to cope with unfavourable changes. The calculation of aggregated adaptive capacity is based on six indices of four determinants (knowledge and awareness, technology, infrastructure and economic resources). The aggregated adaptive capacity index is of diverse geographic distribution. In the Slovakian section the adaptive capacity is medium or high, while in Hungary one can find all degrees of adaptive capacity. The Romanian parts of the river basin are characterized by low and very low values except for Arad, Timiş and Cluj counties.

Vulnerability was calculated on the basis of potential impact and adaptive capacity. The ultimate outcome of the vulnerability analysis justified the results of the two partial analyses namely, that in the catchment area of River Tisza the most vulnerable counties are in Romania.

The adaptability to the harmful impacts of the increasingly extreme weather (warming and drying climate, excess water and flood) can be enhanced in the region by means of the appropriate change of land use; more efficient water retention and discharge regulation; the policies in support of the above, with special regard to the distribution of domestic and EU resources of sustainable agriculture, forest and environmental management as well as water management and flood control and finally joint elaboration of transnational plans of water and land management.

3.7.4 Case study 4: Mediterranean coast of Spain

The Mediterranean coast, together with the Balearic Islands, is the most important tourist area of Spain and a key pillar of the Spanish economy. Climate is a fundamental constituent, and perhaps the key influencing factor in explaining the attractiveness of this area for domestic and international tourists. According to the latest IPCC report (2007), average temperatures in the Mediterranean basin may increase substantially during the 21st century while precipitation may decrease thus limiting the amount of water available for human and non-human uses.

The objective of this case study was to perform a vulnerability assessment to possible water shortages induced by climate change in the tourist areas of the Spanish Mediterranean coast. In order to produce such an assessment the study used variables related to exposure (water availability after changes in temperature and precipitation); sensitivity (characteristics of the tourist sector), and adaptive capacity (water supply alternatives, income). The relative weighing of each variable has been determined from a Delphi panel composed by ESPON experts.

Results show a distinct spatial pattern according to the combined dimensions of exposure, sensitivity and adaptive capacity. Generally, vulnerability tends to increase from North to South, mainly because of increasing exposure and decrease in adaptive capacity (especially concerning income) along this gradient. One extreme case is the Costa del Sol tourist area (one of the most important not only of Spain but of the entire Mediterranean) where scores for exposure, sensitivity and adaptive capacity combine to produce the highest vulnerability of the study area. At the opposite side, certain areas of Catalonia observe low vulnerabilities after a combination of low exposure and high adaptive capacity. Another interesting case are the Balearic Islands which rank low in exposure but medium to high in sensitivity thus indicating the strategic importance of tourism for the economy of the archipelago. Adaptive capacity, however, is in principle high enough to offset sensitivity. Hence, the resulting vulnerability is low.

The variables selected and the method chosen may be useful for other tourist areas of the Mediterranean coast. Generally, one could assume an increase in the vulnerability of Mediterranean tourist areas along a gradient West-East due to increasing exposure, perhaps medium to high sensitivity (due to the enormous growth of the tourist industry in certain areas such as the Balkans or the Eastern coasts), and low to medium adaptive capacities which may change in the future if alternatives such as desalination (already present and growing in many Mediterranean countries) can be implemented. However and given the possible maladaptation character of desalinisation, adaptive capacities should move towards better water management actions such as the control of tourist related urban growth or the exchange of water rights with agricultural users.

3.7.5 Case study 5: Netherlands

The increase of flood hazard, drought and water nuisance are recognized as the biggest challenges of the Netherlands with respect to climate change (V&W 2009). This case study focuses on flood hazards, expected to increase due to both sea level rise and an increase in extreme discharges of the main rivers.

The most recent projections on sea level rise for the Netherlands cover a range of 35 to 85 centimetres for 2100 (KNMI 2006). In the case of high-end/worst-case estimates, the rise is between 130 and 150 centimetres (Deltacommissie 2008). At the end of this century the 1:1250 per year discharge of the river Rhine at the Dutch border is estimated to increase by 15-35% (Klijn, Kwadijk et al. 2010). 56% of the Dutch area, where almost 70% of the population is concentrated, is prone to flooding. Yet even in the most extreme imaginable circumstances only 34% of the area, inhabited by 37% of the Dutch population, is expected to be exposed to flooding (Kolen and Geerts 2006). Due to the more simplified DIVA approach to coastal flooding, used in the ESPON framework, the estimated hazard along the coast is far more extensive than expected on the basis of more realistic flood models.

The sensitivity to flooding is assessed on the basis of five impact dimensions: a) physical - settlement, power plants, infrastructure; b) social – inhabitants, elderly and low educated people; c) cultural – national landscapes, historic towns and UNESCO world heritage; d) economic – jobs, livestock and farming; e) environmental – NATURA 2000 areas.

The individual dimensions show different spatial sensitivity patterns. If merged into one sensitivity indicator the spatial pattern almost fully mirrors the potential exposure pattern. The combination of exposure and sensitivity shows a potential high impact in NUTS 3 regions located along the coast or close to the coastal area and, due to their expected extreme high exposure, in the Lake Ijsselmeer polders. On the municipal level these patterns are more differentiated due to the higher resolution and the dominant effect on the classification of one single municipality (Noordoostpolder) with an estimated extreme high potential exposure.

Merging the various adaptive capacity indicators by averaging shows hardly any differentiation at this level. Therefore the final merging of the adaptive capacity and the potential impact into a vulnerability map on the municipal level resembles the potential impact map, but with a more smoothed pattern due to the almost uniform distribution of the adaptive capacity over the Dutch municipalities. Therefore the final classification is still to a high degree determined by the extreme exposure estimation of one single municipality.

With respect to flooding the analysis shows a high sensitivity to the used hazard assessment method. Two hazard maps were compared, one containing maximum water depths for flooding, irrespective of climate change and a second one taking climate change into account. In the no-climate change map the Netherlands appear to be less sensitive towards flooding, irrespective of the used spatial scale (NUTS 3 or municipalities), which might be based on methodological differences.

3.7.6 Case study 6: Bergen region

Due to Bergen's location in Norway its climate is characterized by cool temperatures and large quantities of precipitation: The annual precipitation reaches up to 5,000 mm in some areas of the Bergen city region – and is still expected to increase according to the latest climate change scenarios for the region, especially in autumn and winter. More importantly, the number of days with heavy rainfall is expected to double, thus increasing the likelihood of river flooding and landslides. In addition, due to rising temperatures worldwide the sea level in Bergen is estimated to increase by 75 cm by the year 2100, but will even increase up to 221-276 cm during storm surges.

Sensitivity to climate change can be measured by how different exposure indicators lead to a detectable change (positive or negative) in the studied object. In the Bergen case study the main sensitivity dimensions are physical sensitivity (infrastructure), cultural sensitivity (world heritage sites) and economic sensitivity (business activities and tourism). The potential impacts are a function of exposure and sensitivity, and regions can be both adversely and beneficially affected. For the Bergen region and Western Norway temperature increase, precipitation and sea level rise are the most important exposure indicators.

The greatest impact of climate change will be caused by the expected sea level rise and subsequent heightened exposure to coastal storm surges. If the estimated sea level rise of 75 cm in 2100 and the expected storm surge rise up to 2.37 metre will overflow buildings related to settlements and industries, historical sites, quays and port facilities, fish farming, roads and transport systems, sewage systems and wetlands. The effects of sea level rise will be most harmful in the central city area. Large part of the business area is located at the waterfront where also new settlements are developed.

A modified cost benefit analysis for sea level rise focussed on a range of adaptation measures. In the exercise the benefits are the reduced damages caused by the adaptation measure, and the aggregated costs have been measured by the expenses of the Norwegian Natural Damage Fund. Benefits are extremely hard to measure not only by using insurance values for buildings, but particularly for cultural heritage. Assessing costs of infrastructure is also difficult since some infrastructure will be replaced irrespective of any climate change through ordinary maintenance and improvement. In all exercises the cost exceeded the benefits which indicate that the adaptation measures should not be carried out. This probably tells us that benefits were underestimated and it also clearly illustrates the large problem of carrying out even a modified CBA in the Bergen case.

The adaptive capacity to deal with climate problems is considered to be fairly high in Bergen. The city has well educated inhabitants, a high score on computer literacy, personal income, GDP per capita, and an active policy towards climate change and adaptation.

Some of the experiences from Bergen may be possible to transfer to other regions. It could be either knowledge of specific adaptation measures or of adaptation processes. Specific measurements towards sea level rise can for instance be relevant for other coastal cities in Europe. Likewise can knowledge of processes and tools used in adaptation policies be useful for other regions regardless of what measures that have been taken. This could include regional governance related to climate change adaptation and successful ways of involving relevant stakeholders in adaptation strategies.

3.7.7 Case study 7: Coastal Aquifers

Freshwater is one of the most important natural resources for life. Water resources and water supply belongs to the critical infrastructure in a society and needs special protection. The aquifers in Europe are unequal concerning their size, location and sensitivity to changes. Small, low-lying aquifers close to settlements, rivers and the sea shore are highly vulnerable to changes of all kind, including the potential impacts of climate change.

The case study on coastal aquifers was aiming to test the ESPON Climate model generated by the ESPON Climate project at the European level in the coastal aquifers of Europe. Low-lying shallow groundwater aquifers located on the Baltic Sea (Finland), the North Sea (Norway and the Netherlands), the Mediterranean (Spain), the Atlantic Ocean (Scotland) and the Black Sea (Bulgaria) were selected for further studies.

By developing the conceptual model for southern Finland coastal areas, it was possible to review the climate change introduced effects to the coastal aquifers. Eight out of ten pre-defined pan-European exposure indicators are relevant or important in the context of coastal aquifers.

The ESPON Climate project had suggested several sensitivity indicators for five sensitivity dimensions: physical, environmental, social, cultural and economic sensitivity. Three of the suggested pan-European indicators were applicable directly for the case study on coastal aquifers. The pan-European indicator 'Settlements prone to coastal flooding' was selected to indicate physical impact. In addition, to better estimate the physical impact of coastal aquifers, two case study-specific indicators were defined: 'Water intakes prone to flash floods' and 'Water intakes prone to coastal flooding'. Both flash floods and sea level rise may negatively affect the coastal aquifers. Deterioration of water quality may have critical effects on water supply infrastructure. The pan-European indicator 'Coastal areas prone to coastal flooding' was selected to indicate the environmental impact, and a new case study-specific sensitivity indicator 'Percentage of the groundwater yield from coastal aquifers' was also developed. The latter indicator reveals how critical the coastal aquifers are for the region. The pan-European indicator 'Coastal population prone to coastal flooding' reflects the social impact. A new indicator 'Drinking water prices in coastal area' was defined for economic sensitivity by comparing the yearly price of threatened coastal water supply with regional GDP.

As the best suitable pan-European indicators to describe adaptive capacity, the following indicators were chosen: 'Resources for technology', 'Capacity for research', 'Water infra-structure' and 'GDP per capita'. Two new indicators were also developed to describe the adaptive capacity in low-lying coastal aquifers: 'Availability of alternative water sources' and 'National, regional and local climate change adaptation strategies'. These indicators show qualitatively how well the regions are prepared for climate change effects on coastal aquifers, i.e. with alternative water sources and in their adaptation strategies.

Vulnerability of coastal aquifers towards potential climate change impacts in Finnish case study regions showed to be marginal at pan-European scale.

3.7.8 Case study conclusions

In order to ensure compatibility with the pan-European analyses of the other research actions of the project and to enable comparisons across the case studies, a common methodological framework was agreed and was followed throughout the case studies: This framework covers the following general aspects:

1. General characterisation of the region
2. Vulnerability assessment
    a. Main effects of climate change on case study region so far
    b. Exposure to climate change
    c. Sensitivity to climate change
    d. Impacts of climate change
    e. Adaptive capacity in regard to climate change
    f. Vulnerability to climate change
3. Response strategies and policy development in regard to mitigation and adaptation
4. Further aspects specific to the respective case study area
5. Discussion of validity of European-wide analysis from a regional perspective
6. Transferability of results to other regions

Table 17 summarises the main features of each case study and is structured along the common framework which was explained above:

Table 17: Main results of the case studies

Case Study	Exposure	Sensitivity	Impact	Adaptive Capacity	Vulnerability	Policy response strategies	Applicability of European method	Transferability
Bergen	Is based on different climatic models All variables for temperature were used + precipitation + sea level rise and flooding	Physical, cultural and economic dimensions were considered for a quantitative assessment Study area (LAU2) was divided into city districts	No quantitative assessment	Pan-European approach (awareness, ability, action) was implemented on a city district level	No quantitative assessment	Bergen was the first municipality in Norway to work out a climate plan in year 2000. Response strategies focus on dealing with extreme events	No general validation, but its applicability to the local level was successfully proved	Test of modified CBA makes clear that use is difficult for assessing vulnerability to climate change
Alpine space (focus on tourism)	All climatic stimuli were considered + inundation	Focus on institutional and cultural dimensions Study is based on NUTS3	No quantitative assessment	Semi standardized survey Al three dimensions were covered Indicators are partly the same, but some adjustments for local needs	No quantitative impact/vulnerability assessment	Several options discussed which are of relevance for mountain areas. Adaption is seen as a multi-level governance issue	No general validation, but adaptive capacity was proved as relevant factor for the vulnerability assessment	Generally speaking possible to transfer to other mountain areas which are dependent from tourism Semi-quantified survey as option for regionalized Delphi weighting
Netherlands (focus on flooding)	Lisflood map for fluvial flooding + coastal flooding + worst credible flood map = focus on indirect climate change	All five dimensions are covered Each indicator has a relative and absolute value = final value as average of relative and absolute values Study is based on LAU2	Impact is calculated by adding exposure and sensitivity score. Exposure and sensitivity are weighted for each dimension (0.44 + 0.56)	In line with the ESPON approach, the estimation of the adaptive capacity is based on generic features: percentage of inhabitants with tertiary degree, computer use, highway density, GDP and age distribution on the municipal level.	The final merging of the adaptive capacity and impact into a vulnerability map on the municipal level resembles the impact map, but with a more smoothed pattern due to the almost uniform distribution of the adaptive capacity over the Dutch municipalities	Focus on national level is on water (sea level rise, flooding) while heat is understood as an issue for some major cities only.	The pan-European concept has been successfully applied. However, it became clear that a full vulnerability assessment is only partly suitable for homogenous regions Moreover, the applicability of the LISFLOOD model was proved.	The approach is transferable to the others since its follows the pan-European assessment

Case Study	Exposure	Sensitivity	Impact	Adaptive Capacity	Vulnerability	Policy response strategies	Applicability of European method	Transferability
Tisza River	All climatic stimuli were considered and extensively validated by using reference runs with other models and literature sources Weighting of stimuli according to results of validation process	Focus on physical, social, environmental and economic sensitivity. Particular attention is paid to agriculture Weighting of dimensions according to regional expert's option Study is based on NUTS3	Matrix with 5 classes (impact on human health and agriculture)	Approach follows the pan-European assessment. Indicators used: technology, infrastructure and economic resources Weighting of the three dimensions according to regional expert's option	Vulnerability is calculated on the basis of potential impact and aggregated adaptive capacity. Additional regional socio-economic assessments for Lake Tisza and Romanian Tisza river based on questionnaires	Seen as a multi-level governance. Particular focus on the transnational Tisza River Program Extensively discussed for national and regional levels of Hungary, Romania, Slovakia	The agricultural vulnerability assessment can be used in regions where the role of the agriculture and the changes in the climate parameters effecting agriculture change similarly to that in the Tisza region. Such are, e.g., the countries of South-Eastern Europe.	Advances validation concept of exposure indicators is principally transferable depending from the availability of other studies
North Rhine-Westphalia	All climatic stimuli were used, but instead of summer days heat days (30°) + storm days as new variable (better represented in study area) Due to the more similar climate in NRW, absolute changes were used for hydrologic variables Own cluster analysis (3 cl) Inundation as indirect climate change	Four dimensions were considered (culture is missing without a justification) Used indicators are almost the same as for the pan-European assessment Study is based on LAU2	Multiplication of exposure and sensitivity values	Consistent with pan-European assessment, but some adjustments concerning indicators due to small size of study areas Economic resources of municipalities and households Knowledge and awareness (education level + participation in climate change initiatives)	No use of regionalized Delphi weighting Results show higher potential impacts in urban areas which are characterized by a low adaptive capacity A large gradient is apparent between NRW (return period as basis for design of dikes 1 in 100 year event) and The Nether-lands which 1250 years apply.	Widely discussed. Need for cross-sectoral as well as vertical integration of response strategies in the political context. Existing political focus on urban areas is in line with the results of the case study Given new scientific finding (projected increase in flood risk) current adaptation to flooding should be re-evaluated in NRW.	The pan-European concept has been jointly developed together with this case study concept. The overall methodological frame could thus be well applied to the regional scale of NRW in a quantified way.	This methodology is in general transferable to other regions. The selection of impacts chains should be adapted to the specific regional relevance. Given a better data source, for some sectors, absolute vulnerabilities or impacts can be determined.

Case Study	Exposure	Sensitivity	Impact	Adaptive Capacity	Vulnerability	Policy response strategies	Applicability of European method	Transferability
Spanish coast	All climatic stimuli were used, but no indirect climate change	All five dimensions are covered, but culture was excluded due to a lack of data. Reduced set of indicators (1 indicator per dimension), tailor-made for case study which is based on LAU2 level.	Impact is calculated by adding exposure and sensitivity score. Exposure and sensitivity are weighted for each dimension (0.44 + 0.56)	Reduced set of indicators: Economic (regional income) + technological (desalinization capacity + water re-use)	ESPON Climate Standard procedure. Case study made use of pan-European weighting scores. The results show hot spots in the south (i. e. Costa del Sol)	Access to resources that are climate independent (desalinization) is currently regarded as important Need for new forms of governance in order to avoid dependency on costly water technologies. Relevance of urban patterns	The pan-European concept has been successfully applied. Exposure to climate change tends to be high, sensitivity tends to be high as well; in consequence impacts are high and adaptive capacity tends to be low at least in comparison with other European regions.	Methods are transferable to other European tourist areas where adaptive capacity actions may produce unintended negative
Coastal aquifers	Particular focus on coastal aquifers = sectoral study Due to data shortcomings, the study focused on Finland mainly All stimuli + indirect effects were considered, eight were proved as important	All five dimensions were considered, but culture excluded due to a lack of data and its irrelevance to coastal aquifer case study. Only three indicators developed for the pan-European study were used, but complemented by four tailor-made indicators Study is based on NUTS 3 level	Quantitative assessment for the Finnish case study came to the conclusion that the physical, environmental, social and economic impacts are marginal	Use of pan-European concept and indicators. Complemented by two tailor-made indicators (availability of alternative water sources+ national, regional, local adaptation strategies)	ESPON Climate – model was used to assess vulnerability. Vulnerability of coastal aquifers towards potential climate change impacts in Finnish case study areas showed to be marginal at pan-European scale.	Discussed by the example of Finland. No need for response actions due to the marginal impact of climate change on coastal aquifers	The pan-European assessment was principally proved and completely applied in Finnish part of the case study areas.	The transferability of the case study approach was shown by the choice of different coastal aquifers

All in all, the case studies proved the applicability of the conceptual framework. It was shown that this framework is flexible in terms of spatial scales and indicators for exposure, sensitivity and adaptive capacity. The seven case studies are very good examples that the new comprehensive ESPON approach meets the demands of spatial planning: a new, more complex picture of the patterns of vulnerability became visible and can therefore be seen as a step forward from pure sector-based studies towards are more comprehensive view on vulnerability.

The spatial patterns between the pan-European assessment and the case study assessments are quite similar when comparing e.g. the pan-European cluster analysis with the analysis conducted for the NRW study: its case study area is divided into the same three different climate change types although slightly different exposure indicators were chosen. However, particularly the more fine-grained case study on North Rhine-Westphalia, but also the Tisa river case study show a more differentiated picture in terms of impact, adaptive capacity and vulnerability than the results of the pan-European assessment for these areas. This is mainly due to the normalisation of data: the existing relative differences between the municipalities of the case study area are quite small compared with the differences across the whole continent; even those municipalities which are marked in red on the case study map are only moderately vulnerable from a pan-European perspective. Thus, the pan-European vulnerability map shows a more homogenous picture for North Rhine-Westphalia. This clearly underlines the scale-dependency of any vulnerability assessment. The Tisza river case study shows what an uncertainty analysis could look like. Each exposure indicator provided by the pan-European assessment was intensively validated by comparing them with available results from other studies and scientific literature which cover the case study area. This approach is principally useful for any vulnerability assessment on the regional and local level in order to reduce the inherent uncertainty in the models and indicators.

Institutional and cultural issues were only partly covered by the case studies mostly to the lack of adequate data, but also available resources. There was a particular focus on these topics in the Alpine study which was based on an extensive questionnaire survey. To conclude, a more qualitative approach is needed in order to understand the driving forces for institutional settings and related response strategies. All the case studies pointed out that adaptation has to be addressed in a more comprehensive way by spatial planning on the different spatial scales.

However, there is no visible connection between the attention paid to spatial planning and the type of administrative or planning system of the respective country. Consequently, other factors such as political priorities of a national government might determine the relevance of adaptation on the political agenda. This observation was also proofed by other studies (Greiving, Fleischhauer, forthcoming).

The results of the economic sensitivity assessment on tourism correspond almost completely with the results of the case study on coastal Mediterranean Spain: there is a gradient from the North to the South where both studies calculated the greatest potential impact and vulnerability. However, the case study results are much more fine-grained (LAU2) and reflect possible situations of “maladaptation” and therefore possible conflicts between mitigation and adaptation measures on the very local level to which national and regional strategies on climate change, at least for the case of Spain, have not responded adequately yet. Here, the added value of the case study approach becomes clearly visible which is also underlined by the in-depth study on coastal aquifers: each cause-effect chain from exposure to sensitivity, impact, adaptive capacity and vulnerability has to be studied in detail in order to create an evidence base for adaptation strategies. This was simply not possible on the pan-European level within the given time frame and budget restrictions. However, it clearly shows further research needs.

4. Policy Implications

This chapter considers the policy implications of climate change. Section 4.1 deals with 'Climate change and its implications for existing European policies' and section 4.2 deals with 'Policy options for climate change mitigation and adaptation'.

4.1 Climate change and its implications for existing European policies

Europe faces a challenging task. It needs to recover from a deep financial crisis, reduce unemployment and social exclusion and at the same time switch to a low-carbon economy while adapting to the climate changes that are already underway. Describing the scale of the economic crisis, *Europe 2020 Strategy* (2010:5)[13] states that, "The steady gains in economic growth and job creation witnessed over the last decade have been wiped out – our GDP fell by 4% in 2009, our industrial production dropped back to the levels of the 1990s and 23 million people - or 10% of our active population - are now unemployed". In addition to this challenging economic landscape, Europe is also facing a major demographic restructuring, as highlighted by *Europe 2020 Strategy* (2010:6) which states: "Demographic ageing is accelerating. As the baby-boom generation retires, the EU's active population will start to shrink as from 2013/2014. The number of people aged over 60 is now increasing twice as fast as it did before 2007 – by about two million every year compared to one million previously. The combination of a smaller working population and a higher share of retired people will place additional strains on our welfare systems." Responding to these challenges requires effective and urgent policy initiatives and actions at European, national, regional and local levels as well as across different policy sectors. This sub-chapter outlines some of the key implications of climate change for firstly (4.1.1) the EU competiveness and cohesion policy and secondly (4.1.2) other EU policies and programmes.

4.1.1 Implications for competitiveness and cohesion policy

Competitiveness

Climate change will have significant economic, social and environmental impacts across the EU with some European regions, economic sectors, and social groups being more affected than others. In responding to the challenges the EU (along with the member states) needs to take both mitigation and adaptation actions. The latter in particular requires a place-based approach. As

[13] 'Europe 2020: A strategy for smart, sustainable and inclusive growth' - COM(2010) 2020, 3.3.2010.

regards mitigation, the EU has already set up a number of energy goals[14] aimed at reducing GHG emissions while increasing energy security. Since the adoption of the *Lisbon Strategy* the EU's overarching competiveness agenda has been to make the EU into the world's most competitive knowledge-based economy. In the light of the recent economic and financial crisis and the realisation of the impacts of climate change, the European Council adopted the *Europe 2020 Strategy* in 2010 to provide a route map for recovery. Crucially, the Strategy recognises that "strong dependence on fossil fuels such as oil and inefficient use of raw materials expose" Europe's consumers and businesses to "harmful and costly price shocks" and threatens Europe's "economic security" while also "contributing to climate change" (p.6). It therefore puts forward three mutually reinforcing priorities as follows: (P.3):

- Smart growth: developing an economy based on knowledge and innovation.
- Sustainable growth: promoting a more resource efficient, greener and more competitive economy
- Inclusive growth: fostering a high-employment economy delivering social and territorial cohesion

Seven flagship initiatives are identified to which the EU and the Member States are committed. One of these is "Resource efficient Europe" which implies: decoupling of economic growth from the use of resources; shifting towards a low carbon economy; increasing the use of renewable energy sources; modernising the transport sector, and promoting energy efficiency (p.4). All these will contribute not only to climate change mitigation but also to future competitiveness of the EU. As part of its "smart, sustainable and inclusive growth" agenda, *Europe 2020* emphasises the need for improving resource efficiency to limit emissions as well as to "save money and boost economic growth" (p.13). Major targets are set up including: a reduction in greenhouse gas emission by at least 20% compared to 1990 or by 30% if the conditions are right, increased share of renewable energy sources to 20%, and a 20% rise in energy efficiency (P.9). The future competitiveness of the EU depends on adequate supply of energy and resources which in the current climate is uncertain given the increasing level of energy in-security and the international obligations to reduce the use of fossil fuels. Hence, it is paramount that the EU member states meet their energy goals which could result in "€60 billion less in oil and gas imports by 2020" (p.13). Further progress with the integration of the European energy market is also needed which could add "an extra 0.6% to 0.8% GDP". On top of that, meeting the EU's objective of 20% renewable energy sources has the potential "to create more than 600000 jobs in the EU" with an extra "1 million new jobs" if the 20% target on energy efficiency is also met (p.13).

The EU-15 is on track to meet its Kyoto Protocol target of reducing average emissions in 2008–2012 to 8% below 1990 levels. Assuming full implementation of EU legislation, the EU-27 should likewise achieve its goal of cutting emissions by 20% by 2020. "However, national pledges under the 2009 Copenhagen Accord are still insufficient to keep average global temperature from rising by more than 2°C above pre-industrial levels" (EEA, 2010)[15]. Indeed, the ESPON Climate project has shown a highly differentiated picture with regard to the mitigative capacity of the different parts

[14] To reduce GHG emissions to 20% below 1990 levels by 2020; to increase the share of renewable energy to 20% by 2020; and to achieve 20% energy efficiency by 2020.
[15] http://www.eea.europa.eu/soer/policy-makers/climate-change-mitigation

of Europe. The eastern and southern regions of Europe have a much lower mitigative capacity than the northern European regions. These are the regions which are already performing less strongly with regard to the EU competitiveness indicators. A low capacity for mitigation implies vulnerability to fluctuations to energy cost and security and as a result a negative impact on competitiveness. The Commission acknowledges the disparities in mitigative capacity and its crucial role in the future competitiveness of Europe. Hence, it intends to pursue a number of other initiatives by 2011 (EEA, 2010). While these measures are aimed at further reduction of GHG in the EU, they do not seem to take into account the significant differences in the mitigative capacity of different European regions and their ability to meet the EU-wide targets. A significant part of the EU-wide attempts to reduce GHG emissions need to focus on enhancing the mitigative capacities of the peripheral regions.

However, even if all the aforementioned initiatives succeed in reducing GHG emissions to the targeted levels, there will still be far-reaching consequences for EU's economic competiveness because of the climate changes that are already underway. This means that adaptation actions are imperative in enhancing the resilience of the EU. While the estimated cost of adaptation for Europe ranges from €2.5–16 billion per year for the infrastructure and coastal zones (UNFCCC, 2007)[16] to €4–60 billion per year for infrastructure (Stern, 2007)[17], it is widely acknowledged that the cost of addressing climate change now is lower that the costs of inaction[18]. An important step taken by the EU is the adoption of the EU *White Paper on Adaptation to Climate Change* in 2009 which proposes a framework for action based on: developing the knowledge base and integrating adaptation into EU policies through increasing the resilience of: health and social policies; agriculture and forests; biodiversity, ecosystems and water; coastal and marine areas; and, production systems and physical infrastructure.

The Commission also adopted a communication on disaster risk prevention in 2009, which aims to integrate policies and instruments related to disaster risk assessment, forecasting, prevention, preparedness and recovery. The communication also called for improving and better sharing data in the context of the EU civil protection mechanism. Such strategies to adapt to climate change are necessary to manage impacts even if global temperature increases are limited to below 2 °C above pre-industrial levels. Therefore the Commission plans to pursue a number of other initiatives by 2011 (EEA, 2010)[19]. As with mitigation, the ESPON Climate project has shown a highly differentiated picture with the peripheral regions in the east and south showing a much lower level of adaptive capacity than the core regions. This will reduce the competitiveness of these regions which already suffer from low economic competitive performance. At the level of the EU as whole, compared with other major economic regions in the world, such as China, South East Asia and the emerging economies such as Brazil and India, Europe will be less affected by climate change (see for example the IPCC 2007 report). This is particularly the case with regard to the economic heartland (the core) of Europe which also has, as shown in the ESPON Climate project, a high level of mitigative and adaptive capacity. If this capacity is capitalized, it will certainly enhance the

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[16] UNFCCC, 2007. *Investment and financial flows relevant to the development of an effective and appropriate international response to Climate Change*. United Nations Framework Convention on Climate Change
[17] Stern, N. H. (2007) The economics of climate change: The Stern Review. Cambridge: Cambridge University Press.
[18] OECD 2009: The Economics of Climate Change Mitigation. Policies and Options for Global Action Beyond 2012
[19] http://www.eea.europa.eu/soer/policy-makers/climate-change-mitigation

competitiveness of the EU in the global market. Another important point to highlight is that the diversity of climatic regions in Europe allows for a degree of economic adjustments which in turn will at least maintain the EU's position in the world market in relation to climate-sensitive economic sectors. For example, as shown in the economic sensitivity analysis of ESON Climate project, while the impact of climate change on summer tourism is negative in the Mediterranean regions, it is positive in the colder regions of the north which will enjoy from a favourable Tourist Comfort Index. For the competitiveness of the EU as a whole, this implies that a potential loss of tourism in one part of Europe may be compensated by a potential gain in another part. Furthermore, climate mitigation and energy efficiency policies are one of the four key priorities of the renewed Lisbon Strategy[20]. This means that through the development of knowledge base and support for research and innovation, EU action on climate change can converge with the Lisbon Strategy. However, as discussed below, without effective adaptation measures, such transformations may lead to increased disparities in Europe.

Cohesion

While climate change will affect Europe as a whole, the severity of its impacts varies in different regions and for different economic sectors and social groups. As regards the latter, for example, older people whose "average age and share of the population 65 and over (in the EU) are among the highest in the world" (5CR, 2010:10) are among the most vulnerable groups in terms of adaptation to climate change. "The EU has one of the highest life expectancies in the world. [...] This has consequences for both health services and the labour force" (ibid.). It is highlighted by several studies that there is a strong distributional effect for vulnerability in Europe. For example, in relation to health[21] or coastal flooding risk[22] there is a correlation between vulnerability and social deprivation. The Impact Assessment of the EU White Paper[23] on adaptation states that, "Adaptive capacity is often positively correlated with economic development, thus access to efficient adaptation is greater for high-income groups and richer areas, and less for the poor, and such effects are often compounded by levels of awareness and access to information (as well as insurance)". The report adds that "more adverse impacts may be expected in some regions with lower economic development (which is often related to lower adaptive capacity)" (p.16-17). These inequalities are important when considering the future of cohesion policy and in relation to solidarity. These differentiated climate change impacts will in turn affect European territorial cohesion and may lead to the widening and deepening of territorial disparities. Therefore, the compounding inequalities which may result due to climate change need to be addressed when considering the future of cohesion policy and in relation to solidarity.

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[20] http://ec.europa.eu/growthandjobs/index_en.htm
[21] Menne, B., and Ebi, K.L. (eds) (2006) Climate change and adaptation strategies for human health. WHO (Europe)
[22] Environment Agency (2006). Addressing Environmental Inequalities: Flood Risk. SCHO0905BJOK-EP Science Report: SC020061/SR1. Authors: Gordon Walker, Kate Burningham, Jane Fielding, Graham Smith, Diana Thrush, Helen Fay. Available at www.environment-agency.gov.uk
[23] Impact assessment, COMMISSION STAFF WORKING DOCUMENT, *accompanying the* WHITE PAPER Adapting to climate change, 2009 {COM(2009) 147 final}

It is evident from the results of the ESPON Climate project those sectors of the economy which are directly affected include: the primary sector (agriculture, forestry and fishery), tourism (winter and summer) and the energy sector (supply and demand). However, the severity and nature of impact on these sectors vary in different parts of Europe resulting in negative impacts in some places and positive impacts in others. Also, depending on the share of these sectors in the overall economy of different regions, the expected impacts can be more or less damaging economically (in terms of GVA) and socially (in terms of employment). It is evident from the economic impact analysis that the primary sector in the peripheral regions is particularly vulnerable to climate change. This plus a low level of adaptive capacity may exacerbate regional disparities in Europe and reduce European cohesion. Hence, there needs to be a mainstreaming of climate issues into the rural development policy in the interest of a balanced territorial development of European rural areas. Such mainstreaming is also required under the Renewed Social Agenda[24] which is based on a holistic approach to social policy. Furthermore, as the frequency and intensity of natural hazards increases, leading to more flooding, drought, heat waves and forest fires, there will be devastating impact on the EU physical capital (such as infrastructures, roads and utilities) and human capital (such as loss of working days and even lives) both of which will significantly affect the EU economies and its competiveness. These, too, are spatially differentiated and can therefore potentially exacerbate the current territorial disparities. On the other hand, some climate change impacts can provide opportunities which, if capitalized, can reduce such disparities in Europe (see Section 5.2). Overall, there is need for a degree of oversight and responsibility at the EU level to complement the actions at national level to ensure cohesion.

"Cohesion Policy is the EU's main instrument for seeking harmonious development across the Union. It is based on a broad vision, which encompasses not just the economic development of lagging regions and support for vulnerable social groups, but also environmental sustainability and respect for the territorial and cultural features of different parts of the EU" (European Commission 2010b, XX). The Fifth Cohesion Report (5CR) (ibid.), published in November 2010 for comments, is the first report which is adopted under the Lisbon Treaty. With the adoption of the Lisbon Treaty a third dimension was added to the objective of cohesion: the EU 'shall promote economic, social and territorial cohesion'. While economic and social cohesion focuses on regional disparities in competitiveness and well-being; territorial cohesion reinforces "the importance of access to services, sustainable development, functional geographies and territorial analysis" (5CR, 2010:24). Compared with previous Cohesion Reports, the 5CR pays more attention to the environmental dimensions of sustainable development[25] and states that, "Environmental protection, climate change and renewable energy production all have a strong territorial dimension" (ibid.). It confirms that "The growing threat of climate change and the political goal to radically increase the share of renewable energy in the EU underlines the fact that policies at different levels will need to be coordinated to respond to these various threats and opportunities in an efficient and effective way and to avoid them counteracting each other" (ibid.). More importantly, the 5CR acknowledges that, "adapting to climate change will be most difficult in southern cities and regions and coastal and mountain areas" and that, "several regions which rely heavily on agriculture and winter or summer

[24] COM (412) of 2 July 2008
[25] See The territorial dimension of environmental sustainability. Technical report No 9/2010, EEA, 2009, Copenhagen,http://www.eea.europa.eu/publications/the-territorial-dimension-of-environmental-sustainability

tourism are likely to have more droughts and less snow in the near future which could undermine these activities" (5CR, 2010:12).

The future competiveness and cohesion of the EU depends to a large extent on successful mitigation and adaptation to climate change. It is therefore important that EU policies for combating climate change take into account its varied impact on different localities in Europe, as mentioned above. The Cohesion Policy itself needs to pay attention to wider drivers of spatial inequality which cannot be determined by solely focusing on economic indicators such as GDP per capita. As ESPON Climate project shows, a significant driver of potential future disparities is the degree of adaptive capacity for tackling climate change. This, however, as shown in this project is highly differentiated across Europe with peripheral regions in the east and south of Europe showing a low level of adaptive capacity. Attentions, therefore, should be paid on the different level of efforts and investments needed to mitigate and adapt to climate change in different parts of Europe. Although the 5CR dedicates a chapter on 'Enhancing environmental sustainability' which acknowledges that climate change will hit southern and eastern Europe hardest, it says little about how these varied climate change impacts will be reflected in future cohesion policy. In fact, it continues to put the emphasis on economic indicators for providing financial support for the regions, stating that, "As today, support would be differentiated between regions based on their level of economic development drawing a clear distinction between 'less' and 'more' developed regions" (5CR, 2010:10)[26]. The findings from the ESPON Climate Project provides a robust basis for identifying the expected social and economic impacts of climate change on different regions and their adaptive capacity to cope with these. These should inform the allocation of EU funds so that regions that are expected to be hit severely and have low mitigative and adaptive capacity are provided with targeted financial assistance to enhance their capacities. To achieve the EU cohesion goals requires European convergence in climate resilience. Also, the evidence provided by this Project should be used to develop criteria for ERDF-funded projects (see below). For example, it could be a requirement that EU-funded infrastructures should demonstrate a high level of energy efficiency as well as adaptability to future climate change. As mentioned in the 5CR (2010:17), "The explicit linkage of Cohesion Policy and Europe 2020 provides a real opportunity: to continue helping the poorer regions of the EU catch up, to facilitate coordination between EU policies, and to develop Cohesion Policy into a leading enabler of growth, also in qualitative terms, for the whole of the EU, while addressing societal challenges such as ageing and climate change". To address these issues, Europe 2020 Strategy (2010: 9) rightly points out to the need for "a greater capacity for research and development as well as innovation across all sectors of the economy, combined with increased resource efficiency will improve competitiveness and foster job creation. Investing in cleaner, low carbon technologies will help our environment, contribute to fighting climate change and create new business and employment opportunities".

[26] Conclusions of the fifth report on economic, social and territorial cohesion: the future of cohesion policy, SEC(2010) 1348 final

4.1.2 Implications for other EU policies and programmes

Transnational cooperation

In the period 2007-2013, 4 inter-regional, 13 trans-national, and 52 trans-boundary programmes have been launched within the framework of the European Territorial Co-operation. In this study we focus on 10 European trans-national regions and the INTERREG IV C Operative Programme covering the entire territory of the EU. The theme of climate change can be found in the operative programs elaborated for each trans-national region, both in the analysis chapter and in the strategy. In the chapter exploring and surveying the situation the following problems became evident: increase of the sea level, floods, forest fires, droughts, extreme weather conditions and events, and increase in the frequency (occurrence) of natural damages. The mitigation of the unfavourable impacts of the climate change is not shown as an explicit priority in any of these programs. However, as an intervention in the interest of achieving other priority goals it appears in the majority of these programs. The various interventions are shown as part of priorities dealing with environmental protection, sustainable development or natural risk. As a rule, they would mitigate unfavourable impacts by the development of water management and the use of various means of risk prevention. As far as recommendations for concrete projects are concerned, R&D tasks requiring international co-operation have been mentioned most frequently in, for example, development of models, development of forecast systems, transfer of knowledge, new methods of planning, development of the spatial and regional planning practice, and its preparation for coping with the impact of climate change, forecasting of and coping with the potential impacts of climate change and natural risks, and coping with trans-boundary risks. As far as project recommendations are concerned, the emphasis is on the theme of water management. The results of ESPON Climate Project may be a help in planning works of the next program period (2014-2020). On the maps presenting the expected impacts of climate change, the geographical differences and the relevance of the climate impacts can be identified for each trans-national region, and the regional importance of the relevant impacts can be ranked, helping thereby the identification of the territories requiring intervention, the regional goals and priorities and the description of the recommended projects. The result maps of adaptive capacity can be the basis for describing the measures necessary for strengthening factors that reduce adaptive ability.

Based on the results of the vulnerability assessment of the ESPON Climate project, the ten assessed trans-national regions can be classified into the following three major groups:

1. Regions where vulnerability is expected, as a rule, to increase at a high or medium rate,
2. Regions where vulnerability is expected, as a rule, to grow at a low rate,
3. Regions, where vulnerability is expected, as a rule, not to change significantly.

The first group includes the Mediterranean Region, South-Western and South-Eastern Europe. Here the projected climate change impacts accrue primarily in the environmental and economic dimension. But the overall growth of vulnerability in these regions is to a considerable degree due to their poor adaptation capacity. Therefore, program measures addressing e.g. water management, preservation of water, forest fire forecasts, preparation for heat waves and regulation of land use would potentially have the greatest importance.

The second group is composed of the Northern Sea region, the North-Western European and the Atlantic coastal regions (and presumably the Alpine region, too). In terms of adaptation capacity these three regions - although not homogeneous – generally exhibit better scores than the regions of the first group. Because the increase of climate change impacts in the second group's regions is projected primarily for the physical and social dimensions, the program measures addressing natural disasters such as floods and coastal storms would have the greatest positive effects.

The third group is made up of the Baltic Sea region, the Northern periphery and Central Europe (although the latter could also be seen as in between the second and the third group). The projected changes of climate impacts are diverse but not extreme in any dimension. Despite of this, adaptation measures may have an important role in these regions, too, especially those related to water management and the prevention of natural disasters.

Potential future cross border cooperation (INTERREG IV A) could enhance climate change adaptation capacities. These could especially focus on close cooperation on climate change adaptation and mitigation concepts. Especially in climate change adaptation competition or contradicting adaptation in cross border areas can be avoided by such cooperation. Due to the manifold INTERREG IV A areas the project has identified here only those border regions with strong differences in their adaptive capacity and would especially recommend future strong cooperation in these border regions: Germany and Poland, Germany and Czech Republic, Hungary and Austria, Austria and Czech Republic, Austria and Slovakia, Austria and Italy, Austria and Slovenia, Switzerland and Italy, France and Italy. The projects should be used as sources for direct support of further policy development.

The overall structure of regional development projects could be enhanced towards delivery of policy recommendations, derived from practical examples of regional cooperation. To this end current INTERREG IV B and C programmes were analysed. Since most programmes already have a clear distinction of climate change related issues no separate policy recommendations were derived. Instead, a more practical approach was chosen by making proposals for enhancement or amendment of current areas of interventions and further programme development. These proposals are directly derived from both the European maps and the case study areas. *Table 18* below gives an overview over current INTERREG IV B & C programmes and selected programme priorities. The table is structured in the following way:

- The 1st column lists the relevant INTERREG IV B and C programme areas.
- The 2nd column lists the climate changes impacts identified by these programme areas.
- The 3rd column lists the climate change stimuli and impacts identified by the ESPON Climate project.
- The 4th column lists the existing relevant areas of intervention of climate change of the respective programme areas as well as proposed amendments to those. Where the identified areas appear suitable for future programmes no changes are proposed. Those

areas where the project identified a potential enhancement of the current programme suggestions are given in *italic*.

- The final 5th column lists potential criteria that could be included in further developments of the programmes.

The INTERREG areas Açores-Madeira-Canarias; Caribbean and Indian Ocean could not be covered in this assessment because the used climate model does not cover these areas.

Table 18: Climate change and INTERREG IV B Operative Programmes

Name of the transnational cooperation OP	**Climate change issues identified by current operational programmes**	**Climate change stimuli and impacts affecting sectors (identified from ESPON Climate project)s**	**Relevant area of intervention current addressed by the programme areas. Proposed amendments are given in *italic***	**Policy related options for further programme area development, derived from map and case study analysis**
Northern Periphery	• flood, • sea level rise • extreme weather events	• flood • sea level rise	• 2.(i.)Environment as an asset in the periphery impact and possible implications of climate change and means to reduce it at a community level	• Risk management for settlements potentially affected by river floods related to climate change
Baltic Sea	• flood • forest fire • extreme precipitation	• storm surges • sea level rise • floods • flash floods • Changing frost conditions • Changing precipitation patterns	• 3.1. Water management with special attention to challenges caused by increasing economic activities and climate changes. Actions, action plans, strategies and legislative frameworks for improved water management in order to minimise impacts of climate change	• Further development of regional adaptation strategies related for climate change impacts on forestry
			• 3.4. Integrated development of off-shore and coastal areas. Preparation of scenarios, adaptation strategies and intervention plans towards mitigation of impacts of climate change on coastal areas *Holistic approaches to identify impacts of climate and global change (including demographic changes), with a special focus on forestry and tourism*	• Climate change impact assessments on coastal and island areas, including tourism and water quality (algae blooming).
North West Europe	• flood • drought • forest fire • increasing frequency of natural hazard	• flood • sea level rise • river floods • flash floods • storm surges	• 2.2. To promote an innovative approach to risk management and prevention, in particular water management (effects of the high concentration of human activities in coastal areas and river valleys; impacts of sea level rise on coastal areas and flood risk; the marine environment) in the context of climate change *Holistic approaches to identify impacts of climate and global change (including demographic changes), with a special focus on heat islands, storms and infrastructure*	• Combination of flood and storm surge prevention and spatial planning as cross border and transnational initiatives.
North Sea	• flood • sea level rise	• flood • sea level rise • river floods • flash floods • storm surges • storms • Sea level rise	• Adapting to and reducing risks posed to society and nature by a changing climate. • *Holistic approaches to identify impacts of climate and global change (including demographic changes), with a special focus on heat islands, storms and infrastructure*	• Combination of flood and storm surge prevention and spatial planning as cross border and transnational initiatives.
Atlantic Coast	• flood • sea level rise • forest fire (south)	• flood • sea level rise • river floods • flash floods • storm surges • Storms • Sea level rise	• 2.4. Protect and promote natural spaces, water resources and coastal zones, *Focus on aspects of climate and global change, taking into account structural development of populated coastal areas and hinterlands.*	• Development of regional strategies to anticipate the impact of river floods • Development of regional strategies to anticipate the impact of storms and storm surges

Name of the transnational cooperation OP	Climate change issues identified by current operational programmes	Climate change stimuli and impacts affecting sectors (identified from ESPON Climate project)s	Relevant area of intervention currently addressed by the programme areas. Proposed amendments are given in italic	Policy related options for further programme area development, derived from map and case study analysis
Alpine space	• Alpine hazards • Floods	• Floods • Flash floods • Changes in precipitation / evaporation patterns	• Climate change is affecting the Alps earlier and rather more severely than the rest of Europe. Coping with effects of climate change in all aspects (from changing river systems to changing cultural landscapes) will be a major challenge for the cooperation area (…) *Holistic approaches to identify impacts of climate and global change (including demographic changes), with a special focus on future development scenarios, including tourism, agriculture, urban expansion and infrastructure.*	• Diversification of tourism, also interlinked with water scarcity • Integration of sustainable cross-border adaptation and mitigation concepts • Options of enhancing synergies to avoid conflicts (especially on adaptation measures) • Over regional and transnational water management approaches, especially focusing on the Alps as a "water tower".
Central Europe	• Flood risk	• floods • flash floods • Changing frost conditions • Changing precipitation patterns • Increase in summer days and summer temperatures • Sea level rise	• 3.2. Reducing risks and impacts of natural and man-made hazards. Developing and applying tools and approaches for mitigation and management of the impacts of climate change and other risks	• Development of regional climate change adaptation strategies on floods, heat waves, forest fires • Development of regional climate change adaptation strategies on water scarcity • Development of regional climate change adaptation strategies on tourism • Development of regional climate change adaptation strategies for agriculture and forestry
South West Europe	• Hydrological risks and forest fires	• Agriculture • Forestry • Flood • Sea level rise	• (… translated from Spanish…) Transnational planning to mitigate environmental challenges and risk (…) • Objective 6: Impulse cooperation strategies to prevent natural risks, particularly forest fires. *Integration of, current and future, hazard and risk concepts into development plans* *Holistic approaches to identify impacts of climate and global change (including demographic changes)*	• Development of regional transnational climate change adaptation strategies on heat waves, water shortage and forest fires.
Mediterranean	• Forest fires, droughts • decreasing rainfall, hurricanes, floods, sea level rise, tidal waves, coastal erosion…) • sea level rise	• Storm surges • Droughts • Floods • Forest fires • Changing precipitation patterns • Changing evaporation patterns • Increase in summer days • Sea level rise	• monitoring the consequences of climate changes; assessment of vulnerability of landscapes, forests and natural resources; monitoring of floods and fires; anticipation of risks related to sea level rise.. • 2.4. Prevention and fight against natural risks within the European Union, the Med area is particularly exposed to natural risks (…) *Integration of, current and future, hazard and risk concepts into development plans* *Holistic approaches to identify impacts of climate and global change (including demographic changes and migration)* *Strengthening of cross-border initiatives to prevent emerging risks*	• Management of public (including tourism) water demand. Identification of possibilities to save water instead of relying on current water management schemes and further development of desalinisation plants. • Avoidance of mal-adaptation, e.g. transferring costs and risks from water sector to energy sector • Management of land take (urban sprawl)
South East Europe	• drought • forest fires • floods • landslides	• Flood • Sea level rise • Changing precipitation patterns • Changing evaporation patterns • Increase in summer days • Sea level rise	• 2.1.Improve integrated water management and transnational flood risk prevention, *including climate change impacts* • 2.2 Improve prevention of environmental risks, including impacts of climate and global changes, also focusing on demography and migration	• Emphasize analysis and management concepts on impacts of climate change on forestry and agriculture • Development of common (cross-border) methodology for land use restructuring, including integrated water management planning
INTERREG IV C		• INTERREG IV B covers all of Europe, thus no particular climate change stimuli or impacts are mentioned here.	*Expansion of cooperation in all fields of analysis and concept development on climate and global change adaptation concepts.*	• Exchange of experiences of different regions to foster on further development of best practices • Endorsement of cooperation concepts for GHG reduction

Other relevant EU policies / programmes

EU nature & biodiversity policy[27]. In 2010 an agreement on a global strategy to combat biodiversity loss over the next decade (2011–2020) has been adopted. The EU will develop its own post-2010 Strategy early in 2011. According to the document in order *to* evaluate and reduce the negative impacts of climate change mitigation and adaptation activities on biodiversity the potential environmental and cross-sectoral impacts of projects and the environmental safeguard policies will be analysed using a set of indicators which will report the achievement of social, cultural and economic benefits for biodiversity, climate change and combating desertification/land degradation. Biodiversity is the most vulnerable component and both the positive and negative impacts of climate change mitigation and adaptation activities on relevant ecosystems should be assessed according to the document.

The ***EU Directive on the assessment and management of flood risks*** entered into force in 2007 (2007/60/EC), to reduce the risk of floods and other adverse consequences of climate change, especially for human health and life, the environment, cultural heritage, economic activity and infrastructure, effective measures have to be coordinated throughout a river basin by elaboration of a river basin management plan. In each river basin district or unit of management the flood risks and need for further action — such as the evaluation of flood mitigation potential — should be assessed, including activities which may increase flood risk. Flood risk management plans should focus on prevention, protection and preparedness, and may also include the promotion of sustainable land use practices, improvement of water retention as well as the controlled flooding of certain areas in the case of a flood event.

The ***EU Integrated Maritime Policy*** established in 2007, for the period between 2011 and 2013, to keep up the good work in favour of a sustainable use of oceans, seas and coasts. It advocates an integrated approach to the management and governance of the oceans, seas and coasts, and fosters interaction between all sea-related policies in the EU. For continuation the "Marine Knowledge 2020" has been adopted[28]. This initiative aims to unlock and assemble marine data from different sources and facilitate their use for purposes of: improving the efficiency of all those private bodies, public authorities and researchers which presently use marine data; opening up new opportunities and drive innovation in the maritime economy; and improving knowledge of the sea can contribute towards Europe's adaptation to climate change*.*

The ***Marine Strategy Framework Directive*** was adopted in June 2008[29]. The aim of this ambitious Directive is to protect more effectively the marine environment across Europe. It aims to achieve good environmental status of the EU's marine waters by 2020 and to protect the resource base upon which marine-related economic and social activities depend. In 2010[30] Commission established precise objectives for the achievement of good environmental status of the marine environment in Europe taking into account the dynamic nature of marine ecosystems, their natural variability, and the fact that the pressures and impacts on them may vary with the evolution of

[27] **(**COP 9 Decision IX/16 Biodiversity and climate change)
[28] Marine Knowledge 2020: A better understanding of our seas and oceans to boost competitiveness and growth" (COM(2010)461 OD 8.9.2010)
[29] (Directive 2008/56/EC)
[30] C(2010) 5956)

different patterns of human activity and the impact of climate change. In view of the dynamic nature of marine ecosystems and their natural variability, and given that the impact of climate change, it is essential to recognize that the determination of good environmental status may have to be adapted over time. Accordingly, it is appropriate that programmes of measures for the protection and management of the marine environment be flexible and adaptive and takes account of scientific and technological developments. Provision should therefore be made for the updating of marine strategies on a regular basis. There are serious environmental concerns, in particular those due to climate change, relating to the Arctic waters which may require action to ensure the environmental protection of the Arctic.

The ***EU Common Transport Policy*** was adopted in 2001 and updated in 2006. In 2010/11 a revision of the 10-year transport policy was undertaken. The rapid growth in road, air and sea traffic is a reality. Road tonne km increased by 49.6% in EU27, and by 2007, road had a modal share of about 45% in intra-EU freight transport. Growth was significantly higher in the new Member States (8.3% per year since 1995). Road freight in the EU is forecast to increase by about 60% between by 2050, and long-distance road freight (trips longer than 150 km) to more than double. Car travel is forecast to increase by about 40% to 70% until 2050. In the future, the EU will concentrate on development of cleaner fuels and vehicles (low carbon transport), and strengthen its efforts to support the development and adoption of new cleaner technologies reducing emissions to tackle climate change[31]. In the longer term, the integration of land use and transport planning should help manage the demand for transport in Europe's towns and cities. Spatial planning can facilitate walking, cycling and the use of public transport for the majority of travel purposes, thereby reducing the negative impacts of private vehicle use on the environment and provide social and economic benefits.

The ***Directive on Environmental Impact Assessment*** [32]is in force since 1985 and has been amended three times, in 1997, in 2003 and in 2009. It aims to provide a high level of protection of the environment and to contribute to the integration of environmental considerations into the preparation of projects, plans and programmes with a view to reduce their environmental impact. The Commission Communication of 10 January 2007 entitled "Limiting global climate change to 2 degrees Celsius – The way ahead for 2020 and beyond" clarifies that the need for reduction of GHG emissions by 60%-80% by 2050. Carbon dioxide capture and geological storage (CCS) is a bridging technology that will contribute to mitigating climate change.

The ***Directive on Strategic Environmental Assessment***[33] has a procedure that ensures that the environmental implications of decisions are taken into account before the decisions are made. SEA aims to provide a high level of protection of the environment and to contribute to the integration of environmental considerations into the preparation of projects, plans and programmes with a view to reduce their environmental impact. SEA can help to ensure that plans and programmes take full account of climate change issues where any plans' impacts on a number of environmental issues, including climatic factors have to be evaluated and proposed measures to minimize and respond to significant impacts identified. Climate change is a cumulative effect: it is caused by many actions.

[31] (IPCC.35 35 IPCC Fourth Assessment Report: Working Group III Report "Mitigation of Climate Change", Ch 5)
[32] (Directive 85/337/EEC)
[33] (Directive 2001/42/EC - SEA Directive)

4.2 Policy options for climate change mitigation and adaptation

Climate change is unequivocal (IPCC 2007) and there is a need for the global society to respond to the unprecedented challenges in the coming decades. Societies can respond by mitigating their emissions of greenhouse gases, thus slowing down the speed and scale of changes. Simultaneously, societies need to take into account the fact that warming has already been loaded into the global climate system that will inevitably lead to impacts that will be felt globally. Thus, societies need to adapt to changes in climate by formulating policies that enable adaptation to take place and by putting into place measures that build capacity to respond to the changes.

Europe plays an important role in global climate policy that aim to reach a global deal for emissions reductions and encourage the take up of adaptation. The EU's latest position on climate change mitigation was outlined in the Climate action and renewable energy package (Commission of the European Communities 2008a). The European Union has stated that its aims for emissions reductions are a 20 per cent reduction of greenhouse gases by the year 2020. The second target of the Union is to increase the share of renewable energies to 20 per cent in energy consumption by 2020. Adaptation, on the other hand, was initially considered a predominantly developing country issue due to their lower capacity and resources to adapt to changes. However, in the past five years adaptation has also become a policy goal in many European countries with majority of the European countries now having started or completed their national adaptation strategies (NAS). The EU, following national developments, published a white paper in 2009 that outlines the Union's approach to adaptation. It outlines the Union's approach to adaptation, which in the next two years focuses on accumulating knowledge and sharing that through a clearing house mechanism (Commission of the European Communities 2007).

This section reviews both mitigation and adaptation policies within the ESPON space, contributing to the work package 2.4 of the ESPON Climate programme. The aim of the report is to review existing policies on mitigation and adaptation in order to address the institutional and governance dimensions of territorial potentials of the NUTS3 regions. Although the focus is specifically on the regions within the ESPON Space, governance of climate change, as can be seen in this report, increasingly takes place across several levels of governance, and thus the regional level cannot be studied in isolation.

Firstly, the section discusses briefly the governance context of mitigation and adaptation, highlighting the multi-level nature of decision-making inherent in both, and secondly discusses matters related to methodology. Thirdly, adaptation policy within the European context is addressed, showing how countries have been able to pursue their own policy agenda. This report reviews studies focusing on the national as well as on the regional level adaptation initiatives. Fourthly, this section reviews the aims of the EU mitigation policy and targets for reducing carbon emissions within the Union. There are also several EU directives and commitments that directly affect regions which will be reviewed. Fifthly, this section discusses the possible synergies that can exist between mitigation and adaptation as policy goals. Finally, the section outlines some possible new development opportunities that pursuing mitigation and adaptation policies can bring to European regions.

Governance of climate change in Europe

There is a growing recognition that the government no longer is a single source of authority when it comes to decision-making in societies but that governance of societies is now more complex and this is also holds true for mitigation and adaptation. Increasingly, actors outside the sphere of the state take part in decision-making, leading to the rise of partnerships between the state and civil society in the form of partnerships and networks (Bulkeley, Betsill 2003). Furthermore, the role of the state has changed from controlling and commanding to steering and enabling in the process of governance. Decision-making processes across multiple levels can naturally take place vertically but also horizontally across multiple sectors of administration. Governance, a terms mainly used in political science, has been defined as a system of continuous negotiation among nested governments at several territorial tiers- supranational, national, regional and local (quoted in (Hooghe, Marks 2003). This discussion of governance, unsurprisingly, arises from the European context and is particularly relevant in the context of the European regions.

ESPON 2.3.2 Governance project focused on the governance of regions in Europe and considered the issue of multiple scales as one of the most important (Farinos Dasi et al. 2006). It is acknowledged that regional models of governance are to a large extent depended on the vertical organisation of the each country. Inherent in the structures of each country are the relationships between the different governmental levels and other stakeholders. In addition, the ESPON Governance project also concludes that the vertical dimensions of governance are much more evolved than those of related to the horizontal dimension. This is particularly interesting, considering that sectoral co-operation and policy integration across sectors is regarded as one of the most pressing challenges of both successful mitigation and adaptation (Mickwitz et al. 2009).

In addition to taking into account the governance system of a country, it is important to note that the traditions of environmental policy-making and planning cultures play significant roles in both mitigation and particularly in designing adaptation measures (Keskitalo 2010). Newton and Thornley have identified ‘families’ of legal and administrative systems in Europe, dividing the systems according to the ways in which balance between central and local power is distributed (Leary 1999). This division into different traditions is based on legal and administrative structures that affect how the countries are governed, and the authors identify five ‘families’ within Europe, see Table 19. The term legal refers to the historical developments of the legal system and its legal sources and ideology, whereas administrative systems are considered to be the administration of local government and local democracy.

Table 19: Legal and administrative ‘families’ in Europe

Family	**Legal ‘families’**	**Administrative ‘families’**
British	England, Wales, Ireland	UK, Ireland
Scandinavian	Norway, Sweden, Denmark, Finland	Norway, Sweden, Denmark, Finland
Germanic	Germany, Switzerland, Austria (Eastern Europe), Greece	Germany, Switzerland, Austria (Spain, Belgium)
Napoleonic	France, Italy, Spain, Portugal, Belgium, Luxembourg, Netherlands, (Greece)	France, Italy, Spain, Portugal, Belgium, Luxembourg, Netherlands, Greece, (Spain, Belgium)

Although the policies of the Community shape national policies more and more, the specifics of the different Member States mainly characterise the design of national policies. In some of the EU Member States e. g., a new development is legally allowed when it is conforms to the regional plan. This so called regulatory function of spatial planning is known under the term "conforming planning" in the international discourse on planning theory (Rivolin, 2008; Larsson, 2006). In most of the EU Member States, the so called development function dominates at the regional planning level which is discussed under the term "performing planning". This planning type is characterised by non-binding programmatic and/or strategic statements. Potential projects are then evaluated against the question whether they support the implementation of the programme or strategy. Furthermore, there are – if at all – only partially binding effects for the subordinated local level. The question in this respect is if the planning system has an influence on the role of territorial development in adaptation strategies.

Although these divisions affect the way in mitigation and adaptation are governed, it does not necessarily mean that they alone determine the shape that climate change policies take in these countries. Even though these differences in legal and administrative traditions are not further discussed in this report, it is necessary to keep in mind that there are several European traditions of decision-making that underlie the implementation of climate change measures within the Union.

With specific attention to the regions in Europe, it has been argued that there has been a steady "regionalisation" of policies in OECD countries since the 1970s (Jeffrey 2008). Environmental problems and their governance have contributed to this trend. Regionalisation of policy and politics, linked with the rise of multi-level governance and the notion of territorial cohesion seem to be driving policy development in the same direction, emphasising the spatial dimension of EU policy (both horizontal and vertical, i.e. sectors and government levels). Hence, territorial cohesion becomes important, focusing on targeting places rather than sectors as a focus of policy (Davoudi 2005). In the perspective of territorial governance, regions can be seen as pivotal for the implementation of climate mitigation and adaptation policies. As functional geographical entities, regions encompass many everyday life cycles that are relevant for climate change may be more appropriate considering the scale of climate change mitigation efforts (e.g. urban sprawl in city-regions) or adaptation (e.g. river basin wide flood risk management). Importantly, policy integration takes place at the regional level.

The need for a regionalised approach is further highlighted in the recently adopted European Union Strategy for the Baltic Sea Region, for example. This transnational regional initiative is interesting because it embodies the idea of territorial governance, focusing on the horizontal integration of policy goals in a given territorial context. It addresses four key challenges of sustainable environment, continued prosperity, accessibility and attractiveness as well as safety and security (European Commission 2009a). The related Baltic Action plan (European Commission 2009b) highlights the added value of a common Baltic Sea Approach, seeing the Baltic as a specific eco-region with particular climate change related challenges. The priority area of mitigation and adaptation, coordinated by Denmark, seeks to create an adaptation strategy at the level of the whole Baltic Sea Region, providing a framework for strengthening co-operation and sharing information across the region. The strategy would also ensure complementarities with the White paper on adaptation and other EU-initiatives, focus on cross-border issues, develop more robust evidence on the impacts of climate change and raise awareness on the issue in the region (European Commission 2009b).

The dimension of territorial governance, together with the example of the EU strategy for the Baltic Sea Region, questions the adequacy of both national and local level responses to pressing policy problems. The Finnish national adaptation strategy can be used as an example of, the problem of territorial integration: Finland has adopted a national adaptation strategy as early as 2005. However, the strategy was based on a sectoral central government approach, lacking a spatial or a territorial dimension, cf. (Peltonen, Haanpää & Lehtonen 2005). Recent experience demonstrates that the strategy has had some effect at the ministry level, but sub-national regional and local implementation has not followed directly from the national strategy. As to the transnational context, the Finnish strategy would also benefit from coordinated action at the Baltic Sea level.

Methodology

The aim of this section is to review mitigation and adaptation policy at the regional level in the ESPON space. It is acknowledged that in terms of both adaptation and mitigation, European regions are greatly affected by policies arising not only from the national level but also from the European Union and from the international fora. In addition to this, sub-national actors across Europe themselves are now pursuing their own strategies in order to adapt and mitigate climate change. In order to clarify this situation, this report analyses all three levels of governance, the European, national and the regional. It is also acknowledged that the local level can be an important level of governance in some European countries, even more so than the regional level but this level is not explicitly addressed in this report. Although extending the analysis across several levels of governance does to certain extent move the emphasis away from the regional level, it nevertheless gives a more accurate picture of the governance environment within which the regions operate.

The aims of this review are accomplished by using secondary sources, and this is mainly due to constraints placed on time and resources. In terms of the EU level, policy documents are the main source of information for both mitigation and adaptation policies. In terms of adaptation policy, national adaptation strategies (NAS) and analyses of them are used for those countries where one existed. There are a number of Union wide studies of comparative NAS development which are used. Secondly, important sources of data are case studies of regional climate strategies and regional adaptation strategies (RAS), although these are very few and present a problem in terms of coverage of the European regions. However, they present a valuable source of information on a rapidly moving policy field, and can be used to get an indication of what is happening on adaptation at the regional level in Europe.

In terms of national mitigation policy, main sources of data are research reports and reviews that have analysed the use of mitigation policy instruments across the Member States, as well as published studies on mitigation policy in Europe. The tables that focus on different policy instruments within the different Member States have been produced with data from the European Environment Agency. In terms of regional mitigation strategies, studies of regional measures are used as well as policy documents from the EU level. Furthermore, it should be acknowledged that in many cases at the regional level both adaptation and mitigation are considered in a joint climate strategy that addresses both concerns. These strategies are generally based on voluntary initiatives with varying sources of funding. Finally, it has to be recognised that due to the newness of the topic, there are only a limited number of analyses of regional adaptation, thus making the sample size of strategies small and by no means comprehensive, nor comparative.

4.2.1 Adaptation to climate change

Adaptation is considered to be the second policy response alongside mitigation in relation to the challenges posed by the changing climate. Adaptation has been defined as the processes, practices and structures to moderate or offset the potential damages of opportunities associated with climate change (Smit, Pilifosova 2001). The internationally accepted definition by the Intergovernmental Panel on Climate Change (IPCC) considers adaptation as 'adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities' (IPCC 2007).

Adaptation can take place through autonomous adaptation by individuals or by business for example. Alternatively, planned adaptation can take place through public policy measures undertaken by governments in order to avoid harm due to climate change or to exploit the possibilities that arise from the changes. In addition to this distinction, adaptation policy can also be reactive, focusing on impacts that have already been felt due to climate change. In contrast, adaptation can also be proactive in that adaptations are developed and designed to counter the effects of projected changes. The main challenges of adaptation to climate change are the sectoral coordination of policies as well as policy integration of adaptation policy across policies in individual sectors (Mickwitz et al. 2009).

Maladaptation

Responses to climate change addressed to avoid or reduce impacts may produce unintended negative effects which are usually referred to as "maladaptation". According to Barnett and O'Neill (2010, p. 211) maladaptation is 'action taken ostensibly to avoid or reduce vulnerability to climate change that impacts adversely on, or increases the vulnerability of other systems, sectors or social groups'. Maladaptation was mentioned in the Third Assessment Report of the IPCC and in the Impact Assessment Report that accompanies the EU White Paper on Adapting to Climate Change (European Commission 2009).

Adaptation is considered as 'maladaptation' when it is not considered to be sustainable in an integrated and long-term understanding. Maladaptations are often connected to high-energy consumption and therefore this implies that negative feedbacks between adaptation and mitigation. Nevertheless, all adaptation actions may produce undesired consequences. Geographical, cultural and social contexts should be carefully appraised before labelling certain actions as 'maladaptation'. Barnett and O'Neill, for instance, observe that temporal migration in certain traditional societies after a drought episode has been defined as 'maladaptation'. However, this is a response that helps the reproduction of households and has been practiced for generations. Likewise, irrigation in response to drought may be a critical alternative for certain rural societies even at the cost of increasing water consumption. The potential for maladaptations exist and three examples are highlighted in this study, which are relevant for several of case studies included in the ESPON Climate project.

Desalinisation. Desalinisation promises a total independence of water supply from the vagaries of climate and related hazards such as droughts by tapping an inexhaustible source which is water from the sea. However, desalinization is energy-intensive and therefore prone to increase carbon dioxide emissions if fossil fuels are used. Desalinisation also depends on energy prices and thus unaffordable for certain users (for instance, farmers). It may also create disincentives to search for more sustainable water options (for instance water saving devices at home) and may use economic resources best employed in more cost-efficient alternatives such as wastewater treatment. Finally, the environmental impact of the brine produced during the process (with extremely high concentrations of salt) may be very damaging for marine biota if not managed properly.

Production of artificial snow. As the current warming trend is increasingly affects winter sport tourism in many areas of the world, alpine ski stations adapt or 'maladapt' turning to this technology in order to produce artificial snow. Some ski resorts already produce artificial snow on a regular basis for snow-management and not only in warm winters with low precipitation. Production of artificial snow can be problematic for the environment as it is a) energy consuming b) water consuming and changing the seasonal water balance and c) having impacts on the natural environment, particularly if chemicals are used in the production process.

Nevertheless artificial snow production is increasingly accepted as a strategy and can prevent economic losses of the aggregated regional income of communities, which are highly dependent on winter tourism (Teich et al. 2007). Therefore in some tourism regions production of artificial snow is subsidised directly or indirectly by the local governments. Climate change thus leads to a double challenge. On the one hand, as temperatures are likely to rise in many ski resorts, artificial snow production will increase, leading to higher energy consumption. On the other hand, precipitation is likely to decrease in some regions, which increases pressure on existing water resources needed for artificial snow production.

*Air conditioning***.** One of the main causes of the fast growth in energy consumption observing during the last decade in Southern Europe and even Western and Central Europe, especially after the summer of 2003, is the result of proliferation of the use of air conditioning. This is a typical case of a technology being available at a low cost and therefore open to mass markets but perhaps not to those most in need, such as the poor and the elderly. Air conditioning can be considered also as an example of maladaptation because of the energy costs involved. Increasing temperature differences between indoor and outdoor spaces leads to the increased use of air conditioning whilst there are no sufficient incentives to design built environments adapted to the emerging climate conditions.

Adaptation policy across multiple scales

The focus in this report is on planned adaptation policy, and in the context of adaptation policy within the European regions. However, it is important to note that governance of other levels within the European Union, namely the national and the EU level, affects the adaptation policy in the European regions. The individual governance frameworks of countries enable or constrain regions to adapt to climate change. Also, the extent to which land use planning and other decisions related to adaptation are taken at the local level inhibits the regions to engage in adaptation. Therefore, in order to understand adaptation policy at the regional level in Europe, it is necessary to detail the approach to adaptation on other levels of governance also.

European Union adaptation policy

The European Union White Paper on adaptation was published in 2008 (Commission of the European Communities 2009b). The White Paper emphasises the need for a strategic approach, recognising that adaptation is already taking place across several member states. The White Paper complements the national initiatives that are taking place and aims to support international efforts of adaptation, also particularly in developing countries. It is stressed that action at the EU level is necessary, although most of the adaptation measures will be taken at the national, regional or local level. This is because the EU has a particularly strong role in instances where climate impacts transcend the boundaries of member states as well as making sure that the most disadvantaged regions will be capable of taking measures needed for adaptation. The role of the EU in coordinating action across certain sectors, such as agriculture, water and biodiversity are seen important and can be implemented by using the single market and common policies.

The objective of the EU's Adaptation Framework is to improve the resilience of the Union to deal with the impacts of climate change by adopting a two-phase approach (Commission of the European Communities 2007). First phase from 2009-2012 is to lay the groundwork for the preparation for a comprehensive EU adaptation strategy that will be implemented in the second phase, beginning 2013. Phase 1 consists of four pillars of action that require close co-operation between the EU, national, regional and local authorities in order to be successful, see

Table 20. First pillar consists of developing the knowledge base for adaptation that is based on reliable data on not only the likely climate change impacts but on related socio-economic aspects, including the costs and benefits of different adaptation options. Secondly, it is necessary to integrate adaptation into existing EU policies by conducting a review of how policies could be re-focused or amended to facilitate and enable adaptation. Thirdly, it is important to employ a combination of policies and policy instruments, ranging from guidelines to market-based instruments. Finally, the EU needs to step up and improve its role in international co-operation on climate change.

Table 20: EU Adaptation Framework: Phase 1.

Pillars of action	
Developing of the knowledge base	Take the necessary steps to establish by 2011 a Clearing House Mechanism
	Develop methods, models and data sets and prediction tools by 2011
	Develop indicators for to better monitor the impact climate change, including vulnerability impacts, and progress on adaptation by 2011
	Assess the costs and benefits of adaptation options by 2011
Integration of adaptation into policies	Develop guidelines and surveillance mechanisms on the health impacts of climate change by 2011
	Step up existing animal disease and control systems
	Assess the impacts of climate change and adaptation policies on employment and on the well-being of vulnerable social groups
Policy instruments	Estimate adaptation costs for relevant policy areas so that they can be taken into account in future financial decisions
	Further examine the potential use of innovative funding measures for adaptation
	Explore the potential for insurance and other financial products to complement adaptation measures and to function as risk sharing instruments
	Encourage Member States to utilise the EU'S ETS revenues for adaptation purposes
Member State and International co-operation	Take a decision to establish by 1 September 2009 an Impact and Adaptation Steering Group (IASG) to step up cooperation on adaptation
	Encourage the further development of National and Regional Adaptation Strategies with a view to considering mandatory adaptation strategies from 2012
	Step-up efforts to mainstream adaptation into all EU external policies
	Strengthen dialogue with partner countries on adaptation issues
	Take the Framework for Action on Adaptation forward in the UNFCCC

Source: (Commission of the European Communities 2009b)

In terms of supporting European regions in their efforts to adapt to climate change, the EU plays an important role. Coordination of adaptation by the EU is considered to be important in order to avoid major gaps in trans-national linkages and to provide common strategic direction to achieve a coherent approach to adaptation within the Union (Ribeiro et al. 2009). There are existing tools that can be used to support the regions' development of RAS, the most important of which is funding from existing EU funding mechanisms. Activities that can be supported from the funds include knowledge development, testing and validation of knowledge development, monitoring of the RAS development, its implementation and generation of awareness amongst relevant stakeholders as well as amongst the general public (*Ibid.*). The existing mechanisms that can be used include the regional development, economic and social cohesion funds, such as the European Regional

Development Fund (ERDF), The European Social Fund (ESF), LIFE + and INTERREG and European Territorial Cooperation (ETC) funding, for example.

National level adaptation policy across Europe

As the White Paper recognises, national level initiatives on adaptation have increased rapidly in the last few years within the European Union. There are now ten member states within the EU that have adopted a NAS, whilst several states are in the process of developing one, see Table 21 for countries that have a NAS. The Table also has details of countries that have yet to adopt or are not in the process of pursuing one. According to the European Environment Agency, the status of development of the NAS within the Union depends on the magnitude and nature of observed impacts, assessments of current and future vulnerability as well as the capacity of the countries to adapt to climate change (European Environment Agency 2009). As this is a policy area that is moving very rapidly, the reader is directed towards the EEA website for the very latest information. It is likely that after this report has been published, majority of EU Member States have published a NAS.

Table 21: European countries that have adopted a NAS (European Environment Agency 2009)

Countries	NAS adopted	Countries without a NAS
Austria	(expected in 2011)	Czech Republic
Belgium	(expected in 2012)	Iceland
Denmark	2008	Liechtenstein
Estonia	(expected in 2009)	Lithuania
Finland	2005	Luxembourg
France	2006	Poland
Germany	2008	Romania
Hungary	2008	Slovak Republic
Ireland	(expected in 2009)	Switzerland (2011)
Latvia	(expected in 2009)	Turkey
Netherlands	2008	
Norway	2008	
Portugal	2010	
Spain	2006	
Sweden	2009	
United Kingdom	2008	

There have been a few studies of adaptation measures and strategies at the national level within the developed world, including the EU. Gagnon-Lebrun and Agarwala analyse the progress and trends of implementation of adaptation in Annex I countries of the UNFCCC (Gagnon-Lebrun, Agarwala 2006, Gagnon-Lebrun, Agarwala 2007). In order to do this, the authors chose to use the NCs as their main source information, as they represent, as discussed above, a source of comparable information from all the parties to the Convention. Progress on adaptation is analysed firstly by focusing on how adaptation has been addressed in terms of policy concerns and measures. Secondly, the article presents the results of an assessment of progress made by countries in the implementation of adaptation.

Gagnon-Lebrun and Agarwala assess the countries based on three criteria, namely the assessment of impacts and vulnerability, identification of adaptation options and implementation of measures, and thirdly, establishing institutional mechanisms to support the above two. The results of the first task show that adaptation issues discussed in NC2 and NC3 are fairly limited, with only a handful of countries discussing specifically addressing adaptation. More emphasis has been placed on impacts and vulnerability to climate impacts in the majority of the NCs. However, there are countries, such as Spain, Liechtenstein and the Netherlands that have broader coverage of adaptation in relation to the impact assessment. The only country that has equal coverage of the three factors is the United Kingdom.

In order to assess the progress on adaptation actions, Gagnon-Lebrun and Agarwala distinguish between intentions and actions, which are further divided into the establishment of institutional mechanisms, formulation or modification of existing policies and the incorporation of adaptation measures at the project level (Gagnon-Lebrun, Agarwala 2007). Three categories of countries are identified, depending on what the level of adaptation actions are. Firstly, there are countries that have early to advanced stages of impact assessment but adaptation is not discussed in the NCs. Countries in this category include, for instance, Hungary, Iceland, Portugal and Latvia. The second category consists of countries that have been very advanced in terms of impact assessment, but have been slow in introducing adaptation measures in that discussion of adaptation options is limited. Countries here comprise of Czech Republic, Estonia, Denmark, Austria, Germany, Greece, Italy, Liechtenstein, Luxembourg and Norway. The final category of countries (with advanced impact assessments and moving towards implementing adaptation) is an interesting one. Gagnon-Lebrun and Agarwala argue that in fact no developed country has yet to formulate a comprehensive approach, although the UK might come close. For other countries in this category that come close formulating a comprehensive approach to climate change, see Table 22.

Table 22: EU countries advanced on adaptation.

Countries moving towards adaptation	Belgium, Finland, France, Ireland, the Netherlands, Poland, Spain, Switzerland, Sweden, the UK

Source: (Gagnon-Lebrun, Agarwala 2007)

As the adaptation policy field is a very fast moving one, an analysis of NAS and adaptation policy can be quickly out of date. A recent analysis of adaptation policies across Europe focused not only on the level of adaptation but also on the objectives of adaptation, as well as aims of adaptation (Massey, Bergsma 2008). Adaptation level is considered to be how far each country has advanced in term of policy activities. The objectives of adaptation are analysed in terms of why or for what reason a country is undertaking adaptation initiatives. Thirdly, the aim of adaptation strategies and measures is assessed in terms of what the vulnerable sectors and domains are the strategies and measures are directed at. Data for the exercise is drawn from UNFCCC country reports, as well as from official government reports that were available in English. In terms of leaders and laggards of European adaptation policy in terms of policy concerns, recommendations and measures in alphabetical order, see Table 23 and Table 24.

Table 23: Leaders of adaptation levels in Europe.

Concerns	Recommendations	Measures
Belarus	Bulgaria	Belgium
Denmark	Czech Republic	Germany
Portugal	Finland	Italy
Norway	France	Netherlands
Sweden	Germany	Switzerland
Switzerland	Slovakia	United Kingdom

Source: (Massey, Bergsma 2008)

Table 24: Laggards of adaptation levels in Europe.

Concerns	Recommendations	Measures
Bulgaria	Estonia	Croatia
Finland	Hungary	Finland
France	Ireland	Hungary
Italy	Italy	Poland
Latvia	Norway	Romania
Poland	Portugal	Slovakia
Romania		Slovenia
United Kingdom		Spain
		Turkey

Source: (Massey, Bergsma 2008)

In terms of percentage of implemented adaptation policy measures, according to Massey and Bergsma, Western Europe is the most advanced of the socio-economic regions, closely followed by Southern Europe (Massey, Bergsma 2008). Northern and Central Europe are more advanced in terms of policy recommendations. In terms of the adaptation level, the report also analyses different physiographical regions that enables one to focus on adaptation within a region rather than across regions.

Massey and Bergsma further divide adaption objectives into four categories; see Table 25 (Massey, Bergsma 2008). For all socio-economic regions, Western, Northern, Southern and Central Europe, the main objective is risk and sensitivity reduction. In addition, a little more emphasis is placed on extreme events where as capitalising on opportunities receives a little more attention in Central European adaptation strategies.

Table 25: Adaptation objectives. (Massey, Bergsma 2008)

Adaptation objective	Details
Building adaptation capacity	Actions related measures that build or enhance governance or societal awareness on adaptation
Reduction of risk and sensitivity	Actions that reduce the risk of damage and reduce sensitivity, implying pre-emptive action
Increasing coping capacity during extreme events	Actions that focus on enhancing the capacity to cope during extreme events
Capitalisation on changed climatic conditions	Actions that will yield benefits arising from climate change

For the physiographic regions[34], the Alpine region reduction of risk and sensitivity are the most important features but capitalisation on climate change is also an important feature. Within the Tatra and Carpathian region, risk and sensitivity reduction feature heavily but on the other hand, no attention is paid on building of adaptive capacity or coping capacity, for example in Czech Republic and Slovakia. Within the Atlantic region, the UK is a leader in all categories, with France and Spain having the most measures in terms of building adaptive capacity. The North Sea region is heavily focused on reduction of risk and sensitivity with over half of the measures in all countries within this category. In addition, Sweden and Denmark have placed most emphasis on capitalisation on climate change. In the Baltic Sea region, Finland and Poland have the most even coverage of all four categories, whilst building of adaptive capacity is relatively low in Germany. In the Mediterranean region the objectives are quite diverse across the region but overall there is less emphasis on enhancing adaptive capacity in relation to the other physiographic regions. In the Black Sea region, there is very little emphasis on adaptive capacity again with most measures targeted towards reducing risk and sensitivity.

Targeted domains, in terms of what adaptation measures are aimed at, are also analysed by Massey and Bergsma (Massey, Bergsma 2008). The report outlines ten areas, drawing on the UNFCCC NCs and the Finnish NAS. These are coastal zone management, landscape management, water management, extreme temperature, energy, biodiversity management, financial management, health and disease management, agriculture, and food security and development co-operation. All socio-economic regions consider the landscape and water management as priority sectors. Food security and agriculture feature heavily in the Central European strategies, whilst biodiversity management receives attention in Northern Europe. In terms of the physiographic regions and their adaptation aims, see Table 26.

Table 26: Adaptation aims across physiographic regions.

Region	Aims
Alpine	Landscape and water management most important, followed by biodiversity management and food security
Tatra and Carpathian	Food production and security most important tailed by water management
Atlantic	Landscape management and water management most important followed. Interestingly no explicit emphasis on coastal zone management
North Sea	Dominant aims landscape management and water management; coastal zone management addressed but varies between countries
Baltic Sea	Landscape, water and coastal zone management dominate, followed closely by biodiversity management and food security
Mediterranean	Relatively diverse portfolios across the region, food security and landscape management most dominant
Black Sea	Water management and food security are considered important, otherwise fairly narrow focus

Source: Massey, Bergsma 2008.

[34] Physiographic regions were Alpine, Tatra & Carpathian, Atlantic, North Sea, Baltic Sea, Mediterranean, and Black Sea. Some countries were analysed in more than one category in order to get a comprehensive view of a particular region. For example, the UK was part of both the Atlantic region and the North Sea region.

In terms of policy sectors, issues related to land use and land cover are becoming increasingly important, in terms of adaptation but also in relation to mitigation of greenhouse gases. For adaptation, land use policies that are important from the point of view of adaptation relate to planning of areas that can be prone to flooding, for example. From the point of view of mitigation, land use is important since decision can adversely affect the carbon sinks available but also lead to increases transport and thus to greenhouse gas emissions. A recent review of European NAS' spatial planning perspective concludes that spatial planning is classified as one of the sectors important for adaptation, and its role as a cross-sectoral coordination is not recognised (BMVBS 2010).

The report also reviews different countries advancement and shows that for some countries, like Finland and Spain, no specific role is given to spatial planning (BMVBS 2010).This situation is different for countries such as Germany, France and Hungary that have assigned a specific role to spatial planning, although this role needs to be further clarified. Finally, there are countries within which spatial planning is given a central role and implementation is already taking place, for example in the Netherlands and the United Kingdom (BMVBS 2010).

Adaptation at the national level has also been analysed in project that assessed adaptation policies at the national level in more detail (Swart et al. 2009). The Partnership for European Environmental Research (PEER) Report compared European NAS in ten countries; see Table 27 for more information on the countries and their respective strategies. The report is structured around six key themes that were considered to be relevant by the research teams, and each country's approach to adaptation within these themes is analysed. Firstly, the report analyses the motivating and facilitating factors for NAS development. Secondly, the role that research plays in the development of adaptation policy is analysed, as well as the role of communication in the NAS across the different countries. Fourthly, aspects of multilevel governance were explored within the project, relating to the vertical linkages between levels of governance. Fifth, integration of adaptation into sectoral policies is considered a vital research area. Finally, the role of monitoring, evaluation and enforcement of adaptation policy was deemed worth focusing on.

Table 27: Details of selected NAS in Europe.

Country	Details
Denmark	The government introduced the strategy in 2008. The Danish Strategy places emphasis on autonomous adaptation in all spheres, including enterprises and individuals. Implementation is to be supported by information initiatives, a research strategy and facilitation in planning and development. The strategy also outlines the challenges faced by the most vulnerable sectors.
Estonia	Estonia's NAS is expected to be completed in 2009.
Finland	NAS process was begun in 2003 and published in 2005. The NAS outlines vulnerable sectors and suggests further improvement of knowledge base and recommendations for adaptation measures. The NAS is to be implemented by each Ministry within their sector. So far, the Environment Administration has made most progress. The NAS was evaluated in 2009 and it was concluded that the need for adaptation has been recognised by many sectors and some adaptation measures have already been implemented.
Germany	The NAS was adopted in December 2008. The NAS aims to integrate the work that is already been conducted in various ministries and establish a transparent mid-term review. Major knowledge gaps are identified and responsibilities of all levels of government are identified.

	The NAS also has inbuilt systems for monitoring and evaluation.
Norway	Scoping study for adaptation was published in 2004. In 2008, the government published a draft consultation on three main objectives; mapping of vulnerability, enhance understanding about adaptation and climate change, and stimulate information and capacity building. A cross-cutting report (13 Ministries) published in 2007 detailing the vulnerabilities of the country.
Latvia	An informative report was submitted to the government in 2008, which will serve as a base for the NAS. A NAS is under preparation by two working groups and will focus on integration of adaptation into existing policies.
Sweden	Sweden will not produce a NAS but has drafted a Climate Bill that effectively aims to integrate and coordinate responses between vulnerable sectors. The Climate Bill is based on the report by the Climate and Vulnerability Commission that summarises all the challenges that Sweden faces and offers a concrete set of proposals.

Source: (Swart et al. 2009).

The project results show that there a multitude of motivating factors that have enabled adaptation at the national level (Swart et al. 2009). These have included the international climate negotiations processes, experiences of extreme weather events and research on climate change to name a few. Furthermore, the existence and availability of climate information was crucial in advancing the national developments on adaptation. There are different stages of development that countries undertake climate change related research, ranging from the physical climate science data to more socially scientific analyses of vulnerabilities and adaptation options. The further ahead the country is on climate research, the stronger the possibility is that the country has considered adaptation. Communication is seen as a cornerstone of a successful NAS but there is yet little evidence of how climate information is effectively communicated to different actors across sectors public administration and other stakeholders.

Multilevel governance is recognised as of crucial importance in the PEER Report (Swart et al. 2009). There is little mention of the international level or the EU level in the existing NAS. Most of the analysed NAS do, however, acknowledge the need to take adaptation measures at the local or at the regional level. Despite this, there is a lack of clarity in terms of roles and responsibilities across levels in many of the countries studied. Many of the NAS identify sectoral integration of adaptation into policies a key challenge but offer very few solutions in order to achieve this. Open questions that remain are how can adaptation actions be designed, organised and financed? Finally, as the NAS processes are fairly new they stress the necessity to have evaluation and review of policies in place but as yet do not offer means to assess the effectiveness of adaptation strategies.

As of yet, there have been relatively few analyses of adaptation across multiple scales of governance. The EUR-Adapt project O*rganising adaptation to climate change in Europe* focuses on adaptation policy development and actions in four European countries, Finland, Italy, Sweden and the UK (Keskitalo 2010). The project findings have indicated that adaptation has emerged in all the countries mainly through international processes at the national level, whilst weather impacts have contributed to the actions on adaptation on the sub-national levels (Keskitalo, Westerhoff & Juhola submitted). The approach that countries take on adaptation is also depended on the framing of adaptation in terms of who is responsible and what adaptation measures should consists of (Juhola, Keskitalo & Westerhoff In press). Finally, in terms of adaptive capacity, different levels of governance vary and different capacities are needed on different levels of governance in order to push the agenda on adaptation forward (Westerhoff, Keskitalo & Juhola In press).

Regional level adaptation policy in Europe

Regional initiatives on climate change adaptation, or regional adaptation strategies (RAS) are a relatively recent development in Europe and there are even fewer studies of them than of NAS. The regional approach is considered to extremely crucial because the severity of climate change impacts will vary from region to region across the continent, and is dependent on the physical conditions of the region, degree of socio-economic development and response mechanisms of the region. Regions play an important role in terms of regulating issues related to built environment, building and maintenance of infrastructure in terms of drainage and piped water, and provision of services, such as fire protection, public transportation and disaster response. The role of regions is not merely limited to the normal maintenance but also should include long-term maintenance, pre-disaster damage limitation, immediate disaster response and rebuilding (Gagnon-Lebrun, Agarwala 2006).

Thus far, there have been a limited amount of studies that have analysed the emergence and content of regional adaptation strategies, mainly due to the reasons that regional initiatives are even more recent than the national ones. Secondly, examining adaptation policy at the regional level across countries or even within one country presents its own methodological challenges. It has been admitted that even national level data can be hard to come by with the UNFCCC country reports presenting the only fairly consistent source of information about adaptation policies in a particular country. Ribeiro *et al*. present some challenges for data availability for analysing regional level adaptation, including the fact that information of measures is almost always only available in the local language and they may not be always easily available across countries (Ribeiro et al. 2009).

The emergence of regional adaptation can be interpreted to be happening through two processes. Some regional strategies are happening because of strategy processes at the national level and as a response to them. At the same time, regional processes are occurring concurrently to the national ones within regions that are forward thinking in terms of climate change and have acquired resources and are able to pursue their own goals irrespective of the actions undertaken at the national level. It is expected that in the future, regional strategies for adaptation will become more important as countries are further developing their approaches and clarifying the roles of responsibilities in terms of adaptation measures.

The development of RAS is hindered by the uncertainties on the scale, timing and consequences of climate change, as well as lack of information, knowledge and expertise at the regional as well as local level (Ribeiro et al. 2009). A study of existing RAS is one of the first attempts to analyse and develop guidelines for regional adaptation. Riberio *et al.* study 31 RAS in six selected countries (France, Germany, the Netherlands, UK, Sweden, and Spain). The case studies were chosen on the basis of an internet survey, interviews and assessment of published reports. The analysis was divided into two phases, the first phase analysing the strategies holistically in terms of the strategies themselves, their preparation process and the information that was used to design them. Secondly, the each strategy was analysed in terms of the individual actions that were proposed in it and these were further categorised.

The results of the assessment show that regional strategies are mostly a response to particular social vulnerabilities, including extreme weather events (*Ibid.*). According to the analysis, most of the RAS so far are concentrated in Northern and Western Europe, and in countries that have a NAS, with the exception of Sweden. Many of these countries have been active in mitigation policy and have had strong commitments to environmental policy in general. An interesting linkage can be observed between regional initiatives and collaborations with the scientific community, examples of this can be seen areas such as transnational river basin, the Baltic Sea region, and the Alps, for example.

The key lessons drawn from the analysis of existing RAS highlight the following issues (Ribeiro et al. 2009). There are two types of regional processes emerging, firstly, those involving sub-national governments with varying degrees of autonomy, *Länder* in Germany or *Communidades Autonomas* in Spain, for example. On the other hand, there are larger cities or urban areas that are pursuing their strategies, for instance London and Paris. Some city level adaptation strategies can also be termed as local adaptation strategies (LAS). Also, many regional responses to climate change do not yet explicitly address adaptation but centre on mitigation or climate neutrality. Alternatively, RASs often incorporate both mitigation and adaptation measures, and are often considered to be climate change strategies, rather than mere adaptation ones.

Secondly, it appears that policy developments are evolving in an interactive fashion between the central and the regional government. This is because many of the countries where RASs were identified had already implemented their NAS. Some NAS explicitly provide a framework for the development of regional strategies, in the form of legal obligations or merely information and encouragement. Overall, however, it appears that there is limited guidance and steering from the national level in terms of regional action on adaptation. Moreover, there appears to be no overall mandate for requiring the development of RAS in any of the countries studied in the report. The UK Climate Bill comes closest to this were the national government can assess adaptation of local authorities through their performance in terms of the national indicators. What remains somewhat unclear in all the RAS, are the allocation of roles and responsibilities of different actors on different levels of governance within the RAS that were examined.

RAS often comprise and are developed on the basis of patchwork of climate information, resulting in strategies that vary in the quality of information on which adaptation options are based on (Ribeiro et al. 2009). In terms of stakeholder involvement in the drafting of RAS, there appears to be one organising and coordinating body at the regional level. This of course varies and there are different ways to involve stakeholders in the drafting of the strategy. The most popular methods of participation were consultation workshops, electronic and telephone consultations, cross-sectoral or sectoral working groups with societal participation. In many of the strategies, public consultation was only a component of the preparation process of the strategy. However, continuous participation was encouraged in the UK regions as well as in the Netherlands.

Although strategies have been pursued, it does not necessarily mean that all RAS include specific implementation measures that are already outlined in the strategy paper. Thus, the existence of a strategy does not necessarily guarantee action on adaptation. In their analysis of level of adaptation process RAS, Ribeiro *et al.* have utilised the division made by Massey and Bergsma (2009) outline earlier in this review. According to this division, policy actions can be divided into policy concerns, policy recommendations and policy measures. Out of the analysed RAS, many put forward general directions on how to respond to the climate challenge, expressing a level of concern. There are, however, strategies that explicitly put forward policy recommendations, particularly in relation to organising and informing the regional response, or setting up implementation bodies, and approximately half of the RAS analysed included these. Actual policy measures were put forward in less than 20 per cent of the strategies (Ribeiro et al. 2009).

As one would expect, priority sectors in the adaptation strategies vary, according to which sectors are considered to be particularly vulnerable within a specific region. According to Miguel Ribeiro *et al.*, two particular sectors stand out, namely health effects of climate change and landscape management in terms of flooding, sea level rise and drought. Regional emphasis on adaptation varies, for example Paris emphasising heat wave related dangers whereas regions of the Netherlands have identified flooding and water related issues as their main focus. Water supply and treatment, biodiversity management and food production and the agricultural sector were also popular focuses of the examined RAS.

In relation to the types of adaptation responses, 40 per cent of the responses can characterised to be contributing to reduction of risk and sensitivity (*Ibid*.). Most of the RAS also acknowledge the limits of national government intervention, and recognise the need to build capacity at the regional level. Although a smaller amount of RAS outline potential future benefits arising from climate change, those that do focus on the tourism sector and consider climate change as an opportunity to improve water and land management within the region.

European regions and adaptation policy

This section discusses the potential adaptation policy options and measures that can be taken in different regions within Europe in relation to climate change. In order to do this, this report examines the impact maps produced as part of this project and identifies particular impacts for which adaptation measures are required. Impact is considered to consist of exposure and sensitivity. The policies suggested here relate to the particular sensitivity indicators used in this ESPON Climate project, and it is acknowledged that many other policies options for adaptation exist and that these detailed here are by no means that only ones.

In order to identify policies, this report uses the classification from Massey and Bergsma in order to identify the adaptation objectives (Massey & Bergsma 2009). Adaptation measures can target four different objectives, building of adaptive capacity, reduction of risk and sensitivity, increase of coping capacity or capitalisation on climate change. The following sections consider each impact dimension and discuss the possible adaptation measures. For more details on specific impact dimensions and related adaptation measures, see Table 28.

Climate change impacts on physical sensitivity relate to all human artefacts that are necessary for territorial development, including settlements and infrastructure. Climate change poses new challenges for this, given that these structures can be subjected to more extreme weather events, like flash floods, large-scale river floods and coastal storm surges. In terms of adaptation options, both building of adaptive and coping capacity are important, since adaptation measures are likely to be required in the short-term as well as in the long term. Reduction of risk is very important in terms of flooding risk in settlements and other crucial infrastructure. Finally, capitalisation on floods and coastal surges has not been a policy area within which much emphasis has been placed so far and it is yet unclear what opportunities exist.

For the social impact dimension, the focus is on human populations that may be adversely affected by climate change. The impacts of climate change is likely to affect particular social groups more than others, for example the elderly and some urban populations, or the poor. Climate exposures that are significant here mainly relate to increased heat and increases flood events and severity and sea level rise. Here, reduction of risk and sensitivity relate to policy measures that aim at preventing losses of human life through policies of planning, i.e. reducing the urban heat island effect. Again, measures are needed to increase the capacity of emergency services in terms of their ability to prevent losses of human life. Measures to increase adaptive capacity can include provision of knowledge and development of early warning systems for flood events as well as heat waves. Policies to capitalise on the social dimension are as of yet not developed.

The cultural dimension of impacts refers to the monuments, historic sites and landscapes that are sensitive to climate change. Here the climate exposure focused on is flooding, and adaptation measures that can be identified closely relate to the policies that are necessary to respond in the physical and social dimension. However, since many historic sites cannot be relocated, more emphasis can be placed on coping capacity and reduction of risk. Protection of culturally important monuments from flood events can be to a certain extent carried out but again this depends on the adaptive capacity of the region in question. Policies that aim to capitalise on the impacts of climate change can relate to tourism here but this can be very regionally dependent, and no examples of this exist yet.

For the economic dimension, climate change impacts are likely to touch on a wide range of economic sector, and all economic sectors, including the primary sector, as well as sectors like tourism, are likely to be affected either directly or indirectly. Some economic sectors will be negatively affected whilst some will experience positive effects as a result of climate change. In order reduce the risk of climate change on the economic dimension, policies need to support autonomous adaptation of businesses and enable them to avoid risks. Policies to increase the coping capacity of the economic sector can focus on preventing interruptions in the production processes, for example in the event of extreme weather. In term of building of adaptive capacity, policies within the economic sector can take the form of supporting education, research and development that will enable new innovations in terms of adapting to climate change. Policies to capitalise on climate change can be identified for many economic sectors. These include, for example, new destinations for the tourism sector, new crop varieties for the agricultural sector and new technologies that are related to adaptation measures, i.e. flood protection.

Environmental impact dimension relates to the impacts that climate change will have on all natural environments and in this ESPON study they mainly relate to soil and ecosystem based indicators. Adaptation measures here can relate to policies and instruments that focus on maintaining the necessary ecosystem services for societies. Here measures to build adaptive capacity can relate to need for more scientific information about the impacts of climate change on ecosystems, Coping capacity and reduction of risk can, for example, relate to policies that aim to prevent and deal with the potential increases in forest fires. The idea that there are opportunities to capitalise on the changes in ecosystems due to climate change is relatively new, and there are no examples of potential policies to do that.

Table 28: Impact dimensions of climate change and adaptation measures.

Impact dimension	Adaptation measure	Examples of policies
Physical	Reduction of risk and sensitivity	Revision of planning and building regulations for flood prone areas and coastal areas
	Increase of coping capacity	Increase the capacity of the emergency services to deal with floods and coastal storm surges
	Increase adaptive capacity	Relocation of settlements away from flood prone areas, policies to increase the technological ability to deal with flooding, provision of information
	Capitalisation on climate change	N/A
Social	Reduction of risk and sensitivity	Land use planning policies that reduce the urban heat island effect, revision of planning and Revision of planning and building regulations for flood prone areas and coastal areas
	Increase of coping capacity	Increase the capacity of the emergency services to deal with floods and coastal storm surges
	Increase adaptive capacity	Provision of knowledge and development of early warning systems for flood events as well as heat waves.
	Capitalisation on climate change	N/A
Cultural	Reduction of risk and sensitivity	Revision of planning and building regulations for flood prone areas and coastal areas
	Increase of coping capacity	
	Increase adaptive capacity	Increase of knowledge of climate change impacts on historically important monuments and possible protection measures
	Capitalisation on climate change	New tourism development opportunities
Economic	Reduction of risk and sensitivity	Policies need to support autonomous adaptation of businesses
	Increase of coping capacity	Policies that focus on securing that there are interruptions in the production processes, for example in the event of extreme weather
	Increase adaptive capacity	Policies to support education, research and development that will enable new innovations in terms of adapting to climate change
	Capitalisation on climate change	Policies that enable the realisation of new destinations for the tourism sector, new crop varieties for the agricultural sector and new technologies that are related to adaptation measures, i.e. flood protection.

(continued)

Impact dimension	Adaptation measure	Examples of policies
Environmental	Reduction of risk and sensitivity	Measures to pre-empt forest fires through information campaigns, policies to reduce the risk of hazards
	Increase of coping capacity	Measures to support the emergency services to deal with forest fires
	Increase adaptive capacity	Support scientific research on the impact of climate change on ecosystem services, policies to reduce the fragmentation of protected areas
	Capitalisation on climate change	N/A

Territorial development has the potential to play an important role in climate change adaptation due to its integrative, cross-sectoral character. As climate change impacts occur in specific places and might cause conflicts with land use and regional development there is a need to find territorially relevant answers to this challenge. At the same time, spatial planning tools offer a variety of approaches to reduce the negative impacts of climate change leading to the question what the role of spatial planning is in fact.

However, planning is able to address these tasks when developing new settlement plans, but Europe is dominated by persistent settlement structures, cultural landscapes and infrastructures which have been developed over centuries and which are most sensitive to climate impacts. Preventive actions, carried out by spatial planning, are under these circumstances less effective than in countries which are still growing rapidly in terms of population and the built environment. Regulatory planning is not well suited to enforce adaptation in already built-up areas due to private property rights and obligatory compensation payments for using land for public purposes. Thus, all strategies regard financial incentives and communication as relevant measures because the acceptance by private property owners needed for implementing climate change strategies. Under these conditions climate change governance becomes crucial for the success of any adaptation strategy.

The PEER-Report on Climate Policy Integration, Coherence and Governance came to the following conclusion: „While the need for co-ordination and integration across sectors, scales and levels is growing, the capacities to respond are frequently shrinking because of the rigidity of administrative and political borders, the stability of departmentalism and the strength of sectoral interests and preferences for small-scale solutions. While it is generally recognised that the role of spatial planning for climate mitigation and adaptation should be strengthened, the practice is not very well developed as yet." (Mickwitz et al. 2009, 60). This statement can be backed up by our report. Only in the Netherlands the national government considers spatial planning a key player. Nevertheless, even there planning practice has not fully adapted yet to the needs of climate change adaptation.

In view of the weak performance of current planning practices the key question is how to strengthen the role of territorial development. This is important for policy recommendations on regional and local level.

Given that adaptation measures at the regional level are considered to be a response to regional vulnerability, it is a very difficult task to give policy recommendations based on a pan-European assessment of regional vulnerability. Climate change impacts vary between regions in countries and between countries. Furthermore, climate impacts are different across different types of regions. Thus, not all metropolitan or mountain regions will experience similar climate change impacts across Europe. However, it will be attempted in the following table to relate the results of the vulnerability assessment to existing spatial typologies of European regions, and on this basis identify some a few general recommendations that are of relevance for these different types of regions.

Table 29: Adaptation recommendations for different types of regions

Type of region	Impact/adaptive capacity/vulnerability	Recommendations
Overall	Most Mediterranean and SE European regions have highest vulnerability (due to high impact and low adaptive capacity) Especially problematic: coastal regions in Southern Europe, metropolitan regions in Southern Europe, tourist regions along Mediterranean and in the Alps	As the ESPON Climate project shows, a significant driver of potential future disparities is the degree of adaptive capacity for tackling climate change. As outlined already by section 4.1.2, attention should be paid to the different level of efforts and investments needed to mitigate and adapt to climate change in different parts of Europe which are particularly vulnerable due to their lack of adaptive capacity. Although the 5th Cohesion Report dedicates a chapter on 'Enhancing environmental sustainability', which acknowledges that climate change will hit southern and eastern Europe hardest, it says little about how these varied climate change impacts could be reflected in future cohesion policy. As outlined by the Spanish case study, responses to vulnerability to water shortages, a key factor for the Mediterranean region, induced by climate change must be seen also in the light of the National and Regional Mitigation and Adaptation Strategies currently being developed in several countries. Territorial development, especially at local and regional scales, is central to the reduction of vulnerabilities in these four areas. Land use regulations, setting for example limits to the expansion of urban and tourist developments, above all those of a sprawling nature, are envisaged as a mitigation tool (for example, through urban planning tools urban and tourist growth, the proliferation of gardens planted by high water consumption species, swimming pools or golf courses may be put under control) or as adaptation (land use regulations may also consider the design of gardens and golf courses using species adapted to climate). Moreover, new forms of governance (for example, joint management of local or regional water cycles by agricultural and urban interests and exchanges of water rights of different qualities) may have to be developed in order to avoid excessive dependency on new and costly water technologies. Incentives and more inclusive discourse-based approaches are regarded as an important success factor by recent literature on adaptation strategies (see EC 2009, Ribeiro et al 2009, Swart et al. 2009, Meister et al. 2009).
Metropolitan/urban regions	Generally high impact (concentration of residents and assets), but low vulnerability (due to high adaptive capacity) Problematic regions: MR along (especially Southern-European) coasts, in the Alps and in South-East Europe have high vulnerability (due to low adaptive capacity	The high impact stems mainly from the concentration of population and infrastructure. In this context, traditional spatial visions such as compact settlement structures have to be rethought due to their potential negative implications for coping with climate change. However, there is a general need for resilience - not only in regard to climate change adaptation. Consequently, planners should together with civil society organisations agree on spatial visions that are characterised by the following elements: • Efficiency: Efficient spatial structures produce and deliver products and services on less space with fewer resources (energy, natural resources). This mitigates greenhouse gas emissions and minimises the exposition of sensitive land-uses against extreme events. In doing so, protected resources could be used only if needed in case of unpredicted or unpredictable developments.

Type of region	Impact/adaptive capacity/vulnerability	Recommendations
		(continued) • Diversity: Diverse settlement structures (mixture of infrastructures, buildings, open spaces) contribute to sensitivity reduction because different land-uses have different sensitivities in regard to a particular extreme event or creeping changes in temperature and precipitation. • Redundancy: The functionality of an urban system could be better ensured if its main elements are redundant and could replace each other. Therefore, the traditional planning principle of bundled infrastructure (roads, telecommunication, water supply etc. using the same space or development corridors) becomes questionable. • Robustness: The level of robustness of infrastructure, buildings and vegetation against the impacts of extreme weather events but also creeping changes. An updated Territorial Agenda should communicate resilience in such a way in order to make it more illustrative and understandable for planning practice. However, adapting the existing settlement patterns to the challenges of climate change can be seen as the main challenge for spatial planning operating in the context of existing private property rights. Thus, adaptation needs should be considered for brownfields development and renewal of city districts (e. g. for extending open space, fresh water channels etc. to cope with urban heat). This could also be used for a retreat from areas exposed to extreme events such as flood zones.
Rural regions	Generally low to high impact Problematic regions: rural areas in SE Europe (hotter & drier climate), low adaptive capacity.	Climate change as such is not a specific problem for rural regions. The agricultural sector is able to adapt to a changing climate and may even benefit (longer vegetation period) except in those areas where water shortage become more and more an issue. However, rural regions – mainly in SE Europe – are economically weak and thus less able to adapt to their limited economic resources and knowledge basis. There, integrated development strategies which aim to enhance the inherent economic development potentials of these regions would help to adapt to climate change.
Mountain regions	Generally medium to high impact and vulnerability Problematic especially mountains in SE Europe, Greece, Spain, southern side of Alps.	The vulnerability of mountain regions is determined by some specific characteristics of this type of region: it is particularly prone to a manifold of natural hazards which are triggered by climate change and they are in most cases less accessible by transport networks as other parts of Europe. Moreover, several mountain areas suffer from adverse demographic changes. Therefore, a sound assessment basis for hazard and risk mapping is needed, ideally coordinated among neighbouring states. Integrated development strategies such as the Alpine plan are useful for coordinating adaptation to climate with other issue such as tourism and nature protection
Coastal regions	Mostly medium to high impact due to sea level and related effects (storm surges), but also economic dependency from tourism	The specific impacts of climate and change of coastal regions call for a specific response strategy. The existing concept of Integrated Coastal Zone Management should be used as a platform for adaption. Not only the improvement of coastal defence systems, but also adjusted settlement restrictions according to the expected impact have to be discussed. This is particularly relevant for dangerous and vulnerable infrastructure. For some coastlines in the North, tourist development strategies become more and more relevant due to the projected increase in tourist comfort.

Type of region	Impact/adaptive capacity/vulnerability	Recommendations
Sparsely populated regions	Interior of Spain negative impact (hotter & drier climate). Scandinavia and Scotland negative impact due to more precipitation (river flooding, flash floods) but agricultural benefits due to warmer climate.	The impact of climate change on this type of region is less relevant in economic and social terms as on other regions, because only a few people and assets are potentially affected in absolute terms. Nonetheless, the relative change may be of relevance. These regions are normally peripheral regions. Improving their accessibility would support their adaptive capacity (i.e. coping capacity).
Islands	Generally severe impacts in Mediterranean and Atlantic islands. Problematic islands in Mediterranean due to generally lower adaptive capacity (thus higher vulnerability).	Particularly those islands in the south which are depended on tourism and agriculture may have a high impact. Here, a diversification of economic activities would enhance the resilience of islands. Supporting less climate sensitive activities would also foster the rehabilitation of the island's environment which is often under extreme stress (i.e. due to the excessive exploitation of fresh water resources and resulting salt water intrusion, land consumption etc.)
Border regions	Generally big disparities between border regions of one cross-border corridor due to different sensitivities (population density, settlement patterns, economic development) and especially differences in adaptive capacity	What are needed are integrative development strategies which balance the challenge of climate change with other issues such as demographic change, economic development and environmental issues. The Tisza Catchment Area Development (TICAD) project may be a promising way forward in consistent transnational cooperation in the area of integrated spatial planning that addresses climate change issues. Such programs should be mutually recognized by the planning teams of the participating countries sharing the Tisza river catchment area that a viable development strategy, a spatial plan and joint policy recommendations are indispensable for addressing the climate change issues, especially in the areas of water management, sustainable economic development, optimal use of pooled natural and cultural resources, a balanced distribution of competitive growth areas and enhancement of internal and external functional relations within the settlement system.

Cross-sectoral character of adaptation as multi-level-governance

Climate change adaptation calls for a cross-sectoral approach because of the variety of impacts on different sectors and the interdependences between impacts and response strategies. Mickwitz (2009) argues for a prominent role for comprehensive spatial planning in this regard, but this has not been implemented yet. This has to be prominently addressed and outlined by the Territorial Agenda. Moreover, following the example of the Netherlands, the role of the ministries responsible for spatial planning has to be strengthened for co-ordinating the implementation of the national adaptation strategies.

The implementation of adaptation strategies calls for a broad involvement of all societal groups in order to guarantee the legitimacy of actions. In particular, quantitative goals have to be justified because they are of a normative character.

Adapting the existing settlement patterns to the challenges of climate change can be seen as the main challenge for spatial planning operating in the context of existing private property rights. Incentives and more inclusive discourse-based approaches are needed, which can be characterised as ‘climate governance’. This aspect is regarded an important success factor by recent literature on adaptation strategies (see EC 2009, Ribeiro et al 2009, Swart et al. 2009, Meister et al. 2009).

The local level is regarded as the most important level for implementing national and regional adaptation strategies and related amendments to planning laws. This is due to local responsibilities for urban development and building permissions, but also to the fact that the population in general has more trust in local authorities (Greiving/Fleischhauer, forthcoming). Table 30 summarises to what extent territorial development is able to cope with climate change. It is divided into three main areas: assessment of long-term consequences, climate proofing and prevention of disasters triggered by climate change:

Table 30: Strengths and weaknesses of territorial development in the context of climate change adaptation

Task	***Milestones***	***Potential of territorial development***	***Description***
Assessment of long-term consequences	Assessment and appraisal of climate change impacts on the human-environmental-system	fair	This is possible based on regional impact studies, that planning has to have at hand. A strength of comprehensive planning is the traditionally integrated view of different change processes (demography, economy, environment, climate)
Climate proofing	Identification of interaction between land-uses and the changing climate	good	Such assessments can easily be integrated in the strategic environmental assessment which is obligatory for any spatial plan or programme.
	New guiding principles (such as “resilience”)	good	The concept of resilience is almost in line with existing planning principles like decentralised concentration and could therefore easily be adopted by planning practice

	Avoiding non-adapted developments	good	This is within the focus of planning which is very much about future developments. The effectiveness of actions depends partly on the existing regulatory framework (zoning instruments)
	Adaptation of existing spatial structures (settlements, infrastructure)	poor	Any adaptation of existing structures is hardly possible through regulatory planning due to the given private property rights. What are needed are incentives and good practices aiming at convincing the private landowners.
Disaster prevention	Assessment of frequency and magnitude of extreme events (exposure)	poor	That is clearly a task for specialised authorities like water management where spatial planning usually does not have any competence.
	Keeping disaster prone areas free of further development	good	At least conforming planning systems have regulatory zoning instruments at hand. Keeping free of areas prone to extreme events is thereby possible.
	Differentiated land-use according to the given risk	fair	Almost possible, but not effective with regard to existing settlement structures
	Adaptation of existing building structures	fair	Almost impossible through regulatory measures due to property rights. Suitable approaches are based on incentives and communication with all stakeholders.
	Relocation/retreat from threatened areas	poor	Again, this is in conflict with property rights. Full recompensation is normally needed, which is mostly impossible due to the lack of public financial resources. It is possible in areas with shrinking population where the existing building stock will be (partly) deconstructed based on planning strategies (see e.g. Eastern Germany)

Source: Greiving/Fleischhauer (forthcoming)

For communicating adaptation needs to decision-makers as well as the public, good practices are of particular help:

- KLARA-Net („Netzwerk zur Klimaadaption in der Region Starkenburg") is a successfully applied Climate Adaptation Governance concept, which has been coordinated by spatial planning: Based on a broad stakeholder involvement this regional network in the German state of Hessen agreed on a set of strategies for adapting several sectors such as agriculture, forestry, water management, tourism, construction industry and health to climate change. Moreover, certain adaptation measures have already been implemented (Buchholz & Riechel 2009).
- The guide „Planning Response to Climate Change: Advice on Better Practice", recognised that planning practice on adaptation to climate change impacts was still at a developmental stage and only a handful of developments have been attempted to take adaptation to climate change impacts into account. Hence, an entire section of the document is devoted to advising local planning authorities on how to put in place policies that deal with adaptation to climate impacts while taking account of the uncertainty of these impacts. The

advice put forward for an adapted version of the decision-making framework for spatial planning decisions on adaptation includes seven key stages (ODPM 2004).

- The U. K. National Indicator N 188 for Local Authorities and Local Authority Partnerships (Defra 2010, LRAP 2010) is based on these key stages and can be seen as a good practice example for parametric governance. The following steps characterise the indicator:
    - Setting the scene: Undertake a climate vulnerability assessment as information basis every five years. This assessment should be integrated into the Strategic Environmental Assessment;
    - Agreement on quantitative objectives for vulnerability reduction by lowering the current sensitivity and/or building adaptive capacities;
    - Implementation of these objectives through an action plan, which has to be updated based on repeated vulnerability assessments,
    - Monitoring of success through qualitative process indicators that are part of annual self-assessments (classes e.g. from 0 to 4 expressing the performance of the actor with regard to the following aspects):
        - Definition of responsibilities,
        - Identification of relevant actors,
        - Assessment of current status of the environment,
        - Assessment of vulnerability to climate change,
        - Development of an adaptation strategy,
        - Setting-up of an action plan,
        - Implementation of adaptation measures,
        - Monitoring and update of the strategy.
- Das Tisza Catchment Area Development (TICAD) project may be a promising way forward in consistent transnational cooperation in the area of integrated spatial planning that addresses climate change issues. It is mutually recognised by the planning teams of the participating countries sharing the Tisza river catchment area that a viable development strategy, a spatial plan and joint policy recommendations are indispensable for addressing the climate change issues, especially in the areas of water management, sustainable economic development, optimal use of pooled natural and cultural resources, a balanced distribution of competitive growth areas and enhancement of internal and external functional relations within the settlement system (Vajdovich 2010).

4.2.2 Mitigating climate change

The main aim of mitigation policy, and the ultimate objective of the UNFCCC as detailed in Article 2, is to achieve stabilisation of greenhouse gas (GHG) concentrations in the atmosphere that would prevent dangerous anthropogenic interference with the climate system (Rogner et al. 2007). Stabilisation should be achieved within a time frame that allows ecosystems to naturally adapt to climate change in order to secure food production and enable economic development to continue in a sustainable manner. Reaching a decision on what is dangerous interference with the climate system is a complex task and one that involves not only scientific judgement but also normative deliberations (Rogner et al. 2007). At the heart of this, is the dilemma between stabilisation of emissions and recognising the risks of climate change and thus potentially implementing measures that can threaten economic sustainability. It is acknowledged that as of yet, there is little consensus of what constitutes anthropogenic interference with the climate system and how Article 2 of the Convention can be put into operation (Rogner et al. 2007).

Currently, the total annual emissions are rising, with carbon dioxide emissions from the use of fossil fuels growing at a rate of 1.9 per cent per year (Rogner et al. 2007). Considering that developing countries are likely to pursue increasingly intensive processes of industrialisation, this upward trend of emissions is likely to continue. It is projected that should there be no substantial change in energy policies globally in the coming decades, more than 80 per cent of the energy supply globally will be based on fossil fuels, resulting in 40-110 per cent increase in emissions compared to the year 2000. Overall, significant increases in emissions are estimated for 2030, and the most recent estimates predicting even higher rises than the earlier projections.

Policies for mitigation of climate change

There have been several important steps globally to implement Article 2 of the UNFCCC, most important of which is the entry into force of the Kyoto Protocol in February 2005. Although it is admitted that even the most efficient mix of well-defined and executed climate policies can potentially be insufficient to curb emissions overall, the need for combining climate policies and sustainable development is underlined. In terms of the global agreements, the UNFCCC and the Kyoto Protocol have been the most important policy measures to deal with climate change, the future of which was recently discussed in Copenhagen in 2009 with no clear results.

In addition to these, there are other agreements that can contribute to the reduction of emissions, such as the Asia-Pacific Partnership of Clean Development and Climate (APPCDC) established by a number of countries in the Asia-Pacific area. Similarly, the EU has signed agreements with China and India in order to enhance the deployment of clean and more efficient technologies. Furthermore, there are several bilateral agreements between countries that contribute to the reduction of emissions. In terms of success and effectiveness of climate policy, within the EU, The Fourth Assessment Report argues that experiences within the Union have demonstrated that while climate policies have been effective, they have often also been difficult to fully implement and coordinate, and require continuous improvement to achieve the agreed objectives (Rogner et al. 2007).

The focus in report is to analyse mitigation policy in the European regions. In order to do that it is necessary to briefly present the EU policies on mitigation and how they affect the Member States as well as the regions within in them. Firstly, this section outlines the EU policy on mitigation after which a brief review of country approach towards mitigation within the EU are presented. This section concludes with a review of regional examples of mitigation initiatives and projects.

European Union mitigation policy

The EU re-established its position in terms of mitigation and climate policy in 2007, when the European Parliament adopted the resolution on climate change in February (Commission of the European Communities 2008a). Furthermore, the agreement by the European council to set legally binding targets to reductions of emissions in March 2007 signalled the determined position to set a leading example in terms of global climate change mitigation policy. A comprehensive package of mitigation measures was put forward by the European Commission in 2008. The EU Climate Change and Energy Package 2020 presents measures to deliver on the ambitious targets set (Commission of the European Communities 2008a). The package outlines two main measures and one complementary one. Furthermore, the package sets out the contribution expected from each Member State to meet the targets and proposes policies and measures required to achieve them.

The first target outlined is for the EU to reach a reduction of at least 20 per cent of greenhouse gases by 2020. This target is to rise up to 30 per cent, if there is an international agreement committing other developed countries to comparable reductions. The second target outlines that 20 per cent share of the Union’s energy consumption should be provided by renewable resources. Finally, the Climate Change and Energy Package states a goal of 20 per cent saving of energy consumption by 2020 through measures that enhance energy efficiency in the transport, building and power generation, transmission and distribution sectors. The targets outlined in the Package rely on principles that aim to ensure that the targets are met whilst simultaneously ensuring that costs are minimised. Furthermore, it is recognised that the efforts required from different Member States must be fair, taking in to account that some States are more able to meet the required targets than others.

The tools to achieve the targets centre around the Emissions Trading System (ETS), a market based system that provides incentives for cutting emissions in the Member States (Commission of the European Communities 2008a). Thus far, companies have received allowances from national governments and companies have then been able to trade the allowances, according to whether they have managed to keep their emissions below their own allowance level. The Climate and Energy Package 2020 does, however, realise that the ETS needs to be strengthened and updated if the objectives of the trading system are to be met. It is acknowledged that the current form of the ETS runs the risk of distorting the functioning of the internal market and competition. The main measures to improve the ETS are to extend the scope of the trading system to include greenhouse gases other than CO_2, as well as including of all major industrial emitters. In addition, a harmonised ETS covering the whole Union will be most suited for a common market within the Union. Finally, the access to the Clean Development Mechanism (CDM) will be limited as this might undercut the efforts to reach the renewable energy target.

The Climate Change and Energy Package states that the increase in the use of renewable energy can contribute not only to the reduction of greenhouse gas emissions but also improve the energy security of the Member States. The current levels of renewable energy consumption are at 8.5 per cent of total energy consumption, and it is calculated that an increase of 11.5 per cent is needed on average to meet the targets (Commission of the European Communities 2008a). In order to achieve the target set on renewable energy, investment on a major scale across the Union is necessary.

Most importantly, as with the ETS, it is recognised that the Member States enjoy different possibilities to deploy and develop renewable energy and the targets should be fair according to the ability of the Member State. Thus, half of the additional effort to reach the renewable energy target is shared equally between the Member States, whilst the other half is modulated according to GDP per capita. Furthermore, the targets are modified to take into account the increases in the share of renewable energy in the recent years. The emphasis placed on different sources of renewable energy can be decided by the Member States themselves whether the potential of individual countries is favourable to solar or wind power or biomass. Each Member State is required to put together a national action plan that sets out the details of how they will intend to meet the targets. Members States are also able to meet their targets outside their own borders, thus hopefully leading to more efficient production of energy.

Finally, the Climate Change and Energy Package recognises the use of biofuels as the only viable alternative transport fuel, and a scheme is proposed that aims to ensure that the increase of the use of biofuels does not lead to environmental disadvantages as a consequence of land use change and changes in biodiversity. For future options, technological solutions for reduction of emissions are considered important, and carbon capture storage (CCS) is considered to be an option (Commission of the European Communities 2008a). Here the emphasis is on construction of demonstration plants by 2015 that can develop the technologies that can be used to reduce emissions even though fossil fuels are used.

Actual EU level policy instruments and directives that influence national level policy making in terms of mitigation were initially explored in the first European Climate Change Programme (ECCP I) that was launched by the European Commission in 2000 in order to identify common policies and measures within the Union that can be used to achieve the Kyoto targets. The second ECCP (II) was launched in October 2005 to review the first programme and explore new policy areas and instruments (EEA 2009). In line with the agreement on the Climate Change and Energy Package in 2009, these measures are now being implemented or are in advanced stages of preparation. For a complete list of key common coordinated policies and measures, see Annex 1.

National level mitigation policy across Europe

The IPCC Fourth Assessment Report lists different national policy options for countries that can be used to achieve the reduction targets (Gupta, Tirpak, et al. 2007), reflecting the different modes of governance of climate change. Firstly, regulations and standards are the most common implements for environmental regulation. These instruments mandate specific technologies for carbon capture and storage or the level of emissions, for example. Secondly, instruments that can be used are taxes and charges, which require emitters to pay a fee according to greenhouse gases they have emitted. Furthermore, one way to curb emissions is to design a system of tradable permits around a particular sector of the economy or to the entire economy, the EU ETS being a good example of this covering several countries. Fourthly, voluntary agreements are made between the government and third sector actors or businesses in order to introduce and encourage mitigation of emissions. Fifthly, subsidies and incentives, such as investment tax credits can help to reduce emissions, although they can also have strong market implications. Research and development can also contribute to the transformation towards low carbon economies. In addition, public information campaigns and other information instruments can also lead to the mitigation of emissions through raising public pressure and awareness. Finally, there are non-climate policies that influence a country's GHG emission balance. These include land use, transport and trade, energy supply and agriculture. In general, it is considered that a policy that increases the use of natural resources is likely to increase emissions (Gupta, Tirpak et al. 2007).

It is argued that a combination of these policy instruments is likely to mitigate emissions and contribute to sustainable development. Furthermore, these policies should be tailored to national circumstances. The selection of policy instruments can be based on a criterion that is composed of the principles of environmental effectiveness, cost-effectiveness, distributional considerations and institutional feasibility (Gupta, Tirpak et al. 2007). A recent study commissioned by the European Parliament's Temporary Committee on Climate Change examined national legislation and national initiatives and programmes that relate to climate change in the Member States (Geeraerts et al. 2007). Information on the various pieces of legislation, initiatives and programmes was collected with a questionnaire that was sent to the national parliaments by European Parliament. As the details of each country in terms of their initiatives within each sector can be quite vast. For information on all countries, the reader is directed to the original publication.

In the recent years, the European Environment Agency has compiled a list of policies and measures to mitigate climate change titled Climate change policies and measures in Europe (PAM). The policies listed in the search engine have been collected from the UNFCCC National Communications that are in turn provided by the Parties to the Convention, and other relevant sources. The policies and measures are detailed in terms of Member States, the type of policies adopted, the sector within which the policy is adopted, the status of the policy in terms of its implementation and the GHG that the measure tackles.

Policies to mitigate climate change are divided into different types, ranging from regulatory instruments to voluntary agreements and educational measures. A total of 1223 have been listed in the database for EU 27 Member States, see Table 10. In terms of the types of the policies majority of them focus on regulatory measures, including for examples directives on energy efficiency and energy saving, and promotion of biofuels. Second popular measures for mitigating climate change are economic ones, such as sectoral development plans and the Emissions Trading Scheme. The remaining policy types are not as popular with education and research policies reported as the least used within the Member States.

Table 31: Number of climate change policies and measures in EU member states by type and status

Policy type	Number of policies	Number of policies by status				
		Implemented	Planned	Adopted	Expired	Other
Regulatory	382	238	93	47	4	-
Economic	311	213	48	26	22	2
Information	157	107	29	19	2	-
Fiscal	102	65	21	15	1	-
Planning	89	56	23	10	-	-
Voluntary/ negotiated agreement	80	52	19	6	3	-
Research	39	22	11	5	1	-
Education	37	28	4	3	2	-
Other	26	17	7	2	-	-
Total	**1223**	**798**	**255**	**133**	**35**	**2**

Source: EEA, Climate change policies and measures in Europe, 2010

The popularity of the regulatory and economic can perhaps be partially explained by the sectors that dominate the efforts to mitigate. Energy consumption and transport feature heavily in terms of the sector that the mitigations policies focus on, see *Table 32*. Overall, nine sectors are specified in terms of sectoral focus, including policies that cover several sectors. Regulatory policies dominate all sectors with economic policies important in many sectors. Multi-sectoral policies consist mainly of economic and regulatory policy tools with planning policies also playing an important role. All sectors apart from Forestry have voluntary or negotiated agreements, although they do not form a significant portion of policies in any sector.

Table 32: Number of climate change policies and measures in EU member states by sector and policy type

Sector	Number of policies	Number of policies in each sector by policy type								
		Regulatory	Economic	Information	Fiscal	Planning	Voluntary/ negotiated agreement	Research	Education	Other
Energy consumption	336	105	84	59	20	15	18	10	20	5
Transport	220	45	49	31	40	20	13	5	6	11
Energy supply	188	65	67	8	9	10	15	6	2	6
Multi-sectoral policies	137	32	44	7	12	20	8	7	5	2
Agriculture	97	23	32	17	2	6	7	7	2	1
Industrial Processes	83	40	4	22	1	1	12	2	1	-
Waste	81	48	9	4	8	10	1	-	-	1
LULUCF	31	10	10	4	-	3	3	1	-	-
Forestry	7	1	5	-	-	-	-	1	-	-
Not indicated	43	13	7	5	10	4	3	-	1	-
Total	1223	382	311	157	102	89	80	39	37	26

Source: EEA, Climate change policies and measures in Europe, 2010

All the Member States (EU27) have policies related to climate change mitigation but the number of policies differs greatly, see *Table 33*. Belgium and the UK lead with the most policies related to mitigation, while some Eastern European countries have the least amount of policies. Certainly for some countries, the low number of policies can be explained by the small size of the country, e.g. Luxembourg but the difference between Belgium with over a hundred policies compared to that of Lithuania with 14 policies is fairly considerable.

Naturally, one should not assume that the number of policies equals efficient, implemented policies but it does nevertheless imply that climate change is considered an important issue. However, what is interesting is that the Member States leading in the number of policies are those that have in past been considered more "fence- sitters" rather than "pace setters" in European environmental policy making (Börzel 2002). Both Belgium and the UK have in the past following EU policy rather than leading it in terms of influencing the agenda or implementing the most policies. Similarly, Spain and Greece have been fairly late in adopting policies but score very highly in the number of policies. For differentiation by policy type in each Member State see *Table 33* and Figure 21.

Table 33: Number of climate change policies and measures in EU member states

Member State	Number of policies	Member State	Number of policies
Belgium	104	Italy	43
United Kingdom	92	Ireland	41
Germany	85	Czech Republic	36
Spain	69	Cyprus	28
Greece	65	Latvia	28
Denmark	64	Netherlands	28
France	63	Bulgaria	27
Estonia	53	Malta	24
Hungary	53	Slovenia	24
Poland	51	Romania	15
Portugal	51	Lithuania	14
Austria	50	Slovakia	13
Finland	49	Luxembourg	8
Sweden	45		
		EU 27	1223

Source: EEA, Climate change policies and measures in Europe, 2010

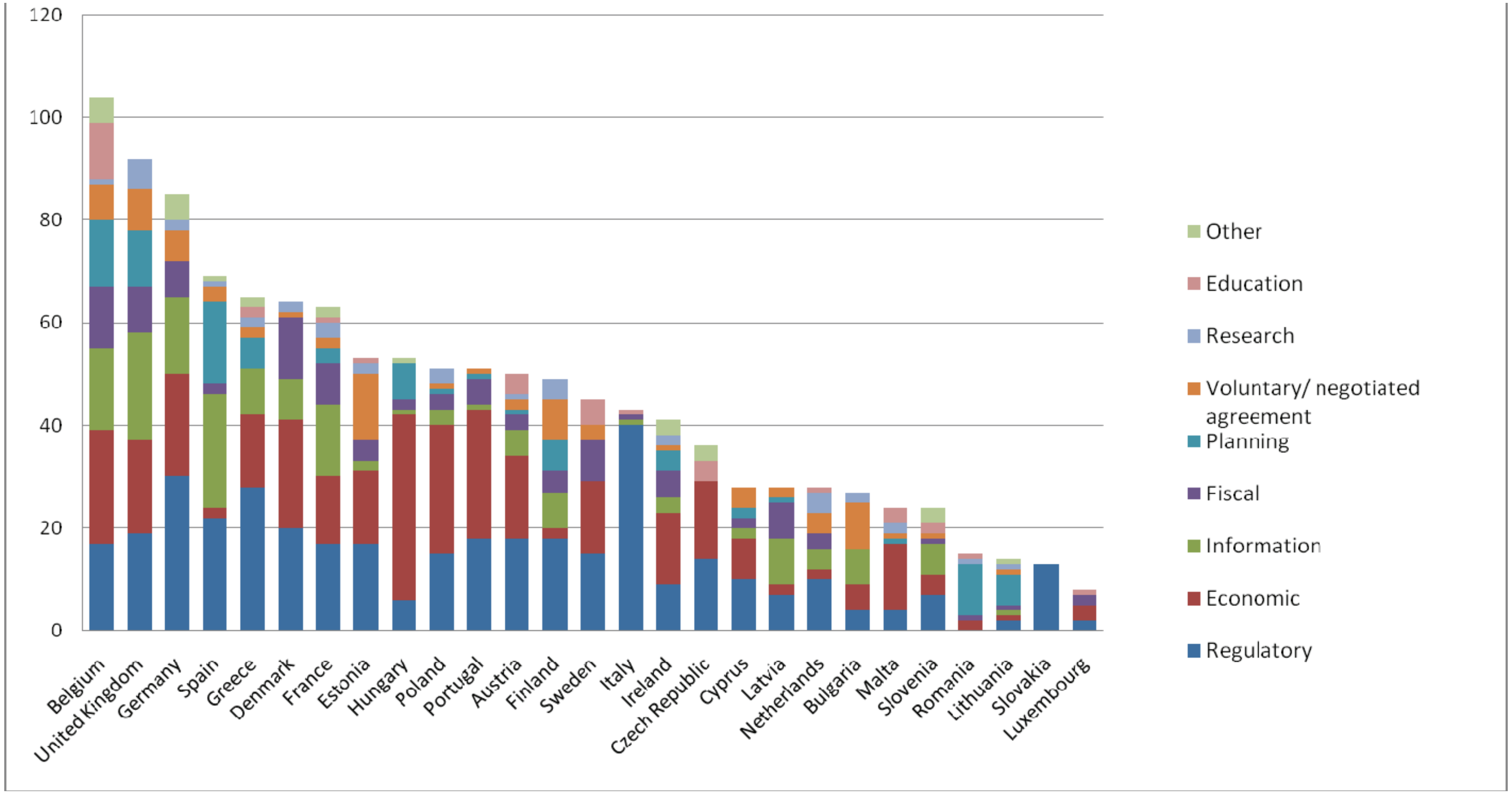


Figure 21: Number and type of climate change policies and measures in EU member states

Regional level mitigation policy in Europe

As argued earlier in this review, the regional level is affected by policy initiatives on other levels of governance and this is also true with regards to mitigation. In addition to steering coming from other levels of governance, there are regions and local actors that have begun preparing their own strategies, developing their own guidelines with regards to mitigation and adaptation. There have been a few studies to analyse how this plays out in climate policy, focusing on the coherence and coordination of policies on different levels of governance. This section firstly summarises research findings from these and secondly introduces a few regional climate strategies within Europe.

The study by Monni and Raes analyses the opportunities and barriers of multilevel decision-making, by concentrating on the implementation of EU directives at the national level in Finland and at regional level in the Helsinki Metropolitan Area Council (Monni, Raes 2008). It is recognised that although the lower levels of government might not have legislative powers, they still make important decisions related to land use, transport and building regulations. The study analyses four of the EU directives that are set to achieve reductions of emissions during the Kyoto Protocol until 2012, namely the directives on renewable electricity (2001/77/EC), cogeneration (2004/8/EC), energy performance of buildings (2002/91/EC), biofuels for transportation (2003/30/EC) and landfills (1999/31/EC).

The results indicate that within the case study example, there are contradictions in terms of the objectives set by the EU directives and endorsed by the Finnish government and the city non-action towards increasing the use of renewable in energy production on the other hand (Monni, Raes 2008). For example, although there have been moves towards renewable energy use in other sectors, energy production continues to heavily rely on natural gas and coal. This results in the city of Helsinki essentially free riding when one considers the need to achieve the reduction targets in the whole country. Furthermore, promotion of renewable energy at the national level is based on tax and investment subsidies, which appear to be not enough to encourage investments in Helsinki. However, in general, it is argued that the climate policy of Helsinki complements the policy outlined by the EU and the national policies. There are also areas within which Finland has been ahead of EU policy and where directives have not meant significant changes.

Similar challenges of multilevel policy with regards to renewable energy have been identified in the UK[35] (Smith 2007). The promotion of renewable energy is happening through national, regional and local networks of businesses and non-state actors in partnership with policy-makers on those levels. Smith identifies both "ordered" and "messy" forms of governance (Hooghe, Marks 2003) within the English regions (Smith 2007). On the one hand, regions have pursued regional renewable energy governance through regional strategies and the authority given by them. This has meant that direct national policy goals and guidelines are implemented to some extent at the national level. On the other hand, the examples emerging from the case study can be characterised as messy in the sense that governance takes place through regional policy networks in the absence of real authority at the regional level. Progress in terms of regional renewable energy policy is furthered hindered by the unwillingness of the national level to empower the regional level (Smith 2007).

[35] It is likely that this going to change with the recent change of Government in the UK.

In addition to activities and policies that affect the regional level, there is also a trend towards regional climate strategies through which regional actors aim to reduce their greenhouse gas emissions. There are a few initiatives that aim to bring together a selection of best practice cases that can act as examples within Europe. Since the publication of the EU Green Paper in 2007, the Assembly of European Regions (AER) launched a Working Group on climate change. The objectives of the Working Group are considered to highlight the role of the regions in this issue by bringing together regional best practices that contribute mitigation but also to adaptation. See details of best practice cases within the regions in Table 34. Many of these strategies feature both mitigation and adaptation in their approach but have a predominantly adopted mitigation as their main goal.

Table 34: Examples of regional mitigation and adaptation strategies.

Region	Details
Catalonia's environmental strategy to tackle Climate change (E)	The document details the various actions undertaken by the Generalitat de Catalunya in order to mitigate climate change (for instance in transport, urban planning, energy, agriculture...) and adapt to the already existing effects (water management, biodiversity)
Hampshire (UK)	The documents presents 3 projects, entitled ESPACE, Climate Change Commission and Hampshire & Isle of Wight Sustainable Business Partnership, along with a series of key messages on the county's policy on climate change
Örebro's Energicentrum project (S)	Documents present its latest energy project, which contributed to the overall strategy to mitigate climate change in the region
Midi-Pyrénées' Regional Climate Plan (F)	Strategy aims at mitigating climate change thanks to a Regional support scheme dedicated to RES, energy efficiency, clean transport and eco-building. Particularity: regional programme entitled: "economical and sustainable social housing"
Limousin's regional wind energy scheme and climate plan (F)	The Regional Council of Limousin has set up a regional wind energy project, as well as an overall strategy on sustainable social housing. A climate strategy is currently being defined
Comunitat Valenciana's project (ES)	The objective is to realise simulations of heat waves and cold invasion and improve the region's capacity to foresee climate sudden variations
Dorset's climate change policy (UK)	Dorset's Carbon Management Action Plan for Mitigation and Local Climate Impacts Profile for Adaptation along with the region's projects
Norrbotten (SE)	The county council's strategy to improve sustainable economic growth, address climate issues and environmental challenges.

Source: (AER 2009).

Similarly, the Environmental Conference of the European Regions (ENCORE) established a virtual Climate Change working group that has details of 19 European regions and their mitigation and adaptation measures. See Table 35 for details of the best practice cases listed.

Table 35: Best practice cases for mitigation.

Region	Details
Vienna, Austria	The Urban Energy Efficiency Programme (SEP) comprises and co-ordinates more than 100 single measures, providing guidelines for the city's consumer-side energy policy until 2015.
Schleswig-Holstein, Germany	Biomass and Energy project was begun in 1996 and several pilot- and demonstration projects for the use of biomass. Until the end of 2007, emissions had been reduced by 414.000 t CO2 annually.
Häme and Päijät-Häme, Finland	Sustainable future for the Region. The objectives of the projects were to promote sustainable development, to increase co-operation among residents, NGOs, companies and the administration and to assess the progress toward sustainable development in six municipalities in the Hämeenlinna region.
Aragon, Spain	Green purchases project that aims green purchases in products and services and Stop climate change: Act with energy! programme that started in Nov. 2004 and aims to create awareness among the Aragonese general public about the problems of climate change. It creates a forum for debate and meeting in which all the Aragonese associations and sectors participate.
Jämtland, Sweden	Biomass-fired power heating plant in Östersund that aims to contribute to regional development and to supply high-quality energy and services at consistently low prices.

Source: (ENCORE 2009).

Territorial policies and mitigation

The focus on territorial development and cohesion within the EU and mitigation of climate change are aspirations that have close linkages. In the recent years, the territorial focus within the EU has been realised through the Territorial Agenda in 2007, which strives towards sustainable territorial development across the Union. This is to be done through strengthening territorial cohesion in Europe by supporting economically, culturally and environmentally sustainable development. Furthermore, the Green Paper on Territorial Cohesion further outlined the ways in which territorial agenda should be developed in order to ensure that all regions within the EU are not disadvantaged (Commission of the European Communities 2008b). The Green Paper considers territorial cohesion to bring together economic effectiveness, social cohesion and ecological balance and thus placing sustainable development at the heart of policy design.

The Territorial Agenda identifies six Territorial Priorities (Territorial Agenda 2007). Firstly, the aim is strengthen polycentric development and innovation through networking of city regions and cities. Secondly, it is necessary to promote new forms of partnerships between rural and urban areas, and thirdly regional clusters need to be promoted for competition. Fourthly, the trans-European networks need to be strengthened. Fifthly, risks need to be managed on a trans-European scale. Finally, it is important to strengthen ecological structures and cultural resources as part of the Territorial Agenda. When one considers these aims, the linkages between the Territorial Agenda with its aim in territorial cohesion and the aims of climate change mitigation are clearly linked.

Sykes and Fischer have analysed the linkages between the Territorial Agenda and mitigation (Sykes, Fischer 2009). The authors identify several territorial policy areas where these issues intersect and where attention is needed to further explore the policy implications. Firstly, the authors are concerned about the role that transport will play in achieving the aims of the territorial policies in terms of creation of new economic zones or improving and increasing mobility across regions. According to the authors, reduction in greenhouse gases is going to prove difficult if no additional transport policy is introduced in addition to the Territorial Agenda. It is important that impacts of increased mobility and accessibility on emissions are understood.

Another area where the Territorial Agenda and climate change mitigation efforts traverse is urban sprawl (Sykes, Fischer 2009). Urban sprawl can lead to increased emissions in relation transport and the Territorial Agenda does not address the urban sprawl phenomenon in adequate detail the authors argue. The authors conclude that the Territorial Agenda, as it currently stands, targets predominantly the economic and social dimensions with no explicit recognition of the impacts of these on the environment or climate change policy aims.

Davoudi also identifies concerns when discussing the demand of energy in terms of territorial policies (Davoudi 2009). Davoudi argues that the territorial policies have been instrumental in managing energy demand through the implementation of land use policies, and of particular interest are policies that focus on reducing car travel as well as policies that increase energy efficiency of the built environment. Territorial policies can be used to, either proactively or through regulatory interventions to steer land use in favourable direction in relation to climate change mitigation. Second concern that Davoudi raises relates to means with which energy efficiency of the built environment can be increased. The ways in which territorial policies can influence climate change mitigation are the location, layout, landscaping and the site for new development (Davoudi 2009).

Territorial potentials for mitigation

The territorial potentials for mitigation are determined by the underlying mitigative capacity of a society. Mitigative capacity, defined as a country's ability to reduce anthropogenic greenhouse gas emissions or enhance natural sinks, see discussion on this in Section on mitigative capacity of this report. Mitigative capacity, in this report, consists of regional greenhouse gas emissions and mitigative capacity, which is comprised of societal factors that enable societies to reduce emissions. Mitigative capacity is measured here by focusing on educational commitment and attitudes towards climate change, availability of technology for reducing emissions, availability of non-carbon energy sources and types of land use, policies for mitigation and government effectiveness as well as income per capita to reflect economic resources. For more details on how to calculate territorial potentials for mitigation, see section methodology of mitigative capacity of this report.

Mitigative capacity is also related to the regional greenhouse gas emissions, demonstrating the territorial potential for mitigation, see Figure 1. Four types of regions can be identified when examining regional greenhouse gas emissions and mitigate capacity. Firstly, there are regions which have high mitigative capacity and low greenhouse gas emissions. Secondly, there are regions which both high mitigative capacity and also high levels of greenhouse gas emissions. Thirdly, there are regions which have low mitigative capacity and low greenhouse gas emissions and finally there are regions which have high emissions and low mitigative capacity.

Although mitigation policies are very similar across countries, particularly those driven by the EU directives, there is scope for examining regions, their capacity and the policies that can target greenhouse gas emissions. The two types regions, which are specifically important, are regions, which have high emissions and high adaptive capacity, and regions, which have high emissions and low mitigative capacity. In both types of regions, it is clear that measures need to be undertaken to reduce emissions.

In regions, which have high capacity, more efforts need to be placed on implementation of mitigation policies. It seems that these regions have the capacity to reduce emissions but emissions still are high. In areas with low mitigative capacity and high emissions, the emphasis can be placed on both increasing mitigative capacity in order to facilitate the development and uptake of cleaner technologies as well as implementation of policies to mitigate emissions.

4.2.3 Synergies between mitigation and adaptation

Although both mitigation and adaptation as policy responses to climate change have been developed for some time now, considerably less effort has been placed on understanding the relationship between mitigation and adaptation rather than each on their own. This is true both at the conceptual level in terms of research on climate policy, as well as on understanding the effects of mitigation policies on adaptation policies and vice versa. The effects of mitigation and adaptation policy on each other have been recognised in the IPCC reports over the years, and it was most extensively discussed in the Fourth Assessment Report in 2007 (Klein et al. 2007). Synergies between adaptation and mitigation were not explicitly addressed in the ESPON Climate project in its European wide vulnerability assessment.

Mitigation and adaptation as policy responses have develop in separate policy spheres. Mitigation was the initial response to climate change with the aim of slowing down the rate of change. Adaptation was initially considered to be of concern to developing countries but in the recent years more and more developed nations have drafted plans for adaptation at the national level. Furthermore, it is recognised that decisions on adaptation and mitigation are taken on different levels of governance, as is their implementation. Stakeholders involved in decision-making related to adaptation and mitigation can be different, according to depending on the organisational structure (public or private), level of decision-making (policy, planning or implementation), spatial scale (national or local), timing (long-term or near term) for example (Klein et al. 2007).

Despite the lack of integration between the two objectives so far, the two are linked together and these inter-linkages need to be explored to ensure a more effective climate policy response. In addition, these linkages can either be a positive or a negative, depending on their impact. The Fourth Assessment Report identifies three different kinds of relationships, with first one being a direct relationship (Klein et al. 2007). In this case, the decisions involve the same resource, i.e. land use, or same stakeholders. Secondly, the relationship can be indirect, i.e. decisions through budget allocations touch on both. Finally, the relationship can be remote in that changes in currency exchange rates affect both mitigation and adaptation efforts.

The IPCC Fourth Assessment Report identifies four types of inter-relationships between mitigation and adaptation (Klein et al. 2007). These can be adaptation actions that have consequences for mitigation, mitigation activities that have impacts on adaptation, decisions that include trade-offs or synergies between adaptation and mitigation and finally, there are processes that have consequences for both mitigation and adaptation. Only the first two are discussed here since the last two are out of the scope of this review.

Firstly, there are adaptation actions that have consequences for mitigation. Adaptation options that are available to societies are likely to require inputs of energy, since by nature adaptation refers to activities that are undertaken either in addition or instead of other activities. These activities can either be a one of large input in the construction of large scale infrastructure or alternatively incremental use of energy in the provision of goods and services related to adaptation measures. The Fourth Assessment Report estimates that the largest amount of construction related to adaptation will take place within the water sector and within coastal zones. Overall, adaptation to the changes in the hydrological regimes and to ensure continuous availability of water is likely to demand continued inputs of energy. Adaptation can also have an impact on the energy supply, particularly the availability of hydropower, if the availability of water for power production is reduced as a result of adaptation measures, particularly if the need for irrigation in agriculture increases.

Secondly, mitigation actions can have consequences for adaptation (Klein et al. 2007). Changes in land use and land cover are the most pertinent area where inter-relationships between mitigation and adaptation take place. Deforestation has resulted in significant greenhouse gas emissions, largely through agriculture. Stopping and reversing this trend can potentially contribute not only to a reduction in greenhouse gas emissions but also contribute to the local climate and water resources and biodiversity. Other mitigation efforts that can influence adaptation are carbon sequestration in agriculture, which can contribute to agricultural yields through improved soil conservation methods and thus increased adaptive capacity. Crops grown for bioenergy and their impact on adaptation have largely been ignored thus far, and it is too early to say whether the relationship is positive or negative. The link between mitigation actions and adaptation can also affect biodiversity indirectly, if the mitigation efforts relate to reforestation. However, there are no studies yet that discuss the nature of these linkages and how possible synergies could be realised.

The Impact Assessment of the EU White Paper on Adaptation also discusses the possible synergies and trade-offs between mitigation and adaptation (Commission of the European

Communities 2009a). It is underlined that measures focusing on adaptation must not hinder actions taken to reduce greenhouse gas emissions. The report identifies several examples where synergies between adaptation and mitigation can be exploited. For example, energy use and exposure to climate change impacts needs to be taken into account in the planning of urban areas. In addition, there can be synergies in terms of afforestation and reforestation can both increase carbon sequestration and benefit biodiversity and livelihoods, which are essential for adaptation.

The Impact Assessment also identifies trade-offs between adaptation and mitigation (Commission of the European Communities 2009a). As already discussed by the IPCC, some adaptation options can lead to an increase in GHG emissions. Particularly adaptation measures that relate to the availability of water in the context changing hydrological regimes can require additional inputs of energy. Similarly the use of hydropower as source of clean energy can lead to increases in vulnerability as a result decreased precipitation. Finally, the cultivation and use of biomass to replace fossil fuels in transport can reduce the availability of water for agriculture and provision of non-market ecosystem services.

In terms of the regional context, the synergies and trade-offs between adaptation and mitigation will increasingly be a concern for local and regional authorities. In the past, local and regional authorities have produced climate strategies that addressed mitigation, and now these strategies are also taking adaptation into account (Ribeiro et al. 2009). Thus, joint mitigation and adaptation strategies at the local and regional level are likely to force more attention to the relationship between the two. However, currently the literature in this respect is growing but 'it does not yet discuss the role of policies and institutions *vis-à-vis* inter-relationships between adaptation and mitigation, nor does it discuss the implications of potential inter-relationships on policy and institutions' (Klein et al. 2007). As more and more regional and local strategies are implemented, it is likely that empirical studies will begin to emerge that describe the ways in which these inter-linkages play out in practice.

4.2.4 New development opportunities through adaptation and mitigation in Europe

It is likely that new development opportunities emerge for the European regions in the wake of climate through adaptation and mitigation. As uncertainty is still relatively high in terms of the expected climate change impacts, it is difficult to estimate the kinds of development opportunities that can emerge across different sectors. Adaptation, as means of capitalising on climate change, is yet relatively rare in Europe, as the focus of adaptation policy has centred on risk management and the avoidance of damages as a result of the changing climate. In terms of mitigation, the opportunities for capitalisation naturally relate to the energy production and consumption. The development of green and carbon-neutral technologies can not only reduce the greenhouse gas emissions produced but also provide new market opportunities.

Adaptation policy plays an important part in the realisation of opportunities that climate change can bring about. Currently, the main focus in adaptation policy in Europe has been on identification of vulnerabilities and management of risk in terms of expected impacts. A recent analysis of adaptation policy divides the objective of adaptation policy into four different aims, reduction of risk and sensitivity, increased coping capacity, capitalisation of changed climatic conditions and building of adaptive capacity (Massey, Bergsma 2008). The study analyses the objectives in terms of socio-economic regions as well as physiographic regions. In Western, Northern and Southern Europe policies that focus on capitalising on the changed climatic conditions have been given the lowest priority in national adaptation strategies. National strategies in Central Europe, however, place more emphasis on capitalisation, 22 per cent of total policies, which is even more than increasing coping capacity. In addition, close to half of the measures in Northern Europe, and over half of measures in the three other regions are targeted towards reducing risk from expected changes.

The analysis of physiographic regions shows how individual countries have defined the objectives of their adaptation measures. In the Alpine region, capitalisation on changed climatic conditions is the second most popular objective after reduction of risk and sensitivity to climate impacts. Within the Alpine region, Italy has no measures for capitalising on climate change and Switzerland has the most, 22 per cent of all policies. In the Tatra & Carpathian region risk reduction is again the most prominent objective. Slovakia and Poland, however, can be considered to be leaders in the region in terms of capitalisation. Within the Atlantic region, Ireland has the most measures focusing on capitalisation whilst France for instance has none. In the North Sea region, Denmark stands out as having fifty per cent of the objectives of the NAS to target capitalisation from the changing conditions. Sweden within the Baltic region has focused, alongside with risk reduction, on capitalisation with close to forty per cent of measures in that category. Out of all the physiographic regions analysed in the study, the Mediterranean region has the least measures overall that focus on capitalisation, with Greece for example not having any measures, alongside with France. In the Black Sea region, reduction of risk and sensitivity are most prominent with capitalisation receiving less attention, albeit more than increasing coping or adaptive capacity.

So far, studies that have focused on opportunities to capitalise on climate change have been very small in scale, and there are no assessments that take into account larger areas, even on a country level. There are some examples from specific sectors, such as agriculture and tourism, and these two sectors are discussed here in more detail. These are by no means the only two sectors that have new development opportunities in Europe but present cases where existing research has been done on the potentials to benefit from climate change and examples of potential developments can be seen.

A study focusing on agriculture and adaptation, produced for the European Commission, analyses the impacts of climate change on European agriculture and identifies adaptation options for the sector (Iglesias et al. 2007). The study relies on a review of relevant literature that includes climate change projections, agricultural modelling and impact assessments, 271 altogether. The study identifies those climate change risks that need to be addressed most urgently and provides a rationale for focusing on the adaptation assessment on key issues. Recommendations for adaptation measures are based on a literature review, a review of national adaptation frameworks and a stakeholder consultation exercise.

The study concludes that the combination of long-term changes and the greater frequency of extreme events are likely to have an adverse impact on the agricultural sector (Iglesias et al. 2007). Changes in the hydrological cycle are likely to have an impact, leading to situations with too much water or too little water available for agricultural use. These problems with water can potentially lead to reductions in crop quality and yield, and they can also increase the need to additional inputs in production. It is also likely that the delineation of agro-climatic zones is likely to change. This can also cause the loss of some indigenous crop varieties and shifts in the patters of agricultural practices across regions, as well as in pests and diseases within agriculture. The study also highlights different risks and opportunities for Europe's agro-climatic zones, see Figure 22.

Description	Bor	Atl N	Atl C	Atl S	Cnt N	Cnt S	Alp	Md N	Md S
Risks									
Crop area changes due to decrease in optimal farming conditions		M	M	M	M	M	M	M	H
Crop productivity decrease		M	M	M	M	M	M	M	M
Increased risk of agricultural pests, diseases, weeds	H	M	H	H	H	H	M	H	H
Crop quality decrease			M	M	M	M		M	H
Increased risk of floods	H		H		H		H		
Increased risk of drought and water scarcity		H	H	H	H	H	H	H	H
Increased irrigation requirements				M		H		H	H
Water quality deterioration	H	H	H		H		H		
Soil erosion, salinisation, desertification	H			M		H	H	H	H
Loss of glaziers and alteration of permafrost	M						H		
Deterioration of conditions for livestock production	H	H	H	L	H	L	H	L	M
Sea level rise	H	H	H	H	H			H	H
Opportunities									
Crop distribution changes leading to increase in optimal farming conditions	H	H	H	M	H	H	H	M	
Crop productivity increase	M	H	M	M	M		H		
Water availability	H	M	H	H	H		M		
Lower energy costs for glasshouses	M			M	M	M		M	
Improvement in livestock productivity	H	H	H		H		H		

H=High M=Medium L=Low

Figure 22: Summary of risks and opportunities by agro-climatic zones. Source: (Iglesias et al. 2007).

According to the report, within Alpine, Boreal and Atlantic north, central and Continental north zones risks related to agriculture mainly focus on potential changes in precipitation patterns (Iglesias et al. 2007). Precipitation is projected to increase during the winter and decrease in summer. Alpine, boreal, Atlantic and continental north agro-climatic zones are likely benefit from the lengthening of the growing season. Rising sea levels present a problem to the Atlantic zones in terms of saline intrusion and land loss due to inundation. New pests and diseases are a risk across the zones. Decrease in the availability of water can present a risk across the Atlantic south, continental south and Mediterranean zones. Overall, the report concludes that 'climatic changes, in general, are likely to shift the zones of optimal production areas for specific crops in the EU and altered carbon and nitrogen cycles may have significant implications for soil erosion and water quality in all zones' (Iglesias et al. 2007, v).

A review of national frameworks highlights how the current policy focus on risk reduction in relation to water rather than on increasing the capture and storage of water to ensure adequate supply for agriculture (Iglesias et al. 2007). The possibility of droughts is, overall, acknowledged better in Southern Europe in comparison to the North. According to the results of the stakeholder survey results, southern agro-climatic zones are more aware and consider adaptation measures and technologies for agriculture than zones in the North. The report further considers the role of the Common Agricultural Policy in adaptation, and concludes that existing CAP mechanisms can be used for adaptation.

Tourism is an important source of revenue and also a sector of which performance, at least to a certain degree, is related to climatic factors. There are regions within the European Union where tourism plays a large role in terms of economic revenue, particularly the Mediterranean as the world's most popular holiday region and the Alpine countries in terms of winter tourism. The Impact Assessment of the EU White Paper on Adaptation recognises that coastal and mountain tourism are sectors which are likely to be impacted by climate change and be most vulnerable to it (Commission of the European Communities 2009a). As an emerging area of interest, the Impact Assessment discussed the issue of cultural heritage of European cities and the impact of climate change on these cultural sites (Commission of the European Communities 2009a).

The PESETA project concludes that climate change is likely to have an impact on the physical resources that support the tourism industry in Europe, although the report urges caution in terms of the results (Amelung, More 2009). Within the mountainous areas snow reliability is likely to decrease further and the Mediterranean region is likely to experience climatic conditions that are less favourable to tourism. Water availability is a key concern since the demand for both tourism and agriculture peak at the same time of the year, as well as with the summer dip in water supply. In comparison, Northern countries in the EU can expect conditions of longer and warmer summers.

Adaptation within the tourism sector is considered to take place for the most part autonomously and it is recognised that there is no clear role for the EU in terms of action at the Union level (Commission of the European Communities 2009a). However, it is admitted that tourism is an important economic sector and cross-cutting linkages can be identified in terms of infrastructure and development that are supported by the EU structural funds. In terms of action on adaptation within the tourism sector climate proofing and building the capacity of the sector is necessary, given that large investments in infrastructure and services are often required (Commission of the European Communities 2009a). Early planning and support measures are likely to be more cost-effective than reactive measures.

Finally, the case studies conducted as part of the ESPON Climate project also have identified new development opportunities for European regions as a result of adaptation and mitigation. Within the Alpine region, new development opportunities are mostly related to tourism as the sector is important to the regions development. In relation to adaptation, new development opportunities include diversification of the tourism industry in order to respond to the challenges of the changing climate. With regards to mitigation, new opportunities also exist within the tourism industry with the development of eco- and climate friendly tourist facilities. The Tisza river case study identified the need to develop a common adaptation strategy that focuses land use and flooding. Furthermore, the case study stresses the need to exploit possible development opportunities in relation to spatial and rural development policies and flood protection and internal waters protection.

4.2.5 Conclusions

This report has reviewed mitigation and adaptation policy in Europe by taking multilevel governance as its starting point. Challenges of policy coherence, integration and coordination are significant challenges in both mitigation and adaptation. European regions and the policy options they are able to pursue are affected not only by national level policies but also by policies from the EU level. In addition, local authorities and municipalities have more influence and power in decision-making in some countries than others within the Union. These factors affect the way that mitigation and adaptation is designed, developed and implemented.

In terms of mitigation policy, the legally binding targets are likely to cause adjustments in the national policy and consequently affect the regional level policy. Adaptation policy, in comparison to mitigation policy, is still being formed, and each of the Member States has been able to pursue their own strategy with little direction from the EU level thus far. An increasing trend within Europe has been the emergence of regional or local climate strategies that tackle both mitigation and adaptation together. These are often based on voluntary initiatives and are related to energy efficiency and concern for climate change in terms of mitigation, and local vulnerabilities to impacts of climate change in terms of adaptation.

5. Research implications

5.1 Comparison with other spatial research and typologies

5.1.1 Comparison with previous pan-European studies on climate change impacts

ESPON Hazards

The ESPON 1.3.1 project on "Territorial effects of natural and technological hazards in general and in relation to climate change" (2003 – 2004) studied the influence of climate change on natural hazards in Europe. Particular attention was paid to extreme temperature events as well as heavy precipitation. To quantify these expected changes, indices of climate extremes derived from output from scenario simulations using high-resolution regional climate models were used. The results showed a future with substantially milder winter cold extremes and a warming during warm extremes for large parts of Europe. Furthermore, the results indicated an increase of heavy precipitation and of dry spells in most of Europe. These general trends fit quite well to the exposure assessment which was undertaken by ESPON Climate.

However, ESPON Climate made use of more climatic stimuli. Much more important is the comprehensive focus of this project, meaning the integration of exposure, sensitivity, impact and adaptive capacity to vulnerability as the final outcome. Moreover, the effects of creeping changes on the different dimensions of sensitivity were studied in addition to extreme events. In contrast the ESPON Hazard project focused only on exposure. The different natural hazards, which are potentially triggered by climate change, were - opposite to ESPON Climate - not related to climate models, but the assessment was only based on statistical data of past events.

Finally, it has to be stated that the understanding of vulnerability differs between the two projects. The main focus of ESPON Hazards was on disaster risks. In this context vulnerability is understood as a sub-component of risk which is context-depended (i.e. dependent on the susceptibility of exposed elements to a particular hazard). The ESPON Climate project defines vulnerability - in accordance with the IPCC – as the final outcome of the analysis.

DG Regio's 2020 Report „The Climate Change Challenge for European Regions"

This study was published in 2009 as a background document to the working document "Regions 2020 - An assessment of future challenges for EU regions". It summarized the main findings regarding changes in climate conditions in Europe. Moreover, it outlined some of the impacts of climate change on socio-economic conditions and identified the regional distribution of these impacts across Europe.

The study made use of similar exposure indicators as ESPON Climate, but included only a few sensitivity indicators. The climate change index only combined information on drought, population affected by river floods and exposed to coastal erosion, exposure to climate change of the agriculture, fisheries and tourism sector. Environmental effects are, for instance, not part of the analysis. Moreover, there no attention was paid to particular typologies of climate change. The final outcome does not differentiate explicitly between different dimensions of sensitivity.

According to the study regions under highest pressure are generally located in the south and east of Europe, the whole of whole of Spain, Italy, Greece, Bulgaria, Cyprus, Malta and

Hungary, as well as most of Romania and southern parts of France. This is due mostly to changes in precipitation and an increase in temperature which have an impact on vulnerable economic sectors, with river floods also contributing to the overall effect in Hungary and Romania. These patterns fit relatively well to the results of ESPON Climate. Therefore, this comparison seems to prove the robustness of the main assessment results.

However, the differences between the core of Europe and the southern and the south-eastern periphery are even bigger when looking at the results of ESPON Climate. These results from the fact that ESPON Climate integrated adaptive capacity in the vulnerability assessment and the DG Region did not. This has a significant effect because the adaptive capacity of these parts of Europe is in general relatively low. Adaptive capacity was not considered by DG Regio's "Climate change vulnerability index" as well as potentially positive effects. Thus, the maps of the study represent only what the ESPON Climate project defined as "impact" of climate change.

The DG Regio study should be seen as a first valuable attempt for an integrated vulnerability index. Here, the ESPON Climate project was able to go a step beyond and address several issues which were not considered by the DG Regio report.

5.1.2 Climate change and migration research

Migration research is an example of a research field in which climate change could play an increasingly important role. Currently climate change is a key issue on the European research and policy agenda. Although the European Union strategy is based on solidarity for the affected member states and other countries outside of the EU, the link between climate change and migration has not been directly addressed yet. Much less has been done regarding the study of this topic at regional and local scales. The complex nature of the atmosphere and the lack of knowledge of all climate processes that affect the climate system make climate change predictions inherently uncertain. Furthermore, the speculative nature of many assumptions on migration trends makes the link of this subject with climate change difficult to unravel. Historical records and empirical studies suggest that migratory responses to climate variability cannot be explained through concepts such as hazard, risk or physical vulnerability alone. Migration implies a variety of factors, including both economic and social capital, to facilitate the process (Lutz, 2009; Kniveton et al 2008). Nonetheless, the long-distance and linear nature of this migration is not supported by robust scientific research, yet many authors agree that climate-related shocks and stresses will lead inevitably to massive migration movements.

Two questions arise while exploring the existing link between climate change and migration in Europe: (a) who are the potential climate change migrants, and (b) what climate change processes might cause population displacements to, within and where in the continent. In order to answer these questions, this brief report attempts to identify the possible impacts of climate change both in international as well as in internal migration within Europe. In this respect we must cite as a fundamental reference ESPON's DEMIFER project (Demographic and Migratory Flows Affecting European Regions and Cities) (DEMIFER 2010). This report highlights the difficulties and uncertainties related to data on migration processes linked to climate change, especially at the regional and local scales but nonetheless it provides certain valuable judgments on this issue for the future decades.

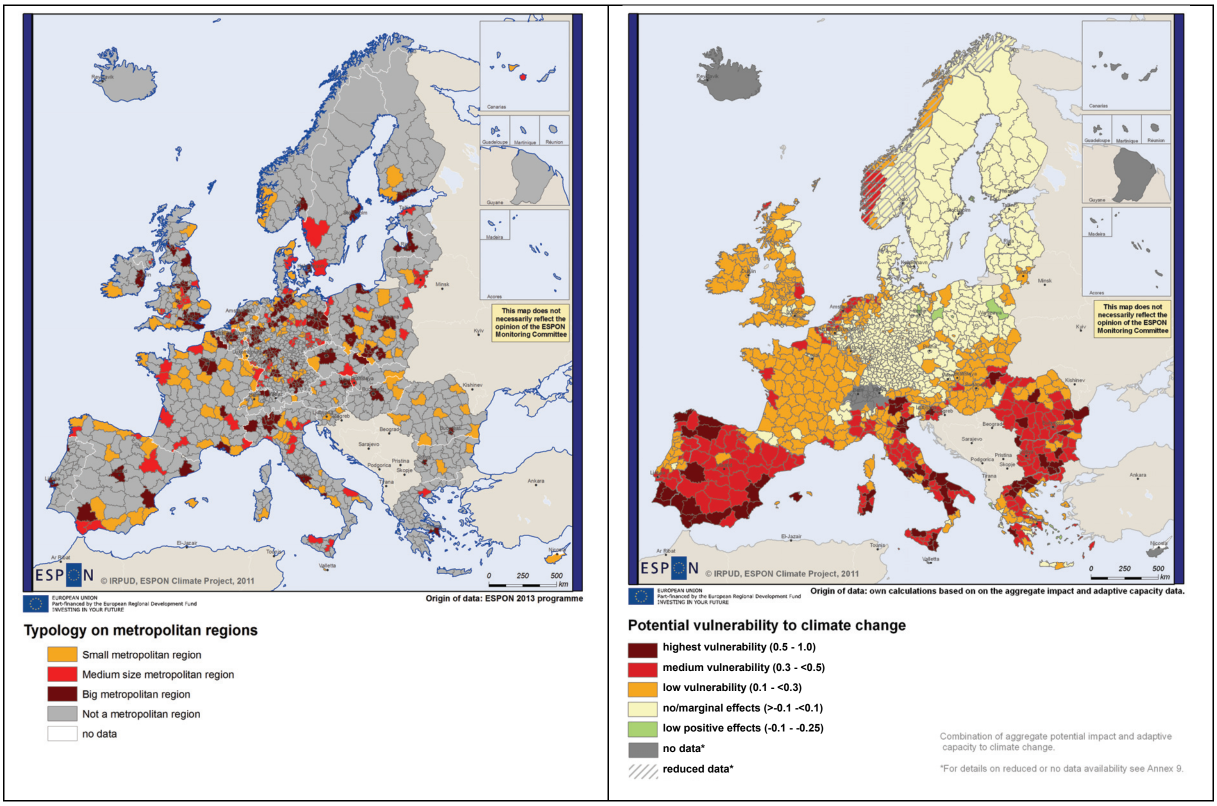
Most of the areas with the largest projected figures of population growth, such as South and Eastern Asia, happen to be also the most densely populated today. These areas, along with many other around the developing world, also likely to become vulnerable to climate change and associated effects over the next decades. Among other impacts this is likely to result in massive human displacements. Thus is predicted that 1 billion people, many of them from developing regions, will migrate due to climate change by 2050. Although slow-onset climate processes are expected to affect short or mid-distance migration flows, mainly within the countries or in neighbouring countries, the increasing frequency and intensity of some catastrophic extreme events related to climate change can also increase the risk of new patterns of migration, including long-distance flows, rather than the reinforcement of existing streams. However, empirical studies show that much of this migration is likely to occur within countries or in neighbouring countries and that people tend to return to their previous settlements after the disaster (Massey et al. 2010). Moreover, climate change displacements from developing countries are unlikely to reach very far because of poverty and because of the existence of mitigation measures through aid efforts. Nearby urban areas are more likely to experience massive arrivals. In sum “international migration is an expensive endeavour with significant resources required both to undertake the journey from other continents to Europe and especially to cross international borders” (Black et al 2008, 7).

Regarding European regions, changes in temperature, rainfall patterns and CO2 concentrations could affect agriculture, resulting in changes in yield productivity fostering internal but also international migration to European areas now sparsely populated such as those located in the North of the continent. On the other hand, the increasing occurrence of extreme weather events such as forest fires, heat waves, droughts or floods is likely to generate migration flows within and across countries, and sea-level rise could foster migration movements from low-lying urbanized areas of Atlantic Europe and the Mediterranean. Decreasing snow availability in certain mountain areas could hamper winter tourism and possibly lead to migration from these areas although perhaps not in appreciable terms given the already relatively small population (DEMIFER, 2010). The Mediterranean climate has proven to be the main factor attracting international migration of retirees from the United Kingdom, Germany or Scandinavia, especially towards Spain and Portugal. These migration flows could also be affected by climate change if the conditions of comfort in the Mediterranean decrease in summer, for instance. This may lead to an intensification of already existing seasonal flows by which especially the most well off European retirees return to their countries in the summer. However, the adaptability of Mediterranean countries could offset climate change impacts, for example with the use of air conditioning or recurring to desalination in case of water shortages. Likewise adaptation could take place by use of reliable technology.

In conclusion, the impact of climate change and related events on migratory flows to, from and within Europe is likely to be small. International migration may be affected by increasing costs and restrictive policies while internal movements within the continent do not appear to be very significant either - unless other adaptation measures fail. Nevertheless, we must add a note of caution to these statements since, as the authors of the DEMIFER report argue, lack of data and further studies make reliable estimations nearly impossible.

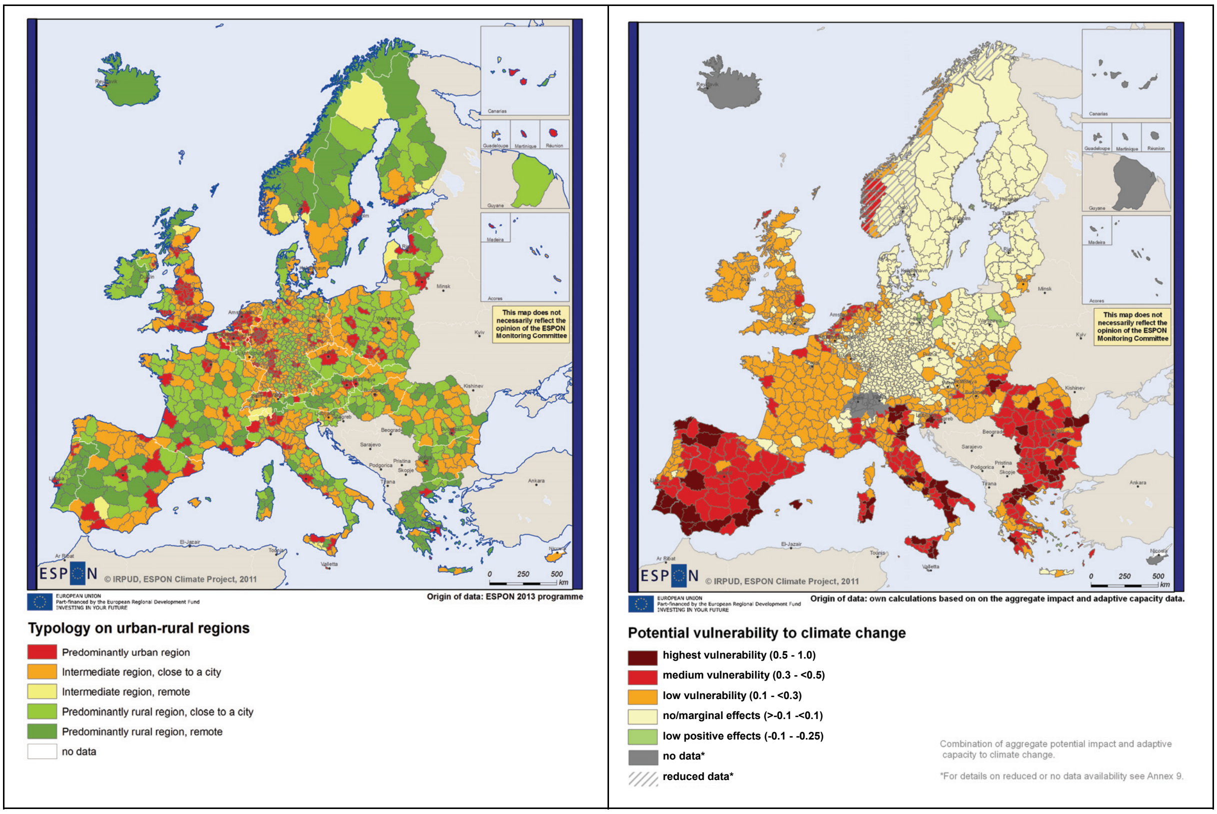
5.1.3 Climate change and other spatial typologies

The new vulnerability typology of regions developed by the ESPON Climate project provides a new perspective on existing regional typologies, many of which are used by EU policy-makers. Based on the findings presented in this report it is already possible to outline implications resulting from climate change for the regions subject referenced by these typologies. These implications point towards more in-depth, quantitative research that will systematically analyse impacts, adaptive capacity and vulnerability specific to each of these various types of regions.



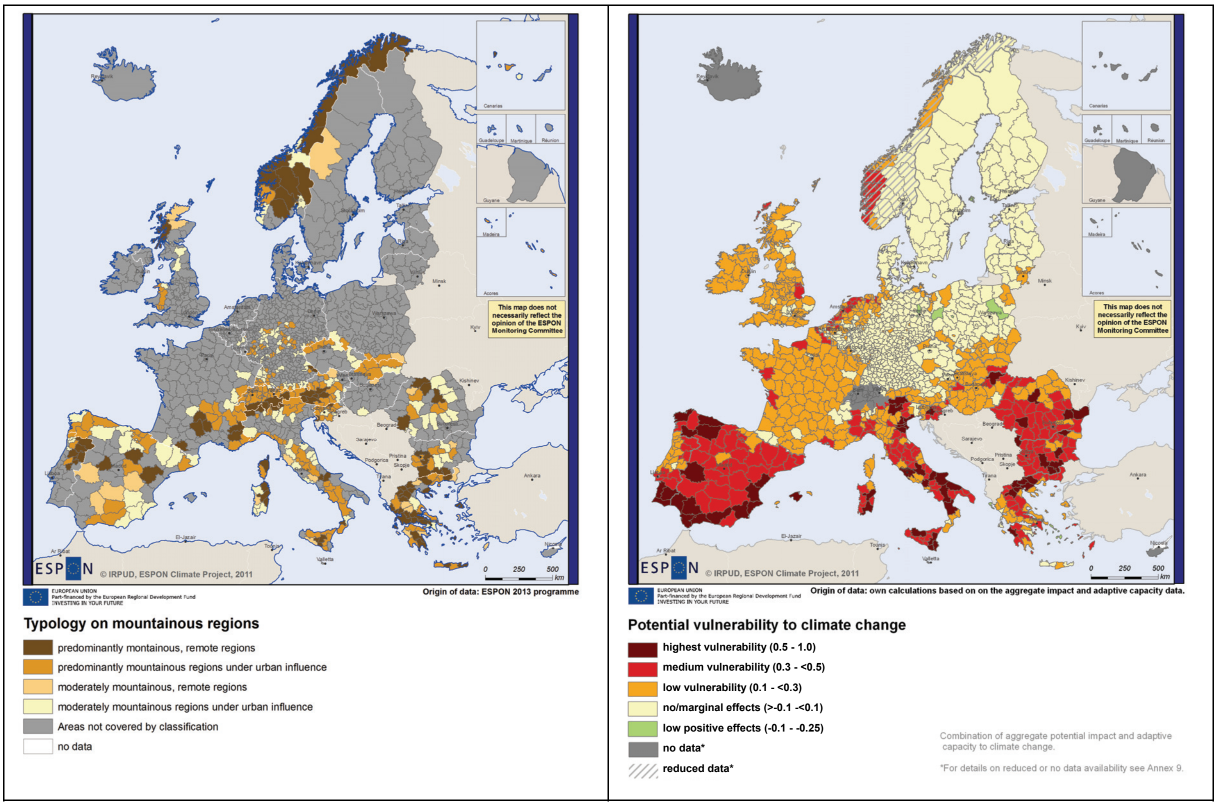
Map 61: Comparison with typology on metropolitan regions

As concerns Europe's *metropolitan regions*, it is clear that most exhibit high climate impact scores. This is not surprising giving the concentration of population, infrastructures and cultural assets in these regions. When looking at their vulnerability scores, many metropolitan regions have only low or even marginal vulnerability, because their adaptive capacity is generally higher than non-metropolitan regions. Particularly big metropolitan regions yield comparably low vulnerability scores on average. However, the metropolises along the (especially Southern-European) coasts, in the Alps and in South-East Europe still have a high vulnerability. Often this is due to a relatively low adaptive capacity (by European standards) in the relevant countries.



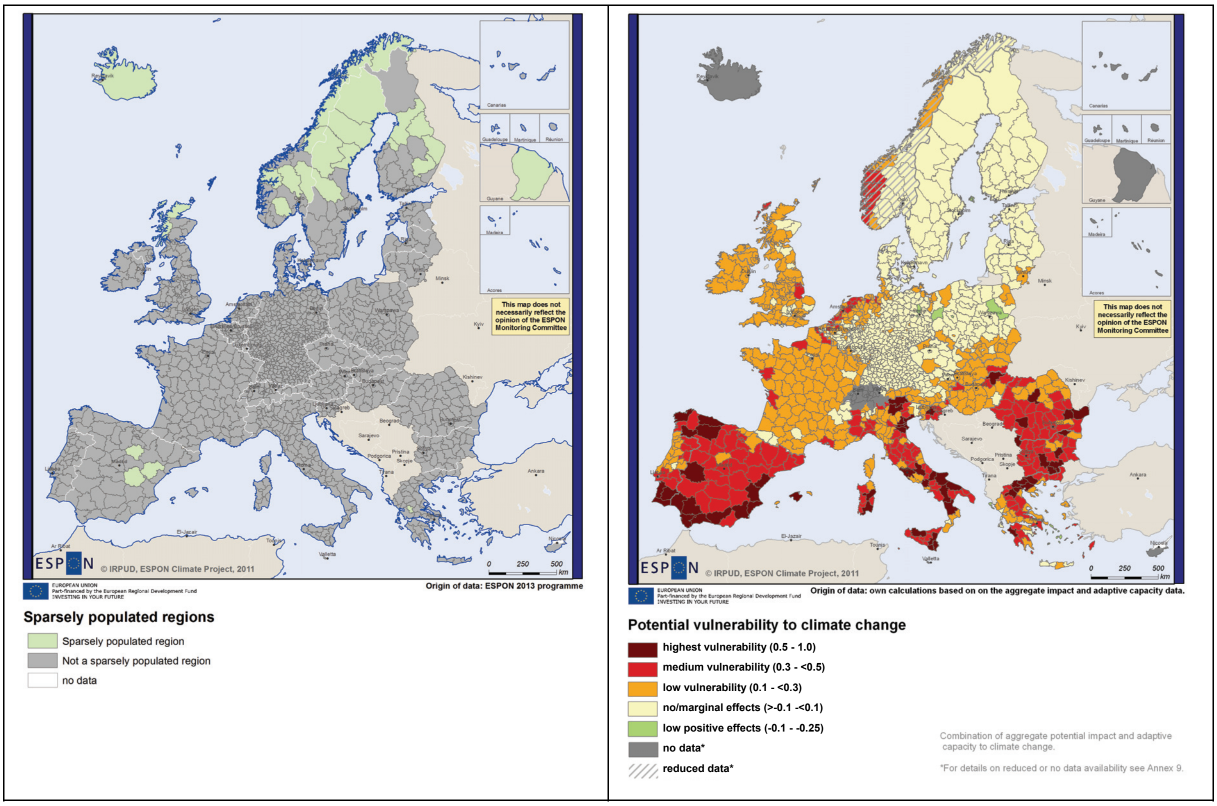
Map 62: Comparison with typology on urban-rural regions

Examining the EU's typology of *urban and rural regions*, the same results as outlined above apply for the major urban centres. Here, regions in the 'predominantly urban' category yield the lowest vulnerability scores on average. In terms of spatial variation urban regions along Europe's coasts are clearly more vulnerable than most rural regions. In contrast, rural areas in Southern Europe exhibit at least moderate vulnerability values (some even high) because of the hotter and drier future climate in these parts of Europe. In contrast, rural areas in central, northern-eastern and northern Europe may undergo only low, marginal or even positive vulnerability changes due to only slightly worsening or even more favourable climatic conditions.



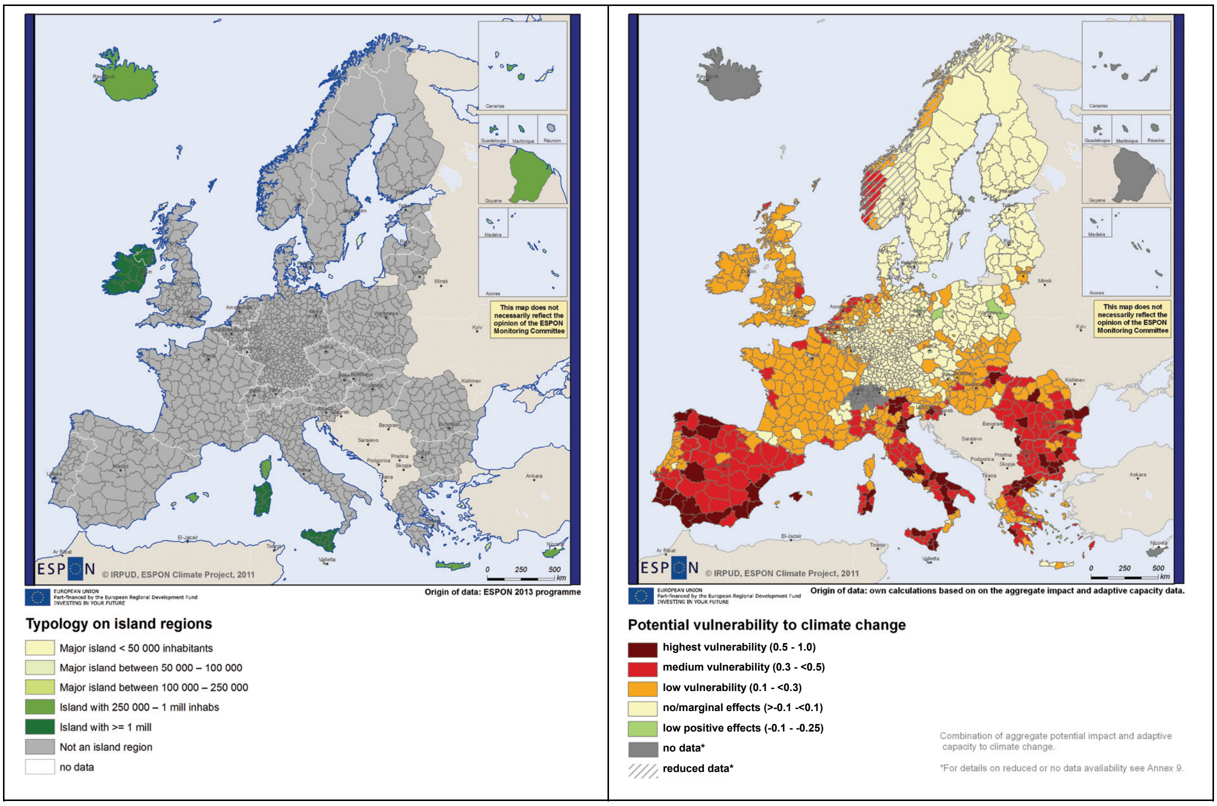
Map 63: Comparison with typology on mountainous regions

Europe's *mountain regions* are expected to be mostly adversely affected by climate change. This is particularly true for mountains in South-Eastern Europe, Greece, Spain and the Alps. In the latter one can clearly see that the most severe impacts are to be expected on the southern side. Again urban influence tends to reduce negative impacts of climate change in respective regions while remote mountain regions display higher changes vulnerability on average. For example, mountain regions in Scotland and Scandinavia also show medium to high vulnerability, but it is difficult to come to clear conclusions as regards the Norwegian regions because of the lack of data for many indicators there.



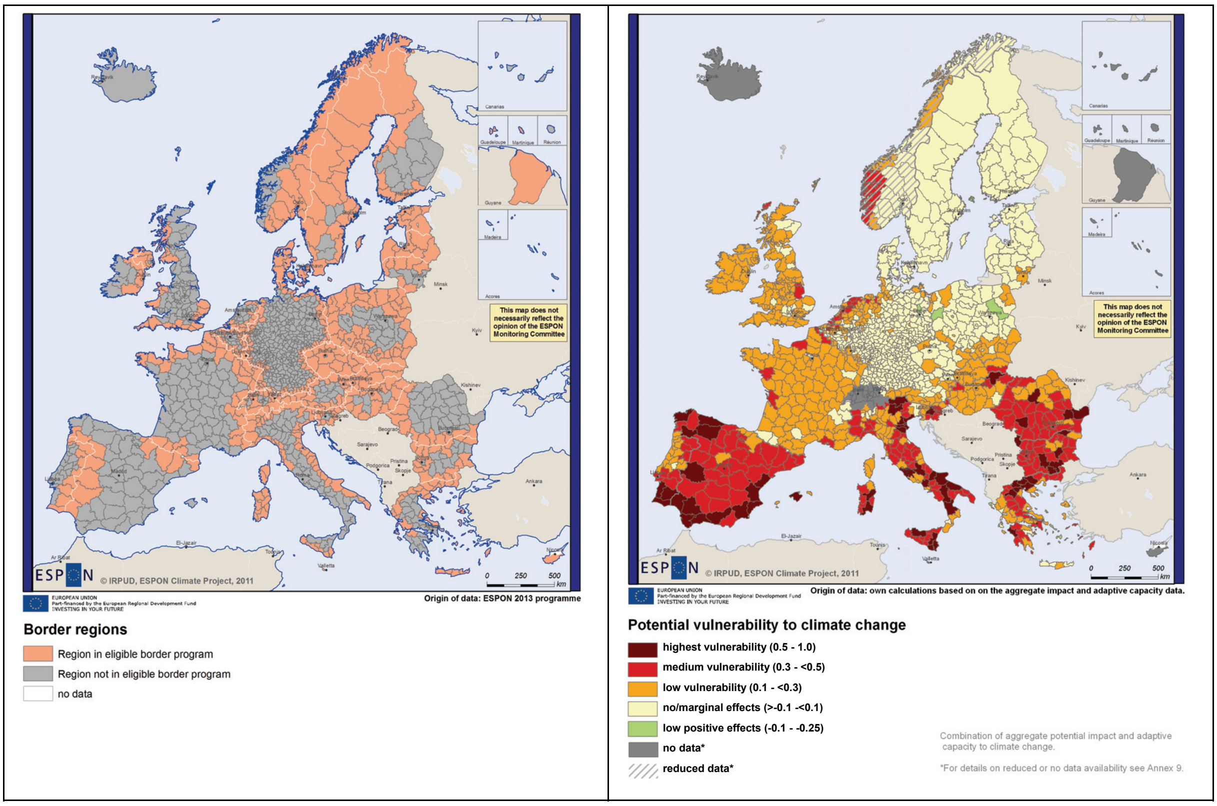
Map 64: Comparison with typology on sparsely populated regions

In Europe *sparsely populated regions* are primarily located in Scandinavia, Scotland and the interior of Spain. The Spanish regions - like most other Mediterranean regions - are negatively affected by a hotter and drier climate. Nevertheless, on the average these regions display a slightly lesser vulnerability to climate change. On the contrary, the northern European regions are projected to suffer mostly from more precipitation and related problems like river flooding and flash floods, but their agricultural sector may benefit from the increase in temperature.



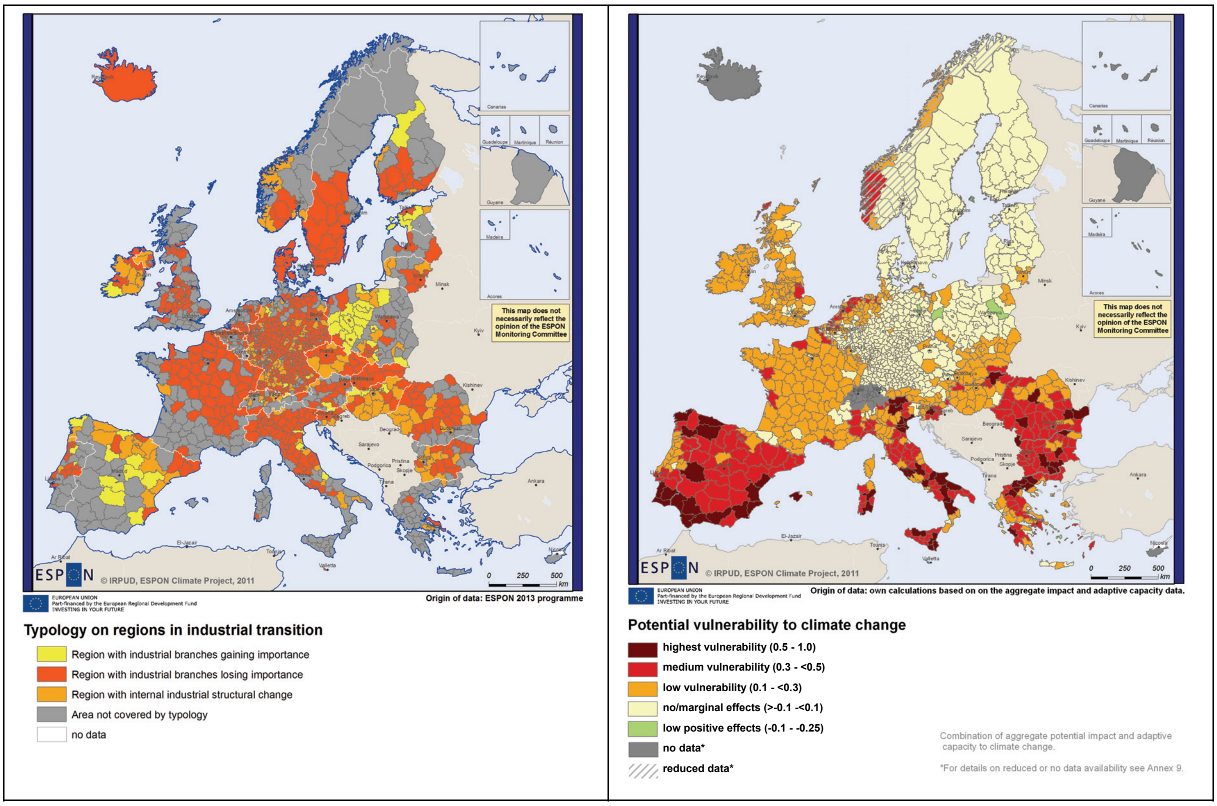
Map 65: Comparison with typology on island regions

Islands can be found primarily in the Mediterranean and the northern Atlantic. On average islands are severely impacted by the projected climatic changes. For the Mediterranean islands (i.e. Mallorca) this is compounded by a relatively low adaptive capacity, leading to even higher vulnerability scores. However, one has to be cautious with conclusions regarding islands, because the CCLM model seems to have problems with climate projections for land cells with oceanic climate. Furthermore, CCLM unfortunately did not allow projections for Iceland.



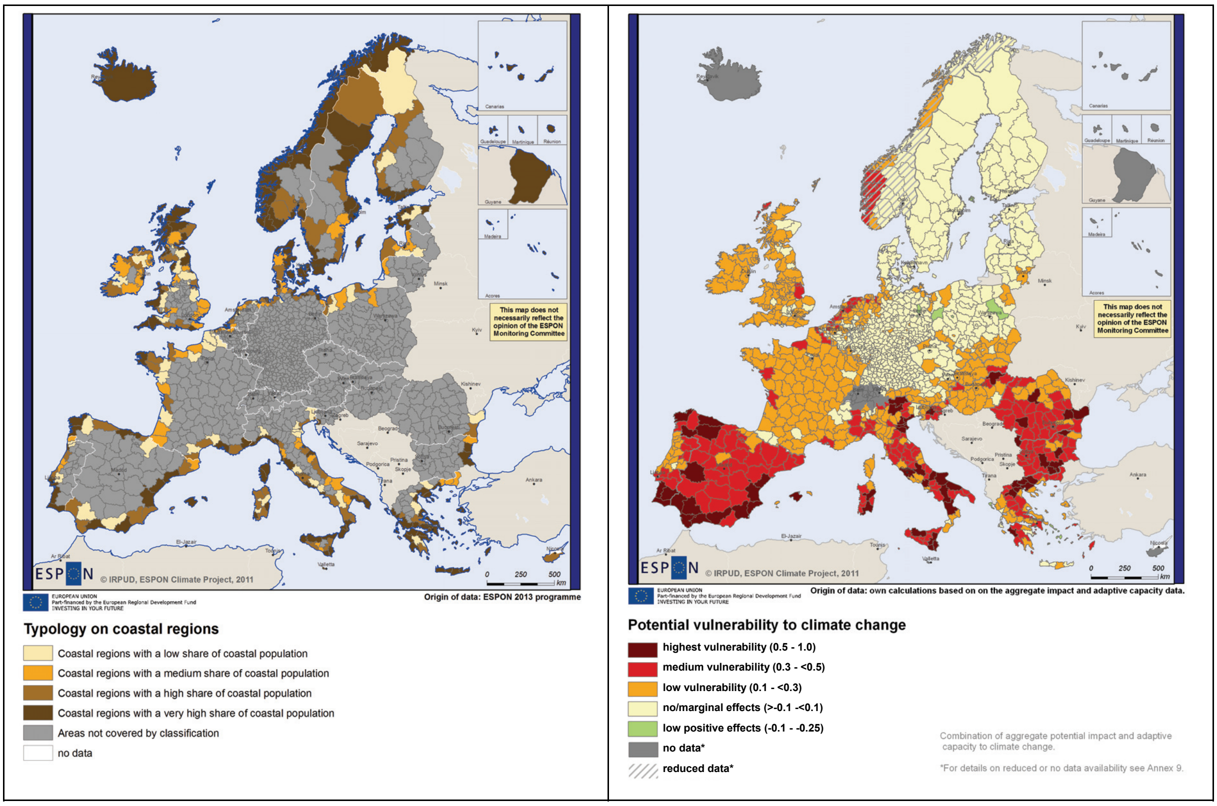
Map 66: Comparison with typology on border regions

Border regions are an important category of regions from a European policy point of view. Examining the impact and vulnerability scores of these regions it becomes apparent that there are considerable disparities between the regions of one cross-border corridor (i.e. between Austria and the neighbouring countries Czech Republic, Slovakia and Hungary). This is in part due to the often very different adaptive capacities of the respective countries, but also some components of sensitivity (e.g. in regard to population concentrations, settlement patterns, economic development) vary significantly across borders.



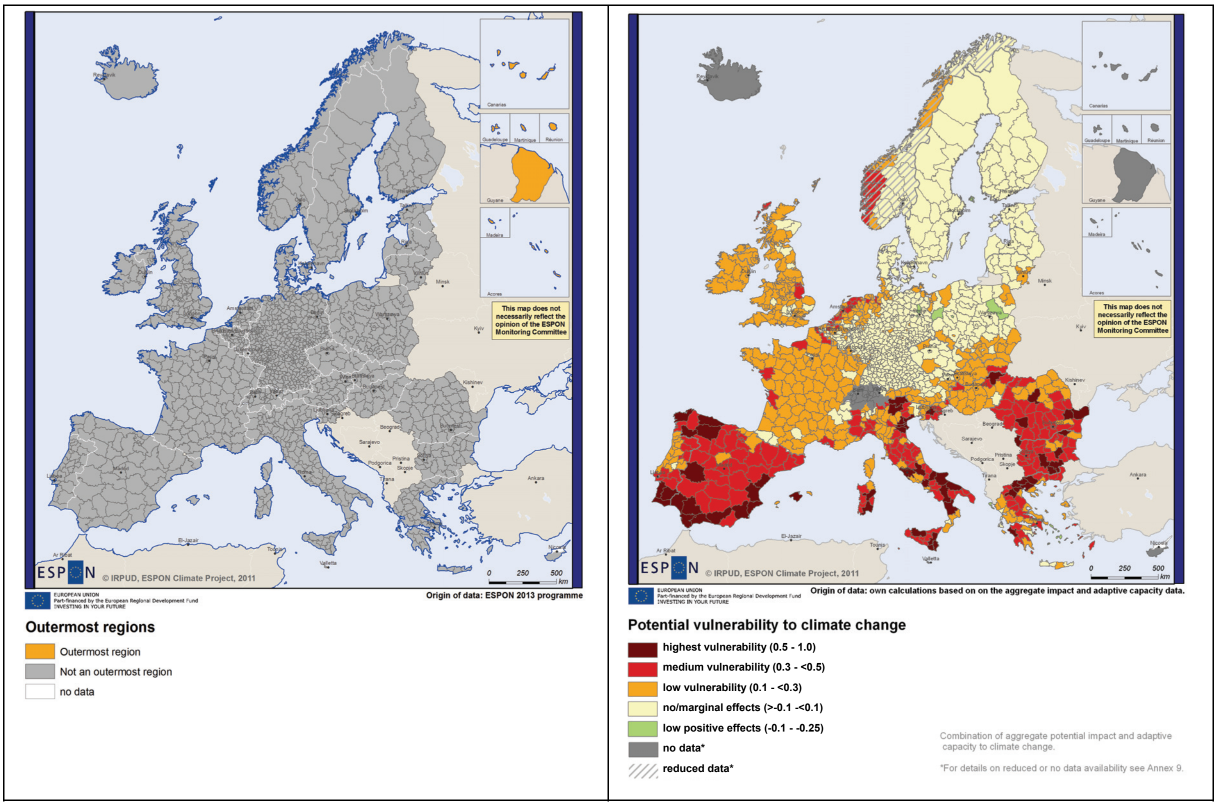
Map 67: Comparison with typology on regions in industrial transition

When analysing climate change implications for *regions in industrial transition*, it may be more important to consider mitigation instead of sensitivity and adaptive capacity. It can be expected that regions with industrial branches that are gaining in importance are likely to emit more greenhouse gases in the future. On the other hand, those regions with a declining restructuring manufacturing sector may in the future emit less greenhouse gases and thus make greater contributions to climate change mitigation.



Map 68: Comparison with typology on coastal regions

In general, *coastal regions* are among the regions most negatively impacted by climate change because coastal flooding is a dominant problem here. However, when considering the impacts of coastal flooding alone, the pattern varies across Europe and not all coastal regions are actually affected. In addition to the issue of coastal flooding, coastal regions often also exhibit quite considerable concentrations of population which often leads to high impact in combination with other climatic stimuli like temperature increase for instance. Thus coastal regions in Southern Europe are generally more impacted by climate change than northern European coastal regions except for the regions adjacent to the North Sea which are considerably prone to coastal flooding.



Map 69: Comparison with typology on outermost regions

Lastly, Europe's *outermost regions* are, by definition, not located in Europe. One can therefore expect that climate change will affect these regions completely differently. Since many of the outermost regions are coastal regions they will probably exhibit moderate or even high impacts, and possibly also have a relatively low adaptive capacity. Therefore these regions may have at least a moderate if not a high vulnerability (by European standards). However, it is not possible to undertake more than these general speculations because the climate change data that the project had access to did not include the outermost regions.

5.2 Proposals for further research

It has to be stated that the ESPON Climate project was the first attempt for a pan-European cross-sectoral climate change vulnerability assessment. The project succeeded in developing and implementing a comprehensive methodology that integrates data and interrelations across a vast range of relevant fields. Nevertheless, for each indicator a detailed methodology had to be developed that built on existing research findings, established causal relations to other indicators and utilised the most appropriate and up-to-date data. In this course the project developed several advanced methods for assessing climate change impacts for the pan-European study on a very fine-grained scale. For example, the assessment of many indicators was performed on a 100 x 100 metre grid cell basis, e.g. to identify exactly those parts of a region's population which are sensitive to river flooding inundation or which live in urban heat islands and are especially sensitive to heat events in the summer.

Further research is needed in just about every aspect of climate change that the project touched upon. This includes research on second-order, indirect effects of climatic changes. For example, the project estimated the potential effects of a changing climate on the tourism sector of each NUTS 3 region. Through backward and forward linkages these direct effects have multiplier effects on other (sub-)sectors. Such further analysis is of course possible and would allow a more complete assessment of the economic impacts of climate change. However, the relevant economic linkages are likely, for example, to also reach into adjoining regions, thus adding an additional layer of complexity. The necessary economic modelling was clearly beyond the scope of this project, but should be pursued in the future and the results be compared with and related to the first-order effects analysed by ESPON Climate. But besides a deeper understanding of detailed mechanisms of climate change, what is needed are pan-European methodologies and comparative research. There are many studies that have been conducted at the national or regional level, which deserve and need to be scaled up to the European level. An expert-based, multi-criteria classification of all 231 habitat types of the NATURA 2000 directive in regard to their climate change sensitivity is a case in point. So far only about 80 of these habitat types, which exist in central Europe, have been classified.

Besides expanding, upscaling and integrating existing research approaches the ESPON Climate project identified a great need to make qualitative, institutional aspects of climate change, adaptation and mitigation compatible with the quantitative assessments conducted. The Alpine space study charted a way forward in this regard, but systematic, pan-European methodologies, reviews and classifications are needed to integrate these crucial institutional aspects into pan-European studies.

It is also well known that current climate models differ greatly in their projections of future climatic conditions. It would be important, that in the future research projects on climate change vulnerability are resourceful enough to be able to make use of all or the major climate model data – both for comparing their results and implications for a vulnerability assessment like ESPON climate and for combining them to a more robust database upon which to perform sensitivity, impact and vulnerability analyses.

Last, but perhaps most importantly, further research is urgently needed with respect to projecting sensitivity indicators into the future. ESPON's DEMIFER project broke new ground in projecting demographic trends up to the year 2100. But what about other social and economic trends? Of course it is difficult, some may say impossible, to make such long-term projections for issues and variables that are volatile and constantly shaped by human intervention. However, the challenge of climate change and the advances made in modelling future climates puts pressure on other disciplines to also develop sophisticated models or scenarios. Without such research, any climate change impact or vulnerability assessment is fraught with the great weakness that one can only relate dynamic, future-oriented climate data to static sensitivity data.

5.3 Recommendations for pan-European monitoring

Our recommendations for future pan-European monitoring are pointing in a similar direction. Up to now there are hardly any data for dynamic sensitivity indicators although a sophisticated vulnerability assessment should be based on projections for both exposure and sensitivity referring to the same past and future time periods. The ESPON Climate project is well aware of this need for further analytical research, which is, however, clearly beyond the scope of a single applied research project. It was possible to underline the relevance of dynamic sensitivity data by using the population projection for 2100 which came from the ESPON DEMIFER project. However, for other relevant data (e.g. settlement changes, economic development and the environment in the year 2100) no data exist at all or only for parts of the ESPON space.

For the sake of a (continuous) pan-European monitoring such data need to be consolidated by central institutions and be provided corresponding to a common analytical framework which may lean on the one developed within this project. A positive indication in this respect is the new clearinghouse initiated by DG Climate Action. Such an institution may be a good starting point for a common shared and harmonized database. Furthermore, adequate tools of data provision and for analysis considering the special demands in the context of climate change may be provided. For a more decentralized pan-European monitoring harmonized methodologies are indispensable. Ultimately all advancements will still face the issues already discussed within this report - uncertainty about future climate change but also about future regional development. Here, a regular monitoring may also hold potential as to provide better projections on dynamic indicators of regional sensitivity and adaptive capacity.

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