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[1] https://esgf-data.dkrz.de/projects/ esgf-dkrz/

1. Introduction

Climate change adaptation and climate-related disaster risk reduction have been recognized as a priority worldwide. Ambitious initiatives have been taken at global level, such as the 2015 Paris Agreement on Climate Change and the 2015 Sendai Framework for Disaster Risk Reduction, as well as several European policy actions like the EU strategy on Adaptation to Climate Change.

The series of PESETA projects of the Joint Research Centre (JRC) have intended to provide a better quantification of the possible consequences of future climate change for Europe. The aim of the JRC PESETA III project is to further improve that knowledge, narrowing uncertainty gaps. The study follows three stages: climate modelling, assessing the climate impacts for a number of impact categories and the economic analysis of the impacts.

The climate dataset come from the EURO-CORDEX regional climate model runs. All climate impact models have run five EURO-CORDEX climate runs, with three sets of results: 2030s climate, 2°C scenario and 2080s or high warming scenario. The results for the 2°C and 2030s runs are rather similar. Eleven climate impact categories have been considered in the study: coastal floods, river floods, droughts, agriculture, energy, transport, water resources, habitat loss, forest fires, labour productivity, and mortality due to heat.

The economic task of the project, documented in this report, has two objectives. The first objective is to integrate and compare the climate impacts in a consistent way from the economic perspective. Each sectoral biophysical impact assessment has its own set of metrics. For instance, impacts in the agriculture sector are measured in terms of agriculture yield changes, while impacts due to river floods are estimated in terms of economic damages and number of people affected.

That integration homogenises the various climate impact vectors, allowing to derive insights regarding the spatial and regional pattern of climate damages in Europe. These patterns can be useful to prioritise adaptation funds at the pan-European scale.

From the eleven sectoral studies in the JRC PESETA III project, five impact areas have been fully integrated: labour productivity, river floods, coastal floods, energy, and agriculture (the agriculture yield change results come from the ISIMIP study, as analysed in the HELIX FP7 project by JRC). For the other sectors, this full, homogenous integration was not possible because, being most of the impacts in non-market sectors, their economic damage estimates were not obtained. This is for instance the case of habitat loss, whose economic consequences are very difficult to estimate, as they would have required the implementation of methods to evaluate non-market environmental services that go beyond the scope of this study.

A sixth integrated impact category is human mortality due to heatwaves. There is not a dedicated human health study in PESETA III but the results from the study of Forzieri et al. (2017) have been integrated into the economic analysis, given their prominent weight in the overall economic impact estimates. In this way, that key component of the climate damage is taken into account in the economic analysis.

A second objective of the economic task is to explore the degree to which climate impacts cross geographical borders. Climate related disruptions in production or consumption in one region affect prices, supply and demand which, in turn, affect other countries via international trade. For instance, climate-induced reduction in agricultural production in one country will lead to increase in imports and reduction in exports of the agricultural goods, all having implications for the trading partners. This transboundary or spillover analysis is conducted at two levels: intra-EU and global spillovers. The intra-EU analysis refers to how much of the impacts in one region of the EU are due to climate impacts in the other EU regions. The global analysis focuses in the additional climate impacts in the EU due to climate impacts occurring in the rest of the world.

The global transboundary analysis has been made for the four sectors for which global impact estimates are available, even if from different climate scenarios. They are labour productivity, river floods, energy, and agriculture.

Two economic models are used, with different methodological approaches and for different purposes too. On the one hand, the multi-sectoral CaGE model has been used for the comparative static and transboundary analyses; on the other hand, the single-sector dynamic MaGE model has been used to explore dynamic aspects of impacts. The comparison is meant to highlight the results found and as an exploratory tool to ascertain and consolidate for future analyses the most suitable approach to this particular type of long-term economic evaluation problem.

The rest of the document is organised in ten sections. Section 2 describes the methodological framework. The next six sections deal with the economic analysis of impacts in each sector: labour productivity (section 3), river floods (section 4), coastal floods (section 5), residential energy demand (section 6), agricultural crops (section 7) and mortality (section 8). The transboundary analysis is presented in Section 9. Section 10 provides an overview of the economic impacts. Section 11 concludes.

2. Methodology

The economic method relies on the use of two economic models with different and complementary features: Climate assessment General Equilibrium (CaGE, Pycroft et al. 2016) and Macro-econometrics for the Global Economy (MaGE, Fouré et al. 2013). CaGE is a multi-sector, multi-country computable general equilibrium (CGE) model. The CGE analysis allows accounting for the direct impacts and the additional indirect effects in the economy due to the cross-sectoral and cross-country or trade adjustments. The computable general equilibrium methodology has been applied in the context of multi-sector climate impact analyses by several teams, like e.g. Bosello et al. (2012), Reilly et al. (2013) and, more recently, OECD (2015) and Hsiang et al. (2017).

The economic integration with the CaGE model is made in a comparative static context where future climate affects the economy as of today. There are two justifications for implementing the static approach: first, to keep consistency with the biophysical impact analysis, where the direct climate damages are computed on the basis of constant exposure data (so current land use, GDP and population); second, to avoid making challenging assumptions about the evolution of the economy and demography over the next eighty years. By referring the impacts to the present economic structure, one does not need to make or derive long-term assumptions on evolution of production factors, growth or economic structure that could distort the key findings of the study.

The relevance of the alternative dynamic framework (in other words, to assess the expected climate impacts on the future, projected economic system.) is explored for the coastal floods case with the MaGE dynamic growth model, which is able to consider how the dynamics of capital accumulation across periods is affected by climate impacts, but does not account for international trade. MaGE has been used in this study to analyse the possible integration of damaging mechanisms in such a growth-accounting modelling paradigm. At the price of losing sectoral detail and cross-country spillovers via international trade, this approach can cope with important dynamic effects highly relevant for the type of long-time impact assessment under analysis (demographic, physical and human capital accumulation and destruction, etc.).

The analysis is performed with five EU regions, aggregating the EU countries as follows:

- Northern Europe: Sweden, Finland, Estonia, Lithuania, Latvia and Denmark
- UK and Ireland: UK and Ireland
- Central Europe North: Belgium, Germany, Luxemburg, Netherlands, Poland
- Central Europe South: Austria, Czech Republic, France, Hungary, Slovakia, Romania
- Southern Europe: Bulgaria, Croatia, Cyprus, Greece, Italy, Malta, Portugal, Slovenia, Spain.

For the analysis of impacts of global transboundary effects the rest-of-the-world regions are aggregated into 13 regions (see Annex for detail of the aggregation).

2.1. Economic models

As already noted, the CaGE CGE analysis allows accounting for the direct impacts (as estimated by the biophysical impact models) and the additional indirect effects in the economy due to the cross-sectoral and cross-country adjustments. The cross-sectoral impacts are effects on other economic sectors or markets of the economy that are linked with the sector upon which the climate shock is imposed on via commercial relations (for instance the relationship between the crop sector and the agrofood industry). There are also indirect effects in other economies due to the trade flows between countries (both imports and exports). For instance, if one country faces a large negative shock, its production level will fall, which will lead to fewer imports from other economies. This kind of analysis is applied to the assessment of the size of the possible transboundary or cross-country climate impacts at two different levels: within Europe and from the rest of the world.

As a consequence, the use of a multi-sector, multi-country general equilibrium model such as CaGE permits that the estimated economic impacts include both the direct impact of climate change (e.g. the losses in the agriculture sector due to lower yields) and the indirect consequences in the rest of the sectors (e.g. in the agrofood industry) and the rest of the EU (considered via trade flows).

Another advantage of the CGE methodology is that it is actually capturing implicit or market adaptation by definition, via the changes in market prices. For instance, when the agriculture productivity is affected by climate change, the agriculture market and all other markets of the economy are adjusted via the economy price system. This is a general and broad process that affects all input and good markets of the country affected by climate and also the same markets in the countries with which the country has trade relationships. Regarding adaptation modelling, the climate impact sectoral results have not taken into account planned or public adaptation, unless otherwise stated. Some sectoral models have considered private-level adaptation, like in the case of using air conditioning for cooling in the energy sector.

The CaGE model considers three main channels in the economic transmission of direct economic damages into the economic system: changes in productivity (e.g. due to lower agriculture yields), changes in capital stock (e.g. due to the flood damages) and changes in consumption (e.g. repairing of flood damages reduces the consumption possibilities of households, which consequently reduces their overall welfare).

The results estimated with the quasi-static framework of the CaGE model address the question: "what the economy would look like if the future climate occurs today?" The framework considers how climate impacts affect the current production, consumption, savings and investment. Because the model's database represents annual stocks and flows of the global economy, the results obtained reflect annual changes to the database. In other words, the estimated economic impacts represent a change in annual welfare or GDP, but the possible effects on long-term economic growth are not considered in this assessment because the framework is static.

A second model, MaGE (Fouré et al. 2013), permits exploring the dynamic implications of the climate shocks. MaGE follows a recursive dynamic approach, insofar as the terminal values from any period are used as the starting point for the next period. It uses future projections of GDP and population from the shared socio-economic pathways (SSPs, Keywan et al. 2017), in particular SSP3. MaGE considers that there is a process of capital accumulation over time and population dynamics, which together with technical progress explain the dynamic evolution of GDP or output. In this study, the MaGE model is tested just for the coastal impact assessment, with the purpose of exploring possible ways of integrating the two described methodologies (e.g. multisectoral comparative statics and single-sector, dynamic growth accounting).

Two metrics of economic impacts are used: gross domestic product (GDP) and welfare changes. GDP is a measure of the value of the production of all goods and services of a country in one year. Welfare refers to the utility or satisfaction obtained by households, closely related to their consumption; the higher the consumption the higher the welfare. The GDP metrics has the advantage of computing how the overall economy would be affected (not just consumption). However, one advantage of welfare is that it focuses on how much the consumption possibilities of households are affected by climate change. A second reason to prefer the use of welfare rather than GDP is that some climate impacts directly affect the consumption possibilities of households (like repairing flood damages in residential buildings) but do not affect GDP, therefore the GDP metrics does not account for the climate impacts, and would underestimate their scale. GDP and welfare are presented in absolute terms (2007 Euro) and as percentage change.

It is important to note that the direct damages of the reference period are assumed to be embedded in the base year of the model. Therefore, the welfare analysis takes only into account the additional damages under the warming levels compared to those of the base year. All reported economic impacts are measured in 2007 Euro.

2.2. Transboundary effects or spillover analysis

The economic effects originating from climate shocks in other regions do not depend on 'own' climate change effects, but is a function of the 'outside' climate impacts and the bilateral trade connection between the 'own' and 'outside' regions, which includes the competitiveness effects. The magnitude of these effects can be measured as a change in absolute GDP or welfare in the recipient region.

For instance, let consider the case a specific climate impact like agriculture yield changes. Let assume that climate impacts lead to reduced yields in EU and also in one of its main agriculture trading partners, the US. There is not only the effect on the EU, which would see a reduction in productivity in the agriculture sector, leading to reduced GDP in the EU. There is an additional effect on the EU associated to the trade flows because lower US agriculture yields will also reduce US GDP, which then will import less products from its trading partners, including the EU, leading to an additional negative effect on EU GDP. Therefore, EU GDP could be indirectly affected by the reduction in US GDP due to agriculture climate impacts. That additional effect is what is identified here as the transboundary or spillover impact.

While the analysis regarding climate impacts in the EU has welfare or consumption as the preferred economic metrics, in the transboundary analysis the GDP seems a more appropriate metrics. This is because the trade channels are directly taken into account in GDP (from the demand perspective, GDP is equal to domestic demand – private consumption, government consumption and investment - plus exports minus imports), while they affect indirectly the consumption possibilities. Anyhow, as climate impacts affecting directly welfare barely affect GDP, the spillover analysis in GDP terms remains also somehow limited in capturing the full range of possible transnational effects.

Two settings are considered:

- Intra-EU transboundary analysis. This evaluates the GDP loss in one EU region due to the impacts in other EU regions. In the results of this study, this transboundary impact is already computed in the overall loss of the specific EU region.
- Global transboundary analysis. In this case, the GDP loss in the EU region is due to the impacts in the rest of the world. That loss is additional to the loss registered by the EU region.

2.3. Climate runs

The PESETA III project has considered a set of twelve bias-adjusted EURO-CORDEX climate change projections. A core set of five runs has been selected because all teams could not run all cases due to resource limitations. The selection of core runs has been made so that it is able to reproduce, as accurately as possible, the inter-model variability of the entire ensemble (see Dosio, 2018). Furthermore, the five core runs have been chosen so that the regional climate models (RCMs) are driven by 5 different global circulation models (GCMs). The economic analysis for Europe builds on the sectoral bio-physical impacts results for the average of the (minimum) 5 core GCM EURO-CORDEX models:

- R1-G1: CNRM-CERFACS-CNRM-CM5_r1i1p1_CLMcom-CCLM4-8-17
- R1-G2: ICHEC-EC-EARTH_r12i1p1_CLMcom-CCLM4-8-17
- R3-G4: IPSL-IPSL-CM5A-MR_r1i1p1_IPSL-INERIS-WRF331F
- R5-G5: MOHC-HadGEM2-ES_r1i1p1_SMHI-RCA4
- R5-G3: MPI-M-MPI-ESM-LR_r1i1p1_SMHI-RCA4

The impacts under the 2030s climate, 2°C scenario and 2080s (or high warming scenario) are evaluated. Since the results from the 2030s climate are very similar to those of the 2°C scenario, this report mostly focuses on the 2°C and high warming scenarios. The impacts under the EURO-CORDEX warming scenarios are compared with those under nowadays (1981-2010) climate conditions (control period).

The agriculture and human health studies use different climate runs (see the relevant sections for details).

Regarding the climate impacts in the rest of the word, the climate scenarios come from a number of different sources: agriculture and labour productivity use the ISIMIP fast track climate scenarios, while river floods and energy use the HELIX project climate runs.

The following sections deal with the analysis of climate impacts for each of the five impact categories taken into account in the economic framework. Each section starts with the description of the direct damages, as they have been computed by the climate impact models, followed by the economic analysis of impacts in the EU.

3. Labour productivity

This section analyses the economic implications of climate-induced changes in labour productivity (defined as the production per unit of labour). The analysis of impacts in Europe are based on the CORDEX climate data (Gosling et al. 2018), while the indirect impact of climate-related labour productivity changes from the rest of the world (i.e. outside of the EU regions) is based on the climate data from global ISIMIP analysis[2]. The ISIMIP study builds on an ensemble of 7 impact models and 5 GCMs.

The main conclusions of this section are the following:

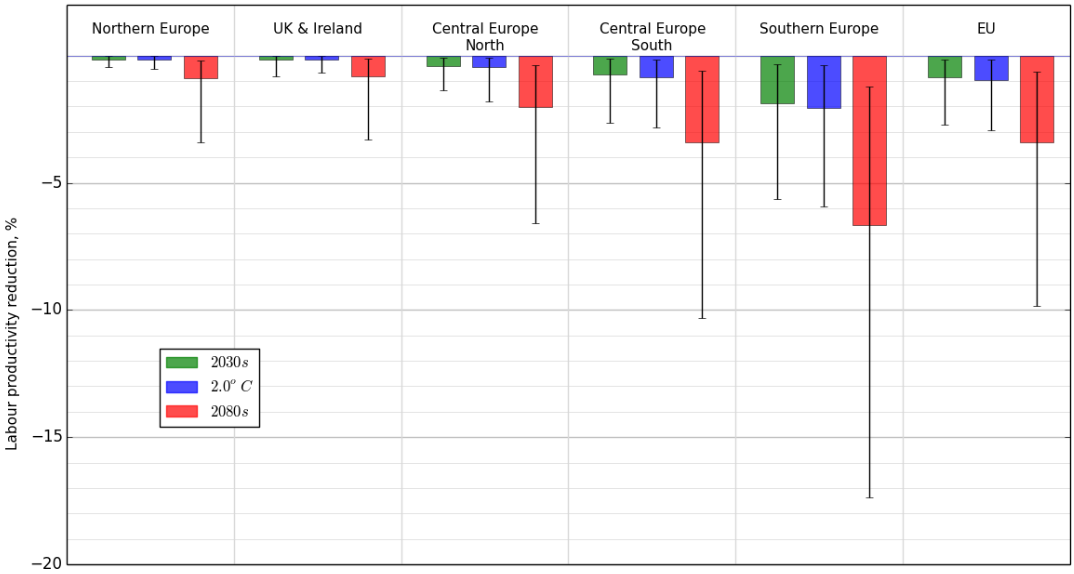
- Climate impacts in Europe: under the high warming scenario, annual welfare losses could be 27 bn €, which would be significantly reduced to 7 bn € under the 2°C warming scenario.
- There is a very clear North-South gradient regarding economic losses, which rise when moving to southern Europe.

3.1. Labour productivity shock and economic integration

Figure 1 and Table 1 show percentage losses in labour productivity for the five EU regions and the EU aggregate for all the climate scenarios, reporting the mean and min/max range across the climate models. The mean EU labour productivity loss can be around 1% (-0.2% to -3%) under 2°C warming and rise to 3.4% (-0.6% to -9.8%) under the higher warming scenario. The range of results across climate model runs, underlying the mean values, indicates that the labour productivity shock can be larger by a factor of 3 when compared to the mean.

In general, the mean labour productivity reductions in Europe increase when moving to lower latitudes, and can almost double the EU average value in Southern Europe under the high warming scenario.

Figure 1: Change in labour productivity (% and bn €)



[2] Assessment of global climate change impacts on labour productivity: JRC/SVQ/2015/J.1/0030/NC.

Table 1: Change in labour productivity (%)

Region	2030s			2°C			2080s		
	min	mean	max	min	mean	max	min	mean	max
Northern Europe	-0.03	-0.16	-0.47	-0.01	-0.16	-0.51	-0.19	-0.88	-3.40
UK & Irland	-0.02	-0.15	-0.83	0.00	-0.16	-0.66	-0.10	-0.81	-3.31
Central Europe North	-0.07	-0.40	-1.38	-0.08	-0.47	-1.79	-0.38	-2.04	-6.62
Central Europe South	-0.13	-0.76	-2.64	-0.16	-0.87	-2.82	-0.61	-3.41	-10.29
Southern Europe	-0.34	-1.87	-5.65	-0.39	-2.06	-5.92	-1.22	-6.67	-17.36
EU	-0.2	-0.8	-2.7	-0.2	-0.9	-3.0	-0.6	-3.4	-9.8

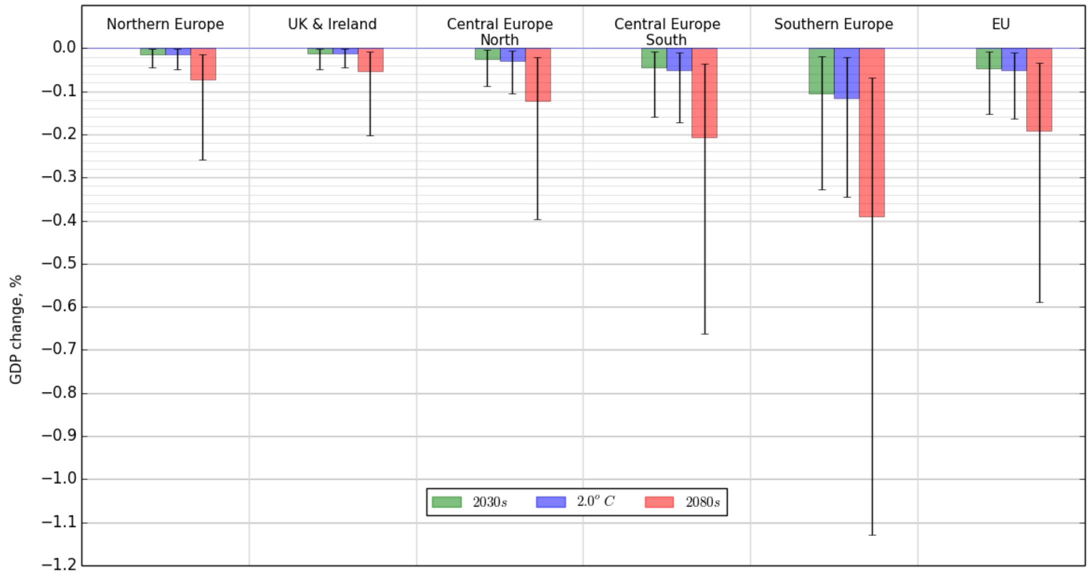
Note: mean and min/max range across the climate models

3.2. Economic implications on EU regions

The shock integrated in the economic model represents the productivity change of a unit of labour (i.e. how much production or output changes per unit of labour). The sectors affected by the labour productivity shocks are construction and agriculture. In these sectors labour is subject to intensive physical work performed outdoors and possible exposure to direct sun heat radiation. The magnitude of the economy-wide impact will depend, inter alia, on the labour intensity of the affected sectors and the relative sizes of the sectors in the economy.

The EU GDP loss would go from a mere 0.05% in the 2°C warming to a more substantial 0.2% in the higher warming scenario (Figure 2, Table 2). There is a clear North-South gradient regarding GDP impacts: the impacts become larger when moving to the southern regions. Southern Europe's GDP can lose from 0.1% (2030s/2°C) to around 0.4% in the 2080s. In value terms about half of the EU GDP losses would occur in the Southern Europe region (Table 2), with Central Europe regions accounting for over 40% of the total, and northern regions for the remaining 5-10%.

Figure 2: Change in GDP due to the labour productivity shock (% of GDP)



Note that the absolute GDP and welfare losses are rather similar (Table 2). Yet the relative welfare losses (Figure 3, expressed as percentage over welfare or consumption of the base year) are higher than those of the GDP losses (in percentage terms of GDP); that is because consumption is one of the components of GDP, which also includes government consumption, investment and net external trade. The same absolute value expressed in welfare terms is higher than in GDP terms.

Figure 3: Welfare change due to the labour productivity shock (% of welfare)

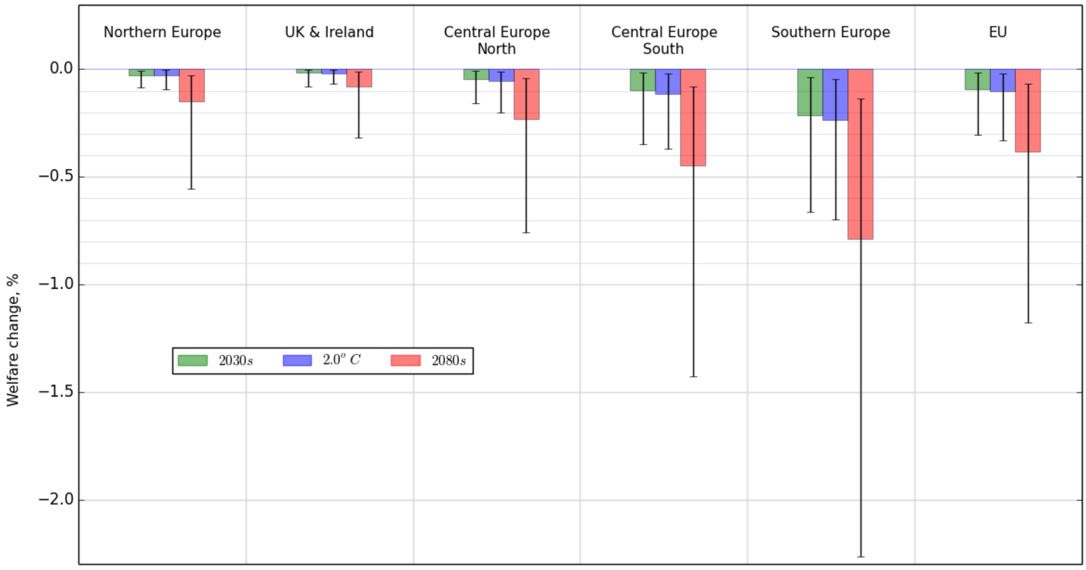


Table 2: Change in GDP and welfare for different scenarios due to the labour productivity shock

Region	GDP, %			Welfare, %			GDP, bn €			Welfare, bn €		
	2030s	2°C	2080s	2030s	2°C	2080s	2030s	2°C	2080s	2030s	2°C	2080s
Northern Europe	-0.014	-0.015	-0.072	-0.028	-0.029	-0.148	-0.1	-0.1	-0.6	-0.1	-0.1	-0.5
UK & Ireland	-0.011	-0.012	-0.054	-0.016	-0.018	-0.082	-0.3	-0.3	-1.2	-0.2	-0.2	-1.1
Central Europe North	-0.026	-0.029	-0.122	-0.047	-0.054	-0.230	-1.0	-1.1	-4.6	-0.9	-1.1	-4.6
Central Europe South	-0.046	-0.052	-0.208	-0.099	-0.113	-0.448	-1.2	-1.4	-5.5	-1.4	-1.6	-6.5
Southern Europe	-0.104	-0.115	-0.391	-0.212	-0.234	-0.790	-3.2	-3.6	-12.1	-3.7	-4.1	-13.8
EU	-0.046	-0.051	-0.191	-0.092	-0.103	-0.383	-5.8	-6.5	-24.0	-6.4	-7.2	-26.6

4. River floods

This section presents the analysis of economic consequences of river flooding in Europe for three target horizons: 2030s, 2°C and 2080s The input into the economic analysis is based on biophysical modelling described in Alfieri et al. (2018).

The main conclusions of this section are the following:

- Climate impacts in Europe: under the high warming scenario, welfare losses could be 15 bn €, which would be reduced to 9 bn € under the 2°C warming scenario.
- There is a very clear North-South gradient regarding damages, increasing when moving to southern Europe.

4.1. River flood damage and economic integration

The damages from river flooding for the EU regions and EU are presented in Figure 4, for the three climate futures (2030s, 2°C and 2080s). The scale of the regional damages is on the left of Figure 4, while the scale for the EU damages is that on the right; the vertical lines represent the min-max ranges of impacts. The EU damage from flooding reaches 7.2bn € in 2030s or at 2°C and 12.1bn € in 2080s. The figure also presents the decomposition of impacts by type of asset damaged. Most of the damage would occur in residential buildings (about 80%), followed by agriculture and capital assets.

Figure 4: Damage due to river floods (bn €)

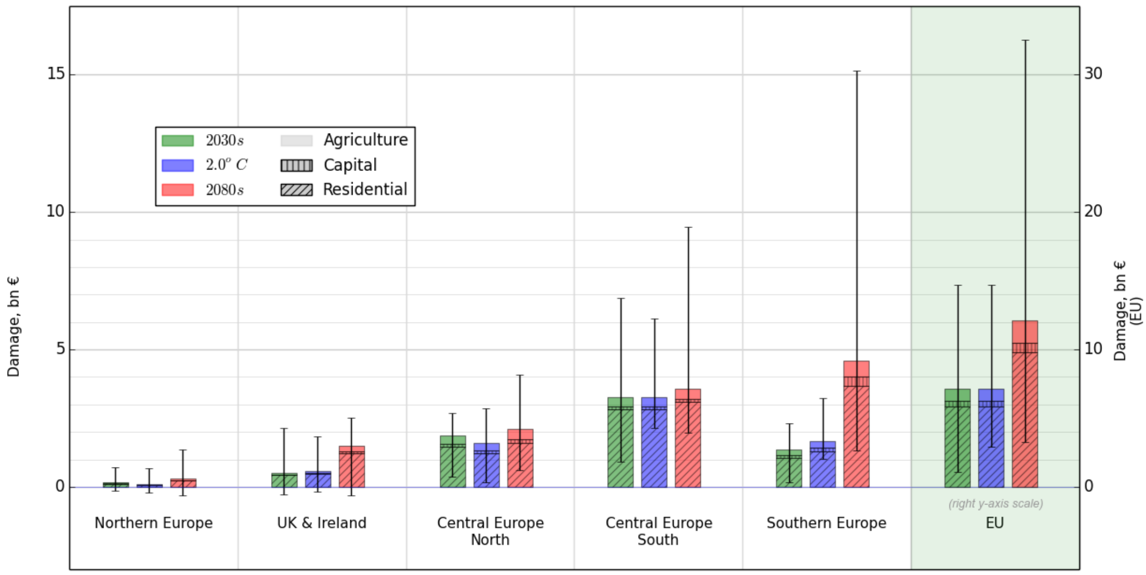


Table 3 shows the value of the direct damages (additional with respect to the damage in the base or control period). The minimum and maximum of the climate model ensemble's results highlight a range of uncertainty associated with the results. For example, while the mean flood damage in Central Europe South in 2080s is estimated at 3.6 bn €, the maximum can be as high as 9.5 bn €, i.e. around 2.5 times higher. Some of the minimum values are negative in some regions because the damage under the climate future is lower than the damage in the base period. This can be due to less extreme precipitation in a particular climate run.

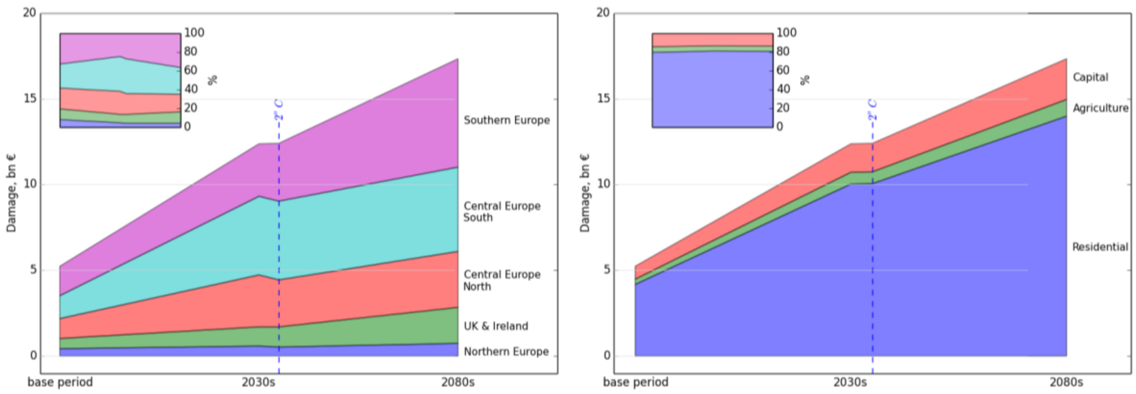
Table 3: Damage due to river floods (bn €)

Region	2030s			2°C			2080s		
	min	mean	max	min	mean	max	min	mean	max
Northern Europe	-0.15	0.16	0.72	-0.21	0.10	0.67	-0.30	0.31	1.36
UK & Ireland	-0.26	0.52	2.13	-0.18	0.58	1.82	-0.32	1.50	2.50
Central Europe North	0.38	1.87	2.68	0.17	1.58	2.84	0.62	2.10	4.08
Central Europe South	0.93	3.25	6.88	2.15	3.26	6.12	1.98	3.58	9.46
Southern Europe	0.16	1.34	2.32	1.01	1.65	3.23	1.31	4.60	15.15
EU	1.06	7.14	14.73	2.94	7.17	14.68	3.30	12.10	32.55

Note: damages are additional to those of the base period (1976-2005). Mean and min/max range across the climate models

The distribution of damage across damage categories (industry, agriculture and residential) and across the EU regions is illustrated in Figure 5, also approximately representing the year at which the 2°C warming is reached (vertical line). The proportion of flood-related damage in each region does not change significantly, with Central Europe North having its share increased by the 2030s and then remains stable until the 2080s. The share of total damage by the categories appears constant over the time horizon.

Figure 5: Damage due to river floods - cumulative by region (left) and damage type (right) for base period (1976-2005), 2030s and 2080s



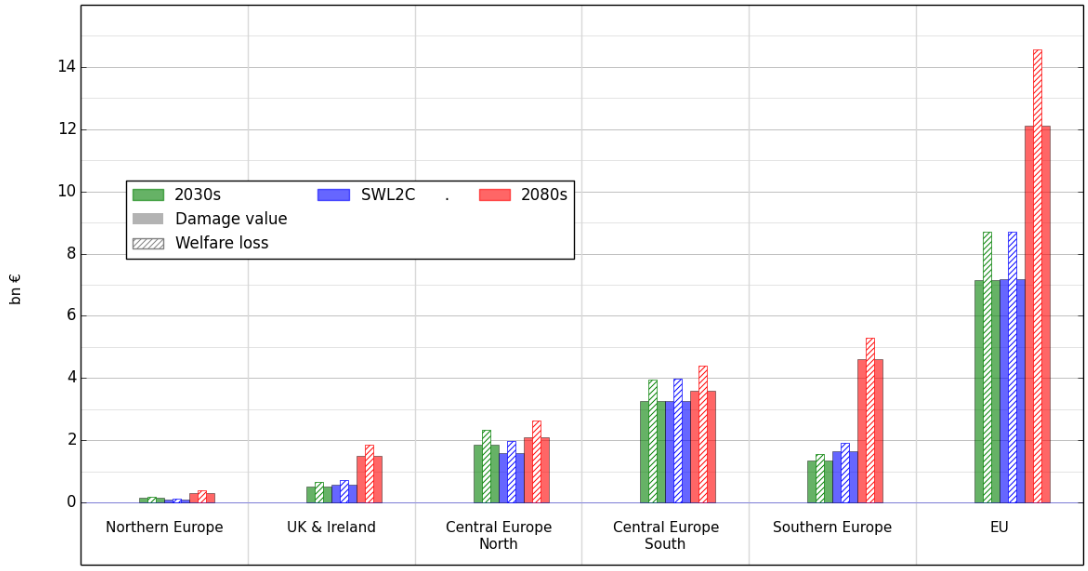
Note: Inset plots show respective damage as fractions of 100% total.

4.2. Economic implications on EU regions

The river flood damage assessment consists of damages to agriculture, industry, commerce, infrastructure and residential buildings. Agricultural direct damages are accounted for in the economic model as a change in the productivity of the agricultural sector. Damages to industry, commerce and infrastructure are represented as damage to the economy's capital stock in those sectors. Damage to residential structures is represented as an increase in households' subsistence spending.

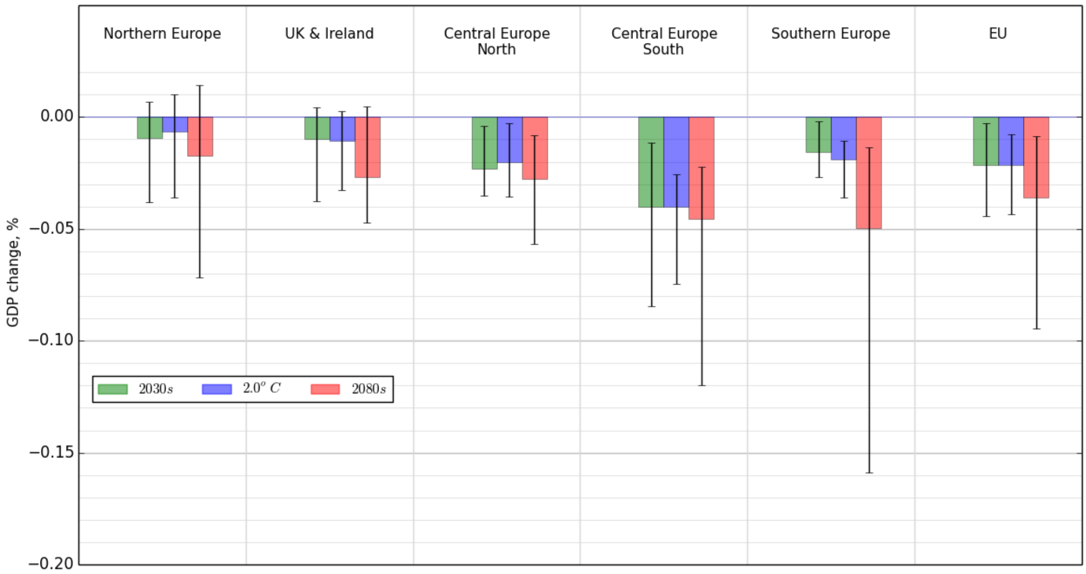
Figure 6 represents the direct and the induced welfare loss (measured in absolute terms, bn €) for the EU and its regions under the various climate scenarios. The welfare loss is about 10% higher than the direct damage. Damages are much smaller in the Northern regions, becoming larger when moving south.

Figure 6: Direct damage vs welfare loss by EU region due to river floods (bn €)



The economic implications in terms of GDP and welfare are reported in Figure 7, Figure 8 and Table 4. The magnitudes of impacts on the EU regions are very similar for the 2030s and the 2°C scenarios. The losses in the 2080 are approximately twice the losses in the 2030s. The total GDP loss in the EU is 2.7bn € (0.02%) in the 2030s/2°C and almost 4.5bn € (0.04%) in the 2080s. The largest GDP losses could occur in Central Europe South (0.04% to 0.05%). The largest relative increase in losses is simulated in Southern Europe, where GDP losses increase steeply from 0.02% in the 2030s to 0.05% in the 2080s.

Figure 7: Change in GDP due to river floods (% of GDP)



The largest welfare losses (Figure 8) could occur in Central Europe South (around 0.3% for all the three scenarios) and Southern Europe (up to 0.3% in the 2080s scenario). In absolute terms, the welfare losses are approximately three times the GDP losses; that can be explained by the large weight of residential damages in the overall direct damage. Residential damages affect households' consumption but not directly to production (GDP).

Figure 8: Change in welfare due to river floods (% of welfare)

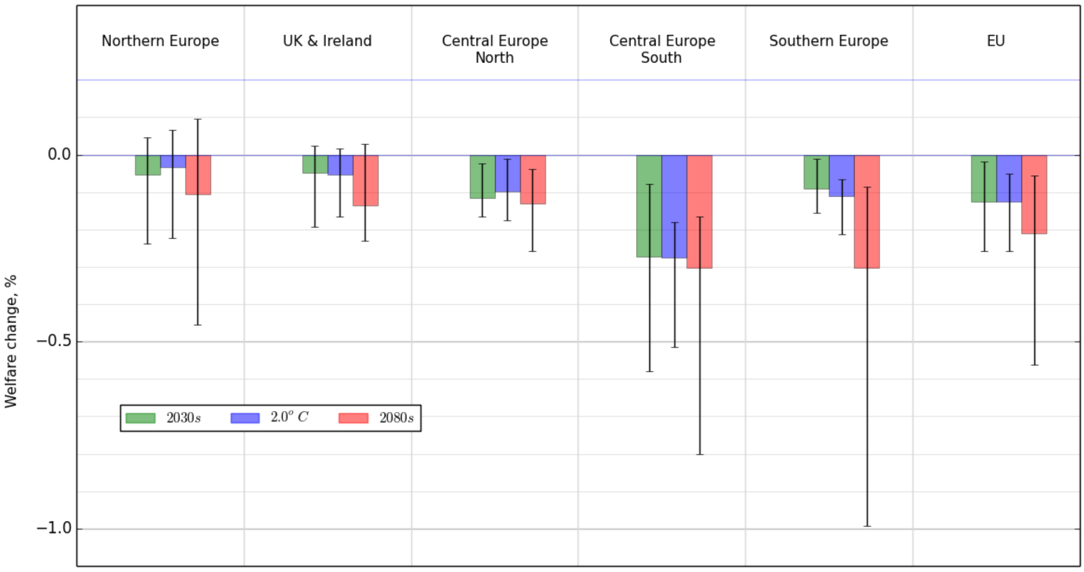


Table 4: GDP and welfare losses from river floods

	GDP, %			Welfare, %			GDP, bn €			Welfare, bn €		
Region	2030s	2°C	2080s	2030s	2°C	2080s	2030s	2°C	2080s	2030s	2°C	2080s
Northern Europe	-0.009	-0.006	-0.017	-0.053	-0.034	-0.105	-0.1	0.0	-0.1	-0.2	-0.1	-0.4
UK & Ireland	-0.010	-0.011	-0.027	-0.048	-0.053	-0.137	-0.2	-0.2	-0.6	-0.7	-0.7	-1.9
Central Europe North	-0.023	-0.020	-0.028	-0.115	-0.098	-0.131	-0.9	-0.7	-1.0	-2.3	-2.0	-2.6
Central Europe South	-0.040	-0.040	-0.045	-0.273	-0.274	-0.304	-1.1	-1.1	-1.2	-4.0	-4.0	-4.4
Southern Europe	-0.015	-0.019	-0.050	-0.090	-0.110	-0.303	-0.5	-0.6	-1.5	-1.6	-1.9	-5.3
EU	-0.022	-0.021	-0.036	-0.125	-0.125	-0.210	-2.7	-2.7	-4.5	-8.7	-8.7	-14.6

5. Coastal floods

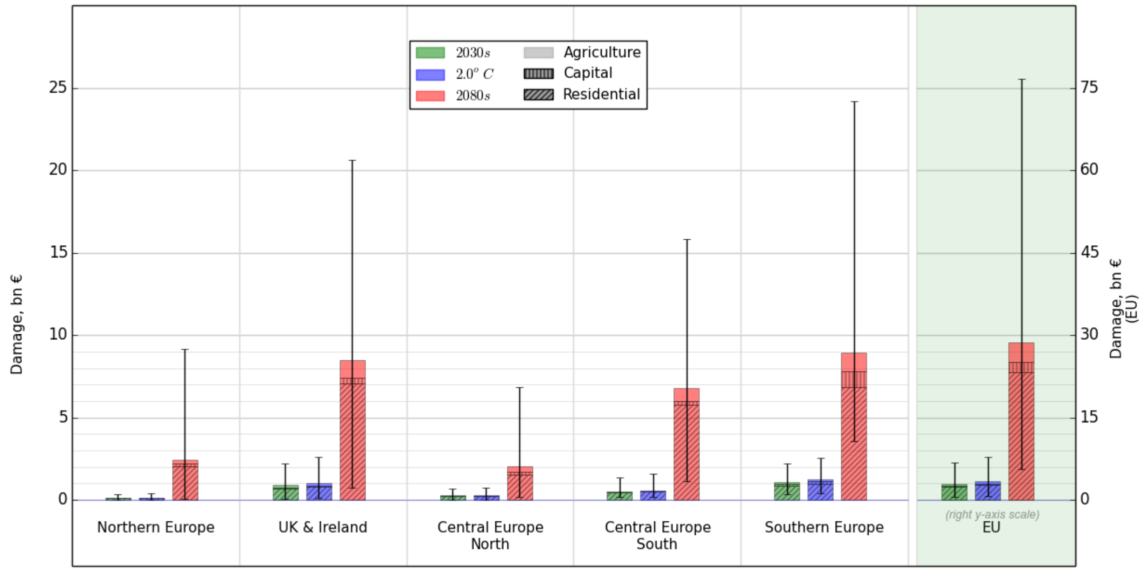
This section presents the analysis of the economic consequences of coastal flooding in Europe for three climate scenarios. The input into the economic analysis is based on biophysical modelling reported in Vousdoukas et al. (2017).

The main conclusions of this section is that under the high warming scenario, welfare losses could be 35 bn €, which would be very significantly reduced to 4 bn € under the 2°C warming scenario.

5.1. Coastal floods damage and economic integration

Figure 9 represents the direct damages due to coastal floods. Those damages relate to the static setting, i.e. with constant population and GDP. The figures are much lower than those under the dynamic framework, where economic growth and population dynamics are considered (the coastal sectoral report explains those differences; Vousdoukas et al., 2017). The scale of the regional damages is on the left of Figure 9, while the scale for the EU damages is that on the right The EU damage from coastal flooding increases to around 3 bn € in 2030s and to 29 bn € in 2080s. The minimum and maximum of the climate model ensemble's results (values in Table 5) highlight the uncertainty range of the results. For example, while the flood damage in Central Europe South in 2080s is estimated at mean at 6.8 bn €, the maximum can be as high as 15.8 bn €, i.e. around two times higher.

Figure 9: Damage due to coastal floods (bn €)



The regions with the highest damage are UK & Ireland and Southern Europe, which together account for around 60% of the total EU coastal damage. A further 25% of the EU damage occurs in Central Europe South.

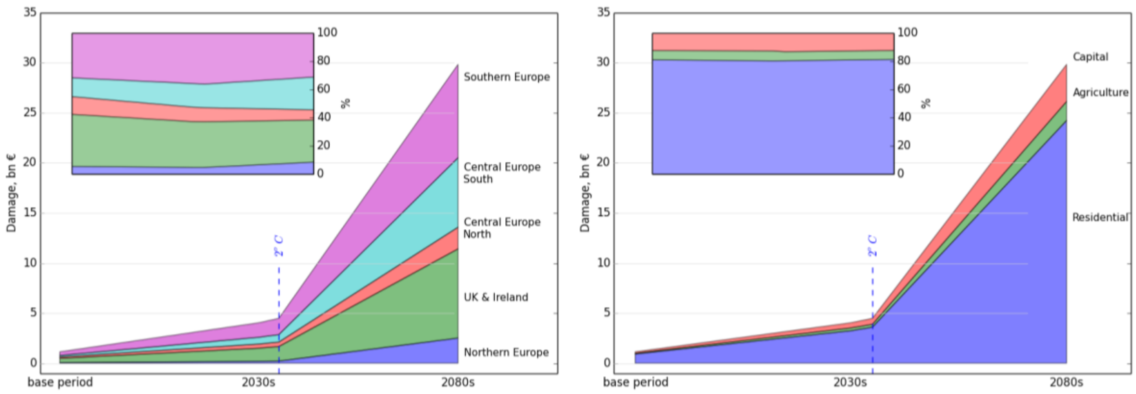
Table 5: Damage due to coastal floods (bn €)

Region	2030s			2°C			2080s		
	min	mean	max	min	mean	max	min	mean	max
Northern Europe	-0.01	0.13	0.36	-0.01	0.15	0.41	0.07	2.45	9.17
UK & Ireland	0.08	0.89	2.24	0.10	1.03	2.58	0.72	8.49	20.65
Central Europe North	0.01	0.27	0.67	0.02	0.30	0.73	0.17	2.02	6.84
Central Europe South	0.15	0.53	1.35	0.18	0.60	1.58	1.13	6.78	15.84
Southern Europe	0.36	1.09	2.21	0.41	1.26	2.54	3.55	8.96	24.17
EU	0.6	2.9	6.8	0.7	3.3	7.8	5.6	28.7	76.7

Note: damages are additional to those of the base period (1980-2010). Mean and min/max range across the climate models

The distribution of damage across the damage categories (industry, agriculture and residential) and across the EU regions is illustrated in Figure 10. With respect to the sectoral damage, most of the damage would happen in residential buildings (about 80%), capital assets (about 15%) and agriculture (about 5%). The share of total damage for each of the damage categories appears constant over the time horizon. The proportion of flood-related damage in each region does not change significantly, with Southern Europe having its share increased by the 2030s and then remains stable until the 2080s. In contrast, the share of the EU damage in UK & Ireland declines slightly until the 2030s, then stays constant.

Figure 10: Damage due to coastal floods - cumulative by region (left) and damage type (right) for base period (1980-2010), 2030s and 2080s



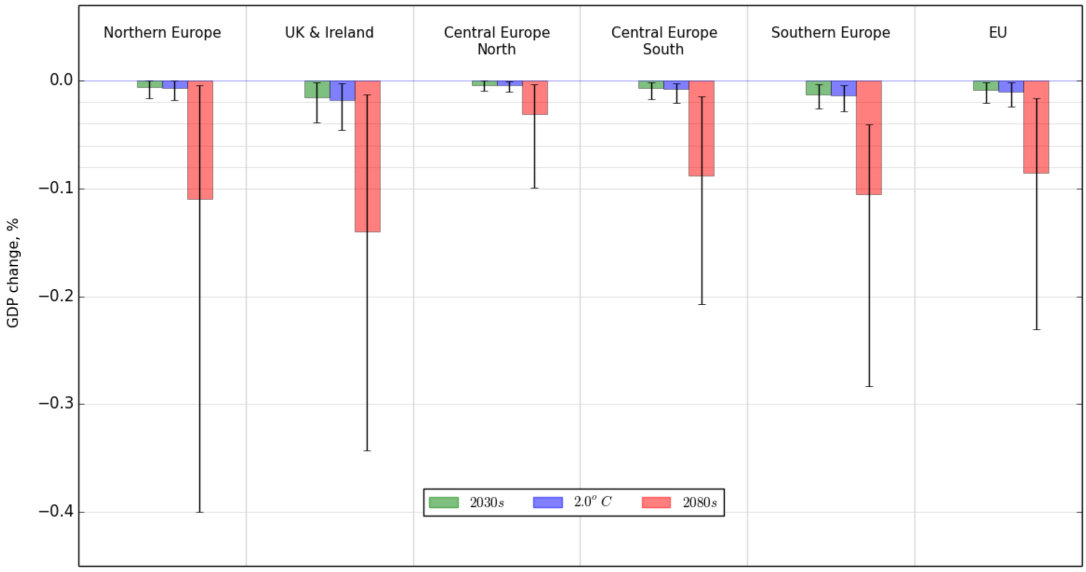
Note: Inset plots show respective damage as fractions of 100% total.

5.2. Economic implications on EU regions

The coastal flood damage assessment consists of damages to agriculture, industry, commerce, infrastructure and residential buildings. Agricultural direct damages are accounted for in the CGE economic model as a change in the productivity of the agricultural sector. Damages to industry, commerce and infrastructure are represented as damage to capital in the economy. Damage to residential structures is represented as an increase in households' subsistence spending.

The magnitudes of impacts on the EU regions are very similar for the 2030s and the 2°C scenario (Figure 11, Figure 12 and Table 6). The losses in the 2080s are approximately eight times the losses in the 2030s. The total GDP loss in the EU is 1.1/1.3 bn € (0.01%) in the 2030s/2°C and almost 10.8 bn € (0.09%) in the 2080s. 2080s GDP losses are higher than the EU value for Northern Europe, UK and Ireland, and Southern Europe.

Figure 11: Change in GDP due to coastal floods (% of GDP)



In absolute terms, the welfare losses are approximately three times the GDP losses (Table 6); the reason is the same as for the case of river floods (i.e., around 80% of the direct damage is a welfare reduction – residential buildings damages). The Northern Europe, UK and Ireland, and Central Europe South regions would have welfare losses (about 0.6%) slightly above those of the EU.

Figure 12: Change in welfare due to coastal floods (% of welfare)

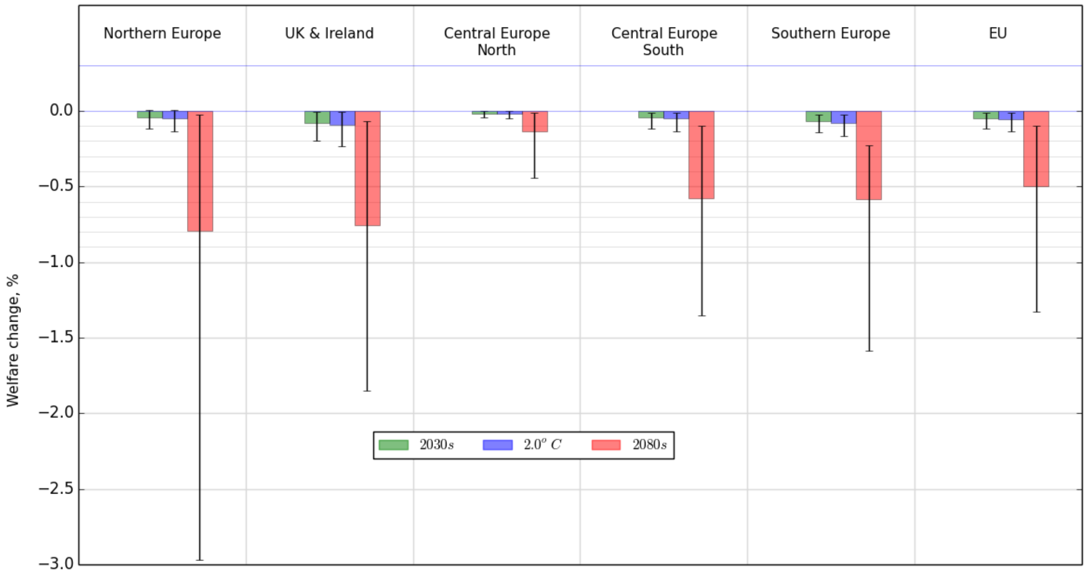


Table 6: GDP and welfare losses from coastal floods

	GDP, %			Welfare, %			GDP, bn €			Welfare, bn €		
Region	2030s	2°C	2080s	2030s	2°C	2080s	2030s	2°C	2080s	2030s	2°C	2080s
Northern Europe	-0.006	-0.007	-0.110	-0.043	-0.049	-0.793	0.0	-0.1	-0.9	-0.2	-0.2	-2.9
UK & Ireland	-0.016	-0.019	-0.140	-0.080	-0.093	-0.759	-0.4	-0.4	-3.2	-1.1	-1.3	-10.4
Central Europe North	-0.004	-0.004	-0.031	-0.018	-0.020	-0.133	-0.1	-0.2	-1.1	-0.4	-0.4	-2.7
Central Europe South	-0.007	-0.008	-0.088	-0.045	-0.051	-0.576	-0.2	-0.2	-2.3	-0.7	-0.7	-8.3
Southern Europe	-0.013	-0.014	-0.105	-0.071	-0.083	-0.588	-0.4	-0.4	-3.2	-1.2	-1.4	-10.3
EU	-0.009	-0.010	-0.086	-0.050	-0.058	-0.498	-1.1	-1.3	-10.8	-3.5	-4.0	-34.6

5.3. Dynamic assessment of coastal floods

This section presents the preliminary assessment of the economic implications of coastal floods with the dynamic model MaGE (see Annex for model's description), using the SSP3 socio-economic projection.

5.3.1. Model integration

It is assumed that the capital losses directly erode the stock of capital, while the impact on the agricultural sector lowers the GDP level. For the effects on private residential buildings, it is assumed that the damages are repaired by reducing households' consumption, leading to a consequent decrease of overall welfare.

In addition to the GDP losses generated directly by the three impacts, the model quantifies the indirect or dynamic effects. MaGE is a recursive model meaning that some of the variables measured at time t influence the results of the model at time t+1. For instance, the capital stock at time t determines, together with the depreciation rate and the investments, the level of the capital stock at time $t+1$; the investment rate at time t affects the investment rate in the following period and the same dynamic mechanism characterizes the equation for the saving rates, which has both the saving rate and the GDP per capita of the previous period as covariates. These dynamic mechanisms allow to quantify the effect on GDP due to a gradual deterioration of these macroeconomic variables, which mean that the direct impacts on agriculture, capital and residential dwellings cumulate across years.

5.3.2. Impacts on EU regions

Table 7 shows the welfare impacts (measured as percentage of GDP) in the EU and its five main regions. The EU welfare losses by the end of the century are around 0.4% of GDP. The regions where welfare losses are relatively higher are Northern Europe, UK and Ireland and the southern European region, a similar regional pattern to that of the static analysis.

Table 7: Welfare losses (% of GDP) due to coastal floods under the SSP3 scenario

	Northern Europe	UK & Ireland	Central Europe North	Central Europe South	Southern Europe	EU
2021-2050	0.01	0.03	0.01	0.01	0.02	0.01
2°C warming	0.08	0.21	0.02	0.09	0.13	0.10
2071-2100	0.44	0.75	0.08	0.41	0.45	0.39

Note: difference compared to the 2015

It is interesting to compare the EU dynamic welfare loss to that under the static case. The EU welfare loss (as a share of GDP) for the 2071-2100 period under the static analysis is lower, almost 0.3%. The higher value under the dynamic framework is due to the previously noted dynamic mechanisms; thus e.g. impacts compound in time because the capital stock gets smaller, leading to additional welfare losses.

6. Residential energy demand for heating and cooling

This section presents analysis of economic consequences of changes in energy demand for heating and cooling in the residential sector in Europe for three target horizons: 2030s, 2080s, and 2°C (always assuming the effect of future climate on the current economy). The input into the economic analysis is based on biophysical modelling of Kitous and Despres (2017).

The main conclusions of this section are the following:

- Climate impacts in Europe: under the high warming scenario, welfare gains could be 6 bn €, which would be reduced to 4 bn € under the 2°C warming scenario.
- Central-North Europe would benefit the most, followed by Southern and then Northern regions.

6.1. Energy demand and economic integration

About 40 % of energy for residential cooling and heating in the EU is used in Central Europe North, a further 25% in Central Europe South, another 30% is evenly split between the UK & Ireland and Southern Europe, and the remaining 5% is used in Northern Europe. Those regional proportions do not change significantly for the estimated future energy use because heating demand still dominates cooling demand.

Demand for energy for heating and cooling in the EU falls in the three climate scenarios (2030s, 2080s and 2°C), when compared to the present (Table 8; Figure 13 represents the residential demand evolution for the EU regions). The min/max range across the climate models are rather small, when compared to those found in other impact categories. The EU demand falls from the current 228 mote to 184 mtoe in the 2030 (176 to 195 mtoe) and 147 mtoe in the 2080s (138 to 156 mtoe). The reduction in demand for heating energy more than compensates the additional demand for cooling energy.

Figure 13: Residential demand for heating and cooling energy (mtoe)

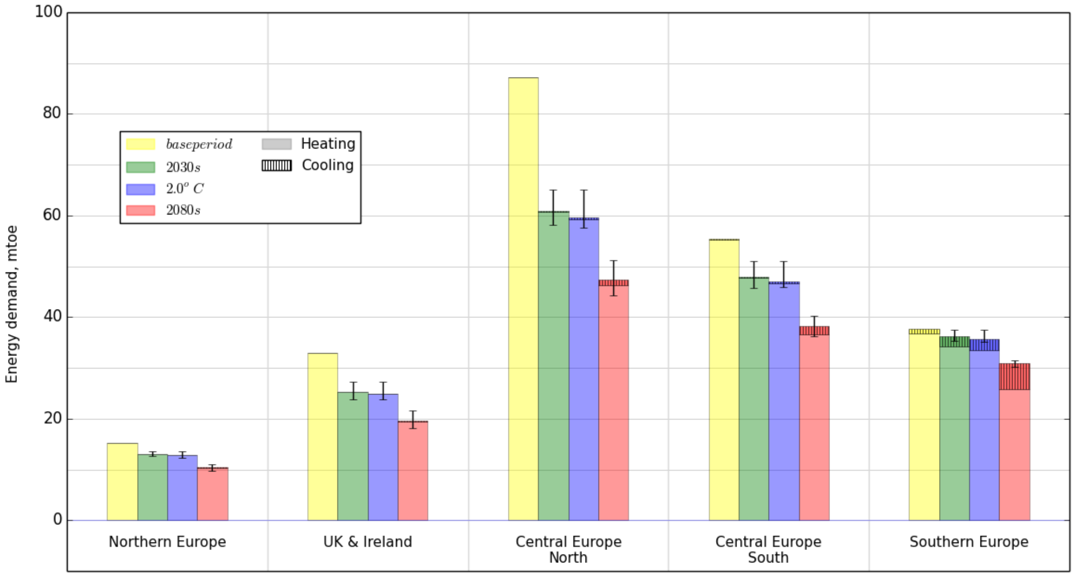


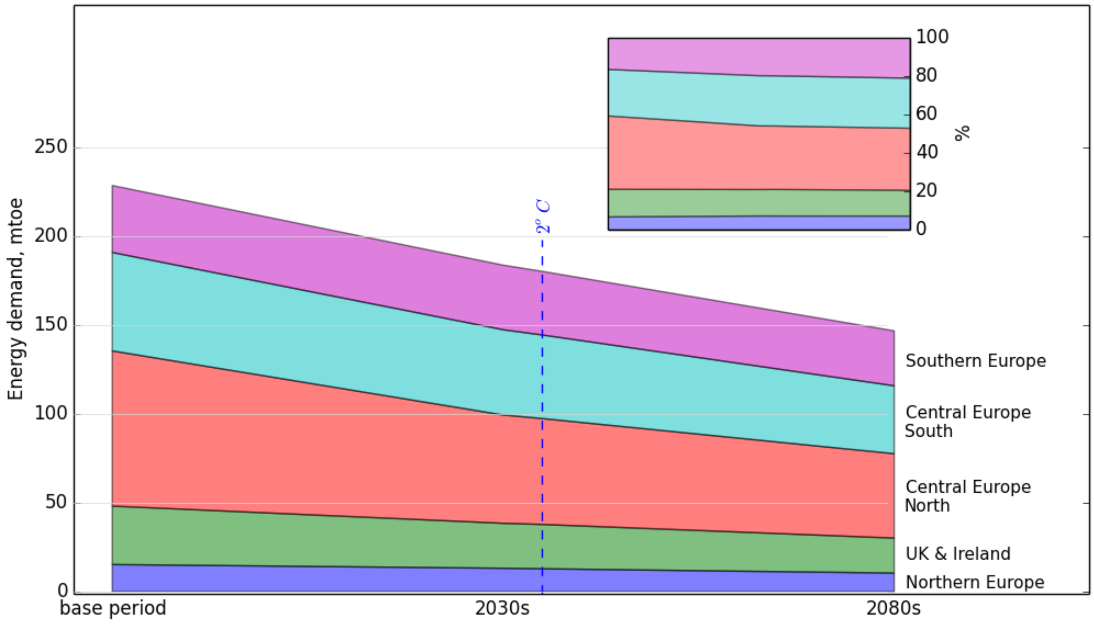
Table 8: Residential demand for energy for heating and cooling (mtoe)

Region	base period			2030s			2°C			2080s		
	min	mean	max	min	mean	max	min	mean	max	min	mean	max
Northern Europe	15	15	15	13	13	14	12	13	14	10	10	11
UK & Ireland	33	33	33	24	25	27	24	25	27	18	20	22
Central Europe North	87	87	87	58	61	65	58	60	65	44	47	51
Central Europe South	55	55	55	46	48	51	46	47	51	36	38	40
Southern Europe	38	38	38	35	36	38	35	36	38	30	31	31
EU	228	228	228	176	184	195	175	180	195	138	147	156

Note: mean and min/max range across the climate models

The proportion of enegy demand changes in each region is depicted on Figure 14. The largest reduction appers in Central Europe North, while the demand in other regions does not change that significantly.

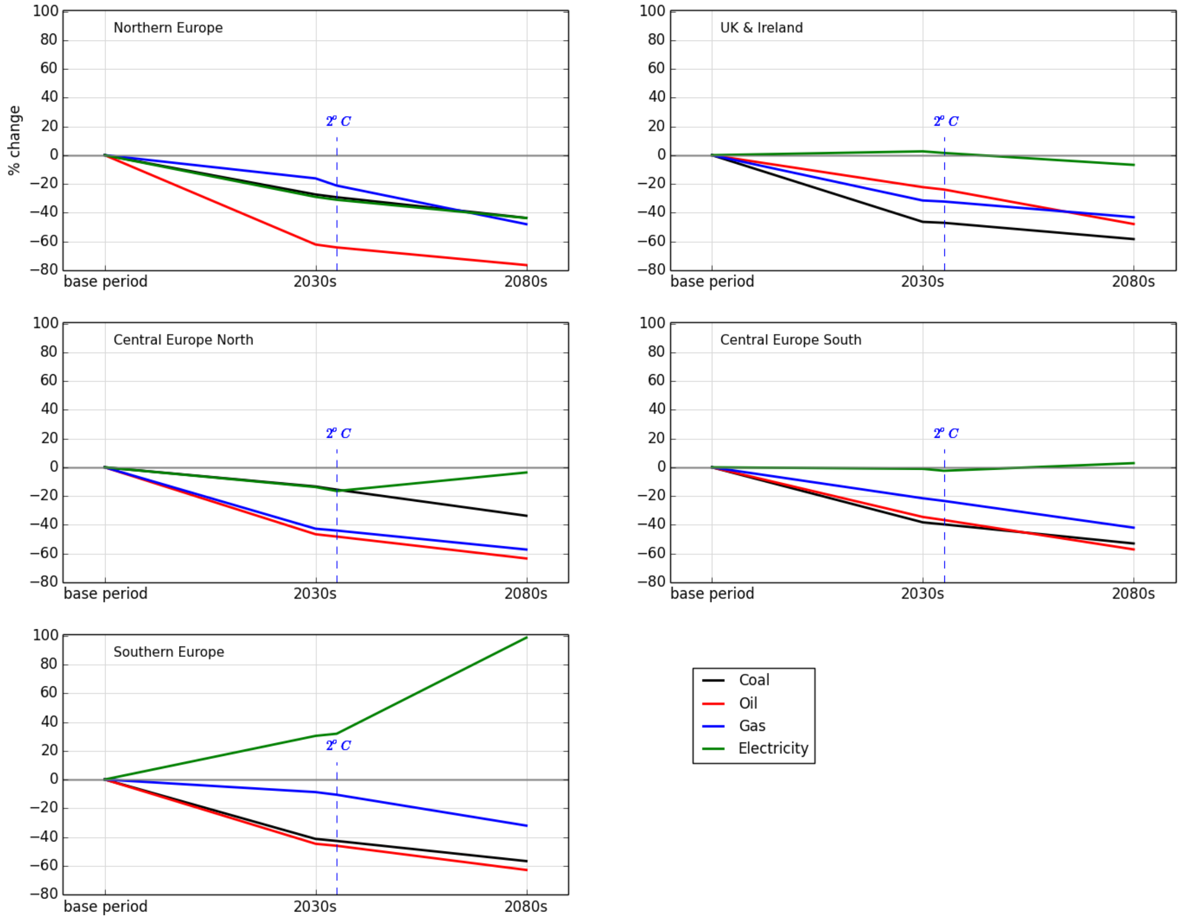
Figure 14: Change in residential energy demand - cumulative by region for the base period, 2030s and 2080s and with the approximate 2oC position



Note: Inset plot shows respective damage as fractions of 100% total.

Figure 15 shows the changes in demand for different fuels used for heating (coal, oil, gas electricity) and cooling (electricity). The reduction in overall energy use for heating and cooling is driven by lower use of fuels (oil, coal, gas), while demand for electricity remains stable or increases.

Figure 15: Change in energy demand for heating and cooling by fuel (%)

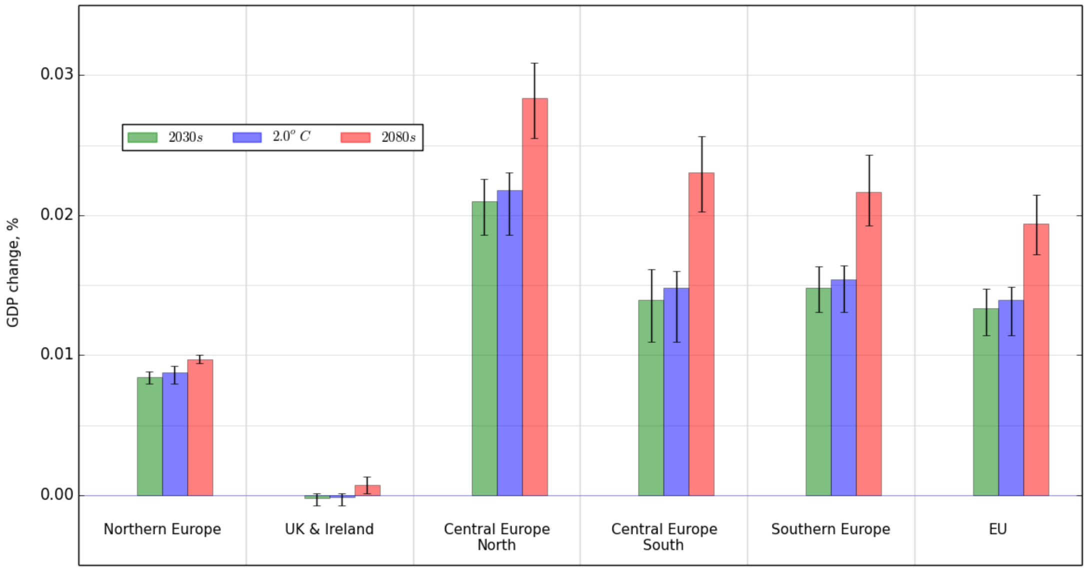


6.2. Economic implications on EU regions

Households spend part of their budget on energy for heating and cooling. These expenses are part of the subsistence expenditures, i.e. expenditures providing the basic necessities of life. A lower energy bill reduces the subsistence spending and allows for increased spending on other, welfare-generating products and services. In the economic model the change in energy consumption determines the change in obliged consumption of the households. Only the portion of households' energy used for heating and cooling is changed; the amount of energy used for other purposes is not altered.

The effect of the reduction in residential energy demand on GDP is small and positive (Figure 16). At the EU level the GDP increases between 0.01% and 0.02% for the 2030s and 2080s (around 2 bn €).

Figure 16: GDP changes due to the residential energy demand shock (% of GDP)



The welfare effects are higher than the GDP effects (Figure 17 vs Figure 16), because the reduction in heating and cooling energy demand reduces the obliged consumption of the household budget, but does not significantly impact on the production or supply side of the economy.

The largest welfare gains are noted in Northern Europe (0.1-0.15%) and Central Europe North (0.1-0.12%). The aggregate EU welfare increase is estimated at 0.06 to 0.08% or 4 – 6 bn € (Figure 17 and Table 9).

Figure 17: Welfare changes due to the residential energy demand shock (% of welfare)

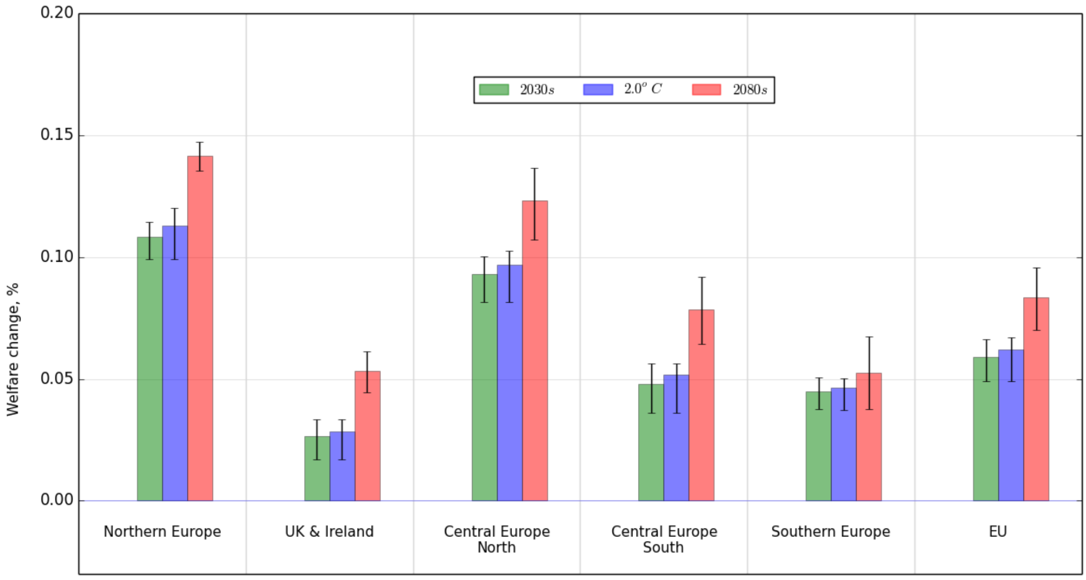


Table 9: GDP and welfare changes due to the residential energy demand shock

Region	GDP, %			Welfare, %			GDP, bn €			Welfare, bn €		
	2030s	2°C	2080s	2030s	2°C	2080s	2030s	2°C	2080s	2030s	2°C	2080s
Northern Europe	0.008	0.009	0.010	0.108	0.113	0.142	0.1	0.1	0.1	0.4	0.4	0.5
UK & Ireland	0.000	0.000	0.001	0.027	0.028	0.053	0.0	0.0	0.0	0.4	0.4	0.7
Central Europe North	0.021	0.022	0.028	0.093	0.097	0.123	0.8	0.8	1.1	1.9	1.9	2.5
Central Europe South	0.014	0.015	0.023	0.048	0.052	0.079	0.4	0.4	0.6	0.7	0.7	1.1
Southern Europe	0.015	0.015	0.022	0.045	0.046	0.053	0.5	0.5	0.7	0.8	0.8	0.9
EU	0.013	0.014	0.019	0.059	0.062	0.083	1.7	1.7	2.4	4.1	4.3	5.8

7. Agricultural crops

— This section analyses the economic consequences of agricultural crops productivity changes resulting from future climate change, without the CO_2 fertilisation effect. The future yield changes provided by the Agricultural Model Intercomparison and Improvement Project (AgMIP) together with the Inter-Sectoral Impact Model Intercomparison project (ISIMIP) are used as an input to the economic model in order to assess the macroeconomic implications in the three target horizons: 2030s, 2°C, and 2080s.

— The AgMIP project has conducted multi-model simulations with harmonised data on future yield changes. The simulations build on 5 Climate (GCM) Models (HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, GFDL-ESM2M, and NorESM1-M)[3] and 7 Global Gridded Crop Models (EPIC, GEPIC, IMAGE, LPJmL, LPJ-GUESS, pDSSAT, and PEGASUS)[4].

The main conclusions of this section are the following:

- Climate impacts in Europe: under the high warming scenario, welfare losses could be 20 bn €.
- There is a clear North-South gradient regarding damages, increasing when moving to southern Europe.

7.1. Crops yields change and economic integration

Figure 18 and Table 10 show the average change in yields (without the CO_2 fertilisation effect), with the mean and min/max range across the climate models. The yield change is mainly positive and fairly similar for the 2030s and the 2°C warning scenarios. The yield changes remain positive for the 2030s/2°C in Northern Europe, UK & Ireland and Central Europe North (2-5%), while Central Europe South and Southern Europe could face small yield reductions (-2%). The results for the 2080s show negative yield impacts for all regions, with 2-10% yield reductions. The severity of the crops response to climate impacts intensifies when moving to the European southern regions.

The large divergence between the average, minimum and maximum values emphasise the high uncertainty associated with the mean estimates.

[3] For details see CMIP5 info at: http://cmip-pcmdi.llnl.gov/cmip5/availability.html

[4] Excellent discussion provided in Rosenzweig *et al.*, 2014.

Figure 18: Changes in agriculture yields (%)

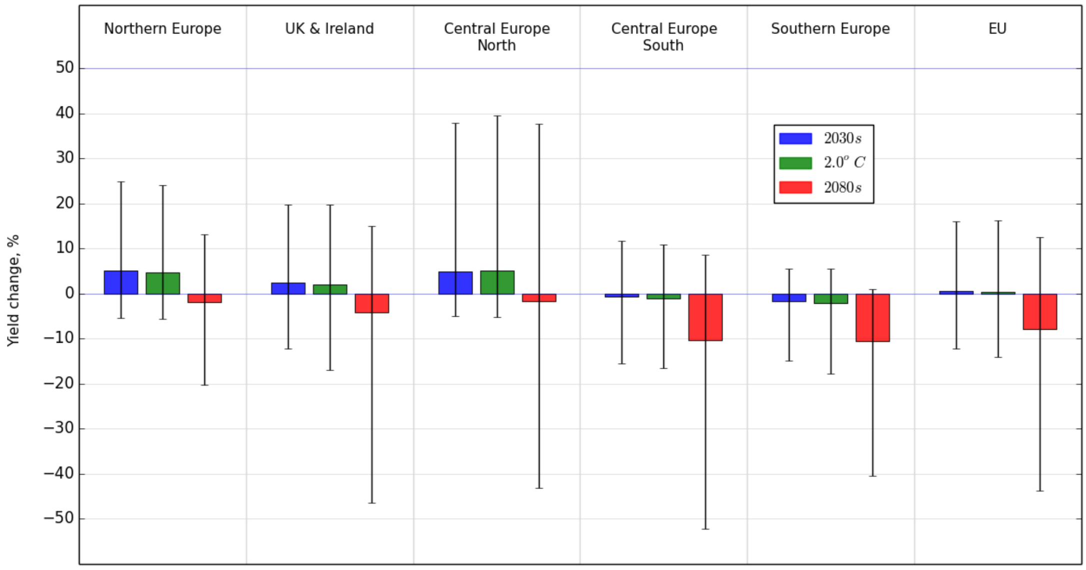


Table 10: Changes in agriculture yields (%)

Region	2030s			2°C			2080s		
	min	mean	max	min	mean	max	min	mean	max
Northern Europe	-5.6	4.7	24.1	-5.3	5.0	25.0	-20.3	-1.8	13.1
UK & Ireland	-17.0	2.0	19.6	-12.2	2.3	19.8	-46.5	-4.2	14.9
Central Europe North	-5.1	5.1	39.5	-4.9	4.9	37.8	-43.2	-1.7	37.5
Central Europe South	-16.6	-1.0	10.9	-15.6	-0.7	11.6	-52.1	-10.4	8.7
Southern Europe	-17.8	-2.1	5.5	-14.9	-1.8	5.6	-40.5	-10.5	0.9
EU	-14.1	0.3	16.2	-12.3	0.5	16.1	-43.8	-7.8	12.6

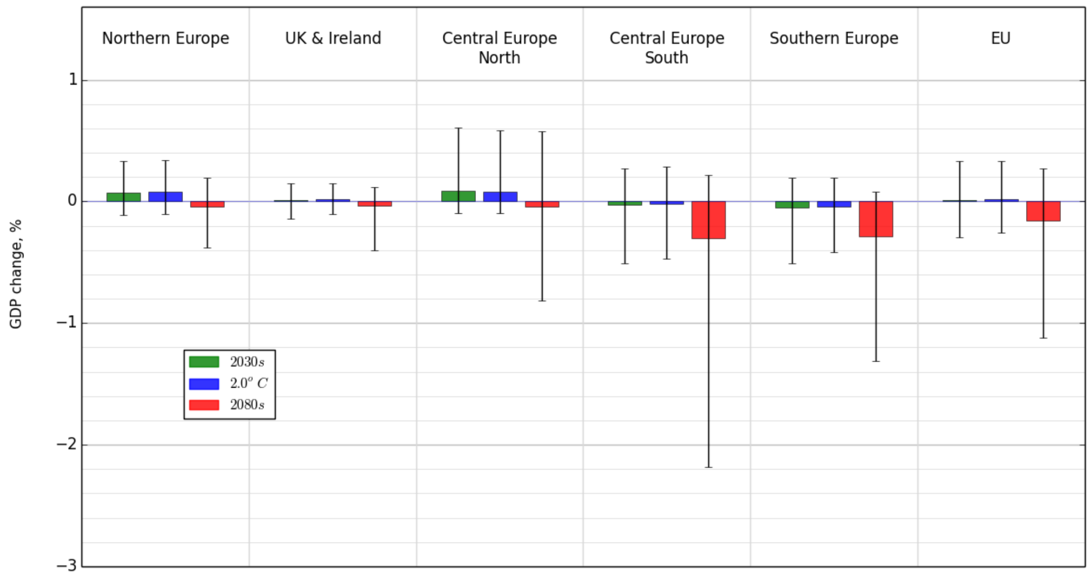
Note: mean and min/max range across the climate models

7.2. Economic implications on EU regions

Yield change is introduced as a total factor productivity (TFP) change on the agricultural crops sector in the CGE model. Total factor productivity is defined as the ratio of production or output to the he weighted average of the production factors. So it is assumed that the climate shock alters the productivity of all the production factors; i.e. climate is considered as an additional production factor.

The GDP and welfare effects (Figure 19, Figure 20 and Table 11) reflect, in large, the pattern of yield change. There is a small positive change in the GDP in the Northern regions in the 2030s/2°C horizon, but the 2080s bring very small GDP reductions. In the Southern regions, GDP changes are negative across all time and warming scenarios.

Figure 19: GDP changes due to the crops productivity shock (% of GDP)



In absolute terms, the welfare changes are similar to the GDP changes (Table 11), but the percent change in welfare is larger than the percentage change in GDP because the household consumption is only one of the GDP components.

Figure 20: Welfare changes due to the crops productivity shock (% of welfare)

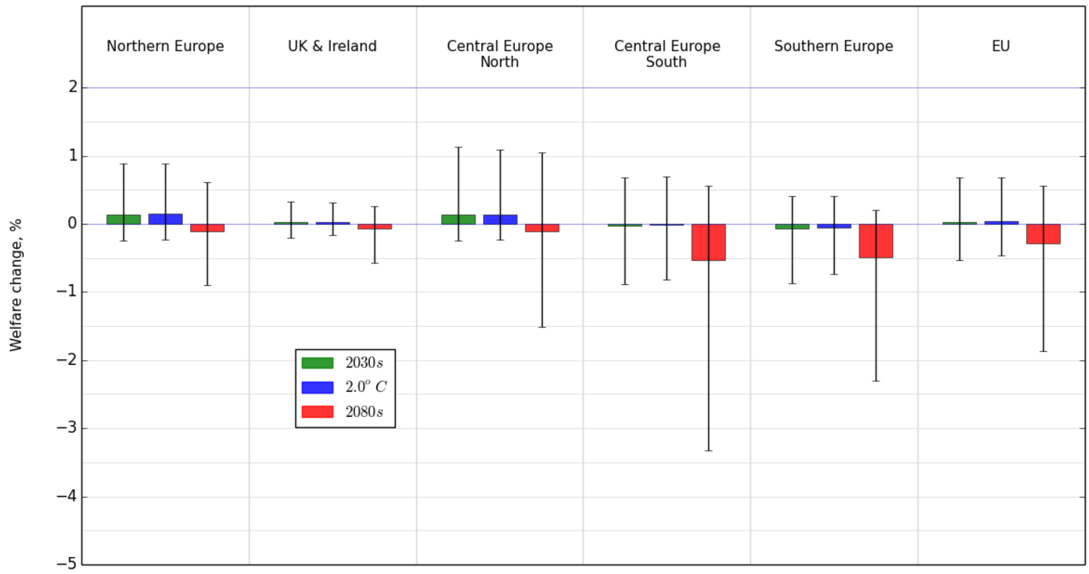


Table 11: GDP and welfare changes due to the crops productivity shock

Region	GDP, %			Welfare, %			GDP, bn €			Welfare, bn €		
	2030s	2^oC	2080s	2030s	2^oC	2080s	2030s	2^oC	2080s	2030s	2^oC	2080s
Northern Europe	0.07	0.08	-0.04	0.14	0.15	-0.10	0.6	0.6	-0.3	0.5	0.6	-0.4
UK & Irland	0.01	0.02	-0.04	0.03	0.03	-0.07	0.3	0.4	-0.9	0.3	0.4	-1.0
Central Europe North	0.08	0.08	-0.04	0.14	0.14	-0.11	3.2	3.1	-1.5	2.8	2.7	-2.3
Central Europe South	-0.03	-0.02	-0.30	-0.03	-0.01	-0.53	-0.8	-0.5	-8.1	-0.4	-0.2	-7.6
Southern Europe	-0.05	-0.04	-0.28	-0.07	-0.06	-0.50	-1.5	-1.2	-8.8	-1.3	-1.0	-8.7
EU	*0.01*	*0.02*	*-0.16*	*0.03*	*0.03*	*-0.29*	*1.8*	*2.3*	*-19.5*	*1.9*	*2.4*	-20.0

8. Mortality

Forzieri et al. (2017) assess the risk of weather-related hazards to the European population in terms of annual numbers of deaths, with specific results regarding heatwaves. The heatwave results have been integrated into the JRC PESETA III study.

The main conclusions of this section are the following:

- Climate impacts in Europe: under the high warming scenario, welfare losses could be 150 bn €, which would be reduced to around 66 bn € under the 2°C warming scenario.
- There is a strong North-South gradient regarding damages, largely increasing when moving to southern Europe.

Forzieri et al. (2017) consider the impact due to climate change and population dynamics, and find that climate change represents approximately 90% of the overall impact. The results refer to the SRES A1B emissions scenario. The ensemble mean of the 2071-2100 period has been identified as reflecting the high warming scenario of PESETA III and the 2040 value (average of the 2011-2040 and 2041-2070 periods) as the 2°C warming scenario. The Forzieri et al. (2017) study assumes also constant vulnerability, i.e. no additional adaptation measures taken to reduce the heatwave impact or enhance human acclimatization to future extreme climate conditions.

Table 12 represents the estimated mortality due to heatwaves per year in the various scenarios: control period (1981-2010) and the 2°C and high warming scenarios; the figures of the 2°C and high warming scenarios are relative to that of the control period. Under the high warming scenario, mortality largely increases (a factor 50 rise) compared to the control or reference period, with around 132,000 additional deaths in the EU. Most of the absolute increase could occur in Southern Europe and the Central Europe South regions.

Table 12: Impact on mortality due to heatwaves

	Northern Europe	UK & Ireland	Central Europe North	Central Europe South	Southern Europe	EU
Control	5	95	472	756	1,364	2,692
Difference 2°C warming - control	46	978	4,407	13,906	38,336	57,674
Difference high warming - control	113	3,498	11,079	35,997	81,462	132,150

Units: deaths/year
Source: Forzieri et al. (2017)

The 2°C scenario mortality change is smaller than that of the high warming scenario, with around 58,000 deaths, a factor 20 rise compared to the control period. The regional pattern of mortality increase is similar to that of the high warming scenario, with most of the increase occurring in Southern Europe and the Central Europe South regions.

The number of deaths is considered as damage to the welfare of the population, and it is not integrated into the CGE economic model. This damage is calculated by using the value of statistical life (VSL) method; the welfare loss is the number of premature deaths multiplied by the VSL; the assumed VSL is 1.14 million euro/person (2007 Euro; same value for all member states), as in the JRC PESETA II study, the low-end of the range of estimates considered in the review of the European Clean Air Policy Package (European Commission, 2013).

9. Transboundary or spillover analysis

The PESETA III study has explored the scale of the possible transboundary effects at two levels: global and intra-EU. The analysis considers the impacts in both GDP or welfare terms, although the welfare metrics is more appropriate for a consistent comparison with the standard measure of economic impact in the project, i.e. welfare.

PESETA analysis builds on the EURO-CORDEX climate data (see section 2.3), which does not have a global coverage. As a consequence, the global analysis has been made with different climate runs from those in the PESETA study (ISIMIP fast track for agriculture and labour productivity and HELIX for river floods and energy). For the global spillover analysis the impacts in the EU and in other global regions have been computed consistently with the same sets of global climate runs.

Table 13 represents the scale of the global transboundary effects for the four sectors with global coverage (agriculture, labour productivity, river floods and energy). The EU column represents the damage in the EU and the RoW (rest of the world) column refers to the additional damage in the EU because of climate impacts in the rest of the world (i.e. beyond the EU). With the GDP metrics the sum of the additional effects is around 40% of the EU impact. With the welfare metrics the additional welfare loss is estimated to be around 20% of the EU impact. The sector that channels most of the transboundary effect is agriculture, because agriculture markets are very much integrated at the global scale via international trade.

Table 13: Global transboundary effects (high warming), bn €

	GDP effects		Welfare effects	
	EU	ROW	EU	ROW
Agriculture	19.5	14.5	20	11.1
Labour productivity	45	10.1	50	3.4
River floods	6.1	2.86	15.3	1.2
Energy	-2.55	0.04	-6.8	-0.2
Total	68.05	27.5	78.5	15.5

Table 14 shows the scale of the EU impacts which are due to the intra-EU trade linkages, using the PESETA III climate runs. The EU column represents the damages in the EU, while the "*so*" column represents the damage that is due to the spillovers (*so*) or transboundary effects. The transboundary effects are already included in the EU effects presented in the sectoral sections of this report. The overall scale of the transboundary effect due to intra-EU trade is much smaller than in the case of the global analysis. For the GDP metrics, it is estimated that around 4% of the overall EU damage is due to climate impacts in other EU countries. The welfare transboundary effect is much smaller.

Table 14: Intra-EU transboundary effects (high warming), bn €

	GDP effects		Welfare effects	
	EU	so	EU	so
Agriculture	19.5	-0.4	20.0	-3.5
Labour productivity	29.0	2.9	26.6	1.7
River floods	4.5	0.3	14.6	0.2
Energy	2.4	-0.2	5.8	0.0
Coasts	10.8	0.5	34.6	0.6
Total	66.2	3.1	101.6	-1.0

The fact that most of the transboundary effects are negative is likely associated to the reduction in economic activity in the trading partners, which reduces their imports. This effect (known as income effect) seems to dominate the possible positive effects due to competitiveness gains (substitution or price effects).

10. Overview of economic results

This section summarises the main findings of the economic analysis of impacts.

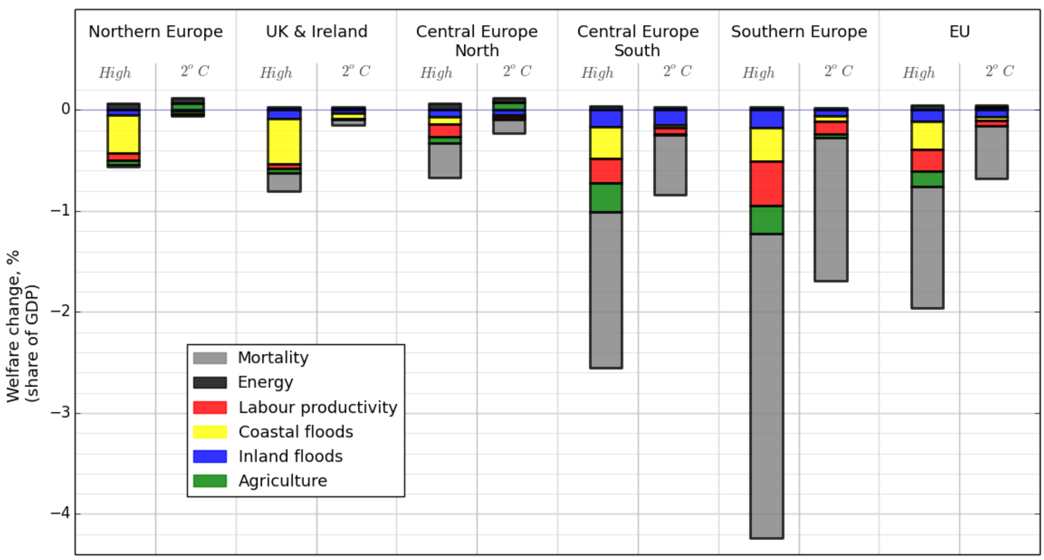
Incomplete perspective of welfare effects

Figure 21 shows the welfare losses (as percentage of GDP) for the six sectoral impacts in the five European regions and the EU in both the high warming and the 2°C scenarios. The EU welfare loss under the high warming scenario is estimated to be around 1.9% of GDP (€240 bn) and could be reduced by approximately 2/3 in the 2°C scenario (€79 bn).

It is important to note that Figure 21, while it provides a good general overview, it can also offer a misleading perspective of the EU climate damages because the list of considered climate impacts is incomplete. The economic climate impacts can be classified into three types: known-knowns, known-unknowns and unknown-unknowns. The impacts of Figure 21 represent the known-knowns type. Some of the PESETA climate impacts, however, have not been integrated into the economic framework (e.g. habitat losses) and, notably, other climate impacts are not integrated into the PESETA study like possible impacts due to ecosystem services losses - those represent the known-unknowns type: it is known that the impacts exist but their economic implication are unknown. Finally, there might be the unknown-unknowns, such as climate phenomena not considered (e.g. unknown catastrophic consequences of climate tipping points) or unknown relationships between climate and the economy. Therefore, the sum of impacts represented in Figure 21 must not be considered as the total economic cost of the specific climate change scenarios.

Another caveat relates to the inclusion of health impacts in Figure 21. The welfare losses of the other five climate impacts are derived from the economic model, so it seems appropriate to compare those welfare losses with GDP. On the contrary, the health welfare losses are valued through the VSL, which is not a market effect and, therefore, its comparison with GDP can be questioned.

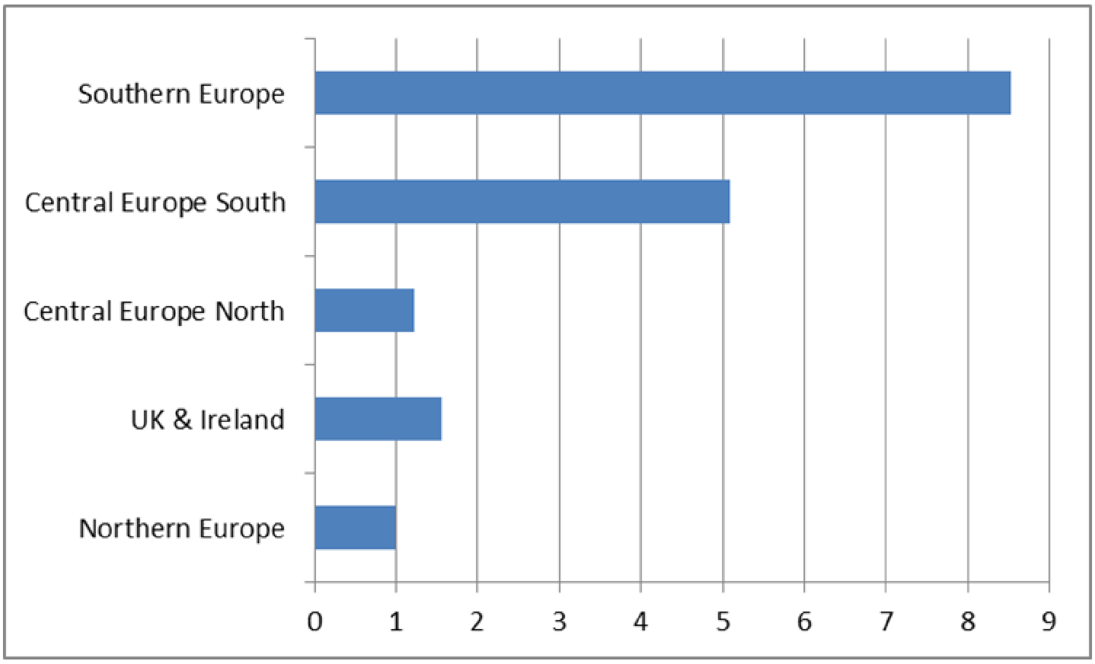
Figure 21: Welfare losses (% of GDP) for the high warming scenario and 2°C



The North-South divide

Figure 22 represents the relative geographical distribution of climate damages; in the figure the region with the lowest net welfare damage (as a share of GDP), Northern Europe, has an index of one. The regional distribution of the welfare losses is highly asymmetric, showing a clear North-South divide in the geography of climate impacts in Europe: the southern Europe regions are much more affected than the rest of Europe, by a factor of five (Central Europe South region) to eight (Southern Europe region).

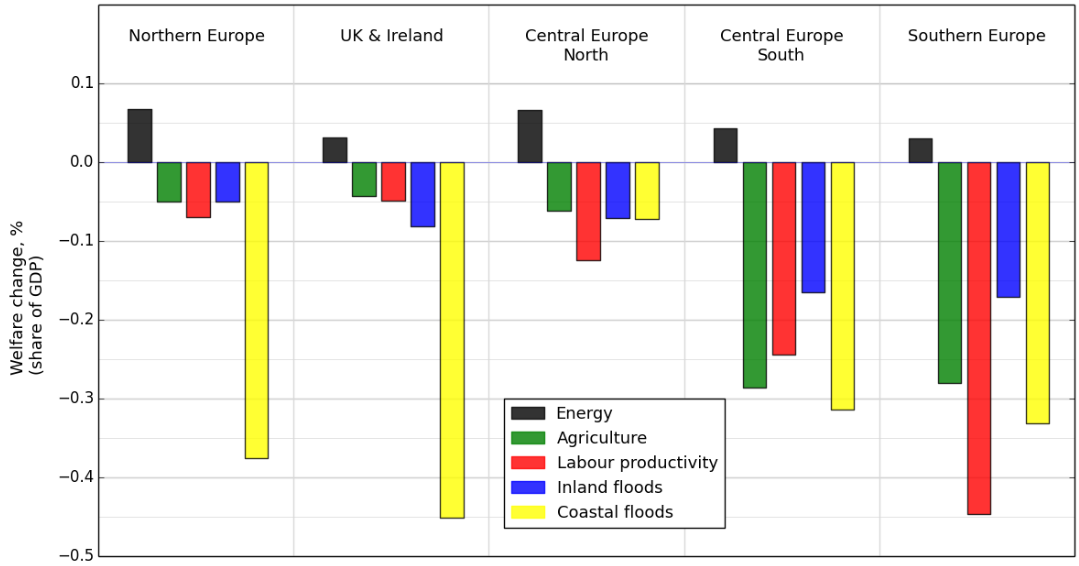
Figure 22: The North-South divide for the high warming scenario



Note: Welfare impact (% GDP) in Northern Europe = 1

Figure 23 shows the relative importance of the climate impacts across the EU regions. Health impacts are not represented because they might distort the relative scale of the other five impacts. As one moves south impacts appear to be higher as a share of GDP; the previous conclusion of the North-South divide is confirmed for agriculture, labour productivity and river floods, but not for coastal damages, which are relatively higher in Northern Europe and UK & Ireland, and the energy impacts, with a net positive effect in all regions. The EU region with the highest welfare losses under the high warming scenario would be Southern Europe.

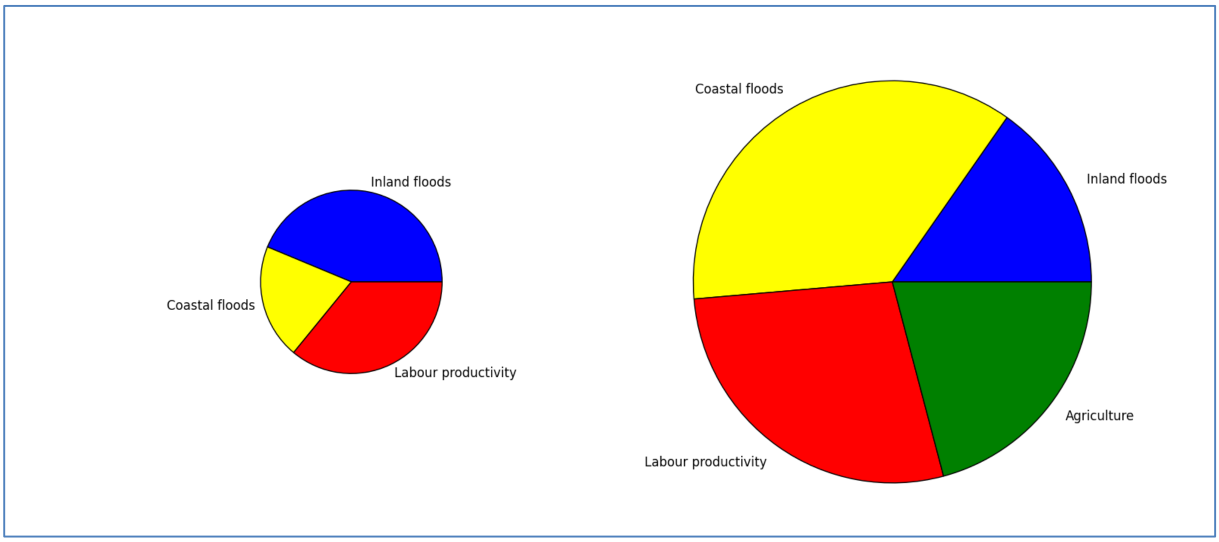
Figure 23: The geography of impacts for the high warming scenario (without health impacts)



Avoided climate impacts with the 2°C scenario

The extent to which climate impacts are avoided under the 2°C scenario is represented in Figure 24 (without neither the health impacts nor the positive impacts). The size of the pies is proportional to the net total welfare loss.

Figure 24: Distribution of climate impacts under the 2oC scenario (left) and high warming scenario (right)



The ranking of sectoral climate damages under the high warming scenario are, in order of importance, coastal areas, labour productivity, agriculture and river flooding. All the sectoral welfare losses would be substantially lower under the 2°C scenario.

Spillovers from the rest of the world

The spillover effects relate to climate impacts occurring outside of the EU regions affecting the EU via international trade. Those effects are estimated for agriculture, labour productivity, energy and river flooding. The global transboundary effect in terms of GDP is represented in Figure 25. Figure 26 shows the transboundary effects in welfare terms.

Figure 25: Global transboundary climate change effects in the EU, via trade, in GDP terms (bn €), under 2ºC and high-emissions scenarios5

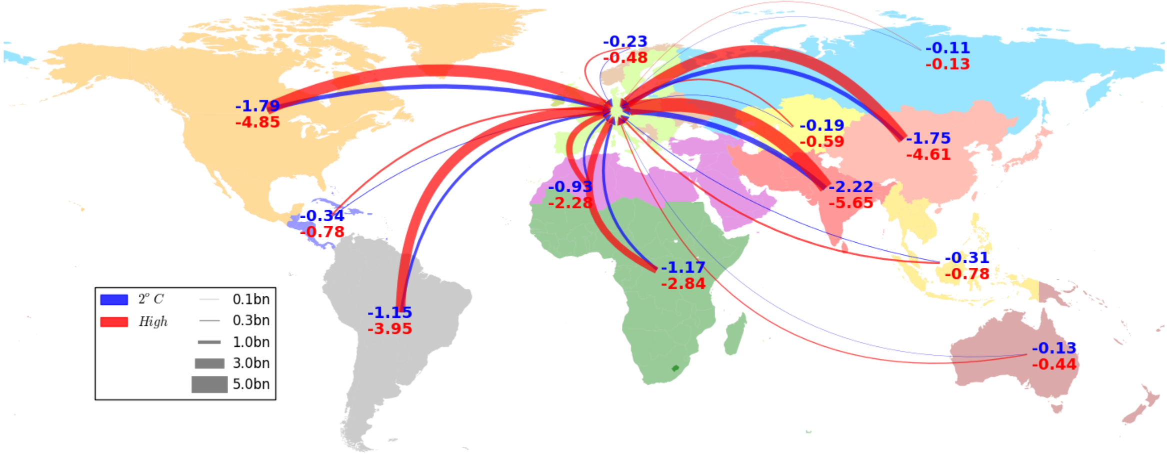
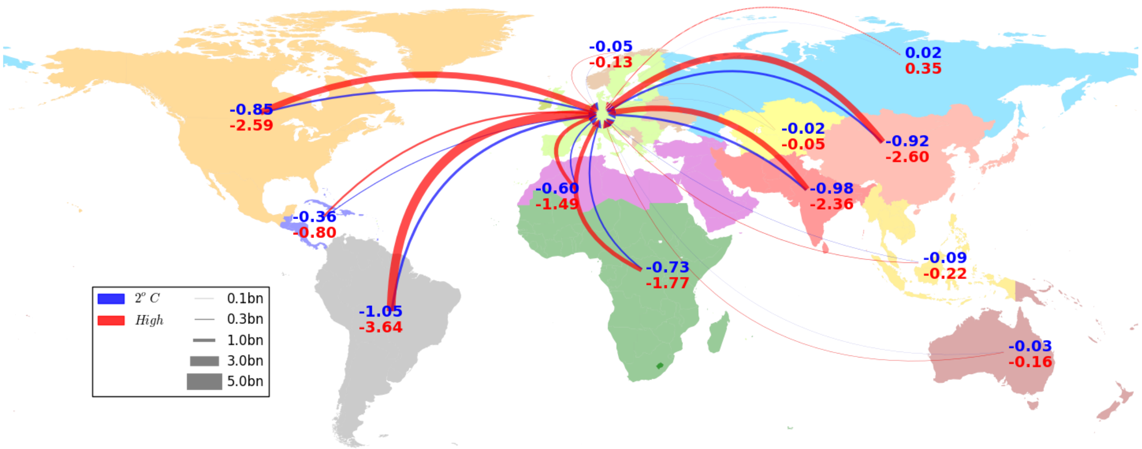


Figure 26: Global transboundary climate change effects in the EU, via trade, in welfare terms (bn €), under 2ºC and high-emissions scenarios (bn €)5



With the GDP metrics the sum of the additional effects is around 40% of the EU impact, while with the welfare metrics the additional welfare loss is estimated to be around 20% of the EU impact. The magnitude of the spillover effect depends on two aspects: the severity of climate impacts in the rest of the world regions and the intensity of trade between the regions and the EU. Most of the EU transboundary effects originate in either the Americas or Asia.

With respect to the sector of climate impact, about half of the GDP transboundary effects to the EU are due to the agricultural crops, which mainly affect central and southern EU regions. Another one-third of the transboundary–induced welfare loss originates in the labour productivity reduction, affecting mainly Central North Europe.

[5] For graphical clarity, the results are further aggregated to 13 regions as detailed in

Table 16 in Annex.

11. Conclusions

This study has integrated six climate impacts into a consistent economic framework and derived a series of economic implications. Several key conclusions can be noted. The EU welfare loss under the high warming scenario may be around 1.9% of GDP (€240 bn) and could be reduced by approximately 2/3 in the 2°C scenario (€79 bn). Yet one cannot derive definitive conclusions about the benefits of climate mitigation (the difference of impacts between the high warming scenario and the 2°C scenario) from this study, as the study covers a limited set of impacts.

It is also interesting that climate impacts would be largely asymmetric across the EU regions, with the southern regions relatively much more affected than the rest of the EU regions (the North-South divide). There can be significant global transboundary effects, i.e. cross-border climate impacts to the EU, coming from the rest of the world.

The study is subject to a series of caveats. There is a vast uncertainty permeating the biophysical and economic analyses. The range of min/max impacts around the mean due to climate model uncertainty is rather large. It is important that the users of the report do not overestimate the confidence with which the quantitative statements are made.

Even if the economic analysis provides the impression of homogeneity, the reader should note that the input to the economic model is a diverse and heterogeneous set of climate impacts, and that the relative comparability is also reached via a set of assumptions that can influence the aggregation of sectoral results and the overall economic analysis.

There are some clear avenues for future research, including further integration across impact models (e.g. connecting water and energy modelling), deepening the analysis of key impact areas (like human mortality) or adding potentiall new key impact areas, like the valuation of ecosystem services.

References

Alfieri L, Dottori F, Feyen L (2018). *Flood impact assessment for Europe in view of climate change, Deliverable 7*: Final PESETA III report for DG CLIMA,

Bosello F, Eboli F, Pierfederici R (2012). *Assessing the Economic Impacts of Climate Change. An Updated CGE Point of View*. FEEM working paper, 2.2012.

Ciscar JC, Feyen L, Soria A, Lavalle C, Raes F, Perry M, Nemry F, Demirel H, Rozsai M, Dosio A, Donatelli M, Srivastava A, Fumagalli D, Niemeyer S, Shrestha S, Ciaian P, Himics M, Van Doorslaer B, Barrios S, Ibáñez N, Forzieri G, Rojas R, Bianchi A, Dowling P, Camia A, Libertà G, San Miguel J, de Rigo D, Caudullo G, Barredo JI, Paci D, Pycroft J, Saveyn B, Van Regemorter D, Revesz T, Vandyck T, Vrontisi Z, Baranzelli C, Vandecasteele I, Batista e Silva F, Ibarreta D (2014). *Climate Impacts in Europe. The JRC PESETA II Project*. JRC Scientific and Policy Reports, EUR 26586EN.

Dosio A (2018). *Climate change projections, bias-adjustment, and selection of models' runs*, JRC Technical Reports, Peseta III.

European Commission (2013). *Impact Assessment, Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions - a Clean Air Programme for Europe. Commission Staff WorkingDocument,*
http://ec.europa.eu/environment/air/pdf/clean_air/Impact_assessment_en.pdf.

Fouré J, Bénassy-Quéré A, Fontagné L (2013). *Modelling the world economy at the 2050 horizon*. Economics of Transition 21.4: 617-654.

Forzieri G, Cescatti A, Batista e Silva F, Feyen L (2017). *Increasing risk over time of weather-related hazards to the European population: a data-driven prognostic study*. The Lancet Planetary Health 5 (e200-e208).

Gosling SN, Zaherpour J, Ibarreta D (2018). PESETA III: Task 13 – *Climate Change Impacts on Labour Productivity*, European Commission.

Hsiang S, Kopp R, Jina A, Rising J, Delgado M, Mohan S, Rasmussen D J, Muir-Wood R, Wilson P, Oppenheimer M, Larsen K, Houser T (2017), *Estimating economic damage from climate change in the United States.* Science 1362-1369.

Keywan R, van Vuuren DP, Kriegler E, Edmonds J, O'Neill B C, Fujimori S, Bauer N, Calvin K, Dellink R, Fricko O, Lutz W, Popp A, Crespo Cuaresma J, Samir KC, Leimbach M, Jiang L, Kram T, Rao S, Emmerling J, Ebi K, Hasegawa T, Havlik P, Humpenöder F, Da Silva LA, Smith S, Stehfest E, Bosetti V, Eom J, Gernaat D, Masui T, Rogelj J, Strefler J, Drouet L, Krey V, Luderer G, Harmsen M, Takahashi K, Baumstark L, Doelman JC, Kainuma M, Klimont Z, Marangoni G, Lotze-Campen H, Obersteiner M, Tabeau A, Tavoni M (2017). *The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview*. Global Environmental Change 42: 153-168.

Kitous A, Després J (2017). *Climate impact on energy demand*, PESETA III.

Müller C, Robertson R D (2014*). Projecting future crop productivity for global economic modeling*. Agricultural Economics 45: 37-50. doi:10.1111/agec.12088

Narayanan, B., Aguiar A. and McDougall R. (2012). *Global Trade, Assistance, and Production: The GTAP 8 Data Base*. Center for Global Trade Analysis, Purdue University, West Lafayette.

OECD (2015). *The Economic Consequences of Climate Change*, OECD Publishing, Paris.

O'Neill B C, Carter T, Ebi K L, Edmonds J, Hallegatte S, Kemp-Benedict E, Van Vuuren D (2012). *Meeting Report of the Workshop on The Nature and Use of New Socioeconomic Pathways for Climate Change Research*.

Paci D (2014). *Human Health Impacts of Climate Change in Europe. Report for the PESETA II project*. JRC Scientific and Policy Reports 26494 EN. doi: 10.2791/64481.

Pycroft J, Ciscar JC, Abrell J (2016). *The Global Impacts of Extreme Sea-Level Rise: A Comprehensive Economic Assessment* . Environmental and Resource Economics, 64:225–253.

Reilly J, Paltsev S, Strzepek K, Selin N E, Cai Y, Nam K-M, Monier E, Dutkiewicz S, Scott J, Webster M, Sokolov A (2013). *Valuing climate impacts in integrated assessment models: the MIT IGSM*. Climatic Change 117(3):561-573. doi: 10.1007/s10584-012-0635-x .

Samir K C, Lutz W (2014). *The human core of the shared socioeconomic pathways: Population scenarios by age, sex and level of education for all countries to 2100*. Global Environmental Change.

Rosenzweig C, ElliottJ, Deryng D, Ruane A C, Müller C, Arneth A, Boote K J, Folberth C, Glotter M, Khabarov N, Neumann K, Piontek F, Pugh T A M, Schmid E, Stehfest E, Yang H, Jones J W (2014). *Assessing agricultural risks of climate change in the 21st century in a global gridded crop model intercomparison*. Proc. Natl. Acad. Sci. 111, 9:3268-3273, doi:10.1073/pnas.1222463110.

Vousdoukas M I, Mentaschi L, Voukouvalas E, Feyen L (2017). *Coastal Impacts. JRC PESETA III project*. Technical report by the Joint Research Centre (JRC), JRC110311

You L, Wood-Sichra U, Fritz S, Guo Z, See L, Koo J (2017). *Spatial Production Allocation Model (SPAM)* 2005 v3.2.

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Annex: Economic models

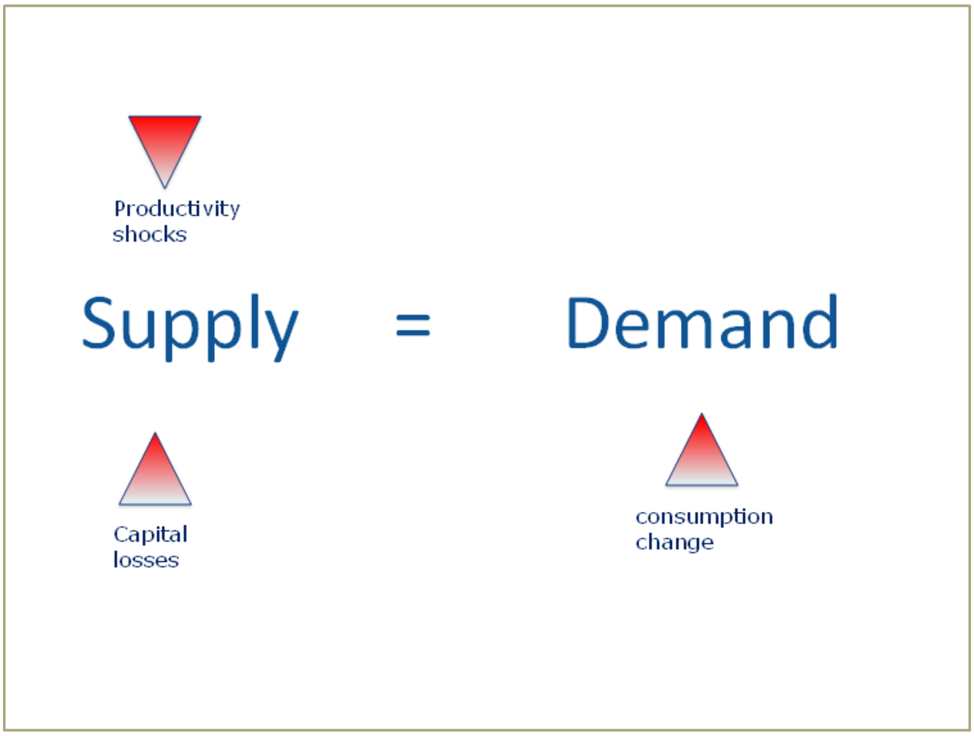
The CaGE model

GEM-E3-CAGE (see Pycroft et al. 2016) is a static multi-country, multi-sector CGE model of the world economy linking the economies through endogenous bilateral trade. The CAGE database is mainly based on the Global Trade Analysis Project (GTAP) database, version 8 (Narayanan et al., 2012). The GEM-E3-CAGE model has 19 sectors (Table 17) and 25 world regions (Table 16).

Making assumptions about the detailed sectoral structure of the European economy over a time-span of many years seems a really cumbersome task, which would introduce more uncertainty than the potential insight gain. Because of this long-term perspective of climate impact, the CGE economic analysis adopted in our study is (quasi-) static; the study looks at what the effects of climate change would be if the future climate would occur today, under the current socioeconomic conditions. The estimated economic impacts represent a level shift or one-off change in welfare or GDP, and not a change in the growth rates. In other words, in the CAGE static assessment the possible effects on economic growth due to the impacts on savings and investment decisions are not considered.
However, this impact assessment provides a solid ground to providing an estimate of the integrated damage: the comparison of the welfare (or GDP) levels obtained with today's economic structure with present-day climate to the welfare (or GDP) levels obtained with a warmer climate with the same economic structure provide a (conservative but robust) measure of the impact that climate change could have with respect to the present levels of welfare (or GDP).

There are three main channels through which the direct damages as computed by the biophysical impacts affect the economy (see Figure 27). Two of the transmission channels would affect the supply side of the economy and a third one the demand side.

Figure 27: Overview of climate shocks affecting the economy



Regarding the supply side, firstly, climate change is affecting the productivity of the economy. The productivity is defined as the unit of output per unit of input. The clearest case is that of agriculture: climate change can lead to reduced yields (output), while all other factors of production (inputs) are the same. Secondly, climate change can alter the capital stock of the economy, for instance when river floods damage infrastructure. These supply-side effects would trigger a series of adjustments in the economy also indirectly affecting sectors and regions different to that where climate change is impacting directly. To further elaborate on those examples, the lack of domestic agricultural production will provoke a higher food imports demand, and the capital equipment destroyed will need replacement, which calls for investments that will impede other investment opportunities.

Regarding the demand side of the economy, climate change can also influence consumption decisions. For instance, damage to residential buildings due to a flood leads to a change in the consumption behavior of households as they would repair the damage and consequently reduce other consumption expenditures. There would be a substitution of consumption: additional consumption to repair the dwellings damage (e.g. buy a new fridge) and an equivalent reduction in consumption (e.g. less leisure expenditure), keeping the overall consumption constant. As the reparation of the flood damage is part of obliged or compulsory consumption (which would not occur in the absence of climate change), the economic model interprets that there is a welfare loss associated to the damage to residential buildings.

Table 15 details how the different impact categories have been implemented in the CAGE model. The agriculture impact model produces estimates of agriculture yields, which have been implemented in the model as changes in productivity in the agriculture sector. The effects due to river and coastal floods have two main components: damages to residential buildings and damages to production sectors. The former component is interpreted as an additional obliged consumption of households, which leads to a welfare loss - due to the fact that there is now less money available for the (non-obliged) consumption of (other) goods. The latter component has been implemented as a capital loss. Heating and cooling demand changes are modelled as changes in obliged consumption. The number of premature deaths (mortality) is considered as damage to the welfare of the population. This damage is calculated by using the value of statistical life (VSL) method.

Table 15: Implementation of sectoral climate impacts in CAGE

Impact	Biophysical model output	Model implementation
Agriculture	Yield change per crop	Agriculture productivity change
Energy	Change in heating and cooling demand	Change in obliged consumption
Labour productivity	Change in labour productivity	Change in labour productivity
River floods	Agriculture losses	Agriculture productivity change
	Residential buildings damages	Additional obliged consumption
	Production activities losses	Capital loss
Coastal areas	Agriculture losses	Agriculture productivity change
	Residential buildings damages	Additional obliged consumption
	Production activities losses	Capital loss
Mortality	Change in mortality	Welfare loss (ex-post)

Table 16: List of region-codes and geographical aggregation

Region	Countries in region	Aggregation for presenting the global spillovers
China	China	East Asia
Japan	Japan	East Asia
Korea	Korea	East Asia
Indonesia	Indonesia	Indonesia
Russia	Russia	Russia
India	India	South Asia
USA	USA	North America
Canada	Canada	North America
Mexico	Mexico	North America
Brazil	Brazil	South America
South Africa	South Africa	Sub-Saharan Africa
UK & Ireland	UK, Ireland	EU28
Northern Europe	Denmark, Estonia, Finland, Lithuania, Latvia, Sweden	EU28
Central Europe (North)	Poland, Netherlands, Luxembourg, Germany, Belgium	EU28
Central Europe (South)	Austria, Czech Republic, France, Hungary, Romania, Slovakia, Slovenia, Croatia	EU28
Southern Europe	Bulgaria, Cyprus, Spain, Greece, Italy, Malta, Portugal, Croatia	EU28
Australasia	Australia, New Zealand, rest of Oceania	Australasia
South Asia	Bangladesh, Iran, Sri Lanka, Nepal, Pakistan, rest of South Asia	South Asia
Sub-Saharan Africa	Botswana, Cote d'Ivore, Cameroon, Ethiopia, Ghana, Kenya, Madagascar, Mozambique, Mauritius, Malawi, Namibia, Nigeria, Senegal, Tanzania, Uganda, South Central Africa, Central Africa, rest of Eastern Africa, Rest of South African Customs Union, Rest of Western Africa, Zambia, Zimbabwe	Sub-Saharan Africa
Rest of Europe	Albania, Switzerland, Norway, Rest of Eastern Europe, Rest of EFTA, Rest of Europe	Rest of Europe
Rest of South-east Asia	Cambodia, Laos, Mongolia, Malaysia, Philippines, Singapore, Thailand, Taiwan, Vietnam, Rest of East Asia, Rest of Southeast Asia, Rest of the World	South Asia
Rest of Former USSR	Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Ukraine, Rest of Former Soviet Union	Rest of Former USSR

Middle East & North Africa	United Arab Emirates, Bahrain, Egypt, Israel, Kuwait, Morocco, Oman, Qatar, Saudi Arabia, Tunisia, Turkey, Rest of North Africa, Rest of Western Asia	Middle East & North Africa
Central America and Caribbean	Costa Rica, Guatemala, Honduras, Nicaragua, Panamá, El Salvador, Rest of Central America, Caribbean, Rest of North America	Central America and Caribbean
Rest of South America	Argentina, Bolivia, Chile, Colombia, Ecuador, Peru, Paraguay, Uruguay, Venezuela, Rest of South America	South America

Table 17: List of sector codes and sectoral aggregation

Agriculture	Bovine cattle, sheep and goats, horses, animal products nec, raw milk, wool, silk-worm cocoons, fishing
Crops	Paddy rice, wheat, cereal, grains nec, vegetables, fruit, nutsv oil seeds, sugar cane, sugar beet, plant-based fibers, crops nec
Forestry	Forestry
Coal Mining	Coal
Crude Oil Extraction	Oil
Natural Gas	Gas, gas manufacture, distribution
Refined Oil	Petroleum, coal products
Electricity	Electricity
Metals	Ferrous metals, metals nec, metal products
Chemicals	Chemical, rubber, plastic products
Energy Intensives	Minerals nec, paper products, publishing, mineral products nec
Electronic equipment	Electronic equipment
Transport Equipment	Motor vehicles and parts, transport equipment nec
Other Equipment	Machinery and equipment nec, manufactures nec
Consumer Goods	Bovine meat products, meat products nec, vegetable oils and fats, airy products, processed rice, sugar, food products nec, beverages and tobacco products, textiles, wearing apparel, leather products, wood products
Construction	Construction
Transport	Transport nec, water transport, air transport
Market Services	Water, trade, communication, financial services nec, insurance, business services nec, dwellings
Non-market Services	Recreational and other services, public administration, Defense, Education, Health

The MaGE model

The long term GDP losses associated with the damages of sea level rise to capital stock, residential buildings and agriculture are assessed with an econometric model called MaGE (Fouré et al. 2013). It is based on a three-factors production function, i.e. labour, capital and energy, plus two forms of technological progress, one for the aggregate bundle of labour and capital and the other specific for energy, i.e. energy productivity. MaGE is fitted with United Nations and International Labour Office labour projections, and includes econometric estimations of the equations for projecting the following variables:

(i) capital accumulation,

(ii) savings rate,

(iii) relationship between savings and investment rate,

(iv) education,

(v) female participation to the labor market

(vi) technological progress (which includes energy and total factor productivity).

The model accounts for energy constraints by including energy use in the production function and by taking account of rents accruing to oil exporting countries. The model therefore proposes a novel approach to growth analysis which assumes limited possibility for energy and the capital/labour bundle to substitute each other; in other words energy is a critical factor of production and capital and labour can compensate its scarcity only to a limited extent. The model's main concept is the idea of convergence, which is also known as the catch-up effect. According to this hypothesis poorer countries income per capita grows faster than in advanced economies thus leading to a convergence or catch up of the first over the second in the long term. The catch up idea is applied in the present analysis for some of the most important equations of the model, i.e. saving rate, technical progress, energy productivity or education. The underlying assumptions regarding total population, population age structure and the education level are based on the IIASA projections for SSP3 (Samir and Lutz, 2014).

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