Collaborative Project

CLIM-RUN

Climate Local Information in the Mediterranean region Responding to User Needs

WP 4 – Climate Services Pilot Case Studies
Task 4.4 - Economic assessment

Deliverable 4.5

Impact cost assessment and cost/benefit evaluation
A methodological guide

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1. Introduction

The purpose of this report is to review existing methodologies for assessing the socioeconomic impacts of climate change and the potential benefits of adaptation. The report complements the other activities of CLIM-RUN Work Package 4 by providing an overview of the methodologies used to estimate the socioeconomic consequences of climate change (usually in terms of monetary valuation), paying particular attention to the Mediterranean region. It also adds value by including three case studies (tourism, forest fires and energy demand) that make use of data gathered as part of the CLIM-RUN project. The report is primarily concerned with the impacts of long-term climate change rather than seasonal to decadal forecasts, although Section 3 (on climate information and climate services) is relevant at the decadal and subdecadal level.

The first part of the report (Sections 2-5) reviews the existing literature on various aspects of the socioeconomic assessment of climate change. Section 2 discusses the methodologies typically employed in socioeconomic assessments of climate change including the main types of modelling methodology; the logic of scenario choices; and the appreciation of vulnerability, uncertainty and risk. Section 3 explores the different techniques that have been employed to estimate the value of meteorological information, and may therefore be deployable for valuation of climate services. Section 4 looks more closely at assessments of adaptation to climate change, while Section 5 examines how climate impacts have been examined in a number of specific sectors.

The second part of the report (Sections 6-8) contains three case studies of the Mediterranean region. The first case study examines the implications of climate change on tourism in selected regions of Croatia, Cyprus, France & Tunisia. The second case study examines how climate change might be expected to affect the Fire Weather Index (FWI, a commonly used method for predicting forest fire severity) in Greece and Spain. The third case study assesses the impact of changing temperatures on demand for energy use in heating and cooling in the Mediterranean region.

2. Methodologies for Economic Assessment of Climate Impacts

This section of the report discusses the methodologies typically employed in socioeconomic assessments of climate change impacts and adaptation. It begins with a comparison of the two main methods for conducting multi-sectoral analysis (top-down vs. bottom-up). It then examines bottom-up analysis in greater detail since this approach has greater sectoral and geographical detail and is therefore more relevant to the needs of the CLIM-RUN project. The section then examines approaches to valuing the importance of climate information & climate services, and discusses issues related to uncertainty, risk and vulnerability.

2.1. Top-down vs. Bottom-up Assessment

Multi-sectoral assessments attempt to quantify the impact of climate change on the economy as a whole by estimating simplified relationships between the climate and the whole economic system (top-down) or estimating the economic impacts of a number of specific climate damages, paying particular attention to how these impacts interact with each other (bottom-up). By contrast, sector-specific assessments usually model interactions between climate signals and the sector in question in detail, without considering interactions among different sectors and markets.

Assessments can also be classified as either top-down or bottom-up. For this analysis, we consider the distinction between them to be as follows:

Top-down approach: the impacts of climate change are calculated by using an empirical or statistical relationship between climate and aggregate economic variables (IPCC, 2001).

Bottom-up approach: sector-specific analysis is used to project (physical) impacts in individual sectors. Multi-sectoral analysis is produced by combining these sectoral effects with some method for estimating the interactions between sectors in the face of climate change (typically a Computable General Equilibrium framework). This allows calculation of the effect on market prices and other sectoral economic variables.

The following subsections present examples of these two approaches. Subsection 2.1.1 deals with the top-down approach, focusing in particular on the three Integrated Assessment Models (IAMs), PAGE, FUND and DICE. Subsection 2.1.2 reviews some of the large-scale bottom-up studies, particularly those employing CGE models as a linking mechanism between sectors.

2.1.1. Integrated Assessment Models (IAMs)

Overview

The defining characteristic of an Integrated Assessment Model (IAM) is that it combines results and models from different sources (e.g. biological, physical and social sciences) into a single, consistent analytical framework (IPCC, 2007; Watkiss et al., 2010).

IAMs have been used in high profile studies of the economics of climate change such as the Stern Review (Stern, 2007) and the IPCC 4th assessment report (Yohe et al., 2007). As Watkiss et al. (2010) notes, they have also been used to derive headline figures. These include: the Stern Review's prediction that climate change will reduce welfare by an amount equivalent to a 5-20% loss in per capita consumption; and Parry et al.'s (2009) estimate that adaptation measures would have mean benefit/cost ratio of 60 in an A2 greenhouse gas emissions scenario (business-as-usual) and 20 in an aggressive emissions abatement scenario.

The best known (and most widely used) IAMs include PAGE (Hope et al., 1993; Hope, 2006), FUND (Tol, 2002), the DICE/RICE family of models (Nordhaus, 2000) and WITCH (Bosetti et al., 2006).

Key Features & Criticisms

The key features, benefits and drawbacks of IAMs (specifically PAGE, FUND and DICE) are reviewed in Watkiss et al. (2010). This study notes that IAMs are characterised by the simplified relationships employed in order to ensure the combined analysis of the climate and physical and economic environments is tractable. These relationships can include reduced form equations linking damages to temperature (see Ackerman & Munitz (2012) for a comparison between DICE and FUND), and mitigation & adaptation modules based on cost curves.

The benefits of IAMs include their ability to produce 'agenda-setting' headline figures. For example, all three models have been employed by the US government to investigate the social cost of carbon (Interagency Working Group on Social Cost of Carbon, 2010), while RICE has been employed to estimate the carbon price required to achieve a global warming target of below 2°C in the context of the 2010 Copenhagen Accord (Nordhaus, 2010).

Other advantages noted in Watkiss et al. (2010) include those stemming from the models' broad scope (capturing all of the relevant time, space and subject matter). This allows them to characterise the two-way relationship between climate and economy, to estimate the economic effect of specific climate policies, and to calculate the optimal policy mix required to meet specified temperature or emissions targets.

Criticisms of IAMs (also summarised in Watkiss et al. (2010)) include the fact that they may be complicated, lack transparency in their documentation and focus on expected central outcomes rather than take account of extreme events — though similar criticisms can be made of other modelling approaches on a case-by-case basis.

Further criticism by Ackerman et al. (2009) relates to the models' reliance on "empirically and philosophically controversial" assumptions underpinning long-term discount rates as well as issues related to quantifying the uncertain prospect of long-run damages and technological progress.

A related criticism is the observation that estimates of the social cost of carbon (SCC) derived from IAMs vary widely according to parameter choices and between models. Watkiss & Downing (2008) found that much of the variation in SCC estimates can be explained by the following parameter choices: discount rate; study-time horizon; equity weighting (between regions); reporting of central tendency (choice of median or mean); and sensitivity of climate to changes in CO_2 concentration. As an illustration of this, Yohe et al. (2007) noted that plausible SCC estimates ranged from 1 - 1000 USD/tC.

Adaptation to Climate Change in IAMs

The strengths and weaknesses of using IAMs for adaptation analysis are similar to those noted above for IAMs in general. Most notable among these is the use of simplified relationships and functional forms (as opposed to bottom-up sectoral detail) to capture the costs and benefits of adaptation. This is discussed in Patt et al. (2010).

Similarly, IAMs may calculate the optimal level of adaptation in order to minimise net damages from climate change, or calculate the benefit of employing specific adaptation strategies that are specified exogenously. An example of the first type is de Bruin et al. (2009a) which involves development of a modified RICE model (AD-RICE) which opens the possibility for quantitative analysis of the trade-offs and synergies between mitigation and adaptation. As an example of the second type, Hope & Newbery (2007) conduct a PAGE experiment in which a policy of increasing the EU's 'temperature tolerance' by 1°C is found to cost 3-25 USD billion per year.

On the question of interactions between mitigation and adaptation in IAMs, one may view mitigation and adaptation as "strategic complements" (Bosello) in the sense that an optimal strategy employs both types of measure. At the same time they should be considered substitutes (Agrawala et al., 2010) since they compete for limited resources and, in a IAM framework, increased deployment of one reduces the requirement for the other. As with other IAM results, quantitative estimates of this substitutability (or complementarity) are sensitive to the models' parameter choices. For example, Bosello et al. (2011) note that adaptation is particularly cost effective in reducing short-term damages, while mitigation is more important for reducing long-term damages. Therefore, the optimal mix of mitigation and adaptation policies depends crucially on decisions regarding the time horizon and discount rate – as noted above.

2.1.2. Bottom-up Assessments of Climate Impacts

This section provides an overview of studies that use a bottom-up multi-sectoral methodology to estimate the economic impacts from climate change. Bottom-up assessments covering multiple sectors have also been used to calculate the cost of adapting to climate change. These studies are discussed later, in Section 4.2.1.

The assessments discussed in this section use CGE models as the means for combining separate sectoral analyses. In this sense the CGE model converts a variety of sectoral impacts and metrics into a common monetised framework. This is useful because it places a monetary value on different climate impacts. Whether or not monetisation is desirable as a goal is debatable. However,, it at least has the advantage of providing a way of comparing impacts that are conceptually different (such as metres of sea level rise and percentage changes in productivity).

It should be noted that monetisation through CGE is not the only way to perform bottom-up multi-sectoral analysis. Alternative methods include the hotspot analysis undertaken by Piontek et al (2013) as part of the ISI-MIP project. This involved examining four sectors

(agriculture, water, eco-systems and health) and defining a "hotspot" as a geographical zone where at least two sectors experience severe change compared to the historical norm. The authors find that for a 3°C temperature rise, roughly 2% of global land area and 2% of population are covered by a two-sector hotspot. Under a 4°C rise, this increases to 6% and 11% respectively, with a small fraction experiencing a three-sector hotspot[1]. These results are underpinned by a "strict" rule stating that for each region, at least 50% of models employed must agree that change is severe. On this basis, Southern Europe is identified as the second-largest global hotspot due to the overlapping of severe reductions in river discharge with severe changes in ecosystem state. When the strict assumption is relaxed to the "worst" case (only 10% of model have to agree that change is severe), the fraction of land and population affected increases by an order of magnitude (from roughly 5% to roughly 50%).

General Equilibrium (CGE) studies

ClimateCost[2] and PESETA are European research projects that involve taking a bottom-up multi-sectoral approach to estimating the economic impacts of climate change (costs of inaction). In both projects, the multi-sectoral analysis used an integrated approach that combines several different types of expertise, culminating in the use of a CGE model to estimate economic impacts (see Figure 1 for example).

[1] Temperature change is relative to 1980-2010 period.
[2] www.climatecost.cc

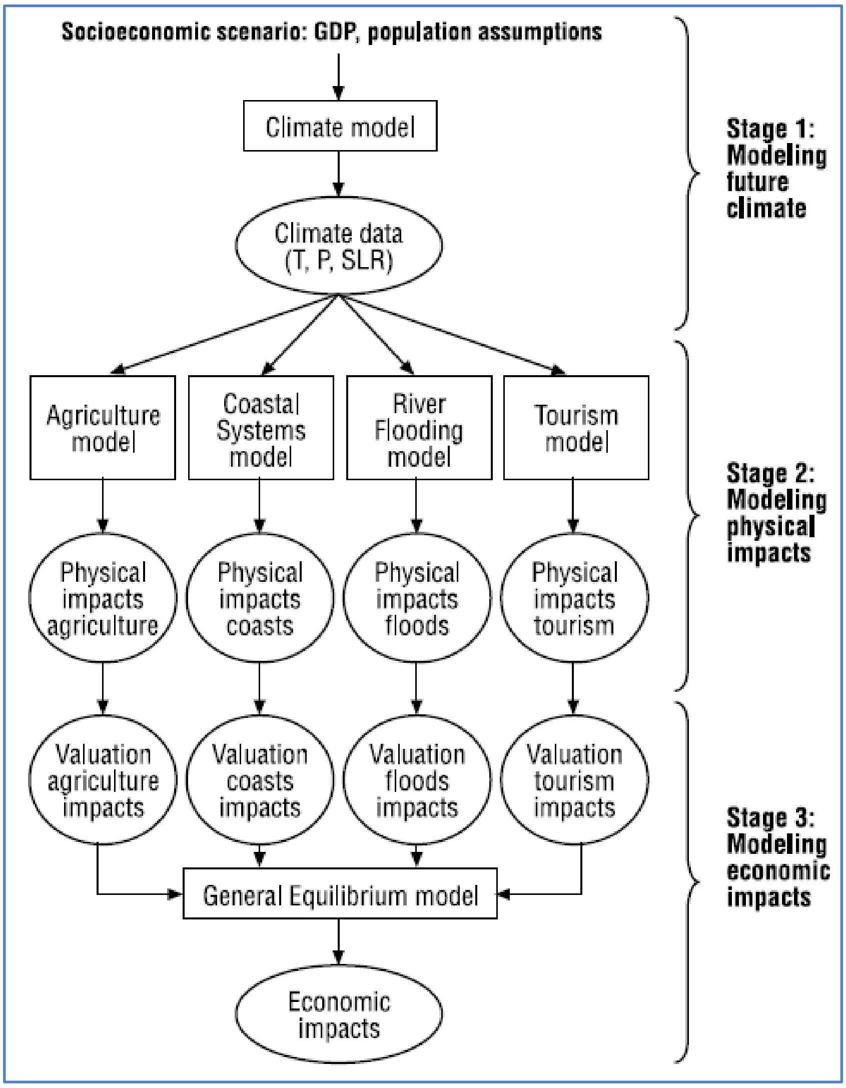

Figure 1: Integrated Multi-sectoral Approach (PESETA project)
Source: Ciscar (2009)

One advantage of using a CGE model for the "stage 3" economic analysis is that it considers the interactions between the sectors directly affected by climate change and the rest of the economy (e.g. the link between agricultural climate change, food prices and general consumer spending). This can be expected to reduce the economic impacts since it allows consumers to minimise their welfare loss by substituting between different products. This process is referred to as 'autonomous adaptation' by Bosello et al. (2009) and Aaheim et al. (2012) and is debated in greater detail in Perry and Ciscar (2014).

In ClimateCost (Ciscar et al.), the sectoral impacts covered are agriculture, coastal damage (sea level rise), energy, human health (labour productivity) and river floods. These are examined under three common climate scenarios (A1B, 2°C or High Emissions).

For agriculture, the climate impact is simulated as a change in sectoral total factor productivity (TFP). The TFP change itself is derived from crop models. For river floods, damages to residential buildings are imposed as additional expenditure by households (from which they do not derive welfare), while other damages are imposed as reductions in TFP and as destruction of capital stock. Coastal damage is also implemented as a combination of obliged consumption and capital destruction. Energy is implemented as a series of exogenous changes in demand for heating and cooling (induced by climate change) while there is assumed to be a negative relationship between heat & humidity exposure and labour productivity.

Relative to a baseline without climate change, the combined economic effect of these phenomena created a GDP loss of 0.83% in the 2080s in an A1B (high emissions) scenario. The extent of these losses varies over time, region and emissions scenario, as Table 1 and Table 2 show. Southern Europe was found to be region worst affected (2.3%) with labour productivity contributing most to this effect (over 1%) followed by agriculture and energy. The GDP loss is reduced to 0.3% if temperature rise is limited to 2°C (the E1 scenario). The percentage change in welfare due to climate change is estimated as a loss of 1.5% in A1B and 0.7% in E1. This is greater than the GDP change since compulsory consumption (spending due to damages) contributes positively to GDP but detracts from consumers' welfare.

Table 1: GDP Change for All Impacts, A1B (% change compared to Reference)

	2020s	2050s	2080s
Northern Europe	0.09%	0.04%	0.03%
UK and Ireland	-0.05%	-0.06%	-0.08%
Central Northern Europe	-0.11%	-0.34%	-0.66%
Central Southern Europe	-0.04%	-0.20%	-0.37%
Southern Europe	-0.36%	-1.21%	-2.28%
Europe	-0.13%	-0.44%	-0.83%

Source: Ciscar et al.

Table 2: GDP Change for All Impacts, E1 (% change compared to Reference)

	2020s	2050s	2080s
Northern Europe	0.21	-0.09	-0.13
UK and Ireland	0.04	-0.18	-0.28
Central Northern Europe	-0.03	-0.30	-0.38
Central Southern Europe	-0.03	-0.07	-0.06
Southern Europe	-0.25	-0.52	-0.47
Europe	-0.06	-0.27	-0.30

Source: Ciscar et al.

Similar analysis was conducted for the PESETA project (Ciscar et al, 2011) involving analysis of agriculture, coastal impacts, river floods and tourism. The analysis considered the economic impact of physical climate change for the period 2071-2100 under scenarios where the average temperature increase in Europe ranges from 2.5°C to 5.4°C. Sea level rise of 49-59 cm was assumed in most cases, with an additional scenario of 5.4°C and 88 cm considered. The resulting impacts, in terms of welfare, are summarised in Figure 2. This shows that the greatest impact at EU level is agriculture, except in the case of high sea level rise where coastal damage becomes the greater impact. The agricultural impact is the main driver behind the welfare losses in Southern Europe, which are greater than in other regions. However, the effect of high sea level rise for the British Isles is particularly notable, doubling the impact compared to the other 5.4°C scenario.

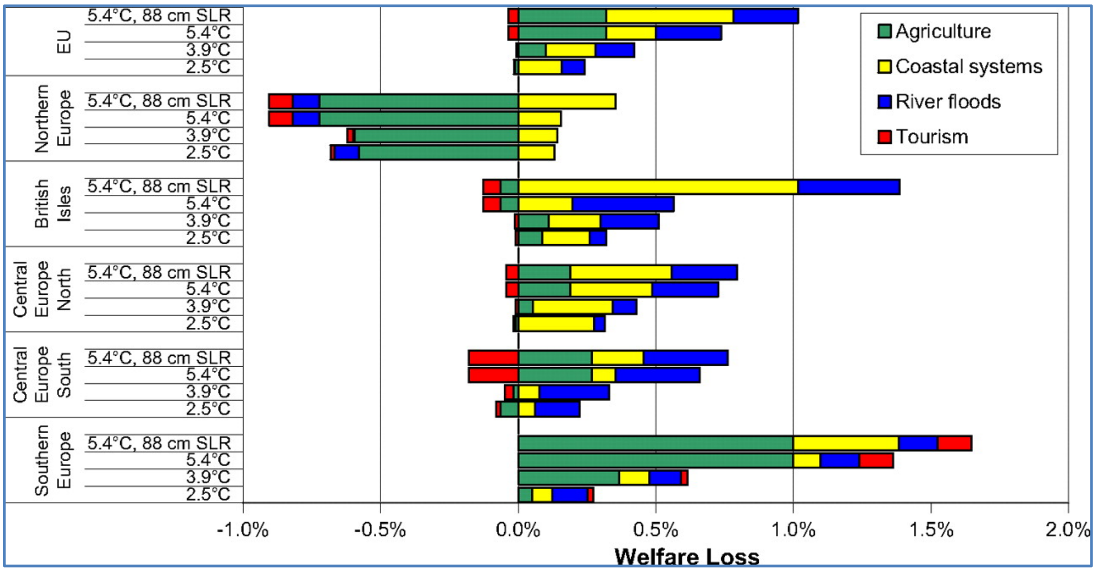

Figure 2: Sectoral Decomposition of Regional Welfare Expressed as Percent Change
Source: Ciscar et al., 2011

Bosello et al. (2012) also conduct multi-sector analysis by feeding sectoral shocks into a CGE model (the ICES model). Key differences between this and the ClimateCost/PESETA analysis are that i) the ICES model is dynamic whereas the GEM-E3 analysis is conducted in a comparative static framework[3]; and ii) the ICES analysis examines the period up to 2050, where ClimateCost/PESETA consider climate change up to the 2080s. Bosello et al. (2012) consider seven sectors and find that for the 2050 period, a total GDP loss of 0.5% is expected compared to a no-climate-change scenario, given a temperature rise of 1.92°C above pre-industrial levels, with the most important losses due to agriculture (around 0.3%) and tourism & sea level rise (around 0.1% each).

Broadly speaking, there appears to be consensus over the magnitude of the economic impacts between the ClimateCost, PESETA and ICES estimates, with ClimateCost and ICES estimating impacts of 0.3-0.5% of GDP by 2050, and PESETA, with its later time horizon, estimating larger impacts. However, it should be noted that the studies are similar, not only in results but also in methodology (for example, both use the DIVA model for estimating sea level rise).

In addition, it is important to note that the economic results of bottom-up, multi-sectoral studies should be considered lower bound estimates of the true economic impact since, by definition, they do not record damages from any sectors not included in the bottom-up analysis.

[3] Comparative static, in this case, means that the expected climate shocks of 2071-2100 are imposed on the present-day European economy.

2.2. Steps in Bottom-up Assessment

This subsection describes in greater detail the steps typically involved in undertaking a bottom-up assessment of the economic impacts of climate change. While the top-down and bottom-up approach both have strengths and weaknesses, we focus on the disaggregated bottom-up approach since this appears to be more in line with the CLIM-RUN Project objectives and structure, which is based around sector-specific local case studies.

2.2.1. Socio-economic and Emissions Scenarios

In order to estimate the cost and/or benefits of a changing climate, it is essential to define the set of conditions within which the change will occur (the scenario). These conditions include the extent of changes in the climate as well as the socioeconomic, political, and institutional environment. It is also important to consider the interactions between these factors. For example the risks and vulnerabilities of regions, sectors and populations to climate change are heavily influenced by demographic, social, economic, political, and technological conditions (Malone & La Rovere, 2005). Therefore, these socio-economic conditions also influence the set of policy options available for responding to climate change.

IPCC Scenario Definitions

A scenario is defined by the Intergovernmental Panel on Climate Change (IPCC) as a coherent, internally consistent, and plausible description of a possible future state of the world (Carter et al., 2007). By this definition, a scenario can be quantitative and/or qualitative and does not have to be a probabilistic forecast of a likely future. However, a scenario should be plausible and internally consistent in the way that its component drivers (biophysical and socioeconomic trends) evolve. The overarching logic for this plausible case is typically provided by a storyline.

Scenarios can be exploratory (descriptive) or normative (prescriptive). The former type refers to the production of a hypothetical future through the continuation of known processes. The latter type refers to the generation of a specified future as well as the steps required to achieve it.

Most existing climate projections use the SRES[4] storylines and associated emissions scenarios published by the IPCC in 2000. In the Fifth Assessment Report, these scenarios have been replaced by the Pathways system. This new classification includes two types of scenarios which are developed in parallel; Representative Concentration Pathways (RCPs) specify the concentration of greenhouse gases (GHGs) in the atmosphere, while Shared Socio-economic Pathways (SSPs) describe the socio-economic conditions.

SRES scenarios represent the outcome of different assumptions about the future course of economic development, demography and technological change (Nakicenovic & Swart, 2000). The scenarios are split into six "families", where each family represents similar technological and socioeconomic assumptions. Furthermore, the scenarios do not take into account specific agreements or policy measures aimed at limiting the emission of GHG emissions (e.g. the Kyoto Protocol).

The RCP (atmospheric) scenarios of the new IPCC system prescribe trajectories for the concentrations (rather than the emissions) of GHGs, and are therefore conceptually different from the SRES emissions scenarios (van Vuuren et al., 2011). The RCPs are intended to serve as input for climate modelling and atmospheric chemistry modelling. They are named from RCP 2.6 to RCP 8.5 according to their radiative forcing level in the year 2100. In this way they cover the full range of plausible stabilisation, mitigation and baseline emissions scenarios available in the scientific literature.

The new SSP (socioeconomic) scenarios are developed according to a process which is designed to take advantage of the latest scientific advances on the response of the Earth system to changes in radiative forcing as well as knowledge on how societies respond through changes in technology, economies, lifestyle and policy (Moss et al., 2010). The five main families of SSP developed to date are described in O'Neill et al. (2012).

SSP1 (Sustainability) is characterised by rapid technological change and high level of international cooperation, which translates into relatively rapid income growth combined with substantially reduced reliance on natural resources. High levels of education induce lower fertility rates. Global emission levels are relatively low. In SSP2 (Middle of the road), current trends in all socio-economic variables are confirmed, with moderate income convergence: global emissions are projected to follow a business as usual trend which implies challenges for both mitigation and adaptation. SSP3 (Fragmentation) illustrates a future with limited international cooperation, slow technological progress, low education levels and high population growth. This will imply slow economic growth and high global emission levels with

[4] Special Report on Emissions Scenarios

severe challenges to both mitigation and adaptation. In SSP4 (Inequality) the divide between high-income and low-income countries is expected to grow. High technological progress and economic growth will be achieved only by high-income countries. This will translate into an increased ability to mitigate, lower global growth and lower global emission levels in the long run, but high challenges for adaptation, especially in developing countries. The storyline of SSP5 (Conventional development), depicts a world where countries focus on economic development without any environmental concern (emphasis on new technologies for high-income countries; fossil energy sources in developing countries), which will mean high global emissions and high challenges to mitigation, while the challenges to adaptation are considered less important as education levels increase worldwide and fertility rates in developing countries are relatively low.

2.2.2. Choice of the climatic models / downscaling

Projections of future climate change are derived from simulations with general circulation models (GCMs) and regional climate models (RCMs) using different emission scenarios for GHGs and aerosols. Often the spatial resolution provided by these models is too coarse for use in impact analysis. In this case, statistical downscaling (SD) can be employed to provide site-specific climate information by establishing a statistical relationship between large scale climatic data and local physiographical conditions (Wilby et al., 2004).

GCMs represent the physical and chemical processes of the climate system depicted on a three-dimensional grid at global level. RCMs provide the same type of output but cover a smaller area at higher spatial resolution (typically 5-50 km). This allows for better representation of topographical features and regional phenomena. The process of obtaining high resolution RCM data from lower resolution GCM data is known as *dynamical downscaling* (EEA, 2012).

Statistical downscaling can be employed when the resolution of the GCM or RCM is too coarse for the requirements of the analysis in question. It can be used to pinpoint individual site locations for measurements such as precipitation and wind speed. This is discussed further in Chapter 9 of the IPCC fifth assessment report (IPCC, 2013). The relative strengths and weaknesses of GCM outputs, RCM outputs and SD techniques are reviewed by Goodess et al. (2003) in the context of producing scenarios for IAMs, and by Christensen et al. (2007) in the context of producing regional projections.

2.3.Dealing with Vulnerability, Uncertainty and Risk

The concepts of vulnerability, uncertainty and risk relate to the extent and likelihood of losses that different actors will face as a result of climate change. This section provides an overview of these concepts.

As the section demonstrates, the literature in this area is abundant but heterogeneous. In particular, there are competing definitions of risk, uncertainty, vulnerability and their related concepts, which does not facilitate comparability between studies. The IPCC SREX report (IPCC, 2012) brings together this diverse literature and produces its own definitions which capture the broad scope of these concepts. Even so, the report's "scene setting" chapter (Chapter 1) is able to provide only 'skeleton' definitions that are elaborated in subsequent chapters.

2.3.1.Sources of uncertainty and uncertainty cascade

Uncertainty related to climate change assessments can take many different forms: scientific uncertainty over climate sensitivity or the distribution of climate changes over space and time; uncertainty over socioeconomic variables (i.e. population, economic growth, or technological development); uncertainty regarding potential climate catastrophes and threshold responses; uncertainty regarding the costs and effectiveness of adaptation strategies; and uncertainty due to differences in model structure. Katz et al. (2013) and EEA (2012) make a distinction between the sources of uncertainty (in climate observations and projections) and its subsequent communication and use by decision makers.

Katz et al. (2013) make several recommendations for improving the treatment of uncertainty in climate change analysis, which they claim exceed the recommendations of the SREX and Fifth Assessment reports. These are: the replacement of qualitative assessment with quantitative ones; reducing the uncertainty in observation, monitoring and projections through use of specific statistical and computational techniques; improving the usefulness of weather assessments to decision makers by using the theory of extreme values[5]; and increasing the participation of uncertainty experts in future IPCC communications.

[5] A statistical technique for dealing with extreme deviations from the median of a probability distribution

Regarding the sources of uncertainty in climate change observations and projections, EEA (2012) identified the following major types:

1. Measurement errors resulting from imperfect observational instruments (e.g. rain gauges) and/or data processing (e.g. algorithms for estimating surface temperature based on satellite data).
2. Aggregation errors resulting from incomplete temporal and/or spatial data coverage.
3. Downscaling of climate or climate impact projections
4. Natural climate variability resulting from unpredictable natural processes either within the climate system (e.g. atmospheric and oceanic variability) or outside the climate system (e.g. future volcanic eruptions).
5. Uncertainties in the future emissions of GHGS
6. Uncertainties in climate models resulting from an incomplete understanding of the Earth system (e.g. dynamic ice sheet processes or methane release from permafrost areas and methane hydrates) and/or from the limited resolution of climate models (e.g. hampering the explicit resolution of cloud physics). These uncertainties are particularly relevant in the context of positive and negative feedback processes.
7. Complex interaction of climatic and non-climatic factors. This complex cause-effect web can impede the attribution of observed environmental or social changes to past changes in climate as well as the projection of future climate impacts.
8. Future changes in socio-economic, demographic and technological factors as well as in societal preferences and political priorities.

The relative importance of different sources of uncertainty depends on the target system, the climate and non-climate factors it is sensitive to, and the time horizon of the assessment. For example, uncertainty about future emissions of long-lived GHGs becomes the dominant source of uncertainty for changes in global mean temperature on time scales of 50 years or more but it is of limited importance for short-term climate change projections (Cox and Stephenson, 2007; Hawkins and Sutton, 2009; Yip et al., 2011).

Regarding the communication of uncertainty, EEA (2012) presents an uncertainty "cascade" developed by Ahmad et al. (2002) by which uncertainty increases as climate change analysis progresses from emissions to radiative forcing estimates and eventually to estimation and valuation of impacts (see Figure 3).

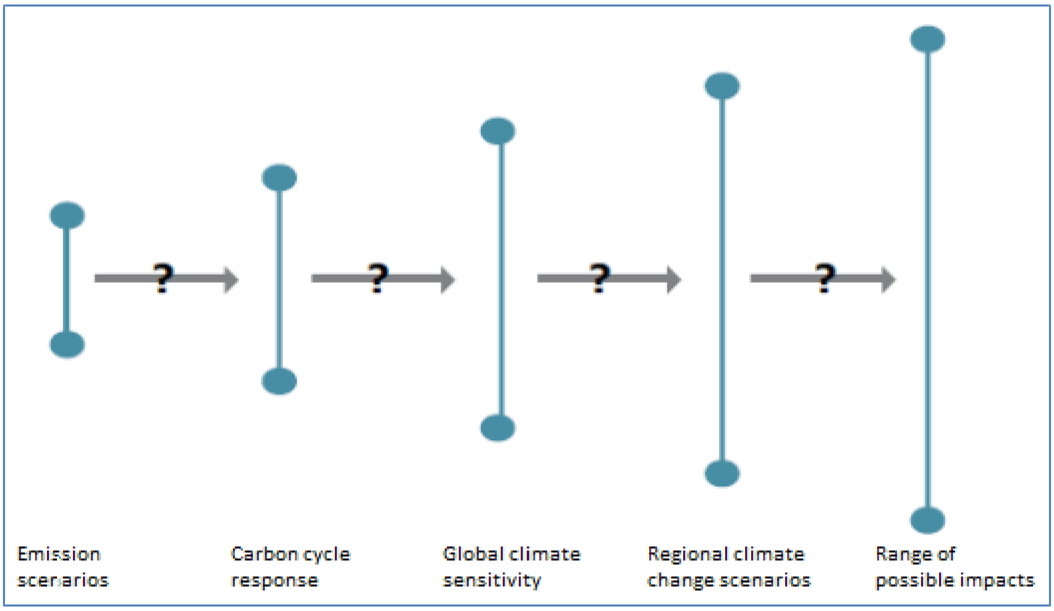

Figure 3: Cascade of uncertainty in climate impact assessment
Source: EEA (2012)
Note: The length of the bars represents the magnitude of the uncertainty

2.3.2. Vulnerability and risk

The concepts of vulnerability and risk are often employed when assessing the potential adverse consequences of climate change. However, the precise meaning of each term can vary substantially between studies and methodologies, to the point where the terms "vulnerability" and "risk" become almost interchangeable. This section attempts to isolate the main points in this semantic tangle, as well as highlighting some of the key literature.

Fuchs et al. (2012) describe a difference in conception of vulnerability between social scientists and natural scientists. In this framework, social scientists see vulnerability as "the *set of socio-economic factors* that determine people’s ability to cope with stress or changes", while natural scientists tend see it as the *likelihood of occurrence* of specific impacts and scenarios. Meanwhile, EEA (2012) makes a distinction between the "climate change community" (for whom risk is an input to vulnerability) and the "disaster risk community" (for whom the opposite is true).

The key point is that, despite differences in terminology, each alternative approach has its own system for taking account of the likelihood and magnitude of human suffering created by

climatic events. We illustrate this in Figure 4, which compares a Disaster Risk (risk-hazard) approach against a risk-vulnerability chain.

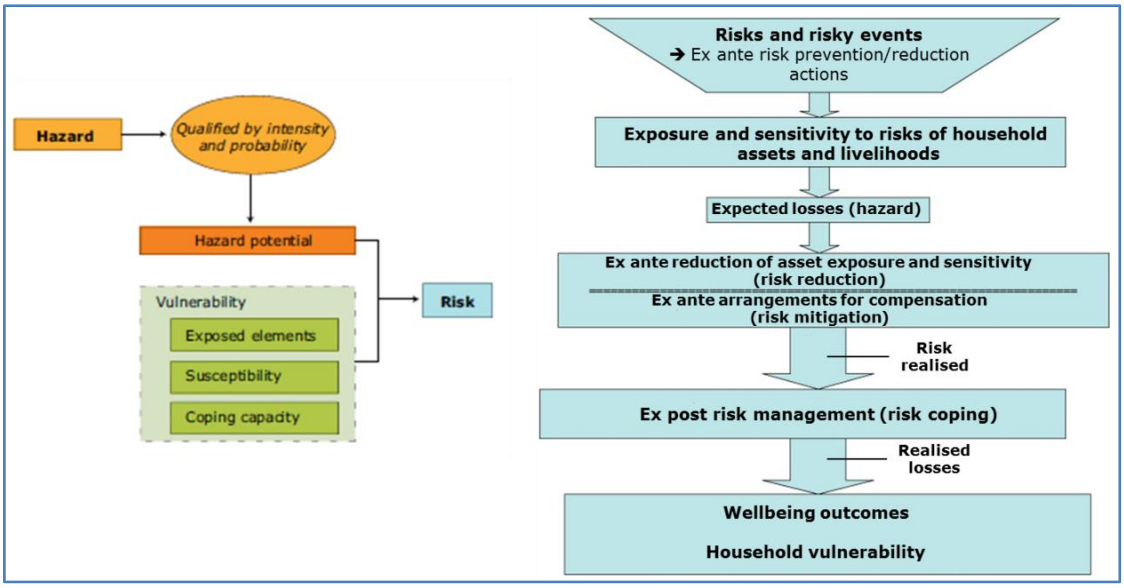

Figure 4: Comparison of risk-hazard framework (left) and risk-vulnerability chain (right)
Sources: EEA (2012) (left) and adapted from Heltberg et al. (2009) (right)

The Disaster Risk approach (from EEA (2012)) consists of hazard (a "potentially damaging physical event, phenomenon or human activity") and vulnerability (the "relationship between the severity of hazard and the degree of damage caused") determining outcome risk (expected losses). By contrast, the risk-vulnerability chain begins with risk ("the chance of danger, damage… or any other undesirable consequences") and ends with vulnerability ("the expectation of wellbeing falling below a benchmark level").

SREX (IPCC, 2012) attempts to bring together the different strands of the literature. It features a broad definition of vulnerability, but nevertheless follows the disaster risk approach since it considers vulnerability as one of several determinants of risk. It lists (and crucially differentiates between) the following risk determinants:

- **Hazard:** the possible, future occurrence of natural or human-induced physical events that may have adverse effects on vulnerable and exposed elements;
- **Exposure:** the inventory of elements (e.g. people, economic resources) in an area in which hazard events may occur;
- **Vulnerability:** the propensity of exposed elements to suffer adverse effects when impacted by hazard events;
- **Disaster Risk:** the possibility of adverse effects in the future.

Note that exposure and vulnerability are both necessary conditions to contribute to disaster risk. For example, a city located on a floodplain will be exposed to disaster risk, but may not be vulnerable if it is able to mitigate losses through investment in flood resistant building stock. SREX (IPCC, 2012) notes that vulnerability is driven by a mix of historical, social, political, cultural and economic factors. It also stresses the context-specific nature of vulnerability. For example, a community that is vulnerable to flooding may not be vulnerable to landslides.

3. Climate Information & Climate Services

3.1.Value of Climate Information: the Cost-Loss Model

According to a theory developed by Katz and Murphy (1997), the value of weather information can be estimated by considering the case of a decision-maker (e.g. a farmer) who incurs different costs depending on weather outcomes. The value of information (e.g. a weather forecast) is calculated as the difference between the costs incurred by the decision-maker when acting on prior beliefs alone and the costs incurred when making use of the weather forecast.

In this section, we present a numerical example of this framework (taken from FWI (2012)) before discussing its theoretical basis and application to the case of climate change.

Expected Loss (no weather forecast)

Consider a case where two weather conditions are available (Adverse and Favourable). Under Adverse weather, the decision-maker incurs the loss L=1. Under Favourable weather, the decision-maker incurs zero loss. The long-run probability of Adverse weather is p=0.2. We interpret this as the probability of Adverse weather based on the historical relationship — which is also the decision-maker's prior belief. Given this information, the decision-maker's expected loss is $p \times L = 0.2$ at any given time.

Possibility of protection

Next, we assume that the decision-maker has the option to invest in Protection against Adverse weather loss. This has the cost of c=0.25, but eliminates damages from adverse weather. Thus the decision-maker is faced with the choice of a certain cost of 0.25, or a probable loss of 0.2. In this case, the decision-maker chooses not to purchase Protection. However, the decision-maker would have chosen Protection if the probability of Adverse weather were higher (p>0.25), or its losses more severe (L>1.25).

Note that the decision not to take Protection in this example relies on the assumption that the decision-maker is risk-neutral. If she were risk averse, Protection would be purchased at a lower probability than 0.25. This framework also assumes that the decision-maker possesses a complete set of prior beliefs concerning the values of c, L and p.

This framework is known as the *Cost-Loss* model. The combination of payoffs mentioned so far is shown in Table 3.

Table 3: Costs under different weather conditions, with and without Protection

Action	Adverse Weather	Favourable Weather
Protection	c = 0.25	c = 0.25
No Protection	p × L = 0.2	0

Source: FWI (2012)

Benefit from Using a Forecast

If the decision-maker has access to a weather forecast which announces a prediction that the weather will be either Adverse or Favourable, she is able to refine her beliefs regarding the probability of Adverse weather. Let p_1=0.28 be the conditional probability of Adverse weather, given that Adverse weather was forecast. The probability of Adverse weather, given that Favourable weather was forecast (p_0=0.18) is derived by the following expression:

$$p_0 = \frac{(1 - p_1)p}{(1 - p)}$$

From this we also derive a measure of forecast quality $0 \leq q \leq 1$, where q=0 denotes a forecast that is no better than the decision-maker's prior belief and q=1 is a perfect forecasting system. In this example q = 0.1:

$$q = \frac{(p_1 - p)}{(1 - p)}$$

Furthermore in this example we assume that probability of an Adverse forecast is the same as the long-run probability of adverse weather [P(Forecast = Adverse) = P(Weather = Adverse) = 0.2].

Under these conditions, if the decision-maker uses the forecast, they will choose Protection in the case of an Adverse forecast but will choose No Protection if the forecast is favourable. This leads to an expected loss (before knowing what the forecast will be) of 0.194, which is lower than the expected loss of 0.2 from ignoring the forecast (see Table 4 below for details).

Table 4: Losses from Adverse Weather with & without use of Weather Forecast

	Adverse Forecast	Favourable Forecast	Prior Belief only
Optimal Protection Choice	No Protection probable loss $p_1 \times L =$ **0.28** Protection probable loss c = **0.25** **Protection chosen**	No Protection probable loss $p_0 \times L =$ **0.18** Protection probable loss c = **0.25** **Protection not chosen**	No Protection probable loss $p \times L =$ **0.2** Protection probable loss c = **0.25** **Protection not chosen**
Expected Loss	0.25 × P(Adverse Forecast) + 0.18 × P(Favourable Forecast) = 0.28×0.2 + 0.18 × 0.8 = **0.194**		Expected loss from No Protection (without using forecast) = **0.2**

Source: numbers taken from FWI (2012)

Value of the Forecast

In the example above, the value of the weather forecast is the reduction in the decision-maker's losses as a result of using the weather forecast. This is (0.2 - 0.194) = 0.006.

Repeating the same exercise with different values for q (and therefore p_1 & p_0) shows that the weather forecast becomes more valuable as its quality increases. When q=0.5, the value of the forecast reaches 0.07, while a perfect forecast has a value of 0.15, and forecasts of $q \leq 0.05$ have a value of zero.

Theory and Application to Climate

Studies of this type are part of the wider economic literature on the value of information which began with the development of the von Neumann-Morgenstern utility hypothesis (Arrow, 1965) and the refinement of decision theory under uncertainty (Knight, 1921; Pratt, 1964). As mentioned above, the numerical example given here implicitly requires that the

decision-maker is rational, risk-neutral and aware of the risks and payoffs from each possible state of the world.

Several authors have underlined the need for elaborating on the evaluation of the forecast quality beyond the basic "Cost-Loss model" and its variations. Some studies try to account in more sophisticated ways for the effects of uncertainty and confidence on the use of climate information (Wilks 2001).

Aside from the accuracy of climatic information, the value of the information is influenced by other factors, including the following (Teisberg and Weiher, 2009):

1. Frequency – the climatological probability of the weather event.

2. Severity – the magnitude of the risk or the expected damage that the event could cause. This in turns depend on vulnerability of a specific location/asset/population affected by the climatic condition

3. Lead-time – the time between the forecast and the occurrence of the event - determines the range of protective action that the decision maker has available, longer lead times means wider range of possible responses and therefor usually smaller response costs

4. Response costs – the costs of possible responses to the warning;

5. Loss reduction – how much are the expected losses from an adverse weather reduced given the protective actions – in the example before, by using protective measures decision maker was able to mitigate the whole loss.

To the best of our knowledge, the current literature does not consider how the application of valuation techniques such as the Cost-Loss model should differ between short-term, verifiable weather forecasts and climate information where the spatial resolution and time-scale are likely to be longer. Studies focus on the benefits of weather or climate information (see citations throughout this chapter) but we have been unable to identify a theoretical or empirical comparison between the two.

Under the numerical framework outlined above, we would expect a 'climate' forecast (longer time horizon, lower spatial resolution) to be less valuable than a standard weather forecast if the improvement of the forecast over the assumed knowledge of the decision-maker is lower

(if p_0 and p_1 are closer to p). However, the proximity of these three probabilities does not mean that climate information is intrinsically less valuable, merely that there is greater scope for improvements in value if improvements in forecast accuracy can be made (such that the difference in values between (p_0 & p_1) and p increases). Furthermore, the longer lead time provided by climate information is a source of value relative to a short-term weather forecast since this should increase the range and effectiveness of protective options available to decision-makers.

3.2.Climate Services & User Needs

Climate Services can be defined simply as "climate information prepared and delivered to meet a user's needs" (WMO, 2011), though several more detailed definitions exist. In order to understand the socioeconomic value of climate services, is therefore necessary to appreciate user needs.

Literature has emerged that pays attention to the capacity of potential users to make use of climate and weather information (Patt et al 2005; Sharma and Patt 2012). For example, Ziervogel et al. (2010) discuss the need to tailor seasonal climate predictions to user needs in the case of water resource planning in South Africa, while Weaver et al. (2013) go as far as to advocate the use of long-term climate models as a scenario-based decision support tool (rather than the traditional probabilistic approach).

Information value chains

FWI (2012) cites Hooke and Pielke (2000) as having created a simple 3-step model of a climate information system: where information is produced, communicated, then used.

Production ⇨ Communication ⇨ Use

Perrels et al. (2012) further decompose the information into seven value-adding steps from generation of the forecast to realisation of benefits by the end-user. The value of each stage depends on the extent to which:

1) weather forecast information is accurate (predict)
2) weather forecast information contains appropriate data for a potential user (predict and communicate)

3) a decision maker has (timely) access to weather forecast information (communicate)
4) a decision maker adequately understands weather forecast information (communicate)
5) a decision maker can use weather forecast information to effectively adapt behaviour (use)
6) recommended responses actually help to avoid damage due to unfavourable weather information (use)
7) benefits from adapted action or decision are transferred to other economic agents (use)

Perrels et al. (2012) also note that users who are less informed or meteorologically skilled should derive greater value from the use of weather services. For example, there may be greater improvement potential in these seven steps for road users (non-professional transport modes) compared to navigation professionals in aviation and marine industries.

Anaman et al. (1997) and Lazo & Chestnut (2002) refer to the economic theory of public goods when discussing the value of meteorological (weather & climate) services. According to this theory, a public good or service is a product that cannot typically be provided in a free market, despite the social benefits deriving from its production and consumption. The defining characteristics of a public good are *non-excludability* (once the good is produced, it is impossible to prevent anybody from consuming it) and *non-rivalry* (one person's consumption does not reduce availability for everyone else). Strictly speaking no climate service can be considered an inherently public good since it is possible to supply information on an exclusive basis (e.g. only to subscribers). Nevertheless Anaman et al. (1997) consider public weather forecasting and disaster warnings provided free-of-charge to be public goods (especially since such services might not be provided if they relied solely on user payments for finance) while fee-paying services tailored to specific users' needs (such as those used by the aviation or mining industries) are considered private goods.

In general there is relatively little data available regarding households' valuation of weather information (Lazo and Chestnut 2002). Several valuation techniques do however exist and have been deployed in a commercial context, as outlined in the following section.

Prescriptive and descriptive approaches

A prescriptive approach to valuation (such as that described in Section 3.1) assumes that decision-makers are rational and capable of maximising their expected utility given the information available. This is underpinned by the normative theory of decision-making (because norms are needed to state the objectives against which optimisation takes place). On the other hand, descriptive models try to model actors' actual behaviour in a decision-making

process. As FWI (2012) points out, differences between the two approaches are inevitable due to their alternative methodological foundations (Hooke and Pielke 2000).

In terms of valuation, prescriptive studies typically use a loss function to evaluate the "best price" that users should be willing to pay for improved information, given its expected benefits. Descriptive studies, on the other hand, typically take the form of anecdotal reports & case studies, user surveys, interviews & protocol analysis, and decision experiments (Lazo and Chestnut 2002).

Examples include Frei et al. (2012), who use a prescriptive method based around structured interviews to value the benefit of weather services to users and operators of the Swiss road network. They identified benefits of around €55m compared to the counterfactual situation where no forecasting information is available. Klockow et al. (2010) cite a number of prescriptive and descriptive studies used in the context of agribusiness. On the descriptive side, these include Hu et al. (2006) and Artikov et al. (2006) who, using both surveys and regression analysis, find that attitudes and social norms are among the most important factors influencing forecast use by farmers. The psychological factors affecting actors' use of climate information is also explored in an experimental setting by Ramos et al. (2013) and Grothmann & Patt (2005).

Valuation based on stakeholder behaviour

Several of the studies mentioned above survey expert opinion in order to derive the value of weather and climate information (e.g. Ziervogel et al. (2010), Frei et al. (2012)). FWI (2012) summarises the main techniques employed to derive a valuation for actors' stated (or revealed) responses to information availability. These are:

1. *Revealed preference.* The observable reactions to some relevant information in his/her decision-making process. Studies that use revealed preference do not exclusively rely on users' surveys, as their behaviour could be observed indirectly (e.g. change in consumption patterns). In surveys, respondents are asked about some verifiable choices they made (e.g. purchases of energy efficient appliances versus standard appliances).
2. *Stated preference.* The declared reaction of an expert or user to some relevant information in his decision-making process.

3. *Stated value.* Surveys try to estimate the maximum amounts people would be willing to pay (WTP) to receive, or would be willing to accept (WTA) to forgo a specific level or quality of a service.

Contingent valuation (CV) methods may also be used to evaluate weather and climate services. These are techniques that use stated value information in hypothetical scenarios to derive the amount users would be willing to pay/accept for information in certain circumstances. Regarding the usefulness of CV for weather information, FWI (2012) points out that some authors are sceptical that survey-based studies or subjective estimates can produce realistic quantitative estimates. Lazo & Chestnut (2002) point out that in order to derive the likelihood that values from a stated value or CV study are "true" it is important to clearly define the commodity to be valued (e.g. weather information) and ensure that participants are aware of the framework of the hypothetical transaction (e.g. the terms of payment and budget constraint).

4. Evaluating Adaptation across Sectors and Regions

As with impact assessments, multi-sectoral assessments of adaptation are important since they provide an estimate of the overall feasibility of adaptation, its costs and the extent to which it is able to prevent climate-related damages from occurring. Moreover multi-sectoral, and multi-regional assessments are able to compare the costs and/or benefits of adaptation between activities and locations, providing a signal regarding the optimal use of scarce adaptation funds.

OECD (2008) describes multi-sectoral adaptation assessment as "a rapidly developing area on two fronts" (the national/regional and global levels). This section provides an overview of multi-sectoral adaptation studies at each of these levels.

4.1.Regional and national level assessments

In Europe, national adaptation plans have been developed by a number of EU Member States[6] while a number of research projects have begun to investigate the science and policy implications of implementing adaptation at a more local (subnational) level.

Swart et al. (2009) review the adaptation plans and underlying research base for nine Member States, identifying three phases of research programme (climate system; impacts; vulnerability & adaptation). Member States' adaptation plans have been compared and reviewed in a number of studies. These include the United Nations International Strategy for Disaster Reduction (UNISDR et al., 2011) who review climate change governance from a disaster risk reduction perspective and recommend improvements related to the coordination and sharing of information between authorities across national and administrative boundaries, and between policymakers and researchers. Similar concerns are raised in reviews of climate change adaptation governance by Peltonen et al., Biesbroek et al. (2010) and Dumollard & Leseur (2011). Peltonen et al. cite examples of adaptation policy at national and subnational from the Baltic Sea region and point out that coherence between adaptation policies and administrative sectors or political/economic interests is often poor. BiesBroek et al.'s (2010) review of seven National Adaptation Strategies found that in many cases the role of the adaptation strategy in implementation and wider governance remained to be defined. Both studies also highlight the need for improved coordination between science and policy, with

[6]Fifteen Member States have developed plans according to European Commission, http://ec.europa.eu/clima/policies/adaptation/what/index_en.htm. Accessed 05/02/2014

Peltonen et al. remarking that "in many cases it is yet uncertain what the localities should adapt to" and Biesbroek et al. (2010) observing that the governance of climate change is moving faster than the science, enhancing the difficulty in discussing specific adaptation options.

One of the first national studies is Holman et al. (2005, 2005a), which provides a multi-sectoral and integrated assessment of climate change impacts in the UK. They developed a methodology for stakeholder-led, regional climate change impact assessment, explicitly evaluating local and regional scale impacts, adaptation options and cross-sectoral interactions between four major sectors driving landscape change (agriculture, biodiversity, coastal zones and water resources). A complete standard methodology for costing climate impacts and adaptation has been provided by the UK Climate Impacts Programme (UKCIP, 2004). Such methodology has been conceived in order to be applied to a range of sectors (coastal zones, water resources, agriculture, buildings and infrastructure) at local, regional and national level in the UK. Resource costs and costs & benefits weighting of adaptation options are both taken into account. A number of techniques are described in detail for valuing different impact types: conventional market-based techniques, taking a change in productivity approach (hedonic analysis, travel cost and contingent valuation methods) or applying cost-based methods (replacement cost and avertive expenditure techniques) and individual guidelines tailored to specific types of receptor for non-marketed goods or services (habitats and biodiversity, human health, recreation and amenity, cultural objects, leisure and working time, non-use benefits). Some case studies are illustrated as concrete applications of the described methodology to four relevant issues (water resources, agriculture, flooding and time losses in the transport system).

At a subnational level, the CIRCLE-2 Climate Adaptation Infobase[7] provides details of over 1,400 studies of climate impacts and adaptation undertaken since 2005 in Europe and the Mediterranean region. In addition, the CIRCLE-Med project has focused specifically on the Mediterranean region (Santos et al., 2014). Plan Bleu (2011) provides an overview of the needs for adaptation in the Mediterranean water sector, reviewing the situation in seven Mediterranean countries. Its recommendations stress the importance of sharing knowledge between regions, and of comparing the costs and benefits of different types of adaptation practice – in particular appreciating the role of natural ecosystems in providing ecosystem services and protection against natural disasters.

[7] http://infobase.circle-era.eu/

4.2. Multinational Assessments

A number of studies have looked at quantifying adaptation costs and investments at multi-national and global level. They can be divided into two main groups. The first group uses top-down models (IAMs) to compute optimal adaptation investment needs at an international level. These studies are discussed in Section 2.1.1 (*Adaptation to Climate Change in IAMs*). The second group ("cost of adaptation" assessments) is discussed in this section. These studies aim at calculating the cost of a defined level of adaptation (not necessarily the optimum as derived from a cost-benefit framework) by summing up the costs of specific adaptation measures in several countries (especially developing countries)

4.2.1. Cost of adaptation assessments

European Level

There are few multi-country assessments of climate impact explicitly modelling adaptation. One recent assessment refers to Europe (Ciscar et al., 2009). The PESETA study integrated a set of coherent climate change projections and physical models into an economic modelling framework to quantify the potential impacts of climate change on vulnerable aspects of the European economy: agriculture, riverbanks, coastal areas and tourism. The study also considers the impacts on human health. All the impact categories assumed some degree of adaptation, ranging from autonomous or private adaptation in agriculture and human health (without any explicit costs) to institutional adaptation in tourism and public adaptation in river floods through protection levels for certain return periods.

Some of the sectoral studies (coastal systems, human health) have taken into account alternative degrees of adaptation as a way to assess the role of such assumptions in the results. The human health study has considered the no acclimatisation case, and two other acclimatisation schemes.

The coastal systems sector study is the only one explicitly considering a cost-benefit module of adaptation, applying the DIVA model scheme (Nichols, 2007, also see Section 5.4.1). It estimates that damages without adaptation are around six times higher than with adaptation. Adaptation consists of beach nourishment and/or dikes. Each measure is undertaken if the benefits of the measure exceed the marginal cost. For dikes, the benefits consist of lower sea

flood damages, river flood damages and costs related to salinisation & migration. For beach nourishment they consist of the value of the protected land for agriculture or tourism.

The main conclusion of the study is that if the climate of the 2080s would occur today, the EU annual welfare loss because of the effects in the four market impact categories (agriculture, river floods, coastal systems and tourism) would be in the range of 0.2% to 1% (see Figure 2). However, there is large variation across European regions for the four impact categories. Southern Europe, the British Isles and Central Europe North appear most sensitive to climatic change. Agriculture impacts, coastal impacts and river flooding are the dominant causes of welfare loss. The assessment for the coastal systems indicates that adaptation policies can be particularly cost efficient for this sector.

Developing Countries

Many studies concerning multi-country adaptation assessment have been undertaken in the context of international development assistance. This is partly due to the importance of National Adaptation Programmes of Action (NAPAs), prepared by the LDCs under the United Nations Framework Convention on Climate Change (UNFCCC). NAPAs follow an approach that focuses on enhancing adaptive capacity to current climate variability and extremes, as this will in turn help address the adverse effects of climate change (Njie, 2008, Hardee and Mutanga 2010).

OECD (2008) review six multi-sectoral adaptation studies, all of which were conducted for governmental bodies or international organisations in the context of funding for international development assistance. Parry et al. (2009) and Fankhauser (2010) named these studies as “first generation global estimates”. Four of those reviewed by OECD (2008) produce rough estimates of the cost of "climate proofing" financial flows[8] into developing countries by estimating the extent to which these flows are "climate sensitive". More recently, the World Bank's EACC study (Economics of Adaptation to Climate Change) (World Bank, 2010) follows a more bottom-up approach, considering the individual detail of adaptation in a number of sectors.

Development-oriented studies often use similar methodologies to those used for studies at regional, national or community level within the EU. For example, EACC makes use of the DIVA model for estimating flood damages and also employs a variety of stakeholder engagement

[8] The financial flows are Official Development Assistance (ODA) & concessional finance, Foreign Direct Investment (FDI) and Gross Domestic Investment (GDI).

techniques in individual country case studies. One key difference is that the development-oriented flows have an emphasis on calculating the (foreign) funds required to compensate for the impacts of climate change. There is therefore the implication that these expenditures have zero opportunity cost from a recipient's point of view (i.e. additional funds should enter the economy to compensate for climate change). In a European context, where no foreign contribution to adaptation is foreseen, adaptation funds must compete for domestic funding with other expenditures.

5. Overview of Sectoral Climate Change Impacts

This section of the report reviews the literature concerning bottom-up assessments of climate impacts. It pays particular attention to energy, forest fires and tourism — the sectors examined in the case studies in Sections 6, 7 & 8. Other sectors covered are coastal impacts, river floods, human health, biodiversity & ecosystem services, and agriculture.

5.1.Energy

Climate change may generate disturbances in both the demand and the supply side of the energy sector. Such disturbances are associated with notable costs (and sometimes benefits) that strongly depend on the energy sector and regional climatic trends.

On the energy supply side, there has been recently a great deal of focus and concern regarding future performance of thermal power plants. This type of power plant uses nuclear energy, fossil fuels or biomass to produce electricity. The thermodynamic process involved in the production of electricity relies heavily on the supply of cooling water which in most cases is assured by nearby river flows. The current concern is that climatic changes might reduce river run-off in certain regions of the world threatened by drought which would force power plants to operate at reduced capacity. In addition, many countries have implemented strict regulations to protect river ecosystems by setting a limit to the maximum temperature at which it is permissible to return cooling water to rivers. This negatively affects the thermodynamic efficiency of thermal power plants which could furthermore be perceptibly altered by ambient temperatures changes as a consequence of climatic change (Van Vliet et al., 2012; Klein et al., 2013). Current methodologies that assess this impact make use of detailed data on plant location, cooling system types, surface temperature and river runoff (e.g. Van Vliet et al., 2012). The main challenge consists in (finding and) linking information from hydrological models with surface temperature and air moisture data from climate models and power plant specificities at high temporal and spatial resolution (daily river flows, dry bulb temperatures).

Climatic changes also have a considerable impact on the production of renewable energy. For example, changes in river run-off due to altered precipitation rates directly affect hydropower generation. The relationship between precipitation and electricity output is not linear and varies from region to region because in addition to precipitation rates other important factors

come into play such as evaporation rates, soil saturation, ground morphology, topography, erosion processes, land-use changes, deforestation, etc. In order to capture the intricate relationships between regional climate changes, the response of the Earth system and the impact on hydropower generation, the results form high resolution regional climate models coupled with detailed hydrological models are needed. Lehner et al. (2005) use a combination of two climate models and the WaterGAP model to nexamine changes in average runoff. They find that by the 2070s, runoff can be expected to fall in most of Europe, by as much as 25% in the South (especially Spain, Romania, Bulgaria and potentially Italy and the Balkan states). However, runoff is expected to increase in the North (Scandinavia, Scotland and the Baltic states). Gaudard & Romerio (2013) provide a more detailed summary of the impacts of climate change on the hydropower sector.

Similarly, biomass production is affected by climatic changes in different ways. A tendency towards more frequent heat waves for example can lead to the destruction of biomass stock through forest fires; increased precipitation and other extreme weather events may lead to losses through floods, etc. In this case too, high resolution data from climate models coupled with outputs from agricultural land-use and forestry models are needed in order to make projections on the evolution of biomass potentials and use.

The climate change impact on electricity production from wind and solar technologies can be assessed using comparatively few climate parameters such as wind speed, or irradiance. However, in these cases as well, results are sensitive to the quality of the climate data at high spatial and temporal resolution. To date, consistent resource potential data sets are available with detailed full load hour information for solar PV, CSP and wind technologies.

To calculate the evolution of solar energy potentials, hourly direct normal irradiance (DNI) and global tilt irradiance (GTI) data derived from climate model outputs are necessary. To have an idea about the level of detail needed from climate models in order to obtain realistic assessments on climate impacts it is useful to consider state of the art methodologies to calculate historical potentials. A research group at the Potsdam Institute for Climate Impact Research (PIK) provided (in the framework of the on-going FP7 project ADVANCE[9]) country-based potentials for solar PV and CSP technologies. The estimates were built on NASA SRB 3.0 data containing 3-hourly global horizontal irradiation (GHI) data on a 1° grid. The data from NASA was modified and downscaled to 1-hourly data on a 0.45° grid using a clear sky model by the Deutsches Zentrum für Luft- und Raumfart (DLR). Direct normal irradiance (DNI) data was then derived from the GHI data, using empirically fitted relationships between the ratios direct / diffuse radiation on the one hand and Clearness Index / optical air mass on the other hand.

[9] See http://www.fp7-advance.eu/

Regarding wind resources, the estimates consider wind speed at different heights and per surface unit. Recently the US National Renewable Energy Laboratory (NREL) has assessed worldwide wind energy potentials using hourly wind speed vectors on a 40km grid[10]. While historical wind speed data is available (e.g. CFDDA reanalysis tool of US NCAR), it is unrealistic to expect results at this level of detail from climate models. It is thus crucial to develop appropriate methodologies in order to downscale climate model data to match with input needs for energy and impact assessment models.

Noteworthy is the fact that in both cases, wind and solar, regional parameters are used to exclude certain zones from the land area suitable for the development of these technologies. Most of the spatial exclusions take into account infrastructures, land-use and agricultural terrain but also climatic factors such as snow cover, permafrost, sea-ice cover, bathymetry, etc. Assessing future resource potentials of solar and wind energy is thus also based on evaluating the consequences of the interplay between all these parameters.

These are just a few examples of how climate change may affect the production and supply of energy: many more can be cited. The increasing occurrences of extreme weather events such as floods, forest fires and hurricanes can cause huge losses to energy infrastructure and production sites that were not built to withstand their destructive forces. The infamous case of hurricane Katrina is a grim reminder of the devastating consequences that this event had on the global oil market. Similarly, electricity transmission and distribution networks are likely to face a greater risk of disruption caused by increased wind storms and lightning strikes. Alluding to a different cause of concern related to future climate change, hundreds of thousands of kilometres of oil and gas pipelines and production sites in Siberia supplying important sources of energy to Central Europe may be affected by the potential melting of permafrost due to a global temperature increase. New shipping routes have already been opened as a consequence of melting ice sheets in the Arctic Sea.

All of these changes are expected to engender important social costs and need special attention from stakeholders and policy makers who are in the process of shaping the future of the energy sector and designing climate adaptation strategies.

Finally, climatic changes have the potential to affect energy consuming sectors such as households, public buildings, industries and transportation. In the residential sector for

[10] This information is derived from NREL work on USA wind potential, and has been made available for the FP7 project ADVANCE. See for instance presentation by Patrick Sullivan at the EMF meeting held in US Colorado, 22 July 2013: http://emf.stanford.edu/files/docs/340/Patrick_Sullivan_7.22_AM.1.pdf

example, an increased use of air-conditioning in summer is expected to accompany rising temperatures and decreased rainfall, such as might be expected in the Mediterranean region. Such a tendency would be exacerbated if these changes in demand occur over the same period as the energy supply constraints mentioned above. Furthermore, under a warming climate scenario, the tendency towards milder winters in the same regions would imply a reduced need for space heating, although this effect would probably be observed to a lesser extent in certain regions of the Mediterranean such as mountain areas for example (Dowling, 2013; Isaac and Van Vuuren, 2009; McNeil and Letschert, 2007; Mima and Criqui, 2009).

5.2.Forests and Ecosystems

In the dedicated case study (Section 7) we examine the influence of climate change on the risk of forest fires in the Mediterranean. Landau (2010) identifies three more general impacts of climate change on forests:

- Affects to net primary productivity (NPP) – NPP is measurement of plant growth obtained by calculating the quantity of carbon absorbed and stored by vegetation;
- Changes to forest distribution and composition;
- Changes to the frequency and intensity of forest disturbances such as fires and insect outbreaks.

In the context of the MOTIVE project, Kolström et al. (2011) summarised the likely effects of climate change on European forests (see Table 5). In the same project, Fitzgerald & Lindner (2013) identify wind to be more important as a damage source in Northern and Western Europe; while fire is more important in the Mediterranean; bark beetles in Atlantic temperate , Alpine and Mediterranean forests; and fungi & wildfire in mountain and boreal forests.

Table 5: Selection of Climate Impacts and Adaptation Options in Different European Forest Types

Forest Type	***Expected Impact***	***Adaptation Options***
Boreal	• Enhanced forest growth • Reduced winter hardening • Increased abiotic damages (e.g. storm damage)	• Better harvesting techniques on non-frozen soils
Temperate Oceanic	• Changes in storm, insect and pathogen disturbance regimes • Shifts in tree species compositions	• Adapt the management to an increased disturbance risk
Temperate Continental	• Vulnerability of trees to frost increasing • Forest fire risk increases • Risk of pest outbreak increases	• Improve fire risk management and adjust afforestation techniques
Mediterranean	• Drought stress increasing • Forest fires become a greater threat • Threat of desertification and soil loss	• Fuel management and the modification of stand structure to reduce fire risk
Mountainous Regions	• Tree line shifts upwards • Forest fire risk line increases	• Promote small-scale management and maintain the forest cover to secure its protective function against natural hazards and erosion
All regions		• Adjust thinning & harvesting to changing forest growth patterns • Select well-adapted species or provenances at regeneration and favour them at tending and thinning stages

Source: Kolström et al. (2011)

On ecosystems more generally, progress has been made in recent years on ecosystem service evaluation, notably through the Economics of Ecosystems and Biodiversity (TEEB) project (TEEB, 2010). Reports produced by the TEEB project itself represent methodological guides for the study or management of ecosystems (e.g. Beaudoin & Pendleton (2012) on oceans, or TEEB (2012) which provides a framework to policymakers for valuation of ecosystem benefits).

Also in the context of the TEEB project, Van der Ploeg & de Groot (2010) developed a database of ecosystem valuation studies consisting of over 1,350 datapoints from over 300 case studies (a datapoint is a piece of information such as the estimated value of a specific ecosystem service expressed in Euros per hectare per year).

5.3.Tourism

The relationship between tourism and climate change in the CLIM-RUN project is examined in a number of case studies, with particular focus on the Mediterranean region. In particular, Dubois et al. (2014) investigate ways of improving the Tourism Climate Index in the region, while Section 6 of this document uses the Hamburg Tourism Model to investigate the effect of future climate on tourist numbers and expenditure. This section provides a more general overview of the literature on how climate change may affect the tourism sector.

Cai et al. (2011) and Nickerson et al. (2011) note that quantity of literature discussing how tourist flows respond to a changing climate has increased in the past decade (from around 2005). However, there is earlier literature on the relationship between tourism and climate, examined by Scott et al. (2005).

Scott et al. (2012) review the key risks for international tourism from climate change, dividing the literature into the following categories:

- **Altered Geographic & Seasonal Demand:** including the degree to which a bundle of climate indicators (e.g. a Tourism Climate Index) influence choice of destination and substitution between domestic (home-country) and international tourism.
- **Risks to Winter Sports Tourism:** balancing the risks of less favourable snow conditions with the potential for adaptation, especially through snowmaking.
- **Sea level rise and Risks to Coastal Tourism:** coastal tourism has been identified as the largest tourism activity segment globally. Assets such as beaches, cultural heritage resources and infrastructure are at risk from sea level rise, while beach nourishment is among the adaptation measures available.
- **Risks to Nature-based Tourism:** the extent to which degradation or disappearance of natural attractions (e.g. glaciers, coral reefs, rainforest, wildlife) result in reduction or displacement in tourist flows.

Nickerson et al. (2011) conducted a scan of the academic literature on climate change and tourism, identifying 220 published works, of which around half deal with the impact of climate

change on tourism (including subjects such as destination choice and impacts in specific areas such as mountains and oceans). In general they find that tourist destinations will be expected to shift in space and time. Popular tourist destinations may change if ideal climatic conditions occur closer to the poles than at present (Amelung et al., 2007). Destinations may also receive fewer visitors in (hotter) summer and (less snowy) winter months, but greater visitor numbers in the spring and autumn (Ceron & Dubois, 2005; Nicholls, 2006).

The scan also cites numerous studies investigating the impacts and scope for adaptation in mountainous regions, particularly those where winter sports are currently favoured (Beniston, 2003 and Bark et al., 2010 amongst others). It also identifies studies proposing specific areas that could benefit from climate change. For example, Ceron & Dubois (2005) suggest that French Mediterranean beaches may benefit from climate conditions that are cooler than those further South. In addition, Jones et al. (2006) predict that climate change will cause visitor numbers to Ontario (Canada) national parks to increase in the period to 2050, based on multiple regression analysis. Other studies highlight the (two-way) interactions between climate change, tourism and environmental degradation. For example, Kent et al. (2002) examine water scarcity in Mallorca, noting that this is exacerbated by tourists, and may be exacerbated further by climate change directly (drier conditions) or indirectly (if a changed climate attracts more tourists).

5.4.Other Sectors

5.4.1.Coastal Impacts

According to EEA (2012), the coastal sector is the most studied impact type to date, in Europe at least. Studies of the socioeconomic implications have been undertaken at various scales (see Nicholls et al., 2007 for a review of earlier studies).

Studies have been undertaken at global level (Hallegatte et al., 2013; Hanson et al., 2011; Nicholls et al. 2010); regional level (Dasgupta et al., 2011 for developing countries); and subnational level (Ranger et al., 2011 for Mumbai; Hallegatte et al., 2011 for Copenhagen). In addition European level studies have undertaken as part of the ClimateCost and PESETA projects.

At European level, the research projects PESETA (Richards & Nicholls, 2009) and ClimateCost (Brown et al., 2011) employ the DIVA model (Hinkel & Klein, 2009; Hinkel et al., 2010).to

estimate the costs of SLR and related impacts at EU level for the period up to the 2080s. The projects produce comparable results from similar, but not identical, input choices such as the extent of SLR (in metres), socioeconomic & emissions scenarios, and climate models. PESETA estimates a cost of coastal damages without adaptation by the 2080s of between €10.3 billion and €44.6 billion (compared to €8.5 billion without SLR). The lower bound estimate reflects an IPCC B2 scenario with 6 cm[11] of relative sea level rise (RSLR) in Europe, while the upper bound reflects IPCC A2 scenario with 67 cm of RSLR. For the same period, ClimateCost estimates mid-range damages of €25.4 billion for an A1B scenario[12] and €17.4 billion for an E1 (mitigation) scenario[13] (E1 refers to a scenario where temperature rise is limited to 2°C).

Adaptation to Sea level rise

A reference study on the costs of adaptation to SLR is the analysis carried out by Nicholls (2007), which estimates total investments at a global level in two adaptation measures (beach nourishment and sea dike construction) to protect coastal areas and infrastructure. The analysis is made with the DIVA model, combining a global database on coastal zones with a suite of specific algorithms. The optimal adaptation decision is based on cost-benefit analysis and balances avoided damages against adaptation costs, with assumptions on sea level rise and socio-economic trends reflecting the IPCC SRES scenarios. Results showed that investment needs will vary from around $14 to 22 billion per year for the year 2030. The difference in costs reflects different climate scenarios. However, this difference is not due to differences in the impact of sea level rise in 2030, but is due the differing requirements for proactive adaptation (with long lead times) in order to avoid climate change in the more distant future.

5.4.2. River floods

Globally, as well as at European level, damages from river flooding have been increasing over time, with damages being influenced by socioeconomic trends (e.g. propensity to develop on floodplains) as well as climate (Kundzewicz et al., 2010). At European level, the estimated damages from increases in river flooding under future climate scenarios have been estimated in work related to the ClimateCost project (Feyen et al.,2011; Rojas et al., 2013). At national level, similar studies include Dumas et al. (2012) for France and Wilby et al. (2008) for the UK.

[11] The same study considers medium RSLR to be 26 cm by the 2080s.
[12] with €19.3-37.2 billion covering a 90% range of SLR expectations, and damages of €7 billion without SLR
[13] with €15.8-€20.1 billion covering a 90% range

The headline finding of Feyen & Watkiss (2011) and Rojas et al. (2013) is that in the absence of adaptation[14], expected mean annual damages should reach €98 billion by the 2080s[15] (see Figure 5). This compares to expected damages of under €50 billion in the absence of climate change and to current damages of €5.5 billion (the difference being due to socioeconomic trends increasing the total value of assets at risk). Furthermore, the climate change scenario has a much wider range of outcomes, with damage estimates between (twelve) GCM/RCM combinations ranging from around €59-200 billion, compared to €45-55 billion with only socioeconomic change.

Adaptation, in the form of upgrading protection to future 100-year flood levels is expected to reduce expected damages to €53 billion. Having reviewed the literature on costs and benefits of adaptation, Rojas et al. (2013) suggest that flood protection investments typically have a benefit-cost ratio of 4:1. On this basis, the annual cost of adaptation (protecting against a future 100-year event) is estimated at 0.07% of GDP on average for EU Member States. This ranges from 0.01% (Sweden) to 0.71% (Slovenia), though absolute costs are highest for the UK (€2.4 billion), France (€1 billion) and Italy (€0.9 billion).

[14] "Adaptation" being improvements in protection beyond current standards – which are assumed to protect against a present day 100-year event.
[15] Under an A1B scenario

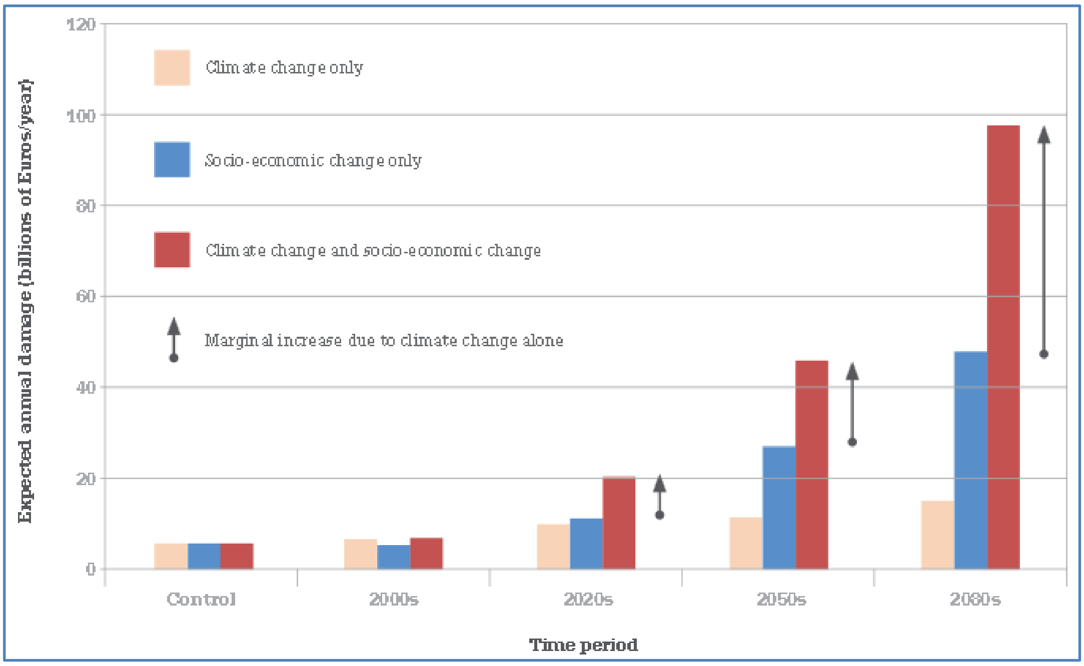

Figure 5: EU27 EAD from floods in billions of Euros for baseline period (1961-1990), 2000s (1981-2010), 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) for the A1B scenario based on LISFLOOD simulations driven by 12 regional climate models (all numbers in constant 2006 prices, undiscounted), assuming no adaptation. The entries per time period relate to the first three rows in Table 2, the marginal change represents the final row.
Source: Feyen & Watkiss (2011)

5.4.3. Human Health

The impacts of climate change on health can be divided into two main types, with several subcategories (Landau, 2010; Kovats et al., 2011):

- Direct impacts from climate variability:
  - Cold weather impacts (may decrease mortality)
  - Hot weather impacts (may increase mortality)
  - Storm and severe event impacts (increase in accidents and deaths)

- Indirect impacts from changes in disease distribution:
  - Food-borne diseases (increasing summer temperatures may increase incidence of food poisoning)
  - Water-borne diseases (e.g. cholera)

- Pest/vector borne diseases (e.g. Lyme disease, tick-borne encephalitis, malaria, visceral leishmaniasis, vibriosis)
- Outdoor air pollution
- Risks to health infrastructure and other critical infrastructure from extreme weather events.

Under the ClimateCost project (Kovats et al., 2011), quantitative estimates were derived at European country level for the heat-related mortality, food borne diseases, coastal flooding and labour productivity under A1B and E1. These impacts are summarised in Table 6, which shows the marginal impact of climate change[16] by the 2080s.

Table 6: Identified Health Impacts of Climate Change from ClimateCost study: EU27, annual figures during period 2071-2100

	A1B	E1
Heat Deaths per year - no acclimatisation	126,727	69,899
Heat Deaths per year - with acclimatisation	39,705	17,641
Salmonellosis cases	9,319 – 16,915	5,709 – 10,407
Coastal flooding fatalities	621	158
Economic cost of labour productivity reduction (€ million)	297 - 743	61-145

Source: Kovats et al., 2011

Notes:

- Figures refer to 2080s. Unit are number of cases (except labour productivity)
- For salmonellosis cases, lower bound assumes current trend of declining incidence (due to better food regulation practices) continues
- For labour productivity, lower bound indicates reduction in intensity of workload in Southern Europe (less manual labour, more services), converging with current intensity in North West Europe

The figures for heat death are obtained using an econometric function that equates deaths in specific age groups per degree Celsius in excess of a threshold (29.4°C in the Mediterranean and 23.3°C in Northern Europe). Under this framework, mortality is greatest in Italy, Germany, France and Spain (see Figure 6). If acclimatisation is assumed (every 30 years an additional 0.5°C is tolerated), the increase in heat deaths due to climate change falls to 40,000 in A1B (18,000 in E1).

[16] additional impact including climate and socioeconomic change less additional impact with socioeconomic change only

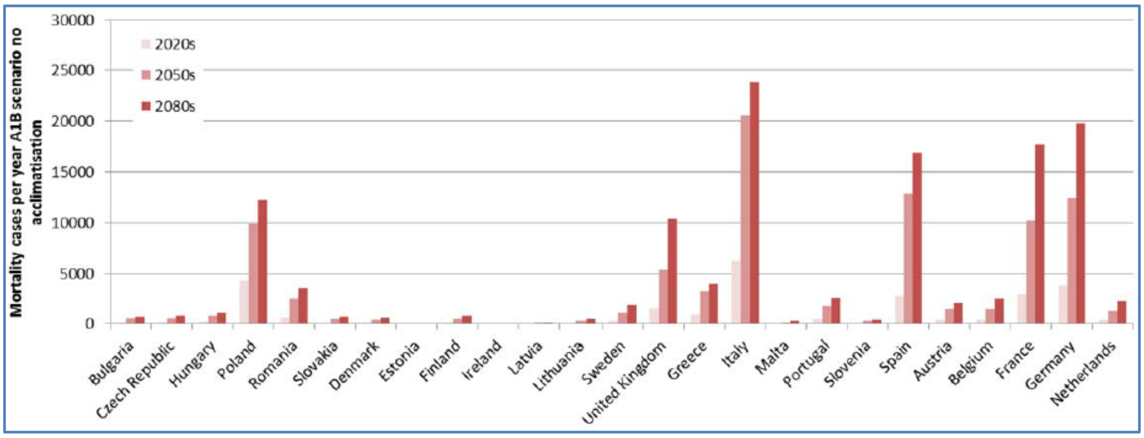

Figure 6: Annual Heat Mortality (number of cases, compared to baseline climate (1961-1990)), for the 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) for the A1B scenario (ensemble mean). No acclimatisation.
Source: Kovats et al. (2011)

Monetisation of Health Impacts

The ClimateCost study also places a monetary value on the identified morbidity and mortality. For heat deaths, Value of Statistical Life (VSL) and Value of Life Years (VOLY) methodologies are both considered. This places the additional annual cost of climate change at €147 million in the 2080s for A1B (€81 million for E1) under VSL. However, under VOLY this increases to €4.0 billion and €2.2 billion respectively. These estimates are based on an assumed value of €1.16 million per prevented fatality and VOLY of €63,000, with an assumed 0.5 years of life lost per heat related deaths. For salmonellosis, a value of €3,500 - €7,000 per case is assumed, which accounts for treatment costs, opportunity costs and disutility. This produced an estimated cost of €49–89 million per year for A1B and €30-55 million for E1.

A critical review of the different methodologies available for valuing climate change health risks is provided by Markandya & Chiabi (2009). The VOLY methodology (or the QALY, which also accounts for quality of life in each year) is intrinsically more attractive than VSL since it takes account explicitly of the life time lost. However, it is also more challenging given the need to calculate robust values for the amount of time lost per death, as well as a monetary value for each year lost. As a result, VSL methods appear to be more common in the literature (see Ščasný & Alberini, 2012; Braathen et al., 2009)

5.4.4. Agriculture

The projected impacts of climate change on European agriculture are summarised in EEA (2012). Though impacts will vary across the continent, it is expected that productivity will increase in Northern Europe due to a longer growing season and the opportunity to grow new crop varieties in regions where crop production is not limited by water scarcity. However, in Southern Europe, productivity is likely to be harmed by extreme heat events and reduced water availability, leading to the winter cultivation of some crops that are currently grown in summer.

For example, Figure 7 shows projected changes in water-limited crop yield across Europe in an A1B climate scenario for the 2050s. The importance of water as a limiting factor in agricultural production is likely to be particularly acute in Mediterranean regions for a number of reasons. Firstly, higher temperatures and lower humidity are likely to increase the evaporative demand of plants by a greater degree than the offsetting effect of increased CO_2 concentration (Olesen et al., 2007).

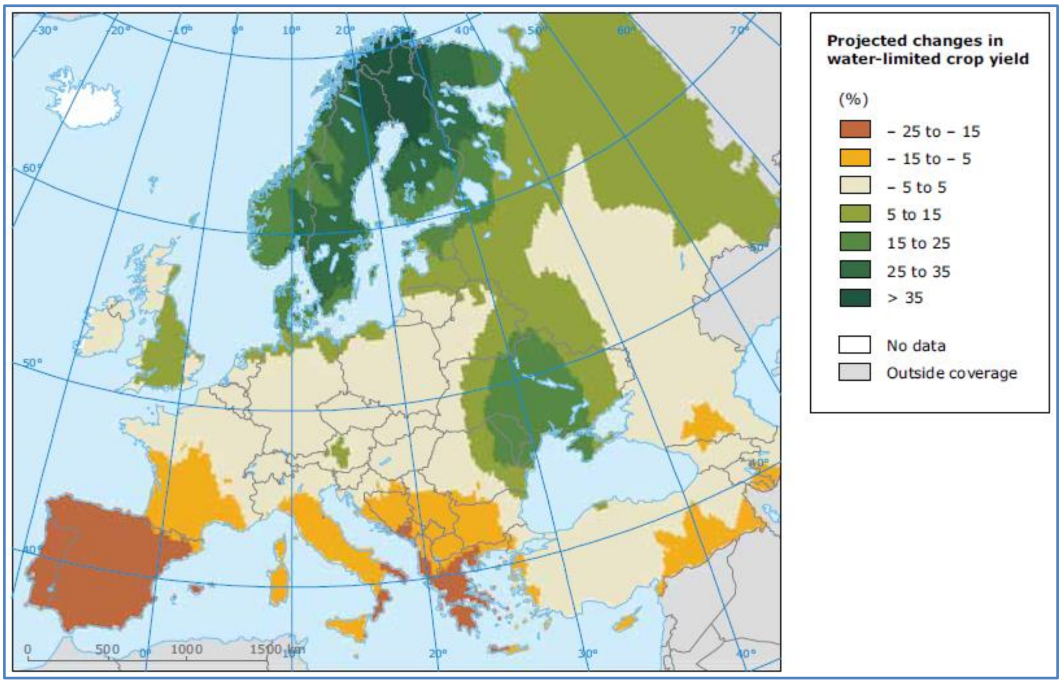

Figure 7: Projected Water Limited Changes (%) in Crop Yield

Source: EEA (2012)

Notes: mean relative changes in water-limited crop yield simulated by the ClimateCrop model for the 2050s compared with 1961–1990 for 12 different climate models projections under the A1B emission scenario.

In terms of stakeholder interaction, there exists a fairly wide body of literature on farmer behaviour (often employing the Theory of Planned Behaviour) though little dealing with adaptation to climate change specifically. For example, Hu et al. (2006) demonstrate the importance of psychological barriers and social norms in determining farmers' use of weather forecast information. Similarly OECD (2012) investigated farmer behaviour in the context of climate change and gave four recommendations which involved understanding farmers' behaviour in a local context, appreciating the insights from behavioural science (such as "nudging") and suggesting that adaptation strategies involving collective action and cooperation among farmers are likely to be more successful than an individualistic approach.

6. Case Study: Mediterranean Tourism

In this section we investigate the effects of climate change on tourist flows in the Mediterranean region during the 21st century. The study considers an A1B climate scenario and uses the Hamburg Tourism Model (HTM), which includes temperature as one of its determinants of tourist flows.

We consider the effect of climate change on (domestic and international) tourist arrivals at country level for 22 Mediterranean countries. In addition we use regional downscaling to consider the same effects for 16 subnational regions spread across Croatia, France and Tunisia. Results suggest that, other things being equal, by 2100, tourist numbers in most of the downscaled regions may decline by 20-38% compared to a counterfactual without climate change. Compared to other tourism analysis carried out within the CLIM-RUN project this section adds value by considering the interplay between domestic and international tourism.

It should be noted that climate change in the countries outside the region (not considered here) could also have an important effect by influencing the destination choice of both domestic and foreign tourists. This would therefore constitute useful additional information for tourist industry stakeholders. Furthermore, the results should be treated with some caution since they show the effect on tourist flows of mean annual temperature per zone (a single annual variable), thereby failing to account for the geographical concentration of tourists within each zone and for changes in seasonal temperatures. Furthermore, temperature is not the only determinant of tourist comfort. For example a composite measure, such as the Tourist Climate Index, would give a broader picture.

6.1.the Hamburg Tourism Model

Most impact studies on tourism and climate change focus on particular countries or on specific types of tourism, while analysis at the global level is often overlooked. This has two main drawbacks. On one hand, the substitution effect between different countries is not taken into consideration. On the other hand, domestic and international tourism are often grouped into a single category, thus disregarding the differences in behaviour and the substitution effects that may arise between domestic and international destinations in the decision process of the tourist.

The Hamburg Tourism Model (HTM) filled some of the gaps mentioned above, by feeding data from different countries and regions into a simulation model that reproduces the flows between 207 destinations and countries of origin. Scenarios accounting for economic growth, population dynamics and, of course, climate change were used to simulate tourist flows' changes over the course of the twenty-first century - with and without climate change. Population growth and per capita income are derived from scenarios taken from the Special Report on Emissions (SRES) of the Intergovernmental Panel on Climate Change (Nakicenovic and Swart, 2001) and implemented in version 2.2 of the Image model's integrated assessment of global scale changes[17]. The simulations of the original SRES were conducted for 17 world regions and the rates of growth of the countries of each region were considered to be equal to the rate of growth of their reference area. Climate change simulations were derived from the model Fund[18] (Tol, 1999) and the Cosmic model (Schlesinger and Williams, 1998).

Results of the HTM simulation model were presented for the first time in 2005 (Hamilton et al., 2005). Other developments have led to the inclusion of domestic tourism, tourist spending and length of stay (Bigano et al., 2007a) . The Hamburg Tourism Model simulates both tourism demand generated by each country, and the demand for tourism at various destinations. The model estimates the total demand for travel using data on population and per capita income of each country, and then the ratio of domestic to international tourists on the basis of per capita income, the national land area, coastline length and mean annual temperature at each destination. The model then identifies the destinations of international tourism by means of a matrix of bilateral tourist flows between all countries and regions considered.

The projections of tourism flows over the twenty-first century have been carried out on the basis of simulations of changes in population and income, in the absence and in the presence of climate change. Income and population affect both supply and demand of tourism. On the supply side, these simulations result in changes in the attractiveness of tourist destinations. On the demand side, these scenarios have implications in terms of total number, in each country of origin, of individuals willing to engage in tourist activities. The model simulates the flow of tourists in five-year intervals over the course of the XXI century, but it can also simulate past periods thus allowing the validation of the results by comparing the actually observed data and the data estimated through simulations [19].

In absence of climate change, the model predicts that, as population increases, each country will increase the number of its outgoing tourists, while with both population and GDP growing,

[17] Netherlands Environmental Assessment Agency http://themasites.pbl.nl/tridion/en/themasites/image/
[18] http://www.fund-model.org/
[19] Bigano et al. (2007a) discuss the issue of validation for the HTM models and find that (p.34): “The correlation between observed and modelled international arrivals in 1995 is almost perfect, because that is the year of calibration. For the other years, the correspondence between observations and modelled values is never below 92%”.

the number of both outgoing and ingoing tourists will grow (since more financial resources mean, *ceteris paribus*, more resources for the tourist sector as well, and hence better ability to attract foreign tourists). Since the economic growth will not be uniform across world countries in the future, these changes will result in variations in the market shares of individual countries. In the absence of climate change, the model estimates that both domestic and international tourists from countries currently leading the tourist market, including European countries, Japan, Australia, New Zealand, USA and Canada will decline gradually over the twenty-first century in absolute terms, while Asian countries will see their share increase.

The model compares these projections in the absence of climate change with the effects of climate change under four different SRES scenarios. As an illustration, we briefly discuss the results of the A1B scenario, i.e. the one with the lowest population growth, but characterized by strong global economic growth. The interested reader is referred to Bigano et al. (2007a, 2007b) for the overall results. Under such a scenario, the Mediterranean countries, including the CLIM-RUN tourism case studies (Croatia, France, Tunisia and Cyprus), are penalised. The last two suffer the most severe impacts, being part of (or close to) the world's most severely impacted regions, such as Africa and the Middle East. On the other hand countries where the climate is not currently seen as one of the main local attractions, such as Canada and Russia, may be visited by many more tourists (again, in relative terms with respect to the no climate change scenario).

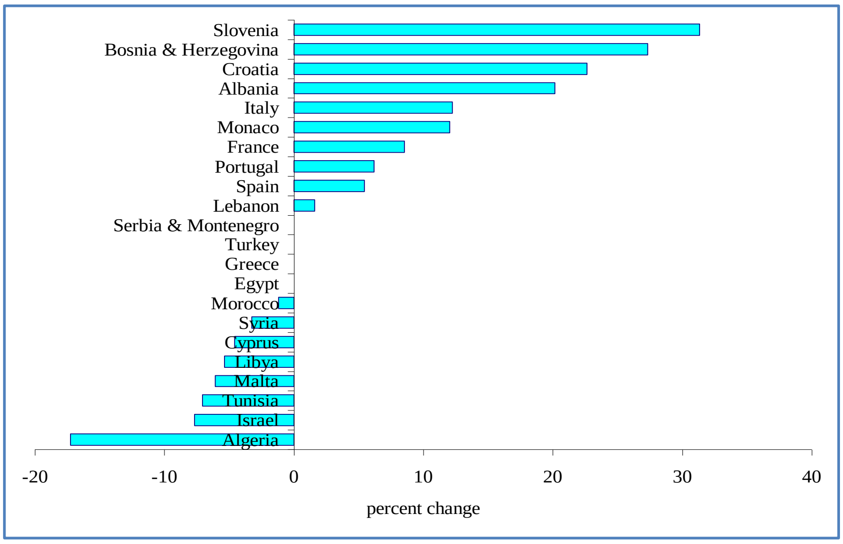

Figure 8: Climate change impact on tourism in the Mediterranean and Portugal in 2100 in HTM (% change compared to the value in the absence of climate change). Domestic tourists

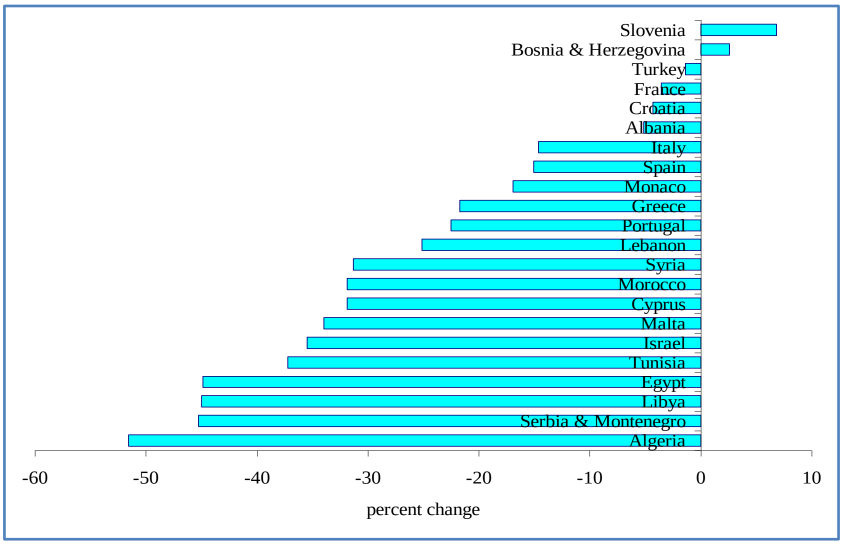

Figure 9: Climate change impact on tourism in the Mediterranean and Portugal in 2100 in HTM (% change compared to the value in the absence of climate change) International tourists (from any country of origin worldwide)

Figure 8 and Figure 9 illustrate, respectively, the impact on domestic tourists and international tourists in Mediterranean countries. From their comparison, the different dynamics of domestic and international tourists are apparent: As temperature rises in a given country domestic tourists tend to increase in relative terms. These are former international tourists from that country, who used to travel to warmer destinations which have become excessively hot under increased temperatures, and thus prefer to revert to domestic tourism instead. Note that domestic tourism is also sensitive to temperature increases, and it can actually decrease due to higher temperatures. This is the potential outcome for some North African

and Middle East countries in the A1B scenario shown here - including Tunisia and Cyprus. The strongest effect is however the one on international tourists, which will increasingly prefer milder destinations to the Mediterranean ones.

6.2.Regional Downscaling

The available background data do not allow a full simulation at the subnational and provincial level for each country in the model. This poses some issues if one intends to draw lessons from the HTM model for our case study destinations, which, with the exception of Cyprus, entail a much smaller area than the one covered by the HTM model's national resolution, and may have different characteristics from those holding on average at the national level.

However, an extension of HTM to a simplified regional model was produced for the United Kingdom, Germany and Ireland (Hamilton and Tol, 2007) and Italy (EURAC, 2007). These simulations were derived by applying a methodology for downscaling of the HTM model results nationwide that splits the national figures for international arrivals and domestic tourists between the various sub-national jurisdictions in a manner consistent with the assumptions of the model. A detailed description of the downscaling methodology can be found in Hamilton and Tol, 2007 (to which, for economy of space, the interested reader is referred). In a nutshell, it amounts to allocate tourist numbers projections generated by HTM across local jurisdictions, on the basis of the same statistical relationships used in the model between said numbers and temperatures, but calibrated on the values of these variables in the base year at the local jurisdiction level, and taking into account the differences between domestic and international tourists. In the remainder of this section, the application of this methodology to the CLIM-RUN case study locations will be described and the results will be briefly discussed.

Data on domestic and international tourist numbers at the provincial level in Croatia, Savoie and Tunisia in 2010 have been gathered from various local statistical sources. Cyprus was already a national destination in the HTM model, and therefore the HTM results for this country did not need further downscaling. Tourist numbers in the base year and observed mean temperatures are shown in Table 7. It should be noted that Savoie differs from the other regions in that it has a much lower average temperature, and winter sports play an important part in its tourist market. Since the methodology of this study considers only average annual temperatures, the results for Savoie should be interpreted with this caveat in mind.

Table 7 Characteristics of case study provinces, 2010, (various sources[20])

	Foreign		Domestic		
Provinces	**Tourists**	**Share of national total**	**Tourists**	**Share of national total**	**Average of Temperature in 2010 (°C)**
			Croatia		
Primorje-Gorski	1843450	17%	307668	21%	14.6
Lika-Senj	369345	3%	34615	2%	15.0
Zadar	811383	8%	159709	11%	15.6
Istria	2467286	23%	160632	11%	14.5
			France		
Savoie	881226	3%	3280278	4%	2.3
			Tunisia		
Tunis-Zaghouan	502516	7%	36648	7%	19.5
Nabeul-Hammamet	1228351	18%	89583	18%	19.8
Sousse-Kairouan	1448332	21%	105626	21%	21
Yassmine Hammamet	587042	9%	42812	9%	19.8
Monastir-Skaness	713297	10%	52020	10%	20.2
Mahdia - Sfax	418573	6%	30526	6%	20.2
Jerba-Zarzis-Gabès	1646225	24%	120058	24%	21.6
Gafsa-Tozeur	193759	3%	14131	3%	22.6
Sbeitla -Kassrine	7	0%	0	0%	19
Bizerte-Bèja	35615	1%	2597	1%	18.4
Tabarka-Ain Draham	122451	2%	8930	2%	18.5

In order to account for the uncertainty in regional climate projections, the downscaling of HTM results has been performed on the basis of mean annual temperature projections (under the A1B SRES scenario) of a suite of 10 different regional climate models (CNRM, KNMI,SMHI-BCM, SMHI-ECHAM5, SMHI-HadCM3, C4I, HadRCM, DMI-ARPEGE, DMI-ECHAM, ICTP) with a spatial resolution of 25 km provided by CNRM-Météo France[21]. For economy of space, Figure 10-Figure 12 below show models' average results in terms of percentage deviations from a no climate change scenario, but individual model results are available from the authors upon request. The standard deviation across model results is however quite modest for most provinces (ranging from 0.06% to 15%, but mostly around 1-2%). Note that the inter-model variability would be greater if considering seasonal changes or, in particular, rainfall changes

[20] For Croatia: Statistic yearbook, Republic of Croatia, 2011. For Savoie:DGCIS, (www/dgcis.gouv.fr/tourisme). For Tunisia, GREVACHOT),
[21] The author is grateful to Clotilde Dubois for her kind help with providing these climate projections from the ENSEMBLES project.

rather than mean annual temperature. Figure 10 focuses on domestic tourists, Figure 11 on international arrivals and Figure 12 on total tourist presences.

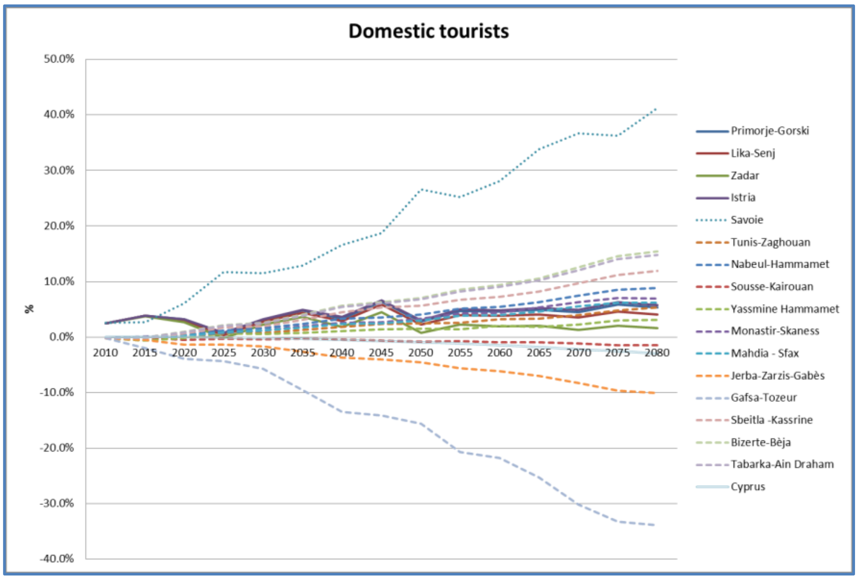

Figure 10: Domestic tourist visits per region. Percentage variation under SRES A1B scenario (averaged over 10 RCM simulations) with respect to no climate change. Domestic tourists are those from any region of origin within the same country. Provincial downscaling of HTM tourist projections for case study locations.

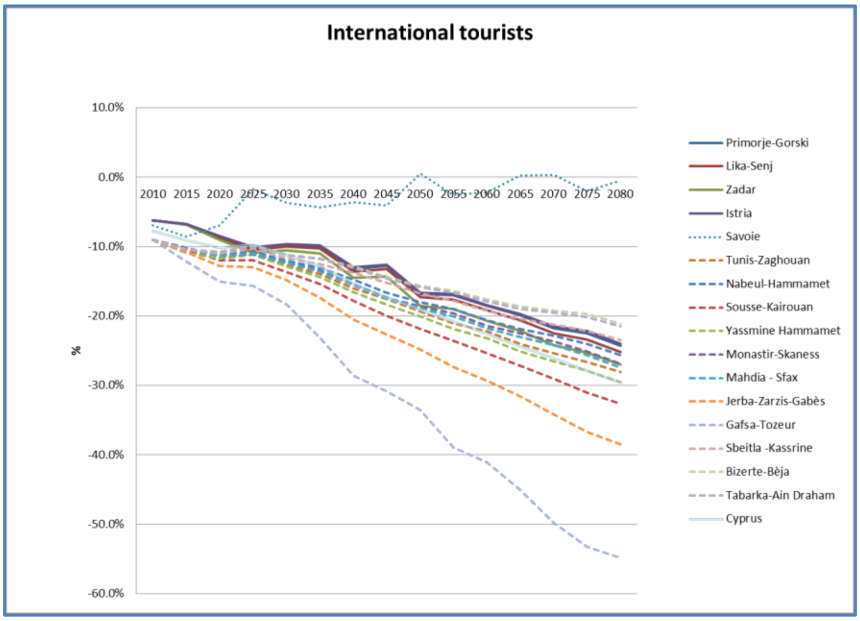

Figure 11: International tourist visits per region. Percentage variation under SRES A1B scenario (averaged over 10 RCM simulations) with respect to no climate change. International tourists are those from outside the same country. Provincial downscaling of HTM tourist projections for case study locations.

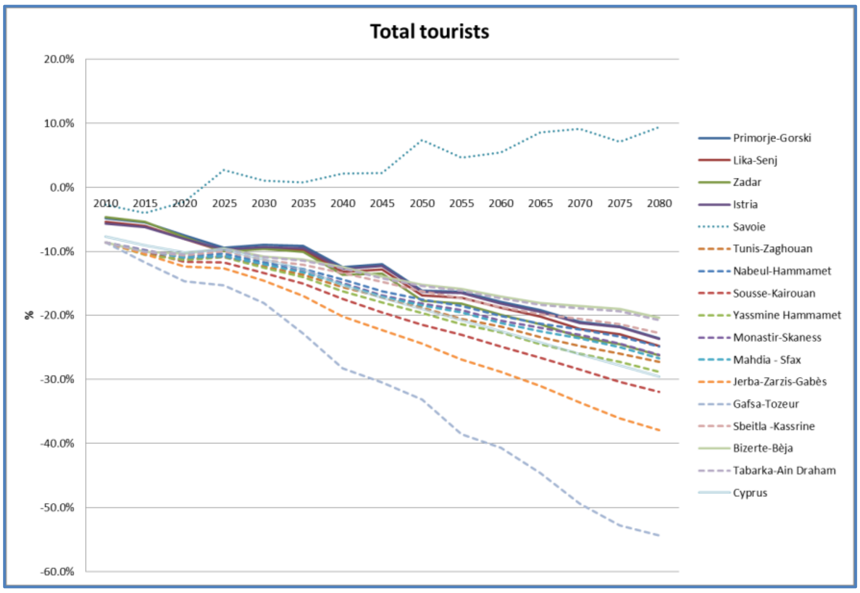

Figure 12: Total tourist visits per region. Percentage variation under SRES A1B scenario (averaged over 10 RCM simulations) with respect to no climate change. Includes both domestic and international tourists. Provincial downscaling of HTM tourist projections for case study locations.

Two important points should be kept in mind.

First, the graphs report percentage changes with respect to the no climate change scenario, and thus the decreases and where present increases must be interpreted in relative terms. In absolute terms, tourist numbers always increase due to demographic and economic growth. Typically, under climate change they increase less than in a world without climate change, and the percentage difference in tourist numbers between these two states of the world is our measure of the impact of climate change on this sector.

Second, complete temperature projections for all locations and all models are available only up to 2080. Therefore, although HTM results cover the whole century, we cut our assessment at 2080.

The comparison between the first two graphs illustrates an important difference between international and domestic tourists. International arrivals tend to dwindle in the first decades of the XXI century and to drop substantially in the later decades. On the other hand, the picture for domestic tourism is more mixed, with Croatia and most Tunisian provinces displaying an increasing share of residents choosing national destinations for their holiday. Only three Tunisian provinces and Cyprus show a consistent negative trend. Time tends to amplify the effect both on domestic tourism and international arrivals. By 2080, most locations are projected to experience an increase in domestic tourists between 1% and 15%, and a

decrease in international tourists between 21% and 39%. Particularly striking is the effect on the Gafsa-Tozeur area, where tourist presence in 2080 could be less than half the one occurring in the no climate change scenario. This is due to the very high temperatures presently experienced and expected in this province located in the inner part of Tunisia.

For Savoie, the HTM projection estimates that higher temperatures will lead to a more pleasant climate and increase in visitor numbers towards the middle of the XXI century. However, as mentioned above, these results should be interpreted with caution due to the importance of winter sports in this region. While it is not impossible that summer temperatures may become more attractive (relative to other destinations) due to climate change, it is difficult to conclude that average annual visitor numbers will increase without undertaking analysis that takes account of seasonal variations in temperature and their effects on winter tourism choices.

Overall, the effect on international tourists prevails and the total effect is negative: In absence of climate change, most locations under scrutiny would have attracted between 20% and 38% more tourists in 2080.

6.3.Concluding Remarks

Our analysis has highlighted substantial adverse effects of climate change at the case study locations in the long run, which can result in visitor number reductions of 20-38% in most locations, with a minimum of 20% and a maximum of 54% respectively in Bizerte-Beja and Gafsa-Tozeur area (excluding the result for Savoie). Given the proportionality between tourist numbers and the revenues of the tourist sector, these impacts are likely to translate into analogous economic losses for the tourist sectors of these areas. Moreover, a quick inspection of Table 7 shows that international tourism dominates the sector at most locations (with the exception of Savoie, international tourist numbers are usually one order of magnitude larger than domestic ones). Thus the strong negative impact on international tourism would have implications in terms of international currencies revenues and in terms of trade balances of the affected countries.

Although substantial and significant, these results must nevertheless be taken with caution. For one thing, these results are based on the sole effect of climate change on mean annual temperatures. Thus they cannot account for seasonal variability and therefore, the adaptation options provided by the adjustment of the tourist season to the changed climate conditions. Nor they can account for other important characteristics of climate that have a bearing on the

comfort of tourists, such as wind and humidity, which are usually considered in approaches based on biometric indexes such as the Tourist Climate Index (Mieczkowski,1985; Amelung & Moreno, 2009), applied also within the Clim-Run project. Nevertheless, they complement the TCI approach nicely, by accounting for the interplay between domestic and international tourism and by providing a comprehensive perspective of global tourist flows and their likely alterations in a warmer world.

7. Case Study: Mediterranean Wildfires

7.1.Introduction

Wildfires are an important part of forest ecosystem dynamics in Europe, contributing to forest renewal and insect & disease control (EEA, 2012). However, they can also cause extensive damage including loss of human life, adverse health impacts and damage to property, infrastructure and land-based industries (Bassi & Kettunen, 2008). Climate is an important determinant of long-term wildfire risk, as noted by Flannigan et al. (2000 and 2009). This section provides an overview of the Fire Weather Index (one of the main methodologies used to quantify the intensity of potential forest fires) as well as exploring the potential future burned area and costs in an A1B climate scenario for Greece and Spain.

Fire danger depends on a number of factors that may be fixed or change over time (e.g., weather, fuel type and condition, forest management practices, demographics, etc.) (Merrill and Alexander, 1987). Even if human activity is considered the main cause of forest fires in Europe[22], the total burned area in Mediterranean Europe, and thus the overall impact of wildfires, varies significantly from year to year especially because of weather conditions (Camia and Amatulli, 2009). Strong winds and high temperatures following prolonged drought periods leads to frequent extreme fire danger conditions in the Mediterranean basin (San-Miguel-Ayanz et al., 2012). These conditions are estimated to worsen in the context of the expected climatic change (Giannakopoulos et al., 2009). These changes in wildfire regimes may have strong impacts on natural resources and ecosystems stability, with consequent direct and indirect economic losses,

In line with the CLIM-RUN wildfires case study the current assessment focuses on Greece. As a term of comparison the projected evolution of fire weather and the estimated damages is also calculated for Spain. Both are considered among the most vulnerable European countries, in terms of climate change fire weather in the Mediterranean basin.

7.2. Methodology

The assessment methodology is based on two main steps:

[22] It is estimated that in European Mediterranean countries more than 90% of forest fires are caused by people (Leone et al. 2009).

1. A meteorological fire danger index is calculated for the selected countries and its future evolution is projected up to 2100 under a climate change scenario;
2. The projected fire danger index is converted into expected burned area according to a statistical relationship calculated from historical data;

7.2.1. Fire Weather Index

The Fire Weather Index (FWI) is a numeric rating of fire intensity, suitable for use as a general index of fire danger (Natural Resources Canada, 2008, Van Wagner, 1987). This index is already widely used in the literature (San Miguel-Ayanz et al. 2003) and it is the fire danger rating system used in the European Forest Fire Information System - EFFIS[23]. The FWI System has six components (see Figure 13): three fuel moisture codes and three fire behaviour indices. Each component has its own numerical scale of relative values, with a high number indicating more severe burning conditions (de Groot).

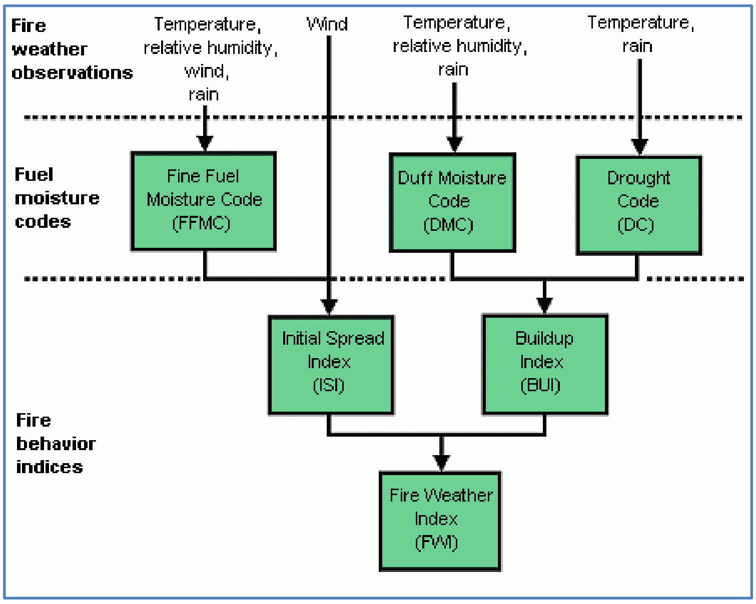

Figure 13: Structure of the Fire Weather Index System
Source: Natural Resources Canada (2008)

The FWI system uses meteorological observations of temperature, relatively humidity, wind speed, and 24-hr precipitation measured at noon in order to predict peak burning conditions expected to occur at around 16.00.

[23] http://effis.jrc.ec.europa.eu/

Figure 14 shows the FWI calculated from regional climate model output running from the recent past (1980) to the end of the 21st century (year 2100). Daily output data from the regional climate model (RCM) RACMO2 developed at KNMI (Netherlands) within the framework of the EU ENSEMBLES project have been used (www.ensembles-eu.org). The model has a horizontal resolution of 25 km × 25 km, uses the A1B greenhouse gases emissions scenario, and is driven by the ECHAM5 global climate model (GCM). For the calculations used to produce the plot in Figure 14, we have taken the yearly average of all daily values of FWI. Subsequently, the national average of all non-sea grid cells covering Greece and Spain has been taken. Though there is high variability, an upward trend can be clearly identified, indicating the impact of climate change in the increase of fire danger for the countries considered. Additionally, it is evident that FWI for Spain starts from lower values than in Greece but increases more rapidly and by the end of 21st century, reaches similar values to Greece.

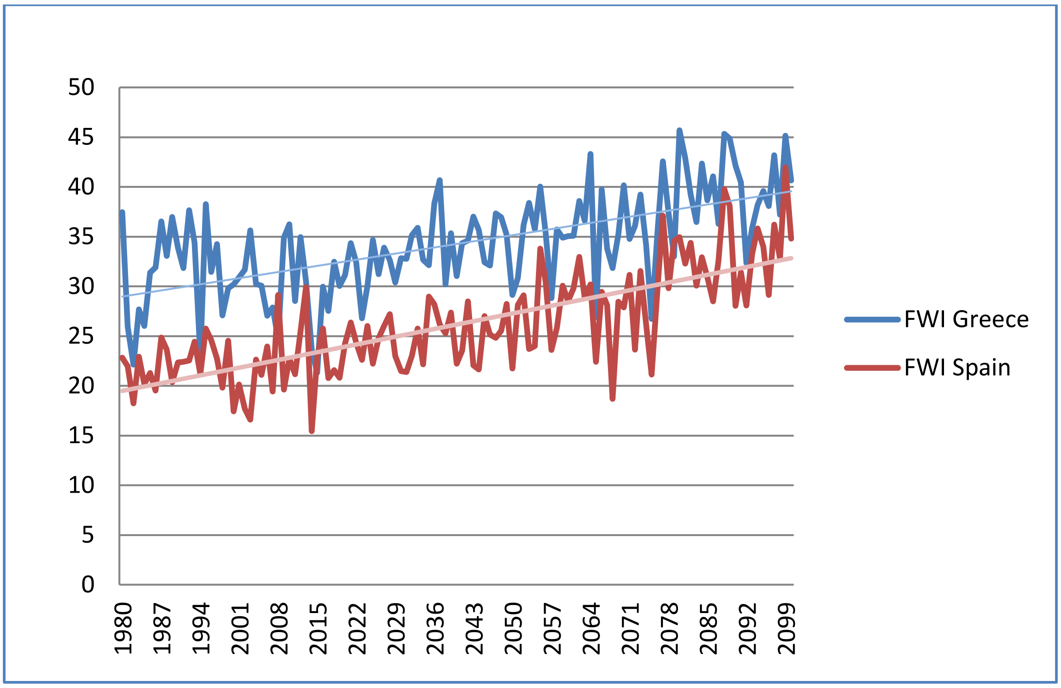

Figure 14: FWI historical observations and projections from a single RCM
Source: Christos Giannakopoulos, WP6. CLIM-RUN wildfire case study

The value of past FWI (1980-2010 average, only summer months) was 31 in Greece, while Spain showed a lower FWI value (21 on average). At the end of the period (2071-2100) the average FWI is expected to increase more for Spain than for Greece, even if the latter still has a higher figure (38 *vs* 32).

7.2.2. Projected Burned Area

Using historical data, a statistical relationship can be established between FWI and forest burned area. Once established, this relationship can then be applied to the projected FWI conditions produced by climate change. Some studies have used a statistical technique known as MARS (Multivariate Adaptive Regression Spline) to establish this relationship (Balshi et al., 2009). This technique is seen as advantageous since it is non-parametric in nature, and is therefore able to capture relationships between the dependent variable and multiple explanatory variables that it would be difficult to reveal with other methods.

However, because of data limitations, we use hypothetical coefficients derived by linear regressions on historical national average values (from 1951 to 2010) to estimate a statistical relationship between FWI and burned areas. We stress that this exercise has only illustrative purposes. Even if the final results are comparable to those found in other works (see Section 7.2.3), the coefficients applied here have very low statistical significance.

The observed annual burned area, averaged over the period 1980-2010, is shown in Table 8 and shows that Spain has a much larger area affected by wildfires then Greece.

Table 8: Observed Average Annual Burned Area

Countries	Average 1980-2010 (ha)
Spain	173,169
Greece	47,309
Total	220,478
Total Mediterranean	471,308

Source: JRC (2011)

As historical observations (as well as projections) of burned area show a large year-to-year variability, it is convenient to compare averages over a sufficiently large time period (20-30 years) in order to appreciate the long-term trend in the wildfire impacts.

In terms of burned area the two countries of the current case study make up almost 50% of the wildfire affected area in the EU Mediterranean region (which includes also Italy, Southern France, and Portugal).

The results of the linear regression analysis are shown in Table 9. This shows the increase in burned area, compared to baseline conditions, that is expected from climate-induced changes

in the FWI. In the two regions combined, increased FWI is expected to lead to an increase in the annual burned area of around 128,000 Ha.

Table 9: Projected burned area (for the A1B scenario and a single RCM run)

Country	Average annual burned area (ha)		
	Current 1980-2010	Projected 2070-2100	Increase
Spain	173,169	290,016	+67%
Greece	47,309	58,156	+23%

7.2.3. Socioeconomic Assessment

A number of studies have proposed methodologies and/or quantified estimates of the socioeconomic loss caused by forest fire. This literature produces a wide variety of values due to the specific characteristics of the areas affected and the valuation methodologies employed. Because of this, we cannot place a robust cost value on the increase in forest fires presented in the previous section. Instead this section reviews the literature that has attempted to quantify economic damages from forest fires in Greece and Spain.

Croitoru (2007) estimates the Total Economic Value (TEV) of Mediterranean forest, producing a value of €173/ha for the Northern Mediterranean region (which covers Greece and Spain). A number of other studies use contingent valuation methods to capture people's willingness to pay for fire protection. These include Varela et al. (2012) for Andalucía and Riera & Mogas (2004) for Catalonia, who find that 63% of people would be willing to pay €6 a year in order to reduce the risk of forest fire by half.

Mavsar et al. (2012) propose two methods of socioeconomic assessment. The first (the Quick Assessment Model) considers the damage to be a product of the restoration cost, restoration period and intensity of the fire — essentially the cost of recreating an equivalent forest asset. The second method (the Analytical Assessment Model) considers damage to be the sum of losses in wood production, non-wood forest products & services, carbon sequestration, soil erosion, biodiversity, and other (extraordinary) costs. Oehler et al. (2012) apply the Quick Assessment Model to Europe and derive cost estimates of up to €78,000 per hectare for the most severe fires.

Barrio et al. (2007) review the estimates of forest fire cost per hectare (mostly related to the United States) and find a range of estimates of €88-500 for loss of wood, €7-291 for tourism, €42-50 for property damage (houses, cars, businesses) and €170-551 for firefighting costs. The

authors then conduct their own estimate of the short-term costs (August-December) created by forest fires in Galicia in 2006, taking into account losses in wood production, bioenergy potential, tourism and CO_2 (direct emissions and loss of potential future incremental carbon storage) as well as firefighting costs and damage to private property. This produces a value of €2,249-3,162[24] per hectare, with the largest contributors being losses in wood production (€856), bioenergy production (€864-928) and the cost of CO_2 emissions (€419-729).

Román et al. (2013) use a similar method, applied to the whole of Spain at 1 km^2 resolution. They value the losses from forest fire as a function of damage to buildings and recreational services, physical harm to humans, and losses in production of wood & non-wood products and recreational services. The losses are not distributed evenly across the territory, with damage to buildings in particular concentrated around areas of wildland-urban interface close to Madrid and Barcelona. At a national average level, they find that the highest monetary losses (by several orders of magnitude) come from damage to buildings, followed by ecosystem services and loss of human life.

In the case of Greece, less literature is available providing quantified estimates of economic damages. Bassi (2008) reports that fires in 2007 caused 76 deaths and health impacts from air and water pollution as well as damage to tourism, livestock and olive oil production (with 78,000 hectares of agricultural land burned in the Peloponnese). The authors also quote an estimate from Standard & Poor's placing total damages at €3-5 billion. On top of this, the national Climate Change Impacts Study Committee (2011) estimates that climate change will require additional expenditure on fire control of €11-17bn[25] by 2050 and €24-78bn by 2100.

7.3. Discussion

This case study takes as its starting point the projected increase in FWI for Greece and Spain calculated as national annual averages for the purposes of this deliverable in collaboration with WP6 wildfires case study. This projected an increase in the index of 7.5 points for Greece and 10.3 for Spain (from a lower starting point). Using linear regression analysis, we estimate this FWI change to lead to an increase in burned area for Greece and Spain of 23% (11,000 ha.) and 67% (117,000 ha) respectively.

The case study has important limitations that have to be made explicit. Firstly, the climate projections come from a single GCM/RCM run and thus do not address uncertainty in the

[24] Lower and upper bounds reflect conservative and less conservative assumptions respectively
[25] Ranges reflect choice of SRES emissions scenario

climate scenarios. Secondly, the assessment makes use of a simple linear regression relationship on national-level data. The small number of observations (not spatially disaggregated) and the impossibility of including additional variables in the statistical model, limit considerably the significance of the relationships calculated. For these reasons we underline that the values found are only illustrative and serve as a numerical example of application of the assessment methodology.

In terms of the socioeconomic value of forest fires, we have seen that a comprehensive assessment would take account of restoration cost, loss of life & health, damage to property and livelihoods and the value of ecosystem services (use and non-use). We have also seen that once these factors are taken into account, the total value of a forest fire is highly case specific, meaning that geographical resolution is an important part of any assessment. In the case of Spain, several studies exist that have attempted to quantify some of these effects on a case-specific basis. Barrio et al. (2007) found that in the case of Galicia, the most costly of these impacts was the direct loss of wood and firewood and the cost of the direct emissions of CO_2. However, in both Spain and Greece further research is needed to produce cost estimates that can be applied more generally.

8. Case Study: Mediterranean Heating & Cooling demand

8.1. Assessing the climate impact on residential heating and cooling

The majority of existing studies about climate change impacts on the energy sector focus on renewable energy production, particularly hydroelectric power related to: changes in rainfall patterns, wind and solar power as a function of wind speed and surface temperature variations respectively (Dowling, 2013); the effect of sea level rise on energy and transport infrastructure; alterations of thermal power plant efficiency and space heating and cooling demand in the residential and services sectors as a result of global temperature rise (Van Vliet *et al.*, 2012; Klein *et al.*, 2013; Dowling, 2013). Several of these studies assess qualitatively these climate change impacts using the POLES energy model (Dowling, 2013; Mima and Criqui, 2009).

The POLES energy model is a simulation tool of the world energy system under environmental constraints. It describes the energy sector at high regional resolution and sectoral detail, and is used to analyse consumption and emission pathways based on the disposability of fossil and renewable energy resources, socio-economic settings, technology evolution and choice, and energy and climate policies. Additionally, it provides details on energy demand, fuel supply, greenhouse gas emissions, international import/export prices and end-user prices (Mima and Criqui, 2009).

The POLES model was improved and further developed in the scope of the FP7 ADVANCE project[26] to account for the climatic dependency of energy consumption for space heating and cooling in the residential sector[27]. The present study makes use of this updated version of POLES to analyse the impact of climate change on domestic consumption in the Mediterranean region. The results of this analysis are presented in the following.

Space heating and cooling are important end-uses of residential energy demand affected by climate. In the POLES model, the projection of space heating and cooling demand is based on the evolution of techno-economic parameters such as energy commodity prices, technology

[26] http://www.fp7-advance.eu/ (accessed on 04 February 2014)
[27] In the frame of the PESETA II project (http://peseta.jrc.ec.europa.eu/) an attempt to capture the climatic effects on the services sector was made (see Dowling, 2013), however for the purpose of this study, only the residential sector will be considered.

choices, efficiency improvements, and the thermal characteristics of the buildings stock. To account for the climatic signal in the demand function, it was necessary to introduce the evolution of heating degree days (HDD) and cooling degree days (CDD). HDDs and CDDs are climate indexes calculated by adding the days within a year during which the daily mean outdoor temperature t_o exceed a certain threshold t_t beyond which heating/ cooling devices are in use. In general, threshold values for heating (t1) and cooling (t2) are the standard values used to define the (average) human comfort zone (15-25°C):

$$HDD = \begin{cases} \sum_{days} (t_{t1} - t_o) \; for \; t_{t1} - t_o > 0 \\ 0 \qquad for \; t_{t1} - t_o \leq 0 \end{cases} \quad and \quad CDD = \begin{cases} \sum_{days} (t_{t2} - t_o) \; for \; t_{t2} - t_o < 0 \\ 0 \qquad for \; t_{t2} - t_o \geq 0 \end{cases}$$

In this study, HDDs and CDDs were calculated for a selection of countries in the Mediterranean region using daily mean surface temperatures from the five CIRCE[28] climate runs. With the contribution of the Climatic Research Unit of the School of Environmental Sciences, University of East Anglia, HDD and CDD indices were re-gridded to a regular 0.5 x 0.5 degree grid and weighted by population data available for each grid cell according to the SRES A1B storyline. The weighting was done to reflect regional variations in consumption due to differences in population density. The temperature thresholds for heating and cooling demand were 15°C (t1) and 25°C (t2), respectively. Historical HDD and CDD data were calculated using observed daily temperature averages (E-OBS[29] version 7.0), whereas for the projection period the climate indices were smoothed out over time using a fourth order polynomial function. No corrections were applied to the CIRCE model data prior to the calculation of the HDD/CDD indices.

The methodology used to model the impact of climate change on residential cooling (exclusively) in the POLES model is based on the previous studies by Isaac and Van Vuuren (2009) and McNeil and Letschert (2007) and is briefly described in the following section. These authors propose to describe residential cooling demand as a function of a climate maximum penetration (CMAX) factor depending on cooling degree days (CDD) and on the air conditioning system ownership rate (AVRES) which depends on income. For a specific region the correlation may be expressed as follows (Isaac and Van Vuuren, 2009):

$$\text{Electricity demand for cooling} = \text{UECRES} * \text{Penetration} * \text{DWL} \qquad (1)$$

[28] see Gualdi *et al*. (2013)
[29] See Haylock *et al.* (2008)

UECRES the annual electricity consumption per equipped household using a typical air conditioning unit (subject to efficiency improvements over time), *Penetration* the evolution of AC system ownership in a given region, DWL the number of dwellings in a given region.

The penetration of AC systems is a function of climate (CDD) and income. This relationship was derived by McNeil and Letschert (2007) and by Isaac and Van Vuuren (2009) through regression analysis using existing data for a set of countries found in the literature. Because the hottest world regions often correspond to the poorest, saturation due to the climate signal alone could not be observed in many countries (McNeil and Letschert, 2007). For this reason the authors had estimated the "climate maximum penetration rate" based on data from various regions in the United States. Thus households in the United States serve as a benchmark regarding the level of penetration of AC systems for a given annual average temperature (CDD) in any country (Mc Neil and Letschert, 2007).

Similarly, McNeil and Letschert (2007) and Isaac and Van Vuuren (2009) estimated *UECRES* (kWh/dwelling/year) via regression analysis with data from 37 countries worldwide. Furthermore, unit electricity consumption is assumed to vary with changing climate conditions and income (richer households will not only purchase more ACs, but will utilise them more, McNeil and Letschert, 2007).

The consumption of energy for heating purposes in residential households is calculated using a linear correlation with the annual temperature gradient. Heating degree days (HDD) are based on a 15°C threshold.

The POLES model with the new, modified cooling demand function as described above is known as the *POLES CLIMRUN* version in contrast with the *POLES PESETA* version, which was used by Dowling (2013)/ PESETA II[27] together with ENSEMBLES[30] climate data.

8.2.Results from the POLES CLIMRUN model

Figure 15 shows results from POLES illustrating the evolution of heating and cooling demand in Southern Europe[31] (left graph) and its correlation with HDDs and CDDs (right graph). To validate the modified cooling demand function in POLES, a comparison was made between the *POLES PESETA* model version run with ENSEMBLES climate data sets by Dowling (2013), the

[30] http://www.ensembles-eu.org/
[31] Bulgaria, Greece, Italy, Portugal, Spain

POLES PESETA version run with the CIRCE MPI climate data set (one RCM) and the *POLES CLIMRUN* model version run with the same CIRCE MPI data.

Discrepancies in the *historical* data (2000 - 2010) of energy consumption for space heating and cooling between the different model versions are the result of data revisions. The variance in cooling degree days between *POLES CLIMRUN* and *PESETA* stems from the different thresholds used to calculate the CDDs (25°C in the former and 18°C in the latter), while the same threshold was chosen in both studies to calculate HDDs (15°C).

The graph in Figure 15 shows that the residential energy consumption in the *POLES CLIMRUN* model version responds well to the corresponding climate signals, and more importantly, that the latter dominate the demand for both heating and cooling.

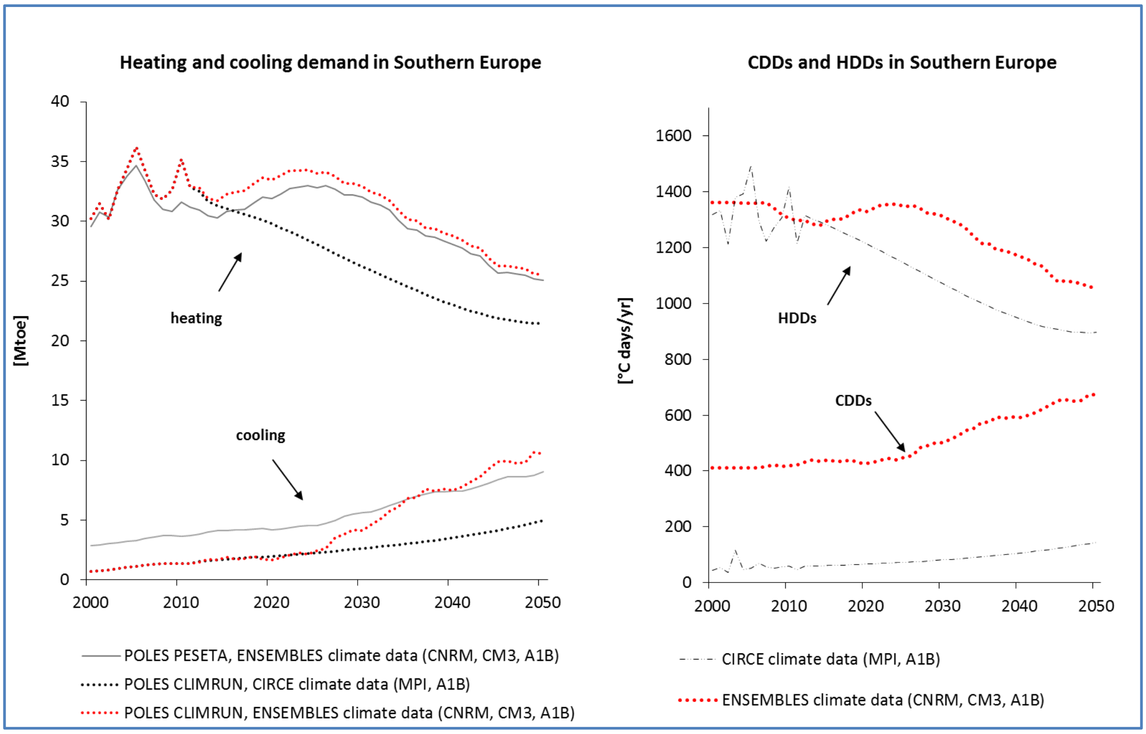

Figure 15**:** Energy demand for space heating and cooling in Southern Europe in response to increasing surface temperatures over the Mediterranean region. Left side shows energy demand (Mtoe). Right side shows CDDs and HDDs (°C days per year)

The overall results indicate that a warming climate will affect cooling demand in Southern Europe in summer through the increased usage of air conditioning systems while in winter the demand for heating will decrease substantially due to milder outside temperatures. The net result in residential energy consumption due to less heating in winter and more cooling in summer appears to be favourable to the household bills in this region since the savings on

heating are projected to offset the increasing demand for cooling. This is consistent with the findings of Dowling (2013), however total savings are expected to be more significant in Northern Europe compared to Mediterranean countries for the reason that in the former region climate change increases the number of degree days close to the comfort zone (18.3°C - ASHRAE, 2009). Because climate data were not available for Northern countries in the framework of CLIMRUN, a direct comparison cannot be made at this time for the purposes of this publication.

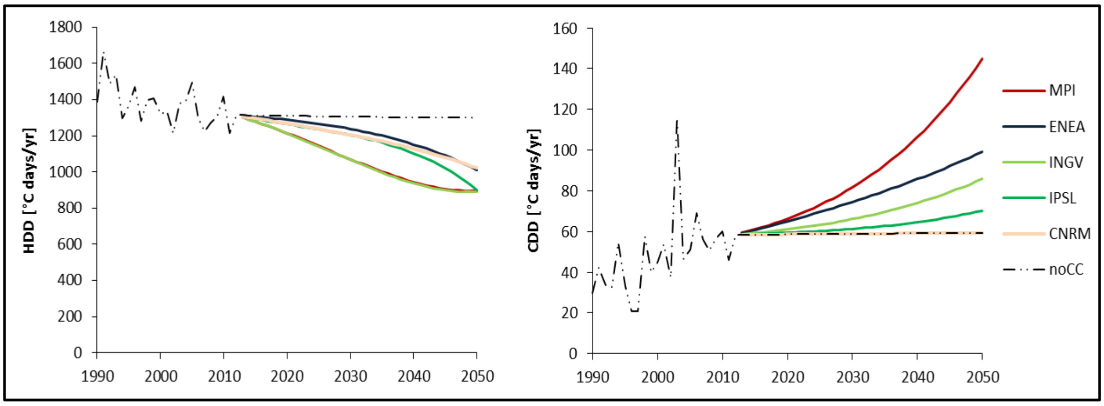

Figure 16: HDD and CDD data (°C days per year) for Southern Europe according to the five CIRCE runs (MPI, ENEA, INGV, IPSL (version 3), CNRM) and the "no climate change" scenario (noCC).

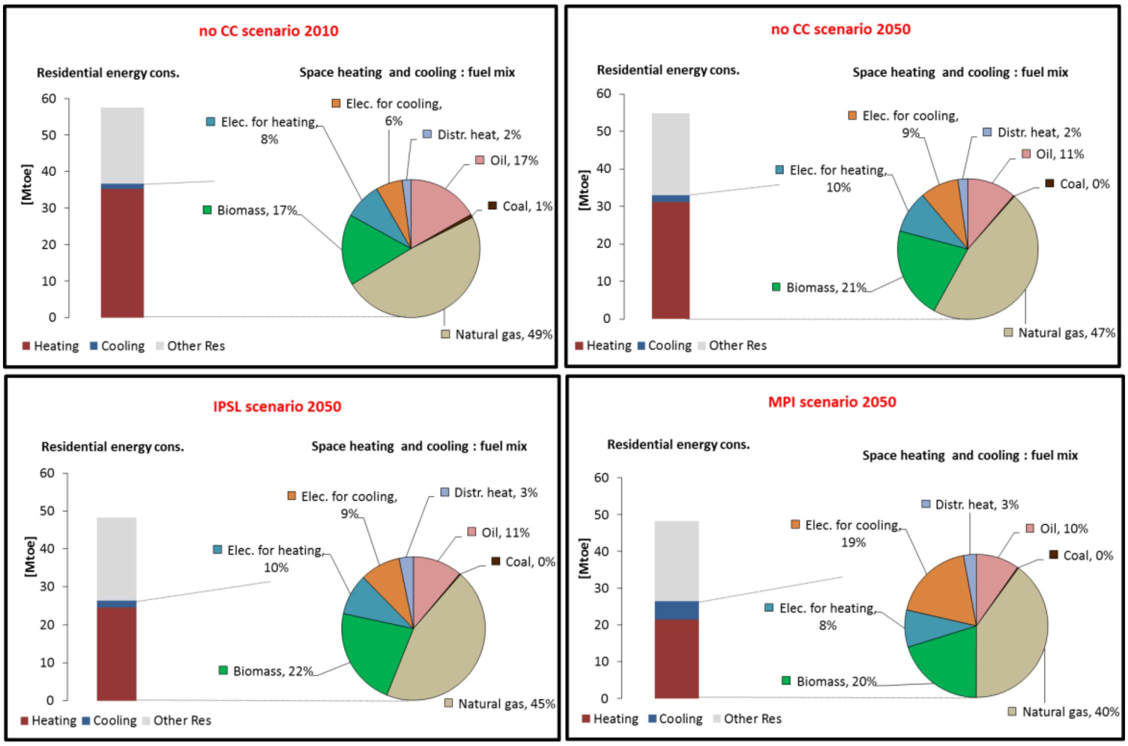

Figure 17: Energy use in residential households in Southern Europe (Mtoe) and fuel mix for space heating and cooling purposes (%) in three different climate scenarios (no change in CDD/HDD between 2010 and 2050, Climrun MPI and IPSL).

The evolution over time of heating and cooling degree days following surface temperature changes in Southern Europe as predicted by the five CIRCE models are shown in Figure 16. The different responses of the energy system to these climate signals are shown in Figure 17 discussed below. MPI and IPSL results are shown because these represent the upper and lower bounds of CDD prediction, with the exception of CNRM which is almost identical to No Climate Change (as Figure 16 shows).

Compared with a baseline scenario where the climate does not vary, a notable change in the fuel mix can be observed in 2050 versus 1990 in scenarios with high average temperature changes such as the MPI scenario. This change is characterised by an increase in electricity consumption in all scenarios due to the increased use of cooling systems. In the MPI scenario, electricity is about 27% of the energy used for space heating and cooling in the average Southern European household. While biomass remains a competitive fuel in 2050, the share of natural gas for space heating is predicted to experience a slight decrease. This might be perceived as an alleviating effect on European energy security issues related to its heavy dependency on natural gas supplies from Russia (in Central Europe), the Middle East and Northern Africa (in Southern Europe). However, the increasing use of cooling devices, particularly during hot summer months will certainly have stringent impacts on electricity peak

demand. This is becoming increasingly problematic in Europe due to high loads, interconnectivity issues, a higher share of renewables in electricity production, water scarcity and prolonged periods of drought that are predicted to become important consequences of climate change, particularly in the Mediterranean region.

On a country-by-country basis (Figure 18), the CLIMRUN results concord with Dowling (2013) whereby in countries with a relatively high utilisation of heating systems, *i.e.* Italy, there is a noticeably stronger impact of climate change versus countries with a relatively low demand for space heating and a high rate of cooling needs such as Spain or Greece. In the example of Greece it may be clearly observed that space cooling strongly influences residential energy needs after 2040 following the MPI and INGV scenarios, both following an upward trend. Conversely, in scenarios where regional warming has a lower impact such as CNRM or IPSL, the overall energy consumption path in the residential sector is dictated by the downward trend of the heating demand in the same time period. This behaviour is typical for a U-shaped dependency of residential energy demand on outdoor temperature as described in the literature (ASHRAE, 2009; Hekkenberg et al. 2009).

In smaller Mediterranean countries such as Cyprus, it may be assumed that both climatic change and space heating and cooling demand occur more homogenously over the entire territory. Cyprus is a good example of how space cooling demand may increase by 2050 to become the primary source of energy consumption in households, exceeding space heating demand. Figure 19a shows that after 2040, the net effect of climate change can be expected to be positive in the Cyprus residential sector (and even more so in the services sector), and that global energy demand in buildings will increase due to cooling needs.

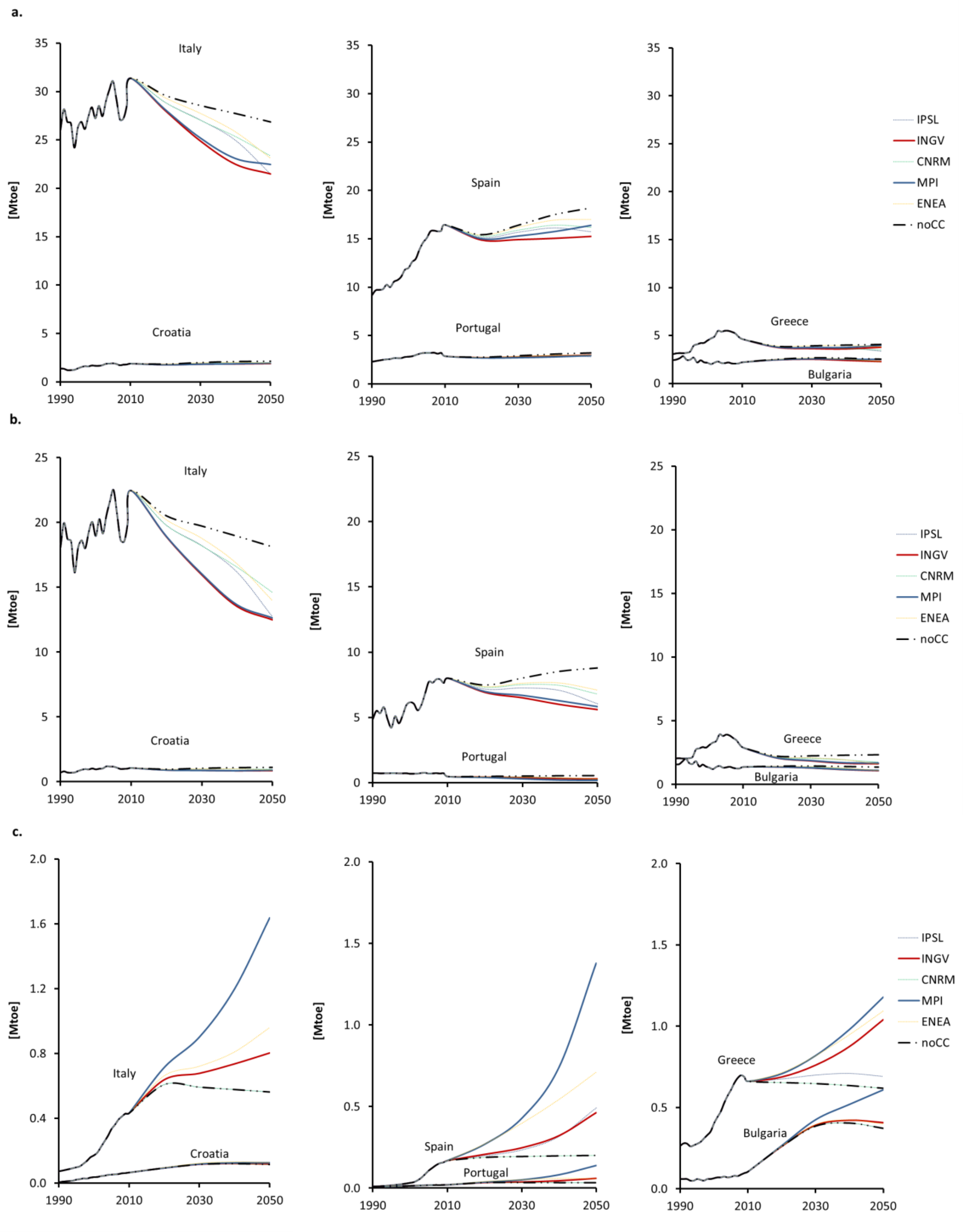

Figure 18: Energy demand (Mtoe) in the residential sector following the "no climate change" scenario (*noCC*) versus the *SRES A1B* scenario results according to the CIRCE runs in Southern Europe by country: **a.** total energy demand; **b.** energy demand for space heating; **c.** energy demand for space cooling.

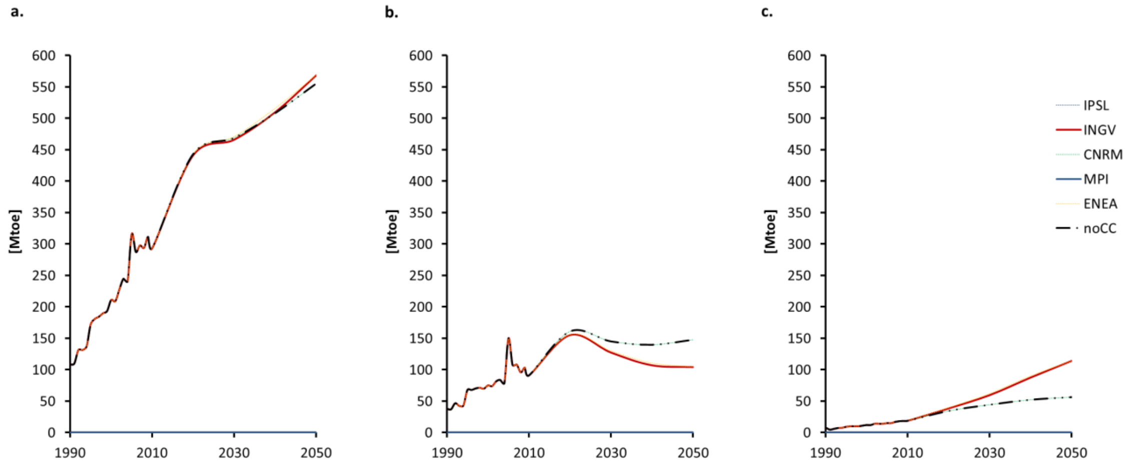

Figure 19: As Figure 18 but for Cyprus

8.3. Caveats and potential for improvement

It is important to note that the results summarised in this publication should be interpreted with a great deal of care. With a view to better these results, various areas of improvement have been identified. Firstly, good data coverage for energy consumption in the residential sector with a consistent split by fuel and end-use (particularly electricity for cooling) is essential. Currently this data is non-existent or of poor quality, even in European and other OECD countries. The calculation of CDDs and HDDs is equally important, and even if weighted by population these climate signals alone do not account for regional differences in customs, human behaviour (including adaptation), the insulation of buildings etc. For example, the relationship between outdoor temperature and indoor comfort could be differentiated by region as was recently proposed by Humphreys et al. (2013). Furthermore, a more realistic representation of the thermal envelope in residential buildings accounting for the characteristics of the present and future stock, building codes and refurbishment incentives would be ideal.

In addition, the economics of climate change presents particular caveats in the underlying assumptions of the POLES model. For example, the correlation describing the fact that in wealthier countries the cost-of-living is higher, which would therefore have a (negative) effect on the penetration rates and consumption rates of air conditioning systems, was not accounted for in this study.

Finally, in order to take better account of uncertainties stemming from climate modelling, it would be desirable to perform the analysis with a larger RCM ensemble (*i.e.* ENSEMBLES) or

more recent climate model runs (*i.e.* the EURO-CORDEX/*MED*-CORDEX simulations). Furthermore, since the CDD/HDD indices are calculated using fixed thresholds, the results are highly susceptible to biases in the model simulations. A simple method of calibrating the indices from model simulations to comparable indices from observed data (i.e., ensuring a smooth transition between the past observed values and future simulate values) was used in this study to help overcome this problem, but a more sophisticated method of first correcting the raw temperature data also needs to be tested, and the effect on the results assessed. It would also be useful to take into account other climate data besides average daily temperature such as relative humidity for example, which is another key factor in human well-being and therefore carries an important weight in the use of heating and cooling devices along with the outdoor (dry bulb), surface temperature. The analysis presented here smooths out year-to-year variability which may also be important for planning and management purposes.

9. Closing Remarks

This report has provided a review of existing methodologies for assessing the socioeconomic impacts of climate change and the potential benefits of adaptation. It has examined the different ways in which climate change impacts have been assessed at different geographical and sectoral resolutions, as well as reviewing the literature on the value of climate information and climate services.

The main conclusion from this review is that there is some disconnect between the scientific and high-level economic evidence of impacts (which is relatively abundant), and the relative scarcity of studies demonstrating: i) how this evidence can be converted into meaningful adaptation support for real-world actors; and ii) what the value of this type of information would be.

On the one hand, the high-level studies described in Section 2 continue to take place alongside studies that have a finer sectoral or geographical detail (such as those described Section 5 and the case study sections 6-8). In addition, studies at all resolutions have begun to provide advice on adaptation as well as impacts (Section 4).

On the other hand, very little peer-reviewed literature appears to exist concerning the ways in which users in real life can make use of such information (*i.e.* the value of climate services). Section 3 identified studies on the value of meteorological information in general, both in terms of quantitative techniques and frameworks examining the usefulness of information to different types of user. However, the review was unable to find any study that distinguished climate services from other categories of meteorological information.

If climate services are to make a major contribution to improving people's adaptive capacity, it is important to identify where such services can add value (in terms of improvements in adaptive capacity and adaptation outcomes); which types of actors are capable of using them (*e.g.* is the information usable by households and firms autonomously or does it require some sort of collective or governmental action?); and therefore what form such services should take.

10. Glossary

During the drafting of this report, the authors have attempted to define key terms at the point where they first appear in the document. For any terms that are not explained adequately, we refer the reader to the glossaries provided by the Intergovernmental Panel on Climate Change (IPCC).

http://www.ipcc.ch/publications_and_data/publications_and_data_glossary.shtml

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