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# **A macroeconomic assessment of impacts and adaptation to climate change in Europe**

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September 2009

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## Summary

This report provides a documentation of the integrated macroeconomic general equilibrium model GRACE\_adapt, and presents results from the macroeconomic analysis of impacts and adaptation in Europe in case of a +2 °C and +4 °C increase in global mean temperature. GRACE\_adapt has been developed for the ADAM project to address economic impacts of climate change and resulting adaptation, interpreted as the economic responses to climate impacts. The development of the integrated computable general equilibrium model GRACE\_adapt represents an attempt to bring consistency between adaptation to climate change and economic behaviour. The model is based on the idea that adaptation to climate change can be interpreted within the context of economic behaviour: Climate change may lead to changes in the availability of economic resources, or shifts in the demand for commodities or services, either from production sectors (shift in technologies) or from final demand (shift in preferences). The resulting shift from one general equilibrium prior to climate change to a new general equilibrium posterior to climate change can be interpreted as adaptation.

GRACE\_adapt is a general equilibrium model for an optional number of regions and economic sectors. The model divides Europe into eight main regions. The selection of regions was made subject to three criteria. First, each region has to be geographically connected, and have similar climatic conditions. Second, the population of all regions should be of similar size. Third, income per capita should be of the same order of magnitude within a region. The model divides the economy into 11 sectors of production expected to be particularly affected by climate change, i.e. sectors that utilize climate sensitive natural resources or sectors for which the demand is sensitive to the climate (the sectors are listed in Table 3.3).

Contrary to most other integrated models where the impacts of climate change are aggregated into a “total cost of damage”, the impacts of climate change in GRACE\_adapt are attached to specific economic activities or variables. Moreover, barriers to adaptation are introduced by splitting each of the eight European regions represented in the model into 9 to 11 provinces, between which we impose constraints to the mobility of primary input factors. Adaptation to climate change can thereby be analysed endogenously by means of the assumptions underlying the behaviour of economic agents.

In addition to providing a documentation of the modelling, this report presents the first results of the model runs, which addresses one of the two questions that were raised as the background for the ADAM project; namely to compare the costs of mitigation to aim at +2 °C increase in global mean temperature with the need for adaptation if the global mean temperature increase by +4 °C.

We found that adaptation contributes to reduce the macroeconomic impacts of climate change, but that the share of costs that is reduced by adaptation decreases as global mean temperature increases. The analysis gives some justification of the +2 °C target advocated by the EU: The +2 °C case shows small economic impacts, with positive changes in some regions and negative in others. For higher temperature increases, the impacts are negative in all regions. We also note that the impacts are non-linear: A +1 °C increase in the global mean temperature results in a doubling of the costs of climate change. Adaptation takes place in terms of changes in quantities, but changes in prices also constitutes an important part of the adaptation process when comparing GDP in the different cases. The total effect of adaptation is substantial, and reduces the impacts by approximately 80 - 85 percent in many regions. However, this large effect of adaptation may partly be explained by the assumptions in the model that the world outside Europe is unaffected by climate change. Both the level of economic impacts and the degree to which adaptation mitigates the initial economic costs of

climate change vary greatly both between the eight European regions and within the regions. The southern regions are the most affected by climate change, whereas the low-income regions seem to take the most advantage from adaptation. This can be explained by the change in relative prices, which turn out in favour of the low-income regions. The low-income regions also exhibit relatively large variations within the region. This can also be considered a result of the changes in relative prices: Some provinces are better capable of taking advantage of this than others. Also the most affected regions exhibit large variations across provinces. In some regions there is a strong correlation between low income per capita and losses in GDP or reductions in wages on the province level, but such a pattern cannot be found in all regions.

It has to be emphasised that the results of the present study are preliminary and subject to notable weaknesses. First, we present only a static comparison between equilibrium under different assumptions about climatic conditions. To get a more realistic picture of the economic consequences, one should run scenarios over a given time period. In that case, a closer examination of the barriers to adaptation would have to be considered, because barriers will diminish over time. Second, we have assumed that the rest of the world is unaffected by climate change. As mentioned, the effect of adaptation depends heavily on the change in relative prices, also on the world market. Implementation of impacts in the rest of the world is therefore likely to affect the results considerably. Hence, the levels of impacts reported here are probably biased, which is why we do not want to highlight them. However, we believe that we have gained some insights when it comes to the comparison of European regions and variability within regions.

We would also like to draw the attention to the uncertainties about the estimates of the impact of climate change. The model is based on external assessments of impacts by activity. This requires, in principle, a comprehensive set of impact studies in which the relationships between climate indicators and impacts on activities can be based. There are, however, few available cost estimates of the impacts of climate change, not to mention adaptation. Those that exist will therefore have to be stretched to their limits, in the sense that a specific estimate will be used as if it applies to more cases than actually addressed in the referred study. In some cases results will have to be transferred to apply in other sectors or sub-sectors, and in some cases to other regions.

Moreover, the impacts that were taken into account probably represent moderate estimates, because some effects of climate change have been disregarded. Health effects, for example, which have economic consequences only to the extent that economic activities are affected, are not included at all in the numerical analysis, and all impacts are imposed by means of expected values. The most severe economic impacts of climate change are related to extreme events, which are stochastic by nature. Stochastic events of certain magnitudes may themselves generate negative impacts, which have been disregarded here. A closer study of these impacts was, however, addressed in Work package A2 of the ADAM project.

Finally, there have been no attempts to include non-market impacts of climate change, which may turn out to be substantial. Hence the results of this study must be considered a “pure” economic assessment of impacts. A full evaluation of the impacts of climate change requires inclusion of many more aspects.

## 1 Introduction

The starting point of the ADAM project was to compare the costs to Europe of limiting the increase in global mean temperature to +2 °C by mitigation efforts with the costs of having to adapt to an increase of +5 °C. Later, it was concluded that an increase in global mean temperature at +5 °C is probably too pessimistic even under a high emissions scenario, and the adaptation case was moderated to somewhere between +4 °C and +4.5 °C. While tools for assessing the costs of mitigation were readily available long before the project started, the attention to the costs of impacts and adaptation has been limited, although so-called integrated models have become more common over the past decade. These models are, however, still in their infancy, and one of the general critiques has been that adaptation is poorly addressed, if at all.

To do an assessment of the costs of adaptation on the macroeconomic level, new modelling tools were therefore required. This is the background for the development of GRACE\_adapt. The model is based on the idea that adaptation to climate change can be interpreted within the context of economic behaviour: Climate change will change the national wealth, such as the value of natural resources, the capital stock and the labour force. Changes in climate will, moreover, lead to a shift in the demand for certain commodities or services, both in production sectors (shift in technologies) or from final demand (shift in preferences). The resulting shift from one general equilibrium prior to climate change to a new general equilibrium posterior to climate change can be interpreted as adaptation.

GRACE\_adapt differs from standard computable general equilibrium models in two respects. First, the impacts of climate change are integrated activity by activity in the model with separate impact functions for each sector in each region. Thus, an impacts function for each activity is needed. For example, the impacts of climate change to agriculture have to be attached to the activity within the agricultural sector where the impacts arise. Thus, a reduction in agricultural productivity because of a drier climate can be interpreted as a reduction in productivity of land. The productivity of land is represented by the input of natural resources, and hence, the impact manifests itself in a reduction in the value of natural resources for agriculture. Damage to buildings because of extreme events is, on the other hand, introduced as damage to the capital stock in the sector.

Most other integrated models include impacts of climate change by means of aggregated damage functions. Then, the aggregated “damage cost of climate change” is subtracted from the output of the economies. The activity based implementation of impacts in GRACE\_adapt has the advantage that economic behaviour is made consistent with adaptation to climate change instead of being considered something different that has to be determined “outside” the model.

A challenge in analysing adaptation in the context of general equilibrium models is that economic markets respond immediately without time to adapt. Thus, capital, labour and natural resources switch from one sector to another within the same economy without frictions. Within larger regions, adaptation to climate change would hardly involve major problems if this was the case. The second difference between GRACE\_adapt and standard integrated models is that adaptation is subject to frictions across sub-regions. Each region is split into sub-regions, called provinces, between which there are constraints to the mobility of primary input factors or goods. The result is that “local markets” develop for factors subject to mobility constraints, so that wage levels can vary between provinces within a region.

The model is based on external assessments of impacts by activity. This requires, in principle, a comprehensive set of impact studies on which the relationships between climate indicators and impacts on activities can be based. There are, however, few available cost estimates of the impacts of climate change, not to mention adaptation. Those that exist, henceforth called

basic estimates, will therefore have to be stretched to its limits, in the sense that a specific estimate will be used as if they apply to more cases than actually addressed in the referred study. In some cases results will have to be transferred to apply in other sectors or sub-sectors, and in some cases to other regions.

When transferring the estimates between sectors or regions, it is nevertheless possible to take into account known conditions that affect impacts, thereby making estimates site or sector specific even when based on studies elsewhere. These are:

- The basic estimates refer to a certain scenario for climate change. A transfer will take into account that the climate changes differently in different regions.
- A basic estimate applies for a certain sector with a given activity. In most cases the sector is a sub-sector of the sectors in the GRACE\_adapt model. Transferring the estimate requires that the sub-activity is adjusted to reflect the relative importance of the activity within the aggregated GRACE\_adapt sector.
- Basic estimates may apply to parallel sectors and commodities or in more general contexts. To draw parallels or to generalise, information which is insufficient to provide a basic estimate may nevertheless apply as support.

This report describes how basic estimates are used to adjust the parameters of the model, and provides some results from the analysis of impacts and adaptation. First, we describe in general what kind of information GRACE\_adapt needs to integrate impacts of climate change. Next, the sectors and regions are described and defined. Moreover, we point out the sectors where we expect to identify impacts of climate change and suggest functional relationships between adjustments and climatic parameters. Then, we present results from studies of climate change impacts to distinguish basic estimates from supportive information. Finally, we come up with the adjusted estimates by sector and region.

## 2 The Integration of climate change impacts

GRACE\_adapt is a general equilibrium model for an optional number of regions and economic sectors. For practical purposes it is necessary to limit the number of sectors and regions to a certain extent. Impacts of climate change are attached to specific economic activities of the model, in accordance with the ideas presented in more detail in Aaheim and Schjolden (2004) and in Aaheim, A. (2007). In general, the way economic activities are adjusted for a change in climate can be divided into three categories:

- i) A change of input to economic sectors. That is, a given change of climate will force sectors to use a different composite of input to produce a unit of output;
- ii) A change in the availability of primary resources (natural capital, real capital and labour);
- iii) A change of preferences, or final deliveries.

The numbers that enter the model are the changes in aggregated *volumes* by sector and region attributable to climate change. The volume is measured by the value in a base year. In this context prices are used as a means to aggregate different physical units within a sector and across sectors. Thus, the volumes are meant to represent physical amounts, and the adjustments i) – iii) are interpreted as a change of the technology in a sector: climate change affects the number and composition of inputs needed to produce a given amount of output. The initial adjustments are made under the assumption that the economic agents adjust their

input and consumption bundles in fixed proportions. Hence, adjustments are imposed to the model as if independent of economic behaviour.

It should be noted, however, that aggregation of firms and groups of final demanders into sectors and final demand, respectively, implies that there is a certain economic behaviour underlying the term “technology”. This is due to the assumption that each aggregate is composed by elements such that the cost of producing the aggregate is minimized. When applied to studies of impacts of and adaptation to climate change, this has two implications.

The first is that the “technology” of a sector is a result of adaptation *within* the aggregated sector. If, for example, climate change improves the agricultural conditions for crops but worsen the conditions for cattle, some farmers will probably switch from cattle to crops because the value of their land increases if used for crops but decreases if used for cattle. To tell how far this substitution will go one may use the basic economic first-order condition that the marginal value of cattle land equals the marginal value of crop land. However, the agricultural sector comprises both crops and cattle in GRACE\_adapt. The substitution between sub-sectors therefore has to be represented by an exogenous shift of the technology in agriculture, even though this change is, in fact, brought about by economic market behaviour.

The second implication is that available measures to adapt to climate change in order to reduce the costs of impacts are assumed to be implemented proactively if the expected benefits exceed the costs. In other words, adjustments of the technology made to represent impacts of climate change should be *net* of proactive adaptation. Analysing adaptation by macroeconomic models does not, therefore, mean that assessments of adaptation are avoided, but one has to make a clear distinction between proactive implementation of adaptation measures and autonomous adaptation.

### 3 Regions and sectors in GRACE

GRACE\_adapt divides Europe into eight main regions. The choice of regions were made subject to three criteria. First, each region has to be geographically connected, and have similar climatic conditions. Second, the population of all regions should be of similar size. Third, income per capita should be of the same order of magnitude within a region. The main regions are described in Table 3.1.



Region	Countries	Pop	Area	GDP pr capita	
				million	1000 km <sup>2</sup>
Baltic states	Estonia, Latvia, Lithuania, Poland	45.7	188.2	6 397	0.41
British islands	Ireland, United Kingdom	64.6	121.6	30 553	0.29
Central Europe East	Czech rep. Hungary, Slovakia, Romania, Bulgaria	55.3	219.7	5 962	1.17
Central Europe North	Austria, Germany, Switzerland	98.1	186.1	28 391	0.45
Southern Europe	Cyprus, Greece, Italy, Malta, Slovenia	72.0	178.7	22 689	0.56
Central Europe West	Belgium, France, Luxembourg, The Netherlands	88.2	240.0	28 371	0.31
Iberian peninsula	Spain, Portugal	51.0	230.6	19 486	0.35
The Nordic countries	Denmark, Finland, Iceland Sweden, Norway	24.6	485.9	36 944	0.61
Other developed countries					
Developing countries					

\*) For each region the range is the difference between the highest and lowest GDP/capita divided by the region average

*Table 3.1. Regions in the GRACE\_adapt model*

To match all three criteria, it is necessary to make compromises. Population ranges from 24.5 mill. in the Nordic countries to 98 million in Central Europe – North. For this reason it might be advantageous to couple the Nordic countries with the Baltic states, which gives a total population of approximately 70 mill. However, the income level differs substantially between two regions. Moreover, the climatic conditions vary to a certain extent, partly due to the fact that the Nordic region covers the largest area among all the European regions. The largest relative range of income inequality by country within a region is Central Europe – east. This is because 1) this region has the lowest average income level, and 2) the low income in Bulgaria. The population of Southern Europe is at the average of all regions and the four countries in this region have a similar climate, although the income differences are substantial between the country with the lowest income (Malta) and the country with the highest income (Italy).

For each of the eight main regions, the basic economic model is calibrated by use of separate national accounts data as reported by the GTAP database (Dimaranan, 2006). Impacts of climate change are integrated by means of estimated impacts functions, which are reported in Section 5. The idea of attributing impacts to economic activity is that the model determines adaptation to climate change when solving for the new equilibrium after the impacts have been implemented. An underlying assumption of this interpretation is that all the available resources within a region can switch from one activity to another without other barriers than the opportunity cost. This is a strong assumption, indeed, and particularly inappropriate when addressing adaptation to climate change. There are reasons to believe that a major share of the costs of adaptation arise as a result of “market frictions”. Labour, real capital and natural resources cannot be moved easily around within a region in order to make them less sensitive to climate change.

To take frictions such as these at least to some extent into account, each region is further divided into between 9 and 11 sub-regions, called provinces, between which we can impose restrictions on the mobility. As there are no national accounts data on the province level, the economic activities of a province in the current version of GRACE\_adapt is a mirror of the total economic activity of the region, but divided according to each province' share of total GDP. With more information about sectoral composition in the different provinces, a more sophisticated split would be possible.

## A macroeconomic assessment of impacts and adaptation to climate change in Europe

Baltic States	litu lves pnov pnoe pnmw pccm pmaz psoe pmse psla psow	lt0 Lithuania lv0 Latvia pl42 Zachodn. pl62 Warm.-Mazur. pl43 Lubuskie pl61 Kujaw.-Pomor. pl12 Mazowieckie pl31 Lubelskie pl33 Swietokrz. pl22 Slaskie pl51 Dolnosl.	ee0 Estonia pl63 Pomorskie pl34 Podlaskie pl41 Wielkopolskie pl11 Łódzkie pl32 Podkarpackie pl21 Malopolskie pl52 Opolskie					
British Islands	ukno uknw uksw york ukwm ukem ukse lond ukea irel	ukm Scotland ukd N-West UK ukl Wales uke Yorksh ukg West Midl. ukf East Midl. ukj Sout-East UK uki London ukh East UK ukn Nor. Ireland	ukc North East ukk South West ie0 Ireland					
Central Europe East	buea buwe rvcs rces rest rsub slov hves heas cwes ceas	bg33 Severoizt. bg31 Severozap. ro11 N-W Rom. ro12 Centru ro21 N-E Rom ro31 S-Muntenia sk0 Slovakia hu10 Közép hu31 Észak cz01 Praha cz05 Severových.	bg34 Yugoiztochen bg32 Severen t ro42 W Rom ro41 S-V Oltenia ro22 S-E Rom ro32 Bucur.-Ilfov hu21 Közép hu32 Észak-Alföld cz02 Strední Cechy cz06 Jihovýchod	bg42 Yuzhen t bg41 Yugozapaden hu22 Nyugat hu23 Dél cz04 Severozápad cz07 Str. Morava cz03 Jihozápad cz08 Moravskosl.				
Central Europe North	dbad dbay dest dnor dnib dnwe dmws dsea swit aust	de1 Baden-Würt. de2 Bayern de3 Berlin def Schl.-Holstein de5 Bremen dea Nordrh.-Westf. dec Saarland ded Sachsen ch Switzerland at Austria	de4 Brandenb. de8 Mecklenb. de9 Niedersachsen de7 Hessen deg Thüringen	dee Sachsen-Anhalt de6 Hamburg deb Rheinland				
Southern Europe	gsou gnor inea inwe imwe ilau isea icam ilom isou	cy0 Cyprus gr1 Voreia Ellada si0 Slovenia itc1 Piemonte itd5 Emilia-Rom ite4 Lazio ite3 Marche itf3 Campania itc4 Lombardia itf5 Basilicata	gr3 Attiki gr2 Kentriki Ellada itd1 Bolzano-Bozen itc2 Valle d'Aosta ite1 Toscana ite2 Umbria itf1 Abruzzo itf6 Calabria	gr4 Krita itd2 Trento itc3 Liguria itf2 Molise itg1 Sicilia itg2 Sardegna mt0 Malta	itd3 Veneto itd4 Venezia Giulia			
Central Europe West	file fpar fcsl fest feas fsoe fces fmoo nsoe nwen belu	fr1 Île de France fr2 Bassin Parisien fr3 Pas de Calais fr4 Est France fr5 Ouest France fr6 S-O France fr7 Centre-Est fr8 Méditerranée nl4 Zuid-Nederl nl1 Noord-Nederl be1 Bruxelles	fr9 French oversea nl2 Oost-Nederland nl3 West-Nederland be2 Vlaams	be3 Wallonne be34 Luxemb (B)				
Iberian Peninsula	pnor pcen escp snwe snor smad scas scat svam sand	pt11 Norte pt16 Centro (PT) pt15 Algarve es11 Galicia es21 Pais Vasco es30 Madrid es41 León es51 Cataluña es52 Valenciana es61 Andalucía	pt17 Lisboa pt18 Alentejo es12 Asturias es22 Navarra es42 la Mancha es62 Murcia	pt20 Açores (PT) pt30 Madeira (PT) es13 Cantabria es23 La Rioja es24 Aragón es43 Extremadura	es53 Illes Balears es63 de Ceuta (ES) es64 Melilla (ES) es70 Canarias (ES)			
The Nordic Countries	fnor fsou dcop dsou dnor ssto smid ssou swmi nord neas nwes	fi13 Itä-Suomi fi18 Etelä-Suomi dk01 Copenh dk02 Sjælland dk04 Midtjylland se11 Stockholm se12 Ö Mellansv se21 Smål + isl se23 Västs se32 Midt Norrl no01 Oslo area no04 Agder-Rogal	fi1a Pohjois-Suomi fi20 Åland dk03 Syddanmark dk05 Nordjylland se22 Sydsverige se31 N Mellansv se33 Övre Norrl. no02 Hedm.-Oppl no05 Vestlandet	fi19 Länsi-Suomi is00 Iceland no07 N-Norge no06 Trøndel.				

Table 3.2. Regions and provinces GRACE\_adapt and associated NUTS codes

The provinces are based mainly on aggregation of NUTS 2 level regions in Europe. Each province is geographically connected, with an exception of the Iberian islands.

Sector	Direct impacts	Affected sub-sectors
Agriculture	Productivity of land	Crops, Vegetables, Livestock
Forestry	Biomass growth	
Fisheries	Recruitment and migration of stock	Ocean, Coastal, Farming
Manufacturing		
Transport	Routes, mode choice tourism	Land, Sea, Air
Service sector	Demand for holiday tourism, energy demand	
Electricity	On renewables, cooling in thermal plants	
Refined oil		
Crude oil		
Gas	Demand for heating purposes	
Coal	Demand for heating purposes	

*Table 3.3. Sector-list of GRACE\_adapt, main impacts and sub-sectors with potential differences of impacts*

The model divides the economy into 11 sectors of production, listed in Table 3.3. The choice of sectors is meant, firstly, to separate those particularly affected by climate change. These are sectors that utilize climate sensitive natural resources or sectors for which the demand is sensitive to the climate. Table 3.3 indicates the main direct impacts and point out certain sub-sectors for which climate impacts are likely to be substantial. Secondly, energy sectors are represented to a certain degree to allow for comprehensive policy analyses of emission control.

The impacts listed in Table 3.3 are specific impacts to each sector. There are also more general climate change impacts, such as extreme events and sea-level rise. These are in most cases integrated by a loss in terms of the total availability on real capital to reflect, for example, damage to buildings. Table 3.4 lists the most important general effects, suggests impacts and how they are incorporated into the model

Category	Impact	Representation in model
Water supply	To agriculture, health, irrigation	Value of land, value of labour
Sea-level rise	Flooded areas, degradation of construction fundamentals, fresh water supply	Capital stock
Extreme events	Damage to buildings and construction, damage to arable land, injuries and killed people, forests	Capital stock, labour. Productivity in agriculture
Biodiversity	Medicine potential, ecosystem resilience, food supply	Value of land
Health	Vector borne diseases, heat/cold stress	Labour stock

*Table 3.4. Cross-over impacts of climate change and possible representation in model*

Final demand in the model consists of private and public consumers, investments and exports. Final demand may be affected directly by climate change, in the case of electricity demand for cooling and energy demand for heating. The demand for tourist services is likely to be affected. Health effects may affect the demand for health services, but also the supply of labour.

The indirect economic impacts of climate change arise because of the integration of sectors in the economy. Restoring capital loss in one sector triggers the demand from the building and construction sectors, a change in the productivity of land in agriculture changes the demand for labour and capital, etc. These indirect impacts are expressions of the socioeconomic adaptation processes, which are addressed by the market behaviour of the model. This behaviour is basically a result of how the demand is modelled. GRACE\_adapt applies so-called nested CES-trees (Constant Elasticity of Substitution) to determine demand. A nested CES tree consists of aggregates,  $X$ , which are being produced by two or more input factors  $V_i$ , which themselves are aggregates or input factors, according to CES production functions. In the two-factor case, the CES function is written as

$$X = A(\alpha V_1^\rho + (1 - \alpha)V_2^\rho)^{\frac{1}{\rho}}$$

The parameter  $\rho$  is chosen on the basis of assumptions about the elasticity of substitution, which is  $1/(1 - \rho)$ , while  $A$  and  $\alpha$  are calibrated by reference to the GTAP database. Figure 3.1 displays the nested CES tree for the production sectors.

Straight lines between the aggregate and the input factors indicate that the input factors are substitutes. An angled line indicates no substitution, or a so-called Leontief technology (aggregates C and H). The implication is that a change of relative prices between input factors affects the composition of the input when substitution is assumed, but not when a Leontief technology is assumed. The bottom line shows the input from the specified sectors, which the model describe as an aggregate of input from sectors domestically and abroad. These so-called Armington aggregates were imported and domestic deliveries are substituted at a relatively high rate.

Impacts of climate change on economic activities may now be divided into three categories:

- i) it may affect the stock of the primary input factors natural resources, capital and labour directly.
- ii) the productivity (output) may be affected directly.
- iii) the productivity (demand) of one of the input factors or aggregates may be affected.

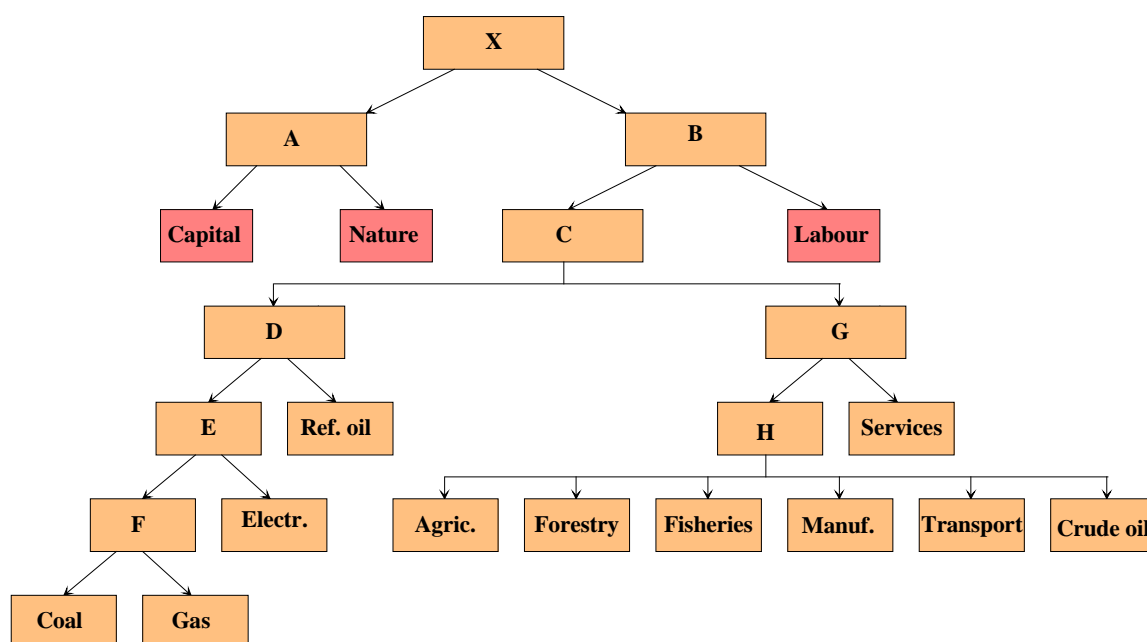


Figure 3.1. Production structure in GRACE-adapt

The corresponding demand tree for the final deliveries are displayed in Figure 3.2:

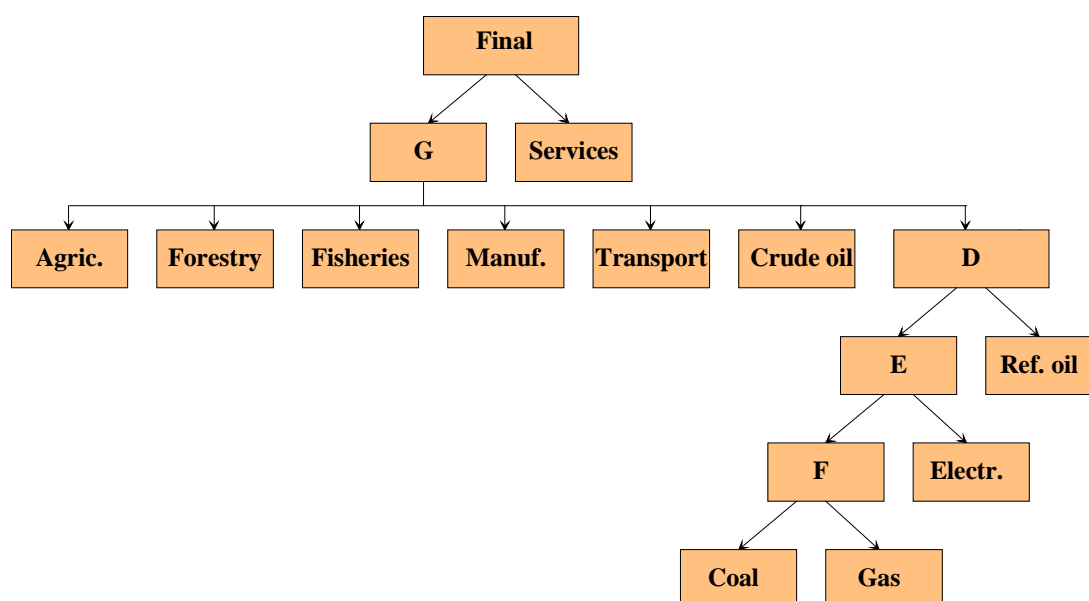


Figure 3.2. Structure of final demand in GRACE-adapt

For primary factors, impacts are represented by adjustments of the availability of resources, that is, the stock of capital and natural resources or the availability of labour. For impacts on output, the scale parameter of the CES aggregate may be adjusted according to the productivity change. Being CES- or Leontief aggregates, which are independent on scale, impacts on sub-aggregates (aggregates other than “top”) are represented by adjusting the

distribution parameter of the aggregate that is being affected. For example, a change of energy demand due to climate change means that the commodity aggregate consists of less input of energy per unit of “commodity”, which leads to an adjusted distribution parameter.

Adjustments imply that the model is recalibrated according to exogenous information about the climate. These adjustments are made independently as if this information is produced without taking market responses into account. In other words, it is assumed that impact studies on which the adjustments are made, estimate impacts only partially. Running the model thus results in a new equilibrium, which in the context of the modelling is interpreted as adaptation to climate change.

The present version of the GRACE model is limited to economic impacts only. Several studies suggest that non-market impacts may be more important when evaluating the threat of climate change. These impacts may be related to impacts to health, which have economic consequences only to the extent that economic activities are affected, or to “services” provided by the nature such as wild-life, or simply the pleasure of a certain, known environment. Even more important are the possibilities of major disasters, such as a collapse of ecosystems. Although possible in principle, an economic evaluation of the costs of such a collapse with the perspective taken in the GRACE model would be of limited interest, however, as the possibility of disasters raises the question of how major risks can be dealt with.

## **4 Economic impacts of climate change in Europe**

This section presents a survey of the literature about expected impacts of climate change on economic sectors in Europe. The purpose of this survey is to provide a reference to create estimates of economic impacts by sector in all European countries. These estimates are results of more or less subjective interpretations of the results in the literature, which are not always easy to compare and transform into numerical terms. The estimates will be used further in Section 5 as “observations” in the estimation of sectoral impacts functions.

The knowledge of economic impacts of climate change is fragmented. Results from different studies are based on different climate scenarios and methods, which partly explains why they come up with different results. In order to make results from different studies comparable, they have to be adjusted to fit into the same climate scenario and in some cases transferred from regions where the study was carried out to regions with similar conditions. These adjustments were made primarily on the basis of our own interpretations, and without any attempt to apply stringent methods. The estimates used for each separate sector should therefore be considered as rough estimates only. The estimated impacts are implemented sector by sector and region by region in the CGE model, in line with the approach presented in Aaheim and Schjolden (2004).

This report comments on the impacts in nine main sub-sections. The first sub-section covers a brief overview of the underlying expected changes in climatic variables. The following sub-sections discuss the main economic impacts by each sector separately. They give a short presentation of the sector followed by a description of sector specific general impacts of climate change. This discussion aims at providing the broad overview. Attempts to establish functional relationships between indicators for climate change and economic activities are presented in Section 5.

#### 4.1 The climate change scenario

The reference climate change scenario used is a scenario from the Prudence project (REF), also used in the PESETA Project (PESETA, 2007). PESETA applied the A2 and B2 global emission scenarios from IPCC (Nakicenovic and Swart, 2000). Our study is based on the A2 scenario, which expects a global warming of 3.1 degrees for the period 2071-2100 compared to the control period 1961-1990. Based on maps showing temperature and precipitation changes, the expected changes in the different regions were approximated to those shown in Table 4.1.

Region	°C change in mean annual temperature	Percent change in annual precipitation
Baltic States	+ 3.0	+ 13
British Islands	+ 2.5	0
Central Europe East	+ 3.5	- 5
Central Europe North	+ 3.5	+ 5
Southern Europe	+ 4.0	- 15
Central Europe West	+ 3.5	0
Iberian Peninsula	+ 4.0	- 25
Nordic Countries	+ 3.5	+ 10

*Table 4.1. Expected changes in climate parameters. From baseline 1961-1990 compared to 2071-2100 in temperature (in degree Celsius) and precipitation (in percentages) in Europe.*

Source: PESETA(2007).

#### 4.2 Agriculture

The contribution from agriculture to the total output varies from 6 percent in the Nordic countries and northern parts of central Europe to 15 and 18 percent the Baltic States and eastern parts of central Europe, respectively (see Table 4.2). Also the relative importance of sub-sectors within the agricultural sector differs. However, fruit and vegetables is the least important in terms of their contribution to total output in all regions, and the sub-sector called “other crops” is the most important, while livestock is second. Most of the output from agriculture is delivered as intermediates to other sectors, such as manufacturing industries and service sectors. The model determines the implications of changes in agriculture on these deliveries.



Region	Share of total output	Sub-sectors share of sector total output		
		<i>Fruit&amp;vegetables</i>	<i>Other crops</i>	<i>Livestock</i>
Baltic States	15	12	54	34
British Islands	6	3	57	40
Central Europe East	18	9	58	34
Central Europe North	6	11	52	37
Southern Europe	7	13	52	35
Central Europe West	7	7	53	40
Iberian Peninsula	9	15	48	37
Nordic Countries	6	4	50	46

*Table 4.2: Overview of the agricultural sector in percentages.*

Source: GTAP (Dimaranan, 2006)

Climate change affects agriculture regions and sub-sectors of the agricultural sector in different ways. On average, it is expected that the productivity of crops in Europe will increase slightly (Alcamo et al., 2007). Crops respond both to increased temperature and to increased atmospheric concentration of CO<sub>2</sub>. In general, the increase in CO<sub>2</sub>-concentrations is expected to offset the negative effect of increased temperature and decreased soil moisture (Long et al., Ainsworth, Leakey, Nosberger & Ort, 2006). However, according to projections using FACE technology studies (Free Air Carbon Enrichment), the effect of higher CO<sub>2</sub> concentration is lower than previously assumed. Experiments by Long et al (2006) projected a 13 percent increase in crop yields if the concentration of CO<sub>2</sub> increases to the expected 2050 level at 550 ppm, compared to 380 ppm in 2006. This is approximately 50 percent less than expected by earlier enclosure studies. In terms of temperature, middle and higher latitudes of Europe will benefit from an extended potential growing season when temperature increase and cropping areas may expand northwards (Maracchi, Sirotenko, & Bindi, 2005). Southern parts on the other hand, may experience increased respiration. Accelerated development may advance maturation of certain crops and cause reduction of yields (Rötter & van de Geijn, 1999). A further complexity is related to the level of tropospheric ozone, which is affected by climate change, and may also offset the positive effect of CO<sub>2</sub> (Reilly et al. (2007)

Livestock can be influenced through direct effects on animals health, reproduction and growth, and indirect effects such as through impacts on productivity of forage crops and pastures (Maracchi et al., 2005). Higher temperatures are likely to generate more frequent heat stress and higher water consumption (Turnpenny et al., 2001), which may affect currently warm regions negatively. In cooler regions, milder cold periods will probably be beneficial due to reduced feed requirements, lower energy costs and increased survival (Maracchi et al., 2005). Further benefits may arise from longer growth seasons in these regions. While droughts may reduce productivity of grasslands in some areas, the overall productivity of European grasslands is expected to increase (Kammann et al., 2005), making possible stocking rates higher (Parsons et al., 2001), given that nutrient and water supply is sufficient (Lüscher et al., 2004)<sup>1</sup>.

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<sup>1</sup> Found in Olesen (2006)

In general, there is a relatively large literature on the impacts on crop yields, but significantly less on the impacts on livestock and fruit and vegetables. The estimated changes in these sub-sectors are, therefore, very rough. For all regions, impacts of climate change on the sub-sector called “other crops” are based on the preliminary results of the PESETA Project (2007). The PESETA study used the crop model DSSAT to quantify the physical impacts of climate change on agriculture. DSSAT includes models that simulate phenological development and growth in response to environmental factors and management. The PESETA agriculture case study modelled European crop yield changes due to climate change for the years 2020 and 2080. The results of the modelling were presented in maps, which form the basis for the approximations on yield changes for the sub-sector “other crops” at country level in our study. Moreover, we calculate the weighted average impact in each region. When a country is not distinguishable at the map, such as Malta, we use the average yield change for the rest of the countries in the region. The PESETA Project uses two global scenarios, A2 and B2, from the IPCC’s SRES. The present study uses the results based on the A2 scenario, expecting a global warming of 3.1 degrees for the period 2071-2100 compared to the control period 1961-1990. For the other sub-sectors, livestock, fruit and vegetables, different studies have been used in the different regions. In the *Baltic States*, agriculture contributes 15 percent to total output. Compared to the rest of Europe, those sub-sectors vulnerable to climate change (fruit, vegetables and other crops) constitute a relatively high share of the agricultural sector (66 percent). According to the PESETA<sup>2</sup> study, the yield might increase by up to ten percent by the 2080s relative to the period 1961-1990 in Estonia, Latvia and Lithuania while expected yields in Poland varies within the country. The results show a decrease between zero and five percent in central parts of Poland, while other parts exhibit a positive change of yield. The changes in fruit and vegetables in Estonia, Latvia and Lithuania are taken from a study by Karing et al (1999). This study focuses on Estonia, but it is assumed here the same holds for Latvia and Lithuania. A potato dynamic model was used to calculate possible yields under climate change, and we assume the impacts on potatoes are also applicable to other vegetables and fruits. It was found that the two climate change scenarios with temperature increases between 1°C and 3°C will increase potato yields between 6 and 8 percent by 2050 (Karing et al., 1999).

Based on this result we assume that the productivity of fruit and vegetables in Estonia, Latvia and Lithuania increase by eight percent by the year 2080, under a regional temperature increase of 3°C and precipitation increase of 13 percent. Expected changes in fruit and vegetables in Poland are based on a study by Stuczynski et al (2000). They used two models. We chose the results of the model that gives the climate change results more close to the climate scenario used for the rest of the agricultural sector. The GISS model predicts an increase in mean annual temperature by 4°C (winter +5°C, summer +2-3°C) and 15 percent increase in precipitation, but the study does not report at what time in the future. It is expected that potato yields decrease by 20-30 percent (Stuczynski et al., 2000). On this basis, we assume that fruit and vegetable yields will decrease by 25 percent by 2080 in Poland.

Studies of expected changes in livestock production due to climate change in this region are scarce. However, Stuczynski et al. (2000) expect poultry production to increase substantially, as the cost of keeping animals will decrease as a result of an increase in productivity of grasslands and an extension of grazing periods. Based on this, we assume that the output of livestock will increase by 5 percent by 2080 in the Baltic region, as a rough estimate. The

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<sup>2</sup> The results of the PESETA study are based on a relatively optimistic assumptions about adaptation, where farmers can use as much additional irrigation water and/or fertilizers as wished, without any constraint.

overall effect of climate change on total output of agriculture in the Baltic region turns out slightly negative. This is because of the dominance of Poland, which contributes approximately 85 percent of total output of agriculture in the region. The expected negative impacts in the country outweigh the positive effects in the rest of the region.

Agriculture contributes only 6 percent of total output on the *British Islands*, but a substantial decrease in yields is expected. In southern parts, the decrease can be as high as 30 percent (PESETA, 2007). Wolf (2002) did a study on potato simulation models under climate change in Europe, including a site in Oxford, England. The use of two climate scenarios from Hadley Centre for the period around 2050 resulted in zero to slight increase in Oxford, both with and without irrigation (Wolf, 2002). Combining this with the expected negative effects on crop, we assumed no change in the total output of fruit and vegetables. For estimates on livestock, we use studies by Parsons et al (2001) and Turnpenny et al (2001). Using IPCC 92 IS92 scenarios for 2050 the result of their studies are the following; the profitability of grazing systems is likely to be small but positive, while the effect on intensive systems is likely to be small, but negative. As a result, we assume no change in livestock. Given the relative importance of crops in the agricultural sector in the region, we expect total output to decrease by approximately 8 percent.

In the region *Central Europe East*, PESETA has projected up to 30 percent decrease in yields in some areas of Bulgaria, and a positive change in the other countries. In most areas of Hungary, Slovakia and Romania the increase could be as much as 15-30 percent. The share of agricultural output in total output in the region is with 18 percent relatively high, but the importance of this sector within the region differs. In Bulgaria the economy highly depends on agriculture, as this sector contributes to 30 percent of total output. This means that a projected decrease in yields up to 30 percent has a strong effect on GDP in Bulgaria. Our estimates on fruit and vegetables are based on the same study as used for the British Islands (Wolf, 2002), in addition to PESETA projections for crops. The British study of potato simulation models under climate change in Europe included a site in Debrecen, Hungary. The result was no change to a slight decrease (Wolf, 2002). This runs counter to the expected effects on crops in other studies, and we therefore expect no change in fruit and vegetables in Hungary, and assume the same will hold for Romania and Slovakia. Due to the expected strong negative impact of climate change on crops in Bulgaria, we expect that there will be a negative impact on fruit and vegetables as well. However, there is little research to build this estimate on, and we therefore choose somewhat more moderate estimates for the impacts in the other countries in this region than those for Bulgaria, namely..

For livestock, there are no studies from this region. However, it is assumed the results from the British Islands are applicable, which implies that climate change will not change the productivity (Parsons et al., 2001; Turnpenny et al., 2001). Even though the expected impacts in most of the countries in this region are positive, the total effect is negative because of the relative size of the agricultural sector in Bulgaria.

Apart from an area in western Germany, *Central Europe North* can expect a positive change in crop yields, especially in Austria, where the projected increase range from 15 to 30 percent (PESETA, 2007). In a study on wine quality, using the SRES A2 scenario, it is predicted that climate changes in cool climate regions like the Mosel Valley and Rhine Valley in Germany could lead to more consistent vintage quality of wine and even ripening of warmer climate varieties as temperature increase, at least to a certain point (Jones, White, Cooper, & Storchmann, 2005). On this background, we assume better conditions for growing fruits and vegetables in the region, and estimate an increase of 5 percent in total output by 2080. No studies on expected changes in livestock production due to climate change has been found for this region, so as for Central Europe East, we expect no changes.

The changes in crop yields projected by PESETA vary throughout *Southern Europe*, from up to 30 percent decrease in southern Greece to a 30 percent increase in Slovenia and southern Italy (PESETA, 2007). Estimates of the changes in production of fruit and vegetables resulting from climate change in the region point in different directions (Jones et al., 2005; Viner, Sayer, Uyarra, & Hodgson, 2006). Viner et al (2006) expect negative impacts on fruits, and decrease in the production of wine and olive oil, while Wolf (2002) calculated both negative and positive effects on potatoes in a study site in Italy. In this study, we assume a 1 percent decrease in total output of fruit and vegetables for the region, except in the case of Slovenia. Based on the results of the PESETA Project (2007), which expect an average of 22,5 percent increase in crop yields, we assume a 5 percent increase in fruit and vegetables. Given that a 15 percent decrease in precipitation is expected (PESETA, 2007), it seems reasonable to expect that the productivity of grasslands will decrease, with a negative effect on livestock production (Parsons et al., 2001). As a result, we expect the cost of keeping animals will increase, taking into account the shortage of irrigation water available, and estimate a 5 percent decrease for countries in the region, apart from Slovenia. The overall effect of climate change on the agricultural sector is expected to be negative, given that the negative impacts in the rest of the region outweighs the positive impacts expected in Slovenia.

According to PESETA (2007), the change in crop yields in *Central Europe West* will most likely turn out negative. A study by Jones et al (2005) on wine quality found that for some of the grape varieties in France, the climate was already too warm for the predicted optimum. Considering the importance of wine production in this region, we assume that climate change will affect the productivity of fruit and vegetables negatively in the region, and assume an estimated 1 percent decrease in total output of this sub-sector. Similar to the British Islands, no change in the livestock sub-sector is assumed. The effect on total agricultural output is then expected to be negative.

The changes estimated for the productivity in agriculture on the *Iberian Peninsula* are negative and large. As much as 15-30 percent decrease in crop yields is expected in most of the region (PESETA, 2007). In a study from the Mediterranean area, a 2 percent decrease of potato yields was estimated in Portugal, while the estimate for Spain was a 9 percent increase, given a global temperature increase of 2 degrees by 2060 (Giannakopoulos, Bindi, Moriondo, LeSager, & Tin, 2005). However, these estimates presuppose that the additional water requirements can be met. Given that the region is already scarce of water, and the negative projected crop yields estimated by PESETA, we assume a 5 percent decrease in total output of fruit and vegetables in Portugal, and no change in Spain. According to our estimates, the Iberian Peninsula will be the far most affected region in Europe. We assume that the direct impact on agriculture is an 11 percent decrease. In both Spain and Portugal, agriculture accounts for 9 percent of total output, and local communities and areas highly dependent on agriculture are expected to be hit hard. Viner et al (2006) found that livestock production is likely to be negatively affected because of increasing costs of keeping animals. Based on this, we assume a 1 percent decrease in total output of livestock.

The agricultural sectors in the *Nordic Countries* are likely to benefit from improved conditions. A Danish study projects an increase in the mean yields of winter wheat between 21 and 37 percent, depending on methods for scenario application (Olesen et al., 2007). The projected crop changes in PESETA are 15-30 percent higher in the 2080s compared to baseline (PESETA, 2007). Potato yields have been estimated to increase by more than 50 percent in Finland, given a temperature increase of 2 degrees, increased precipitation by 8 percent and CO<sub>2</sub> concentration of 515 ppm (Carter, Saarikki, & Joukainen, 2000). This result is in line with the strong increases projected by Wolf (2002). In this study it is assumed that the output of fruit and vegetables in the Nordic countries increases by 50 percent by 2080.

Animal production is expected to be less affected by climate change, but nevertheless, the impact is expected to be positive due to indirect effects (Hildén et al., 2005). We assume a positive impact on total output of livestock of 5 percent in the region. All in all, the agricultural sector in this region appears to benefit from climate change.

Table 4.3 summarizes the assumptions about the impacts to the agricultural sectors in the present study, indicating ranges for changes in the productivity.

Region	Expected changes			
	<i>Fruit&amp;vegetables</i>	<i>Other crops</i>	<i>Livestock</i>	<i>Total</i>
Baltic States	---	+	+	-
British Islands	0	--	0	-
Central Europe East	-	-	0	-
Central Europe North	+	+	0	+
Southern Europe	-	-	-	-
Central Europe West	-	-	0	-
Iberian Peninsula	-	---	-	--
Nordic Countries	+++	+++	++	++

*Table 4.3: Evaluation of change on agricultural sub-sectors by region: 0: no change, single: 1-10 percent, double: 11-20 percent, triple: more than 20 percent*

### **4.3 Forestry**

The direct economic impacts of forestry in Europe today are relatively small (see Table 4.4) although the area covered by forest is generally high in all regions except for the British Islands. To what extent the forest is used for production varies, from a 5 percent share in Central Europe North, to 91 percent in the region Central Europe West.

In addition to timber production, forests play an important role in protecting biodiversity, prevent soil erosion and protect infrastructure and settlements from natural hazards, such as rock fall and avalanches (Lexer et al., 2002). Forests also provide important recreational areas, they are important to the cultural identity, for regulation of ecological systems, etc. The impact of climate change on forest is expected to follow the same pattern as productivity in agriculture. Due to a decrease of current tundra area (White, Cannell, & Friend, 2000) and higher tree lines in mountainous areas (Moen et al., 2004), forest area is expected to increase in the Northern areas of Europe. In terms of how much forestry contributes to total output, this means forest area is expected to increase in economies where forestry is already relatively important. In southern areas on the other hand, number of droughts and fire risk is expected to increase, both in terms of length of season and severity (Arnell et al., 2005). As a result, forested areas in southern areas are likely to contract (Metzger et al., 2004). The expected causes are changes in temperature, precipitation and increased CO<sub>2</sub> and ozone, similar to the effects in the agricultural sector (see Chapter 4.2). Changes in species distribution will be commented below for each specific region. The estimated climate related changes in the forestry sector in the GRACE\_adapt model are based mainly on the expected changes in *net primary productivity* (NPP) of biomass in a study by Fronzek and Carter (2007). NPP of biomass is a less than perfect economic estimate for the total output of forestry, as increased

growth rates may reduce the quality of the timber (Broadmeadow, Ray, Sing, & Poulson, 2003). However, we assume it can be a suitable indication, in terms of direction and size of the expected change. Fronzek and Carter (2007) used a model called the Miami Model, which is based on an empirical relationship between long-term temperature and precipitation and measurements of NPP of natural vegetation, to project mean estimates of percentage change in NPP of biomass between 1961-1990 and 2071-2100 on the basis of the SRES emission scenarios A2 and B2. We use the estimates from the A2 simulation. The largest changes were found in The Nordic region, where the expected increase in the most northern areas is above 40 percent while the largest negative impact is in Spain, where the decrease might be more than 20 percent (Fronzek & Carter, 2007). These findings are similar to findings from other studies (Alcamo et al., 2007).

Region	Share of output	Volume shares		Value of product removals		
		<i>Of total land</i>	<i>Used for production<sup>3</sup></i>	<i>Industr. roundwood</i>	<i>Wood fuel</i>	<i>Non-wood products</i>
Baltic States	0.64	35	54	93	5	2
British Islands	0.03	11	44	80	1	19
C Europe East	0.45	30	41	85	7	8
C Europe North	0.09	34	5	71	15	13
Southern Eur	0.07	34	28	65	7	29
C Europe West	0.10	27	91	72	7	21
Iberian Penin	0.20	37	21	61	4	35
Nordic countries	0.58	52	78	85	5	10

*Table 4.4: Overview of volume and value of the forestry sector in percentages.*

Sources: (Dimaranan, 2006; FAO, 2005).

The share of total output from the forestry sector is relatively high in the three *Baltic States* Estonia, Latvia and Lithuania . The risk of fire, pest outbreaks and wind damages are expected to increase (Arnell et al., 2005; Kellomäki et al., 2000). In Poland, expectations of a decrease in the supply of coniferous and increase of deciduous species are reported (Kellomäki et al., 2000). There are differences throughout the region: the northern parts of the region can expect biomass to increase, while southern parts should expect a decrease. In total, the impact of climate change on NPP is expected to be positive (Fronzek & Carter, 2007).

In the *British Islands*, a change in species composition is expected, with an increase of coniferous species in northern parts and a decrease of deciduous species in southern parts. Southern parts are also likely to face higher risk of drought and fire, while northern parts might expect an increase in the risk of wind and snow damages (Kellomäki et al., 2000). NPP of biomass is expected to increase in northern parts and decrease in southern parts of the region (Fronzek & Carter, 2007). The estimated total effect is slightly positive. This is supported by other research as well. Without including the CO<sub>2</sub> effect, Broadmeadow, Ray and Samuel (2005) found that broadleaf timber productivity is likely to benefit from climate change across the majority of the British Islands. In a case study from a rural estate in

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<sup>3</sup> Share of forested land

Scotland, Viner et al (2006) came to the similar conclusions; with an increase in expected annual growth.

In *Central Europe East*, forestry is a relatively large contributor to total output in Slovakia and Bulgaria. According to an expert assessment on impacts of climate change on forests in Europe, increased temperature and precipitation is likely to decrease timber supply from Norway spruce, European beech and Oak in Slovakia (Kellomäki et al., 2000).

*Central Europe North* can expect higher risks because an increase in pest, bark beetle, forest fires and wind damages is expected (Kellomäki et al., 2000). A negative impact on productivity is expected in Germany (Fronzek & Carter, 2007; Lasch, Lindner, Erhard, Suckow, & Wenzel, 2002; Viner et al., 2006), but this is outweighed by the expected increases in productivity in Switzerland and Austria (Fronzek & Carter, 2007; Viner et al., 2006). The total effect on the forestry sector in the region is expected to be positive.

In *Southern Europe*, one expects a negative impact of climate changes on the forestry sector in all countries except Slovenia. Increased frequency of droughts and fire risk are expected (Giannakopoulos et al., 2005). As a consequence, the NPP of biomass is will decrease (Fronzek & Carter, 2007).

In *Central Europe West*, the risk of fire is likely to increase. NPP of biomass is expected to decrease in France and Luxembourg, but stay approximately the same in Belgium and the Netherlands (Fronzek & Carter, 2007). The total effect is, then, negative.

*The Iberian Peninsula* is the region most negatively affected by climate change in Europe, and the forestry sector is not an exception. Droughts and the risk of fire is likely to increase, and NPP of biomass is expected to decrease throughout the region, and by more than 20 percent in southern Spain (Fronzek & Carter, 2007; Viner et al., 2006).

The projections for the *Nordic Countries*, on the other hand, show benefits for the forestry sector from climate change. This is also a region where forestry is relatively important compared to the rest of Europe, particularly in Finland. The tree line is expected to expand towards higher altitudes and higher latitudes as the temperature increases. The region is likely to see a decrease in coniferous species, but an increased supply of deciduous species (Kellomäki et al., 2000; Moen et al., 2004; Sykes & Prentice, 1996). The productivity of forests is likely to increase, especially in northern parts of the region (Fronzek & Carter, 2007; Kellomäki et al., 2000; Sonesson, 2004).

Region	Expected changes
Baltic States	+
British Islands	+
Central Europe East	-
Central Europe North	+
Southern Europe	-
Central Europe West	-
Iberian Peninsula	--
Nordic Countries	+++

Table 4.5: Main impacts per region in the forestry sector.

0: no change, single: 1-10 percent, double: 11-20 percent, triple: more than 20 percent.

#### 4.4 Fisheries

Fisheries contribute less than a half percent to total output in all regions except Southern Europe (see Table 4.6). In Greece, the fishery sector contributes more than 7 percent to total output. The impacts of climate change differ in many respects between aquaculture, or fish farming, and commercial fishing. While impacts on fish farming depend to a large extent on the ability to control pests, commercial fishing is vulnerable to changes in the location of fish stocks. Hence, the impacts to the sector also depend on the contribution to total output from fish farming. This contribution varies from 2 percent in Central Europe North to 51 percent in the Nordic Countries.

Although there is a general opinion that fisheries will be affected significantly by climate change, the knowledge of biodiversity and ecosystem impacts is still limited, and it is difficult to predict in what directions the changes will go. Socio-economic costs related to climate change are also uncertain, but they may become substantial for enterprises and communities that highly depend on coastal and marine ecosystems (Alcamo et al., 2007). Because of these limitations we do not base the GRACE\_adapt model on specific relationships between climate indicators and economic activity, but we include assumptions about stock changes for illustrative purposes. These are presented in Section 5.3.

Region	Percent of GDP	Fresh-water and diad.	Demer-sal marine fish	Pelagic marine fish	Crustaceans and molluscs	Commercial fishing	Aquaculture
Baltic States	0.1	12	12	70	6	90	10
British Islands	0.1	16	27	37	19	77	23
C Europe East	0.1	89	1	6	4	85	15
C Europe North	0.1	23	22	45	10	98	2
Southern Europe	0.8	8	25	24	33	96	4
C Europe West	0.1	4	26	44	24	77	23
Iberian peninsula	0.4	3	26	43	24	95	5
Nordic countries	0.2	12	49	36	4	49	51

*Table 4.6: Overview of fisheries in each region in percentages.*

Sources: GTAP(Dimaranan, 2006), Eurostat (2005a) and FAO (2007).

Despite limited knowledge, the sensitivity of fish stocks to changes in sea conditions seems to be undisputable, such as the relation between temperature and stock production (Dutil & Brander, 2003), the distribution of species (Hiscock, Southward, Tittley, & Hawkins, 2004; Roessig, Woodley, Cech, & Hansen, 2004) and recruitment (Clark, Fox, Viner, & Livermore, 2003). Distributions of North Sea herring have been found to respond markedly to increases in sea temperatures (Toresen, 2000), and climate change is predicted to drive species ranges towards the poles (Perry, Low, Ellis, & Reynolds, 2005, Drinkwater, 2005).

Aquaculture is a part of the fisheries sector and accounts for approximately 30 percent of the total output (EC, 2006). Expanded geographic distribution and range due to warmer sea temperatures is likely to give opportunities for new species (Beaugrand & Reid, 2003), but ecosystem changes may have negative impacts, such as outbreaks of harmful algae and decreased dissolved oxygen events, which will increase operational costs. Further, increased storm-induced damage on facilities and equipment will increase capital cost (Alcamo et al., 2007).



## 4.5 Energy

Both energy demand and energy supply will be affected by climate change. A part of the energy demand is due to regulation of indoor temperature, both for space heating and space cooling. On the supply side, renewable energy sources for electricity are based on climatic conditions, such as wind speed for wind power and run-off for hydro power. Thermal power plants, moreover, require cooling water, which may be restricted at high temperatures or droughts. We assume that there are no direct effects of climate change on the extraction of fossil fuels.

The five energy sectors in GRACE\_adapt (crude oil, gas, coal, refined oil, electricity) contribute between 2 and 6 percent to total GDP in the eight EU regions. The contribution is highest in the Baltics and in Central Europe East, although the oil and gas sector are important in the Nordic countries and on the British islands as well due to their affluence on fossil resources. The pattern indicates the importance of energy to the lower-income European economies, as the relative contribution from electricity and refined oils increase with lower income levels.

### 4.5.1 Demand

Temperature and energy demand are linked together in a rather intuitive way; higher temperatures lower energy demand for heating purposes in winter, and increases energy needed for cooling devices, such as air conditioners, in the summer. These effects are referred to as the *heating effect* and the *cooling effect* (De Cian, Lanzi, & Roson, 2007; Tol, 2002). Seasonal fluctuations in energy demand are closely related to temperature, but the sensitivity differs across energy carriers. Variations related to heating purposes affect the consumption of refined oils, gas and electricity, but differently and to different extent across regions. Cooling affects only the demand for electricity (Kirkinen et al., 2005).

In a study on the effect of climate change on energy demand, Bigano, Bosello and Marano (2006) found that an increase in temperature affects the demand for different energy carriers differently in households and in production sectors. The so-called temperature elasticity of energy demand (percent change in demand due to one percent change in temperature) is, in general, small and not statistically significant in service and industry sectors. Households, on the other hand, do respond to temperature changes. The response in energy demand to changes in temperature depends on the temperature level in the region and we assume that this is proportional to the residents' share of total final energy consumption (TFC) in the region.

Region	Hot/cold	Residents share of TFC for different energy vectors in percentages		
		<i>Electricity</i>	<i>Gas</i>	<i>Oil products</i>
Baltic States	Cold	25.5	29.3	5.1
British Islands	Cold	33.6	58.5	4.7
Central Europe East	Cold	27.8	35.0	2.8
Central Europe North	Cold	27.4	45.6	15.7
Southern Europe	Hot	24.0	41.0	11.3
Central Europe West	Cold	32.7	38.1	10.1
Iberian Peninsula	Hot	26.3	17.4	6.7
Nordic Countries	Cold	29.6	21.1	4.9

*Table 4.7: Residents' use of total final energy consumption (TFC).*

Source: 2005 Energy Balances in thousand tonnes of oil equivalent (ktoe) on a net calorific value basis (IEA, 2005).

A study of the impact of temperature change on residential energy demand for a series of energy goods reveals that the cooling effect outweighs the heating effect in hot countries and that the heating effect outweighs the cooling effect in cold countries in terms of electricity demand (De Cian et al., 2007). For other energy sources, such as coal and gas, the effect of an increase in temperature on consumption is negative. Moreover, the effect was found to be similar for hot and cold countries. In order to estimate expected changes in energy demand we use the average elasticities for hot countries for Southern Europe and the Iberian Peninsula, and the average for cold regions for the other regions. The elasticities are shown in Table 4.8, which refer to percent change in temperature measured in Fahrenheit. The temperature elasticities are based on seasonal temperatures. To use them directly, we have to assume that the temperature changes equally throughout the year in each region, without implications for seasonal variations. Studies which include seasonal variations indicate that temperatures will increase most during summers in southern parts of Europe, and during winter in northern parts (PESETA, 2007). If so, our study underestimates the impacts on energy demand.

Region	Temperature elasticities for different energy vectors <sup>4</sup>		
	<i>Electricity</i>	<i>Gas</i>	<i>Oil products</i>
Baltic States	-0.38	-2.60	-1.43
British Islands	-0.38	-2.60	-1.43
Central Europe East	-0.38	-2.60	-1.43
Central Europe North	-0.38	-2.60	-1.43
Southern Europe	1.00	-2.80	-1.46
Central Europe West	-0.38	-2.60	-1.43
Iberian Peninsula	1.00	-2.80	-1.46
Nordic Countries	-0.38	-2.60	-1.43

*Table 4.8: Temperature elasticities for the residential sector.*

Source: De Cian et al (2007).

Both the *Baltic States* and *Central Europe West* are defined as cold regions, and energy demand is expected to decrease due to the heating effect.

On the *British Islands*, higher temperatures will decrease demand for space heating in winter, spring and autumn. A reduction in demand of 5-10 percent for fossil fuels and 1-3 percent for electricity due to a 2 degree warming by 2050 was estimated (Smith & Hitz, 2003). Likewise, a 10-15 percent increase in electricity demand due to increased air conditioning was estimated (LCCP, 2002). Our study uses the elasticities estimated by De Cian et al (2007). An expected increase in demand for electricity for cooling purposes during summers is outweighed by the decrease of electricity demand for heating purposes the rest of the year and the total effect are expected to be negative.

In *Central Europe East*, wintertime heating is expected to decrease by 6-8 percent on the average by the period 2021-2050 (Vadja, Venäläinen, Tuomenvirta, & Jylhä, 2004), while the summer cooling requirements are expected to increase (Arnell et al., 2005). However, the baseline use of energy for cooling purposes is low, and the expected increase is outweighed by decreased heating demands. Based on the temperature elasticities estimates in Table 4.8 and expected temperature increases between 12 and 15 percent, the total energy demand is expected to decrease by approximately 4 percent.

In *Central Europe North*, energy demand is expected to shift from winter heating demand to summer cooling demand. In a study of the response of climate change on energy demand in buildings in Switzerland, energy demand for heating was projected to decrease by 33-44 percent, while energy for cooling increased by up to 223-1050 percent, depending on type of building (Frank, 2005). However, baseline cooling demand is not known. The expected temperature increase varies between 12 to 14 percent, and total energy demand is likely to decrease by more than four percent by the period 2071-2100. Energy demand is expected to shift from winter heating demand to summer cooling demand.

In *Central Europe West*, electricity demand is expected to increase due to higher summer cooling requirements (Arnell et al., 2005).

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<sup>4</sup> The elasticities are defined as the percentage change in demand induced at one percent increase in temperature. In this table, temperature is measured in Fahrenheit. Elasticities depend on baseline temperatures. Hot countries tend to have higher elasticities because one percent represents a higher absolute increase the warmer the baseline temperature is (Roson, Bosello, & De Cian, 2007).

Electricity demand in *Southern Europe* will be affected by an increase in summer space cooling needs (Arnell et al., 2005; Cartalis, Synodinou, Proedrou, Tsangrassoulis, & Santamouris, 2001; De Cian et al., 2007). Yet, total energy demand is expected to decrease by approximately four percent because of reduced demand during wintertime.

As for Southern Europe, electricity demand on the *Iberian Peninsula* is expected to increase (Arnell et al., 2005; De Cian et al., 2007). The demand for energy to space heating during winter is likely to decrease, which implies a decrease in the demand for fossil fuels. The total effect is a slight decrease, by less than one percent, in total energy demand by 2071-2100. Despite the low expected change in energy demand, it is important to keep in mind that this is averaged throughout the year.

In the *Nordic Countries*, total energy demand is likely to decrease due to decreased heating demand (De Cian et al., 2007; Tammelin et al., 2002; Venäläinen et al., 2004). Despite the relatively high temperature increases, varying between 13 and 19 percent, the effect on energy demand is among the lowest of all regions at no more than a decrease of 1,2 percent. This is due to the fact that the share of total final consumption by residents is relatively low.

Region	Expected changes			
	<i>Oil</i>	<i>Gas</i>	<i>Electricity</i>	<i>Total</i>
The Baltic States	-	-	-	-
The British Islands	-	--	-	-
Central Europe East	-	--	-	-
Central Europe North	-	--	-	-
Southern Europe	-	--	+	-
Central Europe West	-	--	-	-
The Iberian Peninsula	-	-	+	-
The Nordic Countries	-	-	-	-

*Table 4.9: Main impacts per region on energy demand 0: no change, single: 1-10 percent, double: 11-20 percent, triple: more than 20 percent.*

#### 4.5.2 Electricity generation

Most of the electricity generated in Europe is thermal power, but the share varies from 37 percent in the Nordic region to 95 percent in the Baltics. Among renewable sources, hydro power dominates in most regions, with contributions from 2 percent on the British Islands to 56 percent in the Nordic region. Bio power contributes up to 5 percent (in the Nordic region) and wind power up to 7 percent (in Iberia). Generation of all electricity is subject to climate change, but for highly different reasons and to widely different extent.

Region	Hydro power	Bio power	Wind	Fossil-fired thermal
Baltic States	4	1	0	95
British Islands	2	3	1	94
Central Europe East	13	1	0	86
Central Europe North	13	3	4	80
Southern Europe	13	2	1	84
Central Europe West	8	2	0	90
Iberian Peninsula	8	1	7	83
Nordic Countries	56	5	2	37

*Table 4.10: Shares of total output in the electricity sector in percentages.*  
Source: IEA(2005).

The hydro power potential is closely linked to changes in precipitation. A study by Lehner et al (2005) of the impacts of climate change on hydropower potential in Europe found that most countries will be affected. Our estimates of the real change in hydropower potential are based on the reported hydro power production statistics from the International Energy Agency (IEA, 2005). Lehner et al (2005) base their estimates of changes on production in the period 1998 to 2000. These changes are assumed to apply similarly for the actual production in 2005, hence assuming no significant changes in production of electricity from the baseline of the study by Lehner et al (2005) to the 2005 numbers from IEA. For Europe as a whole, gross hydropower potential was, then, estimated to decrease by 6 percent by the 2070's. Iberia is the most negatively affected region, and is likely to face a reduction in the hydro power potential of 25 percent or more by 2070. For the Nordic countries, on the other hand, a strong increase is projected (Lehner et al., 2005).

Bio power is becoming increasingly important in Europe, but there are few studies on the impact of climate change on this source of energy. Generally, the supply of the raw material can be expected to follow the direction and proportions of the productivity changes in agriculture and forestry (Kirkinen et al., 2005). On this basis, we adopt the forestry results from the study by Fronzek and Carter (2007) to biomass for electricity generation as well. The baseline for this study is the period 1961 – 1990. Similar as for hydropower, we assume that there has not been a significant change up to 2005, so the distribution of biopower across regions reported by IEA (2005) apply directly.

Because of the difficulties in obtaining projections in changes of wind-speed under climate change, it is hard to estimate the effect of climate change on wind energy potential. Moreover, the share of electricity generated by wind power is relatively small in most regions, with an exception of Iberia and Central Europe North. Our estimates are based on a study on climate change impacts on wind energy resources in northern Europe (Pryor, Barthelmie, & Kjellström, 2005).

Climate change is expected to reduce the availability of cooling water needed at thermal power plants during summers, but no estimates of costs have been available. Offshore oil and gas extraction may be negatively affected by climate change if the frequency of extreme weather events increases (Arnell et al., 2005), while less ice cover opens new opportunities for finding oil and gas, but possible impacts on extraction are ignored in this study.

*The Baltic States* get a relatively high share of total output from the electricity sector, but the sector is not particularly climate sensitive, given that the electricity is mainly generated by the

use of fossil fuels, such as coal, oil and gas (IEA, 2005). Bio-, hydro- and wind power potential are all expected to increase under climate change (Fronzek & Carter, 2007; Lehner et al., 2005; Pryor et al., 2005). Given the small market shares from these sources, the total impact on the electricity sector in the region is expected to be just above 1 percent. Latvia is an exception in this region, with a high share of hydropower. Due to an expected increase of 24 percent by 2070 (Lehner et al., 2005), our estimated output increase of the electricity sector is more than 16 percent.

The electricity sector in the *British Islands* is highly dominated by gas, coal and nuclear driven power plants (IEA, 2005), and the expected positive impacts on hydro- and bio power potential is not expected to have a significant effect on the sector.

*Central Europe East* has the highest share of total output from electricity, and both bio- and hydropower potentials are expected to decrease (Fronzek & Carter, 2007; Lehner et al., 2005). The total effect is a decline of approximately 4 percent, the highest decrease of all regions.

The electricity sector in *Central Europe North* is expected to be negatively affected. The hydropower potential has decreased in all countries of the region by 2070 (Lehner et al., 2005). An expected increase in bio power production in Austria and Switzerland is outweighed by the decrease in Germany (Fronzek & Carter, 2007). The share of electricity from wind power is more important in Germany than in most other countries in Europe, with a 4 percent share (IEA, 2005). Due to the expected increase in wind energy potential in northern Europe (Pryor et al., 2005), we find it reasonable to assume an increase in Germany as well.

In *Southern Europe*, the overall effect of climate change on the electricity sector is expected to be negative. Hydropower potential is expected to decrease in all countries, and as much as by 22 percent in Italy (Lehner et al., 2005), which is the largest hydropower producer in the region. The potential for bio power production is also expected to decrease in all countries except Slovenia (Fronzek & Carter, 2007). As wind speed is expected to decrease (Räisänen et al., 2004), we assume the impact on wind power potential will be negative. The net effect on electricity production is estimated to a decrease of 3,5 percent.

Both bio- and hydropower potential is expected to decrease in *Central Europe West* (Fronzek & Carter, 2007; Lehner et al., 2005), because of lower precipitation and declining forest biomass.

On the *Iberian Peninsula*, precipitation will decrease, which has a negative impact on hydropower potential (Arnell et al., 2005; Lehner et al., 2005). A decrease in biomass is also expected, particularly in Spain (Fronzek & Carter, 2007). Mean windiness is expected to decrease as well in the Mediterranean area (Räisänen et al., 2004), and reduces the wind power potential in this region, which has the highest share of wind power in Europe.

*The Nordic Countries* will benefit from enhanced growth of biomass and increased precipitation (Fronzek & Carter, 2007; Lehner et al., 2005). More than 60 percent of electricity is from bio- and hydropower in this region. Climate change therefore implies a positive effect on the electricity sector. Denmark is the country in Europe with the highest share of electricity generated from wind power (IEA, 2005). It will benefit from an expected increase of wind in the region, both on-shore and off-shore (Kirkinen et al., 2005; Pryor et al., 2005). The total effect on the electricity sector is expected to be as much as 15 percent.

Region	Expected changes				
	<i>Hydro power</i>	<i>Bio power</i>	<i>Wind</i>	<i>Other</i>	<i>Total</i>
Baltic States	++	+	+	0	+
British Islands	+	+	0	0	+
Central Eur East	---	-	0	0	-
Central EurNorth	--	+	+	0	-
Southern Europe	---	-	-	0	-
Central Eur West	--	-	0	0	-
Iberian Peninsula	--	--	-	0	-
Nordic Countries	+++	+++	+	0	++

*Table 4.11: Main impacts on renewable electricity generation by sub-sector.  
0: no change, single: 1-10 percent, double: 11-20 percent, triple: more than 20 percent*

#### **4.6 Manufacturing industries**

The impact by climate change on the industry sector is mostly indirectly, such as through the supply of raw materials, intermediates, transport etc. This will be taken care of by the GRACE\_adapt model, as this includes cross-over supplies.

#### **4.7 Tourism**

The contribution of tourism to total economic activity varies throughout Europe, but plays a more dominating role in the southern parts than elsewhere. A change in tourism will affect many economic sectors. We have not found detailed information on what sectors and to what extent they depend on tourism. To keep it simple, we use the numbers from Statistics Finland (2008) where it is assumed that the contribution to GDP from tourism splits into the transport and the service sectors, with 30 percent to transport and 70 percent to services. To compare the size of tourism in all countries, we apply the satellite accounting tables on tourism from World Travel & Tourism Council (WTTC), where all the countries in our model are represented.

Region	Contribution to GDP	Share of arrivals		Season	
		Domestic	International	Summer	Winter
Baltic States	4	67	33	65	35
British Islands	7	77	23	60	40
Central Eur East	4	57	43	64	36
Central EurNorth	6	68	32	60	40
Southern Europe	8	54	46	66	34
Central Eur West	7	60	40	86	14
Iberian Peninsula	12	56	44	64	36
Nordic Countries	5	73	27	68	32

*Table 4.72: Overview of the tourism sector (in percentages).  
Sources: Eurostat (2005b) and TSA (2008).*

The output of tourism is calculated as the sum of direct and indirect gross domestic product and employment associated with travel and tourism consumption. Then, 12 percent of GDP on the Iberian Peninsula is generated by tourism, whereas the contributions in Malta and Cyprus are above 15 (TSA, 2008). The summer season, defined by us as ranging from May to October, is the most important season in terms of both arrivals and nights spent in different accommodation facilities, in all regions. On the other hand, the relative number of domestic and foreign tourists varies, both within and across regions. However, there are more domestic tourists compared with foreign tourists in terms of arrivals in all regions (Eurostat, 2005b).

The total amount spent on travel and tourism will probably not be affected by climate change, but there may be significant changes in destinations (Berrittella et al., 2006). Climate is, in many cases, an important factor when tourists make their choice of destination, including the climate of the source regions (Giannakopoulos et al., 2005). Changes in the length and quality of tourist seasons (such as beach holidays or winter sports activities) are likely to have implications for the competitiveness of destinations and consequently the profitability of tourism enterprises (Simpson, Gössling, Scott, Hall, & Gladin, 2008). Countries closer to the poles may attract more foreign tourists during summer. At the same time, their own citizens may become less attracted to destinations in southern countries (Amelung, Nicholls, & Viner, 2007; Hamilton, Maddison, & Tol, 2005). A shift towards tourist destinations at higher altitudes is expected for these reasons (Hamilton & Tol, 2007; Simpson et al., 2008). If so, the countries most dependent on tourism today will “suffer” the most from climate change in the future. However, an important aspect of tourism is its dominating role in some local communities. Even though tourism may become beneficial to a country or region, changes may become negative in smaller tourist based communities with severe negative impacts.

In order to estimate expected changes in tourism due to climate change, we use the predicted tourism flows by Hamilton et al (2005) for 2025 and a 1 degree global temperature increase as an indication on change in tourism by 2070 using the PESETA predictions of climate change. There are several reasons to consider the estimates with caution, as the knowledge about relationships between climate and tourism are poor. To some tourist activities, the linkage may seem obvious, but for other, such as event seeking or cultural tourism, it less clear. Moreover, we interpret changes in departures as changes in domestic tourism. That is, a five percent decrease in departures implies a five percent increase in domestic tourists, not a reduction of tourism.

Tourism in all countries in Southern Europe and Iberia is expected to be negatively affected by climate change. In all other regions, the increase in domestic tourism cancel out or outweigh the decrease in international arrivals. Countries highly dependent on tourism, like Malta and Cyprus, are likely to be hit hard, both due to the relatively important tourist sector and the high share of foreign tourists.

*The Baltic States* are expected to become more attractive to international tourists. Apart from Poland, domestic tourism will increase as well. The total regional effect on domestic tourism is slightly negative due to the relative size of Poland, but the net effect is an increase in the tourism industry. The negative effect of less international tourists is outweighed by the expected increase in domestic tourists in the *British Islands* as well.

In *Central Europe North*, an increase in international tourists is expected in Austria and Switzerland. This outweighs an expected decrease in Germany. This is because of the assumption that localities at higher altitudes will become more attractive (Hamilton & Tol, 2007; Simpson et al., 2008). All countries in the region will also become more attractive to own citizens, and the total net effect is an expected increase of 12 percent.



*Southern Europe* is the region with the second highest share of GDP generated by tourism, and the share of international tourists is the highest in this region. This region includes the only two countries where tourism contributes more than 15 percent of GDP, namely Malta and Cyprus. In these countries 90 and 79 percent consists of international arrivals, respectively. Climate change is expected to turn the region less attractive to foreigners. The expected decrease in arrivals for the region is 17 percent. Domestic tourism is expected to increase, and the net effect is a 5 percent decrease in tourism.

	<b>Expected changes</b>		
	<i>Domestic</i>	<i>International</i>	<i>Net effect</i>
Baltic States	++	-	++
British Islands	++	-	++
Central Europe East	+	-	+
Central Europe North	++	+	++
Southern Europe	+	--	-
Central Europe West	+	-	+
Iberian Peninsula	+	--	-
The Nordic Countries	++	++	++

*Table 4.83: Main impacts on tourism flows by region.*

*0: no change, single: 1-10 percent, double: 11-20 percent, triple: more than 20 percent*

The region far most dependent on tourism is the *Iberian Peninsula*. Climate change is expected to result in a lengthening and flattening of the season (Maddison, 2001), with a resulting reduction in number of visitors. Hein (2007) estimated a 20 percent reduction in tourist flow by 2080 compared to 2004. We use estimates far below this. Based on the numbers by Hamilton et al (2005) and Eurostat data (2005b), we have estimated a decrease of 5 percent.

Similar to the Baltic States, it is assumed that also the *Nordic Countries* will become more attractive to international tourists, especially during summer (DMI, 2006; RosabyCentre, 2006). The effect on winter tourism is, on the other hand, more uncertain, being dependent on snow. As one of the projected effects of climate change is higher temperatures and less snow, this might have a negative effect on winter tourism in some areas (Aaheim et al., 2008).

## **4.8 Transport**

The sub-sectors rail and road transport constitute most of the transport sector. Apart from sea and air transport, other sub-sectors include pipelines, auxiliary transport activities and travel agencies. Estimating economic impacts on the transport sector is difficult, because little research has been done. Some research has been conducted on the expected damage on infrastructure due to climate change, but to the best of our knowledge, very little has been done on estimating the cost/gains of delays/time saved due to a changing climate. However, tourism is an integrated part of transport sector and we assume that 30 percent of tourism contribution to GDP stems from transport. Based on this, we include a share of the expected changes in tourism due to climate change as expected change on the transport sector.

Region	Share of GDP	Tourism share of total transport	Sub-sectors share of sector total output		
			Sea	Rail and road	Air
Baltic States	7	19	11	84	5
British Islands	6	34	9	76	15
Central Eur East	6	28	9	84	7
Central EurNorth	4	45	14	72	15
Southern Europe	5	44	13	79	7
Central Eur West	5	41	15	67	18
Iberian Peninsula	5	67	7	76	17
Nordic Countries	8	16	31	54	16

*Table 4.94: Overview of the transport sector in percentages.*

Source: GTAP (Dimaranan, 2006).

Road and rail surfaces might be damaged as a result of temperature increases (Eddowes et al., 2003; Wooller, 2003). Increased frequency of extreme weather might damage infrastructure further, and also decrease passability by reducing performance and safety (Wooller, 2003). Changed precipitation patterns, and intense downpours of rain may increase the probability of landslides, and thereby undermine the stability of the infrastructure (DS, 2005). In colder areas, increased temperatures may reduce snow cover. At higher altitudes and latitudes, snow clearing is a demanding activity, and in some cases snow is not even cleared during winter season. Less snow as a result of climate change may increase the utilization of roads in mountainous areas during winter. Maintenance of roads may also be affected in areas where the periods at which the temperature lies around 0 °C expand, because periods with freezing and thaw causes extra damages to roads.

Region	Share of total output
The Baltic States	+
The British Islands	+
Central Europe East	+
Central Europe North	+
Southern Europe	-
Central Europe West	+
The Iberian Peninsula	-
The Nordic Countries	+

*Table 4.105: Main impacts on the transport sector.*

*0: no change, single: 1-10 percent, double: 11-20 percent, triple: more than 20 percent.*

On the other hand, there are indications that future climate change may increase the number of landslides, and if this will be the case, this will affect the transport sector negatively (Aaheim et al., 2008). Changes in passenger preferences and modal shifts as climate changes are unpredictable. Studies from England predict that public transport may be perceived as

more uncomfortable compared to private vehicles when temperature increases, and dry summers could lead to an increase in cycling (LCCP, 2002; Wooller, 2003). A study from Norway estimates a shift from private to public transport as a result of more precipitation. Also, in line with the study from England, people are expected to walk and bike more, and the estimated total effect was a reduction in transportation costs.

Extreme events are also costly to the transport sector. One single flooding of the London Underground had an estimated cost of £0.74 million due to passenger delays alone. For the period between September 1999 and March 2004 the total cost amounted to approximately £14.6 million (LCCP, 2005). Extreme events have, however, implications for many sectors and activities, and we therefore base our estimate on the expected extreme events to each sector as a share of the total expected cost of extreme events. This cost is imposed as an annual “loss of real capital”, allocated to the different sectors.

Sea transport is likely to be affected as a result of less ice cover and more open waters, which may open new international routes, such as the northern sea route, or make old routes more effective. On the other hand, less ice cover increases the height of waves, which is challenging to the sea transport (ACIA, 2004). Possible changes in wind speed, frequency of storms etc. will also affect this sector.

The net economic effect of the physical expected changes due to climate change is hard to predict. In our case, transport specific impacts are due only the changes driven by changes in tourism. Thus, for other possible impacts, the positive and the negative impacts are expected to be balanced in all regions.

#### **4.9 Services**

This sector includes public and private services. Consisting of many sub-sectors, the indirect effects of climate change to the service sector may be substantial. However, direct effects are more difficult to single out, except for the abovementioned impacts on tourism. This industry is mainly dominated by small and medium sized enterprises, and is highly interlinked to the rest of the economy, particularly the service sectors. On this basis we assume that changes in the tourism industry will affect the service sector, such as in hotels and restaurants or the retail sector. Although changes in the service sector induced by changes in tourism might appear small, one should keep in mind that the impacts are likely to be substantial for enterprises and communities highly dependent on tourism.

<b>Region</b>	<b>Share of GDP</b>	<b>Tourism share of total services</b>
Baltic States	21	14
British Islands	32	15
Central Europe East	19	20
Central Europe North	37	11
Southern Europe	33	17
Central Europe West	36	13
Iberian Peninsula	28	29
The Nordic Countries	31	12

*Table 4.16: Overview of the service sector in percentages.*

Source: GTAP (Dimaranan, 2006).

#### **4.10 Non sector-specific impacts**

Apart from the impacts surveyed in Sections 4.2 through 4.9, climate change will have economic consequences for a broad range of sectors which are not specific to certain sectors. The typical example is extreme events, which may destroy capital and infrastructure depending on where the activities are rather than what these activities are about. These overarching impacts are often those most frequently associated with climate change impacts, which besides extreme events, include sea-level rise and health impacts. Despite lots of attention to these impacts, there are few numerical estimates on country level or regional levels. We have made attempts to include these impacts in GRACE-adapt, but they are loosely based on available estimates. Further comments on this are given in Sections 5.7 and 5.8.

### **5 Implementation of impacts functions**

This section presents the impact functions by sector in the GRACE\_adapt model implemented for the eight EU regions. For most sectors, the same function is assumed to apply for all regions. The parameters are estimated on the basis of the assessment of impacts of climate change from underlying studies surveyed in Section 4. In some cases the country estimates are based on a subjective evaluation of reference studies in other countries, applied to the country in question. In other cases the country estimate is based on several studies of the country. Thus, the impacts to a sector in each country is represented with only one estimate, which we refer to as the “observation”. Differences in impacts across regions arise as a result of different changes in the climate indicators. In most cases we use changes in mean temperature and annual precipitation. There are good reasons to question if impacts across Europe can be described only with reference to changes in a few, simple climate indicators as if other country specific characteristics were insignificant. We do not believe so, but on the other hand, the alternative would be to apply regionally specific impacts functions without any reference to studies of that region. Our choice may therefore be considered a result of relatively scarce literature. Recall, also, that most integrated models confine themselves to mean temperature. The indicators we use to represent the climate are, nevertheless, very rough when considering the information needed to establish reliable relationships between climate and various impacts

The advantage of estimating a common impact function for each sector in all regions of Europe is that the impact function becomes based on a broader set of observations than possible if one impact function is made specifically for each sector in each country or region. The general functions chosen here may, however, hide important specifics of a country, and tends to moderate the impacts of climate change in general as compared to the results of country specific studies. It is, however, difficult to tell whether “outliers” are likely to be real or due to assumptions, and the choice was taken on the background of the relatively poor quality of quantitative assessments of impacts.

There are, however, no reasons to hide the fact that the impact functions are extremely uncertain, partly because of the uncertainty of the “data”, but also because the choices of functions are taken primarily with the perspective of simplicity rather than realism. The purpose here is to make clear what has been done, and thereby prepare the ground for a prioritization of future improvements.

## 5.1 Agriculture

Impacts are calculated indirectly on the basis of an estimated direct relationship between total output in the agricultural sector and a combination of temperature, precipitation, income per capita and population:

$$X = (a_1 + a_2P)P + (b_1 + b_2T)T + cR + dN$$

where  $P$  is precipitation in mm per year,  $T$  is temperature in °C,  $R$  is GDP per capita and  $N$  is population. The same parameters apply for all regions (and provinces). Hence, impacts is a result of changes in precipitation and temperature *levels*  $P$  and  $T$ . The estimates are shown in Table 5.1.

To implement this relationship into GRACE, we assume the same sensitivity to the value of natural resource input as to the estimated total production. Denote by  $V_s$  the input of natural resources (i.e. the value of land) in province  $s$ , and by  $X_s$  total output in agriculture. Define  $\alpha_s = V_s/X_s$  and let  $\alpha_{is} = \alpha_s a_i$  ( $i = 1,2$ ) and  $\alpha_{is} = \alpha_s b_i$  ( $i = 1,2$ ). Then, the productivity function for the agricultural sector in can be written as

$$V_s = (a_{1s} + a_{2s}P_s)P_s + (b_{1s} + b_{2s}T_s)T_s + C_s \quad (5.1)$$

where  $C_s = \alpha_s(cR_s + dN_s)$  is the constant referring to the income per capita and population in each province.

Name	Estimate	Std.dev
a1	-49.275	38.086
a2	0.031025	0.025137
b1	2178.3072	2459.8477
b2	-93.3839	98.4645
c	285.896	130.2340
d	2.3061	0.0754

Table 5.1. Estimated parameters of the impacts function for agriculture

## 5.2 Forestry

The forestry sector is the only sector in GRACE\_adapt where the management of the natural resource is addressed. This section discusses both the calibration of equations of the forestry module, and the estimation of impacts. The calibration of the model is based partly on FAO statistics (FAO, 2006) and partly on the GTAP database. Impacts are estimated on the basis of results reported in literature as discussed in Section 4.3.

The point of departure for the forestry module is the Lotka-Volterra equation between the stock of a resource,  $S$ , and its annual rate of growth  $\dot{S}$ :

$$\dot{S} = (B - cS)S$$

$B$  and  $c$  are positive parameters. In principle, the two parameters of the quadratic Lotka-Volterra equation can be calibrated by means of an observed combination of standing mass and the harvest subject to the first-order condition for optimal harvest, which states that the combination of harvest and mass is at the point where rate of change in growth of mass equals the social rate of return on capital.

However, observations of the pair of standing mass and corresponding harvest, as described by the Lotka-Volterra equation, are not available. FAO (2006) provides data for standing mass either in terms of total mass of forest or as potentially commercial mass. Potentially commercial mass is defined with reference to physical criteria about the quality of the forest, and must be separated from mass that is being commercially utilized. An underlying economic explanation to why forest defined as commercial is not utilized, is that investments are needed to get access to and utilize the forest.

The model distinguishes between utilized and non-utilized commercial forests by including infrastructure capital,  $k_2$ , which enables the manager to control the Lotka-Volterra equation and make a part of it apply only to the utilized part of the standing mass,  $V_u$ .

$$\dot{V}_u = (B - bk_2^{-\beta} - cV_u)V_u \quad (5.2)$$

$b$  and  $\beta$  are positive parameters. The owner then has to decide both on the optimal harvest and on the investment in infrastructure. The first-order condition for optimal harvest is:

$$r = B - bk_2^{-\beta} + 2cV_u + \frac{p_F}{p_K} wtp \quad (5.3)$$

where  $r$  is the social rate of return on capital (the discount rate) and  $wtp$  is the willingness to pay for a standing mass of forest. The first order condition for investments in infrastructure is

$$p_F = \frac{p_K}{\beta bk_2^{-(\beta+1)} V_u} \quad (5.4)$$

The parameter  $\beta$  is chosen by assumption. Then  $B$  and  $c$  and  $b$  can be calibrated by (2) – (4) from observations of the variables  $V_u$ ,  $\dot{V}_u$  and  $k_2$ .

What is observed is, however, the total change of the forest,  $\dot{S}$ , the harvest and the total mass of forest,  $S$ . One way out of this problem is to refer all economic behaviour to the utilized part of the forest, such that harvest equals growth in this part of the forest. Moreover, we take advantage of the assumption that the utilized and the non-utilized forests are subject to the same physical conditions. From (2), the utilized forest is controlled by changing the constant term,  $B$ . The “remaining” part of the constant term applies to the non-utilized forest,

$$\dot{V}_n = (bk_2^{-\beta} - cV_n)V_n \quad (5.5)$$

The growth of non-utilized forests is not observed directly, but may be deducted under certain assumptions: As the entire growth in the utilized part is assumed to be harvested, only the non-utilized part of commercial forests will be subject to change. This is partly due to an increase in the forested area, for which data are available, and in the total stock of forests, which is also available. The growth in non-utilized commercial forests,  $\dot{V}_n$ , can be found by subtracting an estimate of mass in new forested land from the observed change in total stock. Currently, the total growth of forest is allocated entirely to new forested area, such that  $\dot{V}_n = 0$  in all regions. The division between the two categories of stock is determined by

$$S = V_u + V_n \quad (5.6)$$

where  $S$  is observed. Now,  $B$ ,  $b$ ,  $c$ ,  $V_u$  and  $V_n$  can be calibrated simultaneously by equations (5.2) through (5.6). The estimates are shown in Table 5.2.

	Capital infr.	$B$	$b$	$\beta$	$c$	Utilized	Non- utilized
	(estimate)					Mill m <sup>3</sup>	Mill m <sup>3</sup>
Baltic states	122.2	0.128524	2.16101	0.8	-2.54149E-05	1184.1	1819.3
British Islands	79.0	0.296632	4.24978	0.8	-6.00833E-04	142.7	214.5
Central East	51.0	0.049465	0.13920	0.8	-5.81622E-06	1630.3	1495.9
Central North	322.9	0.181488	8.51080	0.8	-2.65899E-05	1502.3	0.0
Southern Europe	117.0	0.075640	0.68452	0.8	-4.18879E-05	1137.3	362.0
Central West	336.2	0.213063	10.07123	0.8	-5.99394E-05	946.5	1599.9
Iberia	367.5	0.152306	8.47029	0.8	-5.08071E-05	921.1	0.0
Nordic	818.4	0.406879	46.25677	0.8	-6.07729E-05	1451.3	3519.3

Table 5.2. Calibrated parameters of the forestry module stocks by region

To divide into districts, the parameter  $B$  and the mass variables are divided in accordance with the key for distribution of economic activity on provinces.

Indicator	Estimate	Std. dev.
Precipitation (mm/year)	0.00129	0.00025
Temperature (°C)	0.00887	0.00595

Table 5.3. Estimated linear impacts of precipitation and temperature on the rate of change in forest parameters.

The reported impacts of climate change are interpreted as a percentage simultaneous change in natural growth and productivity of capital. Thus, a 10 percent increase in forests implies a 10 percent increase in the parameters  $B$  and  $b$ . The impacts function explains the *rate* of change in  $B$  and  $b$  as linear functions of changes in precipitation and temperature. The estimates are displayed in Figure 5.3

### 5.3 Fisheries

The complexities of possible connections between the fish stock and air temperature indicate that single functions to represent such a relationship, as we base the GRACE\_adapt model on, should be interpreted with high caution. An alternative is, clearly, to disregard possible impacts of climate change on fisheries. On the other hand, the message from the literature is, that fisheries will, indeed, be affected, but it is difficult to predict in what direction and to what extent. Impacts of climate change on fisheries are therefore included in a very simple manner, mainly to clear the ground for an integrated analysis of possible changes to the sector.

Climate change is assumed to affect the value of the natural resource both in fish commercial fishing and in aquaculture. The stock of natural resource in commercial fishing can be interpreted as the stock of fish, whereas the natural resource in aquaculture is the conditions in the oceans, which include ocean climate. The relationship between air temperature and the natural resource is based on two more or less arbitrarily chosen variables. One is the ideal air temperature at which the stock of fish is at its highest, and the second is the rate of change in stock per °C deviation from this temperature. The ideal temperature as well as the sensitivity

to air temperature is equal for all regions (provinces) in Europe, but they differ between commercial fishing and aquaculture.

Let  $N_s$  denote the value of the natural resource in province  $s$  (according to the reported GTAP data),  $\alpha$  the share of commercial fishing in the fishery sector,  $\sigma_j$  the rate of change in stock value per °C deviation from the ideal temperature in activity ( $j = c$  - commercial fishing),  $a$  - aquaculture),  $T_j^*$  the ideal air temperature for activity  $j$ , and  $T_s$  the actual air temperature in province  $s$ . Then, the change in the value of the natural resource is written as:

$$dN_s = N_s(\alpha\sigma_c T_s - T_c^*) + (1 - \alpha)\sigma_a(T_s - T_a^*)dT_s \quad (5.7)$$

Because of the difficulties in predicting changes in sea temperature from air temperature, we use the same value for  $dT$  for all regions and provinces across Europe. The following parameters have been chosen:

Parameter	Commercial fishing	Aquaculture
$\sigma_j$	0.025	0.020
$T^*$	10.0	5.0

Table 5.4. Choice of parameters in the impacts function for fisheries

#### 5.4 Electricity supply

The electricity sector is based on different technologies which relate to climatic factors in different ways: While thermal power may be constrained by the availability of cooling water, the supply of renewable energy is more directly related to precipitation (hydro power) and wind (wind power). Although the importance of wind power is increasing across Europe, hydro power is still the main renewable source of electricity. Roughly speaking, more precipitation is likely to increase production in both renewable and thermal power production, although to a widely different extent, whereas temperature may have an influence on the supply of thermal power, but have little influence on the supply of hydro power.

On the basis of estimates of each region in GRACE\_adapt, the sensitivity of climate change to generation of electricity is explained by a linear relationship between output and change in precipitation, temperature and the share of hydro power in the system. For seven of the eight regions, hydro power constitutes between 2 and 13 percent of total electricity supply. In the Nordic countries, the contribution is nearly 50 percent. One might, therefore, regard the Nordic countries as an “outlier”, but here, we stick to the same relationship for all regions:

$$dX = adT + bdP + cs \quad (5.8)$$

where  $dX$  is percent change,  $dT$  °C change in temperature  $dP$  is mm/year change in precipitation and  $s$  is the share of hydro power in total electricity supply. The following estimates are being used

Indicator	Estimate	Std. deviation
Precipitation (mm/year)	0.1355	0.1127
Temperature (°C)	-0.0122	0.0049
Share of hydro	0.3811	0.0929

Table 5.5. Estimated sensitivity of climatic parameters on generation of electricity.



The observations refer to the change in output from the electricity sector, but it is interpreted as the percent change in the input of natural resources to the generation of electricity in the model.

### 5.5 Energy demand

The temperature adjustment of energy demand is assumed to affect the household sector (residential energy demand) and the service sector. The changes are based directly on elasticities suggested in the literature (see chapter 4.5.1), where there is a distinction between warm and cold regions. In warm regions, electricity demand is assumed to increase with increasing temperature for cooling, whereas cold regions reduce their electricity demand because of less heating. The demand for gas and refined products is being used only for heating, and the elasticity with respect to temperature is therefore negative. Southern Europe and Iberia are regarded “hot” regions, and the remaining six regions are regarded “warm”. The following elasticities are being used

Regions	Electricity	Gas	Refined oil
S. Europe and Iberia	1	-2.8	-1.46
Remaining six	-0.38	-2.6	-1.43

Table 5.6. Temperature elasticities in residential and service sectors by carrier and region

### 5.6 Tourism

The underlying drivers behind a possible change in tourism are complex and diversified. Little is known about the relationship between climate and tourism, although the emphasis put on climatic conditions in promotion of tourism is a strong indication of the existence of such a relationship. But sensitivities depend on what the tourists are attracted to, and one should distinguish between domestic and foreign tourism, and winter and summer tourism. Moreover, tourism is not an economic sector, neither in GRACE\_adapt nor in the Standard for National Accounts, but it affects different sectors. In GRACE\_adapt, mainly the service sector and transport are likely to be affected.

The current estimates in GRACE\_adapt are based on strong simplifications. First, the percentage change in total tourism is estimated as a linear function of the changes in temperature and precipitation and the product of temperature and temperature change. The possible importance of differences between hot and cold regions is thereby taken into account:

$$dY = (\alpha + \beta T)dT + \gamma dP \quad (5.9)$$

where  $dY$  is the percent change in demand,  $T$  is the °C level of temperature  $dT$  is the °C change of temperature and  $dP$  is the percent change in precipitation. The parameters are

Variable	Estimate	Std. error
Temperature change (°C)	0.08678	0.01410
Change in precipitation (mm/year)	-0.16909	0.13615
Combination of level and change in temp (°C)	-0.00702	0.00133

Table 5.7. Estimated sensitivities of tourism

The product of temperature level and temperature change allows the sensitivity to temperature change to differ across the regions, depending on the temperature level. The estimates indicate that the impact of climate change on tourism changes from positive to negative as the regional level of mean temperature increases above 12.5 °C.

In the model, it is assumed that the changes in the tourism sector are estimated as the percent change of demand for transport and services in the household sector, divided according to the contribution from tourism in these two sectors, ( $j$  = service, transport):

$$dX_j = \varepsilon_j dY_j \quad (5.10)$$

where  $\varepsilon_j$  is the contribution from tourism in sector  $j$ .

### 5.7 Extreme events

It is difficult to deal with extreme events in general equilibrium models for three reasons. First, the events will have to be represented by an expression for expected impacts, unless the model is run with stochastic shocks. The economic implications of the same loss over ten years is likely to differ substantially from a loss of ten times this loss in one year and no losses over nine years. Whether or not to run a model with stochastic shocks depends on the purpose of the analysis. To examine the real impacts of extreme events, stochastic shocks are the most relevant. To evaluate implications of present decisions, an expression for the expectations may be more relevant. The second difficulty relates to the local character of impacts of some extreme events, such as land-slides. Even the province level suggested in GRACE\_adapt is too aggregated to capture the real socioeconomic costs of many extreme events.

It is also difficult to predict how climate change will affect future frequencies of extreme events. It is sometimes made a point out of the fact that if the density functions for variation in temperature, precipitation and wind are kept constant, but only the mean values change, the frequencies of what can be labeled extreme events will increase more than proportionally to the change in the mean values. The assumption of an unaffected density function may even be considered conservative.

The third difficulty is that the impacts of extreme events are very case-specific, and it is difficult to use historic evidence to predict impacts, even if the weather events themselves could be forecasted. It is, therefore, difficult also to draw general lessons about single studies of impacts of extremes from different places. In large parts of Europe, there are expectations of an increase of floods, droughts, windstorms and land-slides resulting from climate change. We have, therefore, included some rough estimates, based on historical records of impacts of weather related natural hazards, and an illustrative assumption about the increase of frequency.

In GRACE\_adapt, extreme events are represented by the average annual cost, and are based on historic data for the weather related natural disasters in Europe, which include droughts, extreme temperature, floods, slides, storms and wild fires.

	Number indicators		Cost	A
	Basis	at +3.5 °C	% of K	
Baltic	0.497	0.994	0.74	0.060533
British	0.449	0.899	0.61	0.049454
East	0.630	1.259	1.19	0.097073
North	0.418	0.835	0.52	0.042703
South	0.465	0.931	0.65	0.053042
West	0.407	0.815	0.50	0.040667
Iberia	0.638	1.276	1.22	0.099620
Nordic	0.378	0.756	0.43	0.034973

*Table 5.8. Indicator for number of extreme events by region by period, associated costs of damage as percent of total stock of capital and constant term of damage function*

We simply assume that the costs of extreme events are quadratic in the number of events to reflect that the distributions of costs of single events are skewed, with long “tails” to cover probable disasters. We moreover assume that the average temperature change for Europe at 3.5 °C implies a doubling of the frequency of disasters. The cost function for extreme events reflects the percent change in the capital stock,  $K_i$ , of region  $i$ :

$$\mu_i = A_i dT_i^\alpha \quad (5.11)$$

where  $A_i$  is the parameter shown in the last column in Table 8 and  $\alpha = 2$ . Note that measuring damage in percent of  $K$  captures some of the often observed phenomenon that damage of natural disasters tend to increase without climatic changes as countries grow rich.

## 5.8 Sea-level rise

A lot of work has been carried out to assess the cost of sea-level rise, and it has been emphasised that estimates vary considerably depending on whether adaptation is taken into account or not. There are available estimates for some EU countries, and for EU total, but a detailed distribution of costs on the EU countries is not available. As a preliminary solution, the current impacts are based on an estimate of total annual cost for Europe of 1 700 mill USD for 1 meter rise of sea level from Tol (2002), and distributed according to (preliminary approximations) of coast-line, low-lying areas and population by province as defined in GRACE\_adapt. The cost function for sea-level rise is quadratic, and is assumed to affect the change the capital stock. The cost in province  $s$  is

$$dk_s = \gamma N_s (\alpha a_s + \beta L_s) dR^2 \quad (12)$$

where  $dk_s$  is the percent change in capital stock,  $a_s$  is province  $s$ ' share of Europe's total coastline, and  $L_s$  is the low lying area (threatened by flooding) in the province. This indicator is presently indexed from 1 to 5 by province.  $\alpha$  and  $\beta$  are parameters that indicate the importance of coastline and low-lying areas, respectively, for the total cost (each are set equal to 1).  $N_s$  is the population in province  $s$  and  $\gamma$  is the scale parameter determined to make sure

that the right hand side sums up to the total annual cost of sea level rise of 0.0102, which corresponds to a capital loss of 1 700 mill USD. Then  $\gamma = 0.00001995$ . Finally,  $dR$  is the increase of sea-level rise in meters.

## 6 Results

Adaptation is a question of transition and time. Some barriers to adaptation are likely to become smaller over time, whereas others sustain over long periods. As for the constraints on mobility addressed in GRACE, the barriers diminish over time at different rates. Natural resources are hardly mobile at all, whereas the mobility of capital in most cases depends on the life-time of the capital equipment. Labour is, in principle, fully mobile, but long-term unemployment in certain areas indicates that the reality is different. Products also are subject to different degrees of mobility. Commodities can be regarded fully mobile, whereas services will in most cases have to be supplied at the place where the demand is.

How the time perspective of adaptation is dealt with is therefore utterly important when running scenarios in integrated models with endogenous adaptation, such as GRACE. In this section, we leave this issue behind by running only static solutions. That is, we compare the reference case with three alternatives where the increase in global mean temperature is +2 °C, +3 °C and +4 °C. The impacts in each province are calculated by linear extrapolations of mean temperature and precipitation from the PESETA study referred to above, where the increase of global mean temperature is assumed at +3.5 °C. For example, in a province where the mean temperature increases by +3 °C according to the PESETA study, we assume that the increase in the +4 °C scenarios is slightly below +3.5 °C in this province. The changes in precipitation are adjusted correspondingly in relation to the PESETA scenario.

In principle, we thereby compare two states where the climate shifts immediately, and impose some restrictions to adaptation. More specifically, we assume no mobility of natural resources and no mobility of labour. Whereas the restrictions on natural resources are real also in the long term, a full restriction on the mobility of labour over the period where the mean temperature increases by +2 °C, +3 °C and even +4 °C is, indeed, an exaggeration. This is to some extent compensated by the full mobility of capital, however. The choice of putting restrictions on labour is due to our wish to address possible social inequalities that may arise from climate change impacts. Moreover, the restrictions apply to the mobility across provinces, which are relatively large. Within provinces, there is full mobility.

GRACE\_adapt is a global model, where the rest of the world is represented by two regions, one for industrialized countries and one for developing countries. There is full trade between the European regions and the two world regions, but we assume no impacts of climate change outside Europe. If negative impacts were imposed on the rest of the world, the negative impacts in Europe would most likely increase. This is why the *level* of changes in this study is of limited importance. What matters are the relative changes between regions, provinces and across the three cases +2 °C, +3 °C and +4 °C.

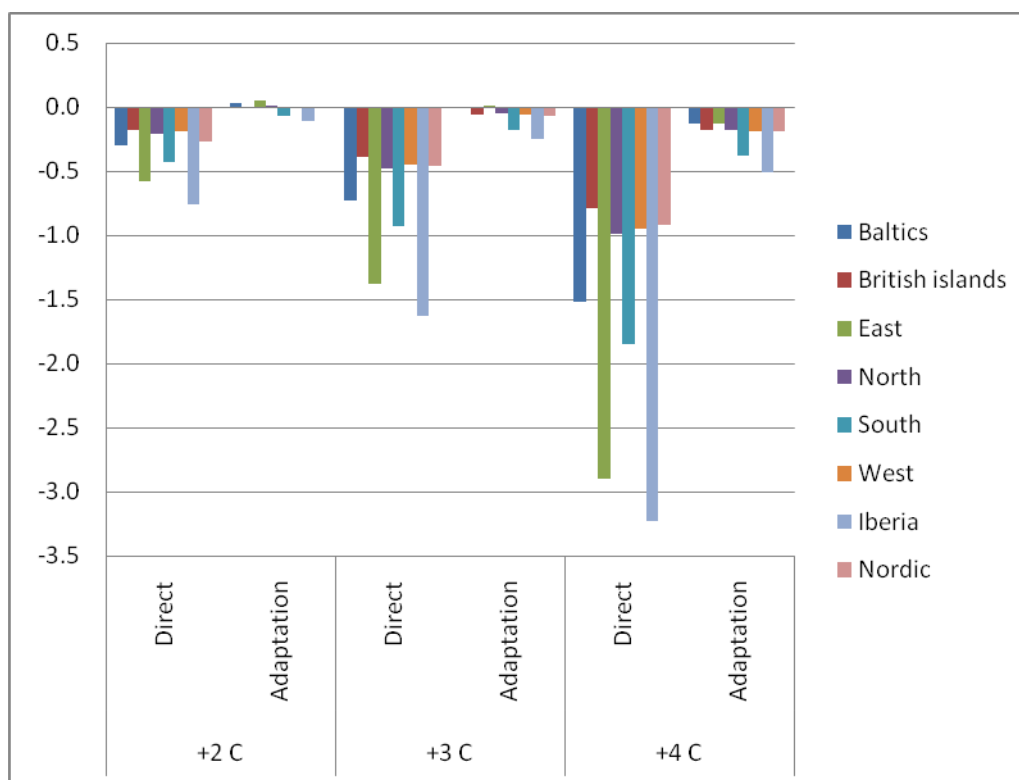


Figure 6.1. Percent change in GDP with and without adaptation with increases in global mean temperature at +2 °C, +3 °C and +4 °C.

Figure 6.1 shows the percent change in GDP in the three cases for the eight regions of Europe. The changes are calculated both with and without adaptation. The impacts “without adaptation” are the estimated impacts directly from the impacts functions described in Section 5 expressed in percent of GDP. The impacts “with adaptation” are the percent change in GDP in the new equilibrium solution. From the figures, we note that the results give some justification of the +2 °C target advocated by the EU: The +2 °C case shows small economic impacts, with positive changes in some regions and negative in others. For higher temperature increases, the impacts are negative in all regions. We also note that the impacts are non-linear: A +1 °C increase in the global mean temperature results in a doubling of the costs of climate change.

Adaptation takes place in terms of changes in quantities, but changes in prices also constitutes an important part of the adaptation process when comparing GDP in the different cases. The total effect of adaptation is substantial, and reduces the impacts by approximately 80 - 85 percent in many regions. This large effect of adaptation may partly be explained by the assumption that the world outside Europe is unaffected by climate change. This opens Europe’s ability to draw advantage of the benefits of climate change and to avoid the disadvantages, and this process is driven by the changes in world market prices.

The implications of the market effects differ a lot from region to region, though. Somewhat surprisingly, it is the Baltic and the Eastern part of Central Europe, with the lowest income among all European regions, which draw most advantage of adaptation. When comparing the direct impacts of climate change, these two regions are the second and fourth most negatively affected. However, it is only these two regions that benefit from climate change in the +2 °C case, when market responses are taken into account. The costs in terms of GDP losses are also the lowest among all regions in the two other cases.

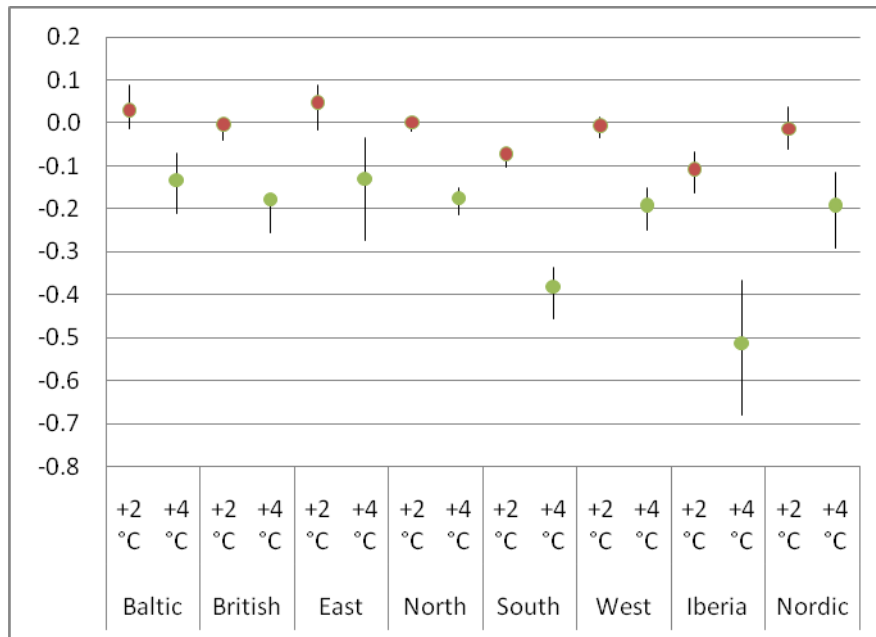


Figure 6.2. Variation of percent change in GDP among provinces by region in the +2 °C and the +4 °C cases.

According to our results, Southern Europe and Iberia face the highest costs of climate change, with more than twice the costs in the northern and western regions of Central Europe, the British Islands and the Nordic countries. As mentioned, the Baltics and eastern part of Central Europe face lower impacts in all cases, but the differences between these two regions and the other regions diminishes as temperature increases. However, when comparing provinces within the regions, the picture changes somewhat and new patterns occur. Figure 6.2 shows the ranges (from maximum to minimum) within which the changes in GDP vary within regions in the +2 °C and the +4 °C cases. The regional averages are marked by dots.

Although the low-income regions lose the least in total, the variations across provinces are substantial. Both in the +2 °C and the +4 °C cases, there are provinces in these two regions where the costs exceed the average European level. Also the two southern regions exhibit large variations, in particular Iberia, where the costs of climate change vary between 0.06 to 0.16 percent in the +2 °C case and between 0.36 and 0.68 in the +4 °C case.

Going further into the details of these variations, it turns out that for most regions, there is a significant correlation between loss in terms of percent change in GDP and income per capita: The lower the income per capita is in a province, the higher is the costs of climate change. The explanation may be that provinces with low income are more dominated by resource dependent economic activities, such as agriculture.

Figures from Eurostat indicate that provinces with large agricultural sectors tend to exhibit higher long-term unemployment than other provinces. One may therefore suspect that climate change can have social implications that have not yet been addressed, because the provincial dimension is absent in previous economic studies. The GRACE\_adapt model has this dimension, but does not address unemployment directly. It is assumed that all resources are used, and unemployment is therefore disregarded by assumption. However, the variability of impacts on the labour market can be indicated by the difference in the changes of wage levels that arise because of climate change.

in four of the eight regions (Baltic and the eastern, northern and western parts of Central Europe) there is a tendency that the wages in low income provinces are more negatively affected. However, we cannot conclude on a general basis whether or not climate change may enforce present social challenges, such as long-term unemployment, but a closer examination of the changes in various provinces may be worthwhile.

## 7 Conclusions and remaining questions

The development of the integrated computable general equilibrium model GRACE\_adapt represents an attempt to bring consistency between adaptation to climate change and economic behaviour. Adaptation to climate change can thereby be analysed endogenously by means of the assumptions underlying the behaviour of economic agents. Apart from providing a documentation of the modelling, this report presents the first results of the model runs, which addresses one of the two questions that was raised as the background for the ADAM project, namely to compare the costs of mitigation to aim at +2 °C increase in global mean temperature with the need for adaptation if the global mean temperature increase by +4 °C.

We found that adaptation indeed contributes to reduce the macroeconomic impacts of climate change, but that the share of costs that is reduced by adaptation decreases as global mean temperature increases. Still, the economic impacts at an increase in global mean temperature at +4 °C are reduced by between 80 and 85 percent European wide as a result of adaptation in the runs presented here.

Both the level of economic impacts and the degree to which adaptation mitigates the initial economic costs of climate change vary greatly both between the eight European regions and within regions. The southern regions are most affected by climate change, whereas the low-income regions seem to take the most advantage from adaptation. This can be explained by the change in relative prices, which turn out in favour of the low-income regions. The low-income regions also exhibit relatively large variations within the region. This can also be considered a result of the changes in relative prices: Some provinces are better capable of drawing the advantage of this than others. Also the most affected regions exhibit large variations across provinces. In some regions there is a strong correlation between low income per capita and losses in GDP or reductions in wages on the province level, but such a pattern cannot be found in all regions.

It has to be emphasised that the results of the present study are preliminary and subject to notable weaknesses. First, we present only a static comparison between equilibria under different assumptions about climatic conditions. To get a more realistic picture of the economic consequences, one should run scenarios over a given time period. In that case, a closer examination of the barriers to adaptation would have to be considered, because barriers will diminish over time. Second, we have assumed that the rest of the world is unaffected by climate change. As mentioned, the effect of adaptation depends heavily on the change in relative prices, also on the world market. Implementation of impacts in the rest of the world is therefore likely to affect the results considerably. Hence, the levels of impacts reported here are probably biased, which is why we do not want to highlight them. However, we believe that we have gained some insights when it comes to the comparison of European regions and variabilities within regions.

We would also like to draw the attention again to the uncertainties about the estimates of the impact of climate change. Numerical assessments of impacts are still scarce and difficult to compare. We chose to base our estimates on an assumption that the same impacts function applies across regions in Europe. This is a strong assumption, indeed. Moreover, the impacts

that were taken into account probably represent moderate estimates, because some effects of climate change have been disregarded. Health effects, for example, are not included at all in the numerical analysis, and all impacts are imposed by means of expected values. The most severe economic impacts of climate change are related to extreme events, which are stochastic by nature. Stochastic events of certain magnitudes may itself general negative impacts, which have been disregarded here. A closer study of these impacts was, however, addressed in Work package A2 of the ADAM project.

Finally, there has been no attempts to include non-market impacts of climate change, which may turn out to be substantial. Hence the results of this study must be considered a “pure” economic assessment of impacts. A full evaluation of the impacts of climate change requires inclusion of many more aspects.



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