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Impacts and adaptation to climate change in European economies

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ABSTRACT

This paper evaluates the impacts of climate change to European economies under an increase in global mean temperature at +2 °C and +4 °C. It is based on a summary of conclusions from available studies of how climate change may affect various sectors of the economies in different countries. We apply a macroeconomic general equilibrium model, which integrates impacts of climate change on different activities of the economies. Agents adapt by responding to the changes in market conditions following the climatic changes, thus bringing consistency between economic behaviour and adaptation to climate change. Europe is divided into 85 sub-regions in order to capture climate variability and variations in vulnerabilities within countries. We find that the impacts in the +2 °C are moderate throughout Europe, with positive impacts on GDP in some sub-regions and negative impacts down to 0.1 per cent per year in others. At +4 °C, GDP is negatively affected throughout Europe, and most substantially in the southern parts, where it falls by up to 0.7 per cent per year in some sub-regions. We also find that climate change causes differentiations in wages across Europe, which may cause migration from southern parts of Europe to northern parts, especially to the Nordic countries.

1. Introduction

The Conference of the Parties of to the United Nations' Framework Convention on Climate Change (UNFCCC) agreed in Copenhagen in 2009 to keep the increase in global mean temperature below +2 °C, and agreed in Cancún in 2010 to consider a further restriction to +1.5 °C. Economic studies undertaken years ago (Nordhaus, 1991; Fankhauser, 1995; Tol, 1995), has shown that the economic benefits of implementing the policies needed to reach such a target are far from sufficient to cover the corresponding costs of cutting emissions. An exemption is Stern (2006), who concluded that immediate and radical cuts in emissions are urgent. The different conclusions among economists do not mainly arise because of different assumptions about the costs of abatement or impacts of climate change. The disagreement is about the choice of discount rate, which is a key to the evaluation of costs and benefits in the approach taken. The focus on the choice of discount rate may explain why there have been relatively few studies on economic impacts of climate change in later years.

Traditional cost-benefit analyses are hampered with severe weaknesses when applied to evaluations of activities with an infinite time horizon, such as emission of greenhouse gases. Aaheim (2010) shows that instead of comparing discounted costs and benefits, climate policy should rather be evaluated with reference to optimal stabilization levels. As it turns out, the optimal stabilization level is subject, first and foremost, to the costs of emissions control and the impacts of climate change, while the discount rate is less important. Hence, assessments of impacts of climate change are essential also in economic analyses, regardless of what one might think about the discount rate.

Macroeconomic modelling studies undertaken to assess the economic consequences of climate change can be broadly categorized in two traditions. One is to estimate the total cost of damage with or without adaptation, and subtract these from the economic values generated without climate change (Nordhaus and Boyer, 2000; Tol, 2002). The other, more recent, tradition applies general equilibrium models, where the impacts of climate change are attached to specific sectors of the economy. The impacts may be represented by damage functions broken down to sectors (Jorgensen et al., 2004; Eboli et al., 2010), or one may integrate micro-based models or results from bottom-up studies (Ciscar et al., 2011b) to distinguish consequences in various sectors of the economy. Climate change then initiates sector substitution due to variations in impacts between sectors. This adaptation is not captured by models that apply aggregated damage functions.

The objective of this study is to assess the macroeconomic impacts of climate change in Europe under a global warming of +2 °C and +4 °C. We build on the second tradition of modelling, but take the specification of impacts of climate change two steps further. First, instead of applying damage functions to sectors, we

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attach impact functions to the specific activity within a sector that will be directly impacted by climate change. For example, climate change will affect the productivity of agricultural land, but not, or at least not to the same extent, those who work on the farms. Hence, different impact functions are used to represent impacts to land and possible impacts to workers. Then, the economic behaviour described in our model is utilized to address (autonomous) adaptation in terms of factor substitution within sectors, similar to how responses to changes in other constraints on economic activities are described. A closer description of the method is given in Aaheim and Schjolden (2004). The impact functions are estimated on the basis of available studies.

The second development in this study is to break regions and countries down to sub-regions. General equilibrium models are usually constrained to national aggregates by their use of national accounts data. At the same time, climatic changes, their impacts and opportunities for agents to adapt may differ substantially over small distances. Moreover, market responses to climate change add to the challenges related to adaptation (Goldhar and Ford, 2010), and market responses may differ depending both on the local climatic changes and on the mobility of the factors of production. To capture some of these variations, this study breaks Europe down to 85 sub-regions.

We use the computable general equilibrium model GRACE (Aaheim et al., 2009) to estimate the economic impacts of climate change under two states of the climate in some future year. In one case, the increase in global mean temperature is +2 °C. In the second case, the increase in global mean temperature is +4 °C. The resulting climatic changes for the different regions in Europe are based on the results of the PESETA study (Christensen et al., 2007). Hence, the results are to be interpreted as snapshots of the European economies under different climate futures.

The paper is organized as follows: Section 2 gives a brief survey of economic impacts of climate change in Europe, based on results of available studies. Section 3 discusses the relationships between selected climate indicators and economic impacts, and presents the methodology underlying the integration of impacts and adaptation to climate change. The main results are discussed in Section 4, while Section 5 concludes.

2. Economic impacts of climate change in Europe

This study is based on available literature on impacts of climate change in Europe. There are a number of difficulties in undertaking such an analysis. First, there is a large number of studies, of which few refer to the same climatic parameters and the same socioeconomic futures. Second, studies of impacts have gradually become more specialized, from general studies of impacts in broad sectors and industries towards impacts on specific activities and recipients. Third, the different European regions are covered to very different extents by impact studies, making comparison between countries difficult. Fourth, studies show that impacts and adaptation depend on local characteristics, while general patterns needed for assessments on the national and regional scale are less highlighted. Fifth, numerical estimates directly applicable for economic assessments are relatively scarce.

To deal with these problems, the impact estimates integrated in the model were established in two stages. In the first stage, available literature was surveyed in order to make a numerical assessment of the impacts by economic sector and region with reference to a given shift of climate. The second stage comprises estimation of impact functions by sector. This section summarizes our interpretations of the outcome of available studies. Section 3 presents the estimation of impacts functions.

2.1. Climatic changes in Europe

Results from available studies were used to assess the impacts on each of the eleven economic sectors represented in the GRACE model. The sectors are affected by climate change in different ways and to different extents, and can be categorized into the following activities: impacts to the productivity of natural resources in agriculture, forestry, fisheries and the electricity sectors, the demand for tourism and energy, and loss of real capital and labour related to natural hazards and sea level rise.

In order to establish a point of reference for the assessment of climate change impacts we have used a climate scenario from the PRUDENCE project (Christensen et al., 2007), based on the IPCC A2 global emissions scenario (Nakicienovic and Swart, 2000). This scenario was also used by the PESETA project (Ciscar et al., 2011a,b), and projects an increase in global mean temperature of +3.1 °C for the period 2070–2100, compared to the control period 1961–1990. The corresponding changes in climate parameters for the eight geographic regions in GRACE are shown in Table 1. The temperatures are expected to increase between +2.5 °C in British Islands and +4 °C on the Iberian Peninsula. The changes in per year precipitation range from −25 per cent in Iberia to +13 per cent in the Baltic states. The minimum and maximum columns show the corresponding variability across the sub-regions.

2.2. Sector specific impacts of climate change in Europe

Productivity in both the agricultural and the forestry sectors depend heavily on climatic factors. Impacts to agriculture are particularly important because the value added to GDP is relatively high in many countries. In the Baltics and Central Europe East, the value added from agriculture is more than 15 per cent of GDP, while less than 10 per cent in the other regions. In most regions, crops contribute more than 50 per cent of the agricultural output,

Table 1
European regions in GRACE and projected changes in mean temperatures and precipitation corresponding to an increase in global mean temperature of +3.1 °C for the period 2070–2100.

Region	Comprises	Change in (annual means)					
		Temperature °C			Precipitation per cent		
		Avg.	Min	Max	Avg.	Min	Max
Baltic states	Estonia, Latvia, Lithuania, Poland	3.4	3.3	3.8	10.5	7.5	25.0
British Islands	United Kingdom, Ireland	2.7	2.3	2.8	0.0	0.0	0.0
Centr. Europe East	Czech. Rep, Slovakia, Hungary, Romania, Bulgaria	3.8	3.3	4.3	−3.4	−15.0	7.5
Centr. Europe North	Austria, Germany, Switzerland	3.3	3.3	3.8	4.5	0.0	7.5
Centr. Europe South	Greece, Cyprus, Italy, Malta, Slovenia	3.9	3.8	4.3	−10.5	−30.0	7.5
Centr. Europe West	Belgium, France, Netherlands, Luxembourg	3.3	2.8	3.8	0.7	−7.5	7.5
Iberian Peninsula	Spain, Portugal	3.8	3.3	4.8	−24.0	−30.0	−15.0
Nordic Countries	Denmark, Finland, Sweden, Iceland, Norway	3.5	3.3	4.3	9.4	0.0	15.0

Source: Ciscar et al. (2011a,b).

while livestock contribute between 34 and 46 per cent. Fruit and vegetables have the lowest share in all regions, but are still above 10 per cent in Baltic, and in wine producing regions. The forestry sector plays a less prominent role to the European economies, contributing to less than 1 per cent in all regions. However, along with the agricultural sector, forests also provide important services beyond their economic contributions.

Crops and forests are impacted by climate change through growth conditions and the length of growth season. Livestock may be affected by diseases and heat stress, while climatic changes may affect the quality of fruit and vegetables, which is particularly important for wine producers. Both agriculture and forestry may also gain some from the so-called fertilization effect of CO_2-concentrations up to a temperature increase of 2–4 °C (Kimball et al., 2002; Long et al., 2004).

There is a large literature on impacts on crops in European countries. Most studies conclude that northern regions will gain (Alcamo et al., 2007), mainly because of temperature increases, while less rain will lead to losses in southern regions (see e.g. Iglesias et al., 2012). The impacts to livestock and fruit and vegetables are less studied, but losses are expected, particularly in the Baltics (Stuczyinski et al., 2000). All in all, the impact to the agricultural sector in Europe is expected to be negative, mainly due to impacts on crops of less precipitation, in particular in southern parts (Giannakopoulos et al., 2005; Jones et al., 2005). The impact of climate change on forests is expected to follow the same pattern as productivity in agriculture, with gains in northern and eastern regions, and with losses in southern regions (see e.g. Fronzek and Carter, 2007). The composite of species will also be affected. Coniferous trees are likely to replace deciduous trees. Further, forested area will change with higher temperatures and expand north and towards higher altitudes (Kellomäki et al., 2000).

Fisheries represent an essential economic activity in several coastal areas of Central Europe South, Iberia and the Nordic countries, but its importance for local communities does not come through in the regional aggregates. In most regions, it contributes between 0.05 and 0.25 per cent of GDP. The exceptions are Iberia and Central Europe South, where fisheries contribute 0.4 and 0.8 per cent, respectively. These figures include fish farming, which tends to become more important the further north we come. The location of fish stocks is known to be very sensitive to sea temperatures, but it is difficult to predict where they will move. Also the size of stocks may be affected, but to which extent depends on where the stock moves. With climate change and resulting impacts on sea temperature migration of stocks northwards is expected with benefits to the northern regions. Substantial losses are expected in the Mediterranean and to Iberia (Perry et al., 2005), while the expected overall effect in Western Europe and British Islands are negative. The uncertainties are large, though. Higher temperature means increased risk of diseases, implying that the impacts of higher sea temperature on aquaculture are unequivocally negative.

The electricity sector is essential to all countries, and its importance tends to be inversely correlated with income per capita. In most of Europe, fossil based power plants contribute between 80 and 95 per cent of total supply. The Nordic countries are an exception, as hydropower dominates with 56 per cent of total production, and only 37 per cent is generated by fossil fuels. New renewables, mainly biomass and wind, contribute between 1 and 8 per cent in European countries. The highest shares are found in Central Europe North, Iberia and the Nordic countries (IEA, 2005).

Impacts of climate change on energy supply depend on the source of energy. Supply of renewables is closely related to the climate. For wind power, however, it is difficult to estimate impacts, because predictions of wind are unavailable or extremely uncertain. Also fossil fuelled plants and nuclear power will be affected by the availability of cooling water. Cost estimates are unavailable, but we include a negative change in the supply of fossil electricity in all regions, based on Arnell et al. (2005) and Lehner et al. (2005). In the Nordic countries, a combination of more precipitation and a high share of hydropower is expected to increase the supply of electricity with 15 per cent (Lehner et al., 2005).

The demand for energy is affected by temperatures to the extent that energy is used for cooling and heating. What dominates depends on the prevailing temperature, and the sensitivity is usually based on measures of degree days, which combines daily mean temperatures and number of heating and cooling days per year. Simpler estimates of temperature elasticities based on De Cian et al. (2007), which refer to the variations in annual energy use and annual mean temperatures are available, and applied in this study. The climatic changes shown in Table 1 lead to a reduction in the demand of gas between 6 (Iberia) and 15 per cent (British Islands). The demand for refined oils declines by between 0.5 (C.E. East) and 2.7 per cent (C.E. North). Electricity demand falls by approximately 1.5 per cent in all regions expect C.E. South and Iberia, where it increases by approximately 3 per cent.

Climate change is expected to affect the choice of tourists' destinations significantly (Hamilton et al., 2005; Amelung and Moreno, 2007). However, uncertainties are large. Little is known about the relationship between climate and choice of destinations, except typical beach holidays destinations. Also winter resorts will be affected, but with unpredictable effects. Estimates of the economic impacts on tourism also suffer from a lack of reliable information of which and to what extent economic activities are stimulated by tourism.

Here, we assume that tourism affects the service and the transport sectors, to an extent depending on the magnitude of tourism in the region. Tourism is expected to decrease in the southern regions of Europe as a result of warmer and drier summers (Hamilton et al., 2005). These are regions with an intensive tourist industry. In all the other regions, tourism is expected to increase significantly. Some of the explanation is that citizens from these regions to a greater extent prefer to spend their holidays within their domestic region. For other regions than those two in southern Europe, international tourism is expected to decline moderately in all regions except Central Europe North and the Nordic countries.

In addition to the sector specific impacts, climate change will also have crossover effects, such as damages related to extreme events, sea-level rise and health effects with economic consequences both for the health sector and for the supply of labour. The costs of sea-level rise in this study apply Tol's (2002) estimate of 1700 mill USD for all of Europe. This estimate is distributed in accordance with approximations of coastline, low-lying areas and population by sub-region. Nearly 670 mill accrue on C.E. West, while the costs to the British Islands are more than 370 mill USD. For the other regions, the costs of sea-level rise at 1 m are less than 200 mill USD per year.

National estimates of material damages of natural hazards are difficult to find. Our estimates are based on Swiss Re (2011) and assume that the frequency of natural hazards doubles at the increase in global mean temperature of 3.5 °C. The resulting costs correspond to a reduction between 0.4 (Nordic countries) and 1.2 per cent (Iberia) of the stock of real capital in European regions.

Climate change will also have health effects, with economic consequences both on the supply of labour and on the demand for health services. National estimates were unavailable when the study was carried out, however, and possible impacts on health are therefore excluded.

Table 2
Summary of applied estimates of impacts at an increase in global mean temperature of +3.1 °C for the period 2070–2100. Per cent of respective activity.

Sector	Agric	Forest	Fish	El.-supply	Energy demand				Tourist	Extr. events	Sea level rise
					Electr	Gas	Ref oil	Total			
Activity	Nat res	Nat res	Nat res	Prod. techn.	Serv & h.hold	Serv & h.hold	Serv & h.hold	Serv & h.hold	Households	Capit.	Capit.
Baltic states	−0.5	3.5	25.3	1.3	−1.3	−10.1	−1.0	−5.4	11.5	−0.7	−0.02
British Islands	−8.4	1.1	−4.8	0.2	−1.2	−14.6	−0.7	−10.1	11.8	−0.6	−0.02
CE East	−1.5	−5.1	−4.6	−3.8	−1.4	−11.9	−0.5	−8.3	6.1	−1.2	−0.02
CE North	3.1	1.9	7.3	−2.0	−1.3	−14.4	−2.7	−6.9	12.9	−0.5	−0.01
Southern Europe	−2.6	−8.3	−50.0	−3.5	2.9	−13.8	−2.0	−7.1	−1.4	−0.6	−0.01
CE West	−5.1	−7.2	−12.4	−1.2	−1.4	−11.1	−1.6	−5.8	2.3	−0.5	−0.02
Iberia	−11.1	−18.5	−51.5	−1.6	3.0	−5.6	−1.1	−0.3	−4.9	−1.2	−0.01
Nordic	15.6	29.2	14.1	15.1	−1.7	−8.1	−1.0	−2.0	17.5	−0.4	−0.01

Referring to the discussion above, Table 2 summarizes the estimates of impacts by region on which this study is based. For some activities, separate numbers were made for each country. A closer description of this assessment is given in Aaheim et al. (2009). The numbers are per cent change of activity, and the activities are indicated in the header of the table. Thus, the numbers are not to be interpreted as the change in total output or total demand. For example, the per cent change in agriculture shows the impact on the productivity of the land in agriculture. Demand for energy is assumed to affect only the service sector and household demand, while the numbers for extreme events and sea-level rise refer to the loss of capital.

3. Integration of impacts and adaptation in the model

The GRACE model (Aaheim and Rive, 2005) is a standard multiregional computable general equilibrium model based on a set of Constant Elasticity of Substitution (CES) production and preference trees, using the GTAP version 7 social accounting matrices (Badri and Walmsley, 2008). The version of GRACE applied in this study was developed to address impacts of climate change and economic aspects of adaptation. Economic effects of climate change are integrated by their impacts on deliveries in an extended input-output matrix based on the national accounts, as described by Aaheim and Schjolden (2004). The basic idea is that economic behaviour described in general equilibrium models captures important parts of the responses to climate change among economic agents. To draw advantage of the modelling of economic behaviour, the impacts have to be attached to specific economic activities affected by climate change, as indicated in the header of Table 2.

However, adaptation is a process with many barriers, which are partly related to the need for time to adapt. General equilibrium models suppose in principle that adaptation happens instantly when resource constraints shift, technologies change or new information arrives. To study adaptation to climate change, one therefore needs to consider how possible macroeconomic consequences of these barriers can be represented.

3.1. Integration of impacts of climate change

The impacts of climate change can be divided into three categories:

(1) Changes in the availability of primary input, labour, capital and natural resources;
(2) Effects on production technologies;
(3) Changes in demand to sustain the level of welfare.

The first category comprises the productive resources of the economy. The productivity of many natural resources can be linked directly to the climate, such as agricultural and forested land and the life in the seas. Other impacts are direct economic costs of climatic events. An increase in the frequency of natural hazards will damage the stock of capital, imply costs of rescue operations and lead to halt of economic activities. Sea-level rise destroys buildings and infrastructure and change options for land use. The effects on production technologies include changes in the minimum input required to produce one unit of output in the sector. For example, higher temperature may increase or lower energy demand in production sectors depending on whether the main effect is more cooling or less heating. Final demand of goods and services are subject to similar effects, but then the change in demand is motivated by sustaining the level of welfare.

The functional forms of the impact functions were chosen to allow one single set of parameters to represent impacts on one activity in all of Europe. This means that the same impact function was used to represent impacts in all sub-regions of Europe. To parameterize the functions, we applied “observations” derived from the studies discussed in the previous section, broken down to the 27 European countries included in the study. An alternative procedure would be to establish country specific impact functions. This may sound more realistic, but few, if any, countries have been studied to such an extent that an impact function can be estimated with reference to more than one or two studies. Hence, the functions would basically reflect the results of single studies, without any statistical evaluation of the parameters. The approach

Table 3
Estimates for constant parameters of four linear impact functions in per cent change of activity in GRACE. Standard deviation in parenthesis (number of observations: 27).

Sector	Affected activity	dT	TdT	dT^2	dP	Hydro share	R^2
Agriculture	Productivity of nature (land)		−0.00248 (0.00534)	0.00923 (0.00534)	0.22125 (0.17736)		0.49
Forestry	Productivity of nature (land)			0.00333 (0.00173)	0.00717 (0.00152)		0.46
Electricity supply	Total output	0.00612 (0.00337)			0.00331 (0.00439)	−0.39 (0.12)	0.88
Tourism	Demand for services and transport	0.08678 (0.0141)	−0.00720 (0.00133)		−0.16909 (0.13615)		0.82

Table 4
Temperature elasticities by energy carrier and region based on De Cian et al. (2007).

Comprises regions	Energy carrier		
	Electr	Gas	Oil prod
Northern regions: Baltics, British, CE East, CE West, CE North, Nordic	−0.38	−2.6	−1.43
Southern regions: CE South, Iberia	1.00	−2.8	−1.46

taken here enables an evaluation of the choice of functional forms, and contributes, moreover, to neutralize results from possible "outlier"-studies. This conforms better with the idea of summarizing and synthesizing results from impact studies.

The impacts on four of the activities (production in agriculture, forestry and electricity sectors and the demand for tourism) are expressed as functions of changes in annual mean temperature (dT), the product of temperature level and temperature change (TdT), the quadrat of temperature change (dT^2) and per cent change in annual precipitation (dP). Variability and seasonal changes are essential to the impacts of climate change, but few studies provide sufficient information to be useful for our purpose. Possible refinements to include this therefore had to be ignored.

Table 3 shows the estimates and the statistics for the four activities. Open cells means that the parameters are set to zero. Electricity production is affected partly by costs related to cooling (Eskeland et al., 2010) and to a change in the potential for hydro power production. The share of hydropower production in a country is therefore included as an explanatory variable in the electricity sector. Tourism is not a sector in GRACE, but the direct impacts on tourism are represented by country specific shares for contributions from tourism to the transport and service sectors.

By including the product of temperature level and temperature change as an independent explanatory variable, it is possible to distinguish between impacts of a given change in "cold" and "warm" regions. A negative parameter to this product combined with a positive term on temperature change, for example, means that the impact may turn from positive impacts in a cold country to negative impacts in a warm country, such as for tourism. A similar effect is found in agriculture, whereas the gain from a combination of higher precipitation and temperature increases the warmer the country is. As expected, the significance of many parameters are weak, but perhaps not as week as one might expect, taking into account the fragmented knowledge about impacts of climate change and the variability of countries across Europe.

For four activities (production in fisheries, energy demand, and the supply of labour and capital) the impacts are described by separate impacts functions. For fisheries, we distinguish between ocean fisheries and fish farming by inclusion of the share of sea fishing in the region s_r. As for agriculture and forestry, both sea fishing and fish farming are affected by a change in the productivity of the natural resource (dX_{fish}), and relates to the deviation of the actual (air) temperature in the region (T_r) from an ideal (air) temperature in the region (T_{sr} = 10 for sea fishing and T_{fr} = 5 for fish farming). The impact function is:

$$dX_{fish} = a_{sr}s_r(T_r - T_{sr})dT + \alpha_{fr}(1 - s_r)(T_r - T_{fr})dT \tag{1}$$

where α_{sr} = 0.025 and α_{sr} = 0.02 are the impact parameters, and dT is the average change in air temperature in Europe. In other words, we do not distinguish regional variations in the change of air temperature. It must be noted that these parameters are chosen without support in other studies, as we have found no numerical estimates of impacts to fisheries.

Impacts of higher temperatures on energy demand in the residential sector will differ depending on the extent to which energy is used for heating and cooling. Hence, the effect is expected to differ across regions, as shown by the temperature demand elasticities displayed in Table 4. The elasticities for the central and northern regions are equal, and different from the elasticities in the two southern regions.

The six functions above address sector specific impacts of climate change. Other impacts, such as extreme events and sea level rise cause damage across sectors to the built environment (real capital) or result in human injuries and loss. They may have serious consequences in smaller communities although the macroeconomic effects may be limited. In this study, an estimate of damages from sea-level rise and extreme events is included as expected loss of real capital in a region. Damages from extreme events are based on observed damages from weather related extreme events over the period 1980–2008, shown in Fig. 1. There is limited knowledge about change of intensity and resulting damages from extreme events under increasing global mean temperature. Here, a quadratic function of temperature rise is simply calibrated under the assumption that +3.1 °C global warming causes a doubling of extreme event frequencies. There are apparent weaknesses in such a simplification. For example, extreme events are more often a result of extreme precipitation than of temperature. The reason for using temperature is partly that it is used as the independent variable in most other integrated studies where little is known about the impacts. Projections of precipitation are also considered more uncertain, and there are few studies with projections of extreme events based on precipitation data.

The costs of sea-level rise are also assumed to be a quadratic function, however referring to the increase of sea-level. The constant term γ_r is calibrated on the basis of the distribution of total costs to Europe at 1 m sea-level rise described in the previous section, which refers Tol's (2002). The total impact of climate change on the capital stock then relates to the increase in mean temperature and to the increase of sea-level in the following way:

$$dk_r = \beta_r dT_r^2 + \gamma_r N_r(\varepsilon a_r + \eta L_r)dS_r^2 \tag{2}$$

where dk_r is the change in capital stock, dT_r is temperature increase in the region, N_r is the estimated population in the region, a_r and L_r are coastline and low-lying areas, respectively, while dS is sea-level rise. The parameter β_r is the calibrated parameter for extreme events. We have set the parameters ε and η to one, while γ_r is chosen such that the sum of all damages from sea-level rise equals the estimate for total costs for Europe when dS = 1.

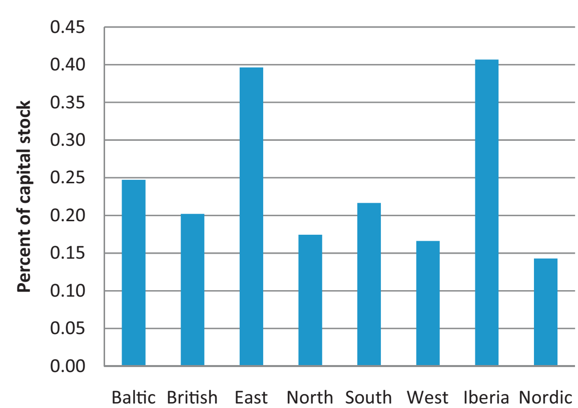

Fig. 1. Average damage from weather related extreme events (1980–2008) in per cent of capital stock by region.
Source: Swiss Re (2011).

3.2. Adaptation and barriers

Sectors and regions in GRACE are aggregated across many firms and many individuals. For example, "technologies" are described as the composite of input needed to produce one unit of output from the sector aggregate. The explicit adaptation that takes place in the model is, strictly speaking, limited to the adaptation for the sector aggregate, such as when manufacturing industries reduce the labour stock as a result of new investments, or when services replace manufacturing industries.

Adaptation within each sector aggregate, such as substitution between hotel services and retail trade, is taken into account only implicitly, and to the extent that they are reflected by the elasticities of substitution for each sector. However, it is difficult to tell if, or to what extent, specific adaptation options are included by our choices of elasticities. This is a weakness of all general equilibrium models, where substitution is a result of a convolution of unidentified technologies.

It is possible to include adaptation options explicitly by adjusting the impact estimates for the net benefits of specified adaptation options. This approach applies for those measures that are beneficial only under climate change. They may be implemented both as a response to observed changes and as a means to prepare for expected changes (Adger et al., 2007). To build dikes as a precautionary action is an example of such an option, which are sometimes called planned adaptation (Benioff et al., 1996; Adger, 2003; Klein and Smith, 2003). Some of the damage estimates underlying the impact functions of this study, including the impacts of sea-level rise, comprise beneficial adaptation options, but it is often unclear to what extent these options are taken into account in studies of impacts. Hence, it is also difficult to tell how, or to what extent, they are included in the impact functions applied here.

When interpreted as market responses in a general equilibrium model, adaptation to climate change is framed into analyses of macroeconomic indicators and national aggregates, which these models are based on. From the outset, the GRACE model divides Europe into eight regions, each consisting of two to six countries. There are reasons to believe that some major challenges of climate change adaptation thereby disappear. Adaptation is commonly considered to be a local issue. Strategies and opportunities therefore ought to be analyzed with reference to local characteristics. The expected changes in climate may vary considerably over relatively small distances, and opportunities of adaptation as well as capacities to adapt will depend on the social and economic dependencies within communities. As a result, constraints and availability of relevant information may differ considerably from place to place, and represent notable barriers to adaptation.

Most macroeconomic models are based on national accounts, however, and the national aggregates do not distinguish between communities. The models assume that all markets work smoothly, as if there are no constraints to adaptation. If, for example, farming in the south of Spain is negatively affected by climate change, the model puts no constraints to farmers who wish to take their farm and family, transform the farm into a restaurant and the family into cooks and servants, and start business in Barcelona. It all happens at no cost. In defence of treating transformation in this manner, it is usually argued that the responses prescribed by general equilibrium models apply only in a long-term perspective, say 10–15 years, or even more. Then, the families are given time to sell their farm, spend the income on a restaurant in the north, and move to learn cooking and serving. Over such a period of time, this change may also take place as a generational process, where the young part of the family, who is expected to take over the farm, give up farming in the south for a life as a restaurant owner in Barcelona.

However, impacts of climate change can usually be described as stepwise, either because they appear as sudden events, or because they are suddenly realized after several years of change in the local climate and related conditions. Barriers to the flexibility described by the model may then become crucial for the evaluation of the social and economic consequences. Leaving these barriers out may, in other words, imply that the main challenges of adaptation are ignored by definition (Barnett and Webber, 2010), with resulting bias in the macroeconomic interpretations. A higher geographical resolution than the national level is, therefore, preferable, even though a representation of local communities is out of the question. In this study, each of the eight European regions of GRACE was divided into 9–12 sub-regions, or provinces. In the absence of available data on the provincial level, however, the economic structure of provinces within a region is assumed identical for all provinces. That is, the composition of sectors, their technologies, as well as the composition of final demand (consumption, investments and exports) is equal across all provinces from the outset. The only thing that differs is the scale of the production, which is set in accordance with Eurostat's distribution of GDP by NUTS-levels.

The higher geographical resolution serves three purposes. First, it enables representation of variations in climatic changes within countries and regions. The possibility of levelling out positive and negative changes in a region, and ending up with zero change, is thereby limited. Second, some of the barriers to adaptation can be addressed. In this study, the availability of natural resources are assumed to be immobile between both provinces and sectors, the supply of labour is assumed immobile across provinces, while capital can be transferred across both sectors and provinces. This constrains the use of natural resources to the province where they are, and to the purpose they are being used for, and it assumes that people do not migrate without costs or inconvenience. As a result, the prices of natural resources are province and sector specific, and wages are province specific. Third, impacts to sectors which are concentrated in certain provinces can be better addressed, both with respect to the specific climate change in a province, and with respect to barriers.

It must be added, though, that this way of breaking down the national accounts for a region as well as the representation of barriers has several weaknesses. If, for example, vulnerable sectors are concentrated in certain provinces, the substitution effects will, in fact, be different from what we read from our model. Moreover, the barriers to mobility are determined in a somewhat arbitrary way: There is full flexibility of labour within each province, but no flexibility across provinces. Referring to the story about the farming family above, GRACE allows them to transform suddenly into restaurant holders within the region they live, but they will not move to any other region under any circumstance. The resulting variations in impacts across provinces from the model must therefore be understood only as indications of what directions activities may tend to move.

4. Results

The model was run only for 1 year, meaning that the results show the impacts of climatic changes as if they happened in the base year, 2004. The impacts are calculated as the effect on GDP of a change in global mean temperature when compared with a European economy unaffected by climate change. All the results presented below are combinations of direct impacts on economic activities and autonomous adaptation resulting from factor- and sector substitution. We have calculated the impacts of an increase in global mean temperature at +2 °C and +4 °C relative to pre-industrial time. This may be considered as economic impacts of climate change in a late decade of this century under an extremely

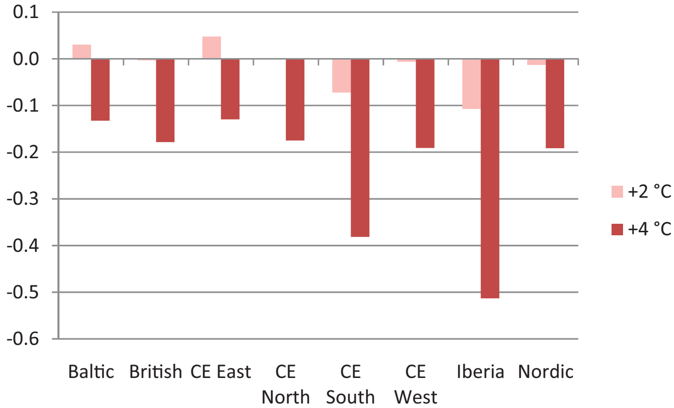

Fig. 2. Per cent change in GDP at shifts in global mean temperature by +2 °C and +4 °C.

strong global climate policy regime, and under modest climate policy globally, respectively. Such a snapshot for 1 year indicates the impact of climatic changes per year, meaning that the scale of the impacts are much lower than the impacts would be if calculated by comparing scenarios, e.g. up to 2100. A comprehensive presentation of the results is given in Aaheim and Dokken (2009).

Climate change by sub-region is indicated by the change in mean temperature and annual precipitation in the model. We had no projections for the climatic changes in European regions and sub-regions under an increase in global mean temperature at +2 °C and +4 °C available for this study. Instead the results from Christensen et al. (2007), shown in Table 1, were adjusted by the same ratio (2/3.1 and 4/3.1 respectively) to determine the change in temperature and precipitation in regions and sub-regions.

The resulting impacts on GDP by region are shown in Fig. 2. A comparison of the two scenarios gives some justification for the +2 °C target. For the European region in total, a global temperature increase of +2 °C reduces the GDP by 0.03 per cent, while the reduction at a temperature increase of +4 °C is 0.26 per cent. The impacts are relatively small in most regions in the +2 °C case, with an economic benefit in several subparts of Europe, in particular in the eastern parts. The strongest negative impacts are found in the two southern regions, where a +2 °C target implies per year reductions in GDP at 0.07 in Central Europe South and 0.1 per cent in Iberia. The effects in these southern regions are caused first

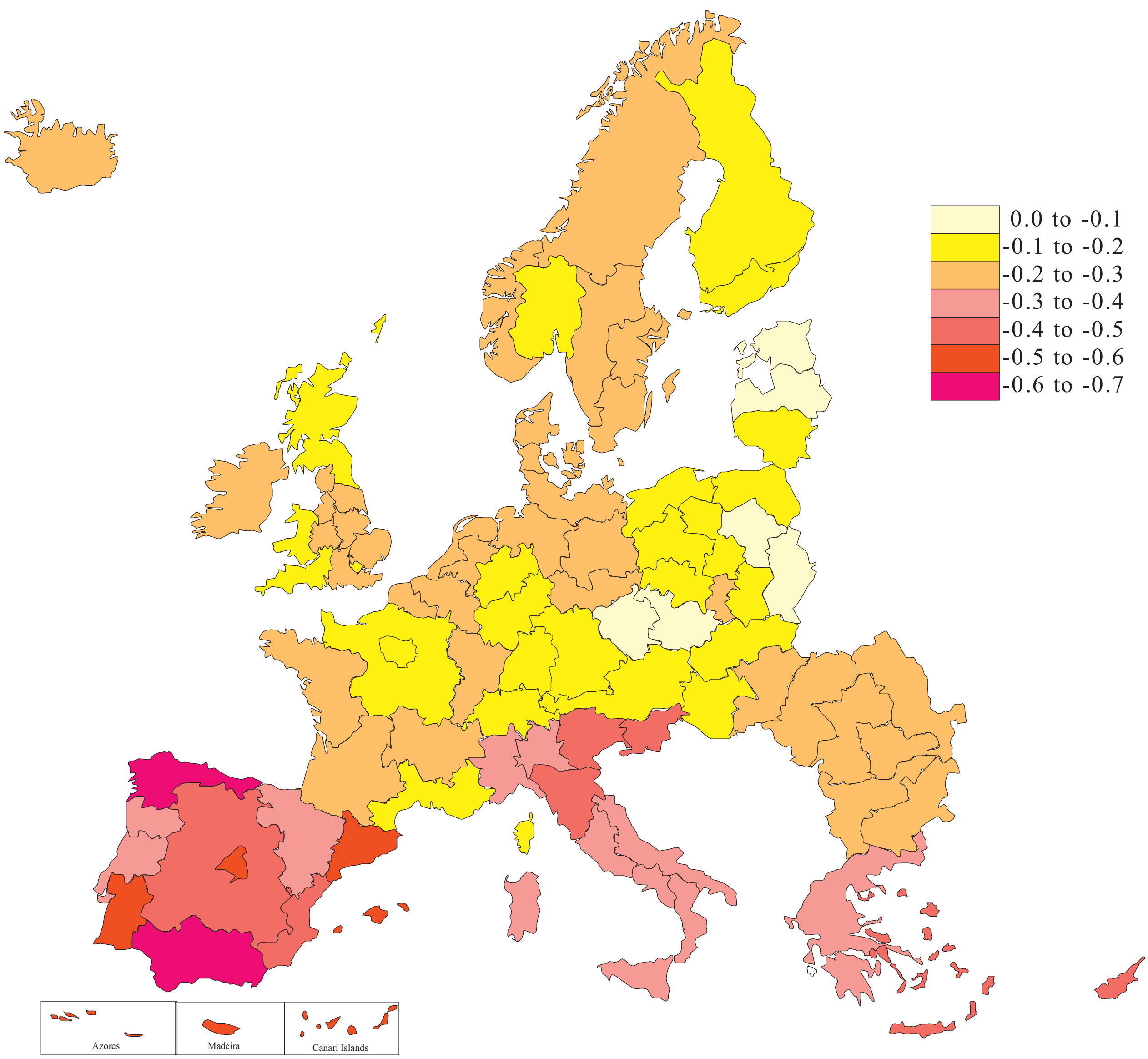

Fig. 3. Estimated perc ent reductions in GDP by sub-region in Europe under a +4 °C increase in global mean temperature.

and foremost by a drier climate, which affects agriculture and forestry. Higher temperature also implies negative impacts to tourism, which reduces the contributions from the service and transport sectors.

Moderate, and even positive, effects in the Baltics and Central Europe East are due to a combination of small effects to agriculture and a positive price effect on the remaining economy, which leads to an increase in the contributions from manufacturing industries. At the same time, these sectors contribute a relatively large share of these economies.

The western regions and the north of Europe are, in general, negatively affected by the +2 °C shift, and with relatively small variations. A +4 °C shift reduces the GDP by between 0.1 and 0.5 per cent, least in Central Europe East and most in Iberia. Impacts across sectors vary from region to region, but in general, all the regions gain from an increase in the values of the natural resources, predominantly the sum of impacts to agriculture, forestry and fisheries. These gains are results of combinations of physical impacts of climate change and resulting responses in the prices of the natural resources. On the other hand, price effects lead to losses in manufacturing, resulting from a change in the terms of trade with the rest of the world.

Although these estimates indicate that Europe will be affected by climate change even under a +2 °C shift, motivations to implement climate policy are based on expectations of what might happen if climate policy is not implemented world-wide. The discussions below on variations across sub-regions therefore focus mainly on the impacts of the +4 °C shift. As it turns out, the regional variations are similar in the two cases: regions that face the most negative impacts in the +2 °C shift are the most severely impacted in the +4 °C shift, and those who gain in the +2 °C shift are the least affected in the +4 °C shift. Fig. 3 is a map over Europe with estimated impacts on GDP in the +4 °C shift for the 85 sub-regions of the GRACE model.

An increase in global mean temperature at +4 °C implies a loss in GDP in the sub-regions of Europe, but with substantial variations, from less than −0.1 per cent in some sub-regions of the Baltic States and in Central Europe East to between −0.6 and −0.7 per cent in the sub-regions of Galicia and Andalucia in Iberia. In the two southern regions, the losses in GDP range between −0.3 and −0.7 per cent, while the corresponding range in the northern regions lies between 0 and −0.3 per cent. Generally, the variations among sub-regions within regions increase as the average loss in GDP increases. A closer look at the sectoral variations exhibit more substantial differences. Most notable for energy use which goes down between 2 and 7 per cent in most regions of Europe. The two southern regions are exceptions, though, where electricity use increases up to 10 per cent.

The pattern of variations is more differentiated for the climate sensitive natural resource based sectors, agriculture, forestry and fisheries. The value of agricultural land increases by 0.6 per cent in the Baltics, by 0.2 per cent the British Islands and by 5.4 per cent in the Nordic countries. In the other regions, the value of land declines, slightly in most of them, although 2.7 per cent in Central Europe South and 4.4 per cent in Iberia. A general reduction of agricultural prices leads to a reduction in the contribution to GDP from agriculture in all regions, although there is a positive change in certain sub-regions.

In relative terms, the value of forested land exhibits the most substantial effect among the natural resources of a +4 °C shift. It increases in all regions except Central Europe South and Iberia, and most in the Baltics and the Nordic countries, by 14.9 and 16.4 per cent, respectively. This reflects a combination of increased physical growth and value of forested land, making a slight increase in the supply of forest products. This results in a reduced price of output, and the overall effect on the contribution to GDP is moderate. It is slightly negative in some of the sub-regions of the six northern regions. In the two southern regions, both the value of forested land and the value of output decrease.

Fisheries exhibit the largest sub-regional variations among the natural resource based sectors. This can be explained partly by its relatively small size in some of the regions. For the regions with notable fisheries, the results show an increase in GDP in the two southern regions and a decline in the British islands and the Nordic countries, which follow the changes in the value of the fish stock. Again, we emphasize that these results are based on very weak estimates of direct impacts.

As for manufacturing industry, also a large part of the service sector is affected only by indirect effects, but impacts on tourism affect sub-sectors within services directly. GDP for services falls in the sub-regions of all regions, except the Baltics, Central Europe East and the Nordic countries. Transport is also being directly affected through tourism, similar to the service sector, but with somewhat less negative effects, in general. The most substantial reductions are found in the coastal regions of the Mediterranean, Southern Portugal and the Iberian islands, which may be explained by the importance of tourism in these parts of Europe.

These results assume that labour is immobile across sub-regions, meaning that climate change give rise to differences in the wage rates across sub-regions. Over time, such an assumption is, of course, unrealistic, but the differences that occur give an indication of which regions will attract new labour and which regions will respond by reducing labour demand as a result of climate change. This again, may be related to occurrence of local unemployment. The dots in Fig. 4 show the average wage rate by region after the +4 °C shift. The range from minimum to maximum rate by sub-regions is indicated by bars. The wage under an economy unaffected by climate change is 1 in all regions.

Not surprisingly, the impacts on the wage rates follow the impacts on GDP to a certain extent: The most negatively affected regions are the two regions in the south of Europe, and where the variability within the regions is also large. For five of the remaining regions, the differences are small, and the variability is also moderate, although the difference between maximum and minimum change is definitely larger in the Baltics and in Central Europe East than in the other three regions.

The Nordic countries stand out as an exception, being the only region with a positive effect on wages on average, and with the largest difference between the maximum and the minimum impact by sub-region. For most sectors, the +4 °C shift leads to a stronger negative shift in commodity prices in the Nordic than elsewhere in Europe. As a result, labour substitutes other inputs, which implies an increase in the demand for labour. In particular,

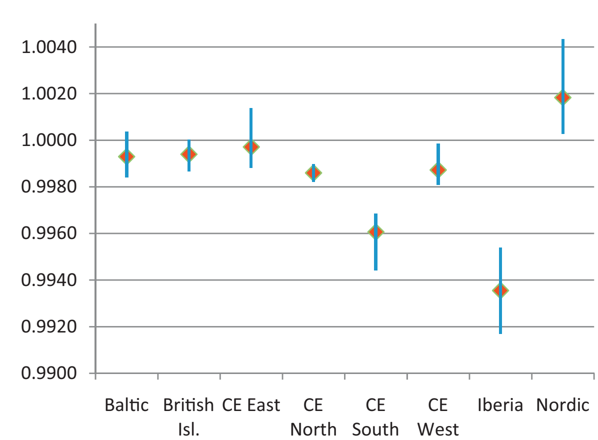

Fig. 4. Wage rates by region with indication of max and min by sub-region after the +4 °C shift. Wage without impacts of climate change = 1.

the price of forestry output, which is an important sector in the region, drops significantly more than in other European regions, while the price of fish from the Nordic countries drops less than the European average. In sub-regions where forestry dominates, such as in the south of Finland, the increase in wages is therefore relatively high, while wages increase less in sub-regions dominated by fisheries, such as northern Norway and Iceland.

To the extent that the impacts on wages indicate movements in the labour force across sub-regions, one may, in other words, expect climate change to contribute to migration from south to north. A closer look at sub-regions show that there is no clear pattern from these calculations showing whether climate change will strengthen or weaken existing patterns in regional labour movements: some sub-regions already exposed to out-migration will be harder affected, whereas the opposite is the case in other already exposed sub-regions. It should also be added that it is difficult to tell from these numbers how strong the effects on migration may become. The numbers as such are small, indeed, but recall again that these are to be interpreted as a 1-year shift. The differences will accumulate over time, and thus motivate people to move.

5. Conclusions

The objective of this paper is to derive the economic impacts of climate change on the European economies, with reference to results from existing literature. Our survey of available impacts studies for European countries constitutes the background for providing an economic interpretation of impacts of climate change by country. Adjustments were made in order to relate the various studies from the survey to a common reference scenario for climate change. The resulting estimates over climate change impacts by country were used to estimate impacts functions by economic activity, which are assumed to be common across Europe. Finally, the impact functions are implemented in the computable general equilibrium model GRACE, which divides Europe into 85 regions, and then estimate the economic consequences of a +2 °C and a +4 °C shift in global mean temperature.

The results of our analysis provide some support for limiting the increase in global mean temperature by +2 °C, in the sense that the European economies are moderately affected by such a shift. Some regions and sub-regions are better off, while others face moderate losses. The total GDP for the European region falls by 0.03 per cent when compared with GDP without climate change. It is not straightforward to compare this with results from other studies, which are usually based on scenarios, where the impacts accumulate over time. However, the PESETA study (Ciscar et al., 2011b) projects a reduction at 0.23 per cent in 2080, under +2.5 °C, which also must be characterized as a relatively small impact.

At a +4 °C shift, all sub-regions lose in economic terms in this study, and the reduction in GDP are considered substantial, especially in the southern regions of Europe, where the per year loss in GDP in some sub-regions amounts to 0.7 per cent. As expected, the sectors based on utilization of natural resources, agriculture, forestry and fisheries, are the most affected, but climate change also leads to a decline in energy use in most regions. With reference to impacts on the wage levels, we also find that climate change may motivate people to migrate from the south of Europe to the north, and to the Nordic countries, in particular.

Comparing again with the PESETA study, where an increase at +3.9 °C reduces annual GDP in 2080 by 0.41 per cent, our result of 0.26 per cent total loss per year for Europe for a 1 year shock of +4 °C is clearly stronger. Hence, while the two studies give similar impacts for lower levels of temperature increase, our study indicates stronger negative impacts at higher levels.

This being said, it must be emphasized that there is substantial uncertainty related to results such as these, and that the achievements of the study are also of a methodological character. First, while previous studies of the macroeconomic impacts of climate change have been based on aggregated or sector-wise damage functions, this study attaches impact functions to activities within sectors. Thereby, autonomous adaptation resulting from factor substitutions can be addressed. Second, in our study the impacts of climate change are broken down to sub-regions in order to identify diversities within regions and countries. We find that the diversity, especially in regions with large impacts, is substantial.

There is a considerable room for improvements of studies of climate change impacts on the macro economy. Apart from those that can always be attached to computable general equilibrium models, the impacts functions applied in this study are weak. To date little has been done to estimate appropriate relationships between aggregated economic sectors and climate indicators. This is a particular challenge as impacts studies tend to go more into detail and to focus on smaller areas. There is also a need to better identify which economic activities are affected by climate change, and what the relationships look like. This study is confined to impacts for which available studies provide sufficient information to give an economic estimate. Other potential impacts are omitted, such as health effects and temperature sensitivity of labour productivity (Friel et al., 2008). Moreover, local barriers to adaptation might be better represented by more careful aggregation of economic indicators. Finally, it is important to note that economic estimates of climate change impacts depend heavily on the underlying climate scenarios and downscaling of the output from global circulation models. The results of this study were generated on the basis of very rough approximations of one climate projection.

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References

Aaheim, A., 2010. The determination of optimal climate policy. Ecological Economics 69 (3), 562–568.
Aaheim, A., Dokken, T., 2009. Macroeconomic Analysis. ADAM Digital Compendium, http://adam-digital-compendium.pik-potsdam.de/macro-economic-analysis/.
Aaheim, A., Rive, N., 2005. A Model for Global Responses to Anthropogenic Changes in the Environment (GRACE). CICERO Report 2005:5, CICERO, Oslo.
Aaheim, A., Schjolden, A., 2004. An approach to utilise climate change impacts studies in national assessments. Global Environmental Change 14, 147–160.
Aaheim, A., Amundsen, H., Dokken, T., Ericson, T., Wei, T., 2009. A Macroeconomic Assessment of Impacts and Adaptation to Climate Change in Europe. CICERO Report 2009:6, CICERO, Oslo.
Adger, W.N., 2003. Social capital, collective action, and adaptation to climate change. Economic Geography 79, 387–404.
Adger, W.N., Agrawala, S., Mirza, M.M.Q., Conde, C., O'Brien, K., Puhlin, J., Pulwary, R., Smith, B., Takahashi, K., 2007. Assessment of adaptation practices, options, constraints and capacity. In: Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., Hanson, C.E. (Eds.), Climate Change 2007: Impacts Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, pp. 541–580.
Alcamo, J., Moreno, J.M., Nováky, B., Bindi, M., Corobov, R., Devoy, R.J.N., 2007. Europe in climate change 2007: impacts. In: Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., Hanson, C.E. (Eds.), Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the

Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, pp. 541–580.
Amelung, B., Moreno, A., 2007. Costing the impacts of climate change on tourism in Europe: results from the PESETA study. Climatic Change 112, 1–6.
Arnell, N.W., Tompkins, E., Adger, N., Delaney, K., 2005. Vulnerability to Abrupt Climate Change in Europe. Tyndall Centre for Climate Change Research.
Badri, N.G., Walmsley, T.L. (Eds.), 2008. Global Trade, Assistance, and Production: The GTAP 7 Data Base. Center for Global Trade Analysis, Purdue University https://www.gtap.agecon.purdue.edu/databases/v7/v7_doco.asp.
Barnett, J., Webber, M., 2010. Accommodating Migration to Promote Adaptation to Climate Change. Commission on Climate Change and Environment, Stockholm.
Benioff, R., Guill, S., Lee, J., 1996. Vulnerability and Adaptation Assessments: An International Handbook. MIT Press, Cambridge.
Christensen, J.H., Carter, T., Rummukainen, M., 2007. Evaluating the performance and utility of regional climate models: The PRUDENCE project. Climatic Change 81, 1–6.
Ciscar, J.C., Iglesias, A., Feyen, L., László, S., Van Regemorter, D., Amelung, B., Nicholl, R., Watkiss, P., Christensen, O.B., Dankers, R., Garrote, L., Goodess, C.M., Hunt, A., Moreno, A., Richards, J., Soria, A., 2011a. Physical and economic consequences of climate change in Europe. Proceedings of the National Academy of Science of United States of America (January), http://dx.doi.org/10.1073/pnas.1011612108.
Ciscar, J.C., Szabó, L., van Regemorter, D., Soria, A., 2011b. The integration of PESETA sectoral economic impacts into the GEM-E3 Europe model: methodology and results. Climate Change, http://dx.doi.org/10.1007/s10584-011-0343-y.
De Cian, E., Lanzi, E., Roson, R., 2007. The Impact of Temperature Change on Energy Demand: A Dynamic Panel Analysis: FEEM Working Paper No. 46.2007. Fondazione Eni Enrico Mattei.
Eboli, F., Parrado, R., Roson, R., 2010. Climate-change feedback on economic growth: explorations with a dynamic general equilibrium model. Environment and Development Economics 15, 515–533.
Eskeland, G.S., Criqui, P., Jochem, E., Neufeldt, H., 2010. Transforming the European energy system. In: Hulme, M., Neufeldt, H. (Eds.), Making Climate Change Work for Us. European Perspectives on Adaptation and Mitigation Strategies. Cambridge Univ. Press, Cambridge.
Fankhauser, S., 1995. Valuing Climate Change. The Economics of the Greenhouse. Earthscan, London.
Friel, S., Marmont, M., McMichael, A.J., Kjellstrom, T., Vågerø, D., 2008. Global health equity and climate stabilization—need for a common agenda. The Lancet 372, 1677–1683.
Fronzek, S., Carter, T., 2007. Assessing uncertainties in climate change impacts on resource potential for Europe based on projections from RCMs and GCMs. Climatic Change 81 (0), 357–371.
Giannakopoulos, C., Bindi, M., Moriondo, M., LeSager, P., Tin, T., 2005. Climate Change Impacts in the Mediterranean Resulting from a 2 °C Global Temperature Rise. WWF.
Goldhar, C., Ford, J.D., 2010. Climate change vulnerability and food security in Qeqertarsuaq, Greenland. In: Hovelsrud, G.K., Smit, B. (Eds.), Community Adaptation and Vulnerability in Arctic Regions. Springer Verlag, pp. 239–262.
Hamilton, J.M., Maddison, D.J., Tol, R.S.J., 2005. Climate change and international tourism: a simulation study. Global Environmental Change Part A 15 (3), 253–266.
Iglesias, A., Garrote, L., Quironga, S., Moneo, M., 2012. A regional comparison of the effects of climate change on agricultural crops in Europe. Climatic Change 112, 29–46.
International Energy Agency IEA, 2005. World Energy Outlook 2005. OECD/IEA, Paris.
Jones, G., White, M., Cooper, O., Storchmann, K., 2005. Climate change and global wine quality. Climatic Change 73 (3), 319–343.
Jorgensen, D.W., Goettle, R.J., Hurd, B.H., Smith, J.B., Mills, D.M., April 2004. US Market Consequences of Global Climate Change. Pew Center on Global Climate Change, Arlington, VA.
Kellomäki, S., Karjalainen, T., Mohren, F., Lapveteläinen, T., 2000. Expert Assessments of the Likely Impacts of Climate Change on Forests and Forestry in Europe: European Forest Institution. University of Wageningen/University of Joensuu, The Netherlands/Finland.
Kimball, B.A., Kobayashi, K., Bindi, M., 2002. Response in agricultural crops of free-air CO_2-enrichments. Advances in Agronomy 77, 293–368.
Klein, R.J.T., Smith, J.B., 2003. Enhancing the capacity of developing countries to adapt to climate change: a policy relevant research agenda. In: Smith, J.B., Klein, R.J.T., Huq, S. (Eds.), Climate Change, Adaptive Capacity and Development. Imperial College Press, London, pp. 317–344.
Long, S.P., Ainsworth, E.A., Rogers, A., Ort, D.R., 2004. Rising atmospheric carbon dioxide: plants FACE the future. Annual Review of Plant Biology 55, 591–628.
Lehner, B., Czisch, G., Vassolo, S., 2005. The impact of global change on the hydropower potential of Europe: a model-based analysis. Energy Policy 33 (7), 839–855.
Nordhaus, W.D., 1991. To slow or not to slow: the economics of the greenhouse effect. Economic Journal 101 (407), 920–937.
Nordhaus, W.D., Boyer, J., 2000. Warming the World. Economic Models of Global Warming. MIT Press, Cambridge, MA.
Nakicienovic, N., Swart, R. (Eds.), 2000. Special Report on Emission Scenarios. Intergovernmental Panel of Climate Change. Cambridge University Press, Cambridge.
Perry, A.L., Low, P.J., Ellis, J.R., Reynolds, J.D., 2005. Climate change and distribution shifts in marine fishes. Science 308 (5730), 1912–1915.
Stern, N.H., 2006. The Stern review. The Economics of Climate Change. Cambridge University Press.
Stuczyiński, T., Demidowicz, G., Deputat, T., Górski, T., Krasowicz, S., Kuś, J., 2000. Adaptation scenarios of agriculture in Poland to future climate changes. Environmental Monitoring and Assessment 61 (1), 133–144.
Swiss Re, 2011. The Effects of Climate Change. Storm Damage in Europe on the Rise. Focus Report, In: http://www.swissre.com/publications/archive/?searchByCategory=Climate%20change.
Tol, R.S.J., 1995. The damage of climate change—toward more comprehensive calculations. Environmental and Resource Economics 5, 353–374.
Tol, R.S.J., 2002. Estimates of the damage costs of climate change—Part I: benchmark estimates. Environmental and Resource Economics 21, 47–73.