BASE

BOTTOM-UP CLIMATE
ADAPTATION STRATEGIES
TOWARDS A SUSTAINABLE EUROPE

EU-wide economic evaluation of adaptation to climate change

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BASE BOTTOM-UP CLIMATE ADAPTATION STRATEGIES TOWARDS A SUSTAINABLE EUROPE

Title: EU- wide economic evaluation of adaptation to Climate change

Summary: This deliverable reports the advancements of the work accomplished by WP6 under Task 6.3: Adaptation pathways and full economic costs and benefits. The Deliverable includes 8 parts. Chapter 1 includes an introduction and the analysis approach in the context of BASE. Chapters 2 to 6 describe the advances in the analysis with the models developed in BASE in different sectors, including a critical discussion of their use for costs and benefits of adaptation strategies. Chapter 7 describes the economic wide costs and benefits of adaptation. Chapter 8 provides and executive summary and outlines the conclusions.

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0 Executive Summary

Within the BASE project the economic effects of adaptation to climate change are systematically evaluated both from a bottom up and top down perspective. This is done by integrating sectoral models and economic models at EU and global scale with information from selected case studies across sectors and regions within Europe. In addition this layered approach builds upon previous studies that have either focused on a top down modelling or bottom up case-based approach. This deliverable 6.3 of BASE is reporting in particular on the results of the modelling exercises executed within the project. Costs and benefits are explored for present and future climates, for different socio-economic developments paths and different adaptation strategies. For all models the SSP (Shared Socio-economic Pathways) 2 ('middle of the road'), 3 ('fragmented world') and 5 ('market driven development') have been explored as well as the climate scenarios according to RCP (Remote concentration pathway) 4.5 (average climate change) and 8.5 (high climate change) for 2050.

Methodological advances made within BASE

The main methodological advances that have been made with respect to the modelling approaches applied for this deliverable are:

- The incorporation of particular adaptation strategies like flood protection, adapted building, water management, irrigation and Heat Early Warning systems with improved evidence based estimates for effectiveness in terms of damage reduction and costs.
- The more detailed sectorial studies on Floods, Agriculture and Health were used to recalibrate and parameterize AD-WITCH damage, adaptation cost, and adaptation effectiveness. This is a major step forward in integrated economic assessment modeling.
- Crop patterns, land use, hydrological and agricultural production models have been combined to obtain new insights in effective adaptation. Especially the estimated changes in future crop patterns, based on regression, present realistic future boundary conditions for agricultural production, allowing for net gains at Northern latitudes
- New cost estimates on flood protection and adapted building were applied in the European scale flood model.
- An improved IO-model has been applied to city flooding cases allowing for better insight in the variety, size and cause of indirect damages.

Verification and uncertainty analysis

In general most models could to some extend (support for some assumptions on costs and cost effectiveness could be gained) be validated with results from the cases as costs and benefits are difficult to compare between the different scales. The measures analysed were also representing a large number of cases but in the models the measures had to be sometimes generalized in to wider strategies (e.g. water management). Deliverable 6.4 will further elaborate the integration of model and case study results into storylines.

Two main types of uncertainty were analysed by the different modellers: the influence of scenario uncertainty and sensitivity to particular model assumptions. From these analyses it showed that (some examples):

- For AD-WITCH leaving aside the role of mitigation, uncertainty in future socioeconomic scenarios could significantly affect adaptation cost estimates, which in Europe could vary between 32 and 56 USD billion in 2050.
- The calibration results for European regions are relatively insensitive to different cost an damage inputs from the sectoral models, as other factors (regions, SSP) dominate.
- For the flood risk analysis uncertainties stemming from input data for the reference climate and especially those in the cost estimates (factor 3 difference in applied methods) are dominating over differences stemming from RCP and SSP.
- An extensive sensitivity analysis conducted with the SARA model concludes that the impact results are especially sensitive to assumptions on projected crop yield and surface water availability (for irrigated agriculture).
- For the BCR for HHWS the lower and upper bound estimates range between a factor 5-9 but all remain much larger than 1.

These results stress the need for further use of bottom up generated evidence to support critical assumptions.

Floods

For riverine flood risks annual expected damage was evaluated in relation to adaptation costs and GDP. Two adaptation strategies were considered: increasing the protection levels along rivers by building new and increasing existing dikes and by decreasing the damage potential through adapted building. Results show that projected climate change can lead to more than a doubling of annual expected river flood losses in Europe, especially in Western and central Europe. This is in line with earlier research by other scholars. The highest flood risk expressed as share of GDP is noted for the Western European region, with an average of some 0.3% GDP loss per year.

Most (if not all) of the impacts of projected climate change can be compensated by adaptation measures. The benefits of flood protection, for instance through dike construction, are slightly higher than through adapted building. The costs of dike construction, as calculated using actual required dike heightening per RCP scenario and per time slice, are lower than the costs of adapted building, especially in the period up to the 2030s indicating that it is more beneficial to invest for longer time horizons (50+) in this type of flood protection infrastructure, as initial costs to upgrade flood defences are high. For almost all European countries benefit cost ratios larger than 1 are found especially when expanding the time horizon until 2080. Countries with large surface areas and small urban areas see relatively low benefit-cost (BCR) ratios, indicating that it is beneficial (from a CB perspective) to apply differentiated protection levels between urban and rural areas (which in most countries already is common practice).It must however be noted that the economic figures were not discounted.

Indirect flood damage

From our results it is evident that effective investment in risk management and adaptation strategies must consider the analysis of indirect damage.

For the case studies, the most directly affected sectors are those with a big proportion of in-built capital, such as manufacturing and light industry sectors. Under a traditional impact assessment, these sectors will appear as the only benefited from flooding adaptation strategies, such as improvement in flood defenses. This usually leads to individual adaptation strategies which works reasonably well for low probability flooding (i.e. return periods shorter than 1:50 years).

However, the flood footprint analysis reveals the potential benefits for the indirectly affected sectors. It should be noted that indirect damage can be as substantial as direct damage. According with the analysis, the indirectly affected sectors normally are at the end of the value chain, such as services sectors (e.g. financial and businesses sectors). These are especially vulnerable to disruptions in infrastructure, mainly when preventing people reaching their jobs. A conclusion from incorporating the results of flood footprint analysis is to invest in the community adaptation strategies more than individual actions, as this will benefit stakeholders along all the production chain. Moreover, this becomes relevant under climate change scenarios, especially in terms of indirect damage; as the flood footprint analysis proves that indirect damage increases more than proportionally regarding direct damage, as the intensity of natural disasters increases.

At the level of flood risk mitigation responsibility, a flood footprint accounting framework would provide an alternative way to allocate financial responsibility for flood risk mitigation interventions by incorporating the value of all stakeholders' economic capacities on the local/regional/national supply chains. This could potentially reduce the government's financial burden for flood risk management and spread the cost between major stakeholders in the supply chain, based on the 'who benefits, who pays' principle. In other words if it turns out through a proper flood footprint assessment that organisation(s) x or y benefit in a large way from flood defence then we could look at alternative flood management payment schemes.

Agriculture

To simulate the costs and benefits of adaptation to CC for agricultural production in Europe a novel modelling framework was used consisting of agro-climatic, land use and water models with statistical responses of economic variables to changes in these three sectors. This framework is then used to explore the benefits and costs of two types of adaptation measures for four regions in Europe. Two main categories of adaptation measures are contemplated: management and development of additional irrigation. Adaptation through management includes a set of strategies to minimize negative climate impacts on agriculture and to increase agricultural productivity like improvement of resiliency and adaptive capacity, technology innovation and improvement of the water use efficiency to increase water availability. Adaptation through development of additional irrigation includes a set of measures to compensate for loss of agricultural production by extending the area under irrigation using the land already equipped for irrigation and by development of additional water resources for instance by reservoirs or waste water recycling.

Three major points emerge from the results of this study, related to the regional effects, benefits of adaptation and choices of adaptation. First, although each scenario projects different results, all scenarios are consistent in the spatial distribution of effects. Agricultural damage is larger in the Mediterranean region followed by the North West region. The results are highly consistent across RCP scenarios and time frames. The SSP scenario is the most influential factor for a given region.

The socio-economic scenarios are key factors for understanding the potential adaptation capacity of agriculture to climate change. Uncertainty regarding future population (density, distribution, migration), gross domestic product and technology determine and limit the potential adaptation strategies. However, evaluating the constraints to policy implementation is difficult. In our study, the demand for and the supply of water for irrigation is influenced only by changes in the hydrological regimes, resulting from changes in the climate variables. Policy driven adaptation priorities may be derived from the impacts reported in this study.

Second, adaptation choices benefit all regions, although the effort to benefit relationship varies across regions and type of measure. The costs of irrigation are higher than the cost of improved water management, especially in the period up to the 2030s. The largest benefit is in the Mediterranean and North West regions. The benefit of adaptation in the Mediterranean is due to the large damage reduction due to water scarcity in all scenarios. The benefit of adaptation in the North West region is due to the large competition of agricultural and industrial water and the large change in land use over all scenarios. Water management is overall the best choice in all cases. In areas will little damage, water management is much more cost efficient. In the Mediterranean region, even if irrigation is more cost efficient in some scenarios, the range of possible implementation of irrigation measures is extremely limited over the crop area.

Health

Health effects of climate change and costs and benefits of adaptation are analyzed using a simple regional model. Two health impacts have been assessed at European levels, heat stresses and salmonella. Other two have been assessed for developing countries, diarrhea and malaria. To mitigate negative health effects three types of adaptation strategies can be distinguished. Primary interventions can be defined as primary prevention put in place to remove the risk before the damage occurs. Secondary interventions aim to prevent the disease once the impact has occurred but before its establishment. Tertiary interventions are applied once the impact has occurred to minimize it and correspond to treatment. Primary interventions correspond to preventive adaptation, while secondary and tertiary interventions correspond to reactive adaptation. As an example of a primary intervention (or preventive adaptation) the costs and benefits of a heat watch warning systems are analyzed. For Salmonella similarly a Public health campaign is analyzed, while treatment of the disease corresponds to tertiary intervention or reactive adaptation. For Malaria and Diarrhea a combined set of reactive and preventive measures are considered. For the health analysis only one RCP8.5/SSP5 combination was considered as a worse case from a climate point of view. By applying this scenario current mortality for diarrhea may increase by 61,000 to 162,000 deaths by 2050. For malaria, results show an increase between 37 million to 75 million DALY.

For HHWWS, the estimated BCR is largely above 1 in all European regions and under all assumptions, indicating that this measure is a low-regret measure as it can provide high benefits with a small cost. These benefits are attributable only to health, in terms of avoided mortality due to heat waves including both premature and displaced deaths. Specific care however is required for vulnerable groups such as the elderly and those with pre-existent cardio-vascular and respiratory problems. Though these measures are low-regret, a timely and accurate specification of the threshold temperature at which to warn is requested over time, in order to be cost-effective.

For salmonellosis, the estimated BCR for treatment is approximately 9, whereas for public health campaigns the BCR range between 5.1 and 37.7 depending on the context. Treatments and public health campaigns are likely to be important in addressing climate related health problems, but the health sector needs to be prepared for action. This also does not consider actions in other areas – e.g. food production or agricultural practices – which may impact on the analysis.

For diarrhea, recommendations depend on the type of measure considered. The first set include basically treatments and immunization programs. They apply specifically to the health outcomes, so that this is the only type of benefit they can provide. The results on the BCR for this first set of measures depend on the geographical area considered and the level of unit costs used. For the lowest unit costs, the resulting BCR is always greater than 1 in all scenarios and regions. For medium unit costs, results differ among geographical region, while for high unit costs the BCR is always below 1. Results indicate that for low unit costs, these measures can provide health benefit large enough to cover the costs. The second set refers to structural preventive measures based on improvements in water and sanitation systems. These are multiple-benefits interventions affecting different sectors and not only health. In this case, the evaluation of the measure for policy should be based on an overall social cost-benefit analysis which takes into account the full set of benefits provided by different sectors and their causal interactions. Improvements in these systems provide benefits that are greater than the costs, when including all societal benefits (Hutton and Haler, 2004). For the purpose of this exercise, however, only the health benefits have been considered, so that results cannot be generalized in terms of BCR. We can nevertheless analyse results in terms of health benefits provided. The highest health benefits associated with interventions for diarrhoea are projected in developing countries, as expected, with the largest figures projected in SSA, India, SASIA and CHINA regions.

For malaria, the combination of bed nets, treatments and spraying are shown to have BCRs well above 1. However, they may not offer the least cost solution – for example here we have not considered actions in the water or construction sectors that may reduce the spread of malaria. There may be low cost options in e.g. improving drainage that may reduce the breeding grounds for mosquitos and hence reduce the spread of disease. Local case studies also suggest that the findings of our analysis at region level may not be appropriate for particular contexts – where indoor spraying may not be so viable in less affected regions. The highest health benefits associated with malaria interventions are found in South Africa, India and SSA.

To conclude, the health sector is difficult to judge since many factors determine human health besides climate. Clearly heat stress and the propagation of vector borne diseases are likely to increase. Potentially, investments in health interventions appear to be very cost effective in many cases. An integrated approach to health adaptation including other sectors may be needed to ensure health issues are appropriately tackled, as well as further research to improve characterization of unit costs, as the references used in this analysis are average unit costs for a set of measures. In this respect it would be more useful to disaggregate further the cost assessment by type of measure, instead of set of measures.

Carbon sequestration

Multiple available land use and land cover change scenarios at the European scale show potential increase of forested areas (VOLANTE, Hurtt et al. 2011). When these changes translate into the amount of carbon stored in terrestrial biomass, our results show that the carbon stocks in EU-27 could potentially increase by 1.3-2.7% by 2050, depending on the scenario. This presents a positive trend, influencing the amount of greenhouse gases in the atmosphere.

In terms of climate mitigation, this trend provides several opportunities. According to the results, a substantial space for reforestation may appear in the next several decades, which can be utilized to efficiently increase the level of carbon stocks. Therefore, it is vital to use sustainable approaches to reforestation and to ensure the newly established and expanding forests will reflect the most desirable species composition and other forest characteristics, with consideration of local ecosystem character and potential future impacts of climate change. At the same time, this situation presents an opportunity to implement ecosystem-based adaptation measures in the forestry sector and to utilize the re-establishment of forests to simultaneously improve the resilience of forests ecosystems, their potential to provide ecosystem services and to sustain biodiversity.

Although the aggregate results show increase in carbon stocks, the overall level of increase is rather low. Furthermore, the spatial pattern of potential change show that the most substantial increase in forested areas and related carbon stocks occurs in the sparsely populated north of Europe, while the densely populated areas of Western Europe undergo decrease in forest cover, mainly due to urban sprawl. Although carbon sequestration and related climate regulation present global ecosystem services, the benefits of which are globally shared, other ecosystem services provided by forests (e.g. cultural, provisioning) are tightly bound to their location and can thus be potentially lacked in these areas.

Finally, it is vital to consider the socio-economical aspect of the changes in forest cover and increasing carbon stocks. The increase of forested areas occurs mainly due to decreasing proportions of agricultural land and pastures, which in turn results from broad socio-economic changes.

Economy wide effects of adaptation

The effects on GDP of individual countries of climate and adaption for Floods, Health and Agriculture were included in the AD-Witch model to calculate overall GDP effects and cost effectiveness of adaptation versus mitigation. Indirect flood damages and the economic value of sequestered carbon within Europe are not considered in AD-Witch (the latter being negligible compared to other world regions).

According to the input data provided by the sectoral models, adaptation, especially to address impacts in the agriculture sector and flood risk, is very effective. The effectiveness of adaptation carries over to the AD-WITCH model, and adaptation can change the sign of climate impacts from negative to positive. It is important to clarify that these results hold only for Europe, which lose only marginally from climate change and not foran high-impact region, such as Sub-Saharan Africa (SSA). It shows that in high-impact regions mitigation is an important strategy, together with adaptation, to reduce climate damages. In low- or positive-impact regions, adaptation seems to play a more prominent role, when considering the regional benefits accruing to that specific region.

In Europe, effective planning and efficient implementation of adaptation measures can significantly reduce the potential regional impacts from climate change on flood risk, agriculture, and heat waves. In Europe impacts are moderate compared to other regions is the world, such as Sub-Saharan Africa, and this explains why significant benefits can be achieved through adaptation, if optimally implemented. Yet, mitigation remains an important complementary strategy because 1) it directly reduces the adaptation expenditure needed in Europe 2) by reducing impacts in high-impacts regions, such as Sub-Saharan Africa where climate impacts can reduce GDP by up to 30% in 2100, it mitigates indirect climate risks that could affect Europe as well through migration and international trade. Adaptive capacity, in terms of socioeconomic development but also human capital, technology, and good institutions, can boost the potential benefits of implementing adaptation projects, and therefore increase adaptation effectiveness.

Summarized conclusions

Base analysis	Urgency and effectiveness of adaptation	Preferences of interventions	Caveats recommendations for further analysis
AD-WITCH	In Europe, effective planning and efficient implementation of adaptation measures can significantly reduce the potential regional impacts from climate change on flood risk, agriculture, and heat waves. This conclusion hinges on the fact that adaptive capacity, in terms of socioeconomic development but also human capital, technology, and good institutions, is high in Europe, and this leads to high adaptation effectiveness.	Mitigation remains an important complementary strategy because it directly reduces the adaptation expenditure needed in Europe. Moreover, by reducing impacts in high-impacts regions, such as Sub-Saharan Africa where climate impacts can reduce GDP by up to 30% in 2100, it mitigates indirect climate risks that could affect Europe through migration and international trade.	
Flood risks	Damage from riverine floods on GDP remain limited below 0.8% for any European country and amount maximally 0.3% for the Western and Central/Eastern European region for 2080 under RCP8.5 compared to 0.1-0.2% of GDP under the current climate. For the Southern Region on average the expected flood damages are not increasing. The adaptation options investigated can fully mitigate the effects of climate change	Benefit Cost Ratios generally are larger than 1 across all regions. Cost efficiency of increasing protection levels through dikes is slightly higher than for adapted building. Further differentiating protection levels between rural and urban areas will improve BCR ratios. This is particularly relevant for large sparsely populated countries	In general more spatially differentiated adaptation should be a next step in the analysis as well as including other adaptation options such as nature based solutions.
Urban flooding	the flood footprint analysis reveals the potential benefits for the indirectly affected sectors which normally are at the end of the value chain, such as services sectors (e.g. financial and businesses sectors). This indirect damage can be as substantial as direct damage. Under climate change indirect damage is likely to increase relatively more than direct damage, as the intensity of natural disasters increases.	Adaptation strategies therefore could profit when including more parties along the supply chain in terms of sharing responsibilities (finances) and finding solutions.	The analysis still has to proceed from a case and event based analysis towards a risk based climate analysis to be able to further generalize the findings

Agriculture	Agricultural damage is largest in the Mediterranean region followed by the Western region. The results are highly consistent across RCP scenarios and time frames. The SSP scenario is the most influential factor for a given region. It is also a major boundary condition for the adaptive capacity and thus adaptation efficiency	Water management as a strategy clearly comes out as the preferred strategy as it is opposed to irrigation widely applicable and cheaper	
Health	***Heat*** Health Warning Systems are a low regret measure – and lead to significant health benefits in terms of reduced mortality. For ***salmonellosis***, both public health campaigns and treatments show significant benefits in the current and future periods. For ***diarrhea***, we distinguish between 2 sets of measures. The first are based on treatment and immunization programs: results depend on the unit cost and the region (for low unit costs there are sufficient health benefit to be cost-effective). The second are structural preventive interventions based on improvement of water and sanitation systems. In this analysis, only health benefits have been considered, while many benefits in other sectors have not been evaluated, so that we cannot generalize results in terms of BCR. Improvements in these systems provide benefits higher than the costs, when including all societal benefits (Hutton and Haler, 2004). For ***malaria***, all adaptations offer high benefits, but this may not be the case in particular case study regions	Specific actions on heat needed with the elderly and those with pre-existent cardio-vascular and respiratory problems More analysis needed of adaptation options in other sectors that affect salmonellosis (e.g. agriculture, food). Improvements in water and sanitation systems are considered cost-effective measures and provide benefits higher than the costs when inter-sectoral benefits are considered. The evaluation of the measure for policy should be based on an overall social cost-benefit analysis which takes into account the full set of benefits provided by different sectors and their causal interactions.	Thresholds for heat alerts need to be set appropriately, as there is evidence of significant spatial differentials in these values. It is also important to update the thresholds (and epidemiological studies) over time to take into account acclimatization processes. Research on effectiveness of public health campaigns in reducing salmonellosis needed For diarrhea adaptation we only consider impacts on health – whereas impacts in other sectors likely significant (e.g. water) (Hutton and Haler, 2004) and should be considered in a climate change context. Adaptation options in other sectors may impact significantly on malaria risk (e.g. water systems, transport infrastructure construction including drainage). These may be lower cost solutions than other options.
Carbon	Autonomous adaptation through land use changes to climate change is likely to increase the future carbon uptake with a few percent within Europe.	This has a positive mitigating effect on net CO2 emissions	Changes are mostly climate induced and derived from old SRES scenarios. Including SSPs and active management of carbons stock is a next step to incorporate also

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1 Introduction

1.1 Aim

Ultimately one of the main central questions of BASE is what the full costs and benefits are of adaptation in Europe. Main questions

- What are the impacts to different sectors of climate change?
- What are options to adapt or more specifically cope with, abate, avoid and/or benefit from these impacts?
- What are associated costs, damages, direct and possibly indirect benefits?
- How do the above questions depend on socio economic and climate development?

Therefore within the BASE project the economic effects of adaptation to climate change are systematically evaluated from a combined bottom up and top down perspective. This is done by integrating sectoral models and economic models at EU and global scale with information from selected case studies across sectors (water management, agriculture, health and forestry) and regions within Europe. In addition this layered approach builds upon previous studies that have either focused on a top down modelling or bottom up case-based approach.

Other top down modelling studies include projects as CLIMSAVE,CLIMWATADAPT and ESPON and institutions like JRC and EEA mainly generating maps and data sets on climate effects impacts and various vulnerability data (Harrison et al., 2015, Floerke et ., 2011, http://atlas.espon.eu/). Vulnerability data are available based on SCENES storylines (Acreman et al., 2011). The Climate-ADAPT portal is hosting the generated data from these projects via its map viewer (http://climate-adapt.eea.europa.eu/tools/map-viewer).

In addition PESETA, Climate Cost have specifically looked at cost and benefits of adaptation at different levels and for similar sectors as within BASE. The PESETA study states that the economic benefits of adaptation far outweigh the costs. In a review done by the climate cost project in 2011 (http://www.climatecost.cc/images/Review_of_European_Costs_and_Benefits_of_Adaptation.pdf) it is concluded that the European scale sectoral studies are highly aggregated, with only partial coverage within and even low coverage across sectors. Moreover, it is stressed that assessing the costs of adaptation at the European scale is challenging, involving high levels of aggregation and simplifying assumptions and that more detailed, national and even local level analysis for validation is needed. Another conclusion is that global scale integrated assessment models and Economy wide models are even more uncertain

It is exactly for these reasons that the BASE project is adopting an integrated multi level approach in which information of case studies, European scale sectoral and integrated global economic analysis are combined. Whereas, BASE is looking at adaptation in agriculture, coastal management, flood risk management, health and forest management, sister project ToPDad (http://www.topdad.eu/news/brief-of-topdads-results) has focussed on

Energy, Tourism and Transport and RAMSES (http://www.ramses-cities.eu/) on cities, both with a similar approach as BASE. Together these three projects have increased sectoral coverage.

This deliverable 6.3 of BASE is reporting in particular on the results of the modelling exercises executed within the project. It builds upon earlier deliverables 3.1 through 3.4 (model setup) and 6.2 (upscaling framework) and feeds into D6.4 (storylines).

1.2 Analysis framework

Costs and benefits are explored for present and future climates, for different socio-economic developments paths and different adaptation strategies. For all models the SSP (Shared Socio-economic Pathways) 2 ('middle of the road'), 3 ('fragmented world') and 5 ('market driven development') have been explored as well as the climate scenarios according to RCP (Remote concentration pathway) 4.5 (average climate change) and 8.5 (high climate change) for 2050. In Appendix 10.1 results it is shown that the various sources for providing SSP data are aligned pretty well.

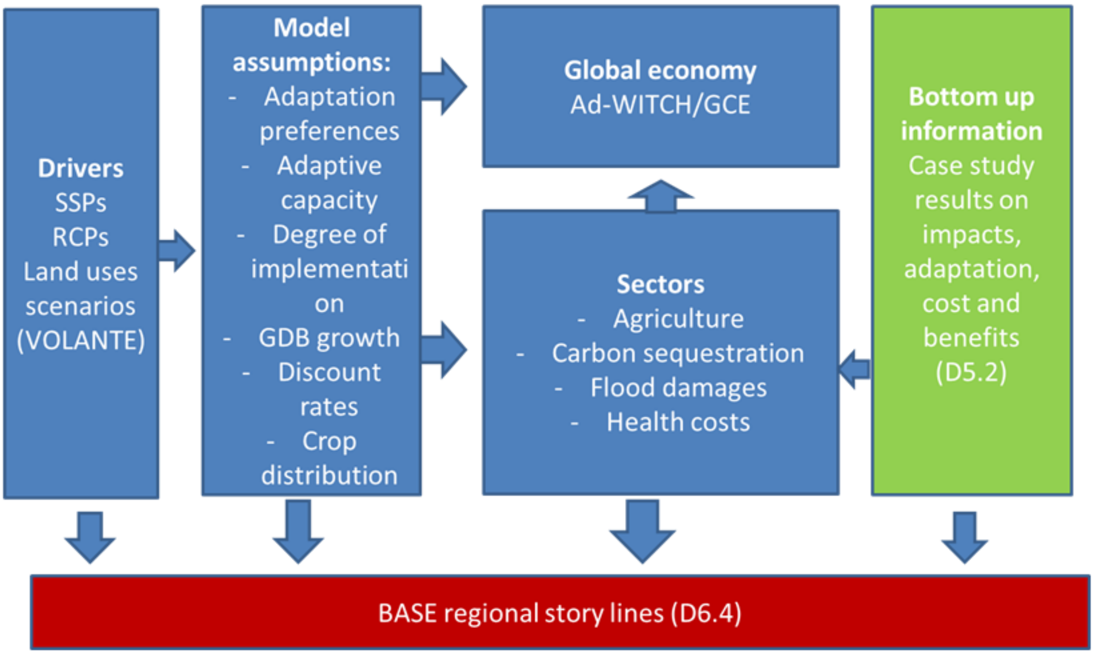


Figure 1 Analysis framework, the blue elements describing the steps executed for deliverable 6.3.

The above schematic describes the main elements (in blue) of this deliverable. The deliverable is organized by sector/model. For each type of model analysis however the same elements are described in sub paragraphs:

- What approach has been followed and how have the methodologies used been advanced under the BASE projects, what are the specific innovations.

- How is bottom up information used to validate or verify model assumptions
- What are the main results organized per region (North, West, South and Central-East), with some examples on country level, in terms of damage and costs for the 3 SSP/RCP (or at least 2) combinations for: 1) no adaptation 2)with adaptation for 2050 compared to 2000 both in absolute as well as relative effect to GDP. For Health and Ad-Witch we report for global regions, 2 of them within Europe
- What is the sensitivity of the results for different assumptions?
- What are the policy recommendations

In all chapters these elements are treated. Chapter 2 is reporting on the riverine flood risk analysis, chapter 3 on indirect damage estimates due to Urban floods, chapter 4 on Agricultural yields, chapter 5 on Health, chapter 6 on Carbon sequestration and in chapter 7 the ecomomy wide analysis is reported. In chapter 8 the discussion and conclusion on the main research question plus first policy recommendations can be found. This chapter also functions as an executive summary.

2 Riverine flood risks across European regions

Laurens Bouwer and Andreas Burzel

2.1 Introduction

Change of the water cycle is one of the most prominent impacts of projected climate change (e.g. Kundzewicz et al., 2013), and related extremes such as flooding and droughts are of particular concern in Europe (EEA, 2012; Kovats et al., 2014). Many studies have assessed the role of projected precipitation change in the occurrence of fluvial floods, with a general expectation that the flooding will occur more frequently, due to more prolonged and intensified rainfall events.

The problem of river flooding in Europe has received much attention in research by ways of modelling impacts of projected changes in precipitation (Dankers and Feyen, 2009; Alfieri et al., 2015a), as well as impacts and costs (Rojas et al., 2013; Jongman et al., 2014; Alfieri et al. 2015b). Also European policy-making has focused on flooding as one of the most urgent natural hazards to address, with ample attention for reducing food risks as part of the Floods Directive (EC, 2007), and the Adaptation Strategy (EC, 2013). Few studies however have analysed the timing of impacts in different parts of Europe, or compared different flood risk reduction measures at the European scale.

An earlier studies by Rojas et al. (2013) estimates costs for adaptation costs for flood protection in Europe to be some 7.9 billion per year by the 2080s (ensemble average for the SRES A1B scenario). Timing and type of adaptation measures are however important elements to consider, given the differentiation of impacts, as well as protection levels across Europe.

The approach used in this study is to simulate future flood risk (expressed as annual expected direct damage) across the European domain, for current and future time periods. The change in flood risk is used as indicator to set up adaptation tipping points (a "do-nothing" scenario). Next, two types of adaptation measures are considered, consisting of flood protection through dikes, and adapted buildings.

2.2 Brief model description and progress in developments under BASE project

For the riverine flood risk analysis, we use the modelling approach developed by Holz et al. (in prep.), which shares similarities with earlier studies by Feyen et al. (2009) and Rojas et al. (2013). Below, we briefly introduce the main elements of the flood risk analysis, while for the extensive discussion we refer to the paper by Holz et al. (in prep.) and Winsemius et al. (2013; in press).

2.2.1 Flood hazard analysis

For the flood hazard we use global flood risk estimation method for rivers, developed by Winsemius et al. (2013) called GLOFRIS. The framework takes into account multiple return periods in order to include frequent and less severe floods, as well as rare and more severe floods. It produces flood hazard maps at 30” resolution and can estimate future flood risk using bias-corrected GCM outputs at 0.5 degree spatial resolution. From the daily flood volume time-series (derived from PCR-GLOBWB daily simulations), an annual time-series of maximum flood volumes is extracted over the run-time period. For each cell, a Gumbel distribution is fitted through the time-series of 40 years (1960-1999, and future scenarios), based on non-zero data. The Gumbel parameters are extracted for the best-fit and the 5 and 95% confidence limits. For cells in which zero flood volume is simulated in one or more years, also the exceedance probability of zero flood volume is calculated. These Gumbel parameters can then be used to calculate flood volumes per grid-cell for selected return-periods (2, 5, 10, 25, 50, 100, 250, and 1000 years). Flood volumes are calculated conditional to the exceedance probability of zero flood volume.

Next the coarse resolution flood volumes are converted into high resolution inundation depth maps, using the downscaling module described in Winsemius et al. (2013) and further applied by Ward et al. (2013). The module includes a high resolution digital elevation model (30 arc minutes or about 1 km resolution) and a map of river cells at the same resolution. For each 0.5 degree grid cell, the module iteratively imposes water levels, in steps of 10 cm, above the elevation of each river-cell in the high resolution, until the flood volume generated for the cell in the coarse resolution model has been depleted.

Baseline climate is taken from reanalysis datasets from the EU-WATCH project (Weedon et al., 2011) for the period 1960-1999. This data is based on other datasets, and interpolated to a 0.5 degree resolution.

The climate projects that are used involve the RCP4.5 and RCP8.5 Representative Concentration Pathway scenarios (Moss et al., 2010; Van Vuuren et al., 2011). We apply the results from the following 5 general circulation models (GCMs): GFDL-ESM2M, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM and NorESM1-M (for details see Winsemius et al., in press). We use the bias-corrected GCM data for these models from the ISIMIP project (Hempel et al., 2013).

Although the GCM data have been bias corrected relatively to the EU-WATCH dataset, these are only corrected for the empirical distributions of the variables on a daily basis. Persistence of rainfall events that can lead to severe flooding is not accounted for in the bias-correction scheme, resulting in differences between the observed and modelled hazard. We performed additional bias corrections, in order to match the flooding in the baseline scenario from as found for the EU-WATCH data, with the results for GCM simulations for the baseline period of 1960-1999. For the future projections, we use two time slice periods: 2010-2049 and 2070-2099.

2.2.2 Simulation of flood protection

Flood protection is in place in most European countries, often in the form of dams, dikes and other structural protection measures. These measures greatly influence the occurrence of flooding and subsequent impacts. To account for flood protection in the flood risk model, we use the database developed by Jongman et al. (2014) that provides information on the return periods for which protection on a river basin scale is provided. This database provides information for various sub-basins across Europe. For the project we use an updated version of the protection database provided by Dr. Philip Ward (personal communication), that is complemented by new information (see Scussolini et al., 2015).

2.2.3 Damage model

The damage model is a modified version of the model developed for the JRC (Huizinga, 2007) that has been extensively applied (Feyen et al., 2009; Rojas et al., 2013; Jongman et al., 2012). The damage model uses information on types of land-use to estimate damages, and includes the following damage categories: Residential; Commercial; Industrial; Infrastructure; Agriculture. For each land-use function, different damage functions are used that tie a damage fraction of the total possible damage to this type of land-use to floodwater depths. These functions are displayed in the figure below.

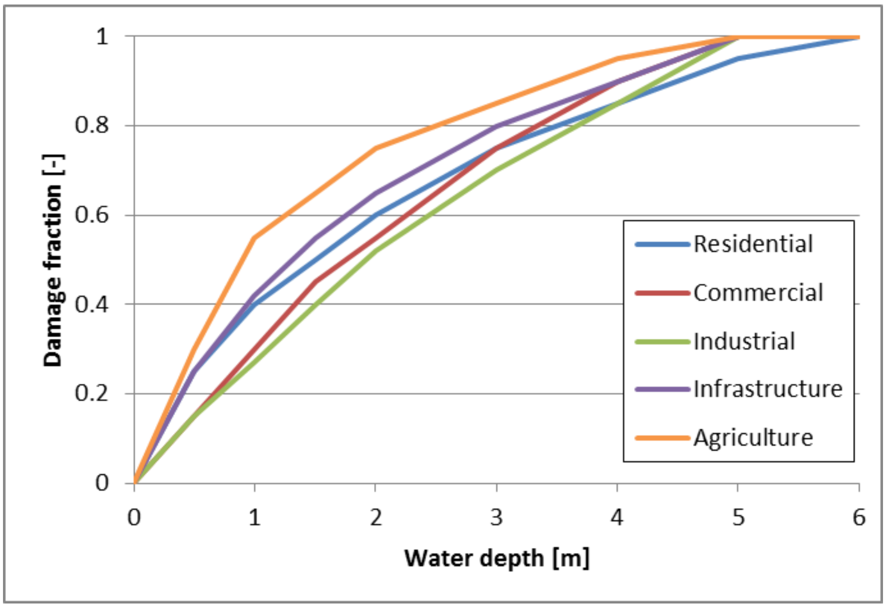


Figure 2 Damage functions for the land-use types residential, commercial, industrial, infrastructure, and agriculture

Linked to the different damage functions are the maximum damages, which were estimated using the methodology described in Huizinga (2007). The table below provides the generic maximum damages for the entire modelling domain. These maximum damages reflect both the buildings as well as inventory. In contrast to earlier studies, no country-specific damage functions have been applied. However, for the purpose of the current study, the maximum damages were scaled for the different countries and regions using GDP data from the NUTS2 level (see Holz et al., in prep.).

Table 1 Maximum damages for the different land-use types (based on Huizinga et al. 2007)

Land-use type	Maximum damage (Euro m^{-2})
Residential	846.7
Commercial	701.1
Industrial	602.9
Infrastructure	27.1
Agriculture	0.87

As input for the damage model we use the CORINE 2006 dataset for land-use in Europe. The output of the damage model consists of damage maps for the different flood return periods of 2, 5, 10, 25, 50, 100, 250, and 1000 years. Based on this output for individual return periods, and taking account of estimated protection level, a value for the annual expected loss is produced.

2.2.4 Adaptation measures

1) In the reference strategy, we assume the estimated existing protection level is maintained, but not upgraded. This means that when climate changes, the flood probability actually increases, as the flood defences are not upgraded. These are the protection levels as reported by Jongman et al. (2014), for both the baseline period (1960-1999) and the two future time slices (2010-2049 and 2060-2099). This means that minimum protection levels are set for floods with 10 years, and maximum 999 years return periods (for the Netherlands). The 'do-nothing' scenario for the baseline period reflects the current flood risk level in Europe, and therefore acts as reference situation.

In order to arrive at the estimate of the impacts of maintaining current protection levels (for instance maintaining current dike heights), we have adapted the future protection levels of the do-nothing strategy to the future mean water level per river sub-basin as follows: First, the current protection level per river sub-basin is related to a mean water level in this sub-basin. For example, a river sub-basin has a protection level of 75 years in the baseline. The 75 years corresponds to a mean water level of 3.00 m, which is a linear interpolation between the water levels expected for a 1/50 and a 1/100 event in the baseline situation. Second, this mean water level is used to derive the return period in the future. For example, from a GCM we can find that 3.00 m is expected between once in 25 years and once in 50 years in the future. We again apply a linear interpolation between both return periods, and find that a mean water level of 3.00m has to be expected every 1/38 years. Finally, we verify that the future protection level does not increase, as it could happen in sub-basins which are expected to see fewer heavy rainfall events that lead to flooding. In this case we assume, the protection level is not increasing in the do-nothing strategy, but remains similar to the today's protection level.

2)' Flood prevention': various measures can prevent flooding, including the creation of new, or improvement of height and strength of existing dikes, dams and levees. In this way the probability of flooding is reduced. Also by retaining water in reservoirs or retention areas downstream, the probability of flooding of vulnerable areas is reduced. Finally, widening of river floodplains, and reduction of obstruction in floodplains (such as bridges) can reduce the probability of flooding.

In this study we simulate improved protection from dikes, using adjustments of the protection levels. Compared to the reference strategy (1) described above, current protection levels are increased to reflect changes (increases) in the flood frequency as the climate changes. This implies that for instance the infrastructure that allows a flood protection level of 100 years in the baseline situation is upgraded so that in the future time periods of 2010-2049 and 2070-2099 also a 100 year protection level is maintained. This could be regarded as a business as usual scenario, however several investments are required (see next section), and therefore this is substantially different from the 'do-nothing' scenario. In addition, in this adaptation measure all areas have a protection of at least 100 years, including areas that have a lower protection in the baseline situation of 1960-1999. This additional upgrade is included in order to account for possible 'adaptation deficits' for many areas around Europe, that are apparent in the baseline scenario.

3) 'Vulnerability reduction': this includes measures to reduce the impacts of river flooding, once a flood occurs. For instance, adapted construction of buildings prevents water from entering the building (dry-proofing), or when water enters it does no harm (wet-proofing). Emergency measures, including local barriers, and sand bags can prevent water from entering vulnerable urban areas. Other measures, including land-use planning, risk zoning, and relocation of vulnerable objects also help to reduce flood impacts.

Here we simulate the effects of dry-proofing, i.e. the reduction of impacts from water levels at the base levels of buildings. Retrofitting of existing buildings is quite costly, and therefore this is usually applied to new buildings. However it is worthwhile to assess whether large-scale adjustment in areas that are very flood prone helps to substantially reduce risk. This measure is therefore applied to areas with a flood protection level of 25 years or less for the categories residential, commercial and industrial. Flood proofing is assumed to be effective up to a level of up to 1.5 metres, above which the normal damages are assumed to occur at that level, thus simulating the effect of dry-proofing of buildings. The damage functions are adjusted as indicated in the figure below.

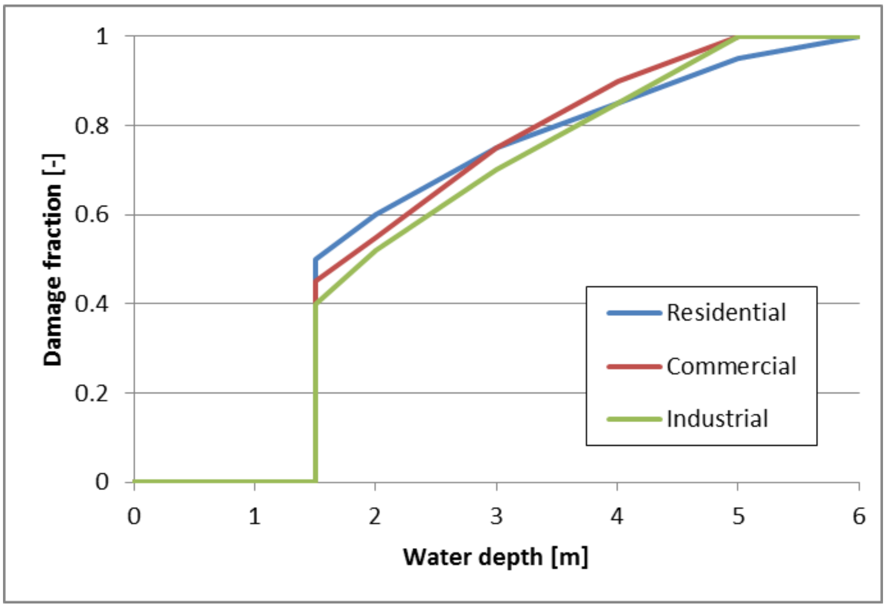


Figure 3 Adjusted damage functions for the categories residential, commercial, and industrial, for adapted buildings

The measures analysed can be seen as proxy for measures that achieve similar effects. Flood prevention in river basins can also be achieved by other measures such as building of new or improving the management of upstream reservoirs and making more room for the rivers by clearing away bottlenecks or create retention areas further downstream. These measures all will decrease the probability of floods but have different associated costs and benefits. Also vulnerability reduction can be achieved by various types of measures. BASE case studies also show this variety of flood risk mitigation measures. For instance the case study of the Rotterdam area includes both dike building and room for river measures, the case study of Holsterbro includes flood retention and the case study for Venice dry and wet proofing measures.

2.2.5 Costs of adaptation

We calculate the following adaptation costs:

For dike protection, adaptation costs are the costs of maintaining current (estimated) river flood protection levels, including a minimum standard across the EU of at least 1:100 years.

This is done by using two approaches:

Calculating avoided impacts (benefits) for the future time periods and estimating costs according to a fixed benefit-cost ratio (BCR) 4:1 and using no discounting;

Calculating the actual required dike heightening for the future time periods and associated costs, using no discounting.

The first approach is the same as taken by Rojas et al. (2013), where they assumed after reviewing the literature that flood protection measures would be taken with a typical BCR of 4. This is a crude assumption, as in reality other economic criteria are likely to be used, such as the protection level at which marginal benefits equal the marginal benefits. Also, reference baseline used to calculate the BCR may differ from location to location, as well as the discount rates used rates used. However, for reasons of comparability the same approach is applied here.

In the second, slightly more advanced approach, an estimate is made of the required dike level increases and associated costs.This approach was first developed for the global level by Ward et al. (submitted). First the river length of major rivers across Europe (Strahler order 6 or higher) is established along which dike protection is required. Note that we disregard smaller streams with smaller flood volumes. This river length is multiplied by 2, as it is assumed that dikes need to be upgraded on both sides of the river in order to improve the protection level. From the hydrological analysis (see Winsemius et al., 2013 and Winsemius et al., in press), a calculation was made of the required dike height increase under each of the RCP climate change scenario's and all five climate models, relative to the present situation.

In terms of costs, it is assumed that the unit costs of dike level increases is uniform across Europe, which is a simplification as local hydraulic characteristics, material, and design standards may vary.

The standard cost applied here is 5.63 million Euros per meter dike level increase per kilometre dike length. This value is found using a number of different databases (Bos 2008; De Grave and Baarse, 2011; Aerts et al., 2013; and see also Ward et al. submitted) and assuming an average value of the costs reported there. Cost levels are varied using differentiation between countries, using the construction cost database published by Compass International Consultants (2009). The total costs for dike height increases per country are then calculated as:

$$C_{dike,j} = \sum_{m}^{i} L_{dike,i} * c_j * 5.63 * I_i,$$

whereL_{dike} is the dike length present in location i, c is the cost factor for country j, and I_j is the required dike height increase as simulated for location i.

For adapted buildings, we estimate the costs of adapting individual buildings to accommodate a water level of 1.5 metres. This dry-proofing, is taken to be implemented in the urban area categories of residential, commercial and industrial.

The total cost of the measure is based on the areas where the measure is simulated. For the categories residential, commercial and industrial, the total land-use is calculated, and for this total area an estimate of 83 Euros per m^2 of land-use, is applied. This cost estimation for flood proofing is based on cost estimation of local flood protection measures, developed for the Dutch Delta programme (Roosjen and Zethof, 2013). Venice and Copenhagen BASE case studies also contain dryproofing measures.

2.3 Cost and benefits for the Reference strategy

The flood risk model comprises a large domain and a wide range of countries in Europe (see Figure 4). This figure indicates the baseline flood risk across European countries, which is a combination of hazard and exposed assets, as indicate by the land-use typologies for these countries. In addition, maximum damages were scaled as explained above, using GDP figures for each country. The risk values therefore also reflect relative wealth distributions and differences between European countries in north and east (higher), and south and east (lower).

Relative risk (expressed for instance as percentage of GDP), yield different distributions, as indicated also in tables, below.

Note also that other types of flooding (coastal, pluvial) may cause very substantial damages, but are not included in the assessment. Finally, because of resolution issues (i.e. the flood hazard is simulated at the 1km scale, and model output from coarse GCMs is used) for small river basins the actual flood hazard may be underrepresented. This can lead to underestimates of the hazard for small river basins and smaller countries.

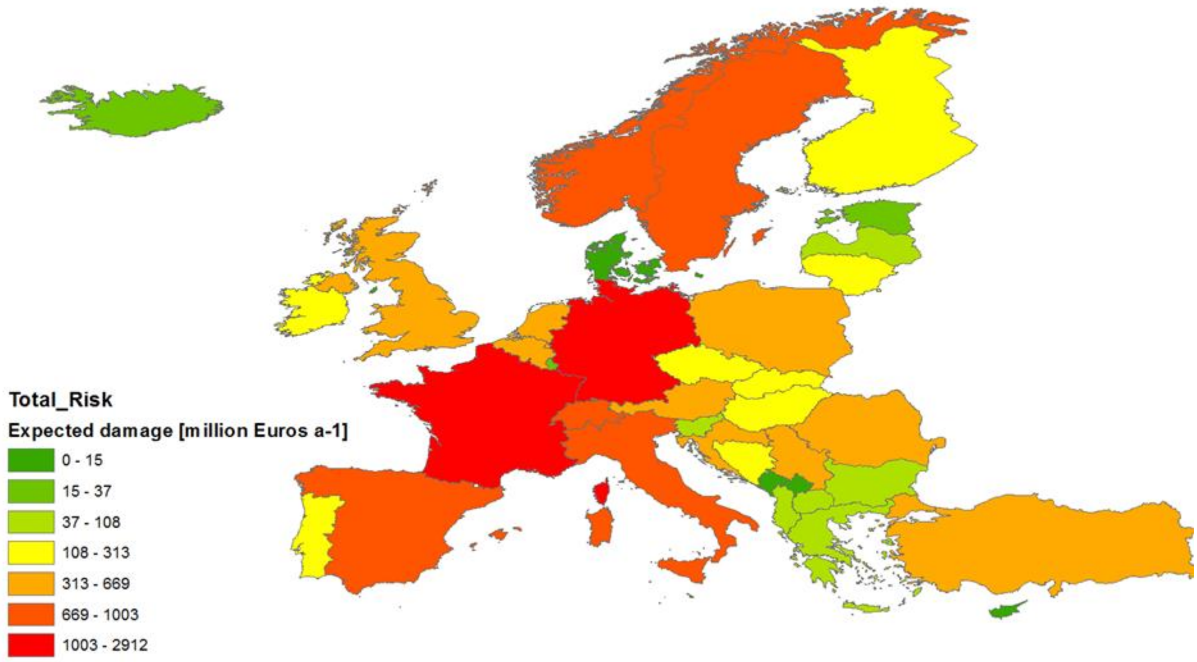


Figure 4 Map of the model domain, with expected annual river flood damages (million Euros per year) for the baseline period 1960-1999 (present climate).

For the analysis in BASE, four regions were defined, being Nordic, West, South, and Central/east. The domain of the flood risk model for Europe comprises a total of 43 countries. For the purpose of the BASE project, the countries indicated in Table 2 were included. These consist of the 28 EU countries (excluding Cyprus and Malta, which are too small to reliably simulate flood risk in this model), and Switzerland and Norway were added. In total 28 countries are thus included in the analysis.

Table 2 Countries assigned to regions in the flood risk model

Region:	Countries included:
Nordic:	Denmark, Finland, Norway, Sweden
West:	Belgium, France, Ireland, Luxembourg, Netherlands, Switzerland, United Kingdom
South:	Spain, Portugal, Italy, Greece
Central/east:	Austria, Bulgaria, Croatia, Czech Republic, Estonia, Germany, Hungary, Latvia, Lithuania, Romania, Poland, Slovakia, Slovenia

The tables below provide an indication of the changes in river flood risk in the future time periods 2030s and 2080s, compared to the baseline (1980s). In the baseline situation, each country in Europe already experiences a certain level of river flood risk. This risk varies across the countries, depending on the level of the hazard (the frequency and intensity of flooding), the exposure (location and value of buildings and other assets), and of the level of flood protection.

Table 3 Flood risk (expressed as expected annual damages in million Euros) per region, average for five GCMs for the two time slices 2010-2049 (2030) and 2060-2099 (2080)

Region:	Baseline (1960-1999)	RCP4.5(2030)	RCP4.5(2080)	RCP8.5 (2030)	RCP8.5 (2080)
Nordic:	1,243	1,558	1,583	1,705	1,591
West:	4,553	10,657	10,453	8,830	14,770
South:	2,136	3,232	3,234	3,011	3,816
Central/east:	8,186	11,205	12,613	12,316	13,112
Total:	16,094	26,652	27,883	25,861	33,290

Table 4 Flood risk (expressed as %GDP) per region, average for five GCMs for the two time slices 2010-2049 (2030) and 2060-2099 (2080)

Region:	Baseline (1960-1999)	RCP4.5(2030)	RCP4.5(2080)	RCP8.5 (2030)	RCP8.5 (2080)
Nordic:	0.14%	0.18%	0.18%	0.20%	0.19%
West:	0.09%	0.22%	0.22%	0.18%	0.31%

South: Central/east:	0.07% 0.18%	0.10% 0.25%	0.10% 0.28%	0.10% 0.28%	0.12% 0.29%
Entire region:	0.12%	0.20%	0.21%	0.20%	0.25%

Table 5 Relative changes in annual average flood risk per region

Region:	RCP4.5(2030)	RCP4.5(2080)	RCP8.5 (2030)	RCP8.5 (2080)
Nordic: West: South: Central/east:	25% 134% 51% 37%	27% 130% 51% 55%	37% 94% 41% 51%	28% 224% 79% 61%
Entire region:	66%	73%	61%	107%

The figure below describes these same changes as changes relative to GDP of the four regions by the 2080s. The relative changes show a consistent increase for the West and South regions, and neutral to significant increase for Central/East, and a slight increase in flood risk for the Nordic region. This distributed pattern of changes in flood risk across Europe is broadly in line with other research (Rojas et al., 2013; Alfieri et al., 2015a), that shows the largest increases in flood risk in Europe to be in the west and central/eastern parts. Moreover, these projected changes also mimic the patterns of observed changes in past extreme river flow in these regions (cf. Hall et al., 2014), with increases being most pronounced in west and central Europe.

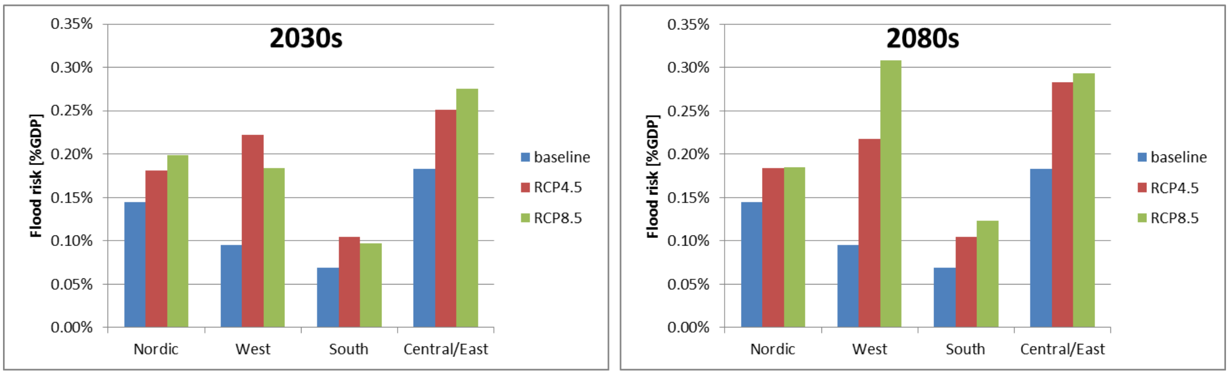


Figure 5 Flood risk for the four regions by the 2030s and 2080s expressed as %GDP, under two different RCP emission scenarios (reference scenario

2.4 Cost and benefits of Adaptation strategies

Below the results from the adaptation cost estimates are presented. Please note again that these costs refer only to river flood risk as simulated by the model. Adaptation costs for other types of flooding such as fluvial and coastal flood hazards are expected to be substantial as well, but are not included here.

2.4.1 Flood protection (dikes)

The tables below indicate the impacts of projected climate change after adaptation measures for flood protection are taken.

The following results are distinghuished:

Costs of impacts: these are the total simulated flood costs, thus the baseline flood damages and the projected impacts of climate change. When adaptation is included, these damages will be lower than in the baseline situation.

Adaptation benefits (or avoided damages): these are the flood damages in the reference situation for a projected future (without adaptation), minus the damages that occur for the same projected period when adaptation is implemented.

Adaptation costs: the estimated costs of the measures, using varyiong approaches of calculation.

Table 6 Costs of total flood impacts after adaptation (dike protection), as %GDP (SSPs not considered)

Region:	Baseline (no adaptation) (1960-1999)	RCP4.5(2030)	RCP4.5(2080)	RCP8.5 (2030)	RCP8.5 (2080)
Nordic:	0.14%	0.05%	0.05%	0.05%	0.05%
West:	0.09%	0.07%	0.07%	0.06%	0.07%
South:	0.07%	0.03%	0.03%	0.03%	0.03%
Central/east:	0.18%	0.08%	0.09%	0.09%	0.09%
Entire region:	0.12%	0.06%	0.06%	0.06%	0.07%

Table 7 Adaptation benefits (dike protection), expressed in reduced annual flood risk (million Euros per year)

Region:	RCP4.5 (2030)	RCP4.5 (2080)	RCP8.5 (2030)	RCP8.5 (2080)
Nordic:	751	1,162	789	1,178
West:	5,561	7,241	4,161	11,318
South:	1,630	2,175	1,402	2,781
Central/east:	4,366	8,814	6,562	9,145
Total:	12,308	19,392	12,913	24,422

The tables below provide estimates of the costs of adaptation for dike protection for the different regions in Europe.

First, the annual adaptation costs have been estimated using the simple approach. Here, we arrive for the entire European region at adaptation costs in the order of some 3 billion Euros per year in the 2030s; and between 4 and 60 billion Euros per year in the 2080s.

Using the more complex method, we arrive at a total estimated adaptation cost for maintaining current protection levels for the entire period up to the 2030s, and the 2080s. These estimates vary between 700 billion Euros for the 2030s, and 900-1100 billion Euros total costs for the 2080s. It is possible to translate these estimates into annual costs, assuming that these are divided over 50 and 100 years, respectively for the 2030s and 2080s (no discounting is used). Then we arrive at between 13-15 billion Euros per year (2030s), and 9-11 billion Euros per year (2080s). The reason that the annual costs for the 2030s per year are higher than for the 2080s is because the costs are spread over a shorter period and include upgrading many flood protection systems across Europe up to a level of 100 years.

Table 8 Adaptation costs (dike protection) in absolute costs (million Euros per year) (simple method)

Region:	RCP4.5(2030)	RCP4.5(2080)	RCP8.5 (2030)	RCP8.5 (2080)
Nordic:	188	291	197	2,945
West:	1,390	1,810	1,040	28,295
South:	407	544	351	6,953
Central/east:	1,091	1,791	1,302	22,863
Total:	3,077	4,435	2,890	61,056

Table 9 Adaptation costs (dike protection) in absolute costs (billion Euros total) (complex method), undiscounted

Region:	RCP4.5(2030)	RCP4.5(2080)	RCP8.5 (2030)	RCP8.5 (2080)
Nordic:	106	164	129	231
West:	215	260	192	398
South:	117	121	100	99
Central/east:	232	337	310	391
Total:	669	882	731	1,119

The numbers presented so far did not consider differentiation between SSP scenarios. In the next step, the SSP scenarios are used to scale the flood damages and to express impacts and adaptation costs as percentage of projected GDP. We use the information from the SSP scenarios as follows. The GDP and population data are taken to calculate an increase in value of exposed assets, such as buildings, infrastructure and so on. The change in GDP is taken to reflect both the increase in value of individual assets, as well as the number of assets. Of course, GDP here is a proxy for the stock values. The incremental increase in values is applied using the following adjustment of the simulated flood damages:

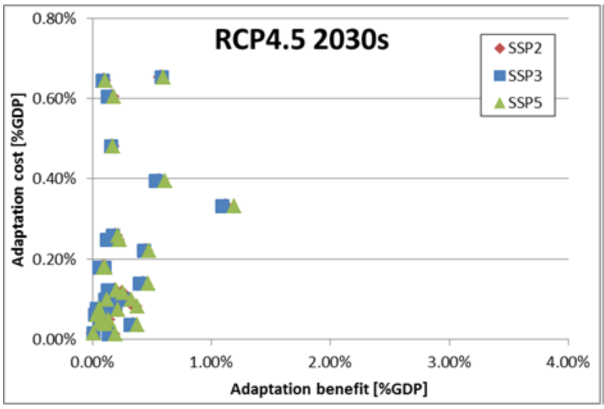
$$D' = D * \left(\frac{GDP_{t,s}}{GDP_{2010}}\right),$$

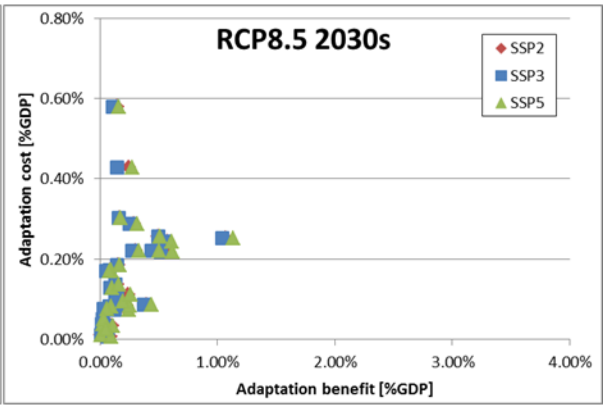
where D is the simulated unadjusted damage, GDP is the gross domestic product for the baseline situation (year 2010) and future time period t (2030 or 2080) and SSP scenario s (being SSP2, SSP3 or SSP5).

As the adaptation benefits depend on the damage cost D', the benefits are represented as percentage of future GDP. The adaptation costs are scaled slightly differently. The complex method for flood protection measures provides costs of the total dike height increases. These measures and their costs can be spread over time. Here it assumed that some costs are taken immediately, while other costs are postponed until a future period. In all, the costs are spread over a 50 or 100-year period for the 2030s and 2080s, respectively. The adjusted annual costs of the adaptation measures for flood protection are expressed as a percentage of GDP of the baseline period:

$C' = \frac{C}{s}/GDP_{2010}$, where is s the scenario period (50 or 100 years).

In the figures below, the variation in adaptation costs versus benefits is presented for the 28 countries included in the analysis. What becomes clear is that while for most European countries maintaining the current flood protection level, and raising the minimum standard is worth the costs, there are a few countries where the benefits do not outweigh the costs. For these countries the costs as percentage of the average of current and future GDP are higher, than the benefits expressed as percentage of future GDP. This is the case especially in the 2030s. Later, the benefits of the measures increase, as the value of the protected assets increases according to the SSP scenarios.





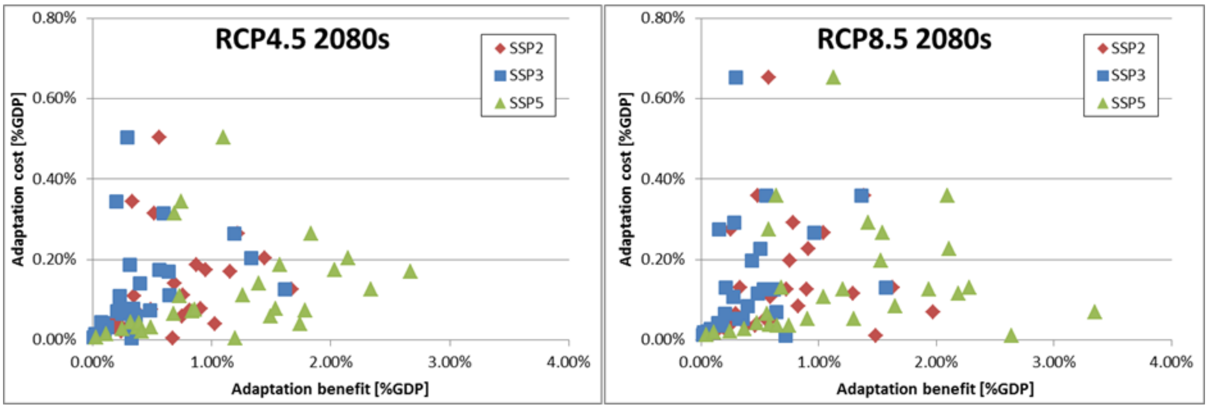


Figure 6 Annual adaptation costs and benefits of flood protection for individual countries, expressed as percentage of current GDP (undiscounted), under RCP climate scenarios 4.5 and 8.5, and including SSP2, 3 and 5 scenarios

The graph above show that there are several countries for which the costs of maintaining the baseline flood protection level under climate change (and introducing a minimum of 100 years protection) do not outweigh the benefits for different SSP scenarios. This is especially the case for the year 2030, when between 12 (RCP4.5) and 13 (RCP8.5) countries the costs of adaptation are higher than the project benefits. This is very different for the year 2080, when almost for all countries the benefits outweigh the costs. There are only two countries in RCP4.5 (Estonia and Finland), and three countries in RCP8.5 (Estonia, Finland and Sweden) where the adaptation costs also in the 2080s remain higher than the benefits. More details on this are presented in the section on the uncertainty analysis.

2.4.2 Adapted buildings

The effect of adaptation through adapted building is indicated in the tables below. Overall, the effects are quite large, as the measures help to keep the annual expected flood damages at the same level as in the baseline. Note that the improved dike protection is not included in this strategy.

Table 10 Impact costs after adaptation (adapted building), as % GDP (SSPs not considered)

Region:	Baseline (no adaptation) (1960-1999)	RCP4.5(2030)	RCP4.5(2080)	RCP8.5 (2030)	RCP8.5 (2080)
Nordic:	0.14%	0.10%	0.10%	0.11%	0.10%
West:	0.09%	0.10%	0.10%	0.10%	0.11%
South:	0.07%	0.07%	0.07%	0.07%	0.07%
Central/east:	0.18%	0.18%	0.18%	0.18%	0.18%
Entire region:	0.12%	0.12%	0.12%	0.12%	0.12%

Table 11 Adaptation benefits after adaptation (adapted building), expressed in reduced annual flood risk (million Euros per year)

Region:	RCP4.5(2030)	RCP4.5(2080)	RCP8.5 (2030)	RCP8.5 (2080)
Nordic:	298	702	315	710
West:	3,978	5,613	2,616	9,534
South:	561	1,116	369	1,765
Central/east:	1,540	4,645	2,266	4,943
Total:	6,377	12,076	5,565	16,952

For adapted buildings, we find that this measure can be best taken for residential buildings, as approximately 17,852 km^2 seems suitable according to the proposed definition for this measure (see above). Another 668 km^2 and 1034 km_2 of commercial and industrial areas would be adapted, respectively. The total cost for this measure across Europe is provided in the table below. This measure is uniform in costs, across the different RCP scenarios. It is clear that this is a very expensive measure, and a bit more expensive than dike protection. However, taken over time periods of 50 years (2030s), or 100 years (2080s,), reduces the annual costs. In the policy recommendations section, these costs are further compared.

Table 12 Adaptation costs (adapted building), total costs in billion Euros

Region:	Total costs
Nordic:	499
West:	295
South:	384
Central/east:	444
Entire region:	1,623

2.5 Verification using case studies

2.5.1 Comparison of cost estimates for flood risk reduction

In order to better understand the uncertainties in the cost estimates used, we compare the cost estimates used in the European-wide flood risk model, with estimates used in the different BASE case studies. A number of cases have assessed effects and costs of flood protection as well as flood proofing measures. The table below provides the estimates from the case studies that provided such cost estimates. Flood proofing estimates are expressed as unit costs per m2 of residential land-use. The costs for flood protection are expressed as costs per km of dike length.

In general, although many case studies were dealing with flood protection and flood risk reduction measures, these did not always provide a full break-down of unit costs, which are compared here. Most often, aggregated costs were reported, for which it was not always possible to bring these back to unit costs. Here, the numbers that were available are compared.

Table 13 Comparison of unit cost estimates for flood protection and flood proofing

Case	Type	Description	Flood hazard	Cost estimate
Venice	Flood proofing	Tank (Vasca)	Coast	193.75 (€/m-2)
Devon	Flood proofing	Flood protection gates	River	2.43 (€/m-2)
Netherlands (multi-layer safety)	Flood proofing	Impermeable ground floor (<1.5m)	River/coast	82.5 (€/m-2)
Kalejoki	Flood protection	Embankements	River	0.2-1 MEuro/km

Table 13 provides indications of the estimated costs of flood proofing. The cost estimates for flood proofing in Venice are in the same order of magnitude (100-200 Euros per m2 of residential area) as the estimate used in the European wide flood risk model. The cost estimate for temporary flood gates in the UK, from the Devon case study, is much lower than the former, but relate only to these gates and not to other measures required to flood-proof residential buildings.

For flood protection, the Kalejoki case study reports costs of between 0.2 and 1 million Euros per km of embankment length. This is lower than the estimate used in the European wide flood risk model (5.63 million Euros per km per meter heightening), but it is not known for what heightening this cost estimate is valid. Also, type of design and construction will influence this cost estimate.

In sum, it is concluded that much uncertainties on the adaptation cost estimates remain, and additional check are required to establish reliable estimates of flood protection costs at the European scale.

2.6 Uncertainty analysis

2.6.1 Flood risk model uncertainties

In order to gain a sense for the accuracy of the flood risk model results for the baseline situation, we compare the simulated level of flood risk with another study into national flood risk levels. A recent study was completed using the JRC flood risk model, by Rojas et al. (2013). This study has assessed baseline flood risk for individual countries in the European Union. In the figure below, the results from the latter study are compared to the JRC model. In order to be able to compare the results, the flood protection database described above included a minimum protection level of 100 years (as also assumed in the study by Rojas et al., 2013).

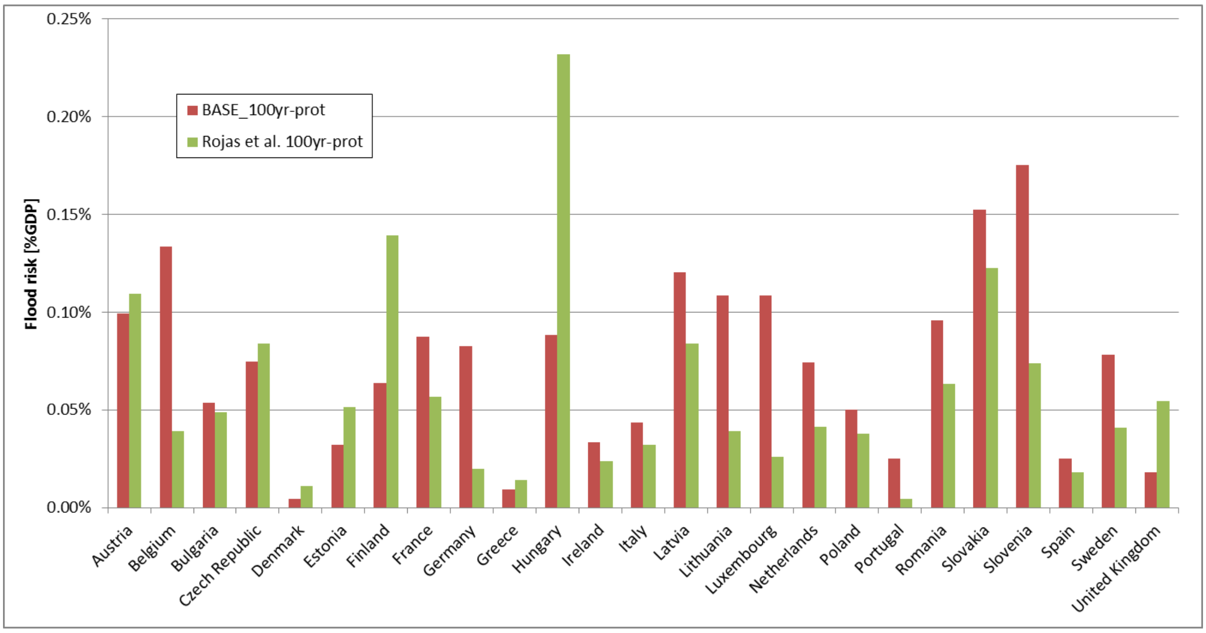


Figure 7 Comparison of the baseline annual flood risk levels (expressed as percentage of GDP) across EU countries, for the current study and the JRC model (Rojas et al., 2013).

Overall, the relative impacts across the EU compare well between the two models. In some areas the model considerably overestimates damages compared to the JRC model (in countries such as Germany, Belgium, Luxembourg, Lithuania, and Slovenia). For other countries the modelled damages are much lower than in the JRC model (countries such as the United Kingdom, Hungary and Finland).

The expected flood damage for the baseline in the current study is 7.8 billion Euros per year (0.06% of GDP) for the countries listed in Figure 7 above, and 5.4 billion Euros per year (0.04% of GDP) according to Rojas et al. (2013) for the same countries.

It should be noted that there are some import reasons why the two estimates deviate. First of all, the baseline periods for which floods are simulated differ (JRC uses 1961-1990, the current study uses 1960-1999). Secondly, the climate data that was used to simulate the baseline period is different. The current study uses observations from the EU-WATCH dataset, whereas the JRC study uses the control run period from the climate models. Also the model does not use county-specific functions for NL, DE and GB, but equal functions (with maximum damages scaled by GDP) for all over Europe. Finally, assumptions about protection levels above 100 years in the current study may also influence the results.

2.6.2 Uncertainties in adaptation cost estimates

Here we compare the two cost estimates on a per annum basis, where we assume costs from the complex method are spread over a 50 (2030s) or 100 year (2080s) time horizon, compared to the baseline (1960-1999). The two estimates deviate on average by a factor of 3.0, with the complex method giving higher estimates. Extreme deviations are found Finland for instance, where the complex method perhaps gives too high adaptation costs, given that large areas that are not inhabited need not to be protected. Overall, the relative distribution of costs across Europe, with exceptions such as Finland, Poland and Sweden, are fairly robust.

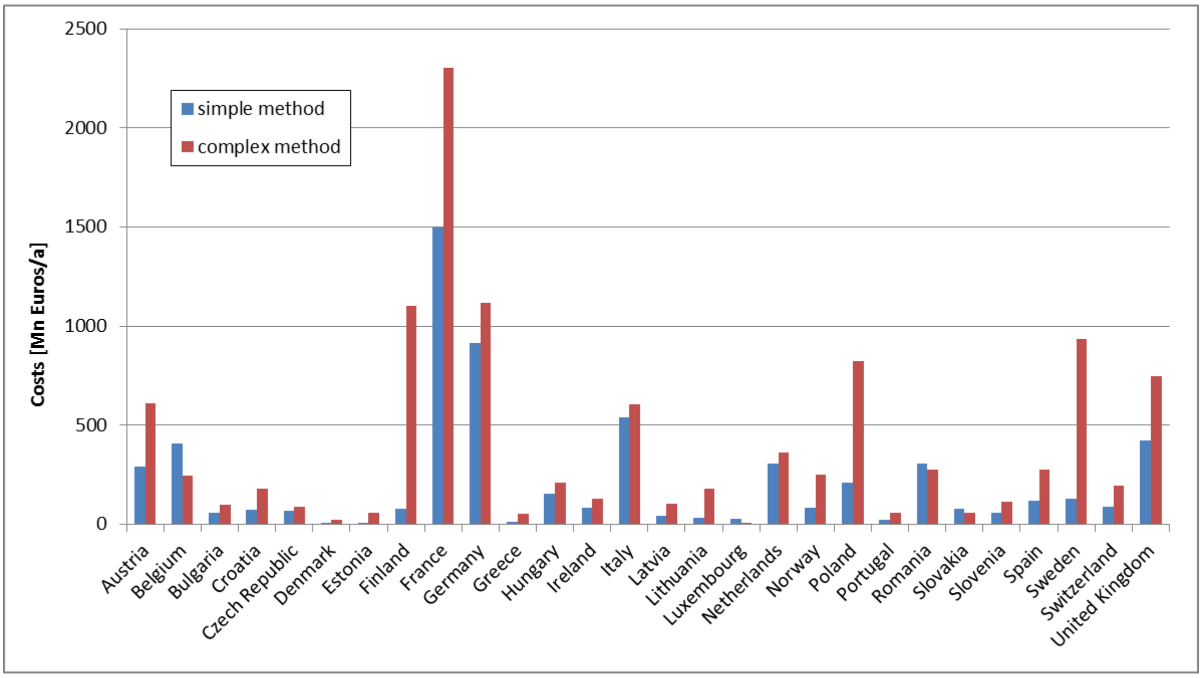


Figure 8 Comparison of annual adaptation cost estimates for flood protection (undiscounted) for flood protection, using a complex and simple method

2.6.3 Scenario uncertainties

Within the BASE project, two RCP scenarios RCP4.5 and 8.5) were chosen, in order to account for differences in effects, adaptation needs and costs, that differ between low and high levels of climate change. Next, three SSP scenarios were chosen, to reflect differential changes in population, economic growth and preferences for types of adaptation measures.

For the flood risk model, the two RCP scenarios were implemented, using output from a total of 5 general circulation models, from the CMIP5 suite. The results from the five climate models were averaged throughout the study. This together accounts for a robust assessment of the potential climate change impacts. The differences between the five climate models have not been further investigated.

For the SSPs the following analysis was made. The SSP scenarios determine the projected adaptation benefits, as the value of the exposed assets increases. The graphs below provide an overview of countries for which the costs of maintaining the baseline flood protection level under climate change (and introducing a minimum of 100 years protection) do not outweigh the benefits for different SSP scenarios up to that time. This is especially true for the period of the 2030s. The level to which the costs are higher than the benefits varies per SSP scenario, as the projected GDP per capita increases determines the level of projected benefits, which in some cases may be high enough to just compensate for the costs. An interesting finding here is that measures taken up to the 2030s are relatively costly, while measures taken up to the 2080s are mostly effective.

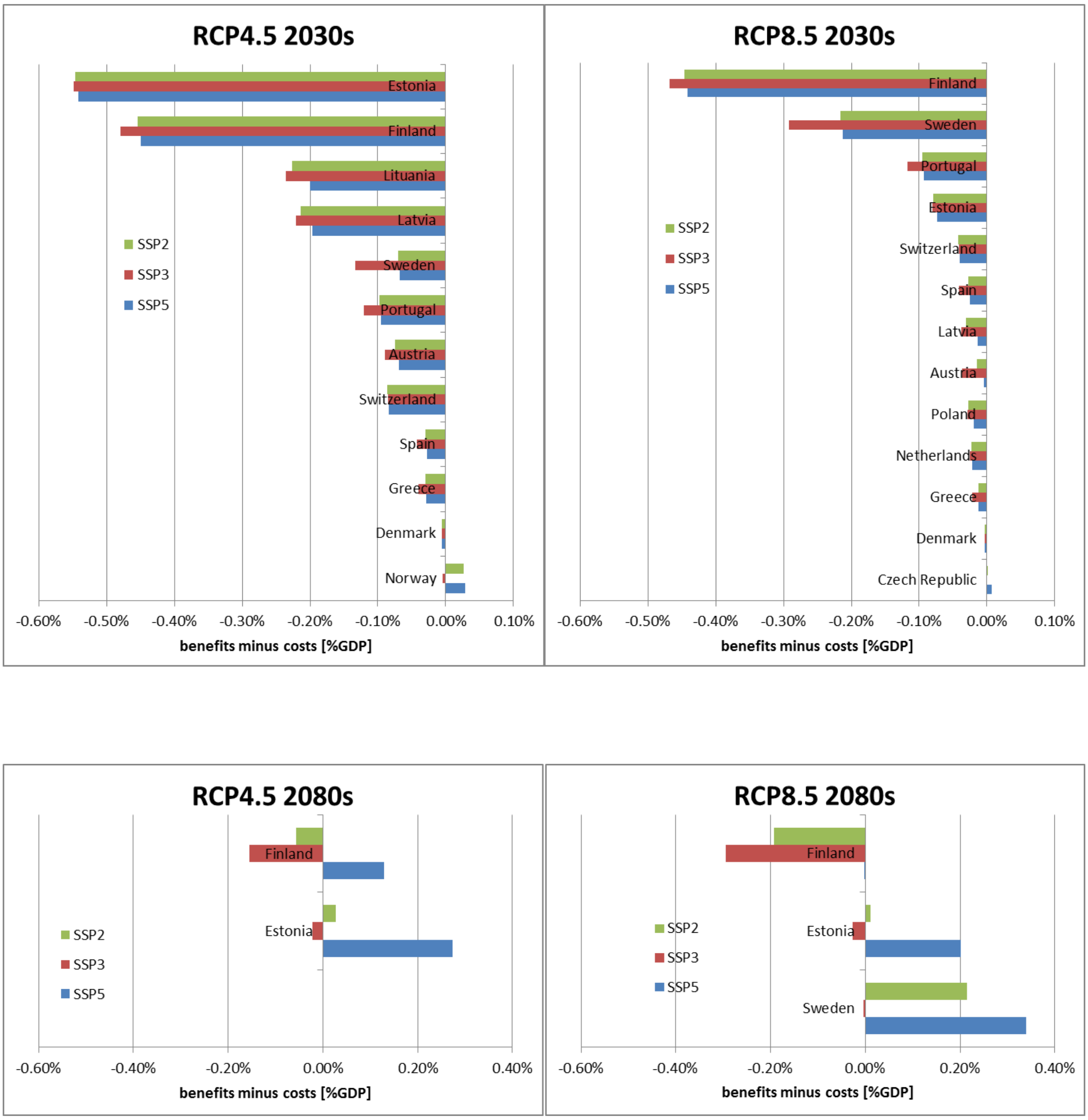


Figure 9 Countries with BCR<1 for flood protection, for the times slices 2030s and 2080s, for different RCP scenarios

It should be noted that the costs for dike protection are conservative in the sense that dike protection is projected all along all main rivers (Strahler order 6 and higher). In the real world, maybe this dike increase is not required in all areas, but rather in the most urbanised parts. This is also why countries with large surface areas and small urban areas see relatively low benefit-cost (BCR) ratios, such as Finland, Sweden, Norway, and Spain for instance.

However, it is also assumed that some protection is already in place along all major rivers, and that costs only include the additional heightening of dikes, and not the construction of new dikes. The latter could substantially increase the costs, in case in many places the flood protection needs to be built up from scratch. Finally, it is important to note that because of limited resources, including financial resources and capacities at responsible organisations, it is unlikely that the full adaptation potential will be implemented in each location across Europe.

2.7 Policy recommendations

2.7.1 Summary of the main findings

In this study the impacts from climate change on river flood risk in Europe were simulated. In addition, estimates of the benefits and costs of two types of adaptation measures were made, for four regions in Europe. Figure X summarise the results, and shows that projected climate change can lead to more than a doubling of annual expected river flood losses in Europe. This is in line with earlier research by other scholars.

Most (if not all) of the impacts of projected climate change can be compensated by adaptation measures. The benefits of flood protection, for instance through dike construction, are slightly higher than through adapted building. The costs of dike construction, as calculated using actual required dike heightening per RCP scenario and per time slice, are lower than the costs of adapted building, especially in the period up to the 2030s.This is because the flood protection costs (dikes) are estimated on the basis of projected climate change in the 2030s, while the costs of adapted building simply result in fixed costs (regardless of the projected climate change by the 2030s) of realising adapted building, as described previously. Under limited (or near-term) climate change, this leads to relatively high costs. On the other hand, the projected adaptation costs for flood protection in the 2030s reflect the projected climate change and flood probabilities for this period, and these costs are thus substantially lower that he costs for adapted building by this time.

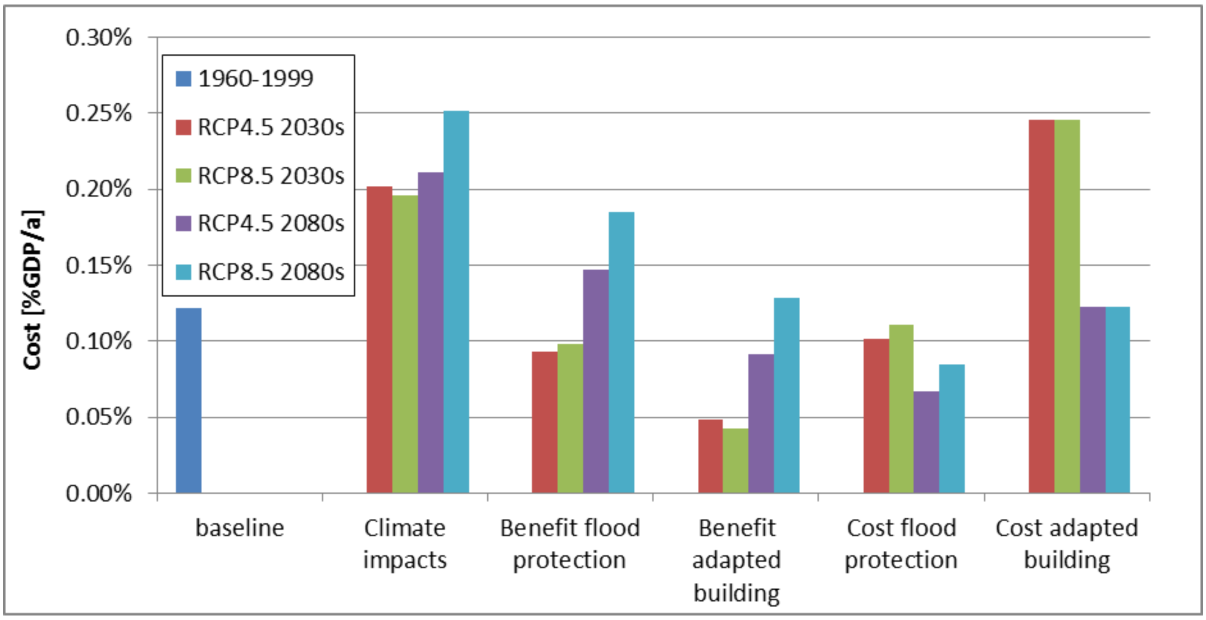


Figure 10 Summary of impacts, benefits and costs of two adaptation measure for river flood risks, aggregated across 28 European countries (no SSP scenarios included).

Interestingly, it is found that the costs for both flood protection and adapted building (flood proofing) are higher during the 2030s, because these investments are made over a short period of time, as explained above. Later, the additional investments needed in for instance dike protection, are easily outweighed by the benefits.

When taking into account the SSP scenarios, it become clear that the increasing value of assets also increase the benefit of the adaptation measures. As shown earlier, especially under the SSP5 and SSP2 scenarios the largest benefits can be expected, while under the SSP3 scenario these are somewhat lower.

2.7.2 Policy implications

The benefits of flood protection and adapted building measures are uncertain, and depend on the level of projected climate change, as well as the time horizon chosen for evaluating cost-benefit ratios. In Europe, a combination of maintaining current flood protection, while at the same time improving the protection in places that are not so well protected today, can help to compensate for climate change impacts under both the high and low climate scenarios that were studied. Flood protection has BCR larger than 1 in almost all of the 28 countries that were studied. This implies that it is worthwhile in all of Europe, to invest in flood protection and keep improving protection as risks increase. Apart from flood protection, it is also possible to adapt residential, commercial and industrial buildings, so that they experience less damage in the case of flooding.

Over shorter periods of time, adaptation measures are relatively expensive compared to the longer time horizon. Overall, flood protection measures are more beneficial, and less costly, than adapted building. At the same time, policymakers may choose to take measures in the built environment, as large dike construction projects may be too costly in some locations, or not desired because of ecological or social considerations.

3 Indirect effect of Urban floods: two case studies

David Mendoza Tinoco, Dabo Guan

3.1 Brief model description and progress in developments under Base project

The Flood Footprint analytical framework allows the estimation of the total economic damage of urban floods. The analysis allow to break down the damage in two categories: direct and indirect damage.

3.1.1 Developing a disaster-specific IO model: the Flood Footprint model

The Flood Footprint framework is based on Input Output (IO) modelling. The core of a standard IO model is a set of balances, this is, supply of each commodity equals demand; total costs or outlays of an economic sector equal its sales; total income equals total consumption, etc. The entire economy can be viewed in terms of a single circular flow with a number of separate "loops" connecting various sub-groups with each other.

Nevertheless, after a flood the post-disaster situation unbalances the economy and two types of costs should be considered, direct and indirect. The damage to buildings, factories, houses, infrastructure, etc., forms the 'direct cost'. This concerns the cost of repair or replacement of the assets that were damaged or destroyed.

The term 'indirect cost' refers to the fact that this loss of capital translates into a loss of production capacity, which affects many parts of the economy, leading to losses of business activity even in those non-affected regions/countries. For example, firms that are dependent on products from the stricken area do not receive the quantities they had asked for. Also, firms that produces articles for damaged or lost factories cannot deliver their products any more. In both cases, damage and costs are involved beyond the immediately affected entities. Indirect costs are usually far more difficult to measure than direct costs, and we need a model to estimate size and composition of the losses.

The challenge was to adapt the IO model so that it can handle these two types of impacts. In fact, there is a two-step operation involved here. In the first step, capital stock is lost or made unusable. This capital, however, is part of the production capacity of a particular sector. Or, in other words, a certain production capacity is 'embodied' in the stock. Consequently, with the loss of the capital stock part of the production capacity is lost. So, the second step is to determine what the capital stock loss means for the sectoral production flows. This translation is the subject of the Flood Footprint model.

3.1.2 Considerations on labour constraints

Furthermore, the model considers the fact that it may be that there is a shortage not just of capital, but in labour. This can have various causes. The labour shortage, e.g. may be a consequence of workers being killed or wounded. However, it also may be the case that the labour force is relatively unharmed, but cannot reach its place of work because of damaged transport systems. In both cases, the supply of labour is affected which also immediately affects production.

3.1.3 Prioritisation and rationing choices

As previously stated, disaster IO analysis is a story of imbalances. Demand and supply change (by factors such as loss of capacity) and there is no guarantee that they will be equal by standard economic forces. That is, supply is not equal to demand.

So, to what purpose to use the remaining capacity is to be determined in one way or another. A rationing scheme may be defined with priorities, for instance some demands may be integrally satisfied before other are, and for demands in the same priority class, repartition between the demands must be established. If intermediate consumption is rationed, or cannot be produced because of a decrease in production capacity, the whole production vector need to be modified to take into account the effect of intermediary consumption decrease on production.

At the end, the development of the Flood Footprint model add-on features that best reflects reality after a flood and its consequences.

The main characteristics taken into consideration by the model are:

- the industrial direct damage as a constraint in productive capacity;
- the role of labour as a constraint in productive capacity;
- the adaptive behaviour of local final demand;
- a rationing scheme for allocation of remaining resources, and
- the temporal dimension of the recovery process.

The first stage of the modelling considered the ‘single’ regional analysis. This approach considers the affected region as an isolated one, where inter-regional trade is not taken into consideration. This gives a good picture of what happens into the reginal boundaries, but let aside the collateral effects to economically paired regions. Further development to consider the latter is developed in the final stage of the modelling, where the Multi-regional analysis is introduced. The study cases presented here reflects both modelling stages.

3.1.4 Flood footprint model based on the multi-regional input output (MRIO) model

Flood footprint is a measure of the exclusive total economic impact that is directly and indirectly caused by a flood event to the flooding region and wider economic systems. Flooding in one location can impact the whole EU or world economy, since the effects of the disaster are transferred through the whole supply chain. In this case, we assess the indirect damage on the world economy that is caused by a flood in a city.

The flood footprint model was originally developed based on one-region input output table. In order to assess the indirect impact to other countries, we adapted it using the multi-regional input output (MRIO) model. The model is capable of assessing the impact of flooding on global economy. Figure 11 presents the work flow (modelling processes) of our estimated total economic impact, i.e. the flood footprint.

Four major results can be obtained, as shown in the green boxes at the bottom Figure 11:

- Direct economic loss (by sector and by region) computed as a proportion of industrial capital damage relative to total capital stock.
- Indirect economic loss (by sector and by region) computed as the accumulation of differences between recovered production capacity and pre-disaster condition at each time-point. (Total Flood Footprint is the sum of direct and indirect economic loss until the economy is fully recovered).
- Time it takes to fully recover.
- Results can be illustrated by sectors and regions.

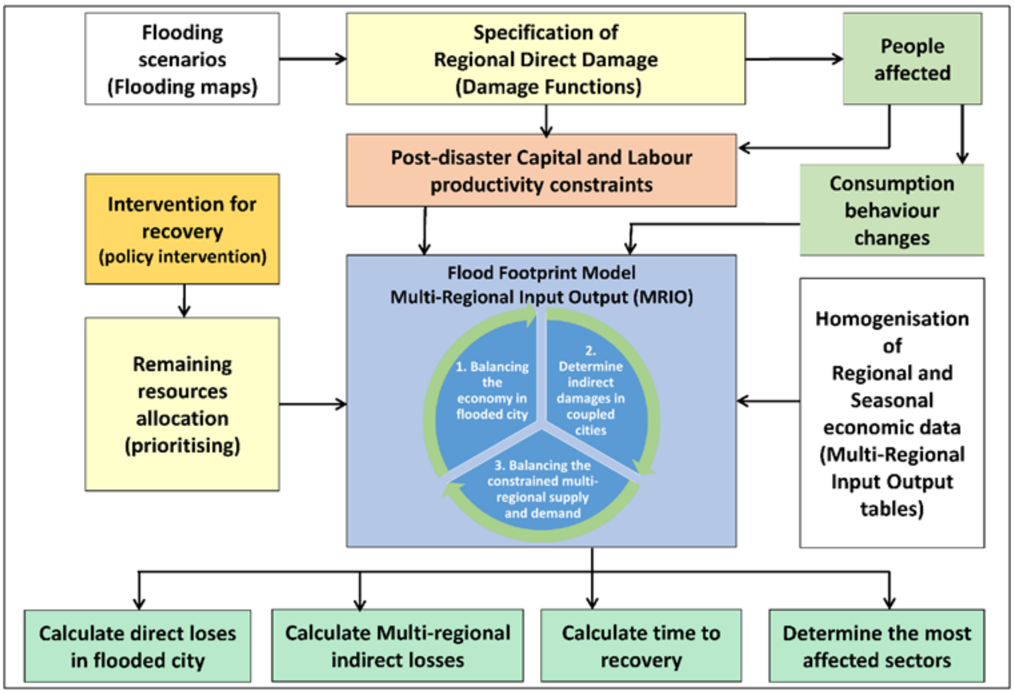


Figure 11 The structure of food footprint model based on multi-regional input output (MRIO) model

3.2 Case study 1: flood Footprint for the City of Sheffield: a single regional modelling result

In 2007 summer floods in England caused the biggest civil emergency nationwide ever. This left a balance of 13 people death and around 7,000 needed to be rescued from flooded areas; 55,000 properties flooded and over half a million people with shortages in water and electricity.

One of the most affected regions was Yorkshire and the Humber (Y&H), especially in South Yorkshire counties which lies within the Sheffield City Region; accounting for 65.5% of total national damage. According with the Environmental Agency, direct damages in the City of Sheffield accounted for over 3% of the 2007 Gross Value Added (GVA), with affectations in 1,793 homes and 2,671 businesses flooded; 4,230 people affected, and 40 Km of A road damaged; among others.

For the City of Sheffield, the model for assessing the Flood Footprint was adapted to focus on the city scale and to quantify the total economic impact of the 2007 Flooding event.

The modelling process consists of gathering data about the regional economy and the damage caused by past events. The latter comprises, for example, damage to capital assets, equipment, households, public services.

On the other hand, information on economic variables relates to the regional economy and provides the context in which the economy's imbalances and restoration process interact during recovery. For this purpose secondary data was used for the calibration of the Flood Footprint model. The information comprises the characterization of business affected, the damage suffered in previous flood events, their response to allocate remaining resources to different client categories, labour reaction and adaptation. This information defined the behavioural parameters of the model for assessing the total economic impact of past flooding in the City of Sheffield.

Results

The model estimates the Flood Footprint, i.e. the direct economic loss computed as a proportion of industrial capital damage relative to total capital stock, plus the indirect economic loss computed as the difference between pre and post disaster output. The model allows analysis at the level of economic industrial sectors.

Table 14 Sheffield Flood footprint summary (£million)

Type of damage	Sector	Damage (million pounds sterling)
Direct damage		298
	Residential damage	13
	Industrial damage	285
Indirect damage		225

The model estimates that after the 2007 flood it would have taken at least 17 months for Sheffield's economy to fully recover and the damage would represent a flood footprint accounting for £571m, or 6.2% of the city's Gross Value Added. From this figure, the direct losses accounts £298m, from which £13m is residential losses, and indirect losses account for £225m. These figures indicate that indirect losses account for around one half of the total flooding damages (see Figure 12).

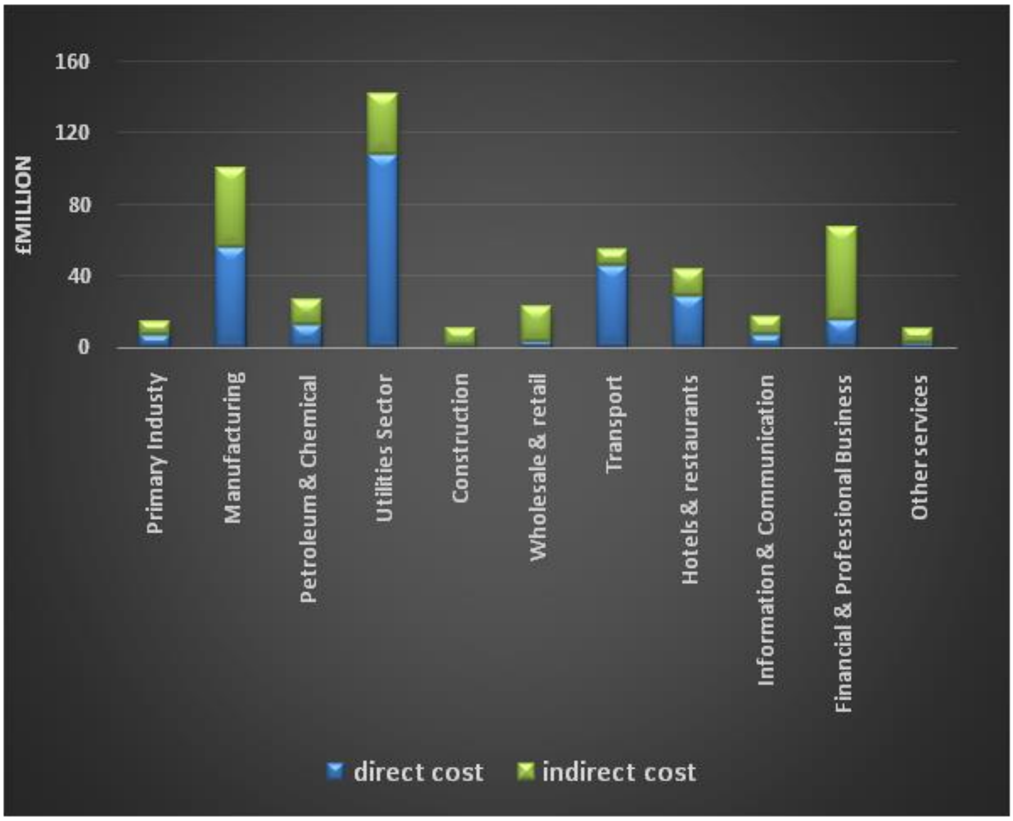


Figure 12 Sectoral distribution of flood Footprint in the City of Sheffield

The model also enables the sectoral analysis. Figure 12 shows the distribution of direct and indirect cost. The most affected sectors in their physical assets (direct damage) are those related with infrastructure, such as Public Services and Transport. Manufacturing sectors are also highly affected. The direct damage in these sectors accounts over three quarters of total direct damage (£209 million). Nevertheless, the graph shows that the indirect damage in these sectors is relatively small. On the other hand, the most indirectly affected sectors are Financial & Professional Businesses sectors, accounting almost one quarter of total indirect damage (£52 million). The sectoral distribution of the damage evidences the vulnerability of sectors at the end of the value chain from flooded assets in manufacturing, public services and transport sectors.

3.3 Case Study 2: flood footprint in the City of Rotterdam: a multi-regional modelling results

The multi-regional flood footprint assessment considers a flooding scenario with a probability 1:10,000 years in the city of Rotterdam. The direct damage data was provided by the Deltares team and is based on a combination of all scenarios for Rotterdam in the Safety Map for the Netherlands.

The results are in US$ million at 2011 prices. The main source of economic data and multi-regional input output table is the World Input-Output Database[1] (WIOD), while secondary data was used to zoom into the city scale. The WIOD is a public database which provides time-series of world input-output tables, covering the period from 1995 to 2011. The world input-output tables cover 27 EU countries and 13 other major countries in the world. The information is disaggregated in 35 industrial sectors and six final demand categories. In addition, the WIOD also provides data of socio economic indicators and environmental indicators. The socio economic indicators include employment, capital stocks, gross output and value added at current and constant prices at the industry level. The environmental indicators contain energy use, carbon emissions and emissions to air at the industry level.

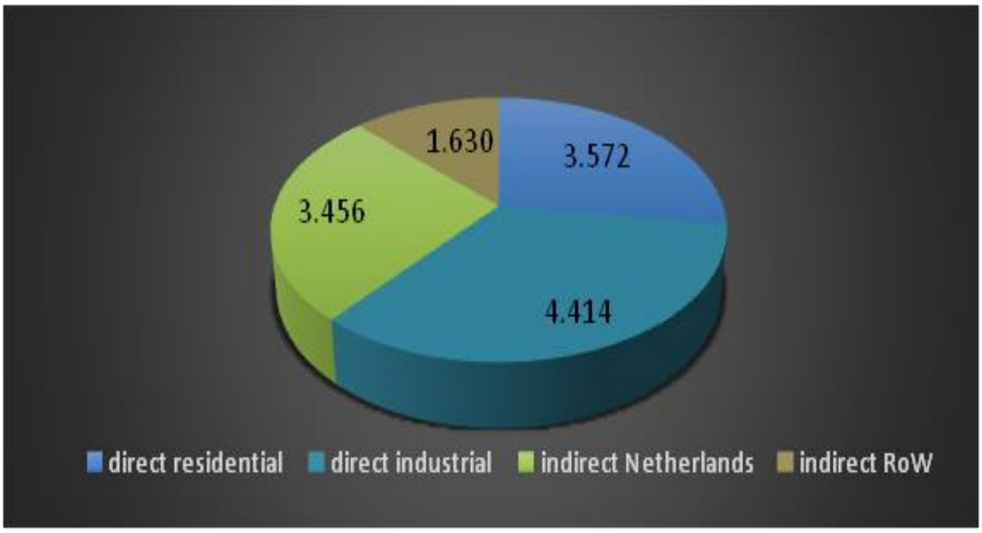


Figure 13 Flood footprint in Rotterdam (US$ million)

Figure 13 shows the distribution of the damage in two dimensions: the type of damage (direct or indirect) and the region (national or international).

The total flood footprint accounts for US$7,986 million (the sum of direct and indirect damage), which represents over 1% of the Netherlands GDP. Under this scenario, the direct damage account for US$7,986 million (~ 61% of the flood footprint), from which US$3,572 million is for residential damage, while US$4,414 million is for industrial damage. The latter represents the main cause of the indirect damage.

The indirect damage –the missed production because of the damage to physical infrastructure– accounts for US$5,086 million (~39% of the flood footprint). Considering the regional allocation of the indirect damage, the national economy where the flood takes place suffer the most. The indirect damage in The Netherlands accounts US$3,456 million (~ 68%

[1] WIOD: http://www.wiod.org/new_site/data.htm

of indirect damage) which represents the lost production in the economy. The main contribution of the multi-regional modelling is the analysis of lost production in other national economies. In this case, the impact to other national economies causes a loss of US$1,630 million (~ 32% if indirect damage). One of the main outcomes of the analysis is the relation indirect/direct damage, as this provides a picture of the damage dissemination. If we considered the indirect damage in relation to the industrial damage we can observe a relation 1:1.15, this is, one unit (in monetary terms) of industrial capital damage leads 1.15 units of lost production.

The contribution of indirect damage in other economies accounts over 12% of total indirect damage. The propagation of damage is through shortages in intermediate inputs, as well as shortages in external demand (from The Netherlands). The regional and sectoral distribution of the indirect damage provides a picture of vulnerable links in the international chain value.

Recovery path

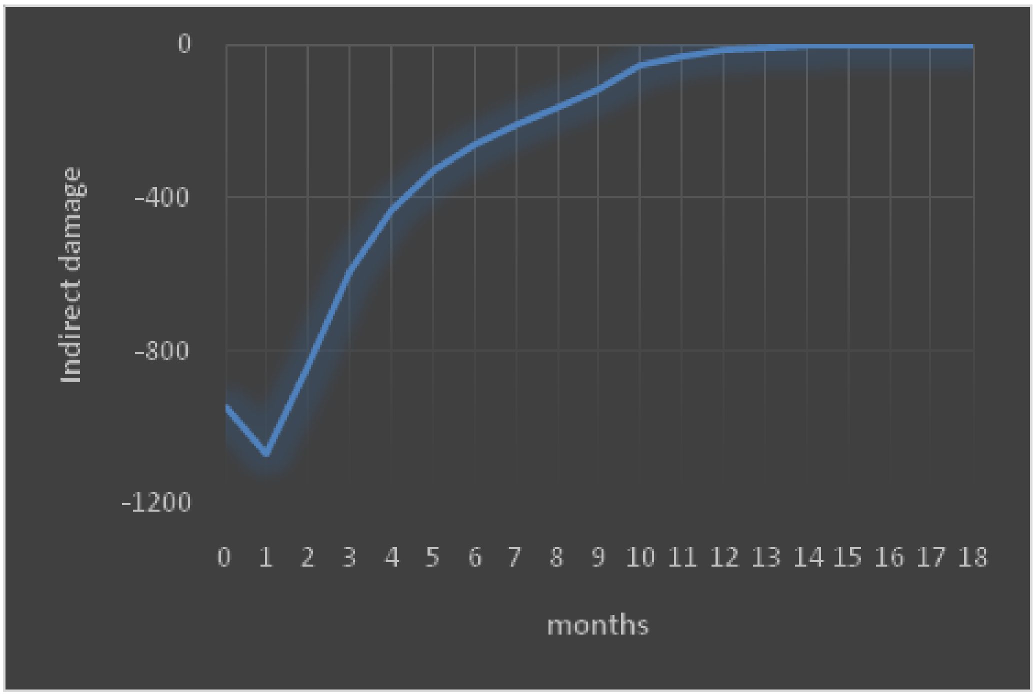


Figure 14 Recovery path

The Figure 14 shows the overall flood footprint recovery curve. This is certainly influenced by the model designing, although it coincides with the literature which establish a fast recovery for the first periods in the aftermath –when resources from emergency plans and international aid is allocated for reconstruction– which slows down as long as it approaches to the pre-disaster level. Actually it can be noted that even when the model predicts a recovery in one and a half years, the production is almost at its pre-disaster level from the 12th month. It must be noted that even when the overall production value can be as in the pre-disaster condition, it can be the case that imbalances between supply and demand persist.

It is important to notice that one month after the disaster there is an additional decrease in the productivity. As the indirect damage in month zero represents the productivity decrease associated to the direct damage, which only affects the national economy, the additional production decrease is explained by the productivity lost outside the flooded economy. This fact points out the relevance of the flood footprint evaluation in considering the broader damages of a flood, which spreads through economical interconnectedness.

Regional distribution of flood footprint

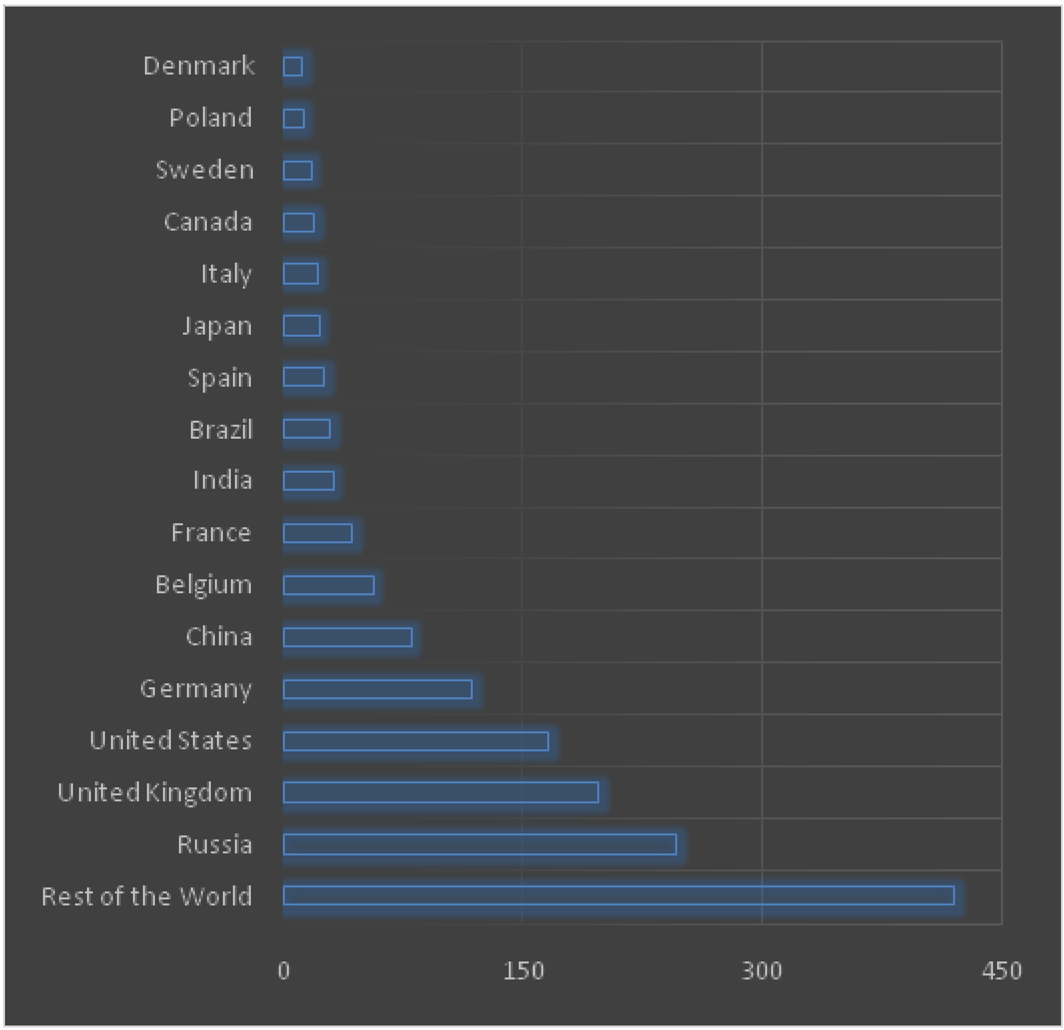


Figure 15 Indirect damage by country

The Figure 15 shows the regional distribution of the indirect damage from the flood in Rotterdam. The distribution is correlated with the economic trade of the Netherlands with the other countries. The case of the Rest of the World regions is just for illustrative purposes as it is the summation of the indirect damage in the 154 countries not individually considered in the database. The top 5 damaged countries represent 16% of the total indirect damage and 50% of the indirect damage outside the Netherlands. It also should be noted that most of the most affected countries are part of the case studies of the BASE project, and particularly within the WP6 which also considers the impact assessment in the United Kingdom and Denmark.

Sectoral distribution of flood footprint

Figure 16 shows the sectoral distribution of both, industrial direct damage and indirect damage in the Netherlands. The indirect damage inside the Netherlands sustain a relation 1:0.8 with the industrial damage in Rotterdam.

The sector which suffered the most the direct impacts of the flood is the Financial Intermediation sector with US$573 million (~ 13% of direct damage), followed by Food, Beverages and Tobacco; Coke, Refined Petroleum and Nuclear Fuel; and Construction sectors. All of them suffer a damage over US$300 million.

In relation with the indirect damage, it is again the Financial Intermediation sector which contributes the most to the damage with US$417 million (~ 12% of indirect damage inside the Netherlands). The other three most affected sectors are Real State Activities (US$395million); Renting of Machinery and Equipment and Other Businesses Activities (US$362million); and Wholesale Trade and Commission Trade sectors (US$328million), which together accounts over 30% of the indirect damage in the Netherlands.

It is remarkable the distribution of the indirect damage, which grouped mostly in Businesses and Professional sectors. The indirect damage in these sectors accounts for over 50% of the indirect damage in the Netherlands.

Several sectors suffer great indirect damage, although they do not have much physical damage. For example, the direct damage of the Real Estate Activities sector is US$8.76 million. However, the indirect damage in this sector is US$394.76 million. In addition, the direct and indirect damage of Renting of Machinery and Equipment and Other Businesses Activities are US$12.62 million and US$362.45 million, respectively.

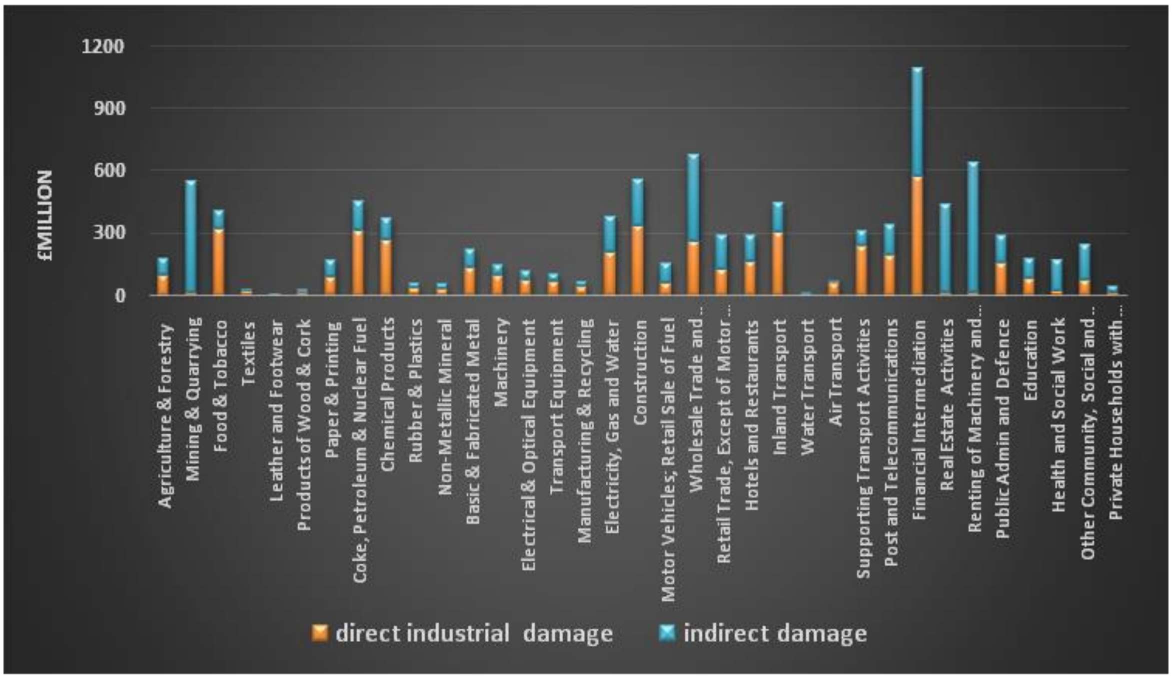


Figure 16 Flood footprint in the Netherlands

3.4 Policy recommendations

Our results show the significant proportion of indirect damage in the total impact of flooding events. It is also relevant the industrial distribution of the indirect damage, as this reveals vulnerability in sectors which is normally hidden under traditional impact assessment.

The case studies provides the following figures: For the case study of Sheffield, the indirect damage represents an additional 75% from direct damage. In the case study of the city of Rotterdam, the indirect damage is 1.15 times the direct damage, this is the indirect damage is 15% higher than direct damage.

From sectoral perspectives, sectors which do not suffer much physical damage may be highly impacted through knock on effects. For the case study of Sheffield, the most directly affected sectors are those which mainly rely on built structure, accounting for over 50% of the total damage. These are the sectors which would be directly benefited from investment in flooding defences, they would see a decrease in their insurance primes as instance. On the other hand, the analysis shows that service sectors are especially vulnerable to damage in public infrastructure, such as transport and energy supply. Increasing flooding defences in this ‘critical’ infrastructure would increase the spectrum of benefits to those business in the end of the supply chain. These sectors have a strong pulling up effect in the economy, and this could bring a faster recovery in the aftermath.

Direct damage in Manufacturing sector (accounting the 25% of direct damage) represent a shortage in intermediate inputs for other factories and services sectors. This represents a high constraint in productivity in other Manufacturing business and Service sectors, reinforcing the effect of damage in public infrastructure.

In the case study of Rotterdam, the direct damage of the Real Estate Activities sector is US$8.76 million. However, the indirect damage of the Real Estate Activities sector is US$394.76 million which is over 45 times as much as the direct damage. Therefore, these sectors need to take more responsibilities on the adaption, because they will benefit great if adaption measures are taken.

From regional perspectives, the flood disaster in one city may have impact on other countries. Because different countries are connected with the international trade, the initial damage in one city may influence other economies. In the case study, the flood in the city of Rotterdam has impact on other countries throughout the economic trade of The Netherlands with the other countries. The indirect damage on other countries is US$1,630 million which accounts for 32% of total indirect damage. The top 5 damaged countries represent 16% of the total indirect damage and 50% of the indirect damage outside The Netherlands.

In addition to the significant contribution of indirect damage to the total cost, the analysis reveals the vulnerability in economic sectors which are hidden to traditional impact assessment methods. The most affected sectors are those in the end of the value chain, which are considered as key sectors due to their ‘pulling’ effect to the economy.

From our results it is evident that effective investment in risk management and adaptation strategies must consider the analysis of indirect damage. Adaptation strategies considering this analysis would incorporate benefits for all stakeholders on the local/regional/national/international supply chains. This would provide an alternative way to allocate financial responsibility for flood risk mitigation interventions among all beneficiaries.

4 Agricultural adaptation across European regions

Luis Garrote, Ana Iglesias, Marianne Zandersen, Mette Termansen

4.1 Brief model description and progress in developments under Base project

4.1.1 The SARA framework

The estimation of agricultural adaptation in WP6 was performed by combining the suite of modelling tools described in Deliverable 6.1. These tools have been developed for the BASE project. The general framework is presented in Figure 17. The objective of the SARA framework is to link agricultural productivity, water availability and land use in an economic framework that allows estimating the projected evolution of agricultural production, accounting for climate and population change, economic development and technological and social evolution. The analysis of agriculture takes into account adaptation of rainfed and irrigated crops. Changes on rainfed agriculture are conditioned by climatic factors and are evaluated through the estimation of changes in agricultural productivity induced by climatic changes using the ClimateCropmodel. Impacts on irrigated agriculture are mostly conditioned by climate variability and water availability and are evaluated through the estimation of changes in water availability using the WAAPA model.

Impacts on agricultural production are also dependent on changes in management practices due to land use o crop share changes. These are estimated through the LAND USE and CROP SHARE specific models developed within BASE project. The suite of physical models is integrated in the SARA framework (developed for BASE) that accounts for the evolution of population, GDP, agricultural land use and other relevant socio-economic variables linked to climate change adaptation. The SARA model is used to estimate the effects of management changes in terms of land productivity and water availability on the economic value of agricultural production in terms of fraction of GDP.

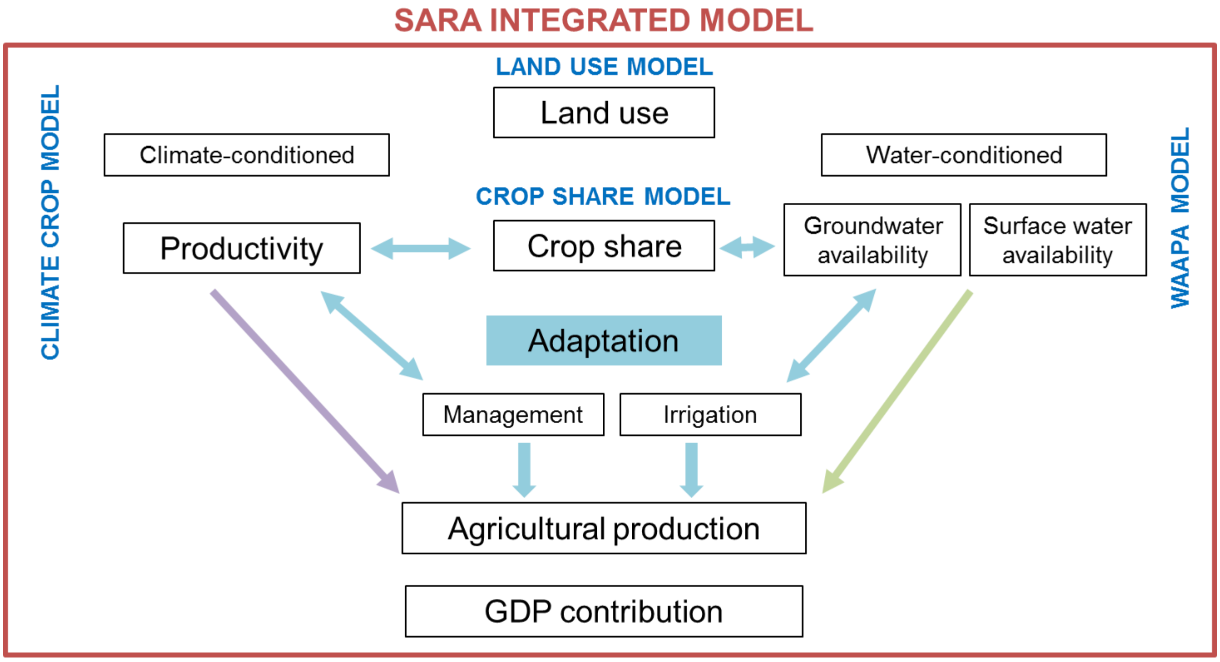


Figure 17 Approach adopted for the analysis of agricultural damage

In addition to climate forcing, management, technology and social factors dynamically affect the equilibrium between variables in SARA model components and introduce changes that represent the adaptation process. These effects are represented in the model by statistical relations between the physical variables and the socioeconomic variables at the country level.

SARA estimates agricultural production for both rainfed and irrigated agriculture using the results of the physical models (runoff, water availability, crop productivity, land use and crop share) and the socioeconomic models. Rainfed agricultural production in future scenarios is estimated from changes in area allocated to each crop and individual crop productivity, accounting for the expected projection of crop yield linked to technological evolution. The comparison of the value added by agriculture to GDP under stationary climate and under climate change scenarios provides a quantitative estimation of impact of climate change on agriculture as a fraction of GDP. Irrigated agricultural production in future scenarios is estimated from water availability. We make the hypothesis that irrigated agriculture is capable of adapting to climate variability through adequate crop selection and agricultural management provided that there is enough water to compensate for climate variability. Therefore the impact of climate change on irrigated agriculture is estimated by comparing future water availability with irrigation demand. Surface water availability is provided by the WAAPA model, while groundwater availability is estimated from expected changes in aquifer recharge. Water availability is compared to expected water needs for domestic and industrial uses in order to obtain water availability for irrigated agriculture. Water needs are obtained from public databases on water abstraction, accounting for the effect of non-consumptive uses and return flows. Changes in water needs are estimated from the expected bulk changes in population and economic activity and changes in water use intensity, which are in turn linked to socioeconomic variables, like per capita GDP or contribution of industry to GDP. The comparison of water availability for irrigation and water need provides an estimate of water deficit and thus an indication of climate change impact on irrigated agriculture.

4.1.2 Model components

a) ClimateCrop model

The objective of the ClimateCrop model is the estimation of changes in agricultural productivity of representative production systems in European agro-climatic regions. At each site, process-based crop responses to climate and management are simulated by using the DSSAT crop models for cereals (wheat and rice), coarse grains (maize) and leguminous (soybeans). Changes in the rest of the crops are derived from analogies to these main crops. For each of the sites we conducted a sensitivity analysis to environmental variables (temperature, precipitation and CO_2 levels) and management variables (planting date, nitrogen and irrigation applications) to obtain a database of crop responses. The resulting site output was used to define statistical models of yield response for each site. Our modelling approach incorporates the direct effect of CO_2 on crop productivity with the estimates. The analysis was performed in a worldwide coverage of point data representing agricultural systems, including 1114 points (400 European) in 79 agro-climatic regions (8 European).The impact on agricultural productivity was obtained by applying the statistical models to the expected values of temperature and precipitation at each site. The point data were aggregated at the country level using the results of the crop share model to produce expected changes in agricultural productivity in different agricultural systems under different climate scenarios. Model results were obtained for RCP4.4 and RCP8.5 in short term (2040) and long term (2070) time slices.

b) WAAPA model

The objective of the WAAPA is to simulate the operation of a water resources system to maximize water availability. Basic components of WAAPA are inflows, reservoirs and demands. These components are linked to nodes of the river network. WAAPA allows the simulation of reservoir operation and the computation of supply to demands from a system of reservoirs accounting for ecological flows and evaporation losses. From the time series of supply volumes, supply reliability can be computed according to different criteria. Other quantities may be computed using macros that repeat the basic simulation procedure: The demand-reliability curve, the maximum allowable demand corresponding to a given storage or the required storage volume to meet a given demand, all according to different reliability criteria.

In this study WAAPA model was used to estimate maximum potential water availability in the European river network applying gross volume reliability as performance criterion. Model topology was based on a division into 1260 subbasins following the “Hydro1k” data set (EROS, 2008). Naturalized streamflow was obtained from the results of the application of the PCRGLOBWB model (van Beek and Bierkens, 2009) to the Inter-Sectoral Impact Model Intercomparison Project (Warszawski, et al., 2014). The PCRGLOBWB model was run for the entire globe at 0.5 º resolution using forcing from five global climate models (GFDL-ESM2NM, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM and NorESM1-M) under historical conditions and climate change projections corresponding to the four Representative Concentration Pathways scenarios. In this study, RCP4P5 and RCP8P5 were selected for analysis. Three time slices were considered: historical (1960-1999), short term (2020-2059) and long term (2060-2099). Average runoff values were corrected for bias using the UNH/GRDC composite runoff field, which combines observed river discharges with a water balance model (Fekete et al., 2002). The reservoir storage volume available for regulation in every subbasin was obtained from the ICOLD World Register of Dams (ICOLD, 2003). Dams in the register with more than 5 hm^3 of storage capacity were georeferenced and linked to the corresponding storage capacity and flooded area. Environmental flows were computed through hydrologic methods. Monthly minimum required environmental flow was defined as the 10% quantile in the distribution of naturalized monthly flows.

Surface water availability was computed for each subbasin applying the WAAPA model. For each climate model a total of five scenarios were analyzed: one historical scenario and two (short term and long term) for each emission scenario. Water availability was routed through the river network and compared to the estimation of projected surface water abstractions obtained in the socioeconomic model under each emission scenario and socioeconomic pathway. The comparison produced estimates of surface water deficits or surplus. Groundwater availability was estimated as a fraction of exploitable groundwater resources per country. Exploitable fraction is assumed to depend on current groundwater use and recharge, which is in turn assumed to evolve as surface runoff computed from the PCRGLOBWB model. Groundwater availability was compared to projected groundwater abstractions to estimate projected deficit or surplus.

c) LAND USE model

The land use model is described in chapter 6 of this deliverable.

d) CROP SHARE model

The Land Use Share Model identifies the impacts of climate, irrigation and farm economic variables on crop choice throughout Europe. The estimation results are subsequently applied to predict future land use shares under a changing climate. The model is conducted using a multivariate fractional logit framework (Papke and Wooldridge, 1996) where the dependent variable (crop-shares) ranges between 0 and 1 and adds up to 1 within each grid cell.

Data used for the land use share model comprise land use data, climate data, farm management data and irrigation data. Land use data originates from CAPRI at HSMU level grid scale comprising 53 crop and animal activities. Climate data is provided by CMCC at a 14x14km grid scale. Climate data has been processed to be suitable for an agricultural land use model. FADN data consists of the economic key numbers, type of land use and activity at average farm level within each FADN region. Irrigation data originates from the GMIA map of FAO. Base year data used is 2004 and predictions are based on 2050 and 2100 for RCP4.5 and RCP8.5. The model is spatially explicit for EU28 and is analyzed at HSMU level. The land use share model only takes into account current agricultural land and does not apply assumptions or scenarios on changes in non-agricultural land use categories over time.

For the analysis we categorize land use into 6 crop shares deemed relevant for our analysis on impacts of climate on agricultural land use change: cereals, maize, soy & leguminous, vegetables, grass and other arable out of total utilized agricultural area within each grid cell. Independent climate variables included in the model include growing season length, growing degree days, total annual precipitation, total annual evapotranspiration and average soil moisture over growing season. Independent farm economic variables included comprise gross farm income, total assets, gross investment, total support for rural development and single farm payments. Finally, irrigation is represented by percentage irrigable area.

The prediction of future land use shares has been carried out based on climate scenarios while holding farm economic and irrigation variables constant.

e) Socio-economic scenarios

Input data for SARA are taken from some of the models that participated in the development The basic socioeconomic variables are population and GDP, which are taken from SSP datasets that include projections of population and GDP for each SSP made with different models (IIASA, OECD and NCAR, see also Appendix 10.1).The projections of population and GDP, together with the storylines corresponding to each SSP, provide an indication of the socioeconomic activity envisioned in each scenario. SARA model uses available data sets from other organizations, such as World Bank, Eurostat or FAO, to account for the basic structural variables through indicators (water abstractions by source and use type, fertilizer use, capital linked to agricultural production, fraction of cultivated land under irrigation, cereal productivity, agriculture contribution to GDP, etc.). These indicators are linked through statistical models that describe the world current socioeconomic structure in quantitative terms.

One critical aspect to estimate the impact of climate change in agriculture is the total value of agricultural production, which in SARA is defined as a fraction of GDP. This figure is estimated from two different methods. Figure 18 presents the projection of agriculture value added (in M$) estimated using the two alternative methods. In the first case, future agriculture value added is estimated in each country from the projection of GDP and the model that relates agriculture value added (in %) as a function of per-capita GDP. In the second case, agriculture value added is estimated from the projections of cultivated area and yield derived from the simulations with the crop module of the SARA model, as detailed in the model description.

The graph on the left shows the comparison for the short term time horizon (2040) and the graph on the right shows the comparison for the long term time horizon (2070). Both methods produce a reasonable agreement.

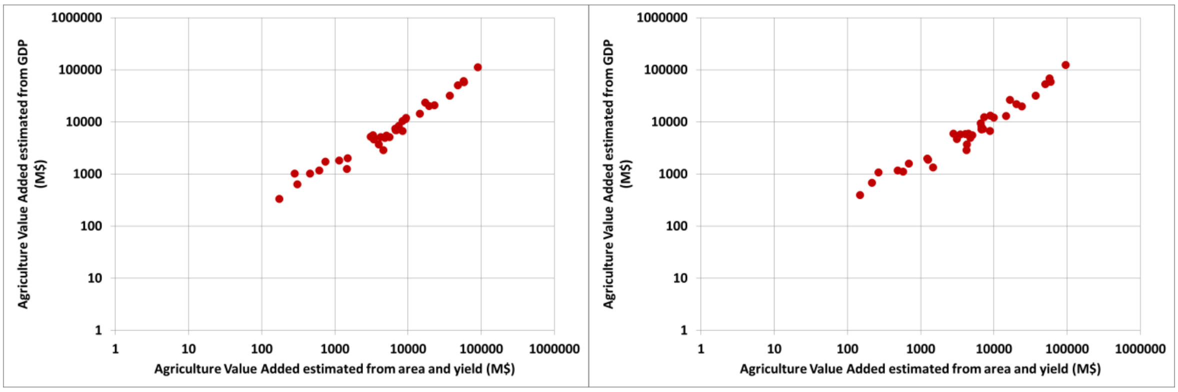


Figure 18 Comparison between agricultural value added estimated from GDP (as a function of per-capita GDP) and from cultivated area, yield and productivity, for the short term scenario (2040, left) and for the long term scenario (2070, right)

4.1.3 Analysis of adaptation

Overall approach

Adaptation is incorporated into the socioeconomic model through a set of measures that may compensate in part the impact of climate change. Two main categories of adaptation measures are contemplated: management and development of additional irrigation.

Management

Adaptation through management includes a set of measures to minimize negative impacts on agriculture and to increase agricultural productivity. A list of specific measures is:

- Improvement of resiliency and adaptive capacity. This can be achieved through the implementation of regional adaptation plans to enhance effectiveness of adaptation measures, improvement of monitoring and early warning
- Development of innovation and technology to improve agricultural practices and to reduce costs. This can be achieved through more intensive use of agricultural machinery and development of better fertilizers, change in crops and cropping patterns to decrease economic risk to farmers, development of climate change resilient crops

- Improvement of water use efficiency to increase water availability. This can be achieved through investment in improved water distribution and irrigation technology improvement of water charging and trade, management practices to improve soil moisture retention capacity.

Irrigation

Adaptation through development of additional irrigation includes a set of measures to compensate for loss of agricultural production through irrigation. The list of specific measures is outlined below:

- Extending the area by using the land already equipped for irrigation, but not currently irrigated. This requires enough water resources to allocate them to irrigation.
- This can be achieved through development of additional groundwater, integration of demands in conjunctive systems, increased storage through large-scale reservoirs or small-scale water reservoirs on farmland, wastewater recycling for agriculture

Efficiency and effectiveness

The basis for the estimation of the efficiency and effectiveness of adaptation measures in agriculture is the assessment of adaptive capacity by country produced by Ad-Witch. The adaptive capacity was transformed into an adaptive capacity index, ranging from 0 (no adaptive capacity) to 1 (full adaptive capacity) that describes the extent to which each country is able to develop the required adaptation measures under each scenario described by SSPs.

Adaptation effectiveness describes the fraction of damages that can be compensated through adaptation. Adaptation effectiveness has been computed through a composite index that depends on three factors: adaptive capacity, intensity of the damage and management potential. Intensity of the damage is computed based on the expected crop productivity changes for rainfed agriculture and on water deficit for irrigated agriculture. Management potential describes the capacity of each country to develop good management practices and depends on variables linked to economic development (research and development, fertilizer use, use of technology in agriculture, etc). In the case of irrigation it describes the potential to develop new irrigation projects and depends on water availability and economic development.

Adaptation efficiency refers to the cost at which damage can be reduced. Adaptation costs are estimated as a function of basic economic variables, using ratios observed in the datasets corresponding to the current scenario. For rainfed agriculture the key variable is the required additional increase in crop productivity due to technology of management to compensate for climate change damages. The cost of this additional productivity increase is estimated from current economic indicators (elasticity of crop yield versus economic contribution of agriculture to GDP). In the case of irrigated agriculture the key variable is the required additional irrigation development to compensate for the decrease in crop productivity. In this case the cost is estimated on the basis of standard costs for irrigation development.

Assumptions and limitations

Uncertainty reflects imperfect knowledge; here the uncertainty is derived from the climate, the agronomic, land use and the economic models, and the choices of adaptation scenarios. In addition to the uncertainty, the results present a range of variation, since we have used several scenarios, several geographical locations within each agro-climatic area, several crops and land use choices for the simulations.

A main source of uncertainty is derived from the climate scenarios, especially in the Mediterranean area where the important increase in climate variability is not included in the climate projections used. The adaptation choices represent the partial view of future development of the agricultural system. Although these adaptation scenarios are based, in part, on the case studies, they do nto represent the multitude ways for possible local implementation.

The main limitations of the analysis derive from the imperfect data (e.g. limited representative sites in each agro-climatic region), limited observations for model validation, limitation of the models to represent complex reality (e.g. climate models, crop models and economic models are a simplification of the climate, agricultural, and social systems), and the assumptions about the future (e.g. evolution of incentives to farmers, land use, technology and biotechnology).

The uncertainty of the models used is derived from the limitations if the model equations to represent agro-ecosystems, land and water dynamics and the data used to validate the imperfect models. The aggregation of the results at the country level is al further soure of uncertainty.

The strength our model results is derived from the recognition that approach and models used here are widely used and that the data to validate the models is consistent with the climate data used to define the baseline of the study (same time period). Crop varieties evolve continuously and have advanced enormously in relation to crop resistance to pests and diseases (e.g. GM crops); nevertheless the main features of crops that determine response to temperature variations (phenology) are quite stable and the choices of crops in each agro-climatic region to define land use are also quite stable. Furthermore, the framework consideration of common assumptions among the crop, water and land use model, are also a strength of the results.

4.2 Verification and validation

The approach adopted to incorporate adaptation is SARA is tested and validated in the case studies analyzed in BASE that are related to agriculture. The validation consists on verifying that adaptation measures adopted in case studies through the participatory process described in Deliverable 5.3 are contemplated in the model. Table 15 presents a list of case studies related to agriculture and the main adaptation measures identified by the stakeholders. In general, there is good agreement and individual measures are well aligned with the main adaptation strategies formulated in SARA.

Table 15 BASE Case studies and the type of adaptation in Agriculture that is addressed.

Case study (1)	Region (2)	Adaptation category addressed (3)	Implementation of the adaptation measures (4)
Holstebro, Denmark	NW	Management Irrigation	Water management and farmers as water managers Improve adaptive capacity Cooperation with municipalities Co-benefits of water scarcity measures and flooding measures Construction of a dam
South Moravia, Czech Republic	CE	Management Irrigation	Measures focus on improving water access to farmers Potential measures not jet implemented, only being discussed
Usti Region, Czech Republic	CE	Management Irrigation	Process of adaptation to extreme events initiated Low participation of stakeholders A survey shows that farmers perceive the need of adaptation strategies to less water
Alentejo, Portugal	SM	Management Irrigation	Measures focus on improving water use efficiency Water retentiondams Farm lakes Collective actions defined involving stakeholders and institutions responsible for the implementation
Tagus basin, Spain	SM	Management Irrigation	Measures focus on the use of non-conventional resources, such as water reuse or recycling Important role of conjunctive use of surface and groundwater Measures adopted and published in the water district management plan
Doñana, Spain	SM	Management Irrigation	Multi-actor derived measures focus on preserving ecosystems Co-benefits of water scarcity measures and flooding measures Measures adopted and published in the water district management plan

(1) See Deliverables D5.1 and D5.2 for a complete description of the Case Studies.
(2) Regions in the economic model. See Deliverable D3.3 for a complete description of the AD-WICH economic model and the regional aggregation in four regions: NA, NW, CE and SM. The NA region does not include an agricultural case study, however, this is not a limitation since there were not significant regional damages on crop production derived from water scarcity in the NA region.
(3) Measures implemented in the SARA framework and described in Section x.x.
(4) See Deliverable D5.2 for a complete description of the concrete measures and their implementation of in the Case Studies.

4.3 The reference scenario without adaptation

The results of model component are presente in this section. Results of the evaluation of climate change adaptation in agricultureare presented in the following sections.

4.3.1 ClimateCrop model

The output from ClimateCrop model are expected changes on agricultural productivity under different climate scenarios. The model works on a set of locations with different agricultural conditions, obtaining changes of croductivity for a specific crop at that locations. These results were aggregated at the country level using the results of the crop share model. Model results are presented on Figure 19, which shows average expected changes in agricultural productivity by country for RCP4.4 and RCP8.5 in short term (2040) and long term (2070) time slices.

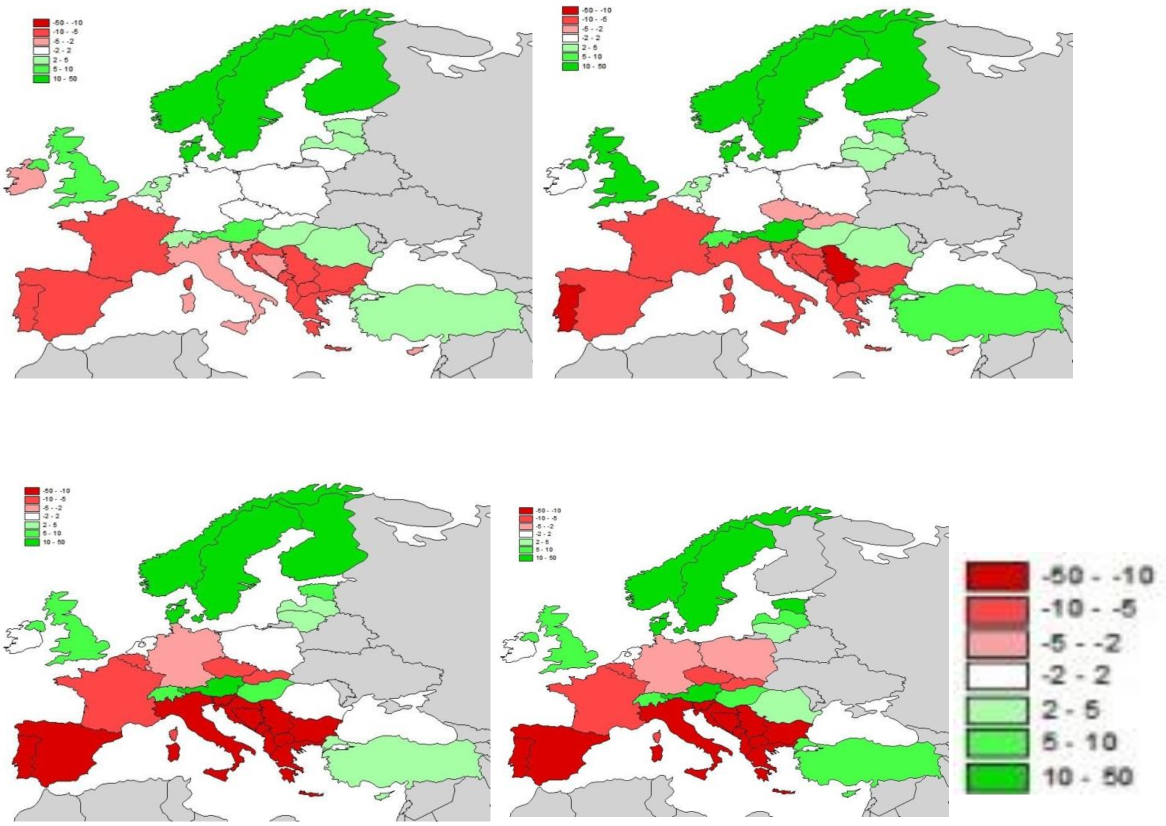


Figure 19 Average results by country of changes(%) in agricultural productivity. Emission scenarios RCP4 (top) and RCP8 (bottom), in short term (left) and long term (right) time slices.

Results show an increase of agricultural productivity in Northern and Central Europe and a decrease in Southern Europe, with the exception of Turkey. In RCP8 emission scenario

Germany, Poland reverse the positive trend. Changes are more intense in RCP8 emission scenario and in the long term.

4.3.2 Water availability

The WAAPA model produces expected changes on surface water availability under different climate scenarios. The model works on a a set of 1200 subbasins, obtaining changes of surface water availability for a specific points in the river network. These results were aggregated at the country level by assigning water availability generated in its own territoryto every country. Therefore the analysis dos not account for water transfers between countries, which were taken into account in the socioeconomic model. Model results are presented on Figure 20, which shows average expected changes in agricultural productivity by country for RCP4.4 and RCP8.5 in short term (2040) and long term (2070) time slices.

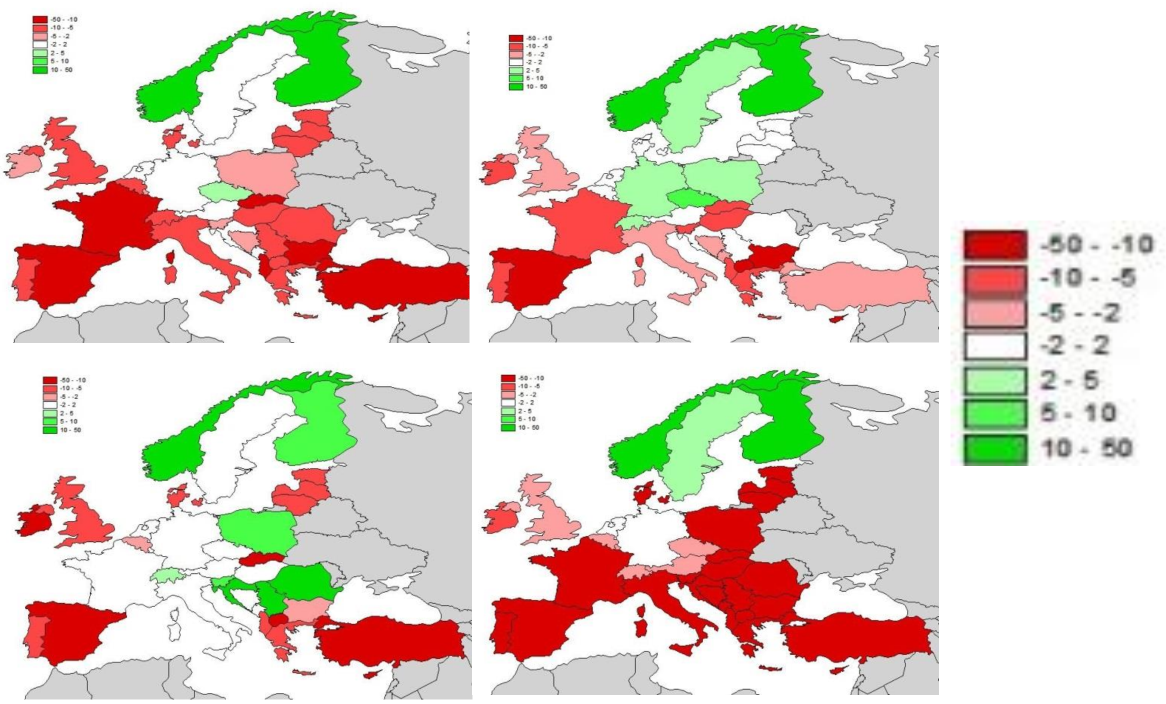


Figure 20 Average results by country of changes in surface water availability. Emission scenarios RCP4 (top) and RCP8 (bottom), in short term (left) and long term (right) time slices.

Results show a general decrease of water availability in Southern Europe and a moderate increase in the North. The trend is different in RCP4 and RCP8 scenarios. While for RCP8 there is a clear internsification of water scarcity in the long term, water availability increases in the long term time slice for RCP4 emission scenario.

4.3.3 Land Use

The results from the LAND USE model are presented on Figure 21, which shows average expected changes in agricultural land by country for RCP4.4 and RCP8.5 in short term (2040) and long term (2070) time slices.

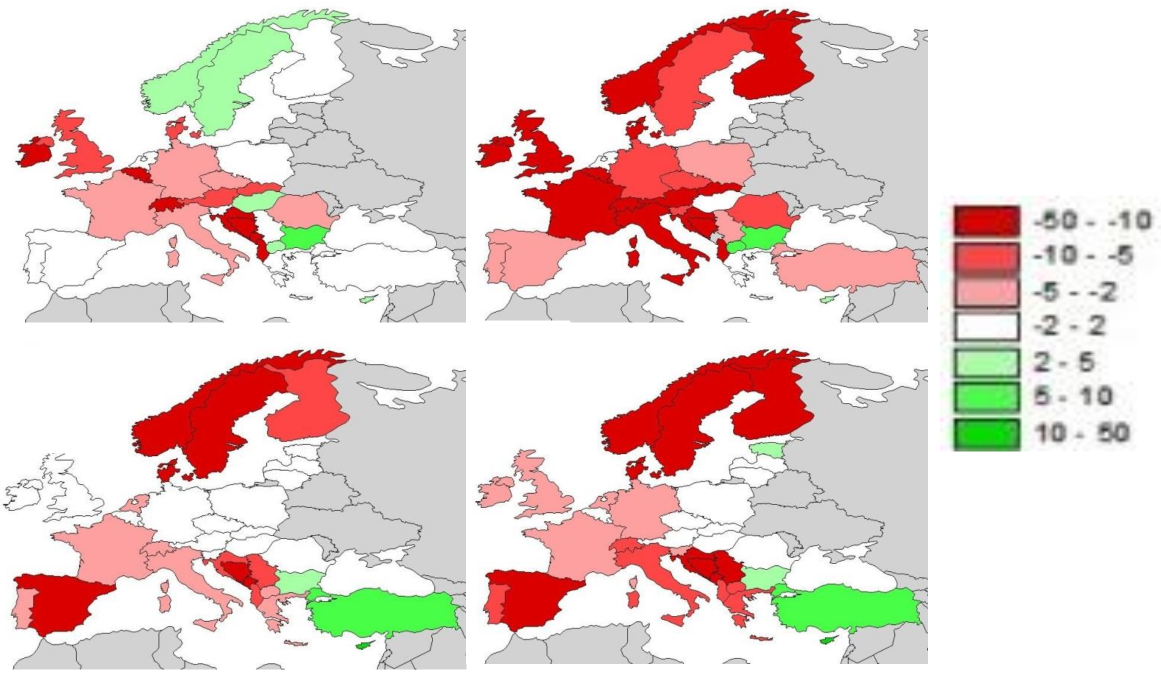


Figure 21 Average results by country of changes in agricultural land. Emission scenarios RCP4 (top) and RCP8 (bottom), in short term (left) and long term (right) time slices.

Results show a general decrease of agricultural land in Eurooe, with the exception of a few countries. The decrease of agricultural alnd is more intense in RCP4 than in RCP8 emission scenario.

4.3.4 Crop Share model

The CROP SHARE model produces an estimation of the land allocated to each type of crop under different cliamte change scenarios. The results obtained are summarized in Figure 22, which presents the crop share distribution for the four European regions under consideration under the two emission scenarios (RCP4 and RCP8) and in the two time slieces (short term and long term).

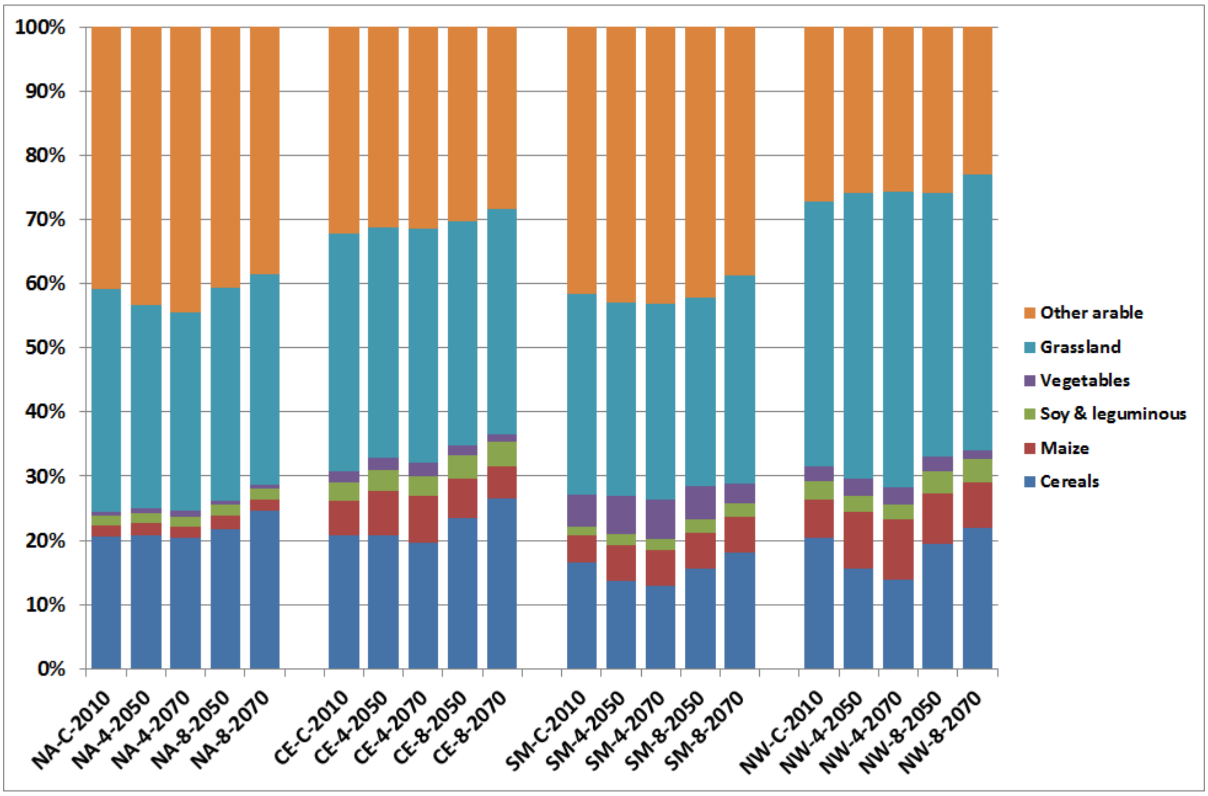


Figure 22 Simulated changes in land use shares by region (NA: North Artic, CE: Central Europe, SM: Southern Mediterranean and NW: North West). C-2010: Baseline, 4-2050: RCP4, short term, 4-2070: RCP4, long term, 8-2050: RCP8, short term, 8-2070: RCP8, long term.

The share of cereals (Wheat, Durum wheat, Rye and Meslin, Barley, Oats, Paddy rice, other cereals) is predicted to decline significantly across all regions under scenarios rcp4.5_2050 and rcp8.5_2100. Under rcp4.5_2100 and rcp8.5_2050, the model predicts an apparent shift of the share of cereals from the Northern Arctic and Central-Eastern climate region towards Southern Mediterranean and North Western climate regions. While the shift in shares of cereals evens out at EU28 the decline in cereals across all regions under rcp4.5_2050 and rcp8.5_2100 reduced cereal shares to between 13 and 17.5% compared to an EU28 share of 20.4 % in the base year.

Maize (grain and fodder) is predicted to increase significantly compared to the base year in all regions apart from in the Central-Eastern climate region. In the latter region, maize is estimated to decrease by ca. 8% under rcp4.5_2100 and rcp8.5_2050. Increases in the share of maize are particularly pronounced in the Northern-Arctic regions and with increasing shares as the climate signals increase (from + 264% under rcp4.5_2050 to +465% under rcp8.5_2100). Overall in EU28, maize is predicted to increase from the current 5.3% to 7.8% or agricultural land by 2100 under rcp 8.5.

Soy and leguminous crops (Rapeseed, Sun flower, Soya) are predicted to increase significantly in the Southern-Mediterranean climate region. Under the rcp4.5, the share of soy and leguminous is expected to increase by some 40%. Under the rcp8.5 scenario, this crop type would according to the model predictions increase its share by more than 80% in 2050 and by 40 % in 2100 compared to the base year. In the Northern-Arctic and Central-Eastern regions, soy and leguminous is set to decline by up to 13%. In the North-Western region, a decrease of close to 10% is predicted under rcp4.5_2050 while rcp4.5_2100 and rcp8.5_2050 foresee increases of 18%. Overall in EU28, the share of soy and leguminous of 2.54% of agricultural land in the base year is predicted to remain fairly stable.

Vegetables (are set to increase significantly for the Central-Eastern, and North-Western regions Under rcp4.5 2050 & 2100 and rcp8.5_2050, the share of vegetables are estimated to increase by 60% and by 186 % - 212 % under rcp8.5_2100. The Southern-Mediterranean region may see a modest increase (5-15%) under rcp4.5 2050 & 2100 and rcp8.5_2050 but a more than 100% increase under rcp8.5_2100. In the Northern-Arctic region, the share of vegetables is predicted to decrease by up to 14 % in all scenarios with the exception of rcp8.5_2100 that predicts an increase of 35%. Overall in the EU28, the current share of vegetables of 2.22% is predicted to increase up to 5.2% of agricultural area under rcp8.5_2100.

Grassland (Extensive grass, Intensive grass) is predicted to increase in the Northern-Arctic climate region only, by between 28-34% compared to today. Grassland is set to decline by 9%-15% in the other regions but most strongly under rcp8.5_2100 where the North-western and Southern-Mediterranean may see a decline of between 25%-34%. Overall in EU28, Grassland is predicted to decline from the current 38% of agricultural area, with the maximum decline up to 31% under rcp8.5_2100.

4.4 Cost and benefits of the Reference scenario

The following tables present the estimation of damages to agriculture in the four European regions considered in the analysis. The values correspond only to countries where negative impacts have been detected. Positive impacts were obtained in several countries, especially in the North Artic region, but they have not been included in the summary tables.

Global impacts to European agriculture are presented in Table 16 and Figure 23 for the short term (2040) and the long term (2070) scenarios. The table presents damages to agriculture per region in terms of current (2010) GDP. Only negative impacts are considered in this summary table. Total damagesrange from 0.05 to 0.3 % of GDP. The areamost affected is the Southern-Mediterranean region, with impacts close to 1% in some scenarios. Impacts are higher in the RCP8 emission scenario and long term (2070) and comparatively smaller in the RCP4 scenario and in the short term (2040).

Table 16 Expected damages to agriculture (0.001 % current GDP) in European regions in the short term (left) and long term (right) time horizons for RCP4 and RCP8 scenarios under SSP2, SSP3 and SSP5

	2040		2070	
	RCP4	RCP8	RCP4	RCP8

	SSP2	SSP3	SSP5	SSP2	SSP3	SSP5	SSP2	SSP3	SSP5	SSP2	SSP3	SSP5
CE	-32	-31	-40	-45	-35	-47	-39	-34	-47	-53	-52	-60
NA	0	0	0	0	0	0	0	0	0	0	0	0
NW	-112	-19	-183	-20	-19	-184	-198	-17	-198	-202	-27	-203
SM	-334	-163	-481	-321	-150	-468	-434	-152	-704	-594	-313	-798
TOTAL	-145	-63	-214	-114	-61	-213	-206	-60	-286	-257	-115	-319

As can be seen in Figure 24, the socioeconomic scenario which presents higher impacts is SSP5, mostly because it is linked to the higher increase in GDP and economic activity, and therefore exerts the greatest pressure on natural resources. The socioeconomis scenario with least impact is SSP3 due to its slow technology development, which hinders big improvements in crop productivity.

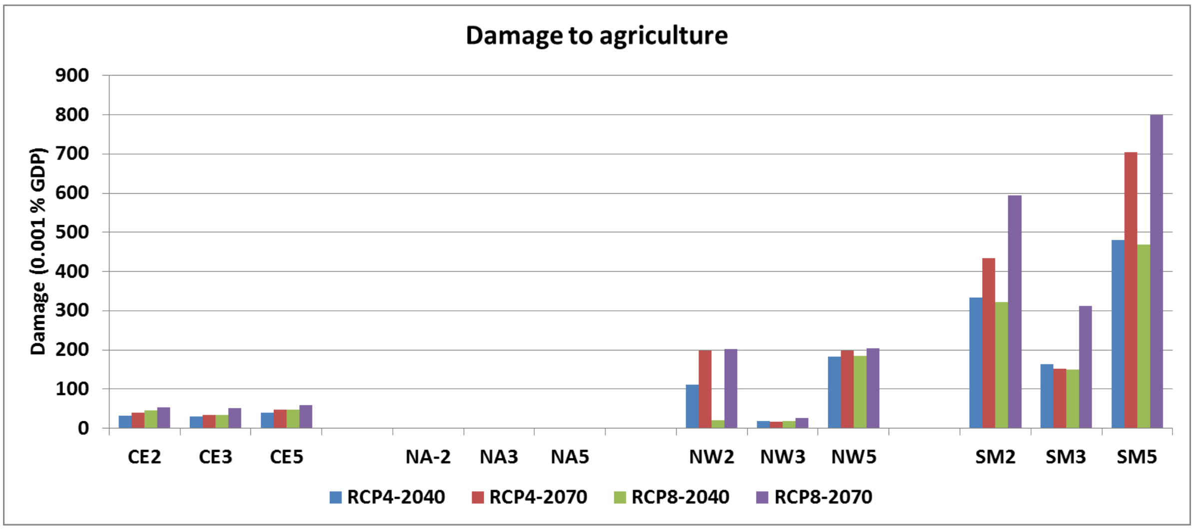


Figure 23 Compared values of expected damages to agriculture (0.001 % current GDP) in European regions in the different scenarios considered.

4.5 Cost and benefits of Adaptation strategies

The results of the evaluation of cost and benefits of adaptation measures are presented in this section. The presentation is divided into the two main strategies for adaptation: improved management and development of additional irrigation.

4.5.1 Management

Table 17 presents the estimation of damage reduction obtained through strategies linked to improved management. Damage reductions in terms of GDP are greatest in the Southern-Mediterranean region, but this is because this region is affected the most. Reductions in this region only represent a relatively small fraction of damage. Differences across socioeconomic pathways are slightly larger than differences across regions. The largest reductions are obtained under SSP3, with global values close to 70% of damage, and the smallest reductions are obtained for SSP5, with reductions around 60% of damage. The region where management is most effective is North Western Europe, where damage is almost completely compensated through adaptation under SSP3. The Southern Mediterranean region is where adaptation is least effective, with reductions smaller than 50% of damage under SSP5 for the long term scenario.

Table 17 Expected damage reduction (0.001 % GDP) obtained through improved management in European regions for RCP4 and RCP8 scenarios under SSP2, SSP3 and SSP5. The short term (2040) time horizon is shown on the left and the long term (2070) time horizon is shown on the right

	2040						2070					
	RCP4			RCP8			RCP4			RCP8		
	SSP 2	SSP 3	SSP 5	SSP 2	SSP 3	SSP 5	SSP 2	SSP 3	SSP 5	SSP 2	SSP 3	SSP 5
CE	20	19	25	32	27	31	25	23	26	36	38	35
NA	0	0	0	0	0	0	0	0	0	0	0	0
NW	79	18	121	20	19	122	126	17	135	129	26	139
SM	209	114	270	215	111	285	244	106	341	286	190	382
TOTA L	94	45	127	79	47	134	121	68	146	99	65	155

The cost of adaptation was estimated also in terms of GDP. The estimation of cost was made on an annual basis. Only actions with cost smaller than reduction of damage were considered in every country. Results for the cost of adaptation through improved management are presented in Table 18., following the same structure of the previous tables and also in terms of fraction of current GDP. Costs are clearly higher for the Southern Mediterranean region, reaching almost 0.3% of GDP in some scenarios. The largest costs relative to reduced damages occur in the SSP3 scenarios, with values around 70% of reduced damage. The SSP5 scenario presents the smaller relative costs because countries are most affected under this scenario and there are more opportunities for adaptation.

Table 18 Expected cost (0.001 % GDP) of improved management measures in European regions for RCP4 and RCP8 scenarios under SSP2, SSP3 and SSP5.The short term (2040) time horizon is shown on the left and the long term (2070) time horizon is shown on the right

	2040						2070					
	RCP4			RCP8			RCP4			RCP8		
	SSP2	SSP3	SSP5	SSP2	SSP3	SSP5	SSP2	SSP3	SSP5	SSP2	SSP3	SSP5
CE	2	2	3	3	2	3	2	2	4	3	3	5
NA	0	0	0	0	0	0	0	0	0	0	0	0
NW	9	2	16	2	2	16	16	1	23	15	2	21

SM	143	62	191	143	47	204	161	49	236	187	91	281
TOTAL	45	19	61	43	15	65	48	30	58	53	23	66

The distribution by country of costs and benefits of adaptation through improved management is shown in Figure 24. The graphs present damage reduction as a function of cost for each RC and time horizon. The results show great variability, but in general costs are significantly smaller than benefits in most countries.

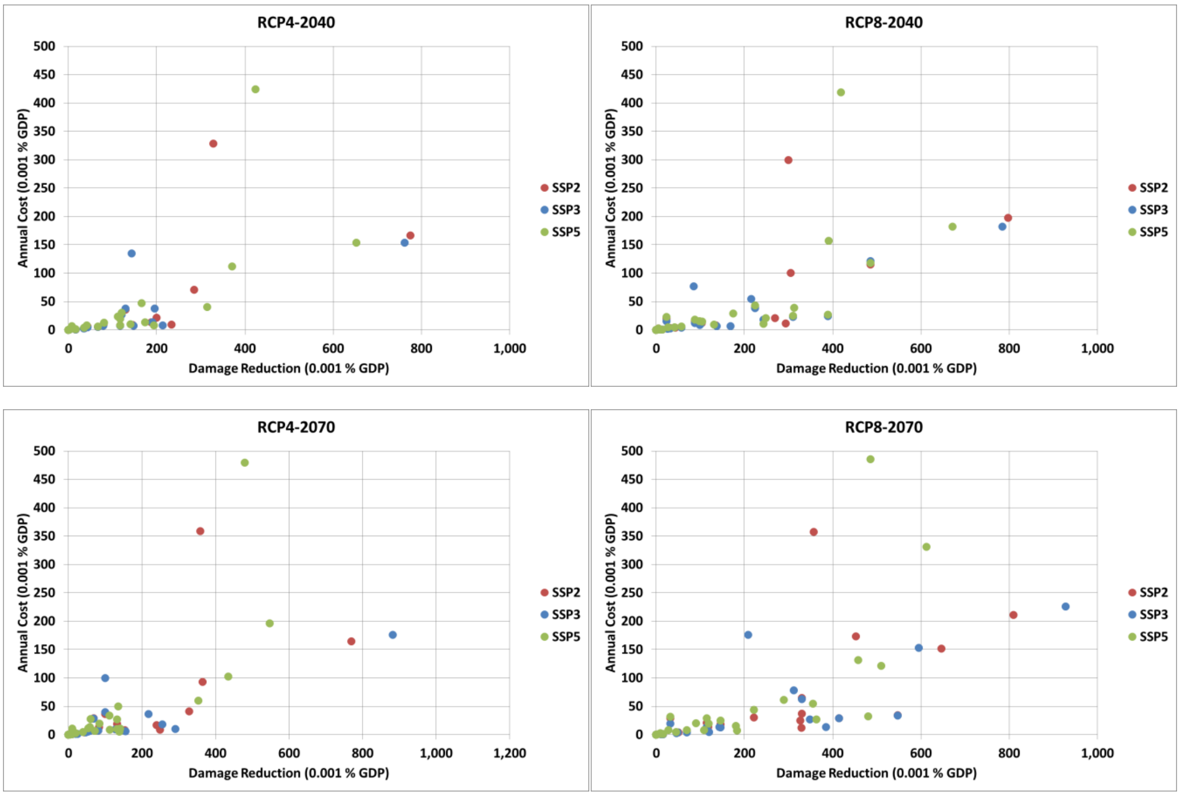


Figure 24 Relationship between damage reduction through management strategy and annual cost for individual countries in the three SSP scenarios. Upper row: short term (2040). Lower row: long term (2070). Left column: RCP4. Right column: RCP8.

4.5.2 Irrigation

The following table presents the estimation of damage reduction obtained through strategies linked to irrigation development. Damage reduction is comparatively much smaller than in the case of improved management because irrigation is severely limited by water availability. The relative behaviour of damage reduction across regions and scenarios is similar to that of management. The largest reductions correspond to SSP3 and the Southern Mediterranean region.

Table 19 Expected damage reduction (0.001 % GDP) obtained through irrigation development in European regions for RCP4 and RCP8 scenarios under SSP2, SSP3 and SSP5

	2040						2070					
	RCP4			RCP8			RCP4			RCP8		
	SSP2	SSP3	SSP5	SSP2	SSP3	SSP5	SSP2	SSP3	SSP5	SSP2	SSP3	SSP5
CE	3	3	4	6	5	6	4	4	5	7	7	7
NA	0	0	0	0	0	0	0	0	0	0	0	0
NW	15	6	23	5	5	23	23	7	25	23	8	25
SM	35	20	45	39	23	49	41	19	56	50	36	62
TOTAL	16	9	22	15	10	24	20	12	25	18	13	28

The cost of adaptation through irrigation is presented in Table 20. Adaptation cost is smaller than in the case of management, because if the infrastructure is ready (the land is equipped for irrigation) and water is available irrigation is relatively inexpensive. In the few cases where new irrigations projects should be developed the cost is much higher. Highest costs correspond to SSP5 and Southern Mediterranean region.

Table 20 Expected cost (0.001 % GDP) of irrigation measures in European regions for RCP4 and RCP8 scenarios under SSP2, SSP3 and SSP5)

	2040						2070					
	RCP4			RCP8			RCP4			RCP8		
	SSP2	SSP3	SSP5	SSP2	SSP3	SSP5	SSP2	SSP3	SSP5	SSP2	SSP3	SSP5
CE	2	2	2	3	2	3	2	2	2	3	3	2
NA	0	0	0	0	0	0	0	0	0	0	0	0
NW	5	2	8	2	2	8	7	2	8	7	2	8
SM	11	7	15	13	8	16	13	7	18	16	12	20
TOTAL	6	3	7	5	4	8	7	4	9	6	5	10

The distribution by country of costs and benefits of adaptation through irrigation development is shown in Figure 25, using the same scale as in the case for management. It can be seen that damage reduction is much smaller than in the case of management. The variability is also smaller, especially in the case of RCP 4.5, where the effectiveness of irrigation is very small.

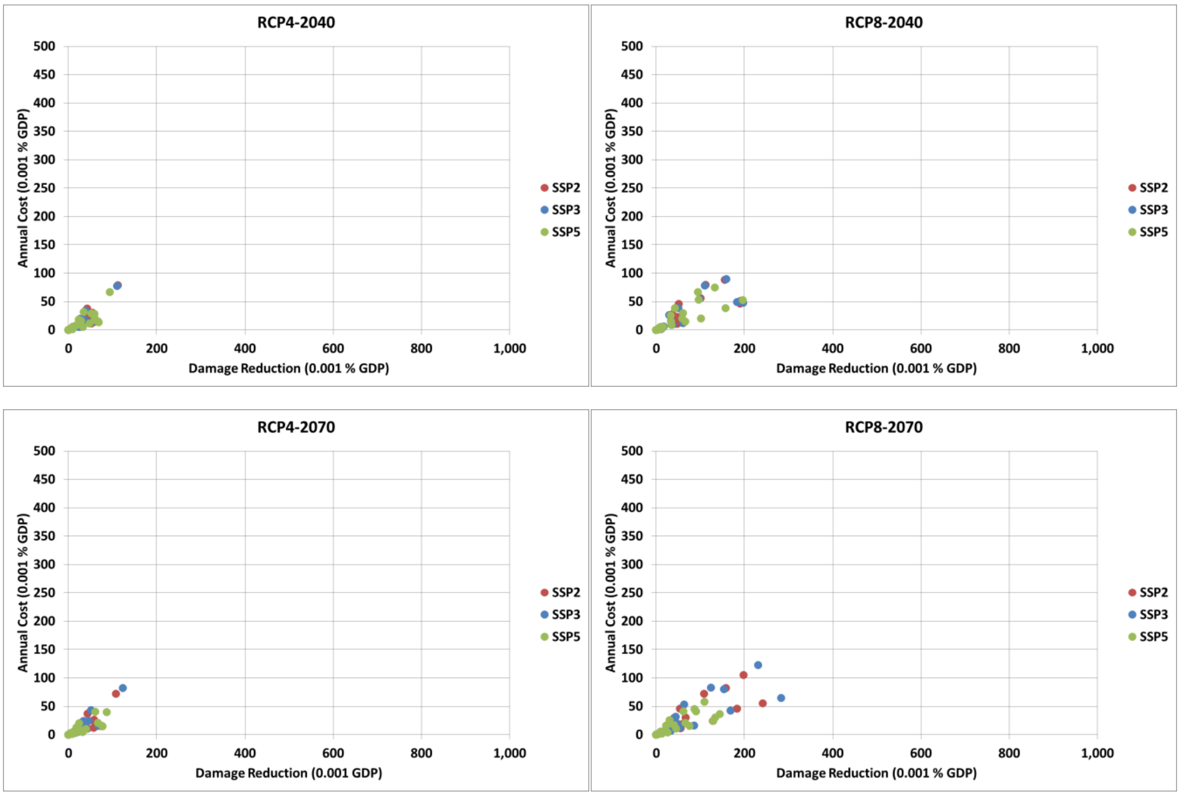


Figure 25 Relationship between damage reduction through irrigation strategy and annual cost for individual countries in the three SSP scenarios. Upper row: short term (2040). Lower row: long term (2070). Left column: RCP4. Right column: RCP8.

4.5.3 Summary

The results obtained in the analysis of cost and benefits of adaptation strategies are summarized in Figure 26. The figure shows, for each RCP and time horizon, the comparative effects of the two adaptation strategies analyzed under the three SSPs for the four European regions under consideration. Positive values of the bars correspond to benefits and negative values to damages. Total damages to agriculture are divided in three categories. The damage remaining after adaptation is represented in dark red. The cost of the adaptation is represented in pink. The remaining value is represented in green and it corresponds to the damage reduced due to adaptation, after adaptation costs have been taken into consideration. The following conclusions can be extracted from this figure.

Regional differences dominate for all emission scenarios, time horizons and socioeconomic conditions. The four European regions present a distinct behavior with respect to climate change effect on agriculture. The two extremes are represented by the North Artic region, which shows positive effects in all cases, and the Southern Mediterranean region, which shows significant negative effects in all cases. The Central European shows minor negative impacts and the North Western regions shows moderate negative impacts.

The two regions with benefits or minor impacts (NA and CE) show very little sensitivity to emission or socioeconomic scenarios, while the two most affected regions (NW and SM) show important sensitivities to socioeconomic scenarios and, to a lesser extent, to emission scenarios. The scenario that produces the most important impacts is SSP5, especially under emission scenario RCP8. Socioeconomic scenario SSP3 produces comparatively less impacts. Scenario SSP2 shows an intermediate effect.

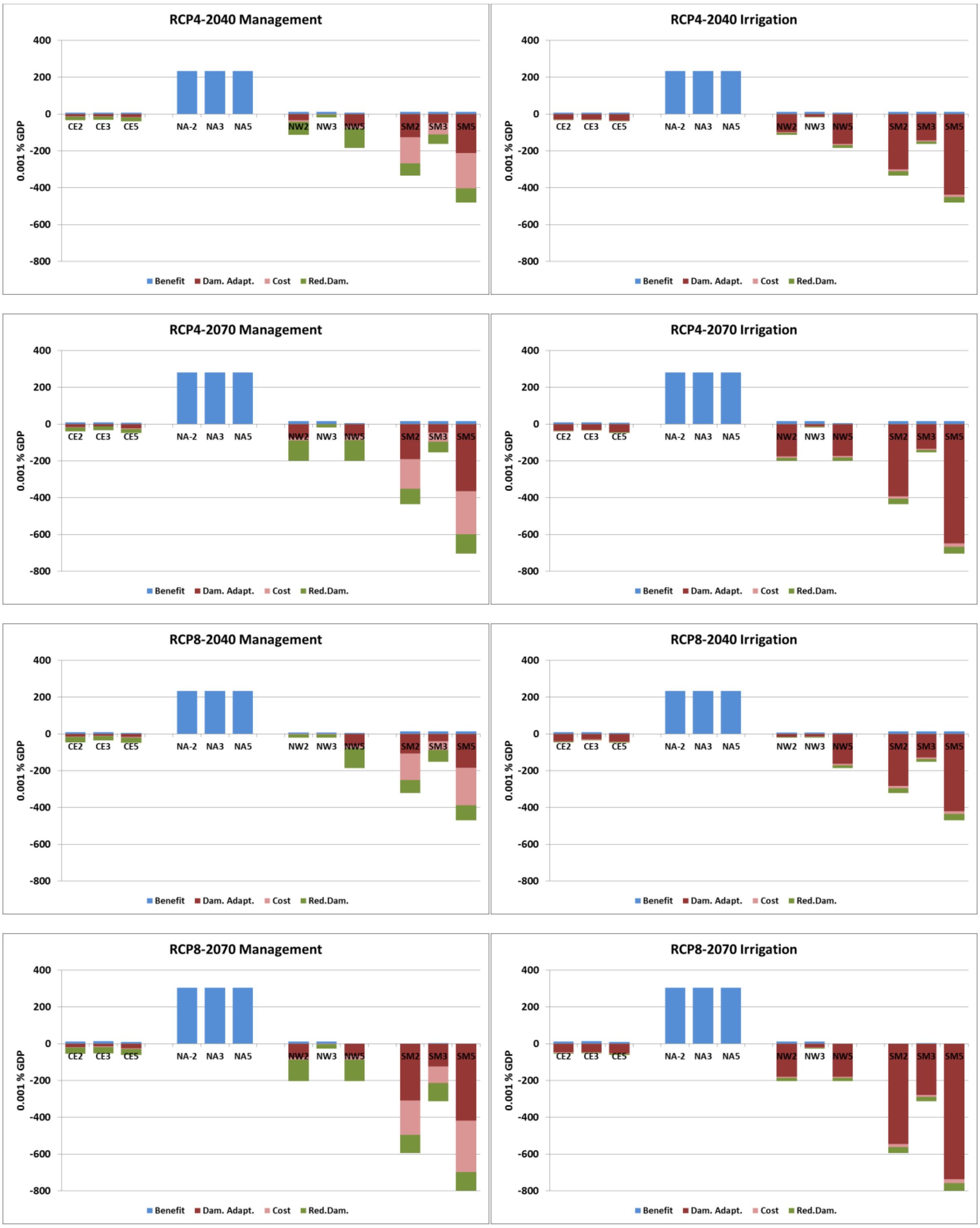


Figure 26 Results of cost and benefit of adaptation for the two strategies: management (left) and irrigation (right).From top to bottom: RCP4 short term, RCP4 long term, RCP8 short term and RCP8 long term.

The strategy of improved management is more effective than development of irrigation. If the cost of adaptation is accounted for, the damage avoided through irrigation is significantly smaller than the damage avoided through management. A comparison is presented in Figure 27, where the damage avoided through adaptation is presented for all regions and scenarios considered. Management shows a large potential for the Central European and North Western regions, with reduction over 50% of damage in most cases and reaching 90% for NW under SSP3. In the case of Sothern Mediterranean, the potential is more limited, ranging from 15%-20% under SSP2 and SSP5 and over 30% for SSP3. For this region, damage potentially avoided through irrigation is around 30%-40% of damage potentially avoided through management for SSP2 and SSP5 and around 20%-25% for SSP3. For the North Western region this figure ranges from 10% to 20% and for the Central European region, from 5% to 15%. The limited effectiveness of irrigation is due to the fact that it requires favourable climatic conditions and enough water availability.

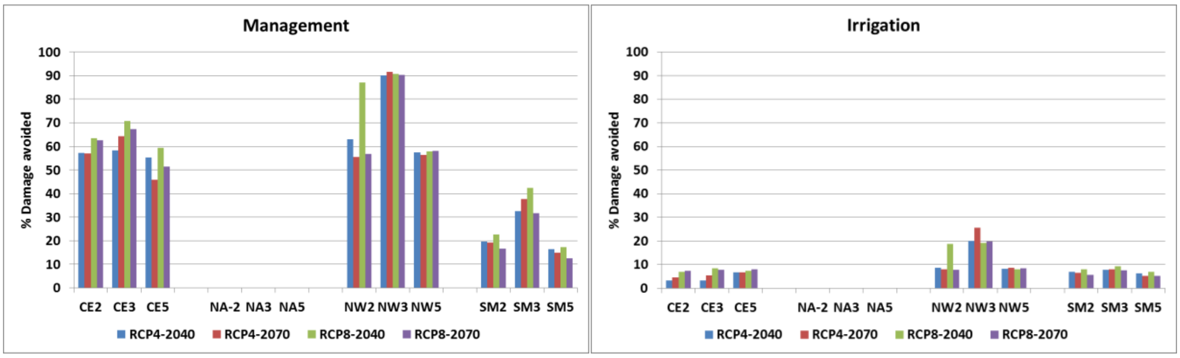


Figure 27 Damage avoided through adaptation for the management (left) and irrigation (right) strategies.

The efficiency of adaptation strategies can be visualized on Figure 28. The figure shows the values of damage reduction achieved through adaptation versus the cost of adaptation for European countries, for the long term scenarios (2070), RCP4 and RCP8 emission scenarios and the three socioeconomic scenarios. The figure includes a linear fit for both management and irrigation strategies. This fit allows the visualization of the average behaviour of both adaptation strategies under different conditions. Efficiency is related to the inverse of the slope of the linear fit. It represents the damage reduction achieved for a certain cost. Except in the case of SSP5, efficiencies are similar for RCP4 and RCP8 scenarios. In SSP2 and SSP3 the efficiency of management is larger than the efficiency of irrigation, while in the case of SSP5 both are similar.

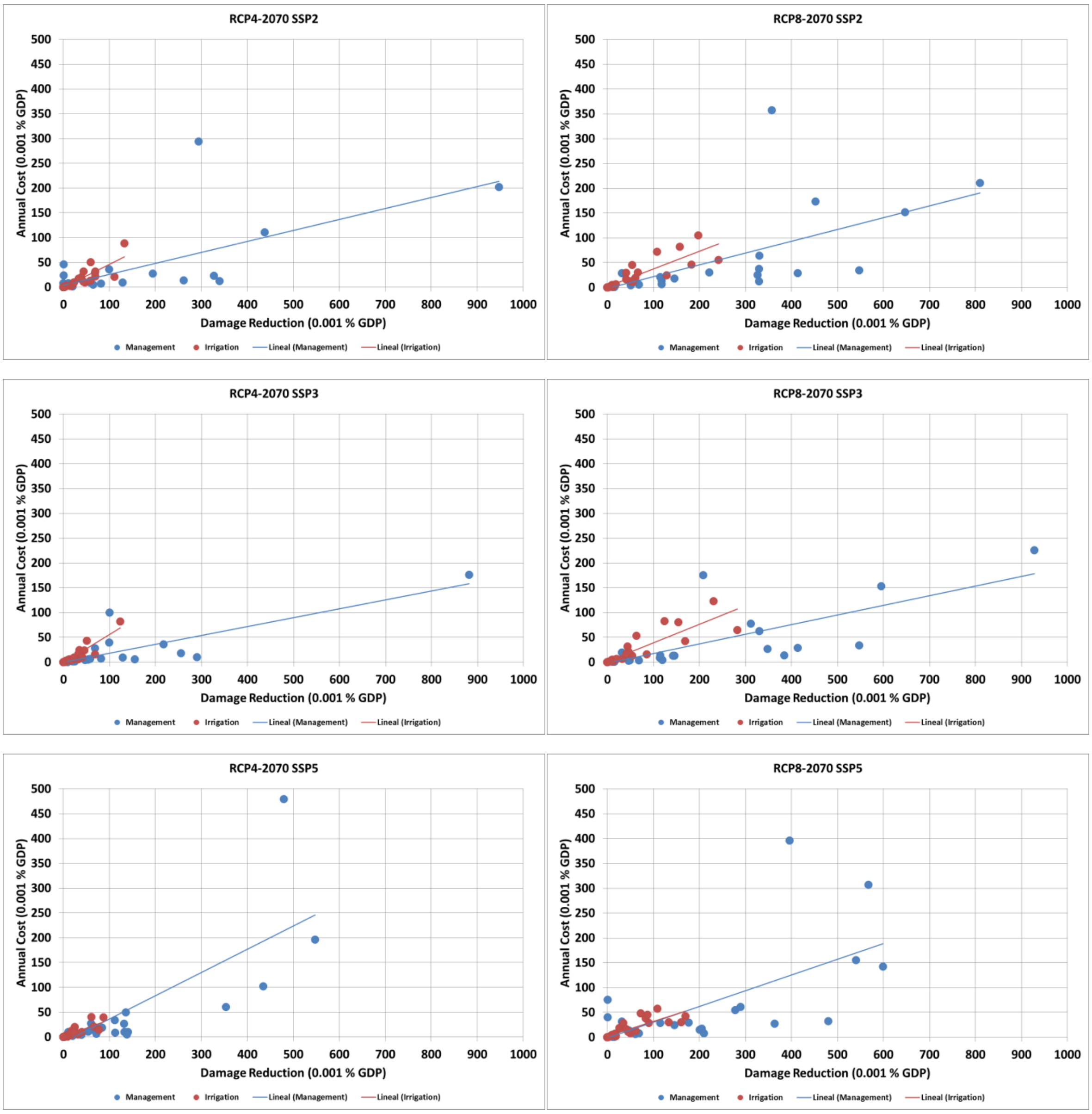


Figure 28 Values of damage reduction versus the cost of adaptation for European countries, for the long term scenarios (2070), RCP4 (left) and RCP8 (right) emission scenarios and SSP2 (top), SSP3 (middle) and SSP5 (bottom) socioeconomic scenarios

4.6 Uncertainty analysis

In this section we present the result of the model sensitivity analyses. Model sensitivity was studied by perturbing relevant variables and analyzing the corresponding change in model results. The study was carried out for one of the scenarios, RCP4 and SSP2 for the long term (2070) time horizon. This scenario was selected because it provides intermediate results for impacts and adaptation. For every variable, the model was run changing the value of the variable from -5% to +5% in 1% increments (11 model runs). The results show the effect on selected variables (Impact on rainfed agriculture, impact on irrigated agriculture, damage reduction through management and damage reduction through irrigation) in terms of relative change as a function of the change in the perturbed variable. The results obtained are presented in the following sections.

Changes in projected population

Figure 30 presents the results of the sensitivity of model results to uncertainty on population projection. While population projection does not have an effect on rainfed agriculture, it has a direct impact on irrigated agriculture for the Southern Mediterranean, because of the competition for water uses. Irrigated agriculture also presents some sensitivity in the Central European, but only for large increments of population, since there is a threshold after which the water supply and industrial uses start to affect the water availability for irrigation.

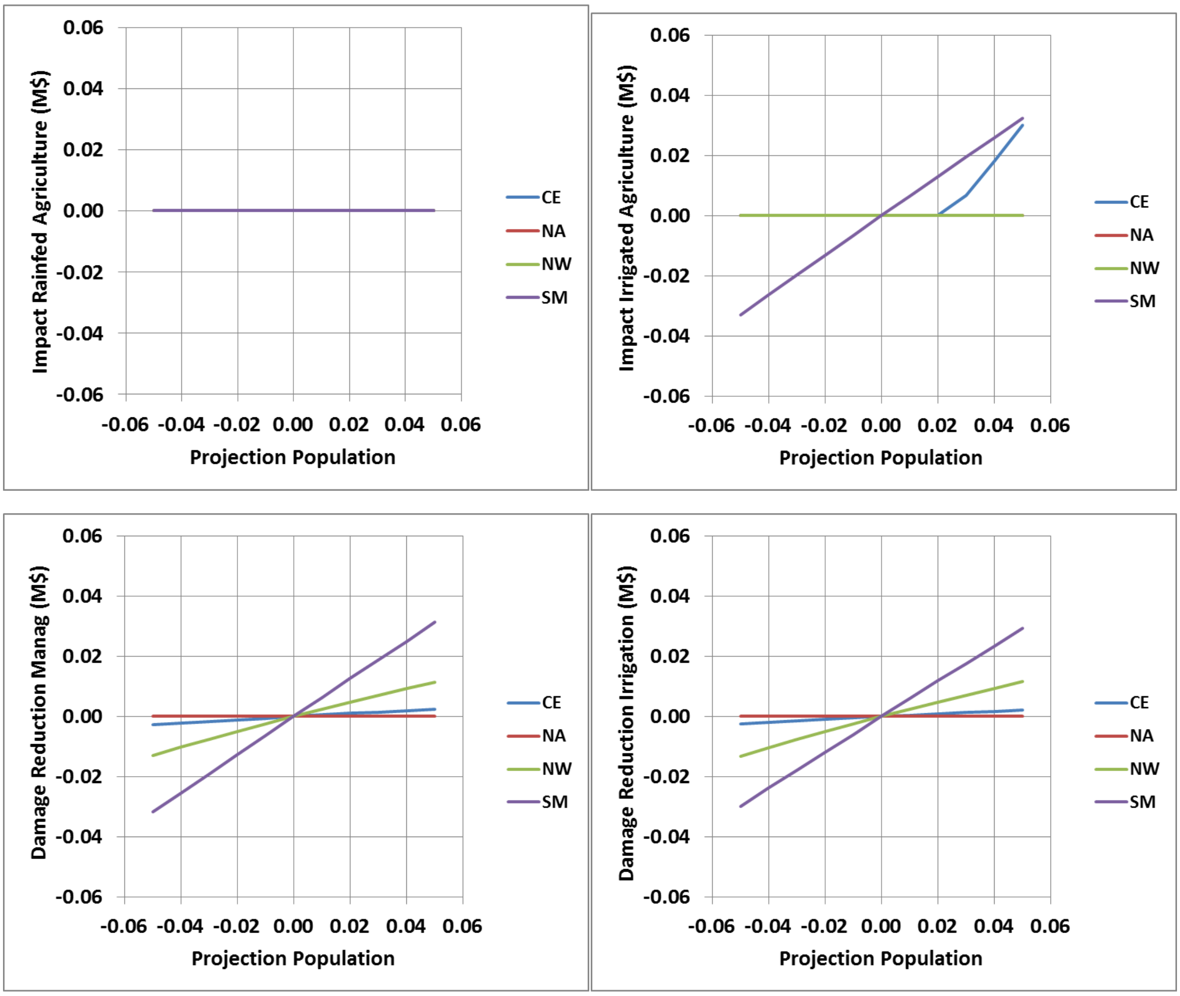


Figure 29 Sensitivity of model results to population projection: Impactonrainfed agriculture (top left), Impact on irrigated agriculture (top right), Damage reduction through management (bottom left) and Damage reduction through irrigation (bottom right).

Both adaptation strategies, management and irrigation, show similar sensitivity to population projection. Sensitivity is, in general, small, except for the Southern Mediterranean region, which presents similar sensitivity to that of impact on irrigated agriculture.

Changes in projected cultivated land

The results of the sensitivity to uncertainty on cultivated land projection are shown in Figure 31. Cultivated land does not have an effect on irrigated agriculture because the model assumes that water availability control irrigation. The sensitivity of the impact on rainfed agriculture is very high for all regions and extreme for the Southern Mediterranean and Central European regions. This is explained because these two regions show the greatest changes in crop productivity.Adaptation strategies show a comparatively smaller sensitivity, especially in the case of damage reduction through management.

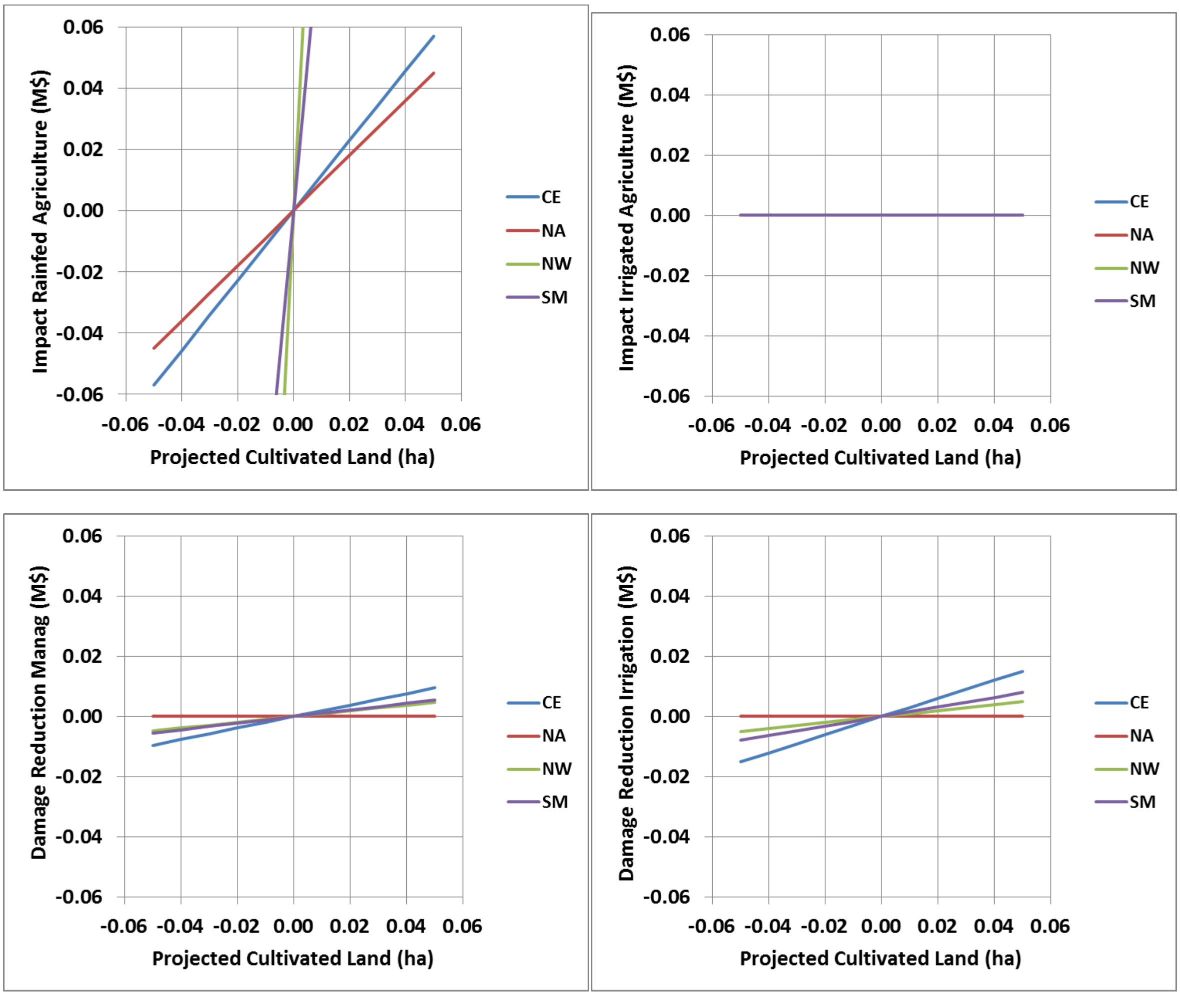


Figure 30 Sensitivity of model results to cultivated land projection: Impact on rainfed agriculture (top left), Impact on irrigated agriculture (top right), Damage reduction through management (bottom left) and Damage reduction through irrigation (bottom right)

Changes in projected crop yield

Figure 32 presents the results of the sensitivity of model results to uncertainty on crop yield projection. As expected, the sensitivity is very high for impacts, because agricultural production is directly related to crop yield. The effect is greatest in the Southern Mediterranean region, which is the most exposed region. The sensitivity of adaptation strategies to crop yield projection is moderate, with little differences between the three regions affected.

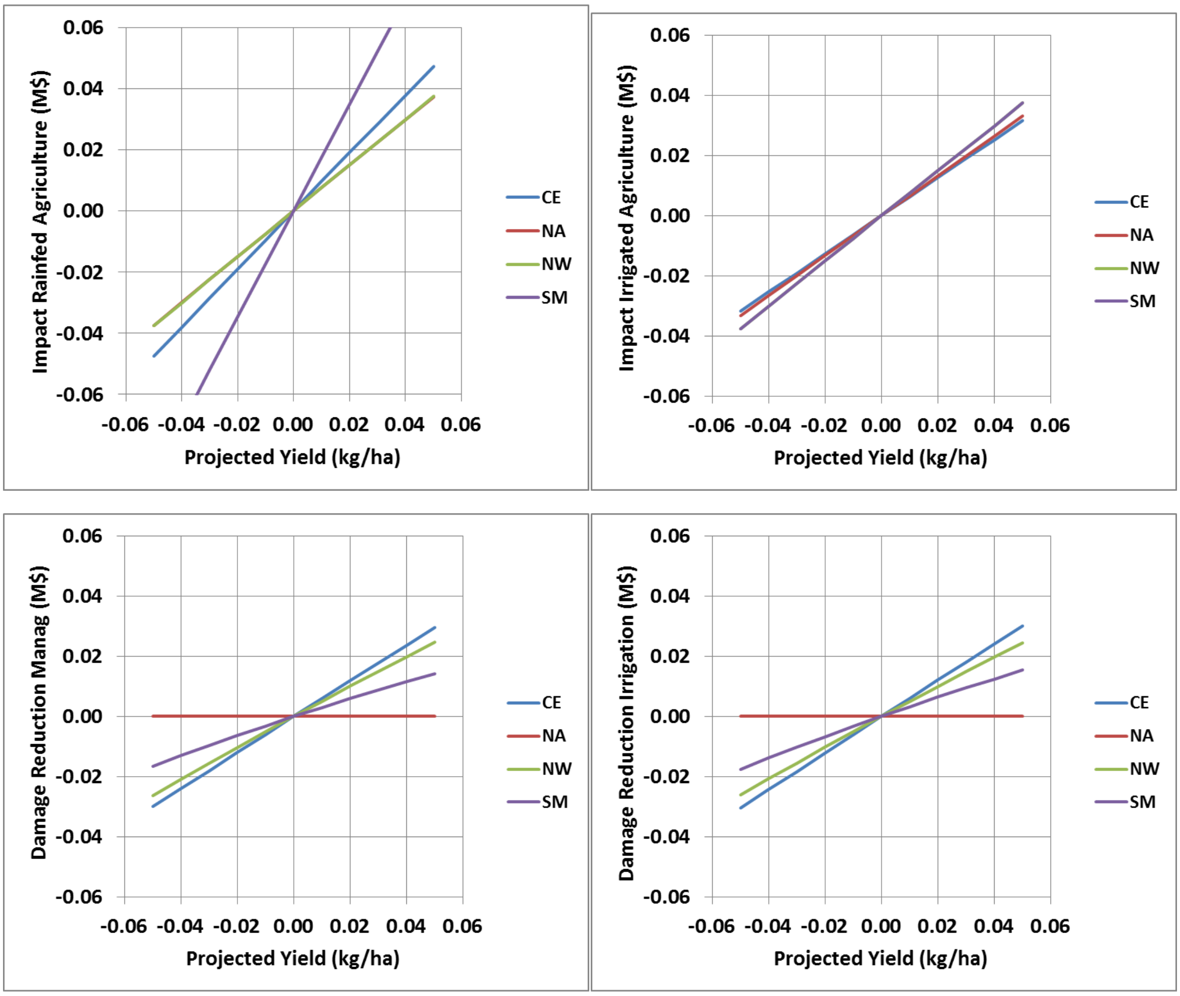


Figure 31 Sensitivity of model results to crop yield projection: Impact on rainfed agriculture (top left), Impact on irrigated agriculture (top right), Damage reduction through management (bottom left) and Damage reduction through irrigation (bottom right).

Changes in projected per capita domestic water withdrawal

The results of the sensitivity to the projection of per capita domestic water withdrawal are shown on Figure 33. The effects are very similar to those of population projection. There is no sensitivity for impacts on rainfed agriculture and the sensitivity for impacts on irrigated agriculture is significant in regions with potential water scarcity. In the case of adaptation strategies the sensitivity is very small, even for the Southern Mediterranean region.

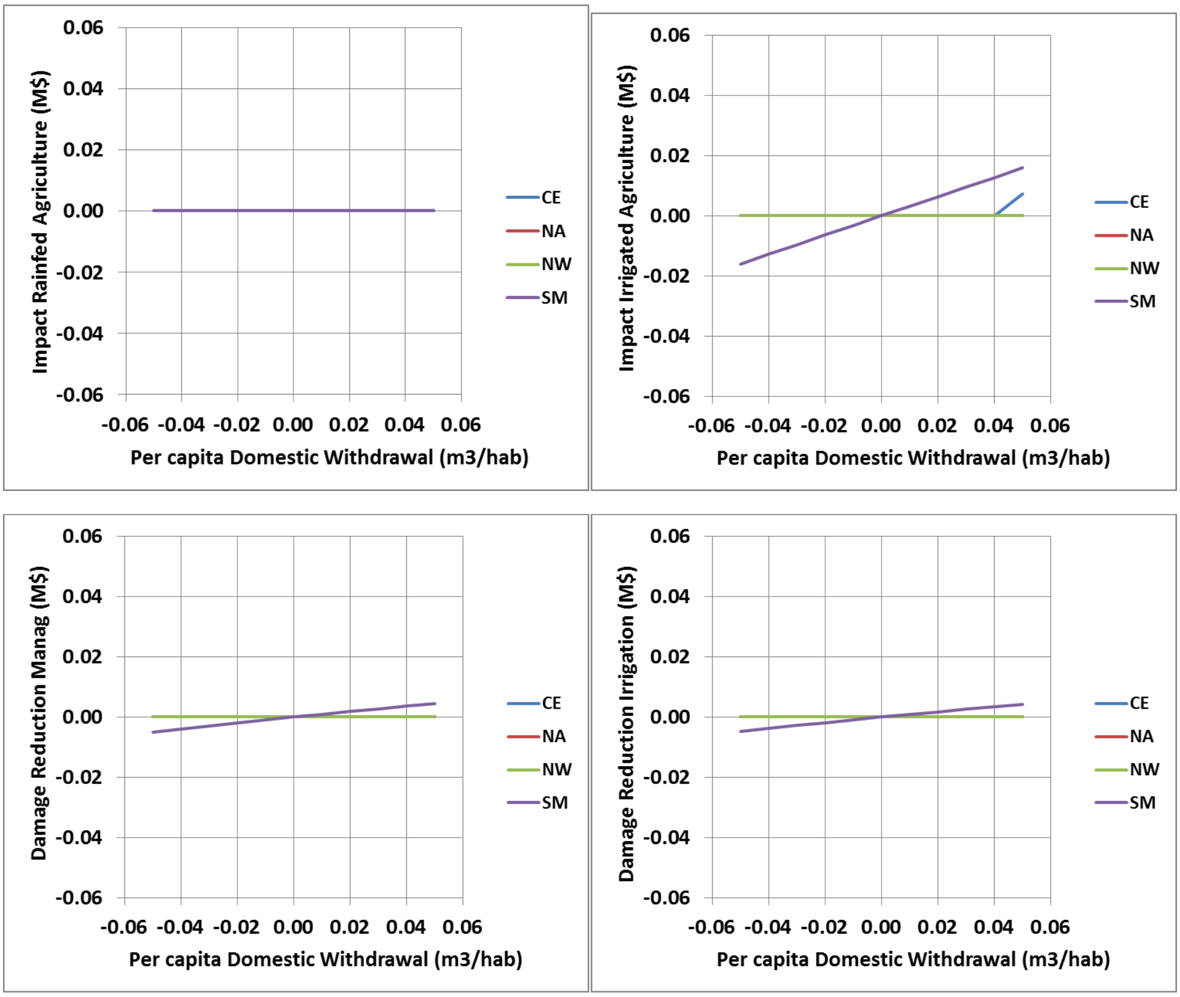


Figure 32 Sensitivity of model results to the projection of domestic water withdrawal: Impact on rainfed agriculture (top left), Impact on irrigated agriculture (top right), Damage reduction through management (bottom left) and Damage reduction through irrigation (bottom right)

Changes in projected surface water availability

The results of the sensitivity to uncertainty on projected surface water availability are shown in Figure 34. Surface water availability does not have an effect on rainfed agriculture, but the effect on irrigated agriculture is very high in the Southern Mediterranean region because the model assumes that water availability controls irrigation. The Central European region also shows some sensitivity is water availability is reduced. The sensitivity of adaptation strategies is also significant.

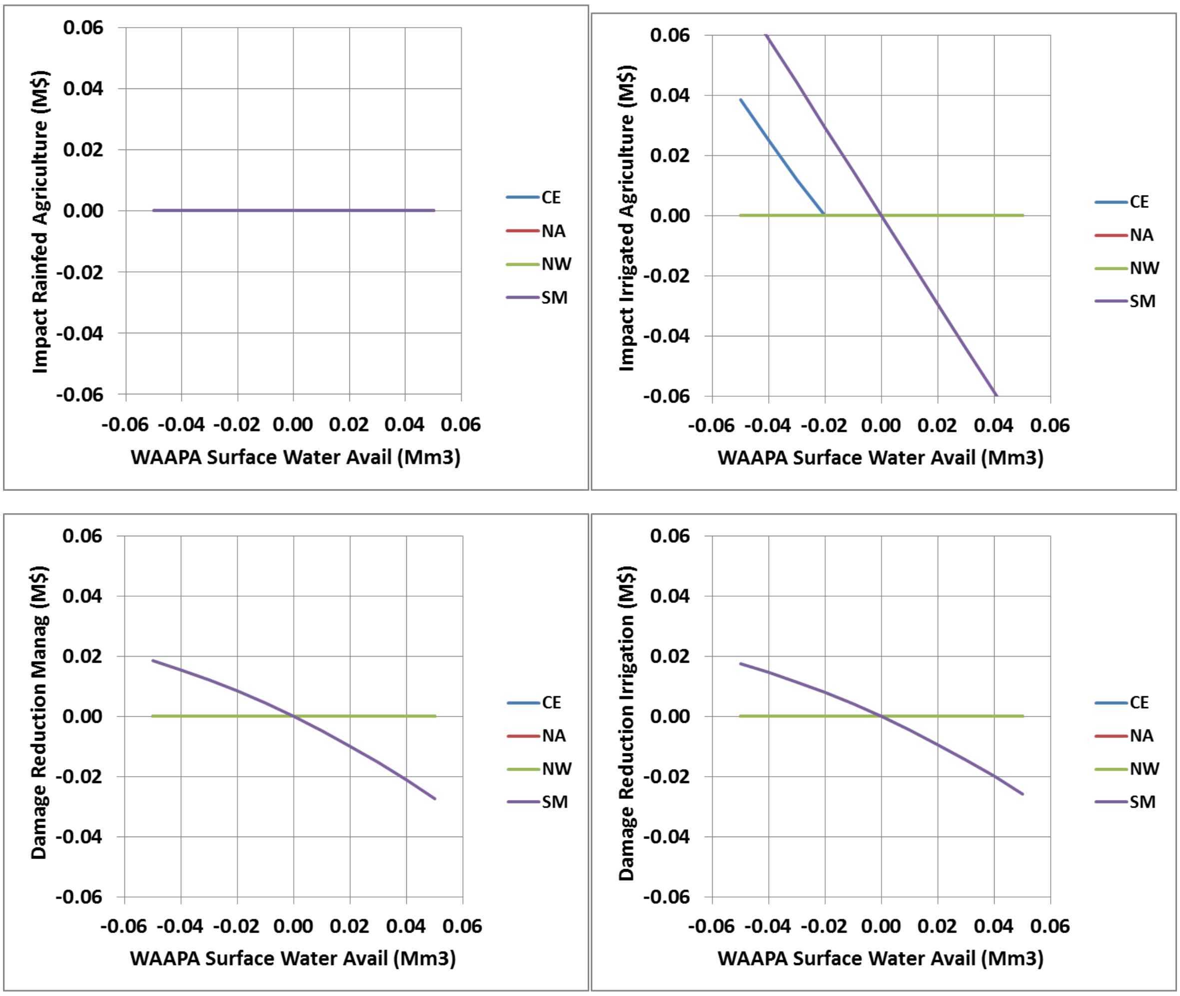


Figure 33 Sensitivity of model results to the projection of surface water availability: Impact on rainfed agriculture (top left), Impact on irrigated agriculture (top right), Damage reduction through management (bottom left) and Damage reduction through irrigation (bottom right)

Changes in projected groundwater availability

Figure 35 shows the results of the sensitivity to uncertainty on projected groundwater availability. Sensitivity to groundwater availability is very similar to sensitivity to surface water availability, but less marked. Sensitivity is significant in the Southern Mediterranean for impact on irrigated agriculture and comparatively less important for adaptation strategies.

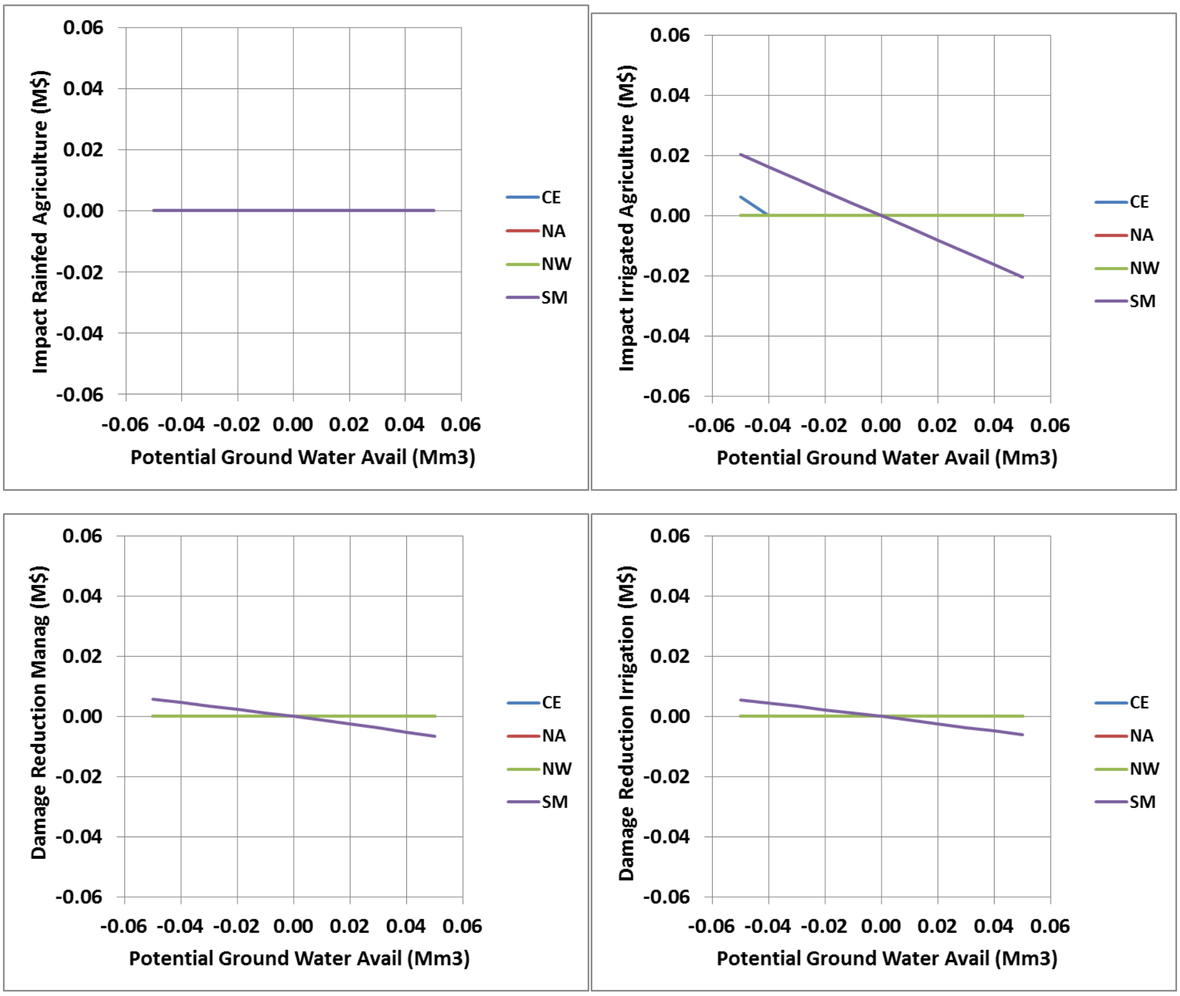


Figure 34 Sensitivity of model results to the projection of groundwater availability: Impact on rainfed agriculture (top left), Impact on irrigated agriculture (top right), Damage reduction through management (bottom left) and Damage reduction through irrigation (bottom right).

4.7 Policy recommendations

This study links agro-climatic, land use and water models with statistical responses of economic variables to changes in these three sectors, to simulate the impacts from climate change on agricultural production in Europe. This framework is then used to explore the benefits and costs of two types of adaptation measures for four regions in Europe. Figure 36 summarises the results, and shows that regional differences dominate the results, followed by the SSPs, the RCPs and finally the time horizon.

Three major points emerge from the results of this study, related to the regional effects, benefits of adaptation and choices of adaptation.

Regional effects

First, although each scenario projects different results, all scenarios are consistent in the spatial distribution of effects. Agricultural damage is larger in the Mediterranean region followed by the Norht West region. The results are highly consistent across RCP scenarios and time frames. The SSP scenario is the most influencential factor for a given region.

The socio-economic scenarios are key factors for understanding the potential adaptation capacity of agriculture to climate change. Uncertainty regarding future population (density, distribution, migration), gross domestic product and technology determine and limit the potential adaptation strategies. However, evaluating the constraints to policy implementation is difficult. In our study, the demand for and the supply of water for irrigation is influenced only by changes in the hydrological regimes, resulting from changes in the climate variables. Policy driven adaptation priorities may be derived from the impacts reported in this study.

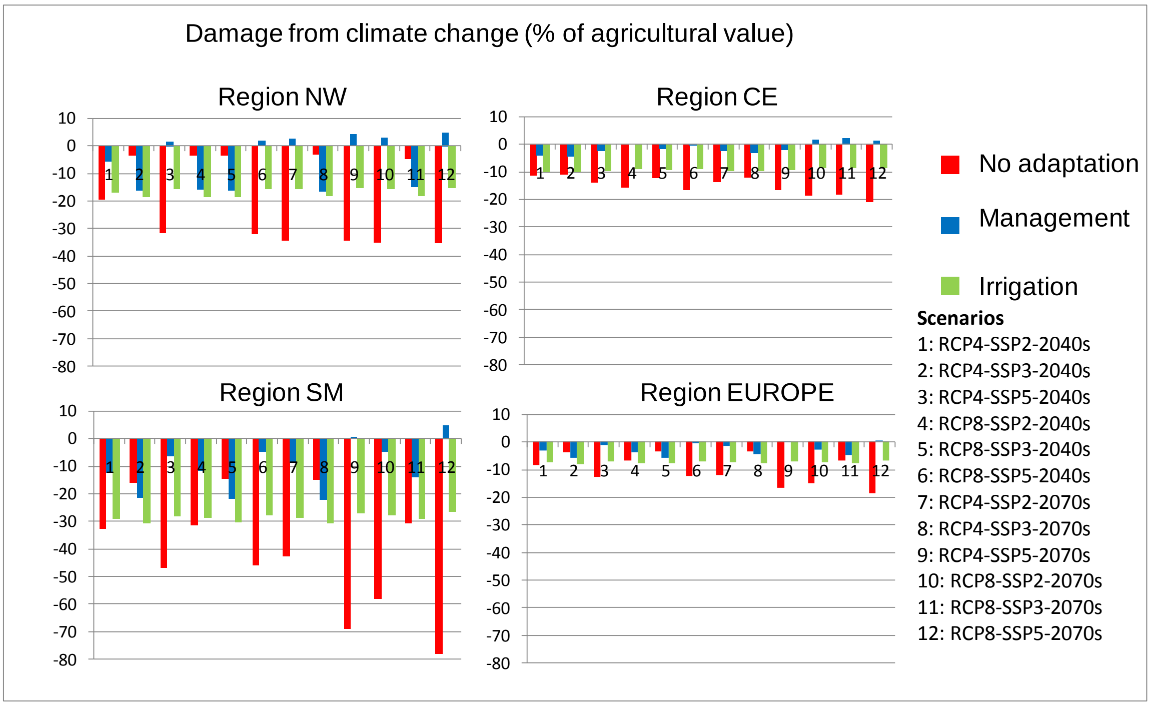


Figure 35 Summary of impacts of no adaptation and of two adaptation measure for agriculture (improved water management and increased irrigation), aggregated across the four regions that suffer agricultural damage due to water scarcity and the 12 scenarios included in the study

Benefits of adaptation

Second, adaptation choices benefit all regions, although the effort to benefit relationship varies across regions and type of measure. The costs of irrigation are higher than the cost of improved water management, especially in the period up to the 2030s. The largest benefit is in the Mediterranean and North West regions. The benefit of adaptation in the Mediterranean is due to the large damage reduction due to water scarcity in all scenarios. The benefit of adaptation in the North West region is due to the large competition of agricultural and industrial water and the large change in land use over all scenarios.

Choice of adaptation

Water management is overall the best choice in all cases. In areas will little damage, water management is much more cost efficient. In the Mediterranean region, even if irrigation is more cost efficient in some scenarios, the range of possible implementation of irrigation measures is extremely limited over the crop area.

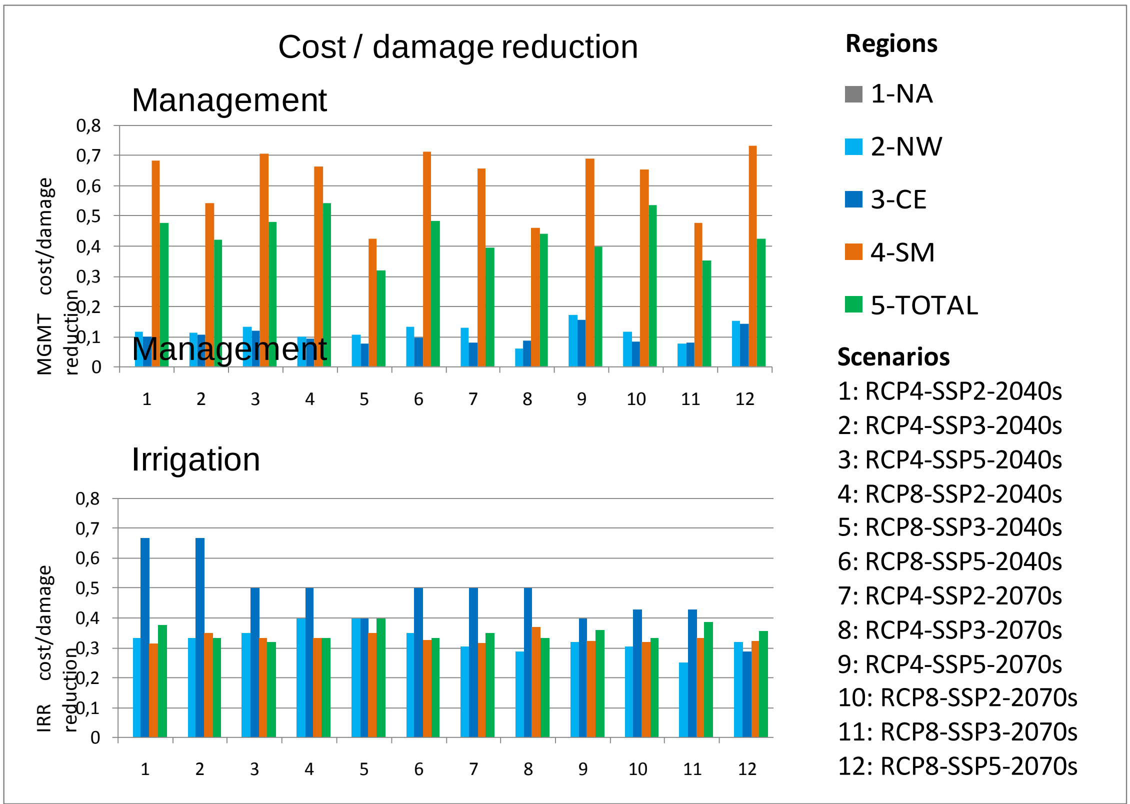


Figure 36 Summary of the relationship of cost to damage reduction of the adaptation measures for agriculture (improved water management and increased irrigation), aggregated across the four regions that suffer agricultural damage due to water scarcity and the 12 scenarios included in the study

5 Health sector

Timothy Taylor, Aline Chiabai and Sebastien Foudi

5.1 Method and assumptions

In order to design effective adaptation measures in public health, there is a need to first understand the current health risks related to climate and the risks which might arise in the future for expected changes in climate. The main impacts expected in Europe include [Source: results from PESETA (Watkiss and Hunt, 2012, Watkiss et al., 2009); ClimateCost (Kovats et al., 2011); cCASHh projects (Menne and Ebi, 2006, EEA, 2012a]:

- Heat stresses in terms of morbidity and mortality for increased risk of cardiovascular and respiratory diseases. The most affected areas are the Mediterranean and Southern Europe and Central-Eastern countries.

- Air pollution and ozone related diseases for synergistic effects between high temperature and air pollutants, due to increased level of summer ozone concentrations in Southern Europe though the quantification of future ground-level ozone is uncertain and complex.

- Flood-related deaths and injuries and associated mental stresses, with most affected countries in northern mediterraneanMediterranean, northern and western Europe.

- Salmonellosis (water-borne diseases) associated with increased flooding and heavy rainfall which can disrupt water treatment and sewage systems. The largest risk has been detected in UK, France, Switzerland and the Baltic countries.

Other health impacts include an increased risk of leishmaniasis, lyme and tick-borne diseases with slight increases. The main adaptation measures are listed by type of health outcome in **Table 21** below (Deliverable 4.1). Primary interventions can be defined as primary prevention put in place to remove the risk before the damage occurs. Secondary interventions aim to prevent the disease once the impact has occuredoccurred but before its establishment. Tertiary interventions are applied once the impact has occuredoccurred to minimize it and correspond to treatment.

Table 21 Adaptation measures by type of health outcome

	Adaptation measures		
Health impacts	Primary	Secondary	Tertiary
Heat stresses	Building and technical solutions. Urban planning (reforestation, green roofs, etc). Heat health warning systems (preventive). Educational campaign.	-	Heat health warning systems (reactive). Emergency plans and medical services.
Extreme weather	Healthy ecosystems	Disease	Emergencyandevacuationplans.

events related deaths, injuries, mental health effects	around systems to provide natural barriers to flooding. Structural measures to reduce flooding (dykes, walls, etc). Land-use and urban planning (flood-resistant). Early warning systems and real-time forecasting.	surveillance and monitoring	
Vector-bornediseases	Healthy ecosystems (including biodiversity) Vector control (vector habitat destruction, bed nets, etc.). Information and health education.	Disease surveillance and monitoring. Vaccination.	Diagnosis and treatment (early detection)
Food-bornediseases	Food sanitation and hygiene (refrigeration, ozone treatment of drinking water, chlorination of drinking water, etc.). Food safetyeducation.	Disease surveillance and monitoring. Zoonosis program to control disease in animals (salmonella). Microbiological risk assessment.	Diagnosis and treatment (early detection)
Water-bornediseases	Regenerate ecosystems and biodiversity e.g. wetland restoration. Improved river water quality e.g. through improved water and sanitation systems Information and health education.	Disease surveillance and monitoring.	Diagnosis and treatment (early detection).

Within WP6, four main health outcomes have been assessed at larger geographical scales to provide impacts, costs and benefits of adaptation for the modelisation within ADWITCH. The choice has been made considering the relevance of the impact as well as the availability of data both for the impact assessment as well as for the analysis of costs and benefits of adaptation measures.

Two health impacts have been assessed at European levels, heat stresses and salmonella. Other two have been assessed for developing countries, diarrhea and malaria. Table 22 below summarizes the health outcomes addressed (cost of impact), the adaptation measures evaluated (costs and benefits) and the geographical level of analysis. For heat waves, the model proposed is framed on the approach used at the local level for Madrid city as detailed in the next sections. For salmonella, the results are built on the project PESETA

II (Paci, 2014), while for diarrhea and malaria the analysis is built on a previous work done by Ebi (2008).

Table 22 Health impacts and adaptation measures assessed

HEALTH IMPACT	ADAPTATION MEASURE	GEOGRAPHICAL LEVEL
Heatwaves and impacts on daily mortality (threshold temperature)	Heat watch warning systems	Europe
Salmonella associated with increased average temperature (threshold temperature)	Treatment are considered adaptation: Medical visits Hospital admission Public health campaign	Europe
Diarrhea	Interventions for children less than 5 years old: Oral rehydration, breastfeeding promotion, rotavirus, cholera & measles immunization Improvement of water supply and sanitation systems	World – mainly developing countries
Malaria	Interventions for children less than 5 years old: Insecticide-treated bed-nets + case management with artemisinin-based combination therapy + intermittent presumptive treatment in pregnancy Indoor residual spraying	World – mainly developing countries

5.1.1 Heat-Health Watch Warning System

Heat Health Warning Systems (HHWS) give early alerts, advisories and emergency measures to mitigate the impact of a heatwave and is effects on health. Dissemination of information can be carried out at national and local levels to inform the general population, the health care system, caretakers, etc. (WHO, 2015). The issue of the alert is under the responsibility of the government health department, and can be done either at the national or local level. The choice mainly depends on the geographical extension of the heatwaves within a country. In case of distinct initiatives at city level, coordination is nevertheless advisable at the national level through a national health agency or emergency authority (WHO, 2015).

In this section we propose a method to estimate benefits of HHWS at the European level, and for this purpose the national scale is considered as a basis to apply the assessment of mortality impacts due to heatwaves and avoided mortality associated with the set-up of HHWS. As for the costs, a simplified procedure is used to compute costs at European level, though this is subject to many uncertainties, as discussed in the next sections.

The use of city scale would entail local-specific assumptions and the use of epidemiological studies at the city level to detect the threshold temperature above which the daily mortality is expected to increase significantly. These studies are available only for a limited set of cities in Europe (Baccini et al., 2008; Michelozzi et al., 2009, 2007). In addition, there is no established and harmonized definition of heat wave; every country defines it according to its climatic condition and to the epidemiologic consequences of high temperature. Lowe et al. (2011) present how heat wave alert temperature have been established in some European countries: some countries use the maximum temperature, an average of the maximum over the last days, an association of minimum and maximum temperature, and other countries use the perceived or the apparent temperature. Finally, climatic methods (based on a specific percentile of the time series of maximum daily temperatures) or epidemiological methods (based on health impacts) can be used to define the threshold temperatures.

In our estimates, we used the maximum daily temperature to define heat. We define the heat alert temperature on the basis of the projected data for the period 2006-2014 and considered an alert situation occurs when the country average maximum daily temperature exceeds the 95th percentile.

Impacts and benefits of adaptation are weighted by the EU GDP growth rate per capita (scenario SSP5) and discounted at a 5% rate. We considered an income elastticity of 0.8.

Climatic data are from the CMIP5 database and informs on the daily maximum temperature for 2015-2099 under the scenario RCP8.5. The European countries to which the methodology is applied are the following (included in the model AD-WITCH):

Eastern Europe (E): Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, Slovenia.

Western Europe (W): Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Portugal, Spain, Sweden, United Kingdom.

Impacts: physical assessment

The total expected mortality under the climate scenarios RCP8.5 has been calculated as follows:

$$EM_{\bar{t}} = AR_{\bar{t}} \times BM \times \Delta T_{\bar{t}} \times L_{\bar{t}}$$

where$EM_{\bar{t}}$ the expected mortality for the threshold temperature $\bar{t}$, $AR_{\bar{t}}$ is the risk attributable to 1ºC above the threshold, applied to the baseline daily mortality *BM*, $\Delta T_{\bar{t}}$ is the excess temperature above the threshold $\bar{t}$ and $L_{\bar{t}}$ is the number of days above the threshold temperature $\bar{t}$.

In order to estimate the $AR_{\bar{t}}$to be applied at country level, a socio-epidemiological regression function has been build using Spanish data from Tobias et al. (2012) in the absence of another available data base at country level. The data base refers to 40 Spanish cities. To transfer data from city level to country level, we modelled this risk as a function of the threshold temperature and the population above 65 years old.

The baseline mortality (BM) is computed as the average age-standardized death rate over 2006-2012 of cardiovascular and respiratory diseases multiplied by the projected population. Country specific death rates are from WHO[2] and projected population from Eurostat[3].

The benefits of HHWS: avoided mortality

The benefits associated with the HHWS are the avoided deaths which can be obtained by running the alert system. The total avoided deaths (*AM*) are calculated as follows, multiplying the expected mortality (expected impact) by the expected number of years of life lost (YLL) and the effectiveness (*E*) of the HHWS as estimated by Fouillet et al. (2008)(avg=68%, low=60%, high=76%). YLL and E are respectively common to all EU countries.

$$AM_{\bar{t}} = EM_{\bar{t}} \times YLL \times E$$

2 sets of results of impacts and adaptation have been estimated: one with an estimated displaced mortality[4] rate (DMR) of 40% and another with a displaced mortality rate (DMR) of 65%.

The valuation of the impacts and of benefits

As for the monetary valuation of the impacts of climate change and of the benefits of adaptation, the following economic values have been considered:

- The valuation of mortality is as follows carried out as follows. The Premature mortality is valued with using the value of statistical life (VSL), and displaced mortality with using the value of life year (VOLY). The latter is more appropriate given that the loss of life in displaced mortality is expected to be very low (Hajat et al., 2005; Saha et al., 2014). We used OECD estimation of VSL for EU27 (OECD, 2011) and transferred the value to €2013. For the VOLY, OECD recommends to use case specific studies whenever possible. We used therefore the study of Chilton 2004: who valued the years of life lost in the case of air pollution and acute mortality. From this study we used the years of life lost in poor health, considered to be considered is 1 month, which can reasonably be applied for displaced deaths in heatwaves (also acute mortality). We use a common VSL and VOLY for all EU countries, both adjusted to the following values: VSL=3.7325 million euros, VOLY= 9,459.58389 euros. VSL has been adjusted only for income elasticity over time (0.8) as recommend by OECD (2011) (and found in Lindhjem et al., 2011), given that the original value is for EU27 in 2005. The VOY has been adjusted using income elasticity of 0.8 for adjustment in both space and time, as the original value was estimated for UK in 2005.

[2] Available at www.who.int/healthinfo/mortality_data/en/

[3] Available athttp://ec.europa.eu/eurostat/data/database

[4] Those people that would have died in a short period of time whatever the heat event

- Premature mortality (=1-DMR) receives therefore a higher valuation than the displaced mortality (VSL>VOLY). The scenario with a DMR 40% will thus be an upper bound estimates of the impacts and of adaptation and the scenario with DMR of 65% a lower bound estimate.

Costs of HHWS

The estimation of costs is subject to many uncertainties, given that the warning systems differ with the geographical location in terms of the type of actions taken and population vulnerability (WHO, 2015). In addition, there is a lack in the literature of a comprehensive analysis of cost categories to be included, as well as physical units referring to the time allocated for different actions.

Given these limitations, we assume the costs estimated by the the study of Ebi et al. (2004) to calculate a possible range of reference for expected costs per day of the alert system, depending on the interventions/actions included. These can be just very basic interventions (the cost of the risk communication to the citizens and targeted groups, and basic emergency services), or more extensive actions related to emergency plans, extra care to vulnerable people such as domiciliary assistance to the elderly and transportation to emergency centres, outreach to homeless, opening of cooling centres, and stopping of electricity and water suspension. We do not make, however, a distinction between urban and rural level, as both are affected during heatwaves, and although cities show a higher vulnerabilities due to heat island effect, rural areas can face higher costs for some interventions related to emergency (such as ambulance transport services).

The number of days of alert is calculated at the national level as the number of days in which the projected maximum daily temperature is expected to be above the stated threshold.

The costs of HHWS then are calculated as follows:

Total annual cost =(Annual fixed costs per cap. + Cost per day of alert per cap. * Number of days of alert (L))*population

The estimation of costs is based on the following data taken from Ebi et al (2004) and adjusted with information from experts' opinions from the case study of Madrid:

Fixed costs of maintenance of the system have been estimated to 500€ per year (2013€/yr), and average variable cost at 3,375€/day (750-6,000€/day).

Estimations on costs have to be taken with caution, given the limitations stated above. Further research would include, at least to some extent, differentiation of costs for urban and rural areas, and for different city sizes. Social and demographical features should also be taken into account. We argue however, that any assessment of costs at national level is necessarily subject to basic assumptions, while warning systems should be evaluated at local level in order to have reliable estimates.

5.1.2 Salmonella

For salmonella, we build on the work in PESETA II (Paci, 2014) and extend on it to develop a cost-benefit analysis of different options in the European context. The relationship between climate and salmonella is based on an exposure-response function derived by Paci (2014) from the work by Kovats et al (2004). A threshold of 6°C is used, with a 7.02% increase in the number of cases per degree increase above the threshold. We take the current incidence to 0.0002975 per thousand of the population based on the incidence rates from the ECDC, again building on the work by Paci (2014).

To derive the estimates of the costs of salmonella, it is necessary to first estimate the impact with no treatment. Here we assume that treatment by itself is an adaptation. To estimate the key impacts of this, we first estimate the mortality impacts without treatment. To do this, we take the mortality rate from a developing country to be a lower bound proxy for the possible impact. The case fatality rate in Nigeria, for example, is 1.03 per 1000 cases (Akinyemi et al, 2012) – this is a fatality rate in hospitals so the true impact of no treatment may be worse. The case fatality rate in Europe is 0.5 cases per 1000 cases.

Morbidity is valued using a value of €3300 per case, based on a willingness to pay study by van der Pol et al (2003).

In terms of costs, GP visits are costed at €52 per visit, based on a UK value of £45 per visit (Curtis, 2013). Hospital stays are valued using estimates from Gil Prieto et al (2009) of €3095 (2014 values).

The costs of a public health campaign are based on UK values of £5.5million for a campaign conducted over 5 years (2001 prices). This equates to a per head per annum cost, applying the value across Europe, of just under 3 eurocents per person per annum. The effectiveness of such a campaign is hard to evaluate – so a value of 1% of cases being avoided is used,

We assume willingness to pay for mortality risk responds to increases in income per capita under the SSP5 scenario – with a value of the elasticity being between 0.4 and 0.6 as in the case for heat warning systems above.

There are clearly limitations with this approach, most notably we have not accounted for spatial variability in the exposure-response functions, which may be affected by a number of factors. In addition, the mortality rate without treatment may be higher. In projecting across time, we also cannot account for factors such as dietary changes and improved food hygiene standards and technological advance.

5.1.3 Diarrhea

For diarrhea, we build on the work of Ebi (2008), who estimated the excess incident cases in 2030 under different climate change scenarios. Ebi used the S550, S750 and UE scenarios – of which the UE scenario (the uncontrolled emissions) was identified as being most similar to the RCP8.5 scenario. The regions used for the analysis were the WHO world regions. Table 23 shows the results obtained by Ebi.

Table 23 Projected excess incident cases of diarrhoeal diseases (000s) for alternative scenarios relative to baseline climate (mid to high estimates))

Sub-region	Climate	2000		2030	
		Mid	High	Mid	High
Afr-D	S550	3,898	11,695	19,492	38,984
	S750	7,797	15,594	23,391	50,679
	UE	7,797	19,492	27,289	62,375
Afr-E	S550	4,492	13,476	22,460	49,411
	S750	8,984	17,968	26,952	58,395
	UE	8,984	22,460	35,935	71,871
Amr-A	S550	0	1,552	0	4,655
	S750	0	1,552	0	4,655
	UE	0	1,552	0	6,206
Amr-B	S550	0	7,812	0	19,530
	S750	0	7,812	0	23,435
	UE	0	7,812	0	31,247
Amr-D	S550	733	2,198	1,465	5,129
	S750	1,465	2,198	1,465	5,862
	UE	1,465	2,931	1,465	7,327
Emr-B	S550	963	2,890	5,779	5,779
	S750	1,926	2,890	5,779	5,779
	UE	1,926	3,853	8,669	8,669
Emr-D	S550	6,912	10,368	0	41,472
	S750	6,912	10,368	0	44,929
	UE	10,368	17,280	0	65,665
Eur-A	S550	0	1,584	0	4,753
	S750	0	1,584	0	4,753
	UE	0	1,584	0	6,338
Eur-B	S550	785	2,355	785	5,496
	S750	785	2,355	785	6,281
	UE	785	2,355	785	7,066
Eur-C	S550	958	1,437	0	3,352
	S750	958	1,437	0	3,352
	UE	958	1,915	0	3,831
Sear-B	S550	1,792	3,584	0	8,960
	S750	1,792	5,375	0	10,753
	UE	3,584	7,169	0	14,337
Sear-D	S550	21,031	1.03	63,092	136,700
	S750	21,031	42,062	73,608	157,731
	UE	31,546	52,577	94,638	199,792
Wpr-A	S550	0	300	0	1,501
	S750	0	300	0	1,501
	UE	0	601	0	2,102
Wpr-B	S550	12,252	36,756	0	73,511
	S750	12,252	36,756	0	73,511
	UE	24,504	61,259	12,252	110,267

Source: Ebi (2008)

In order to integrate diarrhea into the ADWITCH framework, we first had to allocate the excess cases in 2030 in the different regions above to the ADWITCH regions. This was done using the relative populations of the countries to allocate cases to the different world regions. This clearly assumes a uniform distribution of diarrhea across the individual WHO regions.

The number of excess cases for ADWITCH regions in 2030 based on the RCP8.5 scenario were then scaled to take account of expected population changes under SSP5 to yield first estimates of the potential impacts in 2050. This does not account for any further climate change impact beyond the temperatures in 2030 – and so may be considered a lower bound of the impact in 2050. The numbers of cases are presented in Table 24.

Table 24 Estimated number of excess incident cases in 2050 in ADWITCH world regions)

WORLD REGIONS	PROJECTED NUMBER OF CASES IN 2050	
AD-WITCH REGION	Physical impact: Δ cases (000s)	
	S1: Mid estimates	S2: High estimates
SSA	63,236	134,273
CAJAZ	0	2,629
USA	0	4,235
LACA	1,478	38,920
MEA	9,025	9,025
OLDEURO	0	6,560
NEWEURO	171	2,378
TE	613	8,507
SEA	0	14,522
INDIA	72,989	204,732
SASIA	24,127	67,674
KOSAU	4,395	11,103
CHINA	12,073	108,655
TOT	188,108	613,213

Source: Authors estimates

Two different interventions were considered, following Ebi (2008).

Table 25 shows the measures and the associated costs. The first set of measures comprises treatment of diarrhoea as well as prevention of cases through specific immunization programs. These measures apply to health outcomes specifically, meaning that the benefits can be fully attributed to the health sector in terms of reduced number of cases and deaths. The second set of measures refers to structural interventions to improve water and sanitation systems which are multiple-benefits interventions involving different sectors and different types of impacts. For the purpose of this analysis, we have considered only the health benefits.

To bring these into 2050 terms, the costs were adjusted using the ratio of GDP per capita between the different years based on SSP5 and using income elasticity 0.8.

Table 25 Adaptation measures for diarrhea and associated adaptation costs (US$ 2001)

Measures for children<5 year old	Description	Costs (US$2001)		
		Low	Medium	High
Combined set of measures	Treatment and immunization :breastfeeding promotion, rotavirus, cholera and measles immunization, and oral rehydration	0.71	15.09	104.3
Structural preventive measures (multi-sectoral)	Water and sanitation programs	25	53	81

The impact costs form two parts. First, the morbidity costs are represented by the sum of the WTP to avoid a case of gastroenteritis (Barton and Mourato, 2003; Machado and Mourato, 2002) and the cost of illness (COI) of a gastroenteritis case(Dwight et al, 2004), following the recommendations in Hunt, A. (2011) according to which these values can be transferred to other geographical areas in the absence of context-specific estimates. These values can be transferred as the estimates of the original studies converge to similar evaluations. For this purpose, the recommendation falls on an indicative central value of 100 US$ for the WTP to avoid a case of gastroenteritis and 44 US$ for the COI, estimated in US$ PPP equivalents.

This value is then adjusted for GDP/capita in each AD-WITCH region under the SSP5 scenario, with an income elasticity of 0.8 applied.

All cases are taken to have morbidity impacts. We also take into account mortality. In developed countries, mortality from diarrhea is taken to be approaching zero – because of health care systems and availability of treatments. In less developed countries, mortality rates for under 5 diarrhea range significantly. We use the mortality rates from cases of diarrhea in the different world regions based on estimates from WHO 2002 (WHO estimates for mortality and morbidity for diarrhea: http://www.who.int/healthinfo/global_burden_disease/en/index.html and apply this to the excess cases. The attribution was done only for the AD-WITCH regions which are fully comparable with the WHO regions (e.g. South Africa), resulting in an under-estimation of the mortality numbers. Developed countries were excluded in accordance with the results obtained by Ebi (2008) and as explained above.

We took into account future projections of mortality under development growth scenarios assuming that the burden of disease will probably fall down in the future for developing countries. We took the projected average annual rates of change in age-standardized deaths rates for digestive diseases (Mathers and Loncar, 2006), estimated for the 2002-2020 and use these numbers till 2050 as a lower bound, according to the following calculation:

$$Mortality\ rate\ decrease = \frac{1}{(1 + annual\ rate\ change)^t}$$

Where the annual rate change is the projected change as estimated by Mathers and Loncar (2006) and t is 50 years (for the time span 2000-2050).

Results of the final estimates of mortality are presented in Table 26.

Table 26 Estimated number of deaths in 2050 in ADWITCH world regions

WORLD REGIONS	PROJECTED NUMBER OF DEATHS IN 2050	
AD-WITCH REGION	Physical impact: Δ deaths (000s)	
	S1: Mid estimates	S2: High estimates
SSA	28.13	59.72
CAJAZ	0.00	0.00
USA	0.00	0.00
LACA	0.14	3.79
MEA	0.72	0.72
OLDEURO	0.00	0.00
NEWEURO	0.00	0.00
TE	0.00	0.00
SEA	0.00	1.74
INDIA	23.78	66.71
SASIA	7.86	22.05
KOSAU	0.00	0.00
CHINA	0.79	7.12
TOT	61.42	161.85

Source: Authors estimates

To value mortality, we estimate the value of a statistical life based on adjusting existing VSL estimates for children from India and China and adjusting to the 2050 case (De Ayala and Spadaro, 2014). We took the following references for VSL figures from De Ayala and Spadaro:

China: VSL (infants) = 1.8M (€2013) [0.6 – 3 M€]

India: VSL (infants) = 0.68M (€2013) [0.45 – 1.5 M€]

For India and China we take into account the changes in GDP per capita across time and adjust for income elasticity. For the other developing countries we take a population weighted average of the Indian and Chinese values and estimate values for 2005 and 2050 based on GDP per capita and income elasticities.

Table 27 below shows the VSL values by region, adjusted for GDP per capita to 2050 with income elasticity 0.8.

Table 27 Adjusted VSL estimated (US$ 2050)

AD-WITCH region	VSL adjusted
SSA	156,724
CAJAZ	6,274,163
USA	12,081,050
LACA	1,362,356
MEA	845,269
OLDEURO	13,677,870
NEWEURO	3,727,892
TE	3,349,495
SEA	1,283,800
INDIA	1,952,080
SASIA	543,400
KOSAU	4,618,776
CHINA	3,250,793

We estimate the benefits of adaptation by assuming an effectiveness rate for the options in question, as reported in Table 28 below. We took an average (equal to 13.9 % reduction) of the median percentage of expected reduction in the number of cases estimated by type of measure as reported in Keutsch et al, 2007. The estimation is for children under the age of five.

Table 28 Effectiveness of measures as percent decrease in number of cases(Keutsch et al, 2007)

Measure	% min	% max	% median
Oral rehydration, breastfeeding promotion, rotavirus, cholera and measles immunization	0.06	8.54	3.8
Improvement of water supply and sanitation	22	26	24

Source: Keutsch et al, 2007.

5.1.4 Malaria

For malaria, we also drew heavily on Ebi (2008). For malaria, Ebi uses the estimated loss of disability adjusted life years due to increased malaria to indicate the impacts to 2030. In Ebi's paper this is not that clear – with the term "excess cases" being used as equivalent in some place to DALY losses – when the two are quite different.

Table 29 shows the estimated number of QALYs lost due to climate induced malaria under different scenarios.

Table 29 Estimated excess loss of DALYs (000s) due to malaria under different climate change scenarios

Sub-region	Climate	2000		2030	
		Mid	High	Mid	High
Afr-D	S550	0	1804	1804	3607
	S750	0	1804	1804	5411
	UE	1804	1804	3607	9018
Afr-E	S550	3533	7066	12366	26498
	S750	3533	8833	15899	31797
	UE	7066	14132	24731	49462
Amr-A	S550	0	0	0	0
	S750	0	0	0	0
	UE	0	0	0	0
Amr-B	S550	57	115	229	459
	S750	86	143	287	545
	UE	115	258	430	860
Amr-D	S550	7	14	29	65
	S750	7	22	36	72
	UE	14	29	57	122
Emr-B	S550	0	0	0	0
	S750	0	0	0	0
	UE	0	0	0	0
Emr-D	S550	607	1183	2535	5069
	S750	676	1352	3211	6252
	UE	1014	2197	4900	9970
Eur-A	S550	0	0	0	0
	S750	0	0	0	0
	UE	0	0	0	0
Eur-B	S550	0	0	0	0
	S750	0	0	0	0
	UE	0	0	0	0
Eur-C	S550	0	0	0	0
	S750	0	0	0	0
	UE	0	0	0	0
Sear-B	S550	0	0	0	0
	S750	0	0	0	0
	UE	0	0	0	0
Sear-D	S550	0	0	0	70
	S750	0	0	70	70
	UE	0	0	70	139
Wpr-A	S550	0.4	0.8	1.5	3
	S750	0.5	1.0	2	4
	UE	0.8	1.6	3	6
Wpr-B	S550	110	221	404	790
	S750	147	276	478	974
	UE	221	441	772	1526

First, the same method is used to translate the estimates from the WHO regions to the ADWITCH regions as in the case of diarrhea – i.e. population is used to assign malaria to the differing world regions. This assumes uniformity of distribution, which is unlikely to be the case. The impacts are then estimated for 2030 using the SSP scenarios for population. We take the UE scenario to correspond to the RCP8.5 scenario.

To value these impacts, the value of a life year is used. The VOLY for developing countries is based on the VOLYs derived from the PURGE study for India and China (De Ayala and Spadaro, 2015). For India and China, the country specific VOLY is used. For other countries a VOLY based on population weighting of the VOLY for India and China is used. At an income elasticity of 0.8, the VOLY for China is estimated at $6,458, that for India $3,344 and, for example, the VOLY for LACA is estimated to be $8,348. Estimating ahead, GDP per capita is used and an elasticity of 0.8, drawing on the SSP5 scenario.

To calculate the adaptation costs, we have used the cost-effectiveness (cost per QALY) of two adaptive responses – multiplying these by the DALYs gives an estimate of the adaptation cost. We base our values on the costs in Ebi (2008) – as shown in Table 30.

Table 30 Flow regime characteristics, the parameters with which they are described and the resulting set of 16 indicators with which they can be assessed according to Laizé et al. (2010)

Measures for children<5 year old	Description	Cost
Combined set of measures	Insecticide treated nets, plus case management with artemisinin based combination therapy plus intermittent presumptive treatment in pregnancy	$88.50
Preventive measures	Indoor residual spraying plus above	$123.50

Source: Ebi (2008)

To estimate the benefits derived from adaptation, we needed to make an assumption on the effectiveness of the interventions. Morel et al (2006) suggest both options have a 50% effectiveness – suggesting a 75% overall effectiveness rate.

5.2 Verification and validation using cases

Heatwaves and HHWWS

The assessment of the health impacts of heatwaves and the costs and benefits of HHWWS at European level has been constructed following the framework developed for the Madrid cases study, allowing for some simplifications. The Madrid case study basically considered two climatic scenarios, RCP4.5 and RCP 8.5, with the two SSP scenarios 2 and 5, while the European assessment is built on the RCP8.5 only. The methodological framework for estimating impacts, as well as costs and benefits of adaptation, follows the same theoretical steps, with the following simplified assumptions:

- Estimations are provided only for the no-acclimatization scenario. In the Madrid case study we have constructed all projections considering that the threshold temperature could evolve over time, while for Europe this is kept constant for simplifying the assumptions (also because possible evolution paths over time would differ by location and there is no data available at this level of detail).
- For the economic valuation of health, two measures are used at Eu level: the VSL for premature mortality and VOLY for displaced mortality. In the Madrid case study, we have provided a wider range of reference values for the monetary estimates: a lower bound represented by VOLY applied to both displaced and premature mortality; a central estimate represented by VSL applied only to premature mortality (with no value for displaced); a higher bound with VSL applied to premature deaths and VOLY to displaced deaths, the latter resulting in considerably lower estimates. The application of VOLY to both premature and displaced mortality requires to know what would be the expected gain in life years lost in both cases. For premature mortality specifically, this attribution is quite complex to be applied at EU level, due to the differences expected among countries for which we do not have adequate evidence.

We report here below total discounted costs and benefits of HHWWS for the Madrid case study for the RCP8.5.

Table 31 Total discounted costs of HHWWS, period 2020-2100, RCP8.5, SSP5 (M€)

S2 - no acclimatisation, Tcrit constant=34	**d=0**	**d=1**	**d=2**	**d=3**	**d=5**
HHWScost=low	2.70	1.74	1.18	0.85	0.51
HHWScost=avg	12.00	7.71	5.25	3.77	2.25
HHWScost=high	21.30	13.69	9.31	6.69	4.00
S2a - acclimatisation, Tcrit increasing	**d=0**	**d=1**	**d=2**	**d=3**	**d=5**
HHWScost=low	1.85	1.25	0.89	0.67	0.44
HHWScost=avg	8.20	5.53	3.95	2.98	1.93
HHWScost=high	14.55	9.81	7.01	5.28	3.42

Table 32 Total discounted benefits of HHWWS, period 2020-2100, RCP8.5, SSP5 (M€), lower bound (VOLY for premature + displaced)

S2 - no acclimatisation, Tcrit constant=34	d=0	d=1	d=2	d=3	d=5
HHWSeff=low	3,067	1,851	1,174	785	408
HHWSeff=avg	3,485	2,104	1,335	892	463
HHWSeff=high	3,949	2,384	1,512	1,010	525
S2a - acclimatisation, Tcrit increasing	**d=0**	**d=1**	**d=2**	**d=3**	**d=5**
HHWSeff=low	1,591	1,022	696	501	299
HHWSeff=avg	1,808	1,162	791	569	340
HHWSeff=high	2,049	1,316	896	645	386

Table 33 Total discounted benefits of HHWWS, period 2020-2100, RCP8.5, SSP5 (M€), central estimates (VSL for premature only)

S2 - no acclimatisation, Tcrit constant=34	d=0	d=1	d=2	d=3	d=5
HHWSeff=low	24,485	14,781	9,377	6,264	3,256
HHWSeff=avg	27,824	16,797	10,656	7,119	3,700
HHWSeff=high	31,534	19,037	12,076	8,068	4,193
S2a - acclimatisation, Tcrit increasing	**d=0**	**d=1**	**d=2**	**d=3**	**d=5**
HHWSeff=low	12,701	8,162	5,556	3,998	2,391
HHWSeff=avg	14,433	9,275	6,314	4,543	2,717
HHWSeff=high	16,357	10,512	7,156	5,149	3,079

Table 34 Total discounted benefits of HHWWS, period 2020-2100, RCP8.5, SSP5 (M€), higher bound (VSL for premature + VOLY for displaced)

S2 - no acclimatisation, Tcrit constant=34	d=0	d=1	d=2	d=3	d=5
HHWSeff=low	24,490	14,785	9,379	6,266	3,257
HHWSeff=avg	27,830	16,801	10,658	7,120	3,701
HHWSeff=high	31,540	19,041	12,079	8,070	4,194
S2a - acclimatisation, Tcrit increasing	**d=0**	**d=1**	**d=2**	**d=3**	**d=5**
HHWSeff=low	12,704	8,164	5,557	3,999	2,391
HHWSeff=avg	14,436	9,277	6,315	4,544	2,717
HHWSeff=high	16,361	10,514	7,157	5,150	3,080

Diarrhea and malaria

The assessment of impacts and costs and benefits of adaptation for these two health outcomes have been based on the projections of relative risks as in Ebi (2008) who projected costs of adaptation for year 2030. In our assessment, we consider only the unmitigated scenario, which basically corresponds to RCP8.5. Projections are provided for year 2050. They represent nevertheless lower bound estimates, as they are based on relative risks projected for year 2030, while for year 2050 only population growth is considered to inflate health impacts.

As for diarrhea, total costs of adaptation for year 2050 (worldwide, though the most affected are the developing countries) range from 28 to 206 billion euro in the medium impact assessment, and from 101 to 728 billion euro in the high impact assessment (representing a share of GDP per capita of 0.014%-0.35%). Numbers estimated by Ebi (2008) for the unmitigated scenario are much lower with a range of 2.7 to 9 billion euro in 2030.

As for malaria, total costs of adaptation for year 2050 range from 23 billion euro in the medium impact assessment to 48 billion euro in the high impact assessment. Numbers estimated by Ebi (2008) for the unmitigated scenario fall in the range of 3 to 9 billion euro in 2030.

Differences are attributable to the time effect and also to some methodological improvements: we increased costs of interventions taking into account the increase in per capita GDP in each AD-WITCH region till year 2050, based on the assumption that labour costs are included. Our estimates also include the projection of number of cases following population growth in SSP5 from 2030 and 2050 which further increase total costs.

In terms of the assessment of options, we are able to also compare the results to recent work in Uganda, where cost-benefit analysis was used to evaluate insecticide treated nets and indoor residual spraying (Baastel Consortium, 2015)[5]. In this study in case studies in Tororo and Kabale districts the findings were that in all cases insecticide treated nets have a BCR above 1, but for the indoor residual spraying this only had a BCR above 1 in the case of the region with greater malaria prevalence. This is suggestive that no “one size fits all” policy can be applied for malaria – a spatially differentiated approach may be needed. This spatial variation is lost to a certain extent by the aggregation to world region level, so care should be taken in applying these results in particular regions.

5.3 Results for Human Health

5.3.1 Impact of heat wave under RCP 8.5 and SSP5

An increase of extreme temperature as well as longer heat waves observed with climate change would exacerbate mortality (McMichael et al., 2006; Peng et al., 2011; Wu et al., 2014). High temperatures in summer result in excess premature death of the population, those people whose death is unexpected during this time period, (Kovats and Hajat, 2008) and also in an excess displaced mortality of the most susceptible, those people whose death has been displaced by a few days or weeks (Hajat et al., 2005; Saha et al., 2014). Given the uncertainty attached to the estimation of the displaced mortality rate, we use 2 rates: 40% and 65%.

[5] Economic Assessment of the Impacts of Climate Change in Uganda. Briefing Note: Malaria Prevalence in the districts of Tororo and Kabale. Report prepared for Government of Uganda, Ministry of Water and Environment, Climate Change Department.

Table 35 Discounted impacts of heat on mortality, under RCP 8.5 and SSP5, 2015-2099

	Displaced mortality 40%		Displaced mortality 65%	
Billion euros (€2013)	3% Discount Rate	5% Discount Rate	3% Discount Rate	5% Discount Rate
Eastern Europe	202	85.7	117.9	50
Western Europe	749.1	322.5	437.1	188.2
Europe	951.2	408.3	555	238.2

Table 35 reports the discounted impacts of heat over the period 2015-2099 for the 2 EU regions. As expected by the model construction, the higher the displaced mortality the lower the impacts. The choice of the discount rate would produces non negligible changes in the valuation of the future impacts: the lower the discount rate, the higher importance is given to future generation and the higher the future impact of climate change.

The regional differences should be carefully compared having in mind that the total population exposed to heat waves is different in this 2 regions. The classification responds to an objective of matching the Impact Assessment Model Ad-Witch, not to highlight hot spots in Europe based on heat hazard and exposure.

5.3.2 Cost and benefits of Adaptation strategies

Benefits of Heat Health Watch Warning Systems

Table 36 Discounted benefits of HHWS, under RCP 8.5 and SSP5, 2015-2099

	Displaced mortality 40%		Displaced mortality 65%	
Billion euros (€2013)	3% Discount Rate	5% Discount Rate	3% Discount Rate	5% Discount Rate
Eastern Europe	137.4 (121.2-153.5)	58.3 (51.4-65.1)	80.1 (70.7-89.6))	34 (30-38)
Western Europe	509.4 (449.5-569.3)	219.3 (193.5-245.1)	297.2 (262.2-332.2)	127.9 (112.9-143)
Europe	646.8 (570.7-723)	277.6 (245-310.3)	377.4 (333-421.8)	162 (142.9-181)
Note: in parentheses, low and upper bounds				

By construction of the estimation, the benefits increases with the capacity of the HHWS to prevent death as noted by the low and upper bounds estimations. The range reflects the efficiency of the HHWS. Then, it also varies with the vulnerability of the population: the lower the displaced mortality rate the higher the avoided damages. This results from the valuation hypothesis: displaced mortality (i.e. those vulnerable people that would have died whatever the event) has been valued in terms of life year lost while the premature mortality (those people whose death was not expected in the period of the event) is valued as a whole life lost. Therefore, the higher the avoided premature death the higher the benefits of the HHWS. Finally, the benefits vary with the time preferences: a higher discount rate gives more importance to present generation and reduces the flows of future avoided mortality.

Costs of Heat Health Watch Warning Systems

Table 37 Discounted costs of HHWS, under RCP 8.5 and SSP5, 2015-2099

	Discount rates	
Million euros (€2013)	3%	5%
Eastern Europe	42.4 (9.8–75)	22 (5.1–38.8)
Western Europe	281.3 (64.2-498.4)	141.9 (32.6-251.1)
Europe	323.7 (74- 573.4)	163.9 (37.8-289.9)
Note: in parentheses, low and upper bounds		

The total costs of a HHWS (fix and variable costs) vary in a factor of 7. For a 3% discount rate it varies from 74 to 573 million euros. The difference between Eastern and Western Europe should be carefully addressed due to classification effects: there are more countries in Western than in Eastern Europe. By construction the cost varies with the population of the countries and the number of days of alert.

As already mentioned, estimations on costs is subject to a number of limitations, so that these number have to be considered with great caution. The assessment gives a general idea of basic costs, assuming no differentiation between urban and rural areas, and neither for the city size. Further research should include, at least to some extent, differentiation of costs for these aspects, as well as social and demographical features. However, we argue that any assessment of costs at national and European level is necessarily subject to a certain number of simplified assumptions, while these assessments should be done at the local level, if comprehensive analysis is needed.

5.3.3 Salmonella

Costs and Benefits of Adaptation Strategies

For Salmonellosis, we focus on the costs and benefits of adaptation in the European Union. Table 38 shows the present value costs and benefits of adaptation to salmonellosis over the period 2015 to 2099. It can be seen that the costs vary significantly by country, reflecting the spatial distribution of salmonella and that in general in the cooler countries the BCR may be lower than in warmer countries for public health campaigns. Because of the way the analysis has been conducted, the BCR for treatment does not vary by country. Overall costs of treatment may be €20.7 billion in the period 2015 to 2099 (at a 3 percent discount rate), whereas costs of public health campaigns may be €458 million over the same period. The BCR ranges from 4.3 to 21.4 for treatment (mid value 9) and 13.8 to 28.9 for public health campaigns (mid value 17.9).

Table 38 Present Value Costs and Benefits of Adaptation to Salmonellosis in EU, 2015 to 2099, RCP8.5, SSP5, 3% dr.

	Option 1: Treatment									Option 2: Public health campaign						
Country	GP visit cost	Hospital cost	Total cost	Benefit: Value avoided death (mid VSL)	Benefit: Avoided death (low VSL)	Benefit: Avoided death (high VSL)	B/C ratio (mid VSL)	B/C ratio (low VSL)	B/C ratio (high VSL)	Cost	Benefit (mid VSL)	Benefit (low VSL)	Benefit (high VSL)	B/C ratio mid VSL	B/C ratio (low VSL)	B/C ratio (high VSL)
Austria	88.8	161.4	250.2	2247.0	1070.0	5349.9	9.0	4.3	21.4	8.3	99.2	76.3	159.5	12.0	9.2	19.2
Belgium	183.2	333.2	516.5	4638.7	2208.9	11044.4	9.0	4.3	21.4	12.2	204.8	157.5	329.2	16.8	12.9	26.9
Bulgaria	116.2	211.3	327.6	2942.0	1401.0	7004.8	9.0	4.3	21.4	5.5	129.9	99.9	208.8	23.5	18.1	37.7
Cyprus	30.1	54.7	84.8	761.3	362.5	1812.6	9.0	4.3	21.4	0.9	33.6	25.9	54.0	37.7	29.0	60.6
Czech Republic	128.5	233.6	362.1	3252.4	1548.8	7743.8	9.0	4.3	21.4	9.7	143.6	110.5	230.9	14.8	11.4	23.8
Denmark	53.6	97.4	151.0	1356.0	645.7	3228.5	9.0	4.3	21.4	5.5	59.9	46.1	96.2	10.8	8.3	17.4
Estonia	8.8	16.0	24.8	222.6	106.0	530.0	9.0	4.3	21.4	1.1	9.8	7.6	15.8	9.3	7.2	15.0
Finland	31.2	56.7	87.9	789.2	375.8	1879.2	9.0	4.3	21.4	5.3	34.8	26.8	56.0	6.5	5.0	10.5
France	1147.8	2087.1	3234.9	29053.5	13835.0	69175.0	9.0	4.3	21.4	64.3	1282.5	986.7	2062.2	19.9	15.3	32.1
Germany	906.8	1649.0	2555.9	22955.1	10931.0	54655.1	9.0	4.3	21.4	68.2	1013.3	779.6	1629.3	14.9	11.4	23.9
Greece	215.0	391.0	606.0	5442.4	2591.6	12958.1	9.0	4.3	21.4	8.6	240.2	184.8	386.3	27.9	21.5	44.9
Hungary	161.7	294.0	455.7	4093.0	1949.1	9745.3	9.0	4.3	21.4	8.5	180.7	139.0	290.5	21.4	16.4	34.3
Ireland	51.5	93.7	145.2	1303.9	620.9	3104.4	9.0	4.3	21.4	4.4	57.6	44.3	92.5	13.1	10.1	21.1
Italy	1267.1	2304.2	3571.3	32075.3	15273.9	76369.7	9.0	4.3	21.4	57.4	1415.9	1089.3	2276.7	24.7	19.0	39.6
Latvia	14.0	25.4	39.4	353.6	168.4	841.9	9.0	4.3	21.4	1.4	7.3	3.7	16.8	5.1	2.6	11.6
Lithuania	21.0	38.1	59.1	530.9	252.8	1264.0	9.0	4.3	21.4	2.0	23.4	18.0	37.7	11.8	9.1	19.0
Netherlands	194.2	353.1	547.2	4914.8	2340.4	11701.8	9.0	4.3	21.4	15.4	216.9	166.9	348.8	14.1	10.8	22.6
Poland	416.9	758.2	1175.1	10554.2	5025.8	25129.1	9.0	4.3	21.4	31.9	465.9	358.4	749.1	14.6	11.2	23.5
Portugal	204.6	372.1	576.8	5180.0	2466.7	12333.4	9.0	4.3	21.4	8.2	228.7	175.9	367.7	27.8	21.4	44.7
Romania	301.2	547.7	848.9	7624.6	3630.7	18153.7	9.0	4.3	21.4	16.5	336.6	258.9	541.2	20.4	15.7	32.7
Slovakia	61.9	112.6	174.6	1567.7	746.5	3732.6	9.0	4.3	21.4	4.4	69.2	53.2	111.3	15.6	12.0	25.0
Slovenia	29.9	54.3	84.2	756.3	360.2	1800.8	9.0	4.3	21.4	1.8	33.4	25.7	53.7	18.1	13.9	29.1
Spain	988.1	1796.8	2784.9	25012.5	11910.7	59553.5	9.0	4.3	21.4	40.9	1104.1	849.5	1775.4	27.0	20.8	43.5
Sweden	59.1	107.4	166.4	1494.8	711.8	3559.1	9.0	4.3	21.4	10.4	66.0	50.8	106.1	6.3	4.9	10.2
UK	692.4	1259.2	1951.6	17528.3	8346.8	41734.0	9.0	4.3	21.4	65.7	773.7	595.3	1244.1	11.8	9.1	18.9
Total	**7373.6**	**13408.3**	**20781.9**	**186650.0**	**88881.0**	**444404.8**	**9.0**	**4.3**	**21.4**	**458.7**	**8230.8**	**6330.8**	**13240.0**	**17.9**	**13.8**	**28.9**

5.3.4 Diarrhea

Costs and Benefits of Adaptation Strategies

Table 39 shows the distribution of costs across the AD-WITCH world regions and that the total global cost range from 69 to 232 billion US$ without adaptation (representing 0.033 to 0.11% of projected 2050 GDP). This impact would be significant – but it assumes no adaptation. Clearly, as countries develop factors such as improved sanitation services and better education will lead to reductions in these costs – so these are an upper bound of the potential costs of climate change in terms of diarrhea. These also reflect *welfare* costs – as they include estimates of the value of a statistical life.

Table 39 Cost of impact for diarrhea in 2050, no adaptation (morbidity + mortality) (US$ 000s)

WORLD REGIONS	COST OF IMPACT 2050 TOT (US$ 000s)	
AD-WITCH REGION	Economic impact	
	S1: Mid estimates	S2: High estimates
SSA	5,010,942	10,639,929
CAJAZ	0	593,601
USA	0	1,826,740
LACA	311,003	8,188,833
MEA	1,039,138	1,039,138
OLDEURO	0	3,237,144
NEWEURO	26,268	364,639
TE	120,572	1,673,730
SEA	0	3,426,556
INDIA	51,501,979	144,461,643
SASIA	5,063,147	14,201,989
KOSAU	1,134,886	2,867,070
CHINA	4,350,935	39,158,059
TOT	68,558,871	231,679,069

The estimated costs of adaptation in 2050 are shown in Table 40 and Table 41.

Table 40 Costs of Adaptation to Climate Induced Diarrhea under Medium Impact, 2050 (current prices, $k)

AD-WITCH REGION	S1: MID IMPACT								
	Intervention 1: reactive + preventive			Intervention 2 preventive			Interventions 1+2		
	Lower cost	Medium cost	High cost	Lower cost	Medium cost	Higher cost	Lower cost	Medium cost	Higher cost
SSA (without South Afr)	79,901	1,698,169	11,737,508	2,813,401	5,964,410	9,115,419	2,893,301	7,662,578	20,852,927
CAJAZ (+Japan, New Zeal)	-	-	-	-	-	-	-	-	-
USA	-	-	-	-	-	-	-	-	-
LACA	2,853	60,628	419,053	100,444	212,942	325,439	103,297	273,570	744,493
MEA	11,940	253,763	1,753,974	420,416	891,281	1,362,147	432,355	1,145,044	3,116,120
OLDEURO	-	-	-	-	-	-	-	-	-
NEWEURO	434	9,222	63,740	15,278	32,389	49,501	15,712	41,611	113,241
TE	3,240	68,857	475,932	114,078	241,845	369,612	117,318	310,702	845,544
SEA	-	-	-	-	-	-	-	-	-
INDIA	502,609	10,682,216	73,834,001	17,697,508	37,518,716	57,339,924	18,200,117	48,200,931	131,173,926
SASIA	106,355	2,260,409	15,623,636	3,744,879	7,939,144	12,133,408	3,851,234	10,199,553	27,757,044
KOSAU (+South Africa)	11,108	236,074	1,631,713	391,110	829,154	1,267,198	402,218	1,065,228	2,898,910
CHINA	71,904	1,528,222	10,562,861	2,531,846	5,367,513	8,203,181	2,603,750	6,895,736	18,766,042
TOT	**790,342**	**16,797,560**	**116,102,418**	**27,828,959**	**58,997,394**	**90,165,828**	**28,619,302**	**75,794,954**	**206,268,247**

Table 41 Costs of Adaptation to Diarrhea under High Impact, 2050 (current prices, $k)

AD-WITCH REGION	S2: HIGH IMPACT								
	Intervention 1: reactive + preventive			Intervention 2 preventive			Interventions 1+2		
	Lower cost	Medium cost	High cost	Lower cost	Medium cost	Higher cost	Lower cost	Medium cost	Higher cost
SSA (without South Afr)	169,656	3,605,788	24,922,712	5,973,804	12,664,465	19,355,126	6,143,460	16,270,253	44,277,838
CAJAZ (+Japan, New Zeal)	3,336	70,896	490,023	117,455	249,005	380,555	120,791	319,901	870,578
USA	9,007	191,427	1,323,118	317,142	672,342	1,027,541	326,149	863,769	2,350,659
LACA	75,110	1,596,362	11,033,833	2,644,735	5,606,838	8,568,941	2,719,845	7,203,200	19,602,774
MEA	11,940	253,763	1,753,974	420,416	891,281	1,362,147	432,355	1,145,044	3,116,120
OLDEURO	18,737	398,231	2,752,520	659,760	1,398,692	2,137,624	678,498	1,796,923	4,890,144
NEWEURO	6,023	128,013	884,806	212,082	449,614	687,146	218,105	577,626	1,571,951
TE	44,973	955,845	6,606,670	1,583,574	3,357,177	5,130,779	1,628,547	4,313,022	11,737,450
SEA	68,326	1,452,158	10,037,117	2,405,829	5,100,357	7,794,885	2,474,154	6,552,515	17,832,002
INDIA	1,409,805	29,963,322	207,102,353	49,641,024	105,238,971	160,836,919	51,050,829	135,202,294	367,939,272
SASIA	298,322	6,340,385	43,823,870	10,504,283	22,269,081	34,033,878	10,802,605	28,609,466	77,857,748
KOSAU (+South Africa)	28,061	596,396	4,122,206	988,065	2,094,697	3,201,330	1,016,126	2,691,093	7,323,536
CHINA	647,134	13,753,875	95,064,888	22,786,407	48,307,182	73,827,957	23,433,541	62,061,057	168,892,845
TOT	**2,790,430**	**59,306,462**	**409,918,091**	**98,254,576**	**208,299,701**	**318,344,826**	**101,045,006**	**267,606,163**	**728,262,917**

These costs can be compared to the avoided damages – as shown in Table # below. As regards the first set of measures (providing only health benefits, consisting in treatments and immunization programs), the avoided damages are always greater than the costs in the scenarios using low costs. With mid unit costs, the results vary according to the AD-WITCH region, while with the high unit costs the cost of adaptation is always higher than the avoided damages.

For structural preventive measures (water and sanitation systems), the avoided damages are lower than their costs in all scenarios. These are structural interventions with multiple-benefits among which the health benefits represent only a small share. In this analysis, only the health sector is considered, while benefits regarding other sectors have not been included. It must be noted however that improvements in water and sanitation systems provide benefits higher than the costs, when including all societal benefits (Hutton and Haler, 2004, who evaluated costs and benefits of improving these systems in a context of Millennium Development Goas for water supply).

BCR ratios are calculated only for the first set of measures (treatment and immunization programs) as they provide only health benefits can be fully compared with the costs). We do not present BCR ratios for the second set of measures (water and sanitation) as it is not correct to compare these costs with health benefits only, given that inter-sectoral benefits have not been included in this exercise.

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Table 42 Avoided damages for diarrhea (US$ 000s, 2050)

REGION	AVOIDED IMPACT (Δ morbidity)		AVOIDED IMPACT (Δ mortality)		EC BENEFITS morbidity (US$, 000s)		EC BENEFITS mortality (US$, 000s)		EC BENEFITS TOT (US$, 000s)	
	mid	high	mid	high	mid	high	mid	high	mid	high
SSA	8,790	18,664	7	16	83,777	177,888	1,167,141	2,478,236	1,250,918	2,656,124
CAJAZ	-	365	-	-	-	82,511	-	-	-	82,511
USA	-	589	-	-	-	253,917	-	-	-	253,917
LACA	205	5,410	0	1	15,974	420,600	51,916	1,366,961	67,890	1,787,561
MEA	1,255	1,255	0	0	60,208	60,208	160,444	160,444	220,652	220,652
OLDEURO	-	912	-	-	-	449,963	-	-	-	449,963
NEWEURO	24	331	-	-	3,651	50,685	-	-	3,651	50,685
TE	85	1,183	-	-	16,760	232,648	-	-	16,760	232,648
SEA	-	2,019	-	0	-	166,385	-	590,303	-	756,688
INDIA	10,145	28,458	6	18	705,247	1,978,200	12,292,543	34,480,248	12,997,791	36,458,447
SASIA	3,354	9,407	2	6	109,953	308,414	1,131,105	3,172,719	1,241,058	3,481,133
KOSAU	611	1,543	-	-	157,749	398,523	-	-	157,749	398,523
CHINA	1,678	15,103	0	2	247,362	2,226,240	680,802	6,127,159	928,164	8,353,399
TOT	**26,147**	**85,237**	**16**	**43**	**1,400,681**	**6,806,181**	**15,483,951**	**48,376,069**	**16,884,632**	**55,182,250**

Table 43 Cost benefit ratios for adaptation measures for diarrhea for treatment and immunization programs (2050)

REGION	BCR first set of measures						BCR second set of measures						BCR					
	(lowcost) mid impact	(lowcost) high impact	(midcost) mid impact	(midcost) high impact	(highcost) mid impact	(highcost) high impact	(lowcost) mid impact	(lowcost) high impact	(midcost) mid impact	(midcost) high impact	(highcost) mid impact	(highcost) high impact	(lowcost) mid impact	(lowcost) high impact	(midcost) mid impact	(midcost) high impact	(highcost) mid impact	(highcost) high impact
SSA	15.66	15.66	0.74	0.74	0.11	0.11	0.44	0.44	0.21	0.21	0.14	0.14	0.43	0.43	0.16	0.16	0.06	0.06
CAJAZ		24.74		1.16		0.17		0.70		0.33		0.22		0.68		0.26		0.09
USA		28.19		1.33		0.19		0.80		0.38		0.25		0.78		0.29		0.11
LACA	23.80	23.80	1.12	1.12	0.16	0.16	0.68	0.68	0.32	0.32	0.21	0.21	0.66	0.66	0.25	0.25	0.09	0.09
MEA	18.48	18.48	0.87	0.87	0.13	0.13	0.52	0.52	0.25	0.25	0.16	0.16	0.51	0.51	0.19	0.19	0.07	0.07
OLDEURO		24.01		1.13		0.16		0.68		0.32		0.21		0.66		0.25		0.09
NEWEURO	8.42	8.42	0.40	0.40	0.06	0.06	0.24	0.24	0.11	0.11	0.07	0.07	0.23	0.23	0.09	0.09	0.03	0.03
TE	5.17	5.17	0.24	0.24	0.04	0.04	0.15	0.15	0.07	0.07	0.05	0.05	0.14	0.14	0.05	0.05	0.02	0.02
SEA		11.07		0.52		0.08		0.31		0.15		0.10		0.31		0.12		0.04
INDIA	25.86	25.86	1.22	1.22	0.18	0.18	0.73	0.73	0.35	0.35	0.23	0.23	0.71	0.71	0.27	0.27	0.10	0.10
SASIA	11.67	11.67	0.55	0.55	0.08	0.08	0.33	0.33	0.16	0.16	0.10	0.10	0.32	0.32	0.12	0.12	0.04	0.04
KOSAU	14.20	14.20	0.67	0.67	0.10	0.10	0.40	0.40	0.19	0.19	0.12	0.12	0.39	0.39	0.15	0.15	0.05	0.05
CHINA	12.91	12.91	0.61	0.61	0.09	0.09	0.37	0.37	0.17	0.17	0.11	0.11	0.36	0.36	0.13	0.13	0.05	0.05
TOT	21.36	19.78	1.01	0.93	0.15	0.13	0.61	0.56	0.29	0.26	0.19	0.17	0.59	0.55	0.22	0.21	0.08	0.08

5.3.5 Malaria

The projected impacts in 2050 in terms of DALYs lost due to climate change related malaria are shown in Table 44 below for RCP8.5. There are estimated to be 75 million DALYs lost in 2050 due to additional malaria, worth $846 billion in 2050 in the case of no adaptation. These estimates clearly need to be considered with care – adaptation is likely to take place due to development of countries, with better drainage systems and hospital care. There may also be other advances in management of mosquitoes – including genetic manipulation of mosquitoes to prevent the spread of malaria.

Table 44 Projected DALY losses and economic costs, no adaptation

WORLD REGIONS	PROJECTED NUMBER OF DALYS IN 2050		COST OF IMPACT (US$ 000s)	
AD-WITCH REGION	Physical impact: Δ DALYS (000s)		Economic impact	
	S1: Mid estimates	S2: High estimates	S1: Mid estimates	S2: High estimates
SSA (without South Afr)	28,344	58,492	73,991,911	152,694,155
CAJAZ (+Japan, New Zeal)	1	1	67,640	135,280
USA	0	0	0	0
LACA	491	991	11,150,268	22,483,704
MEA	0	0	0	0
OLDEURO	0	0	0	0
NEWEURO	0	0	0	0
TE	0	0	0	0
SEA	0	0	0	0
INDIA	3,833	7,796	124,341,112	252,910,323
SASIA	1,267	2,577	11,468,299	23,326,566
KOSAU (+South Africa)	1,972	4,070	151,751,947	313,152,059
CHINA	761	1,504	41,215,453	81,469,923
TOT	**36,669**	**75,431**	**413,986,630**	**846,172,009**

In terms of the costs of adaptation, these are shown for the ADWITCH regions in Table #. It can be seen that the costs are not equally spread – with the most significant costs falling in Sub-Saharan Africa and India.

Table 45 Adaptation Costs for Malaria – RCP 8.5 – 2050 ($000s)

	COST OF ADAPTATION (US$ 000s)			
AD-WITCH REGION	Intervention 1: reactive		Intervention 2 preventive	
	Low impact	High impact	Lower impact	High impact
SSA (without South Afr)	4,463,979	9,212,134	6,229,394	12,855,351
CAJAZ (+Japan, New Zeal)	90	179	125	250
USA	-	-	-	-
LACA	118,201	238,343	164,947	332,603
MEA	-	-	-	-
OLDEURO	-	-	-	-
NEWEURO	-	-	-	-
TE	-	-	-	-
SEA	-	-	-	-
INDIA	3,290,078	6,692,032	4,591,239	9,338,598
SASIA	696,197	1,416,067	971,529	1,976,093
KOSAU (+South Africa)	621,365	1,282,235	867,102	1,789,334
CHINA	564,743	1,116,318	788,088	1,557,800
TOT	**9,754,651**	**19,957,309**	**13,612,423**	**27,850,030**

The benefits of adaptation are shown in Table 46. These are significant and outweigh the costs under even the most pessimistic scenarios.

Table 46 Benefits of Adaptation

WORLD REGIONS	AVOIDED NUMBER OF DALYs IN 2050		BENEFITS OF FROM ADAPT 2050 (US$ 000s)	
AD-WITCH REGION	Avoided impact: Δ DALYs (000s)		Economic impact (1+2)	
	S1: Mid estimates	S2: High estimates	S1: Mid estimates	S2: High estimates
SSA (without South Afr)	21,258	43,869	55,493,933	114,520,616
CAJAZ (+Japan, New Zeal)	0	1	50,730	101,460
USA	0	0	0	0
LACA	369	743	8,362,701	16,862,778
MEA	0	0	0	0
OLDEURO	0	0	0	0
NEWEURO	0	0	0	0
TE	0	0	0	0
SEA	0	0	0	0
INDIA	2,875	5,847	93,255,834	189,682,742
SASIA	950	1,933	8,601,224	17,494,924
KOSAU (+South Africa)	1,479	3,053	113,813,960	234,864,044
CHINA	571	1,128	30,911,589	61,102,442
TOT	**27,502**	**56,573**	**310,489,973**	**634,629,007**

5.4 Uncertainty analysis

Table 47 and Table 48 provide a range of the Benefit-Cost Ratio (BCR) for each displaced mortality rate scenario, 40% and 65% and each discount rate. It reveals that a HHWS is a no-regret adaptation strategy since in all the scenarios of valuation the BCR is much greater than 1. In both tables, the range of the BCR varies in a factor of 17. In the worst scenario of Table 48, the benefits are 710 times higher than the costs and in the best scenario around 12000 times higher.

Table 47 Benefit-Cost ratio for a 3% discount rate in all Europe, under RCP 8.5 and SSP5)

			Benefits		
			Lower bound	Central	Upper bound
Displaced Mortality rate 40%	Costs	Lower bound	9360	10608	11856
		Central	2153	2440	2727
		Upper bound	1216	1379	1541
Displaced Mortality rate 65%	Costs	Low bound	5461	6189	6918
		Central	1256	1424	1591
		Upper bound	710	804	899

Table 48 Benefit-Cost ratio for a 5% discount rate in all Europe, under RCP 8.5 and SSP5

	Benefits		
	Lower bound	Central	Upper bound

Displaced Mortality rate 40%	Costs	Lower bound	7728	8758	9788
		Central	1794	2033	2272
		Upper bound	1015	1150	1285
Displaced Mortality rate 65%	Costs	Low bound	4509	5110	5711
		Central	1047	1186	1326
		Upper bound	592	671	750

Although the HHWS is a no-regret strategy of adaption, some other sources of uncertainty remains. Following the steps of estimation of the model, a first source is in the estimation threshold temperature above which heat generates significant increases of death. There is no consensus in the literature on the definition of a heat. Each city or country defines its own threshold (Lowe et al. 2011). At the EU scale, homogenous information is missing. We considered the threshold temperature of the 95th percentile of 2006-2014 in each country6. Another temperature related source of uncertainty is the risk attributable to heat at a country scale. Traditionally, the attributable risk is estimated a city scale with epidemiological data. In the absence of any country scale estimation of the risk we up scaled the estimation from city to a country size using socio-epidemiological data. Another source is the estimation of the premature death or the displaced mortality rate. We provide a range of estimates from the literature, between 40% and 65% of displaced mortality. We valued these deaths in a distinct way. Those people, whose death has been displaced by a week days or weeks because of the heat event, are considered as losing about 1 month maximum (year of life lost, YLL) and are valued with the Value of a Life Year (VOLY). However, those people who died prematurely because of the heat were considered to lose their whole life and are valued with the Value of Statistical Life (VSL). These modeling assumption makes no consensus in the literature and a different repartition of mortality between premature and displaced mortality as well as other rules of valuation of the categories of mortality would lead to different ranges of benefits and of BCR but would not deeply change the issue about the no-regret classification of HHWS in the strategy of adaptation to climate change.

For diarrhea and malaria, uncertainty is taken into account for the physical impact assessment mainly. Different ranges of reference estimates have been considered by using relative risks for high and mid impacts, as in Ebi (2008). These variations apply to estimates of impacts and avoided damages. Ranges of estimates are reported in the above tables about impacts and avoided damages.

For diarrhea, in addition, uncertainty in monetary values is taken into account for the cost assessment of adaptation by considering three levels of unit costs for reactive and preventive measures:

[6] We considered this time period in the absence of any other historical data for us, usually used to compute and define heat threshold temperature.

Table 49 Adaptation measures for diarrhea and associated adaptation costs (US$ 2001)

Adaptation measures	Description	Costs (US$ 2001)		
		low	medium	high
Intervention 1 for children<5 (reactive)	Breastfeeding promotion Rotavirus, cholera and measles immunization	0.71	15.09	104.3
Intervention 2 for children<5 (preventive)	Improvement of water supply and sanitation	25	53	81

All estimates of impacts and avoided damages refer to RCP8.5 and SSP5, given that they are based on the reference of the unmitigated scenario provided in Ebi (2008).

For the economic assessment of the benefits of adaptation for malaria and diarrhea, for simplicity only one reference value has been taken either as VSL, VOLY, WTP, COI, or social value of DALY, depending on the health outcome under analysis. All these values have been adjusted for the GDP per capita of each region, and for the GDP per capita increase over time.

5.5 Policy recommendations

For HHWWS, although the big uncertainties especially on the cost side, the estimated BCR is largely above 1 in all scenarios and under all assumptions, indicating that this measure is a low-regret measure as it can provide high benefits compared to expected costs. These benefits are attributable only to health, in terms of avoided mortality due to heatwaves including both premature and displaced deaths. Specific care however is required for vulnerable groups such as the elderly and those with pre-existent cardio-vascular and respiratory problems. Though these measures are low-regret, a timely and accurate specification of the threshold temperature is requested over time, in order to be cost-effective. Otherwise, without an accurate setting of this temperature, the HHWWS would be set at a wrong temperature leading to additional deaths or higher costs than expected.

For salmonellosis, the estimated BCR for treatment is approximately 9, whereas for public health campaigns the BCR range between 5.1 and 37.7 depending on the context. Treatments and public health campaigns are likely to be important in addressing climate related health problems, but the health sector needs to be prepared for action. This also does not consider actions in other areas – e.g. food production or agricultural practices – which may impact on the analysis.

For diarrhea, recommendations depend on the type of measure considered. The first set comprises both reactive and preventive interventions which basically consist in treatments and immunization programs. They apply specifically to the health outcomes, so that this is the only type of benefit they can provide. The results on the BCR depend on the geographical area considered and the level of unit costs used. For the lowest unit costs, the resulting BCR is always greater than

1 in all scenarios and regions. For medium unit costs, results differ among geographical region, while for high unit costs the BCR is always below 1. Results indicate that for low unit costs, these measures can provide health benefit considerably higher than the costs.. The second set of measures considered includes preventive structural interventions based on improvements in water and sanitation systems. These are multiple-benefits interventions affecting different sectors and not only health. In this case, the evaluation of the measure for policy should be based on an overall BCR ratio which takes into account the full set of benefits provided by different sectors and their causal interactions. For the purpose of this exercise, only the health benefits have been considered, so that we analyze in this study only the health benefits but we cannot generalize results in terms of BCR. It must be noted that improvements in these systems provide benefits higher than the costs, when including all societal benefits (Hutton and Haler, 2004, whose assessment is outside a climate change context). Impacts in other sectors, other than health, are expected therefore to be significant and should be considered in future research in a climate change context.

For malaria, the combination of bed nets, treatments and spraying are shown to have BCRs well above 1. However, they may not offer the least cost solution – for example here we have not considered actions in the water or construction sectors that may reduce the spread of malaria. There may be low cost options in e.g. improving drainage that may reduce the breeding grounds for mosquitos and hence reduce the spread of disease. Local case studies also suggest that the findings of our analysis at region level may not be appropriate for particular contexts – where indoor spraying may not be so viable in less affected regions.

To conclude, in the health sector it can be seen there are a number of options for adaptation – some are potentially more viable than others in different contexts. An integrated approach to health adaptation including other sectors may be needed to ensure health issues are appropriately tackled, as well as further research to improve characterization of unit costs, as the references used in this analysis are average unit costs for a set of measures. In this respect it would be more useful to disaggregate further the cost assessment by type of measure, instead of set of measures.

6 Carbon storage across European regions (CG)

Zuzana Harmackova

6.1 Brief model description and progress in developments under Base project

Carbon sequestration presents a biophysical process transforming atmospheric carbon dioxide into biomass and thus decreasing the amount of greenhouse gases in Earth's atmosphere. Therefore, climate regulation through the amount of carbon stored in ecosystems has been included among vital regulating ecosystem services, mitigating the adverse impacts of climate on human well-being and biodiversity (MA 2005).

The present contribution aimed to assess potential future level of climate regulation in Europe in terms of carbon storage provided by terrestrial ecosystems. To assess potential future levels of carbon storage on European scale and its spatial distribution, it was necessary to utilize a spatially explicit modelling approach enabling to operate at the selected spatial scale. Therefore, we utilized a broadly established approach to ecosystem service modelling, the InVEST suite of modelling tools (Integrative Valuation of Ecosystem Services and Tradeoffs) (Daily et al., 2009; Kareiva et al., 2011). The InVEST suite comprises multiple modelling tools for spatially explicit ecosystem service assessment and evaluation in bio-physical terms. The primary input into the InVEST models are land use and land cover (LULC) scenarios and its major output are maps of ecosystem service provision, which are easily communicable to the public and to decision-makers. InVEST models have been utilized in numerous case studies worldwide, mostly embedded within decision-making processes (Nelson et al. 2009, Nelson et al. 2010, Goldstein et al., 2012, Arkema et al. 2013).

The ecosystem service of climate regulation was modelled in biophysical terms as a change in landscape carbon stocks. The input parameters included current and future LULC maps and the amount of carbon stored in four carbon pools (aboveground biomass, belowground biomass, soil carbon and dead organic matter) for each land use category (Table 50). The data were derived from a compilation of European studies and reports (see Table 50). The model sums the amount of carbon stored in each raster cell under the baseline and the future scenarios and calculates the difference between selected time horizons (Kareiva et al. 2011, Sharp et al. 2014, see Harmáčková and Vačkář 2015 and BASE Deliverable 3.2 for further details on the modelling process).

Carbon storage assessment was based on LULC change scenarios in several time slices to 2050. Since the European scale BASE modelling was generally based on SSP/RCP scenarios (Moss et al. 2010), our aim was to utilize future LULC scenarios based on RCP/SSPs (Hurtt et al. 2011, IIASA 2015). However, the data representation, in which the RCP LULC scenarios are currently available (IIASA 2015), is not applicable in the InVEST model, since the scenarios convey the aggregate percentage of different LULC types in coarse-scale cells, while the InVEST models require explicit spatial distribution of different LULC categories in fine-scale raster representation.

Since no fine-scale and spatially explicit downscaled version of the RCP LULC scenarios is currently available at the European scale, we were forced to utilize LULC scenarios based on the previous set of IPCC storylines (Special Report on Emissions Scenarios, Nakicenovic et al. 2000). Specifically, we utilized the LULC scenarios developed during the 7th Framework Programme project VOLANTE (http://www.volante-project.eu/) as a surrogate for LULC projections based on RCPs and SSPs. The VOLANTE scenarios are based on adjusted SRES storylines and named according to the original SRES scenario (e.g. V-A1 for a scenario based on IPCC SRES A1); thus, they reflect the magnitude and effects of climate change (Lotze-Campen et al. 2013).

The VOLANTE scenarios used in this study were selected to represent the SSP-based storylines used within BASE Workpackage 6 to the largest possible extent. The finally selected VOLANTE scenarios for the analysis were subsequent (Lotze-Campen et al. 2013):

- **Storyline V-A1 (corresponding to SSP5):** Represents a globalized world with strong economic growth, high growth of food and feed demand, weak regulation on land use change, declining tropical forest areas, a fully liberalized CAP, and phased-out bioenergy mandates.
- **Storyline V-A2 (corresponding to SSP3): R**epresents a fragmented world with modest economic growth, high population growth, high growth of food and feed demand, weak regulation on land use change, declining tropical forest areas, no change in the CAP, and phased-out bioenergy mandates.
- **Storyline V-B1 (corresponding to SSP2):** Represents a sustainable world with modest economic growth, slow growth of food and feed demand, strong regulation on land use change, protected tropical forest areas, a liberalized CAP, and modest bioenergy demand .

The spatial extent of the VOLANTE LULC scenarios is EU27, with a resolution 1 x 1 km. Since the VOLANTE LULC scenarios were available for the time frame 2000-2040, carbon storage was modelled for several time slices, namely 2000, 2020, 2030 and 2040 as a proxy for 2050 (Figure 37).

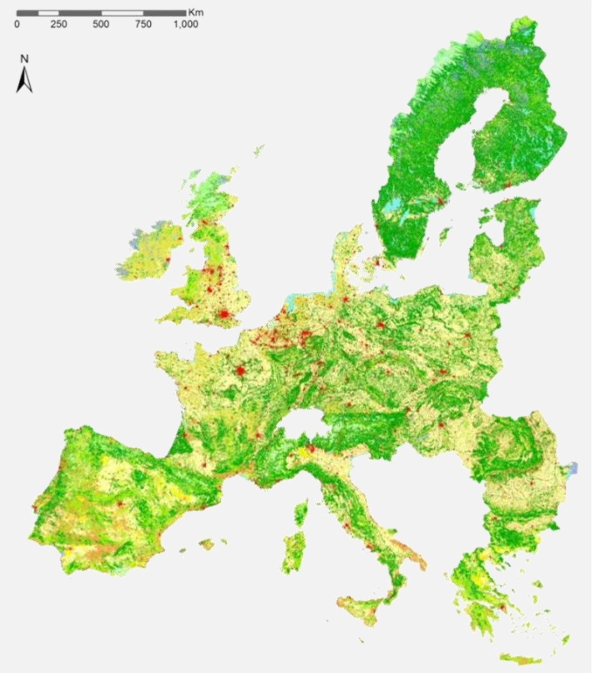
For the sensitivity analysis, we used different volumes of average carbon pools, in the cases when confidence intervals were provided by the source studies (Table 50).

The economic valuation of the net change in carbon storage for different scenarios was calculated using multiple estimates of the social cost of carbon, e.g. the marginal damage cost of climate change (Tol 2008, IWGSCC 2013), based on the biophysical estimates of aggregate annual change in European carbon stocks in the study period calculated by InVEST in the previous step. The social cost of carbon used for the economic valuation ranged between 24 $/t C (as an average value from studies using a 3% pure rate of time preference) and 317 $/t C (as an average value from studies using a 0% pure rate of time preference (Tol 2008).

Table 50 Average carbon pools in aboveground biomass, belowground biomass, soil carbon and dead organic matter used for the European-scale carbon stocks modelling and sensitivity analysis [Mg C ha^{-1}]

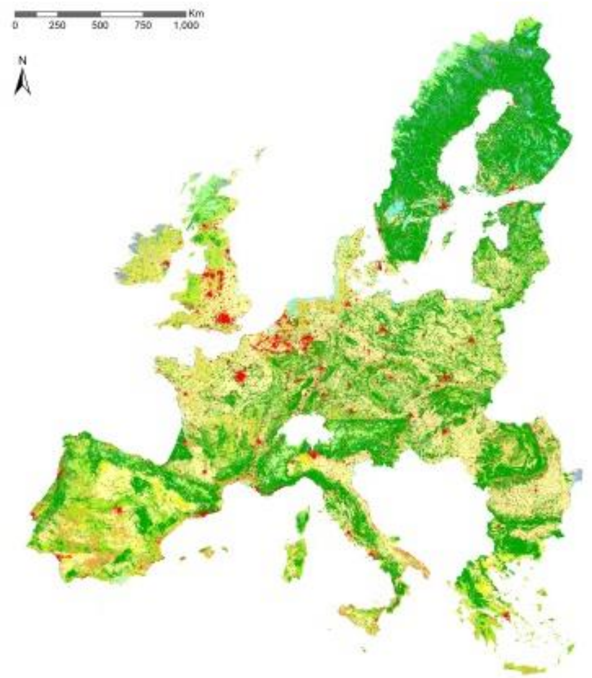
Land use and land cover class	Aboveground biomass	Belowground biomass	Soil carbon	Dead organic matter	Source
Built-up area	0	0	0	0	Sharp et al. 2014
Non-irrigatedarable land	6	2	60	0	EEA 2014, Smith et al. 1997
Pasture	2	4	90	1	EEA 2014, Smith et al. 1997
Transitionalwoodland-shrub	20	8	90	7	Forest Europe 2011
Inland wetlands	10	5	87	0	IPCC 2003, IPCC 2006
Glaciersandsnow	0	0	0	0	Sharp et al. 2014
Irrigatedarable land	6	2	60	0	EEA 2014, Smith et al. 1997
Recentlyabandonedarable land	10	4	60	3	EEA 2014, Smith et al. 1997
Permanent crops	20	10	70	0	EEA 2014, Smith et al. 1997
Forest	50	13	90	15	Forest Europe 2011
Sparselyvegetatedareas	1	1	2	0	Sharp et al. 2014
Beaches, dunesandsands	0	0	0	0	Sharp et al. 2014
Salines	0	0	0	0	Sharp et al. 2014
Water andcoastal flats	0	0	0	0	Sharp et al. 2014
Heather andmoorlands	8	15	50	1	IPCC 2003, IPCC 2006

2000
Baseline

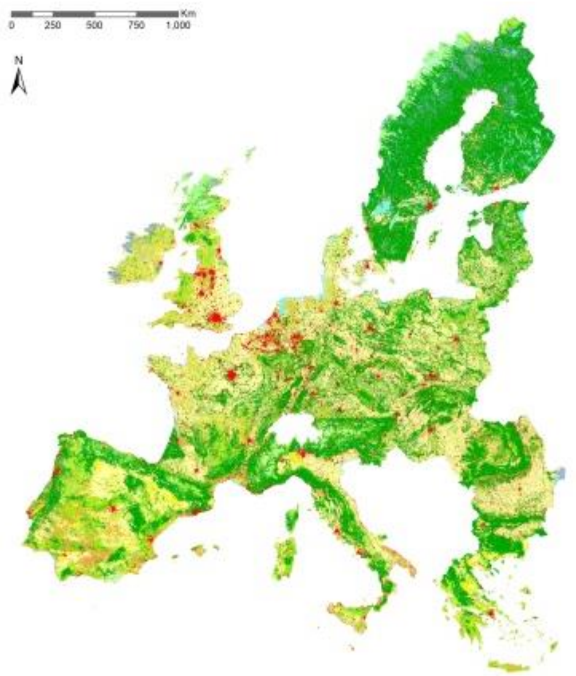


2040
SSP2

2040
SSP3



2040
SSP5



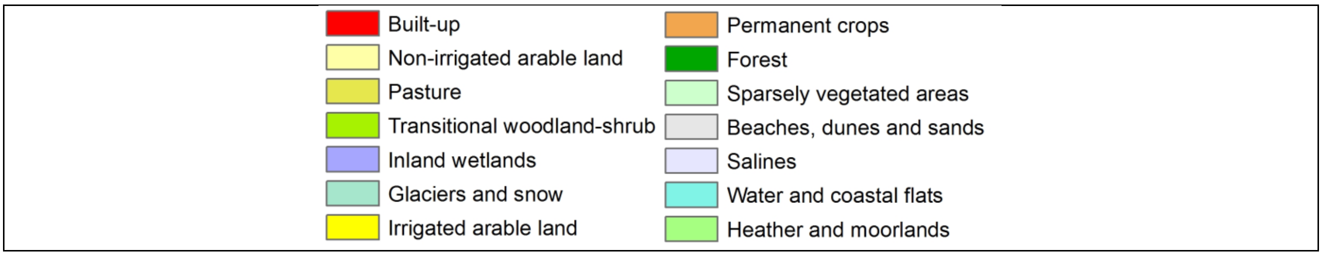


Figure 37 Land use and land cover scenarios corresponding to SSP2, SSP3 and SSP5 for 2000 and 2040.

6.2 Verification/ validation using cases

In addition to the sensitivity analysis, conducted upon the assessment of potential future carbon stocks in Europe, the results were validated by comparing them to existing European-scale studies.

According to Schulp et al. (2008), the majority of the area of Europe is supposed to sequester carbon between 2000 and 2030 and thus increase carbon stocks under all SRES scenarios, which is in line with our results. Carbon stocks are expected to range between a carbon loss of 1100 Mg C km^{-2} and an increase in carbon stocks of 3200 Mg C km^{-2}, while the estimates in our study indicate a range of average change in carbon stocks 72-191 Mg C km^{-2} for different scenarios to 2030. Regarding the current level of carbon stocks, which serves as a proxy for validating future levels, Maes et al. (2011) estimate current carbon storage in EU between 0-116 Mg C ha^{-1}, which corresponds to the average value of 104.9 Mg C ha^{-1} in this study. In addition, according to Schulp et al. (2014), the earlier cited studies further correspond to most of European-wide assessments of carbon-based ecosystem services available.

6.3 Results of the biophysical and economic assessment

The results of European-scale carbon storage modelling show the estimated level of carbon storage in EU-27 under three future scenarios corresponding to selected SSPs, together with its spatial distribution (Table 51, Figure 38, Figure 39).

The results suggest that European carbon stocks are likely to increase under all three scenarios (specifically by 1.3-2.7%) in 2000-2050, although the temporal distribution of change intensity differs substantially between scenarios. The only decrease in carbon stocks modelled occurs under the SSP3 scenario between 2000 and 2020. In general, carbon storage reached the highest levels for SSP2 scenario, followed by SSP5 and SSP3.

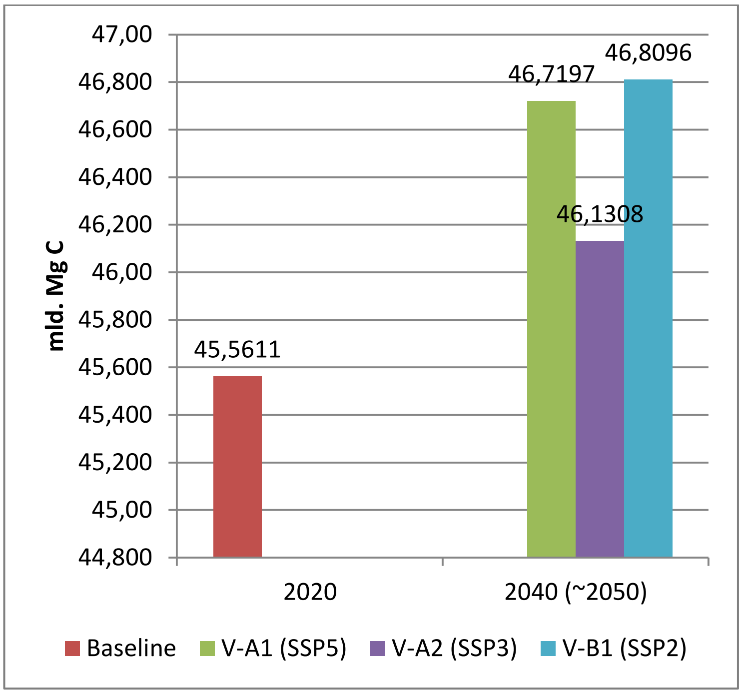


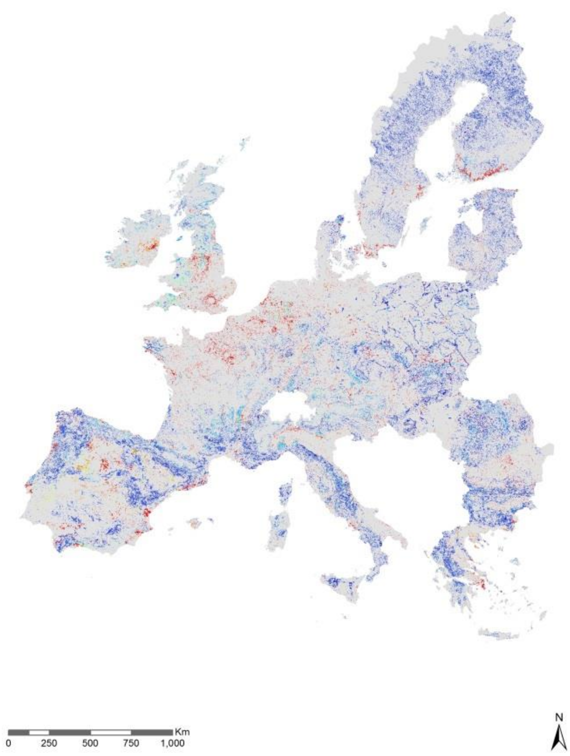
Figure 38 Future carbon stocks in EU-27 for 2000 and 2040, under three scenarios corresponding to SSPs [Mg C].

Table 51 Average carbon stocks in EU-27 for three time slices, under three scenarios corresponding to SSPs [Mg C ha^{-1}].

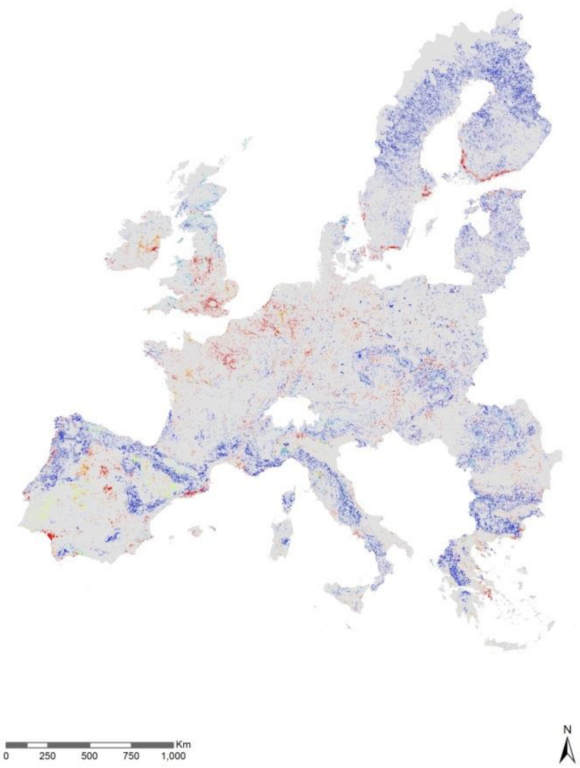
	V-A1 (SSP5)	V-A2 (SSP3)	V-B1 (SSP2)
2020	105.2	104.8	105.4
2030	106.4	105.6	106.8
2040 (~2050)	107.5	106.2	107.7

The spatial patterns of change in carbon storage between 2000 and 2050 suggest that the most substantial increase in carbon storage will occur in mountainous areas and on the fringes of current forests in Europe. Consequently, the largest increase in carbon storage is expected in Northern- and Eastern-European countries, such as Sweden, Finland, the Baltic states, etc. On the other hand, decreasing carbon stocks were modelled in densely populated parts of Western Europe (France, Germany, and the UK).

2040
SSP2



2040
SSP3



2040
SSP5

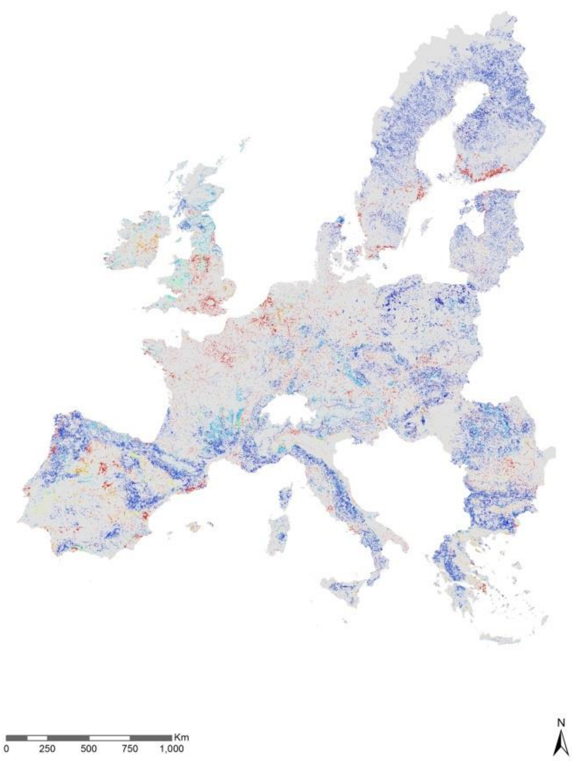


Figure 39 Relative change in carbon stocks in EU-27 under SSP2, SSP3 and SSP5 for 2000 and 2040 [Mg C ha^{-1}].

The estimates of economic value of projected carbon stocks in EU-27 for the study period are reported in Table 52 as the value of annual change in carbon stocks for different scenarios and time slices. Corresponding to the results in biophysical terms, the highest value of sequestered carbon is estimated for the scenario corresponding to SSP2, while the lowest values were modelled under the scenario corresponding to SSP3. Depending on the level of social cost of carbon selected, the economic value of annual change in European carbon stocks for different scenarios between 2000 and 2050 ranges between 342 and 749 million $ $year^{-1}$ as the minimal estimate and between 4,514 and 9,894 million $ $year^{-1}$ as the maximal estimate.

Table 52 Value of annual change in carbon stocks in EU-27 for three time slices, under three scenarios corresponding to SSPs [million $ $year^{-1}$]

Minimal estimate	V-A1 (SSP5)	V-A2 (SSP3)	V-B1 (SSP2)
2000-2020	155	-29	285
2020-2030	1,319	812	1,418
2030-2040 (~2050)	1,150	612	1,009
aggregated 2000-2040 (~2050)	695	342	749
Maximal estimate	V-A1 (SSP5)	V-A2 (SSP3)	V-B1 (SSP2)
2000-2020	2,051	-378	3,764
2020-2030	17,428	10,731	18,724
2030-2040 (~2050)	15,194	8,084	13,324
aggregated 2000-2040 (~2050)	9,181	4,514	9,894

6.4 Sensitivity analysis

The sensitivity analysis was conducted for various levels of carbon pools derived from the source studies on the European level. Where the source studies provided not only the average value of carbon pools, but also their confidence intervals or minimal and maximal values, we used these to calculate minimal and maximal estimates of future carbon pools in EU-27 in addition to their average values (Figure 39).

For the minimal estimates of carbon pools, by 2050 the overall carbon stocks in EU-27 reach levels approximately 20% lower than when using the average pools. In contrast, the maximal carbon pools give an estimate by 6% higher than the average level.

These results show that although the modelled carbon stocks differ substantially for each estimate of carbon pools, the trends remain similar to those calculated for average values of carbon pools, e.g. the carbon stocks in EU-27 increase by 2050 for all scenarios corresponding to three SSPs. Therefore, the minimal and maximal estimates of the economic value of carbon stocks in the previous section are reported based on the average values of carbon pools.

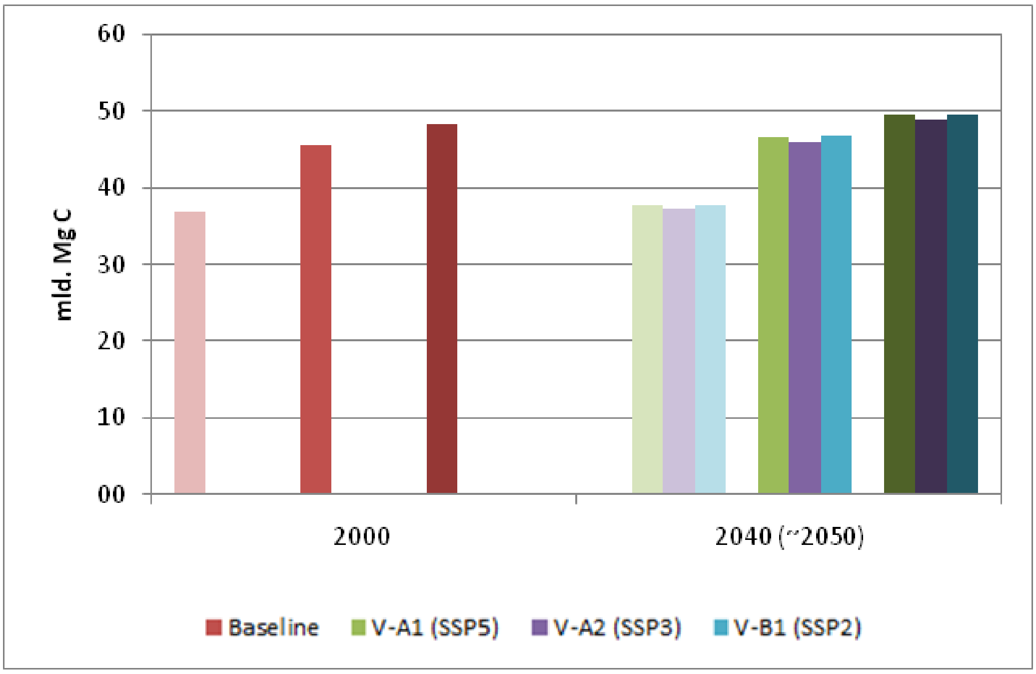


Figure 40 Sensitivity analysis for minimal (in light shaded colours), average (medium shaded colours) and maximal levels (dark shaded colours) of carbon pools

Multiple available land use and land cover change scenarios at the European scale show potential increase of forested areas (VOLANTE, Hurtt et al. 2011). When these changes translate into the amount of carbon stored in terrestrial biomass, our results show that the carbon stocks in EU-27 could potentially increase by 1.3-2.7% by 2050, depending on the scenario, which corresponds to an approximate annual economic value of change in carbon stocks ranging between 342 and 9,894 million \$ year^{-1}. This presents a trend positively influencing the amount of greenhouse gases in the atmosphere.

In terms of climate adaptation, this trend provides several opportunities. According to the results, a substantial space for reforestation may appear in the next several decades, which can be utilized to efficiently increase the level of carbon stocks. Therefore, it is vital to use sustainable approaches to reforestation and to ensure the newly established and expanding forests will reflect the most desirable species composition and other forest characteristics, with consideration of local ecosystem character and potential future impacts of climate change. At the same time, this situation presents an opportunity to implement ecosystem-based adaptation measures in the forestry sector and to utilize the re-establishment of forests to simultaneously improve the resilience of forests ecosystems, their potential to provide ecosystem services and to sustain biodiversity.

Although the aggregate results show increase in carbon stocks, the overall level of increase is rather low. Furthermore, the spatial pattern of potential change show that the most substantial increase in forested areas and related carbon stocks occurs in the sparsely populated north of

Europe, while the densely populated areas of Western Europe undergo decrease in forest cover, mainly due to urban sprawl. Although carbon sequestration and related climate regulation present global ecosystem services, the benefits of which are globally shared, other ecosystem services provided by forests (e.g. cultural, provisioning) are tightly bound to their location and can thus be potentially lacked in these areas.

Finally, it is vital to consider the socio-economical aspect of the changes in forest cover and increasing carbon stocks. The increase of forested areas occurs mainly due to decreasing proportions of agricultural land and pastures, which in turn results from broad socio-economic changes. Therefore, it is vital to consider the trends in carbon stocks in broader perspective, outlined among others by the outcomes reported in the previous chapters of this deliverable.

7 Economy wide impacts of climate mitigation and adaptation strategies across European regions

Francesco Bosello and Enrica Decian

7.1 Brief model description and progress in developments under Base project

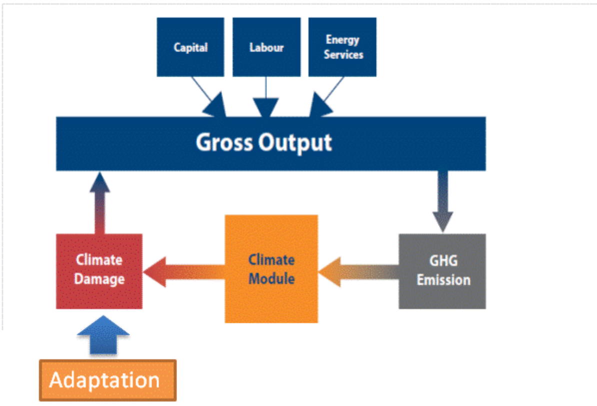
The WITCH model (Bosetti et al. 2006) augmented with adaptation (Bosello et al. 2010, 2013), AD-WITCH thereafter for brevity, is an Integrated Assessment Model (IAM) that can be used to perform cost-benefit and cost-effective analyses of climate change impacts and climate change policies. It is an inter temporal, optimal growth model. Forward-looking agents choose the path of investments to maximize a social welfare function subject to a budget constraint describing the allocation of final gross output among investments and consumptions. A simple climate model links GHG emissions from fossil fuels and industry and land-use change, including avoided deforestation, to global temperature increase through atmospheric concentration. A set of regional reduced-form damage functions link the global temperature increase above pre-industrial levels to changes in regional gross domestic product (Figure 41 left). The model also features a disaggregated representation of the energy system detailed into many energy production technologies. Its geographical resolution depicts 13 major geo-political blocks: Western EU countries (WEU), Eastern EU countries (EEU), the United States, South Korea, South Africa, Australia (KOSAU), Canada, Japan, New Zealand (CAJAZ), Non-EU Eastern European countries including Russia (TE), Middle East and North Africa (MENA), Sub-Saharan Africa (SSA), South Asia including India (SASIA), China including Taiwan (CHINA), South East Asia (EASIA), Latin America, Mexico and Carribean (LAM). Europe is represented as Eastern and Western Europe:

- Eastern Europe (EEU): Central : (Check Republic, Germany, Austria, Poland, Hungary…)
- Western Europe (WEU): West (Netherlands, France, UK, Belgium, Luxemburg, Switzerland…)+North (Denmark, Finland, Sweden, Norway)+ South: (Italy, Spain, Portugal, …)

In AD-WITCH, adaptation consists in a set dedicated regional expenditure or investment items that reduce the negative impacts of climate change on regional GDP. Adaptation is chosen optimally in the optimization process, together with all the other investments, physical capital, R&D, and energy technologies (including energy extraction and infrastructure of the electric grid).

Adaptive responses have been aggregated into four categories, generic adaptive capacity, specific adaptive capacity, anticipatory adaptation, and reactive adaptation. In order to characterize relationships of complementarity or substitutability, these strategies are organized in a nested sequence of Constant Elasticity of Substitution (CES) functions (Figure 41 right). The extent of investments in reactive and proactive adaptation, and in specific capacity, depends on the expected discounted regional damages, on the cost and effectiveness of adaptation, and on the extent of mitigation. Reactive and proactive adaptation also depend on the level of generic adaptive capacity, which is calibrated on the 2005 value of human capital and R&D stock, and grows at the same rate as total factor productivity. Since productivity of production factors, including energy, varies across socio-economic pathways (SSPs), SSP assumptions affect generic adaptive capacity and, ultimately proactive and reactive adaptation.

Simplified structure of the model



Adaptation tree

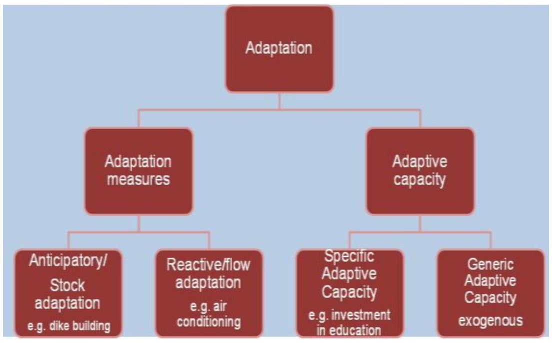


Figure 41 The AD-WITCH model

Using the impact and adaptation estimates developed by three sectoral models for health, flood, and agriculture, AD-WITCH damage, adaptation cost, and adaptation effectiveness functions have been recalibrated and parameterized accordingly. For agriculture and selected health impacts, new adaptation cost and impact estimates are available globally, allowing the recalibration of impacts and adaptation for all thirteen AD-WITCH regions. Flood data are available only for the two EU regions. Table 53 summarizes the type of information that sectoral studies have provided to AD-WITCH. The coarse regional resolution of the top-down model imposes a huge aggregation effort of the spatially resolved data delivered from the sectoral models, ClimateCrop by UPM, the flood risk model by DELTARES, as well as of the work on health developed by BC3 and Exeter University. The result of the aggregation procedure are estimates of adaptation cost and effectiveness with respect to one specific year (the calibration point which is when the temperature increases by 2.5°C above pre-industrial levels). Different sectoral models have provided data for different combination of SSP/RCP scenarios. AD-WITCH has been recalibrated for the common combination of scenarios, SSP5 and RCPP8.5[7]. Costs have been expressed in monetary terms, while effectiveness is measured in percentage of damage reduced.

[7]The other scenarios (SSP2, SSP2 +RCP4.5) have been simulated using the recalibrated model without modifying the damage and adaptation function parameters. In these scenarios, the solution of the model is driven by the different socioeconomic and mitigation assumptions.

Table 53 Data from sectoral studies incorporated in the AD-WITCH model

	Regional Coverage	SSP	RCP	Time	Type of impact	Adaptation type
Flood	EU	ssp2; ssp5	rcp8.5	2050-2099	Land loss due to river flood	Dike building (Proactive adaptation in the WITCH model)
Agriculture	World	ssp2; ssp5	rcp4.5; rcp8.5	2065-2070 in RCP4.5SSP2 2050-2055 in RCP8.5SSP5	Impacts on crop yields	Irrigation and improved management for water use (Proactive adaptation in the WITCH model)
Health	EU	ssp5	rcp8.5	2006-2099, annual	Heat waves	Heat Watch alert system (Proactive adaptation in the WITCH model)

Health	World	ssp5	rcp8.5	2006-2099, annual	Salmonella, malaria, diarrhea	Salmonella treatment (Reactive adaptation in the WITCH model) Salmonella prevention through public health campaigns (Proactive adaptation in the WITCH model) Malaria Insecticide-treated bed nets + case management with artemisinin-based combination therapy + intermittent presumptive treatment in pregnancy indoor residual spraying (Reactive adaptation in the WITCH model) Diarrhea Improvement of water supply and sanitation (Proactive adaptation in the WITCH model) Oral rehydration, breastfeeding promotion, rotavirus, cholera & measles immunization (Reactive adaptation in the WITCH model)

7.2 Cost and benefits of Adaptation strategies: a comparison of the new sectoral estimates with data previously used in AD-WITCH

The AD-WITCH model does not characterize the detail of specific adaptation measures in agriculture, flood, and health, as described in Table 53. The costs and effectiveness of the different measures listed in Table 53 have been aggregated on the basis of the nature of the investment/expenditure into their anticipatory (proactive) or reactive adaptation. It is also important to clarify that the AD-WITCH model before BASE recalibration (Bosello and De Cian, 2014) included impacts and adaptation costs-effectiveness for other sectors beside agriculture, health, and flood, such as coastal protection or cooling demand. The BASE project focuses on the three sectors mentioned, therefore AD-WITCH has been recalibration for those three sectors only, whereas other impact categories have not been included. Furthermore, even within the three sectors of interest, there are differences in the portfolio of adaptation options considered before and after BASE recalibration, see Table 54.

Table 54 Original AD-WITCH representation of adaptation strategies in agriculture, flood risk and health sectors and after the BASE updating)

	AD-WITCH adaptation strategies in Bosello and De Cian (2014) **before** BASE recalibration		AD-WITCH adaptation strategies **after** BASE recalibration	
	Options	Adaptation type	Options	Adaptation type
Agriculture	Irrigation	Proactive	Irrigation	Proactive
	Ground water management	Proactive	Water management	Proactive
	Water conservation	Proactive	--	--
	Crop diversification	Proactive	--	--
Flood	Climate-proof infrastructure	Proactive	Dikes for flood risk protections	Proactive
	Early Warning System	Proactive	--	--
Health	Prevention and treatment of vector-borne, cold- and heat-related	Reactive	Salmonella treatment	Reactive

	diseases		Public health campaigns	Proactive
		Proactive	Heat wave warning systems	Proactive
		Reactive	Malaria Insecticide-treated bednets + case management with artemisinin-based combination therapy + intermitent presumptive treatment in pregnancy indoor residual spraying	Reactive
		Proactive	Diarrhea Improvement of water supply and sanitation	Proactive
		Reactive	Diarrhea Breastfeeding promotion, rotavirus, cholera & measles immunization	Reactive

In the remainder of this section we show the values of impacts and adaptation costs and effectiveness before and after BASE recalibration, bearing in mind the abovementioned differences and the different scenario used for calibration, SSP2 before the recalibration and SSP5 after BASE recalibartion. For brevity we refer to the WITCH model before BASE calibration as AD-WITCH2014.

7.2.1 Recalibration of impacts and adaptation - Flood

AD-WITCH2014 included the investments needed to adapt infrastructure to climate change among proactive adaptation. These were computed by applying the methodology described in UNFCCC (2007) and defined for year 2060. Protection level was set to 40%. Impacts were estimated using a willingness-to-pay approach for both settlements and ecosystems preservation.

The new estimates from the DELTARES flood risk model represent flood losses to five different land-use types due to river discharges and flood inundation. Adaptation costs are the costs for upgrading flood defences or increasing flood protection and are provided as a percentage of GDP. Adaptation effectiveness is more than 100%. This means that adaptation will potentially do more than reduce only the climate impact costs. These numbers are the mean results from 5 General Circulation Models (GCMs). Results are shown in Table 55.

Table 55 AD-WITCH estimates at the calibration point (+2.5°C) of adaptation costs and impacts for floods and new estimates from BASE)

AD-WITCH2014 (Bosello and De Cian 2014) Climate proofing infrastructure				
	Adaptation Type	Adaptation cost		Impacts
		2005 US$ Bn	% GDP	% GDP
EEU	Proactive	03-08	0.023-0.091	-0.537
WEU	Proactive	13- 44	0.023-0.093	-0.606
BASE update Flood protection (from DELTARES flood risk model)				
EEU	Proactive	0.5	0.033	-0.087
WEU	Proactive	4.4	0.038	-0.119

7.2.2 Recalibration of impacts and adaptation - Health

AD-WITCH2014 quantified GDP losses related to adverse climate change impacts on health following Nordhaus (2007), which estimates damages due to malaria, dengue, tropical diseases and pollution. Furthermore, but only for Europe, AD-WITCH2014 includes negative impacts on labour productivity from thermic discomfort reported by Kovats R.S. and Lloyd (2011)). Adaptation costs in the health sector, assumed to be reactive in nature, derive from Tol and Dowlatabadi (2001) who assess the additional climate change-driven treatment cost associated with malaria, dengue, schistosomiasis, diarrhoeal, cardiovascular and respiratory diseases for different scenarios of temperature increases, for all countries of the world. The effectiveness of treatments ranges on average from 20% in Africa to 40% in other non OECD countries and from 60% to 90% in OECD countries.

The new estimates provided by BC3 include climate impacts in terms of:

- Mortality due to heat waves evaluated in monetary terms using the value of one year of life (VOLY), which provides a lower bound, and the value of statistical life (VSL), which provides an upper bound.
- Mortality and morbidity due to salmonella assessed using dose-response functions and it is evaluated in monetary terms using values based on willingness to pay studies.
- Morbidity and mortality due to malaria evaluated using DALYs
- Morbidity and mortality due to diarrheal evaluated using value of statistical life (VSL)

Whereas (1)-(2) have been estimated only for Europe, (3)-(4) have been evaluated for all thirteen model regions. Adaptation costs are the costs of:

- Heat waves warning system, based on a study by Ebi et al. (2004). This is considered a proactive form of adaptation.
- Salmonella treatment costs (reactive adaptation) and the cost of public health campaigns both based on a UK study (proactive).

- Malaria adaptation costs include insecticide-treated bed nets + case management with artemisinin-based combination therapy + intermittent presumptive treatment in pregnancy, indoor residual spraying (Reactive)
- Diarrheal adaptation costs include improvement of water supply and sanitation (Proactive) and breastfeeding promotion, rotavirus, cholera & measles immunization (Reactive)

Effectiveness of heat wave warning system varies between 60 and 76%. The combined effectiveness of public campaigns and treatment is 24%. Effectiveness of adaptation to address malaria is 75%, to address diarrheal 14%. Results for Europe are compared in Table 56.

Table 56 AD-WITCH estimates at the calibration point (+2.5°C, around 2050) and updated impacts and adaptation costs for the health sector. Negative impact figures indicate a benefit from climate change and a negative cost a reduction in adaptation costs)

AD-WITCH2014 (Bosello and De Cian 2014)					
Treatment costs for malaria, dengue, schistosomiasis, diarrheal, cardiovascular and respiratory diseases					
Regions	Type	Adaptation cost		Impacts	Effectiveness
		2005 USD Bn	% GDP	% GDP	(0-100%)
EEU	Reactive	-0.064	-0.0015	-0.06	90%
WEU	Reactive	-0.68	-0.0012	-0.119	60%

BASE update, Health impacts analysis (BCE and University of Exeter)											
	Malaria+Diarreha	Heatwaves	Salmonella	Malaria+Diarreha	Salmonella	Malaria+Diarreha	Heatwaves	Salmonella	Malaria+Diarreha	Heatwaves	Salmonella
	Impacts			Cost of Reactive Adaptation		Cost of Proactive Adaptation			Effectiveness		
EEU	--	0.001	0.189	--	0.004	0.001	0.005	0.000	--	68	24
WEU	--	0.000	0.080	--	0.002	0.000	0.001	0.000	--	68	24

7.2.3 Recalibration of impacts and adaptation - Agriculture

AD-WITCH2014 used the changes in the average productivity of crops from the ClimateCrop model (Iglesias et al. 2009; Iglesias et al. 2010). Adaptation is proactive and represents water infrastructure costs (UNFCCC, 2007). The effectiveness of adaptation in agriculture is instead based on Tan and Shibasaky (2003).

The new estimates provided by UPM include climate change impacts on crop yields. In order to obtain a monetary evaluation we have used the CGE model ICES (Eboli et al. 2010) to compute the indirect economic GDP changes associated with the crop productivity losses. Table 57 compare the direct impacts on crop yields with the GDP changes estimated by the CGE model (indirect impacts on GDP). Because of international trade and cross-sectoral effects, even though a country suffers from negative impacts on yields, GDP changes can be positive, as it is the case in both Eastern and Western Europe.

Table 57 Agriculture: direct and indirect impacts in the RCP8.5 SSP5, around 2050)

WITCH region	Indirect impacts on GDP	Direct impacts on yields
CAJANZ	0.580	11.542
CHINA	0.628	6.872
EASIA	-2.513	-10.713
EEU	0.277	-0.302
INDIA	-7.499	-17.549
KOSAU	-0.081	-2.995
LACA	-0.297	-4.248
MENA	-0.987	-13.908
SASIA	-5.784	-15.390
SSA	-5.539	-11.880
TE	-0.163	-2.822
USA	-0.062	-8.964
WEU	0.299	-5.679

Adaptation costs are the costs of expanding irrigation area and improving management for water use. Both strategies are proactive forms of adaptation. Impacts also include farm-level change in management which does not have costs and therefore it is only implicitly included in the impact estimates. Adaptation costs are provided as % of GDP. For each country, scenario, year we have computed an indicator of cost-effectiveness as ratio between adaptation costs and effectiveness. Instead of aggregating different adaptation strategies, for each country, year, scenario combination we have selected the most effective adaptation option. Countries have two adaptation options, irrigation and water management, which have different costs and effectiveness. For example, consider Belgium. Both strategies could reduce damages by 100%, but water management is more cost-effective and therefore that strategy was selected. Results for Europe are compared in Table 58.

Table 58 AD-WITCH estimates at the calibration point (+2.5°C, around 2050) and updated impacts and adaptation costs for the agricultural sector)

AD-WITCH2014 (Bosello and De Cian 2014)				
	Adaptation costs		Ad. Effectiveness	CC Impacts
Regions	2005USD Bn	% GDP	(0-100%)	% GDP
WEURO	4.7	0.008	43%	0.15
EEURO	7.4	0.171	43%	-0.27
BASE update, UPM crop yields model				
WEURO U	29.6	0.1	78%	0.33
EEURO	1.6	0.07	77%	0.24

7.3 Calibration using sectoral models

Damage functions have the same functional form as in Bosello and De Cian (2014), but they have been recalibrated using the data from the only scenario that was common to all models, namely SSP5 RCP8.5. The data on impacts have all been expressed in GDP and used to calibrate regional damage functions. Figure 42the resulting damage functions for all model regions and Europe. The right panel decomposes European impacts into the three sectors of interest at the calibration point, and compares the BASE updated estimates to AD-WICTH2014.

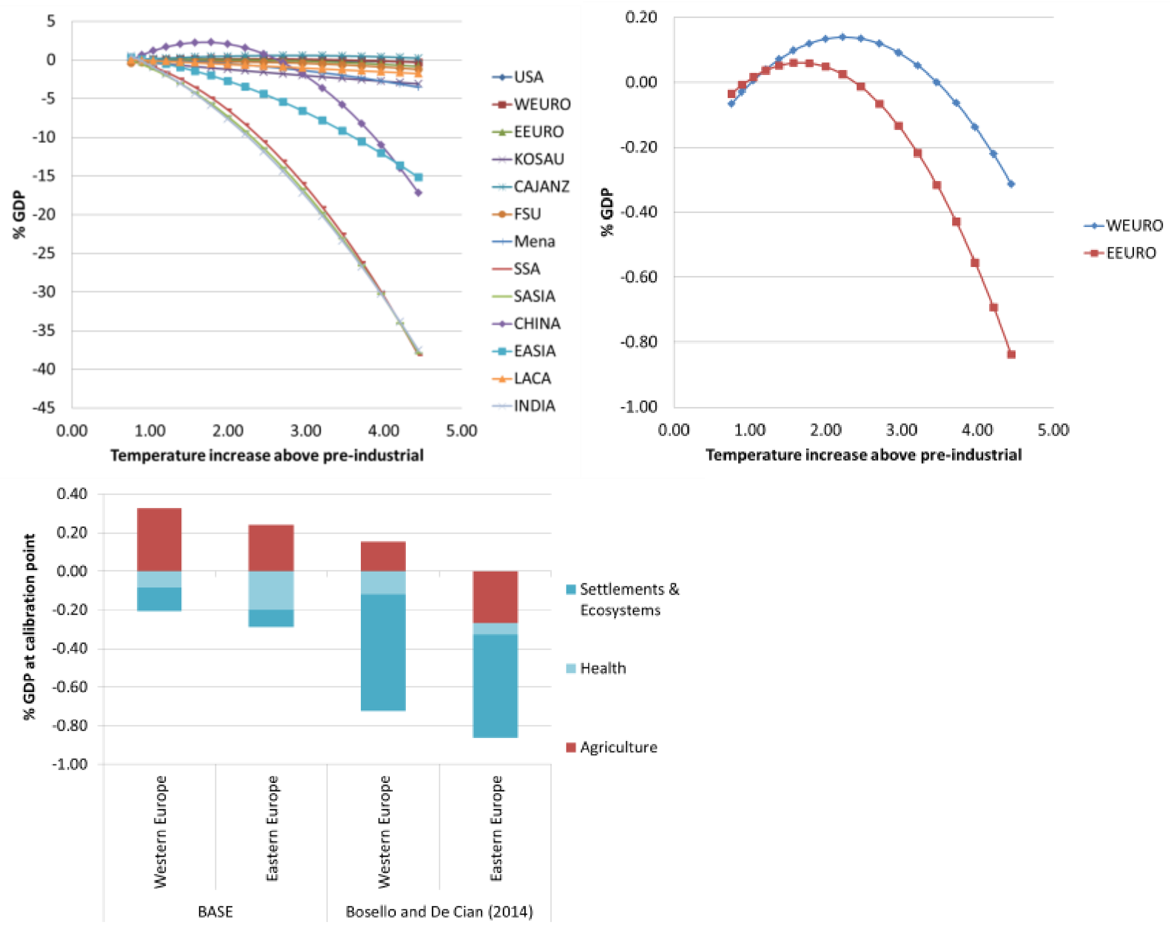


Figure 42 Re-calibrated damage functions and comparison of updated sectoral damages with Bosello and De Cian (2014)

As mentioned, AD-WITCH represents three stylized forms of adaptation, proactive, reactive, and specific capacity. The adaptation costs provided by the sectoral models described in the section above have been aggregated into proactive and reactive measures to obtain the aggregate costs to be used for calibrating regional adaptation costs in the model. Table 59 summarizes the data used for calibration and model's results. In a nutshell, calibration has tried to replicate the total proactive and reactive costs, and the overall adaptation effectiveness, which is computed as a damage-weighted sum of the effectiveness in the individual sectors. A major difference compared to AD-WITCH2014 emerging from Table 56, Table 57, and Table 58, is the much higher effectiveness of adaptation for the impact categories of flood and agriculture, which lead to the high overall aggregate adaptation effectiveness shown in Table 59.

Table 59 Calibration data and model results at the calibration point (+2.5°C, around 2050, SSP5 RCP8.5)

	Cost of proactiveadaptation					Reactive			Effectiveness				
	% regional GDP					% GDP			% reduceddamage				
	Sectoralmodels				AD-WITCH	Sectoralmodels		AD-WITCH	Sectoralmodels				AD-WITCH
	Health	Agr	Flood	Total	Total	Health	Total	Total	Health	Agr	Flood	Total	Total
CAJAZ	0.00	0.01		0.01	0.00	0.000	0.000	0.000	0.75	0.80		0.80	0.36
CHINA	0.01	2.36		2.37	1.20	0.008	0.008	0.003	0.56	1.00		1.00	0.60
EASIA	0.00	0.61		0.61	0.45	0.000	0.000	0.000	0.45	0.44		0.44	0.52
INDIA	0.26	0.81		1.07	0.75	0.127	0.127	0.090	0.38	0.33		0.33	0.52
KOSAU	0.01	0.03		0.04	0.03	0.020	0.020	0.020	0.75	0.63		0.63	0.43
LACA	0.00	0.26		0.26	0.15	0.002	0.002	0.000	0.71	0.48		0.48	0.37
MENA	0.01	0.17		0.18	0.18	0.002	0.002	0.000	0.14	0.31		0.31	0.30
SASIA	0.27	0.22		0.48	0.13	0.131	0.131	0.125	0.27	0.34		0.34	0.21
SSA	0.06	0.08		0.14	0.15	0.132	0.132	0.132	0.59	0.43		0.43	0.16
TE	0.00	0.75		0.75	0.61	0.001	0.001	0.002	0.14	0.62		0.62	0.69
USA	0.00	0.13		0.13	0.10	0.000	0.000	0.000	0.45	0.71		0.71	0.45
WEU	0.00	0.10	0.04	0.14	0.14	0.002	0.002	0.002	0.24	0.78	1.00	0.75	0.51
EEU	0.01	0.07	0.03	0.11	0.11	0.005	0.005	0.005	0.24	0.77	1.00	0.61	0.44

7.4 Cost-benefit analysis of adaptation and mitigation under alternative scenarios

Two different scenarios have been selected for the analysis of trade-offs between adaptation and mitigation:

Storyline 1: SSP5 and RCP 8.5 “Market driven development”

Storyline 2: SSP2 and RCP 4.5 “Middle of the road”

The SSPs represent different scenarios that have been qualitatively described through story lines (O’ Neil et al. 2015). These scenarios have been implemented and quantified in the WITCH model to generate the different scenarios. The scenario SSP2 (without implementing any policy) would achieve a radiative forcing concentration of 6 W/m^2. In order to achieve the 4.5 W/m^{2}radiative forcing target, an active mitigation policy needs to be assumed. For reference, we also include the SSP2 without climate policy.

Population predictions for the different SSPs are from the common scenarios developed at IIASA (International Institute for Applied Systems Analysis) and the OECD. We use the OECD projections aggregated across WITCH regions. GDP baseline projections are from the OECD. These GDP baseline projections are implemented using Purchasing Power Parities (PPP) and based on individual countries. We convert the data into USD using market exchange rates using the conversion factor of 2005 (also given by the OECD and assumed constant over time) and aggregate the series into WITCH regions. The GDP projected is then used to calibrate the time series of total factor productivity for the model.The calibration of factor productivity of energy services is based on the SSP2 and uses an income elasticity rule differentiated across regions. Industrialized countries (OECD members) are characterized by an elasticity of 0.40 in 2005 whereas non-OECD members have an elasticity of 0.55 based on the higher share of energy expenditures. To take into account economic progress and convergence, the elasticity is assumed to fall exponentially to finally reach a value of 0.2 in the year 2150. Based on the obtained time series of regional energy productivity changes for SSP2, the same series is used for SSP5. These values result in reasonable primary energy demand projections for the respective story lines and baseline GDP and population projections.

The two selected scenarios span the range of both mitigation and adaptation challenges. Below we focus on the challenges to adaptation. Table 60 describes the elements that can be used to characterize adaptation storylines. Adaptation has been differentiated across SSPs by assuming different effectiveness and different adaptive capacity pathways. Given these set of assumptions, the three scenarios are implemented in an optimal way.

Table 60 Elements describing challenges to adaptation)

	SSP5 RCP8.5	SSP2		SSP2 RCP45
Options	All	All		All
Green/Gray/AC	Balance between the three	Balance between the three		Balance between the three
Preferences for A/M types	M=0 A=Optimal A>>M	M=0 A=Optimal A>>M		M=CE; A= Optimal
Effectiveness	High	Medium		Medium
Objective	Optimal/efficient adaptation	Optimal/efficient adaptation		Optimal/efficient adaptation
Financial resources	Optimal adaptation	Optimal adaptation		Optimal adaptation
Risks	Higher exposure (GD), lower vulnerability (RD)	Low exposure (GD), low vulnerability (RD)		Low exposure (GD), Reduced vulnerability (RD)
Technology	High	Medium		Medium
Private/public	Balance between private/public	Balance between private/public		Balance between private/public

Table 61 describes the implementation of adaptation across SSPs in the WITCH model. We assume that slow development, low investments in human capital and technology, increased inequality, and bad institutions reduce the effectiveness of adaptation actions, whereas the more optimistic institutional and growth set-up of SSP5 increases adaptation effectiveness. We assume that a dollar invested in proactive or reactive adaptation in SSP5 is 25% more effective at reducing damage than in SSP2 (the marginal productivity of these actions is assumed to be 25% higher). It is important to highlight that, the optimization framework of AD-WITCH implies that adaptation is implemented optimally across regions, and within each region, across sectors and countries. Inefficiencies or barriers to adaptation are not considered, if not implicitly in the level of generic capacity, which is lined to different SSP storylines.

Table 61 Implementation of adaptation across in SSPs in the WITCH model)

	SSP5	SSP2
	Market driven development	Middle of the road with active mitigation
Adaptation	Low challenges due to rapid development, formation of human capital, reduced inequality	Intermediate challenges
	High efficacy	Medium efficacy
Productivity of adaptation activities	1.25	1
Growth in generic capacity	High	Medium

The RCP 8.5 climate scenario that underlies the storyline “Market driven development” would lead to higher gross damages of climate change (Figure 43) compared to the other scenarios, driven by higher GHG emissions. The “Middle of the road scenario” (SSP2+RCP45, also referred to as ssp2_mit to distinguish it to the SSP2 without climate policy, which reaches a radiative forcing of 6 W/m2) would have the lowest carbon budget and gross damages.

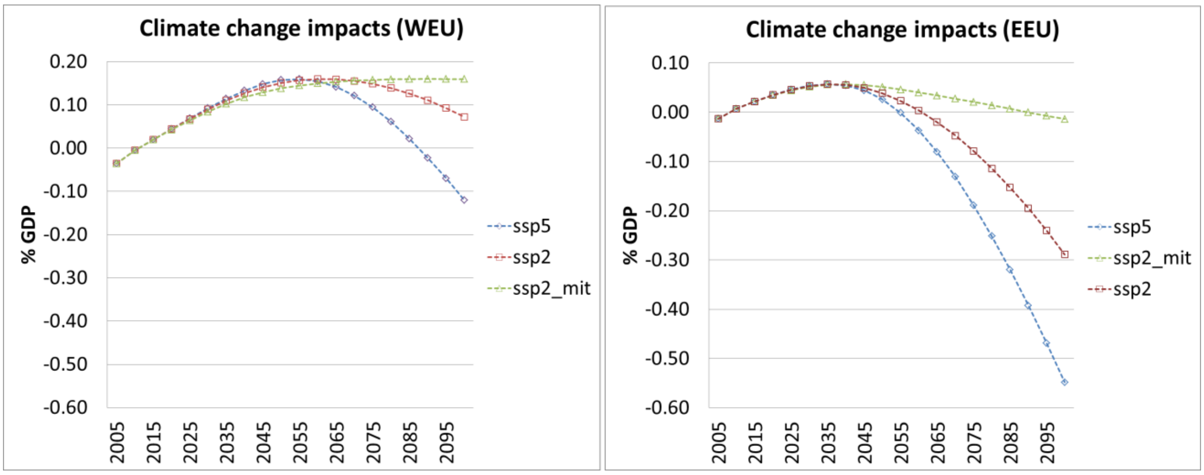


Figure 43 Climate change impacts without adaptation (% change in regional GDP)

Mitigation is assumed to be successful only in the in the "Middle of the road" socio-economic scenario. From 2015 all countries are assumed to cooperate to reduce emissions. Mitigation reduces the long-run needs for adaptation, but mitigation does not significantly affect adaptation until 2030 (Figure 43). The same adaptation expenditure is required both in Western and Eastern Europe to cope with the damages associated with the already committed climate change.

Adaptation needs are the largest under the "Market-driven development" scenario (SSP5), as gross damages are higher than the other scenarios in both Western and Eastern Europe. Gross damages are not the only driver of adaptation expenditure, but adaptive capacity plays a role as well.

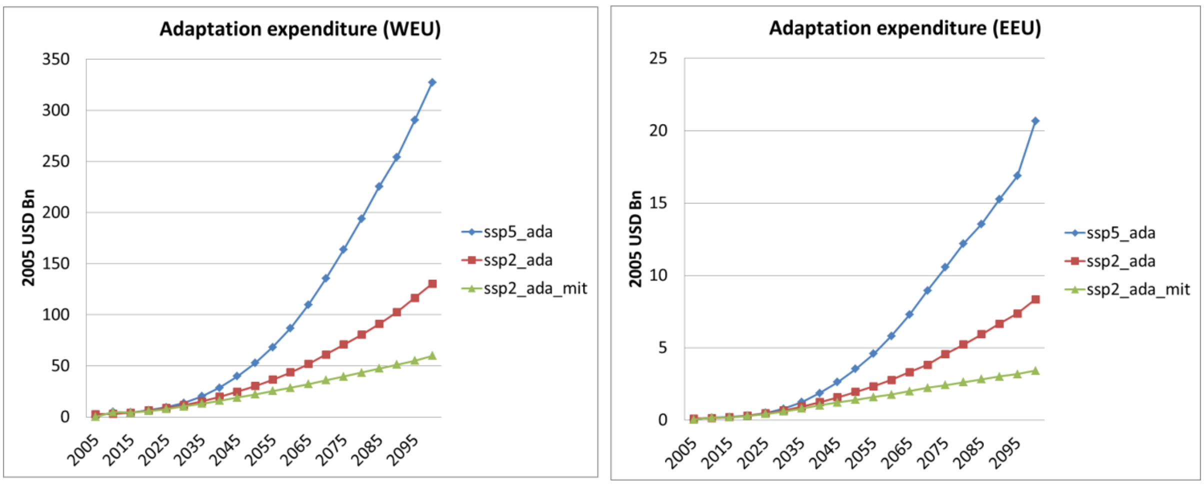


Figure 44 Adaptation expenditure in Western and Eastern Europe

Table 62 summarizes damages, adaptation costs, and adaptation effectiveness in 2050 (and 2100 for damage) across the three scenarios, for Europe.

Table 62 Results from the updated AD-WITCH model

Region	Scenario	2050 Impacts w/o adaptation (% regional GDP)*	2100 Impacts w/o adaptation(% regional GDP)	2050 Proactive adaptation (2005 USD bn)	2050 Reactive (2005 USD bn)	Total adaptation (% regional GDP)	2050 Adaptation effectiveness (% reduced damage)
Western EU	SSP5 RCP85 (Reference)	0.1576	-0.1199	50.36	0.59	0.14%	50%
Eastern EU	SSP5 RCP85 (Reference)	0.0259	-0.5484	3.34	0.13	0.11%	43%
Western EU	SSP2	0.1509	0.0721	28.94	0.35	0.12%	43%
Eastern EU	SSP2	0.0386	-0.2887	1.84	0.08	0.09%	40%
Western EU	SSP2 RCP45	0.1384	0.1596	21.19	0.28	0.08%	37%
Eastern EU	SSP2 RCP45	0.0513	-0.0139	1.33	0.06	0.10%	35%

*Negative numbers represent negative impacts (losses), positive numbers represent positive impacts (gains)

According to the input data provided by the sectoral models, adaptation, especially to address impacts in the agriculture sector and flood risk, is very effective. The effectiveness of adaptation carries over to the AD-WITCH model, and adaptation can change the sign of climate impacts from negative to positive (Figure 45). It is important to clarify that these results hold only for Europe, which lose only marginally from climate change. Figure 46 provides an example for an high-impact region, such as Sub-Saharan Africa (SSA). It shows that in high-impact regions mitigation is an important strategy, together with adaptation, to reduce climate damages. In low- or positive-impact regions, adaptation seems to play a more prominent role, when considering the regional benefits accruing to that specific region.

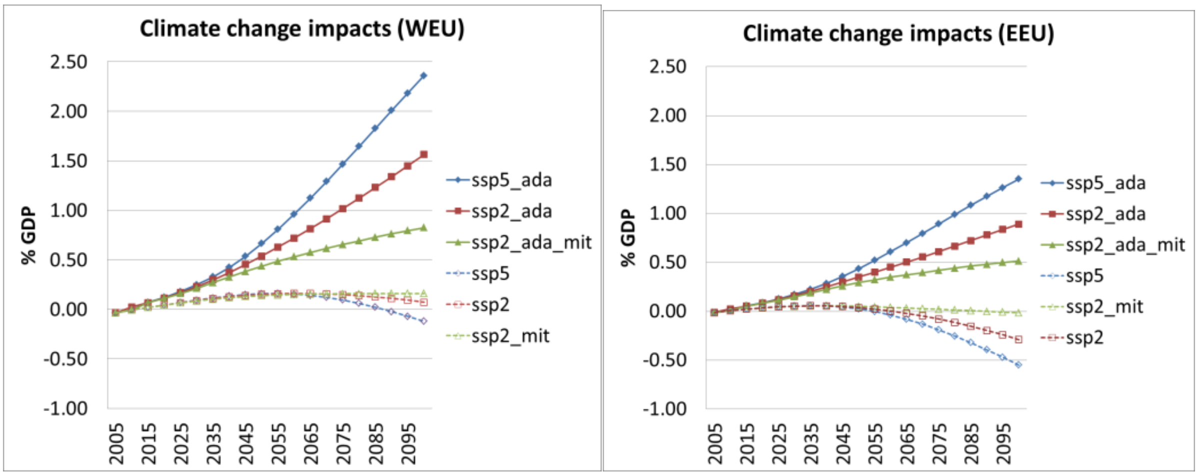


Figure 45 Climate change impacts with (solid lines) and without adaptation (% change in regional GDP)

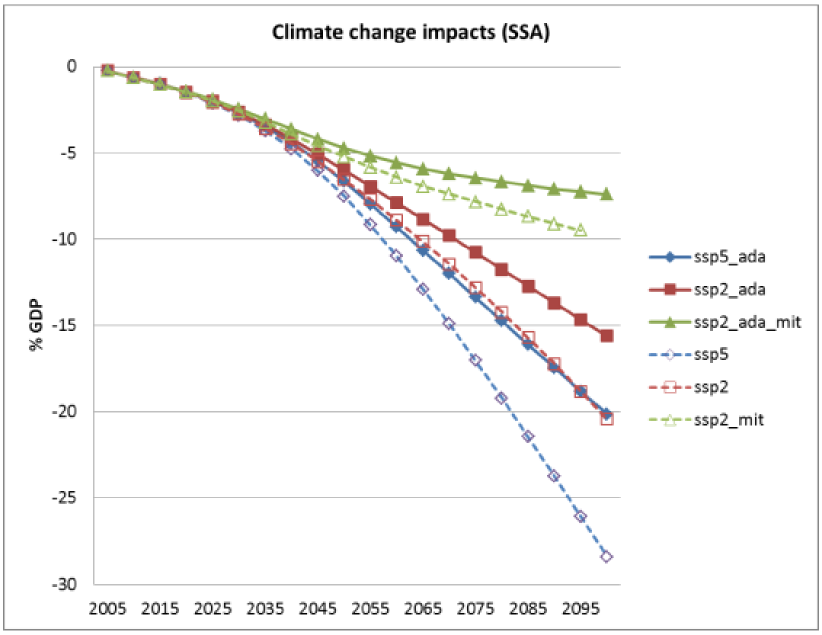


Figure 46 Climate change impacts with (solid lines) and without adaptation (% change in regional GDP)

7.5 Uncertainty analysis

Significant uncertainty exists in each chain of the process, from the impact and adaptation cost estimates from the sectoral studies to the implementation into the AD-WICTH model. For instance, different aggregation methods across countries and regions can lead to different results.

There are at least four sources of uncertainty that have emerged during the data exchange process:

- Uncertainty in the sectoral impact estimates, the case of health impacts
- Uncertainty in the type of adaptation adopted in agriculture
- Uncertainty in the economic quantification of the economic impacts associated with crop yield changes
- Uncertainty in adaptation cost estimates across scenarios

Another issue that can lead to different estimates are the nonmonetary impacts, which are not considered here.

Regarding source of uncertainty (1), Table 63 and Table 64 give the example of health. Table 63 shows a range of estimates for health impacts, which can be significant for some non-EU regions and which tend to be negligible in Europe. Table 64 shows that when sectoral estimates are aggregated with the other sectors, overall they lead to very small adjustments in Europe, though adjustments can be more significant in non-EU regions where health impacts play a larger role. Certainly, considering the uncertainty from all sectors would probably cumulate and show up also at the more aggregate scale of the model. Unfortunately, uncertainty ranges in the bottom-up cost estimates are not available for the other sectors.

Table 63 Range in health impacts (+2.5°C, around 2050, SSP5 RCP8.5)

	Median estimates (used in the calibration)			Higherestimates		
	Grossdamage	Reactive	Proactive	Grossdamage	Reactive	Proactive
CAJAZ	0.00	0.00	0.00	0.00	0.00	0.00
CHINA	0.17	0.01	0.01	0.69	0.05	0.13
EASIA	0.00	0.00	0.00	0.30	0.02	0.05
INDIA	2.21	0.13	0.26	5.54	0.31	0.72
KOSAU	1.79	0.02	0.01	3.68	0.04	0.02
LACA	0.08	0.00	0.00	0.29	0.01	0.04
MEA	0.03	0.00	0.01	0.03	0.00	0.01
SASIA	1.79	0.13	0.27	4.72	0.33	0.75
SSA	1.08	0.13	0.06	2.24	0.27	0.14
TE	0.00	0.00	0.00	0.00	0.01	0.04
USA	0.00	0.00	0.00	0.00	0.00	0.00
WEU	0.08	0.00	0.00	0.92	0.00	0.01
EEU	0.19	0.00	0.01	0.38	0.01	0.02

Table 64 Calibration data at the calibration point considering the higher bound for health impacts (+2.5°C, around 2050, SSP5 RCP8.5))

	Cost of		Reactive		Effectiveness		

	proactiveadaptation									
	% regional GDP				% GDP		% reduceddamage			
					Sectoralmodels		Sectoralmodels			
	Health	Agr	Flood	Total	Health	Total	Health	Agr	Flood	Total
CAJAZ	0.00	0.01		0.01	0.001	0.001	0.75	0.80		0.80
CHINA	0.13	2.36		2.49	0.045	0.045	0.56	1.00		1.00
EASIA	0.05	0.61		0.66	0.015	0.015	0.45	0.44		0.44
INDIA	0.72	0.81		1.53	0.315	0.315	0.38	0.33		0.33
KOSAU	0.02	0.03		0.05	0.043	0.043	0.75	0.63		0.63
LACA	0.04	0.26		0.30	0.015	0.015	0.71	0.48		0.48
MENA	0.01	0.17		0.18	0.002	0.002	0.14	0.31		0.31
SASIA	0.75	0.22		0.96	0.326	0.326	0.27	0.34		0.34
SSA	0.14	0.08		0.21	0.274	0.274	0.59	0.43		0.43
TE	0.04	0.75		0.79	0.011	0.011	0.14	0.62		0.62
USA	0.00	0.13		0.13	0.000	0.000	0.45	0.71		0.71
WEU	0.01	0.10	0.04	0.14	0.003	0.003	0.24	0.78	1.00	0.75
EEU	0.02	0.07	0.03	0.13	0.009	0.009	0.24	0.77	1.00	0.61

Regarding the source of uncertainty (2), as mentioned in the previous sections, the analysis of impacts and adaptation in agriculture consider two adaptation options, irrigation and water management. We have implemented the most cost-effective (See Table 62) strategy, water management, but implementing irrigation would lead to higher aggregate adaptation cost estimates.

Table 65 Calibration data at the calibration point considering the higher bound for health impacts (+2.5°C, around 2050, SSP5 RCP8.5)

		2050			2080		
		Cost-effective	Irrigation	Water Management	Cost-effective	Irrigation	Water Management
EEURO	rcp85	0.084	0.151	0.084	0.095	0.161	0.095
WEURO	rcp85	0.131	0.167	0.146	0.008	0.203	0.009

Regarding the source of uncertainty (3), we have used the indirect impact estimates associated with climate-induced yield shocks estimated using a CGE model. We believe this is the most appropriate measure to be used in AD-WITCH because damages are reported as share of GDP. Moreover, AD-WITCH does not model trade, and therefore CGE-simulated impacts are net of trade effects and market driven adaptation. Yet, using other estimates, such as the direct monetary costs without trade effects, would lead very likely to different impact estimates.

Finally, regarding the source of uncertainty (4), Figure 45 shows that, leaving aside the role of mitigation, uncertainty in future socioeconomic scenarios could significantly affect adaptation cost estimates, which in Europe could vary between 32 and 56 2005USD billion in 2050.

7.6 Policy recommendations

In Europe, effective planning and efficient implementation of adaptation measures can significantly reduce the potential regional impacts from climate change on flood risk, agriculture, and heat waves.

In Europe impacts are moderate compared to other regions is the world, such as Sub-Saharan Africa, and this explains why significant benefits can be achieved through adaptation, if optimally implemented.

Yet, mitigation remains an important complementary strategy because 1) it directly reduces the adaptation expenditure needed in Europe 2) by reducing impacts in high-impacts regions, such as Sub-Saharan Africa where climate impacts can reduce GDP by up to 30% in 2100, it mitigates indirect climate risks that could affect Europe as well through migration and international trade.

Adaptive capacity, in terms of socioeconomic development but also human capital, technology, and good institutions, can boost the potential benefits of implementing adaptation projects, and therefore increase adaptation effectiveness.

Table 66 Economic impacts in 2100. * Negative damages represent benefits

Region	Scenario	Grossdamage*	Proactive	Reactive	Adaptation effectiveness
Western EU	SSP5 RCP85 (Reference)	-0.15	0.14	0.002	0.49
Eastern EU	SSP5 RCP85 (Reference)	-0.03	0.11	0.004	0.43
Western EU	SSP2 RCP45	-0.14	0.08	0.001	0.40
Eastern EU	SSP2 RCP45	-0.05	0.06	0.003	0.35

Table 67 Economic impacts in 2100. * Negative damages represent benefits

Region	Scenario	Grossdamage*	Proactive	Reactive	Adaptation effectiveness
Western EU	SSP5 RCP85 (Reference)	0.12	0.27	0.004	0.72

Eastern EU	SSP5 RCP85 (Reference)	0.55	0.26	0.014	0.63
Western EU	SSP2 RCP45	-0.16	0.12	0.002	0.53
Eastern EU	SSP2 RCP45	0.01	0.09	0.005	0.55

8 Conclusions

Within the BASE project the economic effects of adaptation to climate change are systematically evaluated both from a bottom up and top down perspective. This is done by integrating sectoral models and economic models at EU and global scale with information from selected case studies across sectors and regions within Europe. In addition this layered approach builds upon previous studies that have either focused on a top down modelling or bottom up case-based approach. This deliverable 6.3 of BASE is reporting in particular on the results of the modelling exercises executed within the project. Costs and benefits are explored for present and future climates, for different socio-economic developments paths and different adaptation strategies. For all models the SSP (Shared Socio-economic Pathways) 2 ('middle of the road'), 3 ('fragmented world') and 5 ('market driven development') have been explored as well as the climate scenarios according to RCP (Remote concentration pathway) 4.5 (average climate change) and 8.5 (high climate change) for 2050.

Methodological advances made within BASE

The main methodological advances that have been made with respect to the modelling approaches applied for this deliverable are:

- The incorporation of particular adaptation strategies like flood protection, adapted building, water management, irrigation and Heat Early Warning systems with improved evidence based estimates for effectiveness in terms of damage reduction and costs.
- The more detailed sectorial studies on Floods, Agriculture and Health were used to recalibrate and parameterize AD-WITCH damage, adaptation cost, and adaptation effectiveness. This is a major step forward in integrated economic assessment modeling.
- Crop patterns, land use, hydrological and agricultural production models have been combined to obtain new insights in effective adaptation. Especially the estimated changes in future crop patterns, based on regression, present realistic future boundary conditions for agricultural production, allowing for net gains at Northern latitudes
- New cost estimates on flood protection and adapted building were applied in the European scale flood model.
- An improved IO-model has been applied to city flooding cases allowing for better insight in the variety, size and cause of indirect damages.

Verification and uncertainty analysis

In general most models could to some extend (support for some assumptions on costs and cost effectiveness could be gained) be validated with results from the cases as costs and benefits are difficult to compare between the different scales. The measures analysed were also representing a large number of cases but in the models the measures had to be sometimes generalized in to wider strategies (e.g. water management). Deliverable 6.4 will further elaborate the integration of model and case study results into storylines.

Two main types of uncertainty were analysed by the different modellers: the influence of scenario uncertainty and sensitivity to particular model assumptions. From these analyses it showed that (some examples):

- For AD-WITCH leaving aside the role of mitigation, uncertainty in future socioeconomic scenarios could significantly affect adaptation cost estimates, which in Europe could vary between 32 and 56 2005USD billion in 2050.
- The calibration results for European regions are relatively insensitive to different cost an damage inputs from the sectoral models, as other factors (regions, SSP) dominate.
- For the flood risk analysis uncertainties stemming from input data for the reference climate and especially those in the cost estimates (factor 3 difference in applied methods) are dominating over differences stemming from RCP and SSP.
- An extensive sensitivity analysis conducted with the SARA model concludes that the impact results are especially sensitive to assumptions on projected crop yield and surface water availability (for irrigated agriculture).
- For the BCR for HHWS the lower and upper bound estimates range between a factor 5-9 but all remain much larger than 1.

These results stress the need for further use of bottom up generated evidence to support critical assumptions.

Floods

For riverine flood risks annual expected damage was evaluated in relation to adaptation costs and GDP. Two adaptation strategies were considered: increasing the protection levels along rivers by building new and increasing existing dikes and by decreasing the damage potential through adapted building. Results show that projected climate change can lead to more than a doubling of annual expected river flood losses in Europe, especially in Western and central Europe. This is in line with earlier research by other scholars. The highest flood risk expressed as share of GDP is noted for the Western European region, with an average of some 0.3% GDP loss per year.

Most (if not all) of the impacts of projected climate change can be compensated by adaptation measures. The benefits of flood protection, for instance through dike construction, are slightly higher than through adapted building. The costs of dike construction, as calculated using actual required dike heightening per RCP scenario and per time slice, are lower than the costs of adapted building, especially in the period up to the 2030s indicating that it is more beneficial to invest for longer time horizons (50+) in this type of flood protection infrastructure, as initial costs to upgrade flood defences are high. For almost all European countries benefit cost ratios larger than 1 are found especially when expanding the time horizon until 2080. Countries with large surface areas and small urban areas see relatively low benefit-cost (BCR) ratios, indicating that it is beneficial (from a CB perspective) to apply differentiated protection levels between urban and rural areas (which in most countries already is common practice).It must however be noted that the economic figures were not discounted.

Indirect flood damage

From our results it is evident that effective investment in risk management and adaptation strategies must consider the analysis of indirect damage.

For the case studies, the most directly affected sectors are those with a big proportion of in-built capital, such as manufacturing and light industry sectors. Under a traditional impact assessment, these sectors will appear as the only benefited from flooding adaptation strategies, such as improvement in flood defenses. This usually leads to individual adaptation strategies which works reasonably well for low probability flooding (i.e. return periods shorter than 1:50 years).

However, the flood footprint analysis reveals the potential benefits for the indirectly affected sectors. It should be noted that indirect damage can be as substantial as direct damage. According with the analysis, the indirectly affected sectors normally are at the end of the value chain, such as services sectors (e.g. financial and businesses sectors). These are especially vulnerable to disruptions in infrastructure, mainly when preventing people reaching their jobs. A conclusion from incorporating the results of flood footprint analysis is to invest in the community adaptation strategies more than individual actions, as this will benefit stakeholders along all the production chain. Moreover, this becomes relevant under climate change scenarios, especially in terms of indirect damage; as the flood footprint analysis proves that indirect damage increases more than proportionally regarding direct damage, as the intensity of natural disasters increases.

At the level of flood risk mitigation responsibility, a flood footprint accounting framework would provide an alternative way to allocate financial responsibility for flood risk mitigation interventions by incorporating the value of all stakeholders' economic capacities on the local/regional/national supply chains. This could potentially reduce the government's financial burden for flood risk management and spread the cost between major stakeholders in the supply chain, based on the 'who benefits, who pays' principle. In other words if it turns out through a proper flood footprint assessment that organisation(s) x or y benefit in a large way from flood defence then we could look at alternative flood management payment schemes.

Agriculture

To simulate the costs and benefits of adaptation to CC for agricultural production in Europe a novel modelling framework was used consisting of agro-climatic, land use and water models with statistical responses of economic variables to changes in these three sectors. This framework is then used to explore the benefits and costs of two types of adaptation measures for four regions in Europe. Two main categories of adaptation measures are contemplated: management and development of additional irrigation. Adaptation through management includes a set of strategies to minimize negative climate impacts on agriculture and to increase agricultural productivity like improvement of resiliency and adaptive capacity, technology innovation and improvement of the water use efficiency to increase water availability. Adaptation through development of additional irrigation includes a set of measures to compensate for loss of agricultural production by extending the area under irrigation using the land already equipped for irrigation and by development of additional water resources for instance by reservoirs or waste water recycling.

Three major points emerge from the results of this study, related to the regional effects, benefits of adaptation and choices of adaptation. First, although each scenario projects different results, all scenarios are consistent in the spatial distribution of effects. Agricultural damage is larger in the Mediterranean region followed by the North West region. The results are highly consistent across RCP scenarios and time frames. The SSP scenario is the most influential factor for a given region.

The socio-economic scenarios are key factors for understanding the potential adaptation capacity of agriculture to climate change. Uncertainty regarding future population (density, distribution, migration), gross domestic product and technology determine and limit the potential adaptation strategies. However, evaluating the constraints to policy implementation is difficult. In our study, the demand for and the supply of water for irrigation is influenced only by changes in the hydrological regimes, resulting from changes in the climate variables. Policy driven adaptation priorities may be derived from the impacts reported in this study.

Second, adaptation choices benefit all regions, although the effort to benefit relationship varies across regions and type of measure. The costs of irrigation are higher than the cost of improved water management, especially in the period up to the 2030s. The largest benefit is in the Mediterranean and North West regions. The benefit of adaptation in the Mediterranean is due to the large damage reduction due to water scarcity in all scenarios. The benefit of adaptation in the North West region is due to the large competition of agricultural and industrial water and the large change in land use over all scenarios. Water management is overall the best choice in all cases. In areas will little damage, water management is much more cost efficient. In the Mediterranean region, even if irrigation is more cost efficient in some scenarios, the range of possible implementation of irrigation measures is extremely limited over the crop area.

Health

Health effects of climate change and costs and benefits of adaptation are analyzed using a simple regional model. Two health impacts have been assessed at European levels, heat stresses and salmonella. Other two have been assessed for developing countries, diarrhea and malaria. To mitigate negative health effects three types of adaptation strategies can be distinguished. Primary interventions can be defined as primary prevention put in place to remove the risk before the damage occurs. Secondary interventions aim to prevent the disease once the impact has occurred but before its establishment. Tertiary interventions are applied once the impact has occurred to minimize it and correspond to treatment. Primary interventions correspond to preventive adaptation, while secondary and tertiary interventions correspond to reactive adaptation. As an example of a primary intervention (or preventive adaptation) the costs and benefits of a heat watch warning systems are analyzed. For Salmonella similarly a Public health campaign is analyzed, while treatment of the disease corresponds to tertiary intervention or reactive adaptation. For Malaria and Diarrhea a combined set of reactive and preventive measures are considered. For the health analysis only one RCP8.5/SSP5 combination was considered as a worse case from a climate point of view. By applying this scenario current mortality for diarrhea may increase by 61,000 to 162,000 deaths by 2050. For malaria, results show an increase between 37 million to 75 million DALY.

For HHWWS, the estimated BCR is largely above 1 in all European regions and under all assumptions, indicating that this measure is a low-regret measure as it can provide high benefits with a small cost. These benefits are attributable only to health, in terms of avoided mortality due to heat waves including both premature and displaced deaths. Specific care however is required for vulnerable groups such as the elderly and those with pre-existent cardio-vascular and respiratory problems. Though these measures are low-regret, a timely and accurate specification of the threshold temperature at which to warn is requested over time, in order to be cost-effective.

For salmonellosis, the estimated BCR for treatment is approximately 9, whereas for public health campaigns the BCR range between 5.1 and 37.7 depending on the context. Treatments and public health campaigns are likely to be important in addressing climate related health problems, but the health sector needs to be prepared for action. This also does not consider actions in other areas – e.g. food production or agricultural practices – which may impact on the analysis.

For diarrhea, recommendations depend on the type of measure considered. The first set include basically treatments and immunization programs. They apply specifically to the health outcomes, so that this is the only type of benefit they can provide. The results on the BCR for this first set of measures depend on the geographical area considered and the level of unit costs used. For the lowest unit costs, the resulting BCR is always greater than 1 in all scenarios and regions. For medium unit costs, results differ among geographical region, while for high unit costs the BCR is always below 1. Results indicate that for low unit costs, these measures can provide health benefit large enough to cover the costs. The second set refers to structural preventive measures based on improvements in water and sanitation systems. These are multiple-benefits interventions affecting different sectors and not only health. In this case, the evaluation of the measure for policy should be based on an overall social cost-benefit analysis which takes into account the full set of benefits provided by different sectors and their causal interactions. Improvements in these systems provide benefits that are greater than the costs, when including all societal benefits (Hutton and Haler, 2004). For the purpose of this exercise, however, only the health benefits have been considered, so that results cannot be generalized in terms of BCR. We can nevertheless analyse results in terms of health benefits provided. The highest health benefits associated with interventions for diarrhoea are projected in developing countries, as expected, with the largest figures projected in SSA, India, SASIA and CHINA regions.

For malaria, the combination of bed nets, treatments and spraying are shown to have BCRs well above 1. However, they may not offer the least cost solution – for example here we have not considered actions in the water or construction sectors that may reduce the spread of malaria. There may be low cost options in e.g. improving drainage that may reduce the breeding grounds for mosquitos and hence reduce the spread of disease. Local case studies also suggest that the findings of our analysis at region level may not be appropriate for particular contexts – where indoor spraying may not be so viable in less affected regions. The highest health benefits associated with malaria interventions are found in South Africa, India and SSA.

To conclude, the health sector is difficult to judge since many factors determine human health besides climate. Clearly heat stress and the propagation of vector borne diseases are likely to increase. Potentially, investments in health interventions appear to be very cost effective in many cases. An integrated approach to health adaptation including other sectors may be needed to ensure health issues are appropriately tackled, as well as further research to improve characterization of unit costs, as the references used in this analysis are average unit costs for a set of measures. In this respect it would be more useful to disaggregate further the cost assessment by type of measure, instead of set of measures.

Carbon sequestration

Multiple available land use and land cover change scenarios at the European scale show potential increase of forested areas (VOLANTE, Hurtt et al. 2011). When these changes translate into the amount of carbon stored in terrestrial biomass, our results show that the carbon stocks in EU-27 could potentially increase by 1.3-2.7% by 2050, depending on the scenario. This presents a positive trend, influencing the amount of greenhouse gases in the atmosphere.

In terms of climate mitigation, this trend provides several opportunities. According to the results, a substantial space for reforestation may appear in the next several decades, which can be utilized to efficiently increase the level of carbon stocks. Therefore, it is vital to use sustainable approaches to reforestation and to ensure the newly established and expanding forests will reflect the most desirable species composition and other forest characteristics, with consideration of local ecosystem character and potential future impacts of climate change. At the same time, this situation presents an opportunity to implement ecosystem-based adaptation measures in the forestry sector and to utilize the re-establishment of forests to simultaneously improve the resilience of forests ecosystems, their potential to provide ecosystem services and to sustain biodiversity.

Although the aggregate results show increase in carbon stocks, the overall level of increase is rather low. Furthermore, the spatial pattern of potential change show that the most substantial increase in forested areas and related carbon stocks occurs in the sparsely populated north of Europe, while the densely populated areas of Western Europe undergo decrease in forest cover, mainly due to urban sprawl. Although carbon sequestration and related climate regulation present global ecosystem services, the benefits of which are globally shared, other ecosystem services provided by forests (e.g. cultural, provisioning) are tightly bound to their location and can thus be potentially lacked in these areas.

Finally, it is vital to consider the socio-economical aspect of the changes in forest cover and increasing carbon stocks. The increase of forested areas occurs mainly due to decreasing proportions of agricultural land and pastures, which in turn results from broad socio-economic changes.

Economy wide effects of adaptation

The effects on GDP of individual countries of climate and adaption for Floods, Health and Agriculture were included in the AD-Witch model to calculate overall GDP effects and cost effectiveness of adaptation versus mitigation. Indirect flood damages and the economic value of sequestered carbon within Europe are not considered in AD-Witch (the latter being negligible compared to other world regions).

According to the input data provided by the sectoral models, adaptation, especially to address impacts in the agriculture sector and flood risk, is very effective. The effectiveness of adaptation carries over to the AD-WITCH model, and adaptation can change the sign of climate impacts from negative to positive. It is important to clarify that these results hold only for Europe, which lose only marginally from climate change and not foran high-impact region, such as Sub-Saharan Africa (SSA). It shows that in high-impact regions mitigation is an important strategy, together with adaptation, to reduce climate damages. In low- or positive-impact regions, adaptation seems to play a more prominent role, when considering the regional benefits accruing to that specific region.

In Europe, effective planning and efficient implementation of adaptation measures can significantly reduce the potential regional impacts from climate change on flood risk, agriculture, and heat waves. In Europe impacts are moderate compared to other regions is the world, such as Sub-Saharan Africa, and this explains why significant benefits can be achieved through adaptation, if optimally implemented. Yet, mitigation remains an important complementary strategy because 1) it directly reduces the adaptation expenditure needed in Europe 2) by reducing impacts in high-impacts regions, such as Sub-Saharan Africa where climate impacts can reduce GDP by up to 30% in 2100, it mitigates indirect climate risks that could affect Europe as well through migration and international trade. Adaptive capacity, in terms of socioeconomic development but also human capital, technology, and good institutions, can boost the potential benefits of implementing adaptation projects, and therefore increase adaptation effectiveness.

Summarized conclusions

Base analysis	Urgency and effectiveness of adaptation	Preferences of interventions	Caveats recommendations for further analysis
AD-WITCH	In Europe, effective planning and efficient implementation of adaptation measures can significantly reduce the potential regional impacts from climate change on flood risk, agriculture, and heat waves. This conclusion hinges on the fact that adaptive capacity, in terms of socioeconomic development but also human capital, technology, and good institutions, is high in Europe, and this leads to high adaptation effectiveness.	Mitigation remains an important complementary strategy because it directly reduces the adaptation expenditure needed in Europe. Moreover, by reducing impacts in high-impacts regions, such as Sub-Saharan Africa where climate impacts can reduce GDP by up to 30% in 2100, it mitigates indirect climate risks that could affect Europe through migration and international trade.	
Flood risks	Damage from riverine floods on GDP remain limited below 0.8% for any European country and amount maximally 0.3% for the Western and Central/Eastern European region for 2080 under RCP8.5 compared to 0.1-0.2% of GDP under the current climate. For the Southern Region on average the expected flood damages are not increasing. The adaptation options investigated can fully mitigate the effects of climate change	Benefit Cost Ratios generally are larger than 1 across all regions. Cost efficiency of increasing protection levels through dikes is slightly higher than for adapted building. Further differentiang protection levels between rural and urban areas will improve BCR ratios. This is particularly relevant for large sparsely populated countries	In general more spatially differentiated adaptation should be a next step in the analysis as well as including other adaptation options such as nature based solutions.
Urban flooding	the flood footprint analysis reveals the potential benefits for the indirectly affected sectors which normally are at the end of the value chain, such as services sectors (e.g. financial and businesses sectors). This indirect damage can be as substantial as direct damage. Under climate change indirect damage is likely to increase relatively more than direct damage, as the intensity of natural disasters increases.	Adaptation strategies therefore could profit when including more parties along the supply chain in terms of sharing responsibilities (finances) and finding solutions.	The analysis still has to proceed from a case and event based analysis towards a risk based climate analysis to be able to further generalize the findings

Agriculture	Agricultural damage is largest in the Mediterranean region followed by the Western region. The results are highly consistent across RCP scenarios and time frames. The SSP scenario is the most influential factor for a given region. It is also a major boundary condition for the adaptive capacity and thus adaptation efficiency	Water management as a strategy clearly comes out as the preferred strategy as it is opposed to irrigation widely applicable and cheaper	
Health	***Heat*** Health Warning Systems are a low regret measure – and lead to significant health benefits in terms of reduced mortality. For ***salmonellosis***, both public health campaigns and treatments show significant benefits in the current and future periods. For ***diarrhea***, we distinguish between 2 sets of measures. The first are based on treatment and immunization programs: results depend on the unit cost and the region (for low unit costs there are sufficient health benefit to be cost-effective). The second are structural preventive interventions based on improvement of water and sanitation systems. In this analysis, only health benefits have been considered, while many benefits in other sectors have not been evaluated, so that we cannot generalize results in terms of BCR. Improvements in these systems provide benefits higher than the costs, when including all societal benefits (Hutton and Haler, 2004). For ***malaria***, all adaptations offer high benefits, but this may not be the case in particular case study regions	Specific actions on heat needed with the elderly and those with pre-existent cardio-vascular and respiratory problems More analysis needed of adaptation options in other sectors that affect salmonellosis (e.g. agriculture, food). Improvements in water and sanitation systems are considered cost-effective measures and provide benefits higher than the costs when inter-sectoral benefits are considered. The evaluation of the measure for policy should be based on an overall social cost-benefit analysis which takes into account the full set of benefits provided by different sectors and their causal interactions.	Thresholds for heat alerts need to be set appropriately, as there is evidence of significant spatial differentials in these values. It is also important to update the thresholds (and epidemiological studies) over time to take into account acclimatization processes. Research on effectiveness of public health campaigns in reducing salmonellosis needed For diarrhea adaptation we only consider impacts on health – whereas impacts in other sectors likely significant (e.g. water) (Hutton and Haler, 2004) and should be considered in a climate change context. Adaptation options in other sectors may impact significantly on malaria risk (e.g. water systems, transport infrastructure construction including drainage). These may be lower cost solutions than other options.
Carbon	Autonomous adaptation through land use changes to climate change is likely to increase the future carbon uptake with a few percent within Europe.	This has a positive mitigating effect on net CO2 emissions	Changes are mostly climate induced and derived from old SRES scenarios. Including SSPs and active management of carbons stock is a next step to incorporate also

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10 Appendix

10.1 Appendix: comparison of SSP datasets

The evolution of population and GDP are major socioeconomic drivers under SSP scenarios. Figure 47 presents the validation of the data provided by the population dynamics model for the current scenario (2010), developed by IIASA. These data were validated with the global dataset provided by the World Bank databank (available at http://data.worldbank.org/) and by the Gridded Population of the World product of the Global Rural-Urban Mapping Project (GRUMP), available at the Center for International Earth Science Information Network (http://sedac.ciesin.columbia.edu/gpw/). The comparison between IIASA model and the World Bank data (left) and GRUPM data (right) for European countries is shown in Figure 47. In general the agreement with World Bank data is very good, while for the gridded datasets there are some discrepancies.

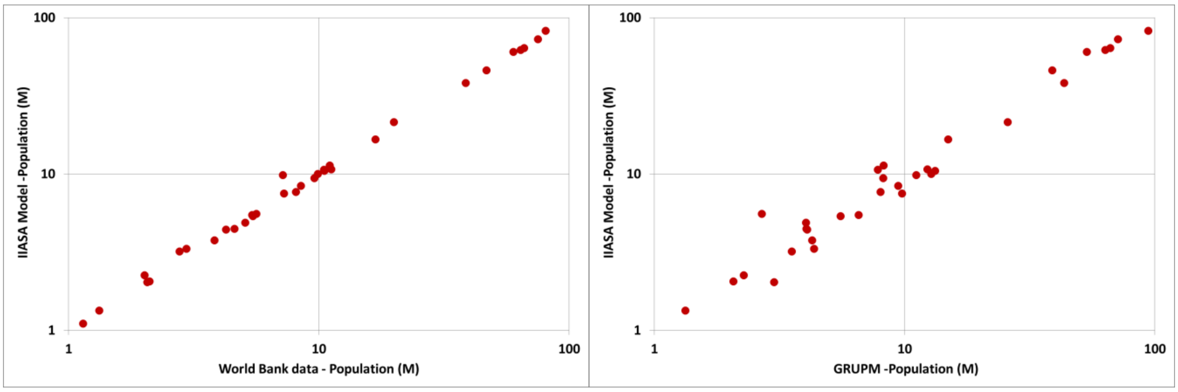

Figure 47 Appendix. Comparison between country population data in IIASA model for current horizon (2010) and two additional sources of information: World Bank (left) and GRUMP (right)

The analysis of GDP input data is presented in Figure 48. GDP is taken from the average of two GDP dynamics models: the IIASA and OECD models. These data are validated with the World Bank databank. The comparisons between World Bank data and IIASA model (left) and OECD model (right) for European countries are shown in Figure 48. Both provide a reasonable agreement.

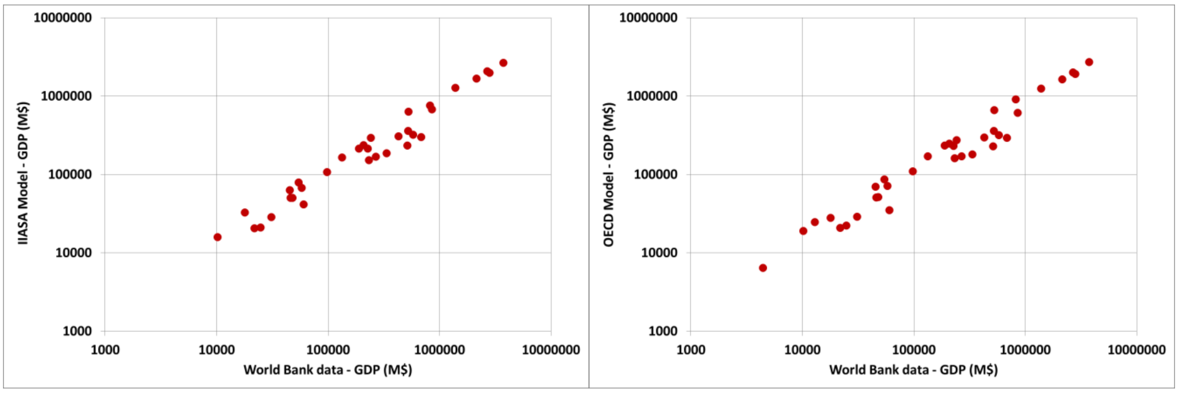

Figure 48 Appendix. Comparison between World Bank country GDP data and IIASA model (left) and OECD model (right) for current horizon (2010)

10.2 Appendix: Additional results from AD-WITCH

Table 68 Appendix: Damages (% of GDP), SSP5 RCP8.5, 2050

	Agriculture	Health
CAJANZ	0.650	0.000
CHINA	0.728	-0.166
EASIA	-4.439	0.000
FSU	-0.309	-2.207
INDIA	-10.191	-1.786
KOSAU	-0.149	-0.082
LACA	-0.518	-0.027
Mena	-1.483	-1.789
SASIA	-10.191	-1.078
SSA	-10.045	0.000
USA	-0.094	0.000

Table 69 Appendix: Adaptation costs (% of GDP), SSP5 RCP8.5, 2050

	Health		Agriculture
	Proactive	Reactive	Proactive
CAJAZ	0.000	0.000	0.001
CHINA	0.015	0.008	2.361
EASIA	0.000	0.000	0.741
INDIA	0.257	0.127	0.810
KOSAU	0.010	0.020	0.013

LACA	0.001	0.002	0.261
MENA	0.008	0.002	0.086
SASIA	0.266	0.131	0.144
SSA	0.064	0.132	0.181
TE	0.003	0.001	0.287
USA	0.000	0.000	0.134

Table 70 Appendix: Adaptation effectiveness (% of damage reduced), SSP5 RCP8.5, 205

	Health						Agriculture		
	Proactive			Reactive			Proactive		
	Heat wav eale rtsys tem	Salmonel la public campaig n	Diarrhea: Improvem ent of water supply and sanitation	Diarrhea: Breastfeeding promotion, rotavirus, cholera & measles immunization.	Malaria: treatment and spray	Salmo nella treatm ent costs	Irrigati on	Water mana geme nt	Cost-effective combinat ion of the two
CAJAZ	.68	.24	.14	.14	.75	.24	0.710	0.803	0.803
CHINA	.68	.24	.14	.14	.75	.24	1.000	1.000	1.000
EASIA	.68	.24	.14	.14	.75	.24	0.316	0.445	0.445
INDIA	.68	.24	.14	.14	.75	.24	0.150	0.330	0.330
KOSAU	.68	.24	.14	.14	.75	.24	0.063	0.627	0.627
LACA	.68	.24	.14	.14	.75	.24	0.374	0.478	0.478
MENA	.68	.24	.14	.14	.75	.24	0.145	0.314	0.314
SASIA	.68	.24	.14	.14	.75	.24	0.187	0.343	0.343
SSA	.68	.24	.14	.14	.75	.24	0.317	0.428	0.428
TE	.68	.24	.14	.14	.75	.24	0.384	0.623	0.623
USA	.68	.24	.14	.14	.75	.24	0.080	0.710	0.710

Table 71 Appendix: Adaptation effectiveness (% of damage reduced), SSP5 RCP8.5, 2050

	SSP5 RCP85				SSP2 RCP4.5			
	Damag e	Proactiv e	Reactiv e	Adaptatio n effective	Damage	Proactiv e	Reactiv e	Adaptatio n effectiven

				ness				ess
cajaz	0.520	0.000	0.000	0.450				
china	0.053	1.072	0.000	0.793				
easia	-3.242	0.538	0.000	0.552				
india	-7.437	0.804	0.000	0.517				
kosau	-0.097	0.005	0.000	0.390				
laca	-0.597	0.184	0.000	0.410				
mena	-0.903	0.193	0.000	0.418				
sasia	-6.765	0.620	0.000	0.276				
ssa	-6.133	0.552	0.000	0.439				
te	-0.433	0.558	0.000	0.612				
usa	-0.115	0.108	0.000	0.611