Territorial effects of climate change on Europe's regions

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Abstract

Climate change and its effects on Europe's regions are highly political issues. The European Commission and its member states, as well as regional and local governments and civil society organizations are exploring and debating how to adapt to the projected climatic changes. It is clear that Europe's regions will be affected differently and will also have different means available for adapting to climate change. Thus territorially differentiated adaptation strategies are necessary. However, there are hardly any studies that employ a territorial perspective to the issue of climate change impacts and adaptation in Europe. Most studies are strictly sectoral in outlook. But what is needed, from a policy-making perspective, is a cross-sectoral assessment that provides an evidence base for regionally differentiated, tailor-made adaptation strategies.

The paper presents the methodology and key findings of the recently concluded research project ESPON Climate.[2] The project conducted an integrated climate change vulnerability assessment with a prime territorial focus. Building on a widely accepted conceptual framework the study used ten climate change variables based on the CCLM climate model, 19 sensitivity indicators and 15 adaptive capacity indicators to calculate the climate change vulnerability of 1,350 European regions. The results are presented as maps and discussed from a pan-European perspective.

One of the core findings is that Europe's climate change vulnerability runs counter to territorial cohesion. The assessment indicates that climate change would deepen the existing socio-economic imbalances between the core of Europe and its Southern and South-Eastern parts because many economically lagging regions also are the most vulnerable to climate change.

Finally, implications and options for EU and regional policy making are discussed. For example, the project's findings could inform the allocation of EU funds that would provide targeted financial assistance to regions that are projected to be severely affected by climate change and also have low adaptive capacity. This would ultimately contribute to a more balanced territorial development of European regions. The paper concludes with methodological reflections and a careful outlook.

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1. Introduction

Climate change is a high profile political issue in Europe with a distinct territorial dimension. For example, in the "Europe 2020 Strategy for smart, sustainable and inclusive growth" (COM 2010) the EU took up the challenge of climate change and set ambitious targets for greenhouse gas emissions, renewable energy use and energy efficiency. Likewise the Territorial Agenda 2020 (EU 2007) regarded climate change and environmental risks as very important and as containing both challenges and potentials for territorial development. Finally, the EU White Paper "Adapting to climate change: Towards a European framework for action" (EC 2009) explicitly related climate change to territorial development in Europe and called for a planned response.

But such a systematic response to the development challenges of climate change requires an appropriate evidence base. Many European studies have until now focused on different types of impacts of climate change. The focus has usually been on very specific impacts or on particular sectors. While these studies contributed to the overall understanding of climate change mechanisms in Europe, their findings have seldom been transferable or comparable between sectors or between regions. What was missing was an overall, cross-sectoral assessment of climate change that would allow European policy-makers to understand the diversity of climate change impacts and develop territorially differentiated adaptation strategies at the European, national and regional level.

Taking up this challenge, this paper presents findings of the EU financed research project ESPON Climate, which conducted an innovative, integrated and pan-European climate change vulnerability assessment with an explicit territorial focus.

2. Concepts and methodology

2.1 Conceptual framework

The ESPON Climate project is based on 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.

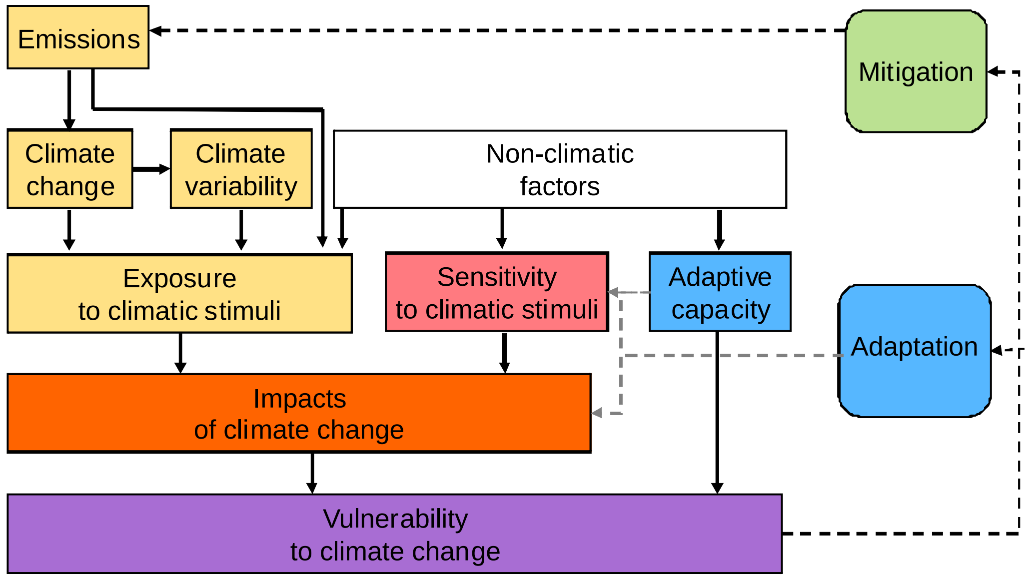

Figure 1: Conceptual framework (adapted from Füssel & Klein, 2002, p. 54)

In order to provide a clear basis of understanding these key concepts are further defined below:

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.
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.

2.2 Methodology

Following this framework the ESPON project's methodology consisted of five main components (see Figure 2 for a graphical overview).

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.[3] 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 of the 19 sensitivity indicators[4] was calculated in absolute and relative terms and then combined. This integrates 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 aggregation of the various impact dimensions (and later the integration of exposure, sensitivity and adaptive capacity) raises normative issues induced by the theoretical framework. At these stages of the assessment process weighting takes place, for even if no weighting is deliberately performed, this then amounts to simply giving equal weights to each object. This weighting ultimately refers to cultural

[3] Exposure indicators used by ESPON Climate related to change in annual mean temperature, frost days, summer days, winter precipitation, summer precipitation, heavy rainfall days, snow cover days and evaporation.

[4] Sensitivity indicators used by ESPON Climate related to roads, railways, airports, harbours, thermal power stations, refineries, settlements, coastal population, population in river valleys, heat sensitive population in urban heat islands, NATURA 2000 protected areas, occurrence of forest fires, soil organic carbon, soil erosion, museums, cultural World Heritage Sites, energy supply and demand, agriculture and forestry employment and GDP, tourism comfort index and tourist beds.

beliefs and political preferences, e.g. how one values human lives in comparison to economic damages. The ESPON Climate project decided to address these normative issues openly and conducted a Delphi survey among the members of the ESPON Monitoring Committee, which represented the European Commission, 27 European countries and four Partner States. Committee members were asked to propose individual weights for all relevant stages and dimensions of the assessment (see results in Table 2).[5]

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 dimensions of adaptive capacity. The 15 individual indicators were subsequently combined for each dimension 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.

Finally seven *case studies* at the trans-national, regional and local level cross-checked and deepened the findings of the pan-European assessment and explored the diversity of response approaches to climate change.

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5 The survey yielded equal weights for exposure and sensitivity as well impact and adaptive capacity.

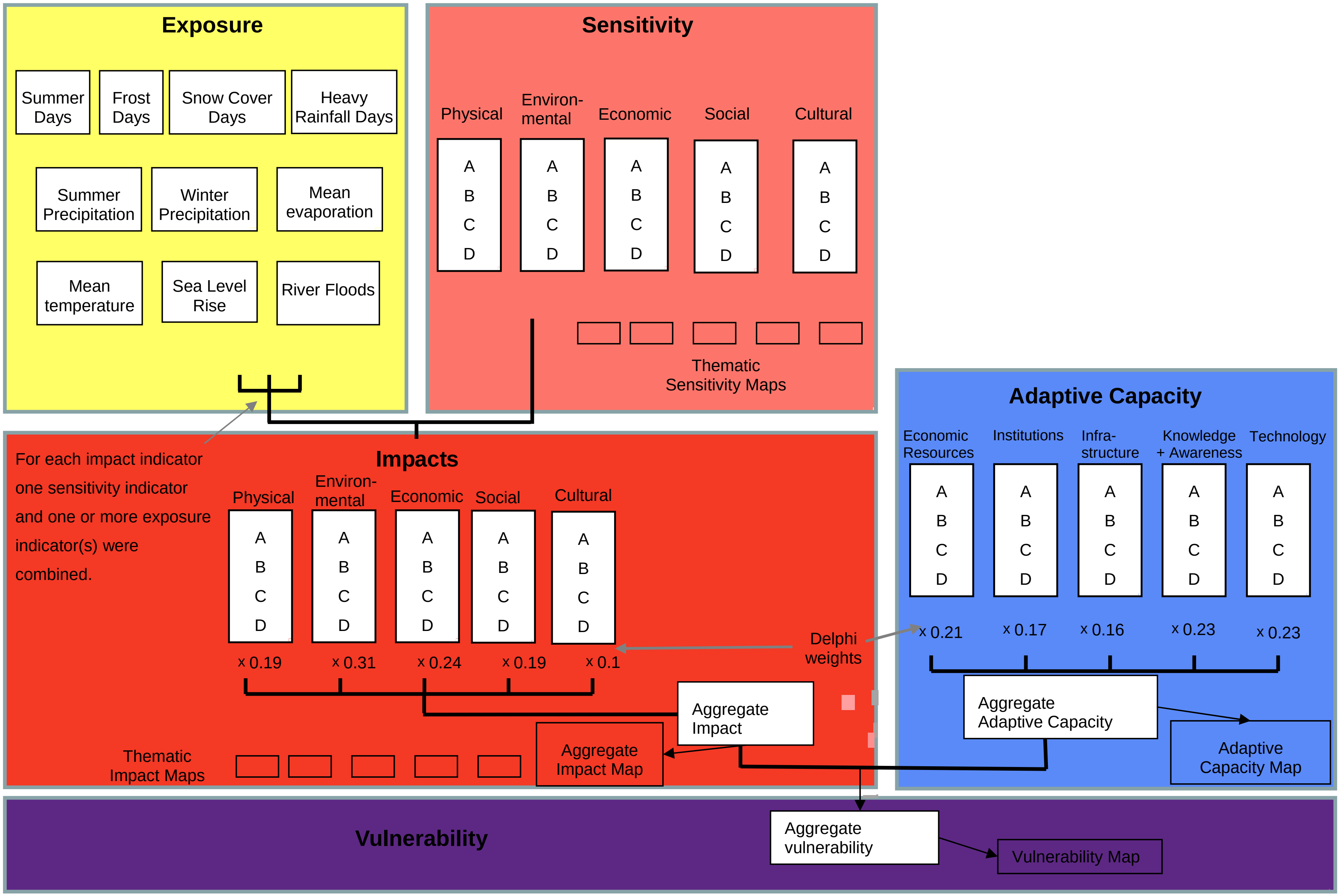

Figure 2: Overview of the ESPON Climate vulnerability assessment methodology (Greiving et al. 2011)

3. Main results

This section presents key outcomes of applying the methodology described above. For a full presentation and discussion of individual exposure, sensitivity and impact indicators one may refer to the Scientific Report of the ESPON Climate project (Greiving et al. 2011). Instead this paper focuses only on aggregated results regarding impacts, adaptive capacity and vulnerability to climate change.

The project's findings regarding impacts of climate change may be grouped into impacts primarily caused by extreme events (flooding and heat) and those caused by changes of average climate conditions. The former group consists of potential physical, cultural and social impacts (see maps in Figure 3).

Potential **physical impacts** relate to physical structures such as settlements, roads, railways, airports, harbours, thermal power plants and refineries. These structures are especially sensitive to flood events. Consequently, the adjustment of coastal storm surge heights with the projected sea level rise accounts for most of the high impacts in north-western European regions bordering the Atlantic Ocean (sometimes exacerbated by fluvial and pluvial flooding). Projected increases in river flood heights are responsible for regional 'hot spots' in Italy, Slovenia and Hungary. However, large parts of Europe may not expect significant impacts on their infra-structure resulting from climate change. In fact, physical structures in some central and southern European regions may even experience less climate-related impacts due to decreasing precipitation in these regions.

The potential **cultural impacts** of climate change focused on tangible cultural assets, because intangibles like norms and attitudes were considered part of the adaptive capacity of a region. More precisely ESPON Climate analysed what impact the projected climatic changes may have on the 350 UNESCO World Heritage Sites and ca. 20,000 museums in Europe. Not surprisingly the impact patterns for these cultural assets resemble those for infrastructures and settlements: The high impacts in Italy, Slovenia, Slovakia, Hungary and northern France, Belgium, the Netherlands, parts of Denmark and Finland are a consequence of the projected increase of flood hazards and the density of cultural sites in these regions. On the other hand, cultural assets in some Central European regions, especially in Poland, would benefit from decreasing flood hazards.

The potential **social impacts** of climate change relate to Europe's population, which is also mainly sensitive to extreme events that are driven by climate change: coastal storm surges exacerbated by sea level rise, increases in river flood heights, increasing flash floods, but also increasing heat events. Sensitivity to these changes is a matter of location, age group distribution, but also the density and size of urban areas that create urban heat island effects. Hence the social impact patterns again largely resemble those of physical impacts, because population centres are also concen-trations of buildings and infrastructures. The highest impacts are primarily flood related and are projected for urban agglomerations on the Belgium, Dutch and Norwegian coasts as well as the city regions around Barcelona, Venice and

Ljubljana. In addition, southern Europe would be more affected because of the more compact urban form of its cities and greater increases in hot summer days. In contrast, the population of most non-coastal areas of Europe is potentially not or only marginally affected by climate change and some regions are even projected to have positive impacts due to declining flood hazards, e.g. in Poland and Portugal.

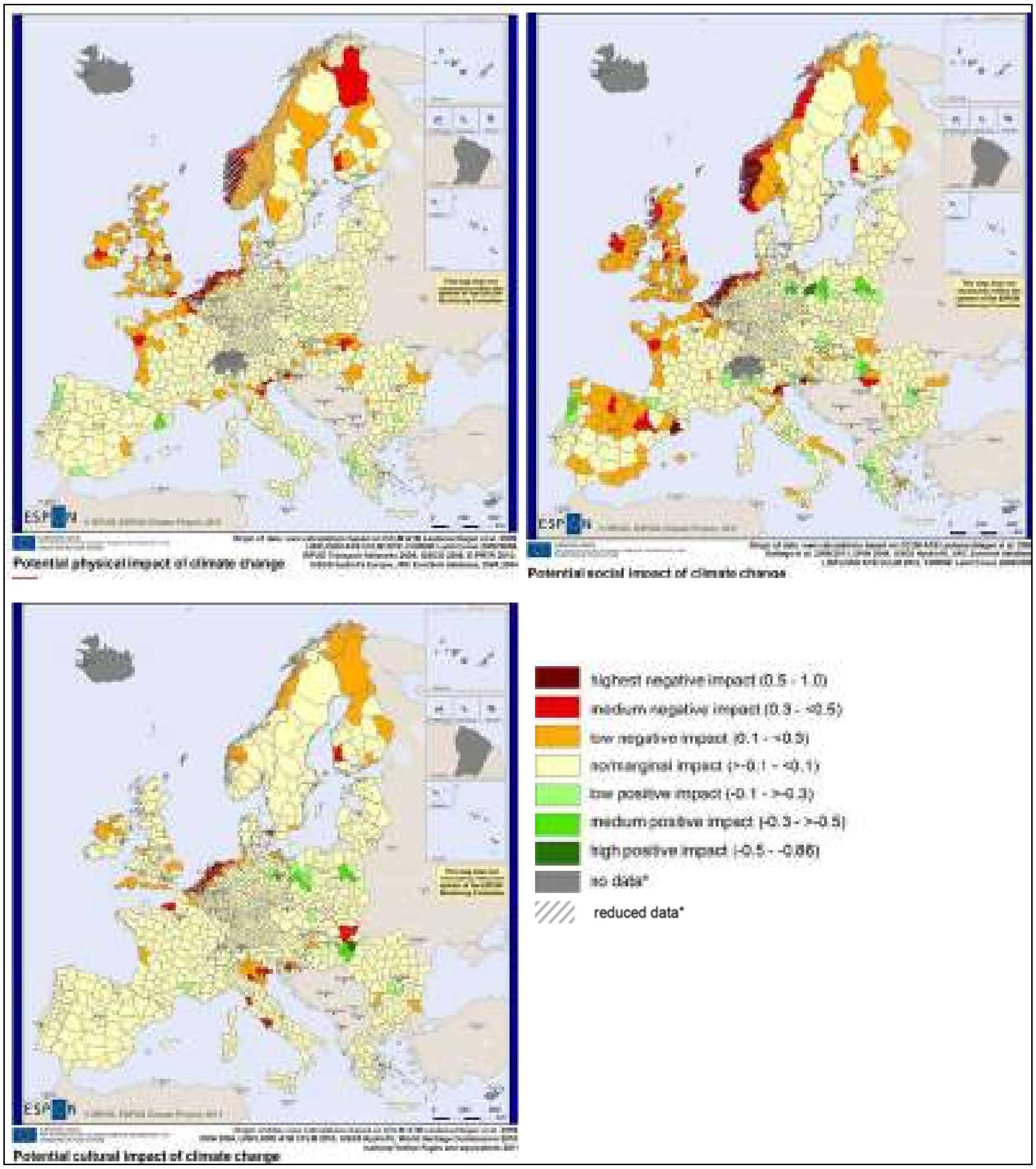

Figure 3: Potential physical, cultural and social impact (Greiving et al. 2011)

The second group of climate change impacts relate to changes of average climate conditions. In contrast to more robust sub-systems that are primarily affected by extreme events like e.g. floods, the economic and environmental sub-systems are sensitive even to creeping climatic changes (see Figure 4).

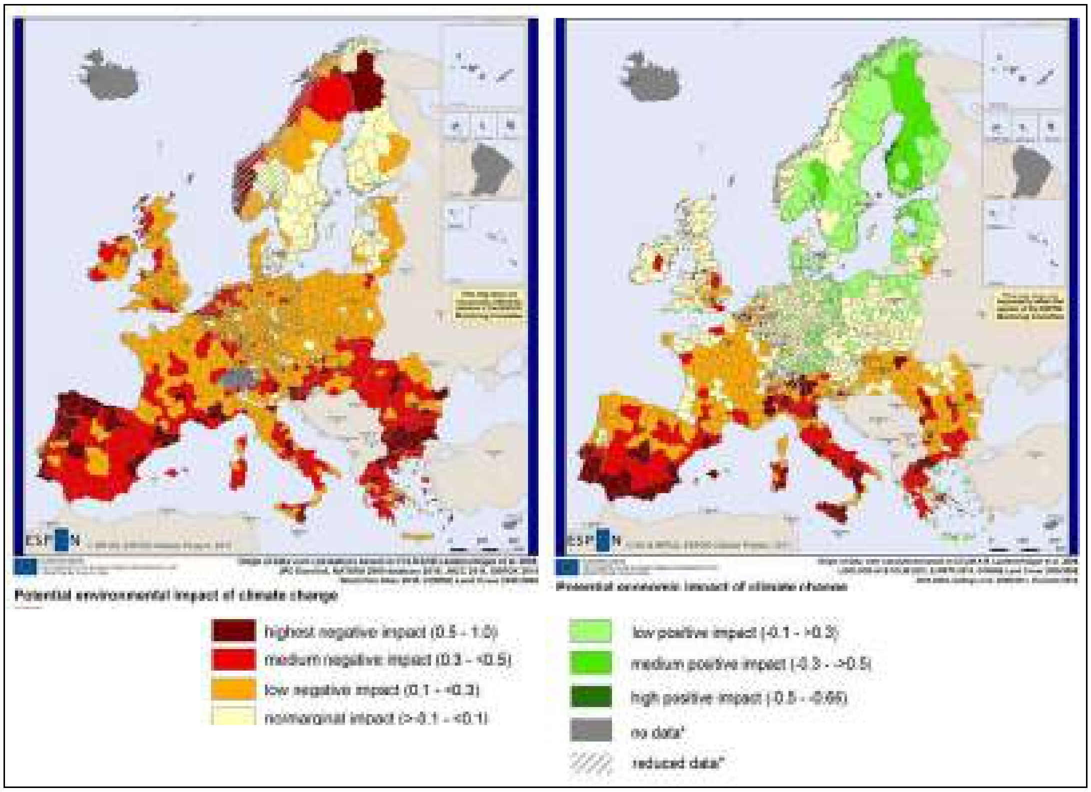

Figure 4: Potential environmental and economic impact (Greiving et al. 2011)

The potential **economic impacts** of climate change were analysed in regard to especially climate-sensitive economic sectors, namely agriculture and forestry, energy production and consumption as well as summer and winter tourism. Overall the economic impacts of climate change show a clear south-north gradient: many Central European regions and almost all Scandinavian regions are projected to have positive impacts, while almost all southern European regions would experience negative impacts. This is largely due to the economic dependency of large parts of southern Europe on (summer) tourism and agriculture. Both sectors are projected to be negatively impacted by increasing temperatures and decreases in precipitation, whereas the environmental conditions for agriculture in north-eastern Europe tend to improve. In addition, energy demands would rise in the south for cooling purposes and decrease in the north due to less heating. Finally, the Alps as a premier tourist dependent region can be identified as an impact 'hotspot', which mainly results from the projected decrease in snow cover days.

The potential **environmental impacts** that were analysed relate to protected natural areas, soil organic carbon content and the propensity of soil erosion and forest fires.

The overall findings show that for these environmental variables negative impacts are projected for almost all European regions. But the highest negative environmental impacts are expected in the north and south of Europe. In southern European regions the drier and hotter climate is projected to increase the likelihood of forest fires and to also degrade soil conditions in mountainous and coastal areas. The severe environmental impacts in northern Scandinavia are mainly due to very large protected areas where any climatic change (in this case warmer and wetter climate) is considered as negatively affecting the specific ecosystems under protection.

Moving beyond sectoral impact assessments was a defining feature of the ESPON Climate project. In a first step the sectoral impacts were aggregated and then combined with the capacity to adapt to climate change, which yielded the potential vulnerability (see maps in Figure 5).

ESPON Climate's cross-sectoral **aggregate potential impact** results exhibit the following general patterns: coastal regions are projected to be negatively affected, because their high concentrations of physical, economic, social and cultural assets would face increasing flood hazards. Southern European regions are expected to be negatively impacted because their hotter and drier climates severely worsen conditions for their populations, economies and natural environments. Highly negative impacts are therefore projected for southern Europe's agglomerations and tourist resorts along the coasts. But inland mountain regions that are dependent on agriculture, forestry and winter and/or summer tourism would also be highly affected. In contrast, many central, eastern and northern European regions would face virtually no negative impacts or would even experience positive impacts of climate change – mainly due to marginal climatic changes or projected decreases in river and flash floods.

The **adaptive capacity** was defined by indicators on knowledge and awareness, economic resources as well as technological, infrastructural and institutional capacity to adapt to climate change. For example, national and regional governments may or may not have developed climate change adaptation strategies that serve as the basis for sectoral and cross-sectoral development policies (cf. Greiving and Fleischhauer, 2012). Interestingly, mapping the overall adaptive capacity yields an almost inverted pattern compared to the impact map: Most regions for which climate change impacts are expected to be the most severe (mainly in the South) are in fact the least aware and capable to adapt to these impacts.

Finally, combining impacts and adaptive capacity leads to the **potential vulnerability** to climate change in Europe. The vulnerability map seems to mirror the territorial pattern of potential impacts, but with an even more pronounced South-North gradient. This is due to the high adaptive capacity in Scandinavian and Western European regions, which partly compensates for the potential impacts projected for these regions. On the other hand, in the Mediterranean region and in South-East Europe, where medium to high negative impacts are expected, the ability to adapt to climate change is generally lower thus resulting in even higher levels of vulnerability. The overall most vulnerable types of regions are: (1) Coastal regions with high population and high dependency on summer tourism, (2) mountain regions with high dependence on winter and summer tourism, and (3) agglomerations with high population density, where *inter alia* the problem of urban heat is more severe.

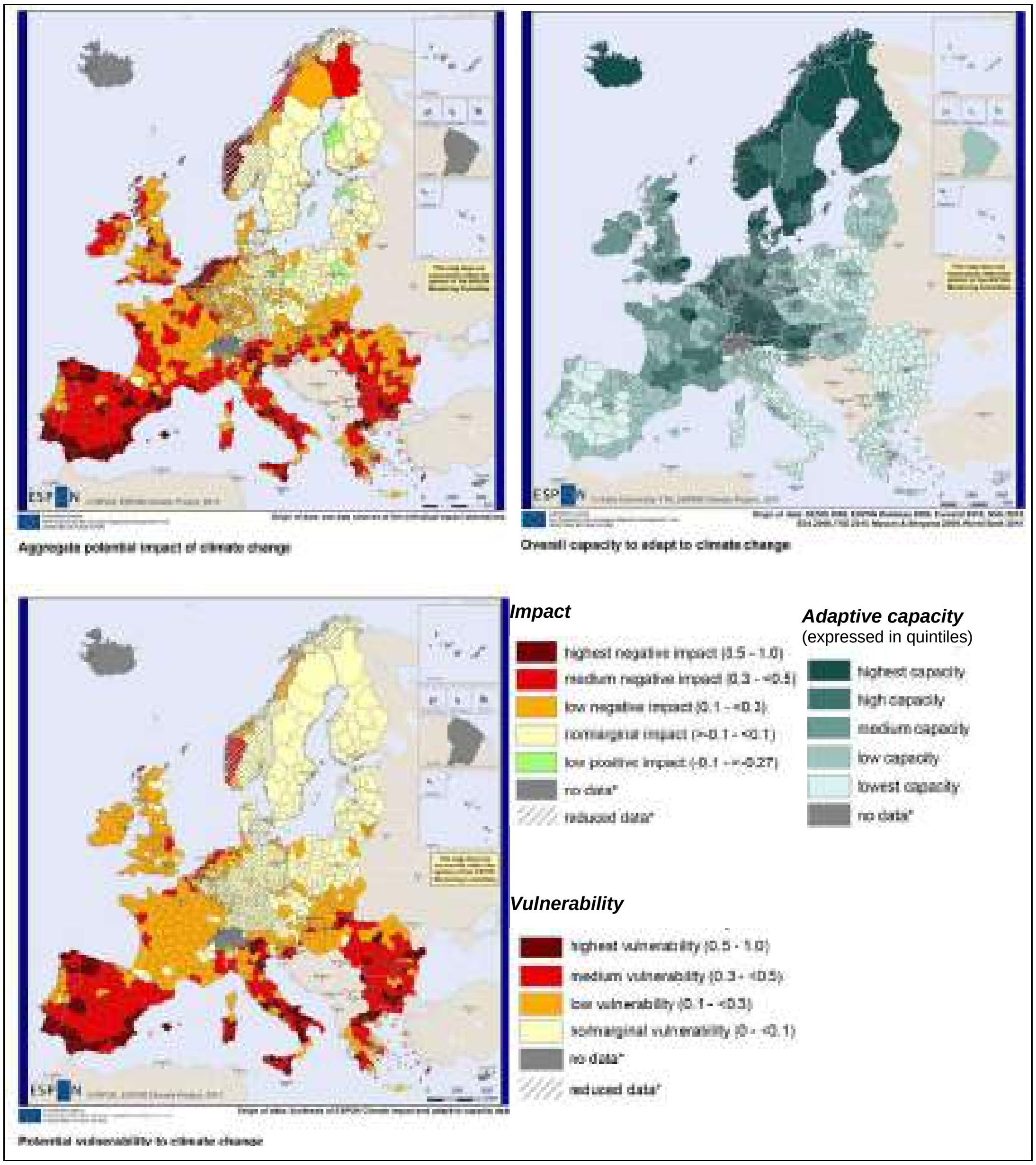

Figure 5: Potential aggregate impact, adaptive capacity and vulnerability (Greiving et al. 2011)

4. Conclusions

The ESPON Climate project constitutes the most comprehensive pan-European climate change vulnerability assessment to date. The project provides not only regionally specific results but also aggregated, cross-sectoral findings that lend themselves to high-level European policy-making. In contrast, most existing vulnerability studies have a sectoral focus and lack a clear territorial focus. However, several new EU-funded research projects are currently being conducted that also employ an integrated methodology for assessing climate change impacts, adaptation and vulnerability. But these projects (e.g. ClimSAVE, RESPONSES and MEDIATION) will only conclude and deliver their final results by the end of 2012 and 2013 respectively.

4.1 Climate change and EU development policies

ESPON Climate created a comprehensive pan-European evidence base needed for a climate change responsive European territorial development policy. For example, ESPON Climate demonstrated that Europe's climate change vulnerability exacerbates territorial differences and poses additional challenges to ensuring cohesion. The assessment indicated that climate change will probably deepen the existing socio-economic disparities between the core of Europe and its southern and southeastern parts because many economically lagging regions there are also the most vulnerable to climate change. Most likely these imbalances will even increase in the future: the current economic and financial crises in Greece, Italy, Spain and Portugal are reducing both individual and collective adaptive capacities. And in eastern Europe severe demographic changes like massive outmigration and ageing are projected to continue, which would further increase regional climate change sensitivity and decrease adaptive capacity levels (e.g. an older regional population is more sensitive to heat and less able to adapt to climate change).

ESPON Climate's methodologies and results could possibly become part of an evolving policy support tool that would enable policy-makers at European, national and regional level to (a) identify regional 'hot spots' with projected high impacts and weak capacity and devise appropriate support and response mechanisms, (b) develop a more strategic and climate change responsive approach to territorial cohesion, (c) identify especially vulnerable (sub)sectors and then mainstream climate change adaptation in the respective sectoral policies, (d) develop territorially differentiated adaptation strategies that take into account the regional variations in regard to climate change exposure, sensitivity, impact and adaptive capacity and (e) coordinate and integrate sectoral policies with a view to preventing potential negative climate change impacts and capitalising on positive development opportunities.

4.2 Critical reflection and outlook

It has to be kept in mind, however, that the ESPON Climate project is based on only one climate forcing scenario (A1B), one global circulation model (ECHAM5/MPI-OM) and one regional circulation model (CCLM) due to time and financial constraints and the fact that Europe as a whole needed to be covered. Furthermore, long-term socio-economic development trends that influence future regional sensitivities to climate change could hardly be integrated in the assessment (only some demographic scenarios could be tested based on data from the ESPON project DEMIFER). Thus the project's results have to be seen as a vulnerability scenario, which shows what Europe's future in the wake of climate change *may* look like (based on current knowledge, data and particularly assumptions), and not as a clear-cut forecast.

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 operationalise 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. Lastly, most of the indicators finally used in the project are made up of several input variables. The construction of such composite indicators is challenging as it involves different choices on selection of data, normalisation procedures, weighting schemes and aggregation methods (cf. Saltelli, Nardo et al. 2004).

Despite these inevitable challenges the prospects for major advances in the field of integrated vulnerability assessments in Europe are encouraging. The European projects mentioned above (ClimSAVE, RESPONSES and MEDIATION) will soon conclude their research and it will be interesting to analyse how their results will compare to the results of the ESPON Climate project: whether they will reinforce, complement or contradict each other. But also comparing and learning from the comprehensive methodologies that these projects are currently developing will cross-fertilize the scientific research in this field. Furthermore, ENSEMBLE datasets that combine climate projections based on several climate models are now available and can be used to drive assessment models like the one presented in this paper. This makes impact and vulnerability assessments less dependent on one climate model and thus makes their results more robust. As regards data availability the new online platform CLIMATE-ADAPT provided by DG Climate Action (http://climate-adapt.eea.europa.eu) facilitates sharing of research results and data on climate adaptation and enables further integration and dissemination of climate change focused research.

6. References

Commission of the European Union, 2010. Europe 2020: A strategy for smart, sustainable and inclusive growth' - COM(2010) 2020, 3.3.2010.

Greiving, S., Flex,F., Lindner, C., Lückenkötter, J., Schmidt-Thomé, P., Klein, J., Tarvainen, T., Jarva, J., Backman, B., Luoma, S., Langeland, O., Langset, B., Medby, P., Davoudi, S., Tranos, E., Holsten, A. Kropp, J., Walter, C., Lissner, T., Roithmeier, O., Klaus, M., Juhola, S., Niemi, P., Peltonen, L., Vehmas, J., Sauri, D., Serra, A., Olcina, J., March, H., Martín-Vide, J., Vera, F., Padilla, E., Serra-Llobet, A., Csete, M., Pálvölgyi, T., Göncz, A., Király, D., Schneller, K., Staub, F., Peleanu, I., Petrisor, A., Dzurdzenik, J., Tesliar, J., Visy, E., Bouwman, A., Knoop, J., Ligtvoet, W., Minnen van, J., Kruse, S., Pütz, M., Stiffler, M., Baumgartner, D., 2011. ESPON Climate: Climate Change and Territorial Effects on Regions and Local Economies. Scientific Report. Luxembourg.

Greiving, S. and Fleischhauer, M., 2012. National climate change adaptation strategies of European states from a spatial planning and development perspective. In: European Planning Studies Vol. 20 No. 1, pp. 27-47

Füssel, H.-M. &. Klein, R. J. T, 2006. Climate Change Vulnerability Assessments: An Evolution of Conceptual Thinking, Climatic Change 75 (3), pp. 301-329

European Commission (EC), 2009. White Paper - Adapting to climate change: Towards a European framework for action.

European Union (EU), 2007. Territorial Agenda of the European Union – Towards a more Competitive and Sustainable Europe of Diverse Regions. Leipzig.

Füssel, H-M.; Klein, R.J.T, 2002. Assessing Vulnerability and Adaptation to Climate Change: An Evolution of Conceptual Thinking, pp. 45-59 in: A Climate Risk Management Approach to Disaster Reduction and Adaptation to Climate Change. Proceedings of the UNDP Expert Group Meeting on "Integrating Disaster Reduction and Adaptation to Climate Change", Havana, Cuba, 17-19 June 2002.

Intergovernmental Panel on Climate Change (IPCC), 2007. Climate Change 2007 - Impacts, Adaptation and Vulnerability. Contribution of working group II to the Forth Assessment report of the Intergovernmental Panel on Climate Change.

Nakicenovic, N., Alcamo, J., Davis, G., de Vries, B., Fenhann, J., Gaffin, S., Gregory, K., Grübler, A., Jung, T.Y., Kram, T., La Rovere, E.L., Michaelis, L., Mori, S., Morita, T., Pepper, W., Pitcher, H., Price, L., Riahi, K., Roehrl, A., Rogner, H.-H., Sankovski, A., Schlesinger, M., Shukla, P., Smith, S., Swart, R., van Rooijen, S., Victor, N., Dadi Z., 2000. IPCC Special Report on Emissions Scenarios. Cambridge University Press, Cambridge (UK) and New York.

Saltelli, A., M. Nardo, et al., 2004. Composite indicators - the controversy and the way forward. OECD World Forum on Key Indicators. Palermo.