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Economic analysis of selected climate impacts

JRC PESETA IV project – Task 14

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Contents

Abstract

Climate change damages the capital stock, affects economic production and the welfare of households in regions suffering the impact or that are economically linked with them. These economic effects have been quantified for seven climate impact categories: river floods, coastal floods, agriculture, energy supply, droughts, windstorms and human mortality. Due to the limited coverage of climate impacts, the assessment does not evaluate the full economic impacts of climate change in Europe. Human mortality from extreme heat dominates the economic climate impacts, yet its contribution is strongly dependent on the monetary valuation of human lives. The magnitude of welfare losses in the Southern regions (Central Europe South and Southern Europe) is estimated to be several times larger compared to that in the North of Europe. Limiting warming to 2°C would halve economic impacts compared to a 3°C scenario, while achieving the stringent Paris target of 1.5°C would lower welfare loss by 75%.

Executive summary

Climate change damages the capital stock, affects economic production and the welfare of households in regions suffering the impact or that are economically linked with them. For seven climate impact categories those economic effects have been quantified: river floods, coastal floods, agriculture, energy supply, droughts, windstorms and human mortality. Due to the limited coverage of climate impacts, the assessment does not evaluate the full economic impacts of climate change in Europe. Human mortality from extreme heat dominates the economic climate impacts, yet its contribution is strongly dependent on the monetary valuation of human lives. The magnitude of welfare losses in the Southern regions (Central Europe South and Southern Europe) is estimated to be several times larger compared to that in the North of Europe. Limiting warming to 2ºC would halve economic impacts compared to a 3ºC scenario, while achieving the stringent Paris target of 1.5ºC would lower welfare loss by 75%.

Quantifying economic impacts of climate change

The JRC PESETA IV project considers three future global warming levels (compared to pre-industrial): those set out in the Paris Agreement (1.5 and 2°C) as well as a high level of warming (3°C).

The economic analysis was done for seven impact categories: river floods, coastal floods, agriculture, energy supply, droughts, windstorms and human mortality from extreme heat and cold. It is very important to stress that the economic assessment of climate impacts is incomplete: the four other climate impacts categories of the PESETA IV project were not considered because these impacts could not be monetized (e.g., loss of alpine tundra, shift in ecological domains). There are other relevant climate impacts whose economic valuation is not possible given the current state-of-the-art. That is for example the case for effects associated with triggering climate tipping points, ecosystems degradation and loss of habitats and species. Therefore, the integrated economic impacts presented here do not constitute the totality of economic impacts of climate change in Europe.

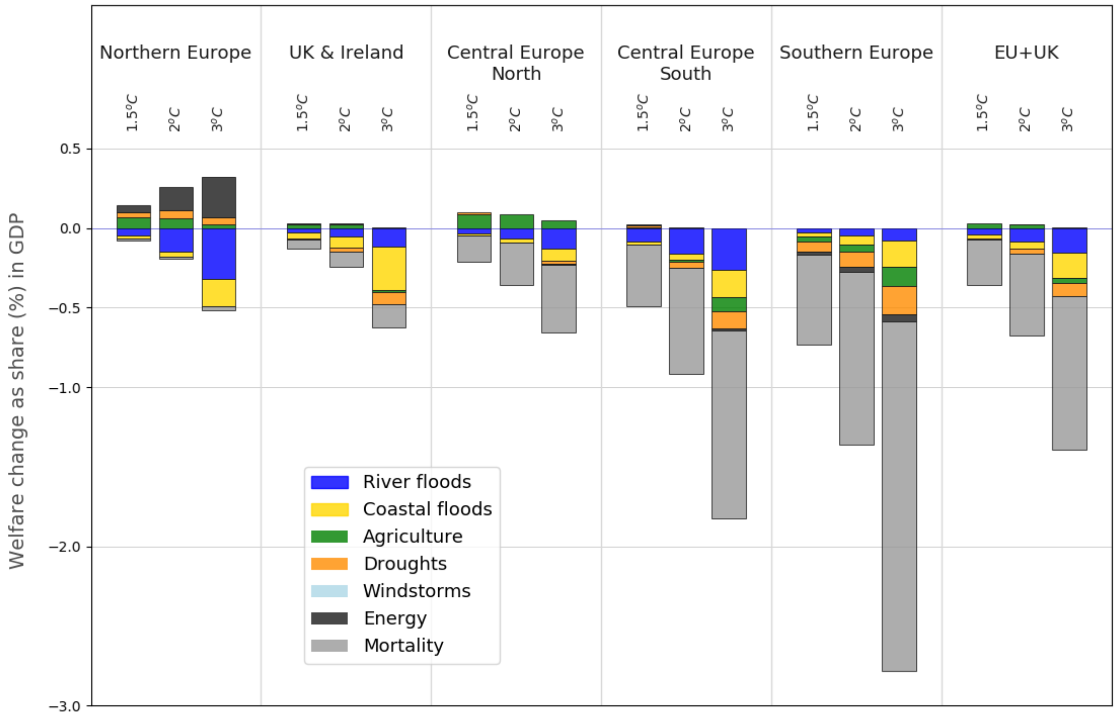
The economic analysis was made with a general equilibrium model in a comparative static context, in which we evaluated how climate conditions at different levels of global warming affect the economy as of today. Hence the results estimated address the question: "How the current economy would be affected if 1.5, 2 and 3ºC of global warmings would occur today?" This method avoids making assumptions about highly uncertain demographic trends and the future structure and size of the economy, and allows to report results which are due to climate impacts only.

Economic impacts of climate change

Exposing present economy to global warming of 3ºC would result in an annual welfare loss of at least 175 €billion (1.38% of GDP). Under a 2ºC scenario the welfare loss would be 83 €billion/year (0.65% of GDP), while restricting warming to 1.5ºC would reduce welfare loss to 42 €billion/year (0.33% of GDP).

While the estimated welfare loss with 2ºC global warming is very similar to that in PESETA III, the welfare loss with 3ºC global warming is lower than in the high emission scenario of PESETA III. That is because in the PESETA III high emission scenario the temperature is considerably higher than 3ºC. This effect is most pronounced for coastal flooding, with impacts in PESETA III nearly 4-fold those of PESETA IV, as sea level rise is projected to accelerate in time.

Figure 1: Welfare loss (% of GDP) from selected climate impacts for the EU and UK, and for the constituent EU macro regions, for three levels of global warming. The results represent change with respect to current economy. The numerical values for each region and impact category can be found in **Table 7**.



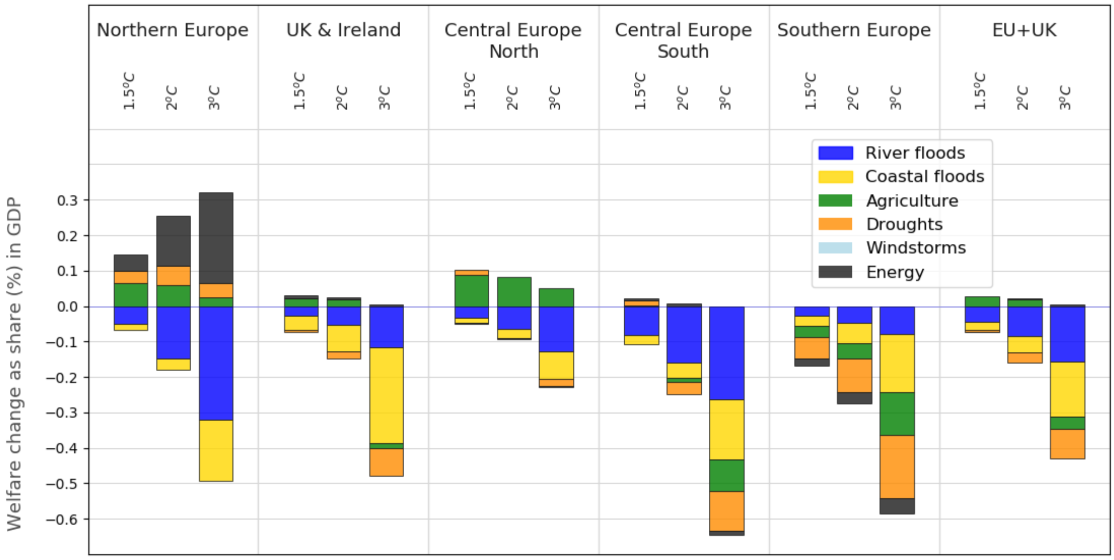
Source: PESETA IV, 2020.

Sectoral impacts

Human mortality from extreme heat dominates the (incomplete) overall economic impacts. The related welfare loss would reach 36, 65 and 122 €billion at 1.5°C, 2°C and 3°C global warming, respectively. More than 80% of the mortality related EU welfare loss is estimated for southern EU regions. It should be noted that the share of human mortality loss to the total economic impact depends strongly on the appreciation of the economic value of life.

River and coastal floods are the second most significant source of welfare loss in the EU, particularly in northern and central EU regions. Flooding impacts constitute 8.5 €billion of welfare loss with 1.5°C, which increases to 16 €billion with 2°C and to 40 €billion with 3°C global warming. It should be noted that sea levels will continue to rise long after climate has stabilised at a specific warming level, e.g. sea levels with 2°C in 2160 will be much higher than with 2°C in 2060. This means that coastal flood impacts projected here for a warming level are very conservative.

Figure 2: Welfare change (% of GDP) from selected climate impacts excluding mortality for the EU and UK, and for the constituent EU macro regions, for three levels of global warming. The results represent change with respect to current economy. The numerical values for each region and impact category can be found in **Table 7**.



Source: PESETA IV, 2020.

Changes in droughts impacts lead to an increase in welfare in northern Europe, but become a source of welfare reduction in southern and western EU regions. With 1.5°C global warming the overall welfare loss from drought is limited to 0.7 €billion, but it grows to 10.6 €billion with 3°C global warming.

Changes in agriculture yield also lead to an increase in welfare in the north and a reduction in the south of Europe. For the EU and UK, this results into a small positive welfare effect at low levels of warming (1.5 and 2°C), which is reversed at higher levels of warming (3°C). The energy model simulates a positive effect of global warming on energy supply in the north and an opposite trend in the south. These regional effects are balanced at 1.5ºC and result in a small increase in welfare at 2ºC and 3ºC.

The North-South divide

There is a clear North-South divide in the regional distribution of welfare losses. The sum of impacts in northern regions are relatively small or even positive (e.g. northern Europe with 1.5ºC and 2ºC) as the regions experience gains from climate change for some of the sectors considered (agriculture, drought, energy supply). In southern EU regions almost all of the impacts are negative (except droughts in Central Europe South with 1.5ºC and energy supply). As a result, the magnitude of overall welfare loss in southern regions is several times larger compared to those in the North of Europe.

Spill-over effects from climate impacts in the rest of the world

The EU economy is affected not only by climate change impacting upon its economy, but also indirectly through international trade with countries that also experience climate-related damages. The findings of PESETA IV confirm a more comprehensive analysis performed in PESETA III, which showed that international spill-over effects could increase the internal EU welfare loss by approximately 20%. A detailed analysis of agricultural yield in PESETA IV shows that agricultural spill-over effects can reach 2 €billion with 1.5ºC and 8 €billion with 3ºC. With 2ºC the negative transboundary effects dominate the positive EU's own welfare increase leading to a welfare loss from agriculture. Further exploratory research on probabilistic perspective on climate change impacts illustrated that the increase in global temperature leads not only to reduction in potential yields but also to increase in uncertainty regarding the production levels.

Approach

The economic analysis is made with a multi-sector, multi-country computable general equilibrium model (Climate assessment General Equilibrium, CaGE model), which integrates the various climate impact channels in a consistent system. The economic integration with the CaGE model is made in a comparative static context, where future climate affects the economy as of today. The resulting estimates thus address the question: "what the economy would look like if the future climate occurs today?"

The methodology interprets the direct impacts estimated by the biophysical models in the economic framework. Some of the main features of the interface between the biophysical damage and the economic modelling include damage to capital stock, sectoral productivity reduction, and change in consumption.

The economic analysis for each climate impact computes the economic impacts in terms of welfare (consumption) changes, using as input the direct damages estimates from the biophysical impact assessments. Welfare losses are in general larger than the direct damages because it accounts for indirect effects in the rest of the sectors of the economy (e.g. agricultural yield losses impacting the agro-food industry).

1 Introduction

The new European Commission's political guidelines place climate action on top of its agenda, in particular with the recently announced European Green Deal (European Commission, 2019). The European Green Deal will reinforce at the European level global ambitious initiatives, mainly in the framework of the 2015 Paris Agreement on Climate Change.

The Joint Research Centre (JRC) PESETA projects have helped to improve the understanding of the possible consequences of climate change for Europe. The aim of the JRC PESETA IV project is to further improve that understanding, narrowing the remaining knowledge gaps[1]. The study follows three stages: climate modelling, assessing the biophysical impacts for a number of sectors and hazards (called 'impact categories'[2]), and the economic analysis of selected impacts.

The JRC PESETA IV project (Feyen et al. 2020) considers three future global warming levels (compared to pre-industrial): those set out in the Paris Agreement (1.5 and 2°C) as well as a high level of warming (3°C)[3], which can be interpreted as a scenario with only limited mitigation. The biophysical assessment is made for eleven climate impact categories: river floods, coastal floods, droughts, agriculture, energy supply, mortality from heat and cold waves, windstorms, habitat loss, forest fires, water, and forest ecosystems.

This report focuses on the economic analysis of impacts, considering the six sectors that have provided impact information expressed in economic terms (river floods, coastal floods, droughts, agriculture, energy supply, and windstorms[4]), and impact information that can be interpreted in economic terms (mortality impacts of heat and cold extremes). The results are presented in three perspectives: firstly, the individual results of each of the seven impact categories; second, the ranking of the impacts in Europe according to their relative magnitudes; and, thirdly, the broad regional pattern of climate impacts across Europe.

At this point, it is very important to stress that the economic assessment of climate impacts in Europe is incomplete for a number of reasons. There are four other climate impacts categories of the PESETA project which are not economically integrated because they do not provide impacts in monetary terms. Furthermore, there are other relevant climate impacts which are not considered within the project because their quantification is not possible given the current state-of-the-art; for example, that is the case of losses due to climate catastrophic events, ecosystems degradation and loss of habitats and species. In fact, those difficult to quantify impact categories are the ones which can be potentially more harmful. In a sense, the more demanding the quantification of the impact is, the more relevant that impact category seems to be.

Therefore, summing the estimates of the seven climate impact does not constitute the totality of climate impacts in Europe. In a similar study of climate impacts in the US[5], aggregated economic impacts are not reported in order to avoid misinterpretation of the aggregate as the overall climate damage.

The economic assessment in this report consists of a welfare analysis that integrates the impacts into an economic multi-sector, multi-country model[6], in a similar way to the analysis made in the JRC PESETA III project (Szewczyk et al. 2018)[7]. The integration allows for the assessment of each impact considered with a uniform economic metric, consumer welfare measured as real private consumption. The valuation of climate impacts with that model also allows to consider the indirect effects of climate change (e.g. due to trade flows), in addition to the direct damages.

The report also explores the degree to which climate impacts from the rest of the world could affect Europe. Climate-related impacts on production and consumption in non-EU countries affect EU countries via

[1] One of them relate to the role adaptation can play to reduce climate impacts. The project has assessed adaptation options with a cost-benefit framework for river floods and coastal flooding.

[2] The climate impact categories refer both to specific impact sectors (e.g. agriculture and energy) and hazards (e.g. river flooding). Some of the hazard studies consider several sectors (e.g. droughts considers impacts on the agriculture sector), yet the project has not integrated them in a consistent way.

[3] Those warming levels are achieved at different times, depending on the specific RCP (RCP4.5 and RCP8.5) and climate model (the project considers 11 climate runs for each RCP). 1.5°C is approximately reached by 2025-2030, 2°C by 2040-2050 and 3°C by 2060-2070.

[4] The windstorms results (Spinoni et al. 2020) are negligible (with welfare changes smaller than 0.01% of GDP). Then this sector does not have a dedicated section in the economic report.

[5] Martinich and Crimmins (2019).

[6] The model uses the results from the RCP8.5 scenario.

[7] The methodology used is the same as in the JRC PESETA III report; the coverage of sectors differs slightly (labour productivity was in PESETA III but not in PESETA IV; PESETA III focused on energy demand while PESETA IV focuses on energy supply; and PESETA IV considers droughts, which was not covered in PESETA III).

international trade. For example, climate-induced reduction in agricultural yields in North America will lead to an increase in its imports and a reduction in exports of agricultural goods, all having implications for its trading partners, including the EU. This report analyses the transboundary effects from agricultural crops production[8] from out-of-the-EU regions onto the EU economy,

The report finally presents an exploratory work on the risk perspective of climate impacts for agriculture impacts in Europe. The risk approach employs a probabilistic framework, which allows estimating the likelihoods of a variable of interest (crop yield, welfare) falling within a certain range.

The document is organised in nine sections, including this introduction. Section 2 describes the main elements of the methodological framework. The next six sections deal with the economic analysis of impacts in each sector: river flooding (section 3), coastal flooding (section 4), droughts (section 5), agriculture crops (section 6), energy supply (section 7) and mortality (section 8). The transboundary analysis and exploratory work on climate risk in agriculture appear in the Annexes. Section 9 summarises the main results and concludes.

[8] Only agricultural crops spillovers are analysed because the required global impacts data was available for this sector only.

2 Methodology

As it has been already noted, it is very important to be aware that the sum of sectoral results presented in this report does not reflect the overall climate damages in Europe since several key impact categories have not been considered in the analysis. The results of this report should therefore not be interpreted as providing the full cost of climate change to Europe.

The economic method relies on the use of Climate assessment General Equilibrium (CaGE, Pycroft et al. 2016)[9] model, which is a multi-sector, multi-country computable general equilibrium (CGE) model. 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 sectoral studies provide direct damages either in monetary terms, as expected annual damage (EAD), or in a non-monetary metrics that can be linked to the parameters of the economic model. For instance, the river flood sectoral study computes the direct damage to infrastructure, measured as EAD in Euros; the agriculture study provides estimates of percentage changes in yields, which can be implemented into the CGE economic model as a productivity change. The CaGE model considers three main channels through which the direct damages affect the economic system: changes in productivity (e.g. due to lower agriculture yields), changes in capital stock (e.g. as a consequence of flood damages) and changes in private consumption (e.g. the repairing of the flood damages to residential buildings reduces the consumption possibilities of households, which consequently reduces their overall welfare).

The CGE analysis accounts for the direct damages of climate change and the additional indirect effects in the economy due to the cross-sectoral (across sectors within the economy) and cross-country adjustments (across countries via international trade). The cross-sectoral impacts refer to effects on other economic sectors or markets of the economy that are linked to the sector undergoing the climate shock via commercial relations (for instance the relationship between the agricultural crops sector and the agro-food industry). There are also indirect effects in other economies due to the international trade flows between countries (both imports and exports). For instance, if one country faces a large negative shock, its production level will change, affecting imports from and exports to other economies. The CGE model has considered the international trade across the EU member states and, furthermore, the trade relationships with the rest of the world.

Another advantage of the CGE methodology is that it considers the implicit, or market, adaptation 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 adjust via the economy price system. This is a general and broad process that involves all production factor and good markets of the country affected by climate and also the markets in the countries with which the country has trade relationships.

The limitations of CGE modelling relate to the detailed parametrisation made e.g. for all the substitution elasticities in the nested production function (e.g. between capital and labour), which are challenging to estimate econometrically due to the lack of detailed data for all the production factors, sectors and regions considered in the model. Another limitation is due to the implicit structure imposed with the selected functional forms of the model equations, which influence the reactions of the model to external shocks.

The results of the economic model are presented in welfare terms. Welfare refers to the utility or satisfaction obtained by households, closely related to their real consumption above the subsistence level.

The economic analysis presented here looks into the valuation of the damage *additional to the base period*, so the current direct damage is subtracted from the direct damage of the climate scenarios[10]. This is because the current damage is implicitly accounted for in the database of the base year of the model; the current impacts of climate change in the base year have already been taken into account in the model database (the social account matrix, based on the input-output tables).

The economic integration with the CaGE CGE model is made in a comparative static context, where future climate affects the economy as of today. 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?" Therefore,

[9] The model database is based on GTAP 9; all economic figures in the report are expressed in 2015 Euro.

[10] For example, today's river flood related losses (EAD) in the EU are estimated at 7.8bn€ annually, while they could reach 16.8bn€ under the 2ºC scenario. The economic analysis estimates the consequences of the additional 9bn€ of damage (16.8bn€ - 7.8bn€).

for instance, the 2°C scenario results are to be interpreted as how much would be the losses if the 2°C climate would occur today, i.e. affecting the economy and society 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, i.e. current land use, GDP and population; second, to avoid making questionable assumptions regarding the evolution of the economy and population to the end of the XXI century. For instance, land use can radically change in a generation therefore producing very different estimates of damages for the same inundation area due to a flood. By referring the impacts to the present economic structure, one does not need to make long-term assumptions on evolution of production factors, growth or economic structure, which could largely influence the key findings of the study.

Because the model's database represents annual stocks and flows of the global economy, the results obtained reflect annual changes. In other words, the estimated economic impacts represent an annual change in welfare, but the possible effects on long-term economic growth are not considered in this assessment because the framework is static. Some studies in the literature have modelled how climate change can affect economic growth. For instance, Burke et al. (2015) used an econometric approach to estimate how climate change can affect economic growth. That approach does not consider the sectoral or bottom-up perspective implemented in this study.

The CGE analysis considers the human mortality effects in a similar way to that of PESETA III. The economic or welfare loss due to the extreme temperature fatalities are valued using the value of statistical life (VSL; 1.3 million Euro/person, same value as in PESETA III). The use of VSL can be controversial; the selected value is in the low end range of the literature. For instance, OCED (2012) proposes a range for the EU-27 average adult of USD 1.8 million to 5.4 million (2005-USD), with a base value of USD 3.6 million.

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.

3 River floods

The input into the economic analysis is based on the biophysical modelling described in Dottori et al. (2020). The biophysical analysis provides estimates of direct damage for the base period (1981-2010) and for the three warming levels. The economic implications of river flooding for the 1.5°C, 2°C and 3°C scenarios are presented with respect to today's economy, that is, as additional to the current losses[11].

Main conclusions:

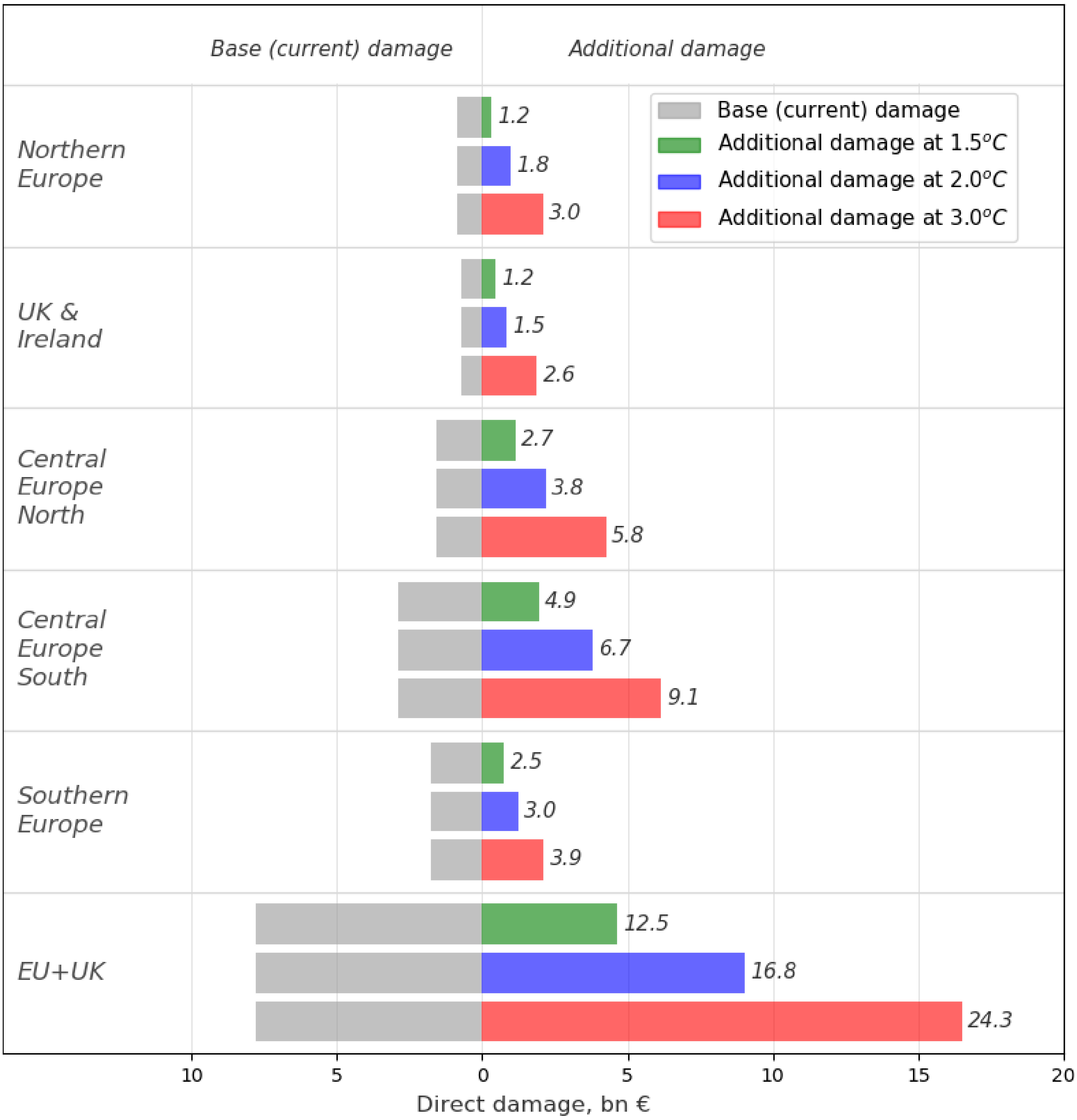
- EU welfare losses due to further warming could range between 5 bn € (1.5°C scenario) and 20 bn € (3°C scenario).
- About 60% of the EU absolute welfare losses concentrate in the Central Europe regions.
- Proportionally (as a share of GDP), the largest welfare losses are estimated for Northern Europe (0.32% of its GDP for the 3°C scenario) and for Central Europe South (0.26% of its GDP for the 3°C scenario).

Figure 3 details the direct damages from river floods[12]. The grey bars reflect the base (current) level of damage and the green, blue and red bars show the additional damage estimated for the climate scenarios. The numbers plotted to the right of the bars show the total damage (base + future). The EU current direct damage is 7.8 bn €. The direct damage is estimated to increase by 4.7 bn € in the 1.5°C scenario, by 9 bn € in the 2°C scenario, and by 16.5 bn € in the 3°C scenario. The level of direct damages (including the base year damage) appears to be approximately linear with the warming level because doubling temperature from the 1.5°C scenario to the 3°C scenario would roughly double the direct damages (from 12.5 bn € in the 1.5°C scenario to 24.37 bn € in the 3°C scenario). Comparing the damage *additional* to the base level in the three warming scenarios, shows a steeper increase in the damage levels, by a factor of almost 4 (from 4.6 in the 1.5°C scenario to 16.5 bn € 3°C scenario), and those proportions also translate to welfare loses at the different warming levels.

[11] See the Methodology section for detailed explanation.

[12] The direct damage is specified for three different damage categories: agriculture, industry and residential buildings; each damage type would have a different effect on the economy. The agricultural direct damages are accounted for in the economic model as a change in the productivity of the agricultural sector. Damages to industry are represented as damage to the economy's capital stock, and damage to residential buildings is represented as an increase in households' subsistence spending.

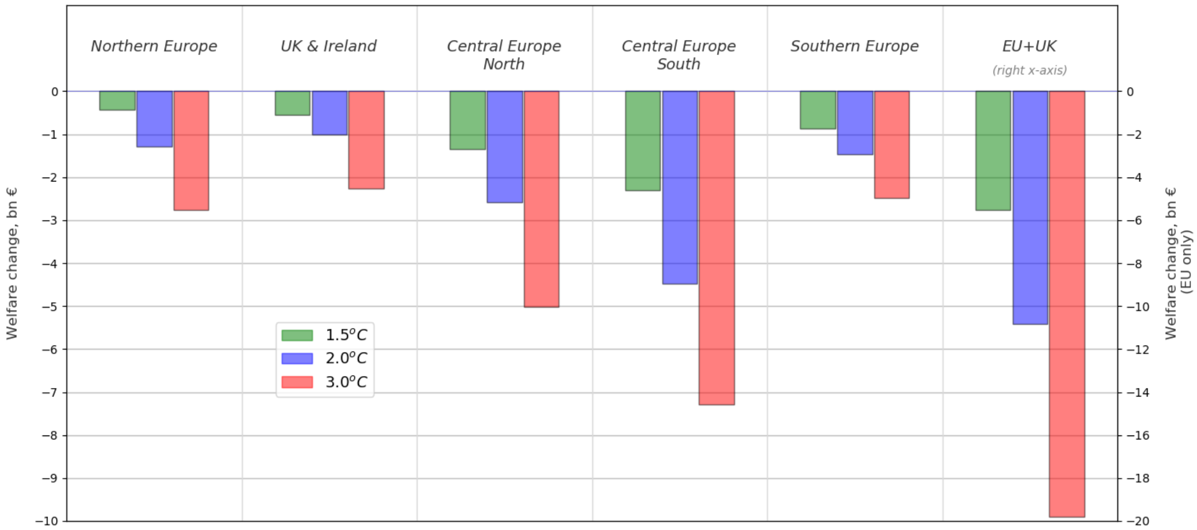
Figure 3: Direct damage (EAD, bn €) from river flooding for the EU+UK, and the EU regions at the three climate scenarios. The grey bars reflect the base (current) level of damage and the green, blue and red bars show the additional damage estimated for the climate scenarios. The numbers plotted to the right of the bars show the total damage (base + future).



Source: PESETA IV, 2020.

The welfare losses (additional to those in the base year) are reported in **Figure 4** (in absolute terms), **Figure 5** (in relative terms, as a share of GDP) and in **Table 1** (all the numerical values from the two previous figures). In absolute terms, the additional EU welfare losses are estimated at 5.5, 11 and 20 bn € at the three climate scenarios (1.5°C, 2°C and 3°C), respectively. The welfare losses are approximately 15-20% higher than the direct damages. About 60% of the additional EU welfare losses could be in the Central Europe North and Central Europe South regions, up to 20% in the Southern Europe, and about 10% in each of the Northern Europe and UK and Ireland regions.

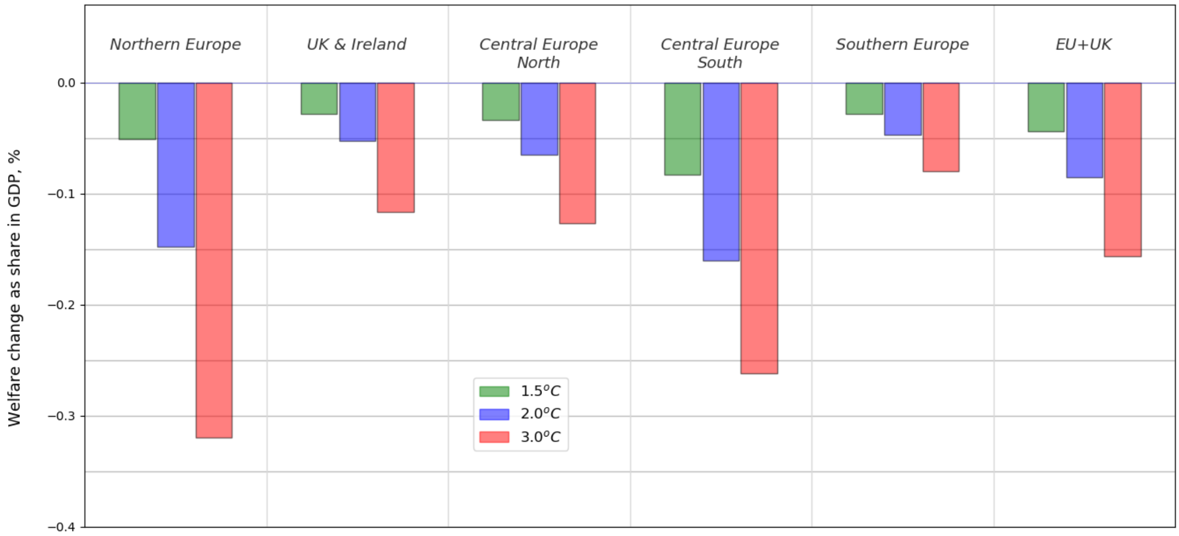
Figure 4: Change in welfare from river flooding (bn €) for the three climate scenarios. The losses reflect the additional damage (EAD) with respect to the base (current) damage. The right axis refers to the EU results.



Source: PESETA IV, 2020.

When taking into consideration the relative sizes of the regional economies (GDP), the welfare reductions as a share in GDP (**Figure 5** and **Table 1**, percentage change results) for the EU aggregate are 0.05%, 0.1% and 0.16% for the respective three climate scenarios. The largest welfare loss is estimated for Northern Europe (0.05% of GDP in the 1.5°C scenario to 0.32% of GDP in the 3°C scenario) and Central Europe South (0.08% of GDP in the 1.5°C scenario to 0.26% of GDP in the 3°C scenario). The welfare losses of the other three regions are lower than the EU average (up to 0.13% of GDP in the 3°C scenario).

Figure 5: Change in welfare from river flooding as share in GDP (%) for the three warming levels. The losses reflect the additional damage (EAD) with respect to the base (current) damage.



Source: PESETA IV, 2020.

Table 1: Welfare losses from river flooding (bn € and % of GDP) for the three climate scenarios; the losses reflect damage from warming additional to any current losses.

Region	Welfare (bn €)			Welfare (% of GDP)		
	1.5°C	2°C	3°C	1.5°C	2°C	3°C
Northern Europe	-0.4	-1.3	-2.8	-0.05	-0.15	-0.32
UK & Ireland	-0.6	-1.0	-2.3	-0.03	-0.05	-0.12
Central Europe North	-1.3	-2.6	-5.0	-0.03	-0.07	-0.13
Central Europe South	-2.3	-4.5	-7.3	-0.08	-0.16	-0.26
Southern Europe	-0.9	-1.5	-2.5	-0.03	-0.05	-0.08
EU + UK	-5.5	-10.8	-19.8	-0.04	-0.09	-0.16

Source: PESETA IV, 2020.

4 Coastal floods

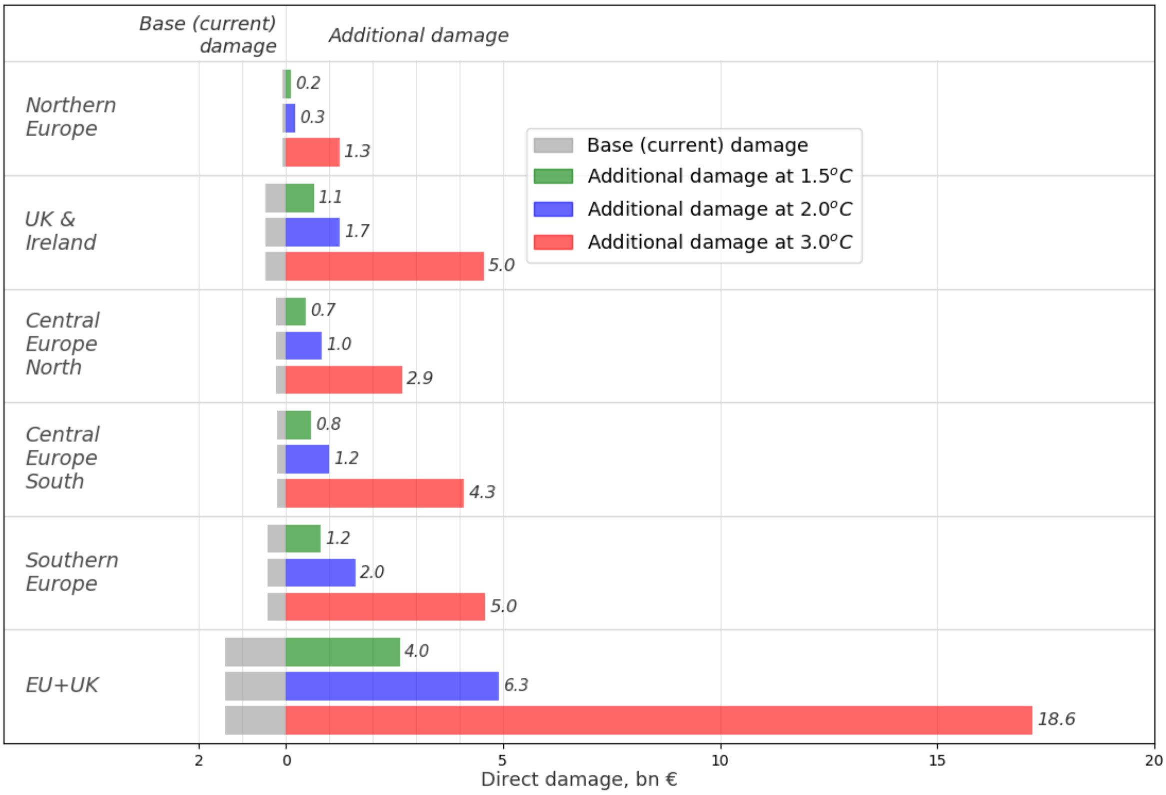
The input into the economic analysis is based on the biophysical modelling described in Vousdoukas et al. (2020). The biophysical analysis provides estimates of direct damage for the base period (1981-2010) and for the three climate scenarios. The economic implications of coastal flooding in the 1.5°C, 2°C and 3°C scenarios are presented with respect to today's economy, i.e. additional to the current losses.

Main conclusions:

- EU welfare losses from coastal floods due to further warming could increase by 3 bn € in the 1.5°C scenario, 5.6 bn € in the 2°C scenario and up to 20 bn € in the 3°C scenario, compared to nowadays.
- About 50% of the EU welfare losses would occur in the two South Europe regions.
- Proportionally, the largest welfare losses are estimated for UK & Ireland: up to 0.3% of its GDP in the 3°C scenario.

Figure 3 presents the direct damages from coastal floods[13]. The grey bars reflect the base (current) level of damage and the green, blue and red bars show the additional damage estimated for the climate scenarios. The numbers plotted to the right of the bars show the total damage (base + future). The current EU direct damage is 1.4 bn €. The direct damage is estimated to increase by 2.6 bn € in the 1.5°C scenario, by 4.9 bn € in the 2°C scenario, and by 17.2 bn € in the 3°C scenario. While in the river floods case the direct damages were rather linear with respect to the warming level, in the case of coastal floods the damages grow much faster than the warming level, with a very non-linear relationship.

Figure 6: Direct damage (EAD, bn €) from coastal flooding for the EU regions at the three climate scenarios. The grey bars reflect the base (current) level of damage and the green blue and red bars show the additional damage estimated for the climate scenarios. The numbers plotted to the right of the bars show the total damage (base + future).



Source: PESETA IV, 2020.

[13] The direct damage has three different damage categories: industry, agriculture and residential buildings. Each type of damage would have a different effect in the economy, in the same way as the three categories of flood damages. The agricultural direct damages are accounted for in the economic model as a change in the productivity of the agricultural sector. Damages to industry are represented as damage to the economy's capital stock, and damage to residential buildings is represented as an increase in households' subsistence spending.

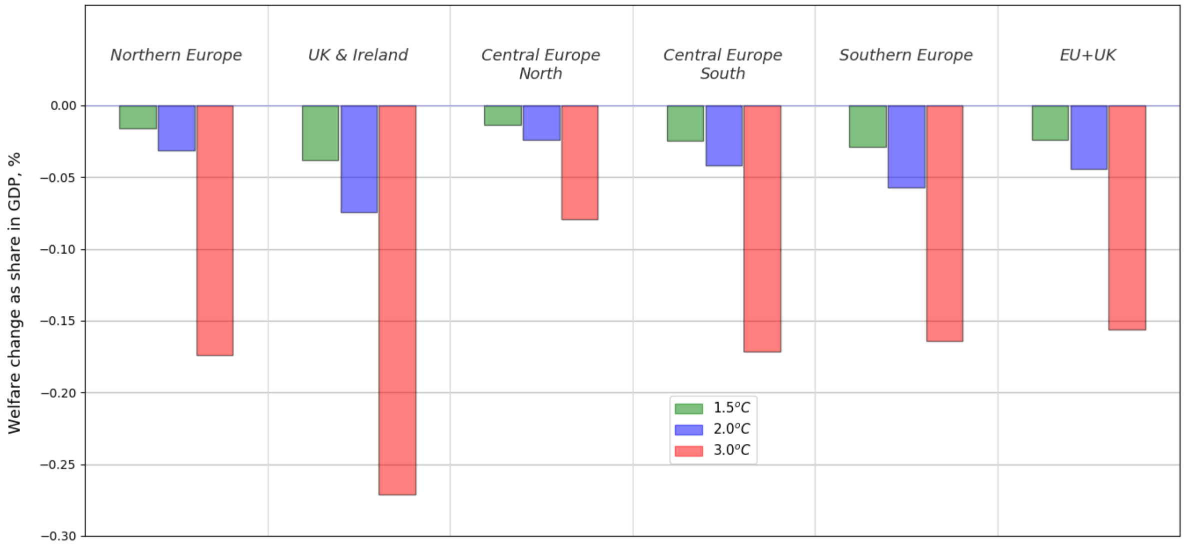
The welfare losses (additional to those in the base year) are reported in absolute terms in **Figure 7**, in relative terms (as a share of GDP) in **Figure 8**; **Table 2** provides all the numerical values from the previous Figures. In absolute terms, the additional EU welfare losses are estimated at 3, 5.6 and 20 bn € for the three climate scenarios (1.5°C, 2°C and 3°C, respectively). The welfare losses are approximately 10% higher than the direct damages. About 75% of the additional EU welfare losses are equally divided between UK & Ireland, Central Europe South and Southern Europe. Further 15-20% of the EU losses are in Central Europe North, and about 5-10% in Northern Europe.

Figure 7: Change in welfare from coastal flooding (bn €) for the three climate scenarios. The losses reflect the additional damage (EAD) with respect to the base (current) damage. The right axis refers to the EU results.

Source: PESETA IV, 2020.

The welfare reductions as a share of GDP (**Figure 8** and **Table 2**) for the EU aggregate are 0.04%, 0.08% and 0.3% for the respective three climate scenarios. The largest welfare loss is estimated for UK & Ireland (0.04% of GDP in the 1.5°C scenario to 0.27% of GDP in the 3°C scenario) and Northern Europe (0.02% of GDP in the 1.5°C scenario to 0.17% of GDP in the 3°C scenario); Central Europe South has welfare losses in range 0.03% of GDP in the 1.5°C scenario to 0.16% of GDP in the 3°C scenario. The welfare losses of the other two regions are lower than the EU average (up to 0.16% of GDP).

Figure 8: Change in welfare from coastal flooding as share in GDP (%) for the three climate scenarios. The losses reflect the additional damage (EAD) with respect to the base (current) damage.



Source: PESETA IV, 2020.

Table 2: Welfare losses from coastal flooding (bn € and % of GDP) for the three climate scenarios.

Region	Welfare (bn €)			Welfare (% of GDP)		
	1.5ºC	2ºC	3ºC	1.5ºC	2ºC	3ºC
Northern Europe	-0.1	-0.3	-1.5	-0.02	-0.03	-0.17
UK & Ireland	-0.7	-1.4	-5.2	-0.04	-0.07	-0.27
Central Europe North	-0.5	-1.0	-3.1	-0.01	-0.02	-0.08
Central Europe South	-0.7	-1.2	-4.8	-0.02	-0.04	-0.17
Southern Europe	-0.9	-1.8	-5.2	-0.03	-0.06	-0.16
EU + UK	-3.0	-5.6	-19.8	-0.02	-0.04	-0.16

Source: PESETA IV, 2020.

5 Droughts

The input into the economic analysis is based on the biophysical modelling described in Cammalleri et al. (2020). The biophysical analysis provides estimates of direct damage for the base period (1981-2010) and for the three climate scenarios, 1.5°C, 2°C and 3°C. The results show that global warming will progressively increase the frequency and severity of hydrological droughts in the Mediterranean and Atlantic European regions, while in Boreal and Continental Europe drought hazard will decline with warming. The economic implications of droughts in the 1.5°C, 2°C and 3°C scenarios are presented with respect to today's economy, that is, additional to the current losses; hence, if future direct damage is estimated lower that the current damage it would be modelled as a net reduction (benefit) in drought-related losses (see **Figure 9** for an overview).

Main conclusions:

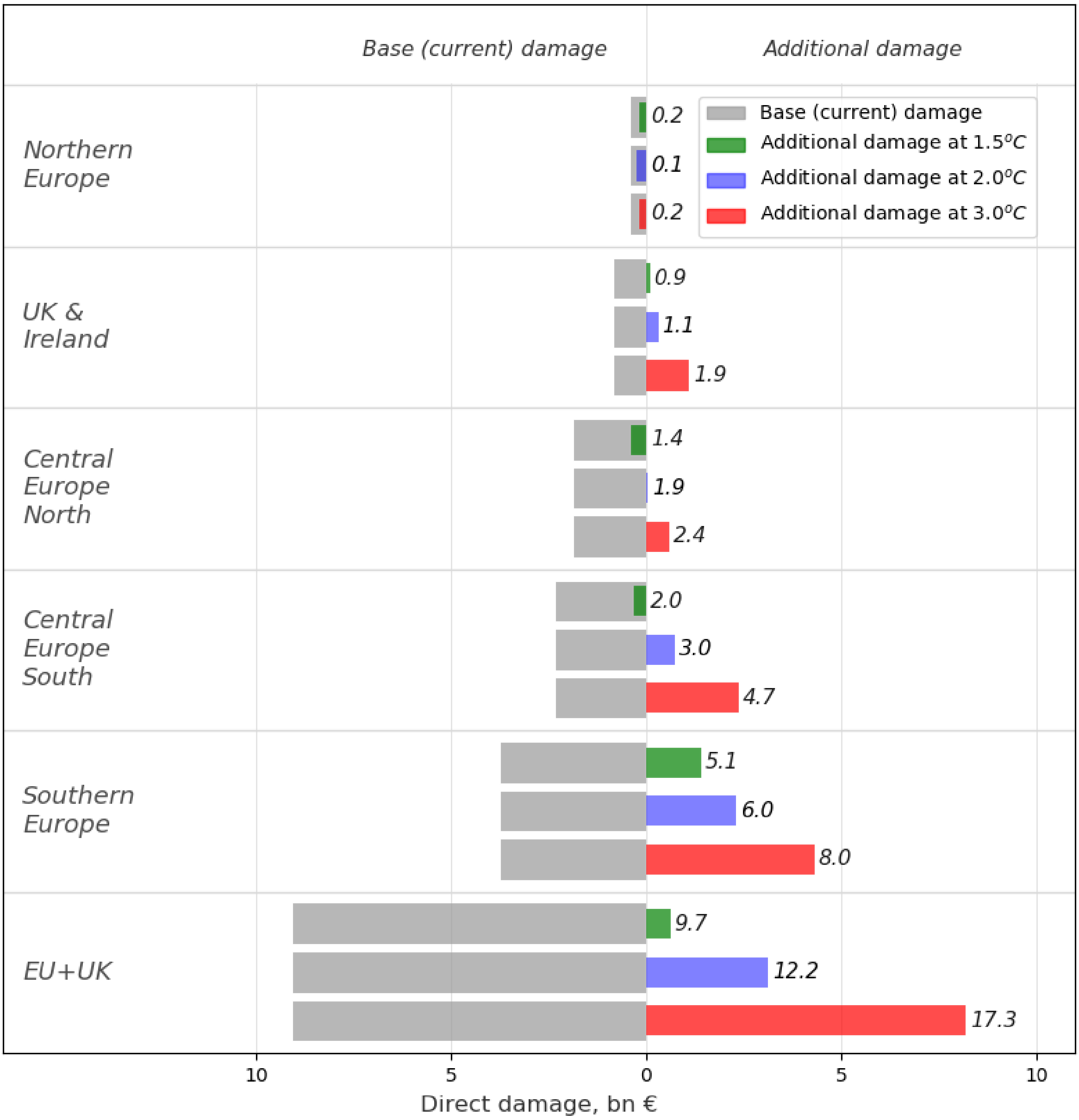
- Aggregate EU welfare losses from drought-related damage could increase from an additional 0.7 bn € in the 1.5°C scenario to 10.6 bn € in the 3°C scenario.
- Over 90% of the drought-related damage is estimated for the Southern Europe region in the 1.5°C scenario. The share remains very high, 75%, in the 2°C scenario and more than 50% under the 3°C warming scenario.

Figure 9 depicts the direct damages from droughts[14]. The grey bars reflect the base (current) level of damage and the green, blue and red bars show the additional damage estimated for the three climate scenarios; the colour bars overlapping to the left onto the grey bars indicate the reduction of the damage for the respective warming level. The numbers plotted to the right of the bars show the total damage (base plus the future damages).

The current EU direct damage is 9 bn €. The direct damage is estimated to increase by 0.7 bn € (7%) in the 1.5°C climate scenario (green bar), by 3.2 bn € (35%) in the 2°C scenario (blue bar), and by 8.3 bn € (91%) in the 3°C scenario (red bar). At the regional level, the Northern Europe direct damage decreases with higher warming, from a current 0.4 bn € loss to a 0.2 bn € total loss (sum of the current and future impacts) under the 3°C warming level. UK and Ireland's direct damage more than doubles from 0.8 bn € today to a total loss of 1.9 bn € in the 3°C scenario. The Central regions' direct damage is estimated to decrease in the 1.5°C scenario (compared to the current damage), and then increase in the 3°C scenario, reaching a total damage of 2.4 bn € in Central Europe North and 4.7 bn € in Central Europe South. Southern Europe has the largest regional current damage from droughts at 3.7 bn €, which is estimated to increase, with a total damage of 8 bn € in the 3°C scenario.

[14] The direct damage is specified for different damage categories: agriculture, public water supply, power generation, commercial shipping, and subsidence in industry and in residential buildings - each type of the damage would have a different effect on the economy: agriculture: change in productivity of the agricultural sector; public water supply: change in productivity of the water supply service; power generation: reduced efficiency of energy production (sectoral productivity loss); commercial shipping: reduction in efficiency of water transport; subsidence: divided between capital loss in industry and damage to residential buildings .

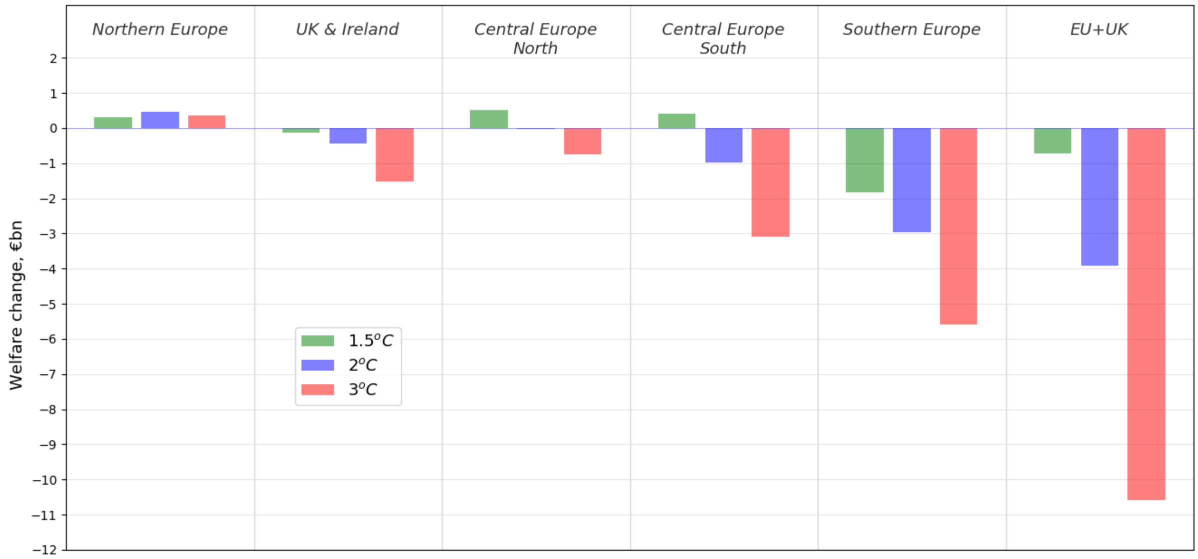
Figure 9: Direct damage (EAD, bn €) from droughts for the EU regions at the three climate scenarios. The grey bars reflect the base (current) level of damage and the green, blue and red bars show the additional damage estimated for the climate scenarios; the colour bars overlapping to the left onto the grey bars indicate the reduction of the damage for the respective warming level. The numbers plotted to the right of the bars show the total damage (base plus future).



Source: PESETA IV, 2020.

The welfare losses (additional to those in the base year) are reported in **Figure 10** (in absolute terms), **Figure 11** (in relative terms, as a share of GDP) and in **Table 3** (all the numerical values from the two Figures). They largely reflect the magnitudes and regional pattern of the direct damage (**Figure 9**). In absolute terms, the additional EU welfare losses are estimated to be 0.7, 3.9 and 10.6 bn € for the three climate scenarios (1.5, 2 and 3ºC, respectively). The most affected region is Southern Europe, whose drought-related welfare losses constitute almost all of the EU losses in the 1.5ºC (1.8 bn €), three-quarters of the EU losses at 2ºC climate scenario (3 bn €), and half of the welfare losses under the 3ºC scenario (5.6 bn €). In the 3ºC climate scenario, significant welfare losses are also estimated for UK & Ireland (1.5 bn €) and Central Europe South (3.1 bn €).

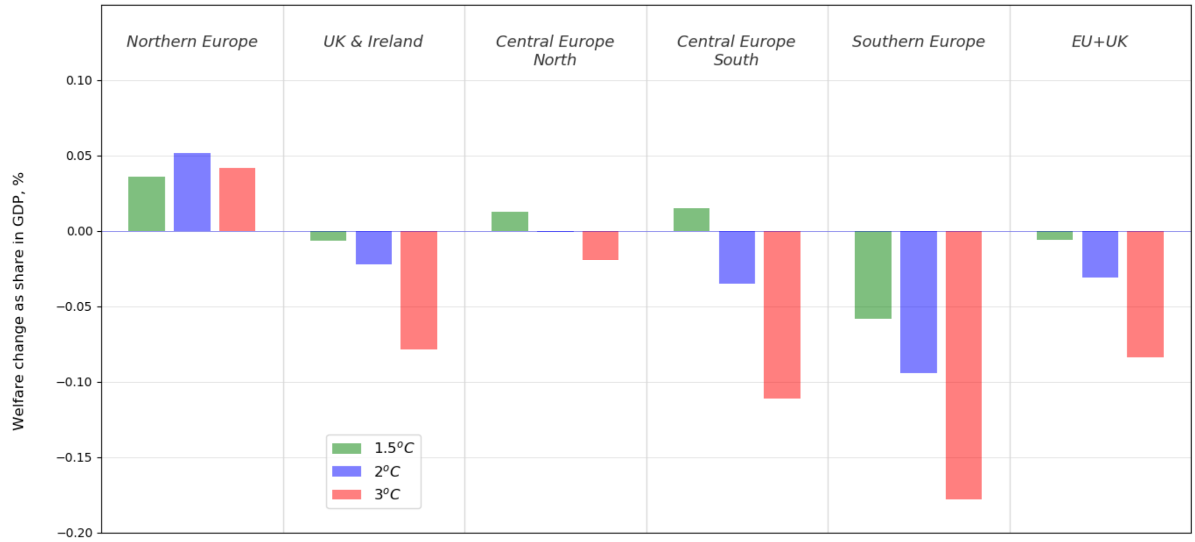
Figure 10: Change in welfare from drought (bn €) for the three climate scenarios. The losses reflect the additional damage (EAD) with respect to the base (current) damage.



Source: PESETA IV, 2020.

Relative to the size of the economies (as a percentage share in GDP, **Figure 11**, and three last columns of **Table 3**), the EU welfare loss ranges from a small 0.01% reduction in the 1.5°C scenario to a 0.08% loss in the 3°C scenario. At the regional level, the welfare gains in Northern Europe are of around 0.04% of GDP in all scenarios. The UK and Ireland region could have a small welfare reduction in the 1.5°C scenario, and welfare losses of 0.08% of GDP in the 3°C scenario. The Central Europe regions show a similar small welfare increase in the 1.5°C scenario (0.01%-0.02% of GDP), and welfare losses in the 3°C scenario (0.02% in Central Europe North and 0.11% in Central Europe South). Welfare losses in Southern Europe are estimated to be the largest in the EU also in relative terms. The welfare loss is 0.06% in the 1.5°C scenario, 0.09% in the 2°C scenario and 0.18% in the 3°C scenario.

Figure 11: Change in welfare from droughts (% of GDP) for the three climate scenarios. The losses reflect the additional damage (EAD) with respect to the base (current) damage.



Source: PESETA IV, 2020.

Table 3: Change in welfare from droughts (bn € and % of GDP) for the three climate scenarios. The losses reflect the additional damage (EAD) with respect to the base (current) damage.

Region	Welfare (bn €)			Welfare (% of GDP)		
	1.5ºC	2ºC	3ºC	1.5ºC	2ºC	3ºC
Northern Europe	0.3	0.5	0.4	0.04	0.05	0.04
UK & Ireland	-0.1	-0.4	-1.5	-0.01	-0.02	-0.08
Central Europe North	0.5	0.0	-0.8	0.01	0.00	-0.02
Central Europe South	0.4	-1.0	-3.1	0.02	-0.03	-0.11
Southern Europe	-1.8	-3.0	-5.6	-0.06	-0.09	-0.18
EU + UK	-0.7	-3.9	-10.6	-0.01	-0.03	-0.08

Source: PESETA IV, 2020.

6 Agricultural crops

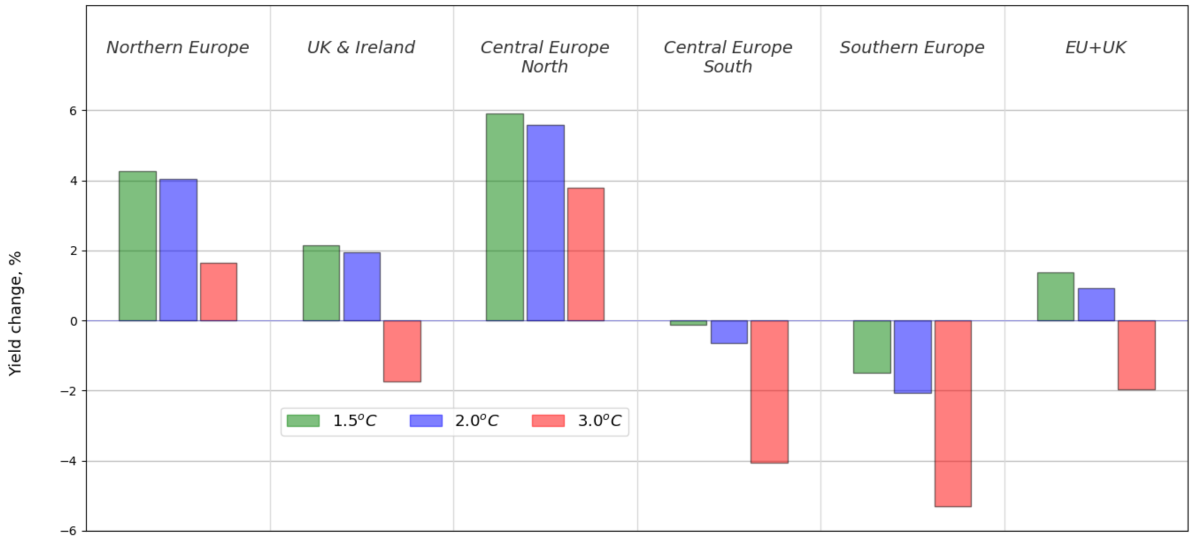
The results of the economic analysis presented in this section are based on future yield changes provided by the Agricultural Model Intercomparison and Improvement Project (AgMIP) together with the Inter-Sectoral Impact Model Intercomparison project (ISIMIP). The changes in productivity of agricultural crops resulting from future climate change, without the CO_2 fertilisation effect, are used as an input to the economic model in order to assess the macroeconomic implications in the three warming scenarios: 1.5°C, 2°C and 3°C.

Main conclusions:

- The EU welfare change is positive in the 1.5°C and 2°C scenarios, but the aggregate masks large regional differences.
- In the 3°C scenario the welfare loss is estimated to be 4.3 bn € (with respect to the current economy).
- Northern regions experience an increase in yield productivity, while southern regions face reductions in yields.

The AgMIP project provides harmonised data on future yield changes based on multi-model simulations[15]. The yield changes for the EU regions[16] are described in **Figure 12**. The yield changes are mainly increasing in the Northern regions of the EU and decreasing in the Southern regions. The difference in yields between 1.5°C and 2°C are very small (less than 1%) and smaller than the difference between 2°C and 3°C, which can be of almost 4% and change sign, as in the UK and Ireland region, or the aggregate EU + UK.

Figure 12: Changes in agricultural yields (%)



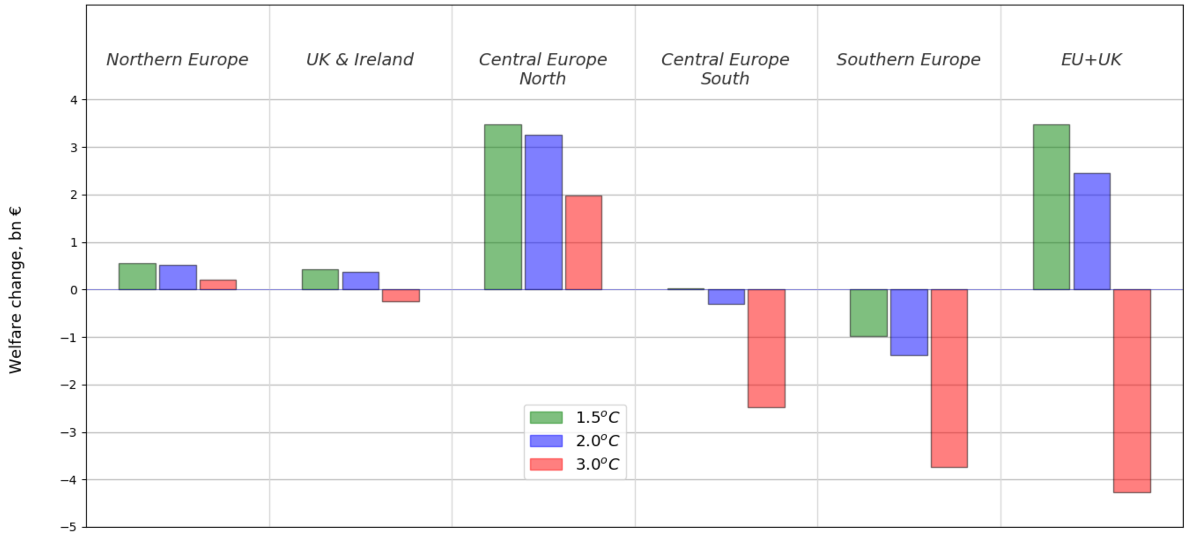
Source: PESETA IV, 2020.

The welfare effects (additional to those in the base year) are reported in **Figure 13** (in absolute terms), **Figure 14** (in relative terms, as a share of GDP) and in **Table 4** (all the numerical values from the two previous figures). At the aggregate EU level, there is a 3.2 bn € increase in welfare in the 1.5°C scenario, which, however, turns into a loss of around 4 bn € in the 3°C scenario. There is a small positive change in welfare in the Northern regions, which decreases with the warming level (becoming negative for UK and Ireland in the 3°C scenario). The Southern regions' welfare is in general negative (with a marginal small effect in Central Europe South in the 1.5°C scenario), reaching a 3.7 bn € welfare loss in the Southern Europe region in the 3°C scenario.

[15] The simulations build on 5 Climate (GCM) Models (HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, GFDL-ESM2M, and NorESM1-M) and 7 Global Gridded Crop Models (EPIC, GEPIC, IMAGE, LPJmL, LPJ-GUESS, pDSSAT, and PEGASUS). This report uses the average values across the models.

[16] Yield change is introduced in the CGE model as a total factor productivity (TFP) change on the agricultural crops sector. Total factor productivity is defined as the ratio of production or output to the 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.

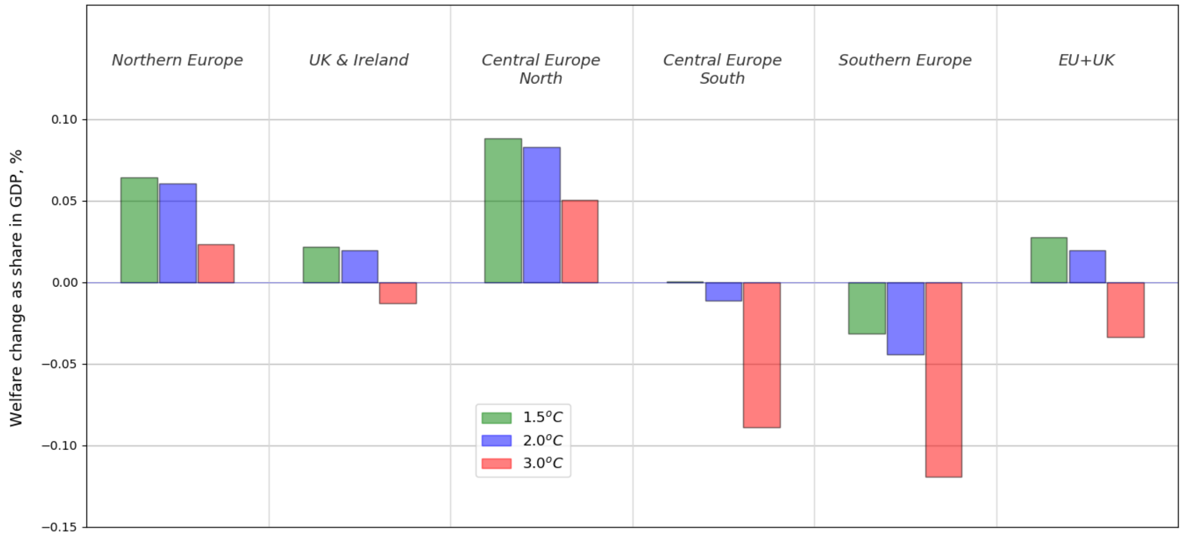
Figure 13: Change in welfare (bn €) from crop productivity change for the EU regions for the three climate scenarios. The reported changes are with respect to current economy.



Source: PESETA IV, 2020.

Placing the results in relation to the relative size of the regions (Figure 14, welfare change as a share of GDP, %) allows to illustrate the importance of the welfare changes for the regions. The proportional welfare losses are still the largest in the Central Europe South and Southern Europe regions, reaching around 0.1% in the 3°C scenario, both above the EU average.

Figure 14: Change in welfare as share in GDP (%) from crop productivity change for the EU regions for the three climate scenarios. The reported welfare changes are with respect to the current economy.



Source: PESETA IV, 2020.

Table 4: Welfare change from crop productivity change (bn € and % of GDP), additional to current welfare levels

Region	Welfare (bn €)			Welfare (% of GDP)		
	1.5°C	2°C	3°C	1.5°C	2°C	3°C
Northern Europe	0.6	0.5	0.2	0.06	0.06	0.02
UK & Ireland	0.4	0.4	-0.3	0.02	0.02	-0.01
Central Europe North	3.5	3.3	2.0	0.09	0.08	0.05
Central Europe South	0.0	-0.3	-2.5	0.00	-0.01	-0.09
Southern Europe	-1.0	-1.4	-3.7	-0.03	-0.04	-0.12
EU + UK	3.5	2.5	-4.3	0.03	0.02	-0.03

Source: PESETA IV, 2020.

7 Energy supply

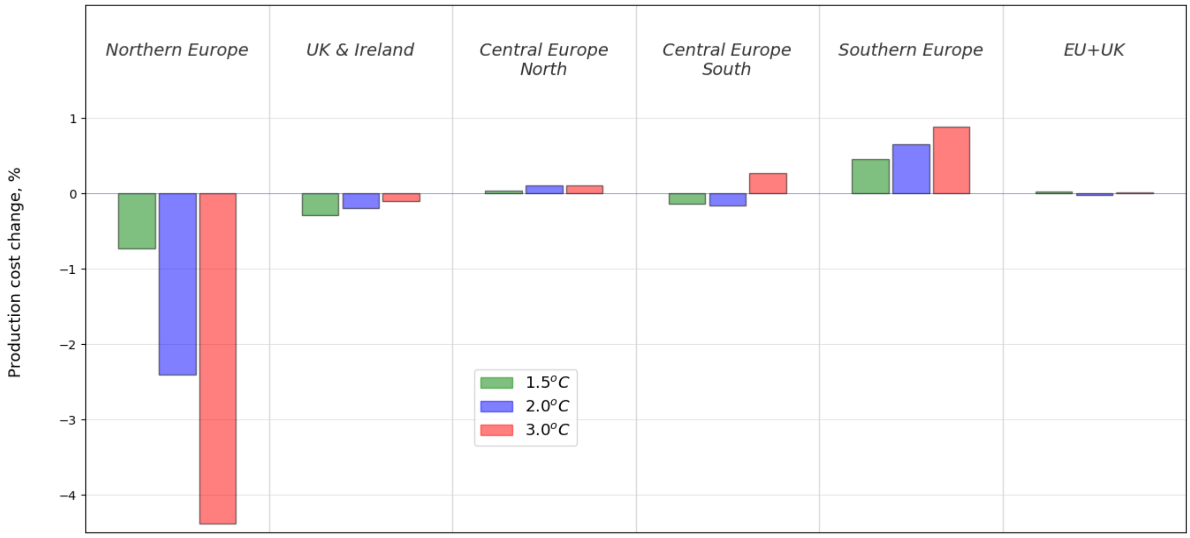
This section presents the analysis of the economic consequences of changes in electricity production in Europe for the three climate scenarios: 1.5ºC, 2ºC and 3ºC. The input into the economic analysis is based on the biophysical modelling of Després and Adamovic (2020), who estimate the potential effects of climate change on electricity production.

Main conclusions:

- The changes in electricity production lead to welfare gains in Northern Europe and welfare losses in Southern Europe.
- For most of the EU regions, the electricity supply reduction is the largest in the 1.5ºC scenario, then at higher warming levels it becomes smaller or even turns into an increase.

Figure 15 represents the change (%) in electricity production costs for the three climate scenarios. The energy modelling (Després and Adamovic, 2020) estimates almost no change in the electricity production cost for the EU and UK for the three climate scenarios (right bars of **Figure 15**). This net EU aggregate, however, is underpinned by significant regional differences. The largest reduction in electricity production cost is estimated for Northern Europe, in a range between 0.7% in the 1.5ºC scenario and 4.4% in the 3ºC scenario. Smaller reductions in the production costs, in the range of 0.1%-0.3%, are also modelled for UK and Ireland and for Central Europe South (1.5ºC and 2ºC only). Central Europe North is modelled to have a small increase in the electricity production cost, but in a very small range: from 0.04% to 0.1%. The largest increase is estimated for Southern Europe, where the production cost of electricity could increase by 0.5% in the 1.5ºC scenario, by 0.6% in the 2ºC scenario and by 0.9% in the 3ºC scenario.

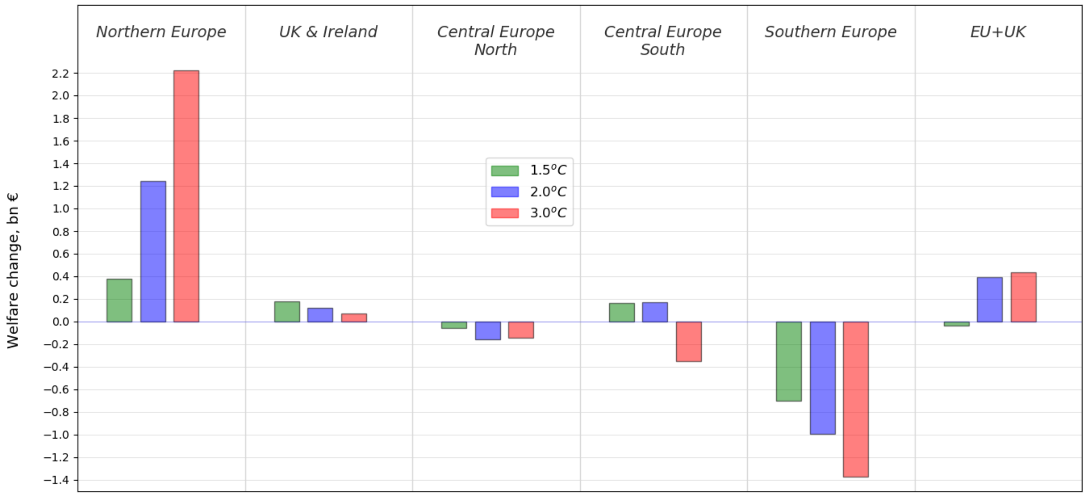
Figure 15: Change (%) in electricity production cost for the three climate scenarios (1.5ºC, 2ºC and 3ºC).



Source: PESETA IV, 2020.

The welfare losses (additional to those in the base year) are reported in Figure 16 (in absolute terms), Figure 17 (in relative terms, as a share of GDP) and in Table 5 (all the numerical values from the two previous figures). At the regional level, Northern Europe has the largest welfare increase in all the climate scenarios: 0.4 bn € in the 1.5ºC scenario, 1.2 bn € in the 2ºC scenario and 2.2 bn € in the 3ºC scenario. For two other EU regions, UK and Ireland and Central Europe South (1.5ºC and 2ºC only), the change is also positive but of a smaller magnitude, in a range of 0.07 bn € to 0.18 bn €. Estimates for Central Europe North show a small welfare loss no larger than 0.16 bn €. The largest welfare losses are modelled for Southern Europe which could lose 0.7 bn € in the 1.5ºC scenario, 1 bn € in the 2ºC scenario and 1.4 bn € in the 3ºC scenario.

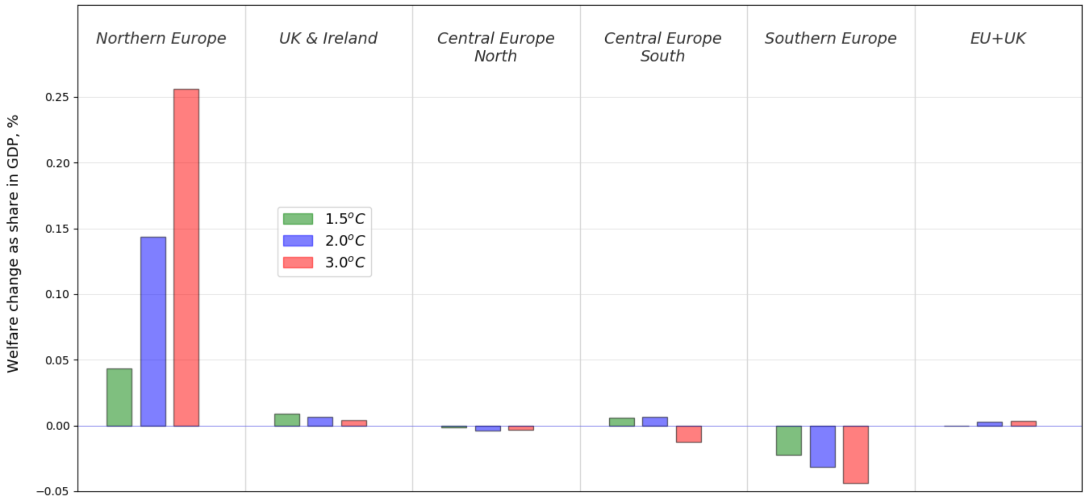
Figure 16: Change in welfare (bn €) for the three climate scenarios. The losses reflect the change in production cost of electricity with respect to nowadays.



Source: PESETA IV, 2020.

When the welfare change is considered relative to the GDP size of the regions (as % of GDP, **Figure 17**), the largest proportional change is found in Northern Europe: 0.04% to 0.26% of GDP. The second most significant change is for Southern Europe, where the welfare loss is in range of 0.02% to 0.04% of GDP. For the rest of the EU regions, UK and Ireland, Central Europe North and Central Europe South, the proportional change is very small, in a range of 0.001% to 0.01% of GDP.

Figure 17: Change in welfare as share in GDP (%) for the three climate scenarios. The losses reflect the change in production cost of electricity with respect to nowadays.



Source: PESETA IV, 2020.

Table 5: GDP and welfare changes due to the electricity production cost change

Region	Welfare (bn €)			Welfare (% of GDP)		
	1.5ºC	2ºC	3ºC	1.5ºC	2ºC	3ºC
Northern Europe	0.38	1.24	2.22	0.044	0.143	0.256
UK & Ireland	0.18	0.12	0.07	0.009	0.006	0.004
Central Europe North	-0.05	-0.16	-0.14	-0.001	-0.004	-0.004
Central Europe South	0.16	0.17	-0.35	0.006	0.006	-0.013
Southern Europe	-0.70	-0.99	-1.37	-0.022	-0.032	-0.044
EU + UK	-0.04	0.39	0.43	0.000	0.003	0.003

Source: PESETA IV, 2020.

8 Mortality from heat and cold

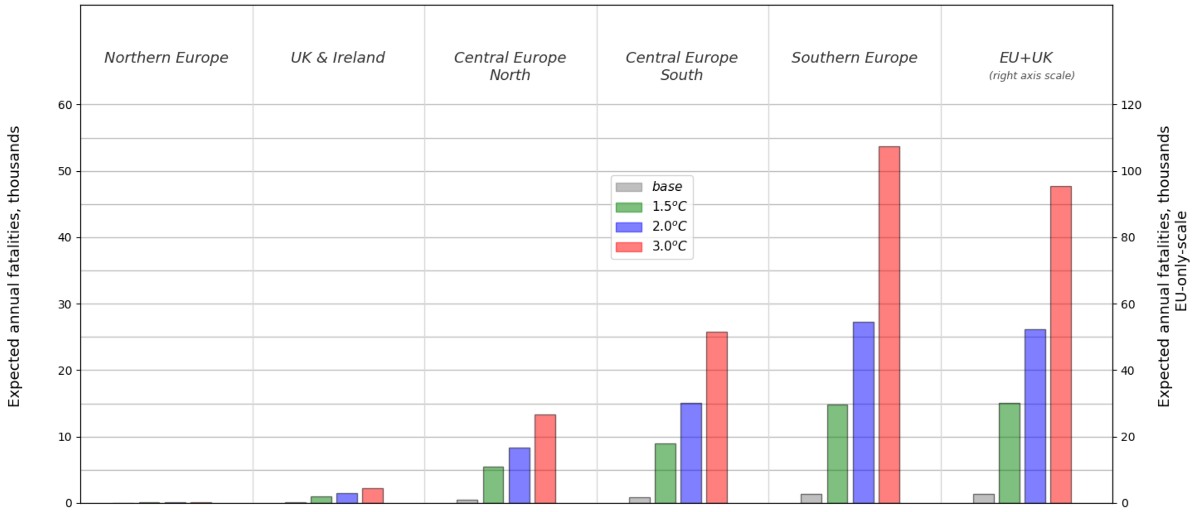
Naumann et al. (2020) provide a quantitative assessment of human mortality from temperature extremes (both cold and heat waves) in Europe for the three climate scenarios, compared to the current period. The morality is estimated under the current socio economic conditions[17].

Main conclusions:

- Under the 3°C climate scenario, the EU fatalities due to heat and cold waves can be 33 times higher than under the current climate.
- The welfare losses can reach 36, 65 and 122 bn € for the three climate scenarios 1.5°C, 2°C and 3°C, respectively.
- Around 80% of the welfare losses are estimated to occur in the two southern EU regions.

Figure 18 presents the heat-and cold-related mortality for the EU and the UK and the EU regions in the current period (base) and the three climate scenarios. The EU mortality increases rapidly with warming. Today's 2,800 EU fatalities increase more than ten-fold to 30,000 people in the 1.5°C scenario, then to 52,000 in the 2°C scenario and to the 95,000 in the 3°C scenario. The mortality also strongly increases southwards, with more than half of the EU fatalities (95,000 in the 3°C climate scenario) occurring in the Southern Europe region alone (53,000 in the 3°C climate scenario).

Figure 18: Expected annual fatalities from heat and cold in the three climate scenarios (thousands of persons). The right axis refers to the EU + UK results.



Source: PESETA IV, 2020.

The rate of increase of fatalities with warming across regions is relatively similar in the 1.5°C scenario (about ten times the base level) and 2°C (about 15 times the base level), but diverges in the 3°C scenario: it is about 25 times the base level in the Northern regions, but almost 35 times the base level in the Southern regions.

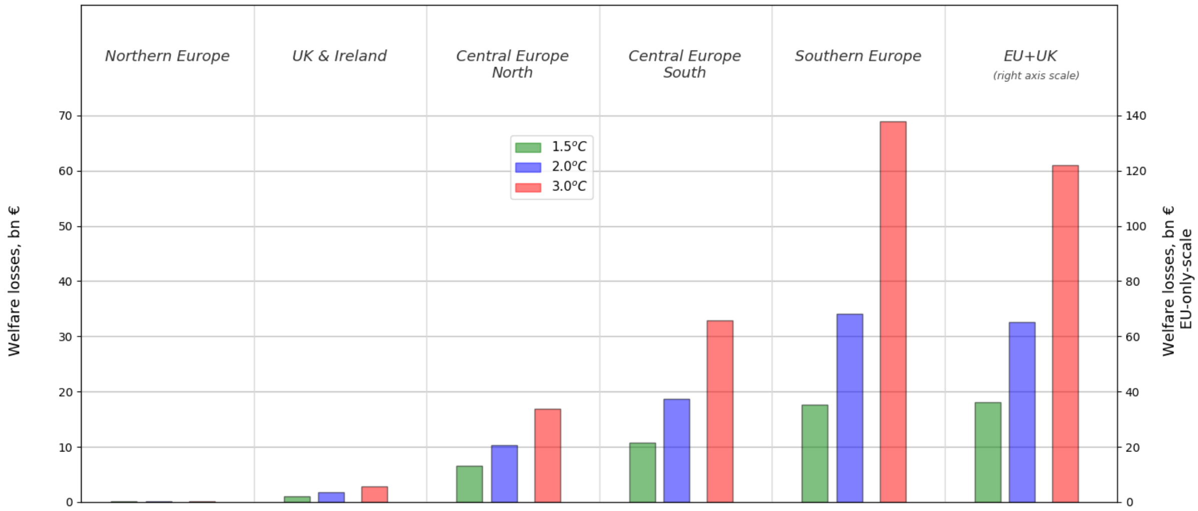
The welfare loss is calculated with a monetary estimate of mortality, using the value of statistical life (VSL) method. The number of premature deaths is multiplied by the VSL, which provides an estimate of the welfare loss. The assumed VSL is 1.3 million euro/person (2015 Euro; same value for all member states), as in the previous PESETA studies, the low-end of the range of estimates considered in the review of the European Clean Air Policy Package (European Commission, 2013).

Figure 19 and **Table 6** show the welfare losses for the EU and the UK and its regions. The welfare losses are calculated with respect to the current mortality levels, i.e. they show the *additional (net)* loss due to the increase in temperature. Since the monetised damage is computed as a product of the number of fatalities

[17] 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.

(**Figure 18**) and a constant VSL, the proportions between the welfare losses for the regions and the warming levels reflect those of mortality.

Figure 19: Welfare losses due to increase in mortality from heat and cold (difference from current period), bn €. The right axis refers to the EU + UK results.



Source: PESETA IV, 2020.

The aggregate EU welfare loss in the 1.5°C scenario is estimated to be 36 bn €, compared to today, increasing to 65 bn € in the 2°C scenario and to over 122 bn € in the 3°C scenario. More than 80% of the losses are in the two South EU regions.

Table 6: Welfare losses due to increase in mortality from heat and cold (difference from base period, bn €)

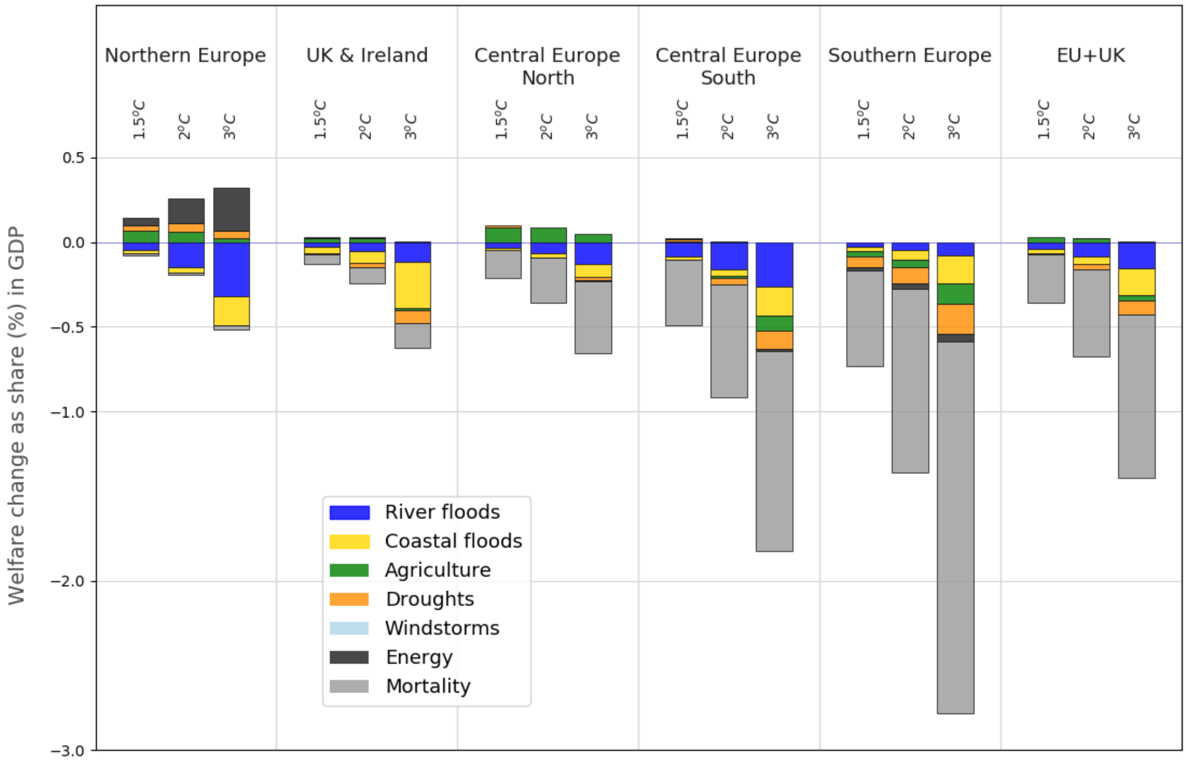
Region	1.5°C	2°C	3°C
Northern Europe	0.09	0.14	0.22
UK & Ireland	1.11	1.81	2.85
Central Europe North	6.56	10.33	16.96
Central Europe South	10.70	18.67	32.91
Southern Europe	17.65	34.10	68.93
EU + UK	36.10	65.05	121.88

Source: PESETA IV, 2020.

9 Summary of impacts

Global warming of 3°C would result in an additional annual welfare loss of 175 bn € (1.38% of GDP). Under a warming of 2°C the annual welfare loss would be 83bn € (0.65% of GDP) and if the warming is limited to 1.5°C the welfare loss would be reduced to 42bn € (0.33 % of GDP). The 3°C welfare loss is lower than that of the JRC PESETA III project because of the much lower warming level considered.

Figure 20: Welfare change from selected climate impacts (% of GDP) for the EU-27 and UK, and for the constituent EU macro regions, for three levels of global warming. The results represent change with respect to current economy.



Source: PESETA IV, 2020.

Sectoral impacts

Human mortality from heat dominates the (incomplete) overall economic impacts. The related welfare losses can reach 36, 65 and 122 bn € for the three climate scenarios (1.5°C, 2°C and 3°C, respectively). More than 80% of the mortality related welfare losses are estimated for southern EU regions.

River and coastal floods are the second most significant sources of welfare loss in the EU, particularly in the northern and central EU regions. Those two impact categories alone constitute 8.5 bn € of additional welfare loss at 1.5°C, increasing to 16 bn € at 2°C and to 40 bn € at 3°C warming level.

When compared to nowadays, changes in the frequency and severity of droughts lead to a small increase in welfare in Northern Europe, but become a major source of welfare reduction in the southern EU regions: 8.7 bn € in the southern EU regions compared to 10.6 bn € for the EU total in the 3°C scenario.

Climate impacts due to changes in agriculture yields lead to an increase in welfare in the north of EU and a reduction in the south. The additional welfare losses in the southern EU regions increase from 1 bn € in the 1.5°C scenario to more than 6 bn € under the 3°C scenario. At the same time, in northern EU regions the welfare increases by 4.5 bn € in the 1.5°C scenario but the gain declines with further warming to 2 bn € under the 3°C warming level.

The energy model simulates a positive effect of global warming on electricity supply in the north and an opposite trend the south. These regional effects are balanced at 1.5°C and result in a small increase in welfare at 2°C and 3°C global warming.

In general, the welfare losses (excluding mortality) are around 20% higher than the direct damages computed in biophysical models. Those 20% reflect how the rest of the overall economy would be indirectly affected by climate change.

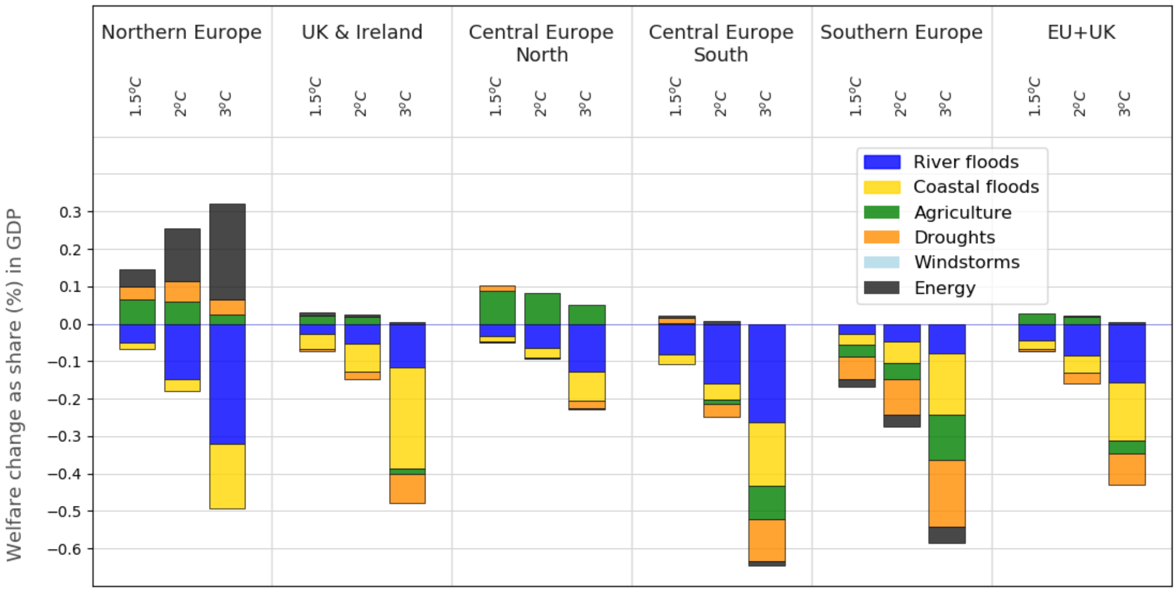
The North-South divide

There is a clear North-South divide in the regional distribution of welfare losses. The sums of impacts in northern regions are relatively small or even positive (e.g. Northern Europe at 1.5°C and 2°C), and the regions also experience gains from climate change for some of the sectors (agriculture, droughts' frequency, energy supply). In the southern regions almost all of the impacts are negative (except droughts in Central Europe South at 1.5°C and energy supply at 2 and 3°C). The magnitude of welfare losses in the southern regions is several times larger compared to those in the North of Europe.

Transboundary effects from the rest of the world

The EU economy is affected not only by climate impacting directly upon its economy, but also indirectly through international trade with countries which also experience climate-related damages. The findings confirm a more comprehensive analysis from PESETA III that the international spillovers could increase the internal EU welfare losses by approximately 20%. A detailed analysis of agricultural yields shows that the agricultural spillovers can reach between 2 bn € at 1.5°C to 8 bn € at 3°C; at 2°C the negative transboundary effects dominate the positive EU's own welfare increase leading to an overall welfare loss. Further exploratory research on probabilistic perspective on climate change impacts illustrated that the increase in global temperature leads not only to reduction in potential yields but also to increase in uncertainty regarding the production levels.

Figure 21: Welfare change from selected climate impacts excluding mortality (% of GDP) for the EU-27 and UK, and for the constituent EU macro regions, for three levels of global warming. The results represent change with respect to current economy.

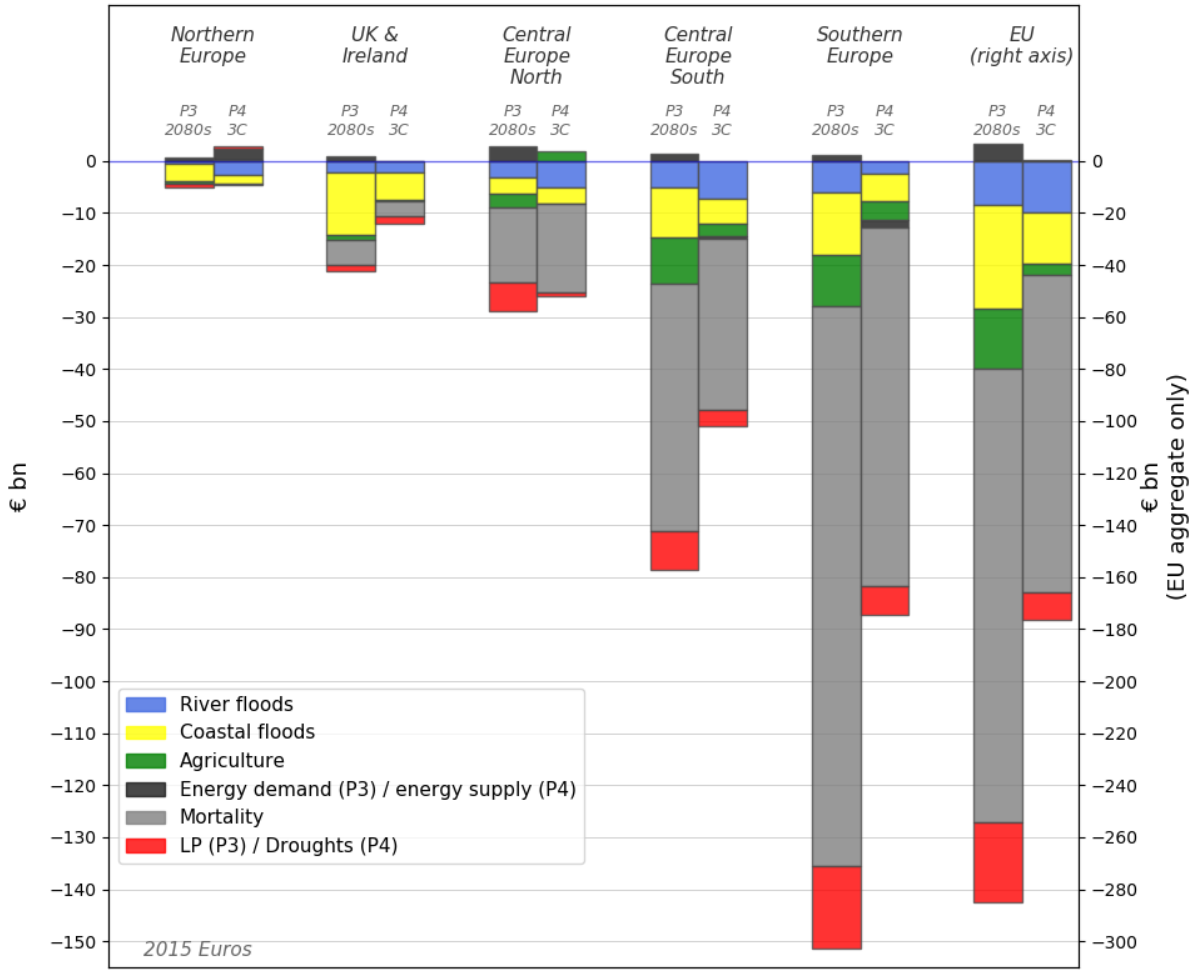


Source: PESETA IV, 2020.

Comparison of PESETA IV vs PESETA III

The economic valuation of climate impacts in PESETA IV are different when compared to the results of PESETA III for three main reasons. Mainly, the reported damages in PESETA IV are lower because they are estimated for 3°C warming level, which would occur in the 2060s for the RCP8.5 scenario, while PESETA III reported damages for the end of the century (2100) time horizon. Secondly, there is a different set of sectoral impacts covered in the two projects. While PESETA III included river floods, coastal floods, agriculture, residential energy demand, mortality and labour productivity in the economic valuation, PESETA IV has included river floods, costal floods, agriculture, energy supply, mortality, windstorms and droughts. Finally, there have been some improvements in the sectoral biophysical methodologies since PESETA III.

Figure 22: Comparison of results of the PESETA III (P3) and PESETA IV (P4) projects.



Source: PESETA III (2018) and PESETA IV (2020).

Table 7: Welfare change from selected climate impacts (bn € and % of GDP) for the EU-27+UK, and for the constituent EU macro regions, for three levels of global warming. The results represent change with respect to current economy.

Sector	Region	Welfare change, bn € (additional to base)			Welfare change as share in GDP (%)		
		1.5°C	2°C	3°C	1.5°C	2°C	3°C
Inland floods	Northern Europe	-0.4	-1.3	-2.8	-0.05	-0.15	-0.32
	UK & Ireland	-0.6	-1.0	-2.3	-0.03	-0.05	-0.12
	Central Europe North	-1.3	-2.6	-5.0	-0.03	-0.07	-0.13
	Central Europe South	-2.3	-4.5	-7.3	-0.08	-0.16	-0.26
	Southern Europe	-0.9	-1.5	-2.5	-0.03	-0.05	-0.08
	EU + UK	***-5.5***	***-10.8***	***-19.8***	***-0.04***	***-0.09***	***-0.16***
Coastal floods	Northern Europe	-0.1	-0.3	-1.5	-0.02	-0.03	-0.17
	UK & Ireland	-0.7	-1.4	-5.2	-0.04	-0.07	-0.27
	Central Europe North	-0.5	-1.0	-3.1	-0.01	-0.02	-0.08
	Central Europe South	-0.7	-1.2	-4.8	-0.02	-0.04	-0.17
	Southern Europe	-0.9	-1.8	-5.2	-0.03	-0.06	-0.16
	EU + UK	***-3.0***	***-5.6***	***-19.8***	***-0.02***	***-0.04***	***-0.16***
Agriculture	Northern Europe	0.6	0.5	0.2	0.06	0.06	0.02
	UK & Ireland	0.4	0.4	-0.3	0.02	0.02	-0.01
	Central Europe North	3.5	3.3	2.0	0.09	0.08	0.05
	Central Europe South	0.0	-0.3	-2.5	0.00	-0.01	-0.09
	Southern Europe	-1.0	-1.4	-3.7	-0.03	-0.04	-0.12
	EU + UK	***3.5***	***2.5***	***-4.3***	***0.03***	***0.02***	***-0.03***
Droughts	Northern Europe	0.3	0.5	0.4	0.04	0.05	0.04
	UK & Ireland	-0.1	-0.4	-1.5	-0.01	-0.02	-0.08
	Central Europe North	0.5	0.0	-0.8	0.01	0.00	-0.02
	Central Europe South	0.4	-1.0	-3.1	0.02	-0.03	-0.11
	Southern Europe	-1.8	-3.0	-5.6	-0.06	-0.09	-0.18
	EU +UK	***-0.7***	***-3.9***	***-10.6***	***-0.01***	***-0.03***	***-0.08***
Energy	Northern Europe	0.4	1.2	2.2	0.04	0.14	0.26
	UK & Ireland	0.2	0.1	0.1	0.01	0.01	0.00
	Central Europe North	-0.1	-0.2	-0.1	0.00	0.00	0.00
	Central Europe South	0.2	0.2	-0.4	0.01	0.01	-0.01
	Southern Europe	-0.7	-1.0	-1.4	-0.02	-0.03	-0.04
	EU +UK	***0.0***	***0.4***	***0.4***	***0.00***	***0.00***	***0.00***
Mortality	Northern Europe	-0.1	-0.1	-0.2	-0.01	-0.02	-0.03
	UK & Ireland	-1.1	-1.8	-2.8	-0.06	-0.09	-0.15
	Central Europe North	-6.6	-10.3	-17.0	-0.17	-0.26	-0.43
	Central Europe South	-10.7	-18.7	-32.9	-0.38	-0.67	-1.18
	Southern Europe	-17.6	-34.1	-68.9	-0.56	-1.09	-2.20
	EU +UK	***-36.1***	***-65.0***	***-121.9***	***-0.29***	***-0.51***	***-0.96***
Sum of the sectors	Northern Europe	0.6	0.5	-1.7	0.07	0.06	-0.20
	UK & Ireland	-1.9	-4.2	-12.0	-0.10	-0.22	-0.62
	Central Europe North	-4.5	-10.8	-24.0	-0.11	-0.27	-0.61
	Central Europe South	-13.1	-25.4	-50.9	-0.47	-0.91	-1.83
	Southern Europe	-23.0	-42.7	-87.3	-0.73	-1.36	-2.78
	EU +UK	***-41.9***	***-82.6***	***-175.9***	***-0.33***	***-0.65***	***-1.39***

Source: PESETA IV, 2020.

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List of abbreviations and definitions

CaGE	Climate assessment General Equilibrium
CGE	Computable General Equilibrium (model)
EAD	Expected Annual Damage
PESETA	Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis
RCP	Representative Concentration Pathway

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Annex 1. Global spillovers

The EU economy is affected not only by climate change impacting upon its businesses, infrastructure and resources, but also indirectly through international trade with the rest of the world, which also experiences climate-related impacts. Those additional impacts are called spillover or transboundary effects. This section presents an illustrative example of the transboundary effects for agricultural yields changes in the three warming scenarios, 1.5°C, 2°C and 3°C.

The transboundary effects are computed using the CGE CaGE model. In a hypothetical scenario, only the regions outside of the EU are subjected to the change in agricultural yields from climate change. Under that scenario the model evaluates the changes in economic activity (GDP) and welfare in the EU and the UK because of the international trade linkages with the rest of the world.

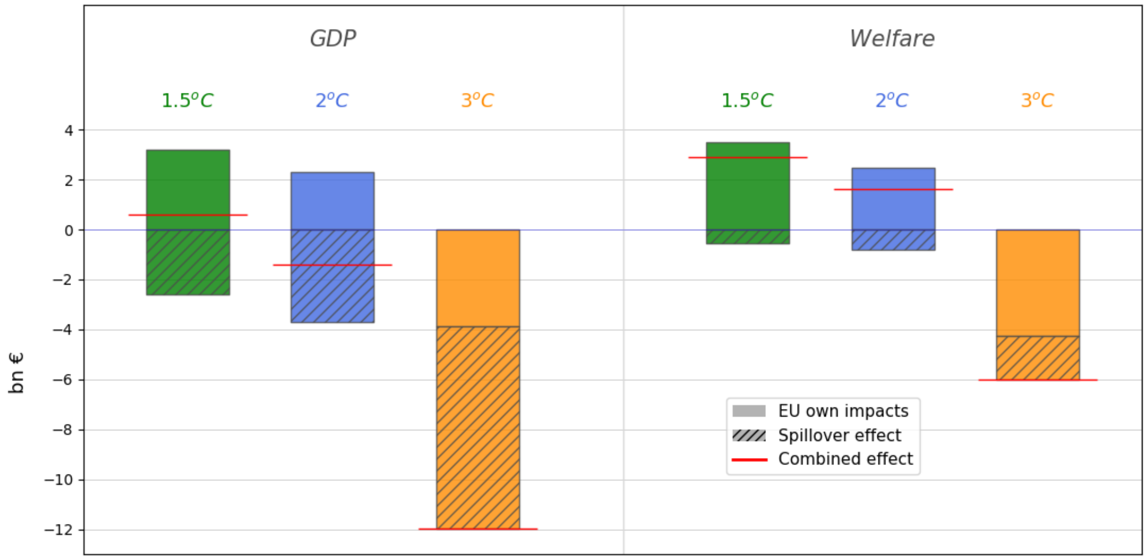
The main conclusions of the exploratory analysis are:

- Agricultural spillovers in the EU and the UK are significant and can reach between 2 bn € in the 1.5°C scenario to 8 bn € in the 3°C scenario.
- In the 2°C scenario, the negative transboundary effects are of greater magnitude than the positive EU's own GDP growth from yields increase (section 6).
- Most of the agricultural transboundary effects originate in the Americas and Asia.

The agricultural transboundary effects amount to a reduction in EU's GDP of 2.6 bn € in the 1.5°C scenario (0.02% of GDP), 3.7 bn € in the 2°C scenario (0.03% of GDP) and more than 8 bn € in the 3°C scenario (0.06% of GDP). Those losses are *additional* to the GDP changes due to the climate impacts occurring *within* the EU as presented in section 5. The respective welfare losses amount to 0.6 bn € in the 1.5°C scenario (0.008% of welfare), 0.8 bn € in the 2°C scenario (0.012%), and 1.7 bn € (0.024%) in the 3°C scenario.

Figure 23 presents the impacts on GDP and welfare due to the transboundary effects (diagonally striped areas) and also to the own EU effects (plainly coloured areas); the combined affected is represented with the red lines. The spillover values are significant in comparison to the economic losses from the internal EU climate changes on agriculture (section 6). For the 1.5°C and 2°C scenarios, the sign of the climate impact from the rest of the world is negative (damage), while the domestic impact is positive (benefit). Although the 1.5°C scenario in the EU is estimated to produce an increase in yields, which could lead to an increase in GDP by 3.2 bn €, more damaging climate impacts in the rest of the world are estimated to have a negative impact on the EU GDP of almost as much (2.6 bn €), netting a small positive balance. In the 2°C scenario the spillover impact is larger than the domestic EU effect: 3.7 bn € vs 2.3 bn €, respectively, with the negative balance of 1.4 bn €. In the 3°C scenario both the EU's impact and the spillover are negative, adding up to a 12 bn € GDP loss.

Figure 23: Comparison of GDP and welfare changes (both in bn €) from EU agricultural climate impacts and from the transboundary effects in the rest of the world

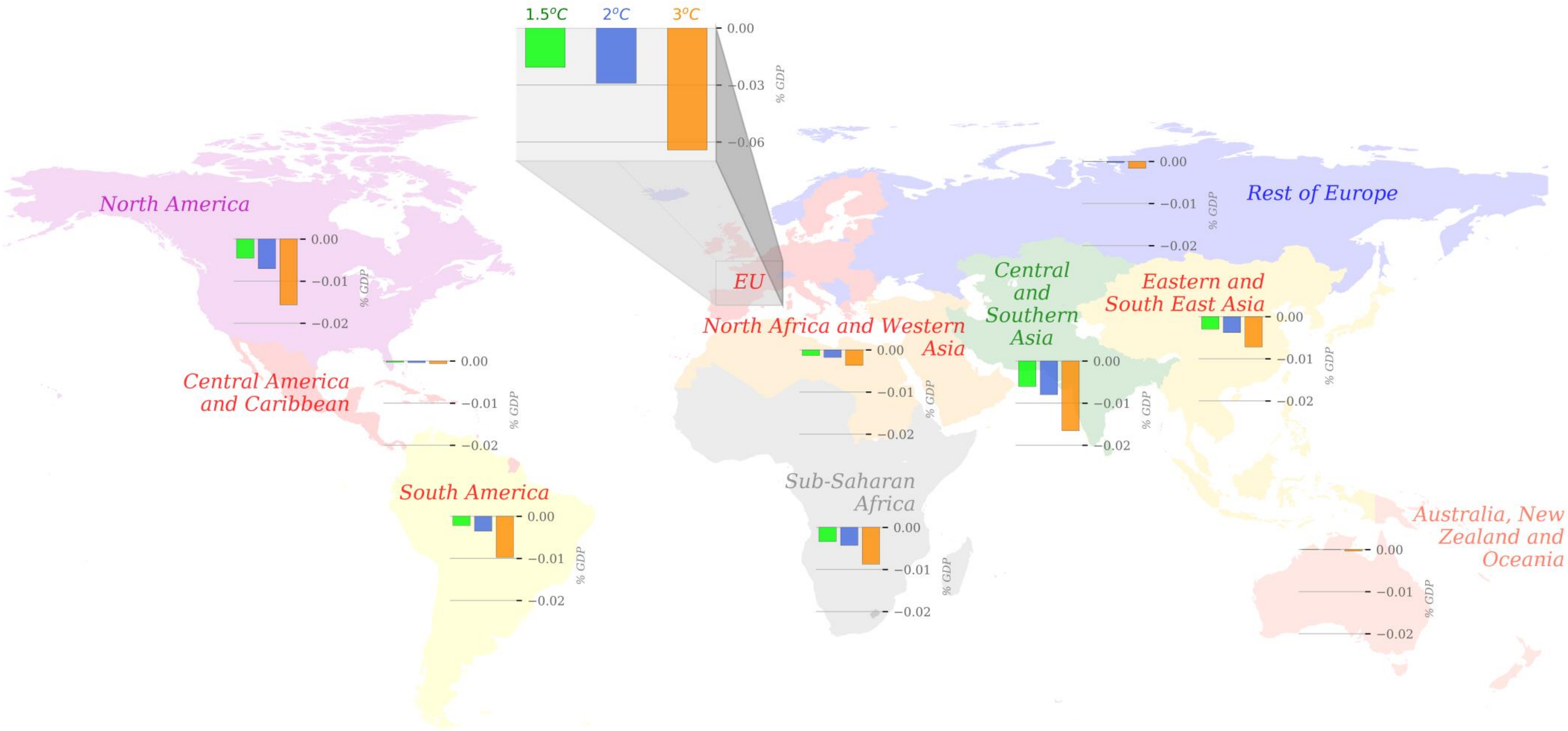


Source: PESETA IV, 2020.

Figure 24 and **Figure 25** show the geography of the transboundary effects on the EU for GDP and welfare impacts, respectively. The figures present the total EU loss from global spillovers (the large central bar chart) and how this total loss originates from the different global regions (smaller regional graphs). The numerical values are reported in **Table 8**. The extent of the spillover effect is a function of two features: firstly, it depends on the magnitude of climate impacts in the third regions and the regions' vulnerability to climatic change. Secondly, since the regional climate damage affects the EU via trade and prices, the intensity of international trade serves as a vehicle for the spillover effect.

Most of the EU agricultural transboundary GDP effects originate in North America and Central and Southern Asia and, to a lesser extent, in South America, Sub-Saharan Africa and Eastern and South East Asia. Welfare losses from other global regions are smaller than the GDP effects, and are mainly due to climate impacts in the Americas and Africa. Small but positive welfare effects due to climate changes in Central, South and East Asia are due to reductions in import prices and trade diversion, when the EU agricultural production becomes more competitive relatively to other regions affected by climate change.

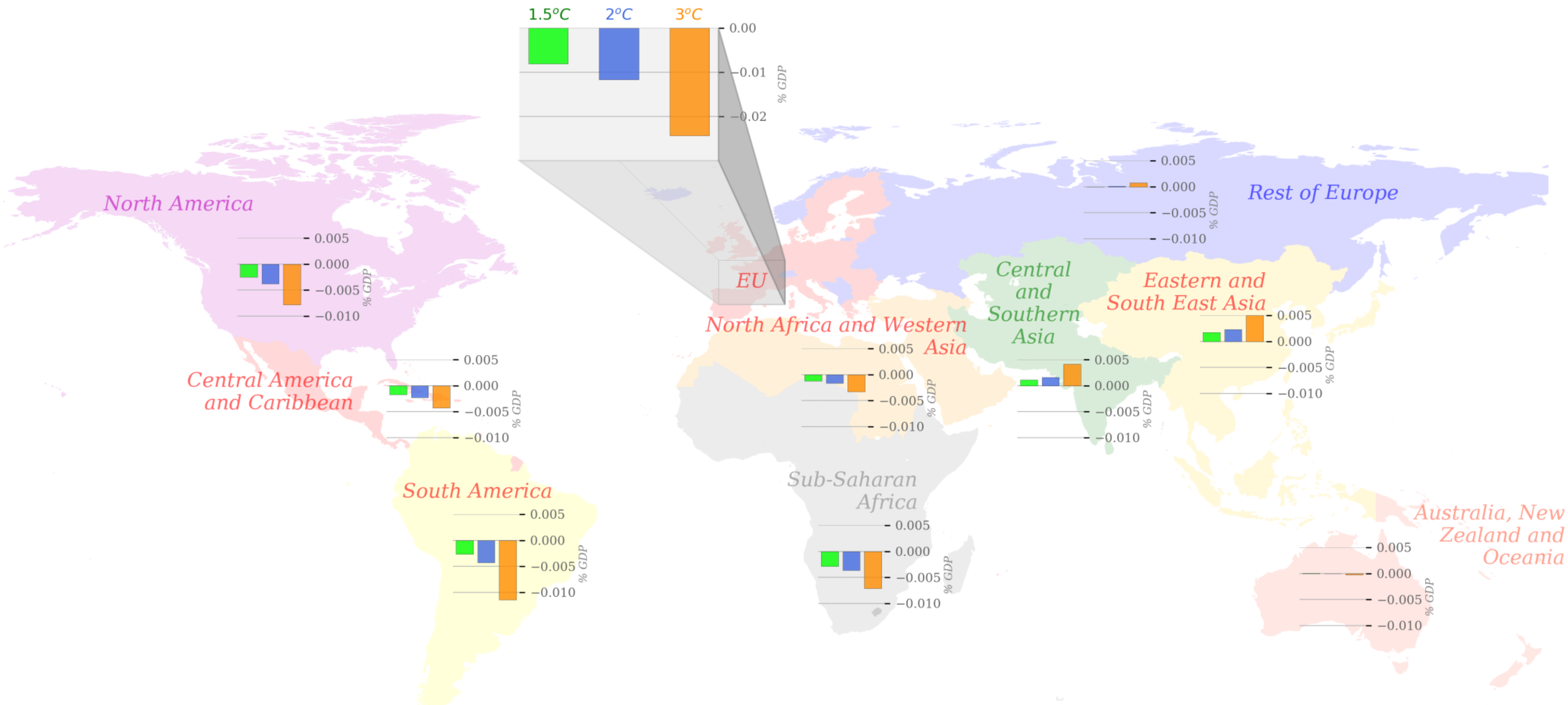
Figure 24: GDP loss (%) in the EU from climate impacts on agriculture in other global regions in the 1.5°C, 2°C and 3°C scenarios.



Source: PESETA IV, 2020.

Note: The large bar graph shows the total EU GDP loss from the spillovers, while the smaller regional charts show the EU GDP loss due to climate impacts in the individual regions.

Figure 25: Welfare loss (%) in the EU from climate impacts on agriculture in other global regions in the 1.5°C, 2°C and 3°C scenarios.



Source: PESETA IV, 2020.

Note: The large bar graph shows the total EU welfare loss from the spillovers, while the smaller regional charts show the EU welfare loss due to climate impacts in the individual regions.

Table 8: GDP (%) and welfare losses (%) in the EU from climate impacts in agriculture in the rest of the world for the 1.5°C, 2°C and 3°C scenarios

Region	GDP, %			Welfare, %		
	1.5°C	2°C	3°C	1.5°C	2°C	3°C
North America	-0.005	-0.007	-0.016	-0.002	-0.004	-0.008
Central and Southern Asia	-0.006	-0.008	-0.017	0.001	0.002	0.004
Rest of Europe	0.000	0.000	-0.002	0.000	0.000	0.001
North Africa and Western Asia	-0.001	-0.002	-0.004	-0.001	-0.002	-0.003
Sub-Saharan Africa	-0.003	-0.004	-0.009	-0.003	-0.004	-0.007
Central America and Caribbean	0.000	0.000	-0.001	-0.002	-0.002	-0.004
South America	-0.002	-0.004	-0.010	-0.003	-0.004	-0.011
Australia, New Zealand and Oceania	0.000	0.000	0.000	0.000	0.000	0.000
Eastern and South East Asia	-0.003	-0.004	-0.007	0.002	0.002	0.005
EU total	-0.021	-0.029	-0.064	-0.008	-0.012	-0.024

Source: PESETA IV, 2020.

Annex 2. Exploration of risk analysis - agriculture

The climate model runs underlying the scenarios of the JRC PESETA IV project do not consider that they can occur with certain probabilities. This section presents an exploratory analysis of a formal probabilistic perspective on climate change impacts, taking into account the risk of occurrence of different magnitudes of climate change. This exploratory study focuses only on wheat production. The main finding is that higher global temperature leads not only to a higher reduction in potential agriculture (wheat) yields but also to an increase in the uncertainty range regarding the yield changes (in other words, higher warming may lead to higher wheat yield reductions, but also they are more uncertain).

The method builds on a probabilistic climate ensemble constructed for Europe as in Rasmussen et al (2015). The ensemble provides daily projections of temperature and precipitation for the period 1981-2099, gridded at 0.25°. The ensemble consists of 33 global circulation models (GCMs), of which 21 are the CMIP5 models and 12 are 'surrogate' models created in order to obtain the complete probabilistic distribution, complementing the CMIP5 models. Each of the 33 climate models carries a probability (weight) of its occurrence in the future, such that the sum of probabilities for all GCMs is equal to one (i.e. $\sum_{i=1}^{33} P(GCM_i) = 1$), where *P(GCM$_i$)* is the probability of the climate run from the *ith GCM*. The temperature and precipitation series, together with data on soil and CO_2 concentrations, were fed to a crop growth emulator (Blanc, 2017) to calculate wheat yield at 0.5° grid level. The wheat yields were further aggregated to country-level using gridded values of production data (FAO). Finally, the change in wheat yield was simulated in the CAGE economic model to obtain the implications on economic activity and welfare.

The working example presented here concerns climate impacts in a single agricultural crop – wheat. **Figure 26** represents the share of wheat production in total crop production for each of the EU regions (bar chart on the left), and the shares of the total EU wheat production in each region (pie chart on the right). Three quarters of wheat in the EU are produced in the two Central Europe regions, although the share of wheat production in the total crop production in any of those regions does not exceed 20%, and it is as low as 3% in Southern Europe.

Figure 26: Share of wheat production in all crops production for each of the EU regions (bar chart), and shares of the total EU wheat production by the sub regions (pie chart)

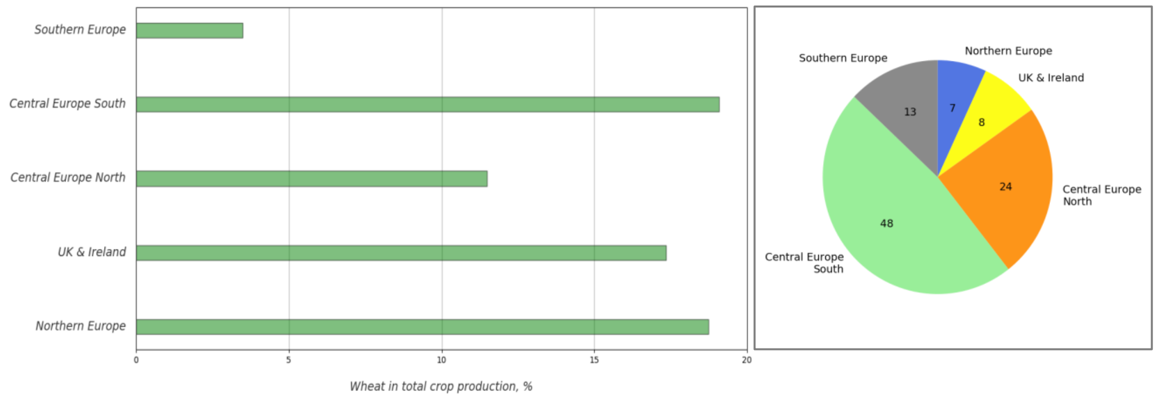


Table 9 presents the main results, yield changes in percentage terms with respect to the current production. The yield changes are represented in probabilistic terms, following the terminology of the IPPC AR5 (Mastrandrea et al. 2010); the term '*likely*' indicates that the likelihood of the range of yield changes reported is between 66% and 100%, '*very likely*' refers to results with a likelihood between 90% and 100%. For example, in the Northern Europe region for the 1.5°C scenario (first row of **Table 9**) it is *likely* (67% chance or more) that the wheat production change will be between a 0.83% reduction and a 0.45% increase, and it is *very likely* (90% chance or more) that the yield change will be between a 1.34% reduction and a 0.83% increase.

Table 9: Impact of climate on wheat production, percentage change from current production levels

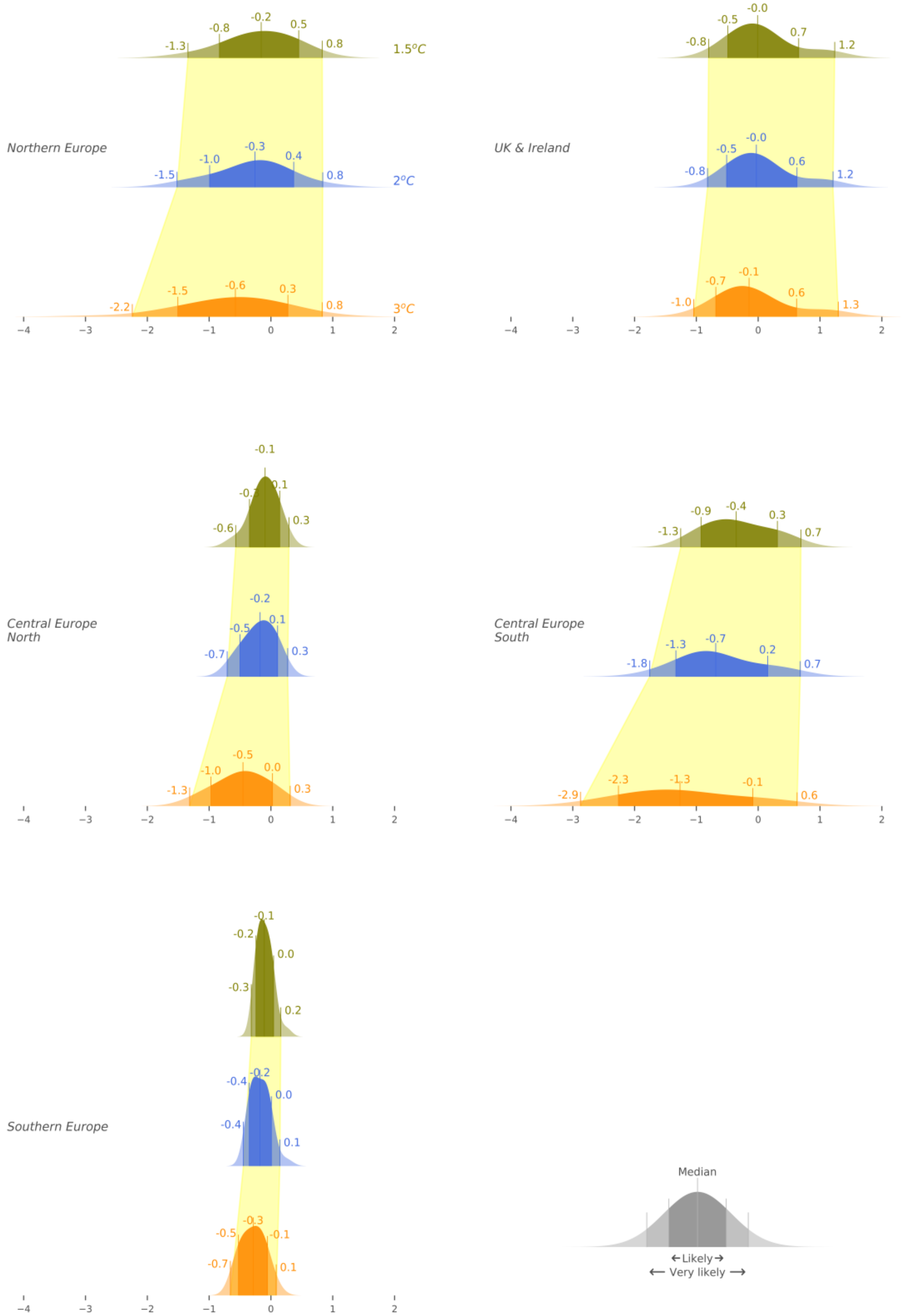
Region	1.5° C		2° C		3° C	
	Very likely	Likely	Very likely	Likely	Very likely	Likely
Northern Europe	-1.34 to 0.83	-0.83 to 0.45	-1.52 to 0.84	-0.99 to 0.37	-2.24 to 0.83	-1.51 to 0.27
UK & Ireland	-0.80 to 1.24	-0.49 to 0.65	-0.82 to 1.21	-0.51 to 0.63	-1.04 to 1.30	-0.69 to 0.62
Central Europe North	-0.57 to 0.29	-0.35 to 0.14	-0.71 to 0.27	-0.50 to 0.11	-1.32 to 0.31	-0.97 to 0.02
Central Europe South	-1.25 to 0.69	-0.92 to 0.31	-1.76 to 0.68	-1.33 to 0.15	-2.87 to 0.63	-2.26 to -0.09
Southern Europe	-0.32 to 0.16	-0.24 to 0.04	-0.45 to 0.14	-0.35 to 0.01	-0.66 to 0.08	-0.53 to -0.06

Source: PESETA IV, 2020.

Figure 27 represents the probability distribution of the EU regions wheat yield changes (percentage compared to nowadays) for the different climate scenarios (1.5ºC, 2ºC and 3ºC). The median yield change is the value at the top or the centre of the distribution function. The solid areas represent the *likely* ranges and the shaded area represent the *very likely* ranges. The median yield change decreases with temperature in all regions. The reduction is most significant in Central Europe South (0.4%, 0.7% and 1.3% for the three climate scenarios, respectively). Furthermore, the distribution of potential yield changes widens with the increase in temperature. For instance, in Northern Europe the *very likely* spread in yield changes increases from 2.1 % in the 1.5ºC scenario (sum of 1.3% and 0.8%, first row of **Table 9**) to 2.4 % in the 2ºC scenario and to 3.0 % in the 3ºC warming level scenario. In Central Europe South the spread increases to 2, 2.5 and 3.5 percentage point for the three climate scenarios, respectively. Therefore, the increase in global temperature leads not only to a reduction in yields changes but also to an increase in the uncertainty regarding the yield changes.

The Northern Europe and the Central Europe South regions have the widest uncertainty ranges among the EU regions, while the Central Europe North and Southern Europe regions have much narrower uncertainty ranges.

Figure 27: Distribution of wheat yield percentage change (compared to nowadays) for the different climate scenarios (1.5ºC, 2ºC and 3ºC) for the EU regions. The median yield change is the value at the top or the centre of the distribution function. The solid areas represent the likely ranges and the shaded area represent the very likely ranges.



Source: PESETA IV, 2020.

Table 10 and Figure 28 show how the wheat yield changes translate into GDP changes.

Table 10: Impact of wheat yield change on GDP (percentage change)

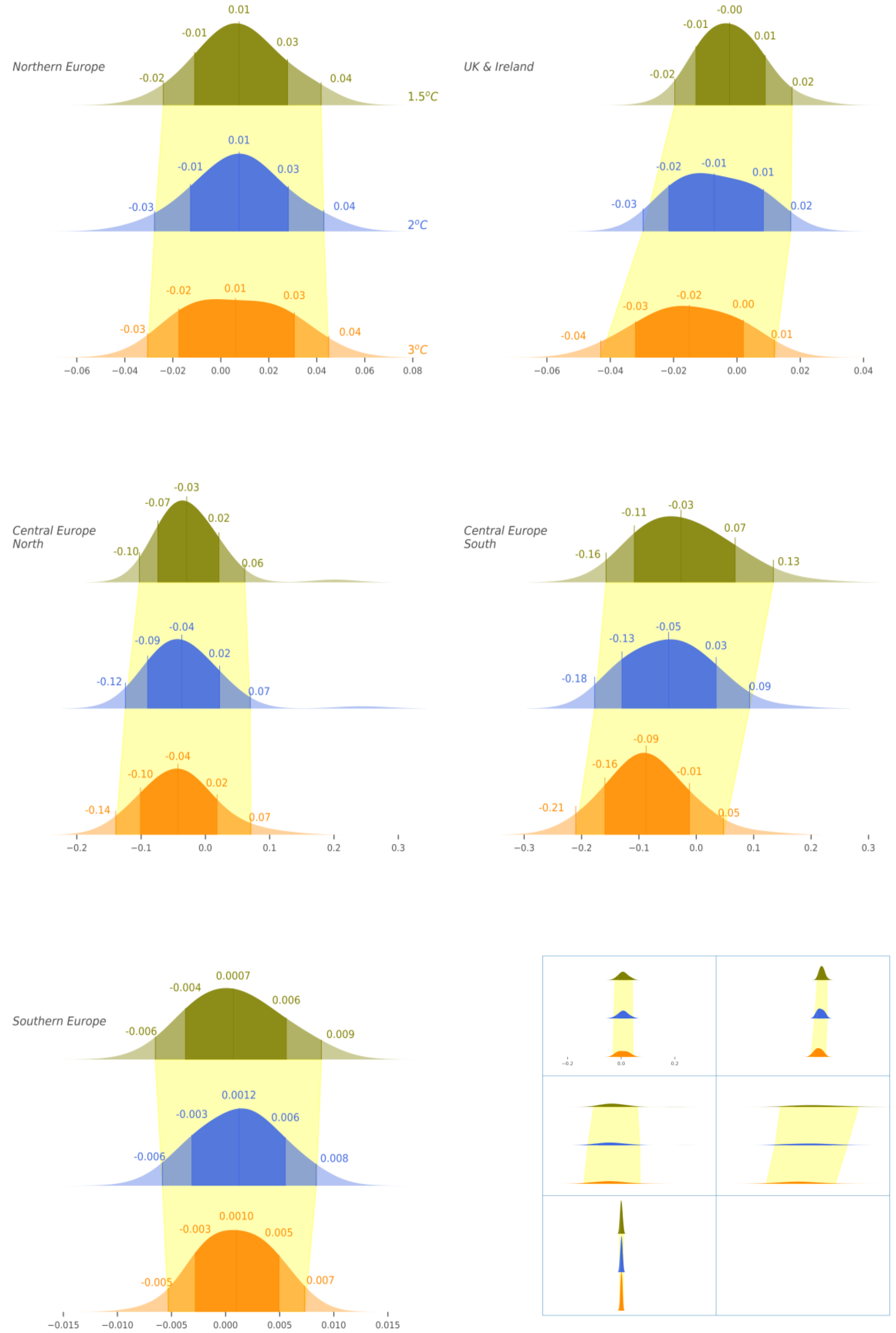
Region	*1.5°C*		*2°C*		*3°C*	
	Very likely	*Likely*	*Very likely*	*Likely*	*Very likely*	*Likely*
Northern Europe	-0.024 to 0.042	-0.011 to 0.028	-0.028 to 0.043	-0.013 to 0.028	-0.031 to 0.045	-0.017 to 0.031
UK & Ireland	-0.020 to 0.017	-0.013 to 0.009	-0.030 to 0.017	-0.021 to 0.008	-0.043 to 0.012	-0.032 to 0.002
Central Europe North	-0.103 to 0.061	-0.074 to 0.021	-0.124 to 0.070	-0.090 to 0.022	-0.139 to 0.071	-0.101 to 0.018
Central Europe South	-0.157 to 0.134	-0.108 to 0.068	-0.177 to 0.093	-0.130 to 0.035	-0.210 to 0.047	-0.159 to -0.012
Southern Europe	-0.006 to 0.009	-0.004 to 0.006	-0.006 to 0.008	-0.003 to 0.006	-0.005 to 0.007	-0.003 to 0.005

Source: PESETA IV, 2020.

It is interesting to note that the magnitude of the GDP change depends not only on the wheat yield change, but also on the importance of wheat production in the regional economy (left side of **Figure 26**) and on the scale of the indirect effects of climate change through other regions via the spillover effects[18]. Those mechanisms are well illustrated for the case of Southern Europe: the median yield changes from 0.1% in the 1.5ºC scenario to 0.2% in the 2ºC scenario and 0.3% in the 3ºC scenario. The resulting GDP effect, however, is relatively small compared to, for example, Central Europe North, whose wheat yields change is of similar magnitude but the GDP reduction is greater by around an order of magnitude; in fact, the Southern Europe GDP marginally increases. The small GDP effect is due to a very small portion of the crops sector in Southern Europe producing wheat (less than 3% - **Figure 26**), which gives a small leverage to the yield percentage reduction. The actual increase in Southern Europe's GDP steams from the transboundary effects: because the other EU regions are relatively more affected by climate change, the Southern Europe wheat production becomes more competitive and expands, stimulating GDP growth.

[18] The economy is affected not only by climate impacting upon its businesses, infrastructure and resources, but also indirectly through international trade with countries that also experience climate-related damage. Annex 1 illustrates the impact of the rest of the world regions in the EU economy, but the spillovers also exist between the EU regions.

Figure 28: Distribution of GDP percentage change from wheat yield under the three warming scenarios (the bottom-right graphics shows how the regional distributions comparison with a uniform scale)



Source: PESETA IV, 2020

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