Technical Policy Briefing Note

03

River Floods

The Impacts and Economic Costs of River Floods in the European Union, and the Costs and Benefits of Adaptation

Summary of Sector Results from the ClimateCost project, funded by the European Community's Seventh Framework Programme

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ClimateCost

SEVENTH FRAMEWORK PROGRAMME

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Key Messages

- Floods already cause major economic costs in Europe. Climate change could increase the magnitude and frequency of these events, leading to higher costs. However, these events need to be seen in the context of other socio-economic drivers.

- The ClimateCost study has assessed the potential impacts of climate change on river flood damage in Europe, and the costs and benefits of adaptation. The analysis used the LISFLOOD model, and considered future climate and socio-economic change. As floods are probabilistic events, the results are presented as expected annual damage (EAD) costs (undiscounted). It should be noted that the damages reported here only include direct physical losses and could, therefore, be conservative.

- The study first assessed the number of people potentially affected by river flooding in the EU27. The expected annual people (EAP) flooded in the baseline climate period (1961-1990) was estimated at around 167,000/year.

- The economic damages from flooding of the residential and other sectors were then assessed. The EAD in the baseline climate period (with current socio-economic conditions) is estimated at around €5.5 billion in the EU27. The analysis then looked at the increase in the EAP and the EAD from future climate change, considering three future time periods (averaged in 30-year periods), for a medium-high emission and mitigation scenario.

290,000

projected number of people affected by flooding annually by the 2050s under an A1B scenario

€46bn

expected annual damage costs from flooding in the 2050s (A1B)

€3bn

estimated annual costs of adaptation for the 2050s to maintain protection levels (A1B)

European policy should stimulate the implementation of sustainable flood protection measures that are flexible or are robust to changing conditions

- **Under a medium-high emission baseline (A1B)**, with no mitigation or adaptation, the projected mean EAP affected by flooding in the EU27 is 300,000 by the 2050s (the years 2041-2070), rising to 360,000 by the 2080s (2071-2100). This includes the combined effects of socio-economic change (future population) and climate change.

- The EAD for the A1B scenario in the EU27 is estimated at €20 billion by the 2020s (2011-2040), €46 billion by the 2050s (2041-2070) and €98 billion by the 2080s (2071-2100) (mean ensemble results, current values, undiscounted). However, a large part of this is due to socio-economic change (population and economic growth). The marginal effect of climate change (alone) is estimated at €9 billion/year by the 2020s, €19 billion/year by the 2050s and €50 billion/year by the 2080s. Analysis at the country level shows high climate-related costs in the UK, Ireland, Italy, the Netherlands and Belgium.

- There is a very wide range around these central (mean) estimates, representing the range of results from different climate models. The study considered 12 alternative climate outputs (global climate model/regional climate model combinations). These reveal that the potential costs vary by a factor of two (higher or lower). Differences are even more significant at the country or local level, with some models showing opposite directions of change in flood risk (i.e. some models project relative reductions in future flood risk due to climate change in areas where other models show an increase). This highlights the need to consider this variability (uncertainty) in formulating adaptation strategies.

- **Under an E1 stabilisation scenario, broadly equivalent to the EU 2 degrees target,** the EAD is estimated to amount to €15 billion by the 2020s, €42 billion by the 2050s and €68 billion by the 2080s in the EU27 (current values, undiscounted). The marginal impact of climate change alone (i.e. with socio-economic change not included) is estimated at €5 billion/year by the 2020s, €20 billion/year by the 2050s and €30 billion/year by the 2080s – significantly lower than for A1B estimates above, especially towards the end of this century. However, this analysis is built around a limited number of E1 climate data sets, mostly focused on one climate model. Therefore, the lower damages under the stabilisation scenario are more likely to be related to the climate model choice rather than to the effect of mitigation.

- The study also assessed **the costs and benefits of adaptation**. The analysis first assessed the benefits of maintaining 1 in 100-year levels of flood protection across Europe in future time periods, set against the projected changes in flood hazard under the A1B scenario. The benefits of these minimum protection levels (i.e. the reduction in damage costs) are estimated at €8 billion/year by the 2020s, €19 billion/year by the 2050s and €50 billion/year by the 2080s for the results (mean ensemble, EU27, climate and socio-economic change current values, undiscounted). It should be noted that the benefits vary with the climate variability, so there is a significant range around these values. There are also significant residual damages in later years under these minimum protection levels. This suggests higher protection levels would be justified.

- The analysis then assessed the costs of achieving these protection levels. This has transferred information from detailed protection studies to derive indicative costs of adaptation at the European scale. The costs to maintain minimum protection levels are estimated at €1.7 billion/year by the 2020s, €3.4 billion/year by the 2050s and €7.9 billion/year by the 2080s for the EU (mean ensemble, A1B, undiscounted). It should be noted that the costs of adaptation vary significantly with the level of future climate change, the level of acceptable risk protection and the framework of analysis (risks protection versus economic efficiency).

- The socio-economic uncertainty and climate-model variability make a large difference to the actual adaptation response at a country level. The need to recognise and work with uncertainty – as part of integrated and sustainable policies – requires an iterative and flexible approach.

- A number of implications arise from the analysis, the most important of which is to start including these issues in policy across Europe.

1. Introduction

The objective of the ClimateCost project is to advance the knowledge on the economics of climate change, focusing on three key areas: the economic costs of climate change (the costs of inaction), the costs and benefits of adaptation, and the costs and benefits of long-term targets and mitigation. The project has assessed the impacts and economic costs of climate change in Europe and globally. This included a bottom-up sectoral impact assessment for Europe, as well as a global economic modelling analysis with sector-based impact models and computable general equilibrium models.

This technical policy briefing note[1] (TPBN) provides an overview of the European-wide assessment of the impacts and economic costs of floods as part of the ClimateCost project. It should be noted that coastal flooding is included in TPBN 2 and that the analysis here does not include intra-urban flooding.

1.1 Background

Floods are among the most important weather-related loss events in Europe and can have large economic consequences. Indeed, there have been a number of recent severe flooding events, which have led to major losses: the EEA (2010) reports total losses of over €50 billion from flood events over the past decade, including the floods in Central Europe (over €20 billion in 2002), in Italy, France and the Swiss Alps (about €12 billion in 2000) and in the United Kingdom (over €4 billion in 2007). However, while there are observations of rising flood costs over recent decades, this is largely attributed to socio-economic change rather than to climate change (see Barredo, 2007).

Climate modelling suggests that, in the coming decades, climate change will intensify the hydrological cycle, and increase the magnitude and frequency of intense precipitation events in many parts of Europe.

Previous studies have reported potentially large economic costs from climate change for individual large river basins (Feyen et al, 2006) or at country level (Evans et al, 2004). The analysis here expands this to consider the potential costs at the European scale, reporting on potential impacts at the EU27 level. It considers climate scenarios broadly consistent with a medium-high emission scenario and the EU's 2 degrees target, but also considers the uncertainty across the model projections for these two scenarios. The analysis also assesses the potential costs and benefits of adaptation.

2. Scenarios

2.1 Climate and socio-economic scenarios

In the assessment of the future damages of climate change, assumptions have to be made on future conditions that require scenarios. The most widely used are the emission scenarios of the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emission Scenarios (the SRES, Nakicenovic et al. 2000). These define a set of future self-consistent and harmonised socio-economic conditions and emission futures that, in turn, have been used to assess potential changes in climate through the use of global and regional climate models. There is a wide range of future drivers and emissions paths associated with the scenarios. Thus, the degree of climate change varies significantly, which has a major effect on the results. The ClimateCost study focused on two scenarios.

The first is the SRES **A1B scenario**. This is based on the A1 storyline with a future world of rapid economic growth, new and more efficient technologies, and convergence between regions. The A1B scenario adopts a balance across all sources (fossil and renewable) for the technological change in the energy system. This scenario has been extensively used in recent European regional climate modelling studies, notably in the ENSEMBLES study. For this reason, it was also used in ClimateCost. It reflects a medium–high emission trajectory and leads to central estimates of global average surface temperatures of around

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[1] The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007- 2013) under grant agreement n° 212774. This TPBN was written by Luc Feyen (JRC ISRPA) and Paul Watkiss (Paul Watkiss Associates). The citation should be: Feyen, L. and Watkiss, P. (2011). Technical Policy Briefing Note 3. The Impacts and Economic Costs of River Floods in Europe, and the Costs and Benefits of Adaptation. Results from the EC RTD ClimateCost Project. In Watkiss, P (Editor), 2011. The ClimateCost Project. Final Report. Published by the Stockholm Environment Institute, Sweden, 2011. ISBN. 978-91-86125-35-6.

3°C to 4°C relative to pre-industrial levels, though individual models show a wide range. For details, see the TPBN 1 on climate model outputs.

The second is the ENSEMBLES E1 scenario (van der Linden et al., 2009: Lowe et al., 2009), which leads to long-term stabilisation at 450 ppm (450 ppm CO_2 atmospheric stabilisation in the 21st century after a peak of 535 ppm in 2045). This is a mitigation scenario that would limit the global warming to less than 2°C, relative to pre-industrial levels, with a high probability.

2.2 Future time periods

The assessments here consider the projected impacts of climate change, set against a modelled baseline from 1961 to 1990. There is a range of potential future time periods that could be considered, reflecting different information needs. These vary from projections of short- and medium-term changes that can help inform early adaptation priorities to more significant, longer-term changes that can help inform mitigation policy. The ClimateCost study considered three future time periods to 2100: the 2020s (i.e. 2011-2040)[2]; 2050s (i.e. 2041-2070) and 2080s (i.e. 2071-2100).

2.3 Climate model output and uncertainty

The standard approach for the development of climate scenarios is to run the above emissions scenarios in global climate models (GCMs) and, in turn, to downscale these for a region such as Europe, with the use of coupled regional climate models (RCMs). The ClimateCost study followed this approach using the results of the ENSEMBLES project. However, different models may lead to very different results. Thus, the choice of GCM and coupled GCM-RCM makes a large difference to modelled future climate change, and to the impacts and economic costs.

Whereas projections of average changes in temperature are fairly robust across climate models, much more variability exists in the spatial and temporal distribution of precipitation. In particular, small-scale patterns of intense precipitation are highly dependent on climate model resolution and parameterisation, which renders flood simulation very sensitive to variability among climate projections.

The projections of future flood risk are uncertain. There are considerable model differences, and projections for some areas of Europe even vary in the direction (+/-) of change across different models.

It is stressed that the variation between model outputs (for any given emissions scenario) is as large – and in cases larger - than across different scenarios. The background to the climate models and the outputs for Europe are set out in TPBN 1 on climate models and uncertainty.

It is good practice to use multi-model information to capture at least some of the uncertainties associated with climate modelling and projections. The ClimateCost project ran impact assessments for a large number of GCM-RCM outputs. This captures the variability among the models for relevant outputs to flood damages.

The results presented in this TPBN for the A1B scenario are based on simulations with the hydrological model LISFLOOD. The model was run for 12 separate climate model inputs (i.e. 12 different combinations of global and regional climate models (a so called multi-model ensemble)). The climate model combinations used in the floods analysis are given in Appendix 1. For the E1 scenario, outputs from only three regional climate runs were available and these were all based on one regional model, but driven by three different global boundary conditions. Therefore, there is much less uncertainty captured in the development of future climate for the E1 mitigation scenario.

The ClimateCost flood simulations based on the A1B and E1 ensembles of climate projections show considerable variability across the alternative models in the magnitude of change and, at the local level, even in the direction of change.

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[2] It should be noted that the climate-change signal, such as the change in extreme events, is still relatively weak for the 2020s, with natural variability and initial conditions playing a more important role than in later time periods, when choice of emissions scenarios becomes increasingly important.

As an illustration, Figure 1 shows the changes in flood discharge magnitudes for 100-year floods for the A1B scenario across the 12-member multi-model ensemble.
The panels on the left show (in red) the number of models (out of 12) with a consistent (less than 5%) decrease in 100-year flood magnitude (in the respective time period compared with the baseline period), whereas the panels on the right show (in blue) the number of models (out of 12) with a consistent increase in flood magnitude.

In Figure 1, darker colours of red and blue indicate a larger number of models projecting changes in the same direction. Increasing flood magnitudes are consistently projected over the British Isles, western and central Europe, along the Danube and in northern Italy, whereas the majority of models show a decrease in central regions of Spain and the regions around the Baltic Sea (north-eastern Germany, northern Poland, southern parts of Sweden, Baltic states and Finland).

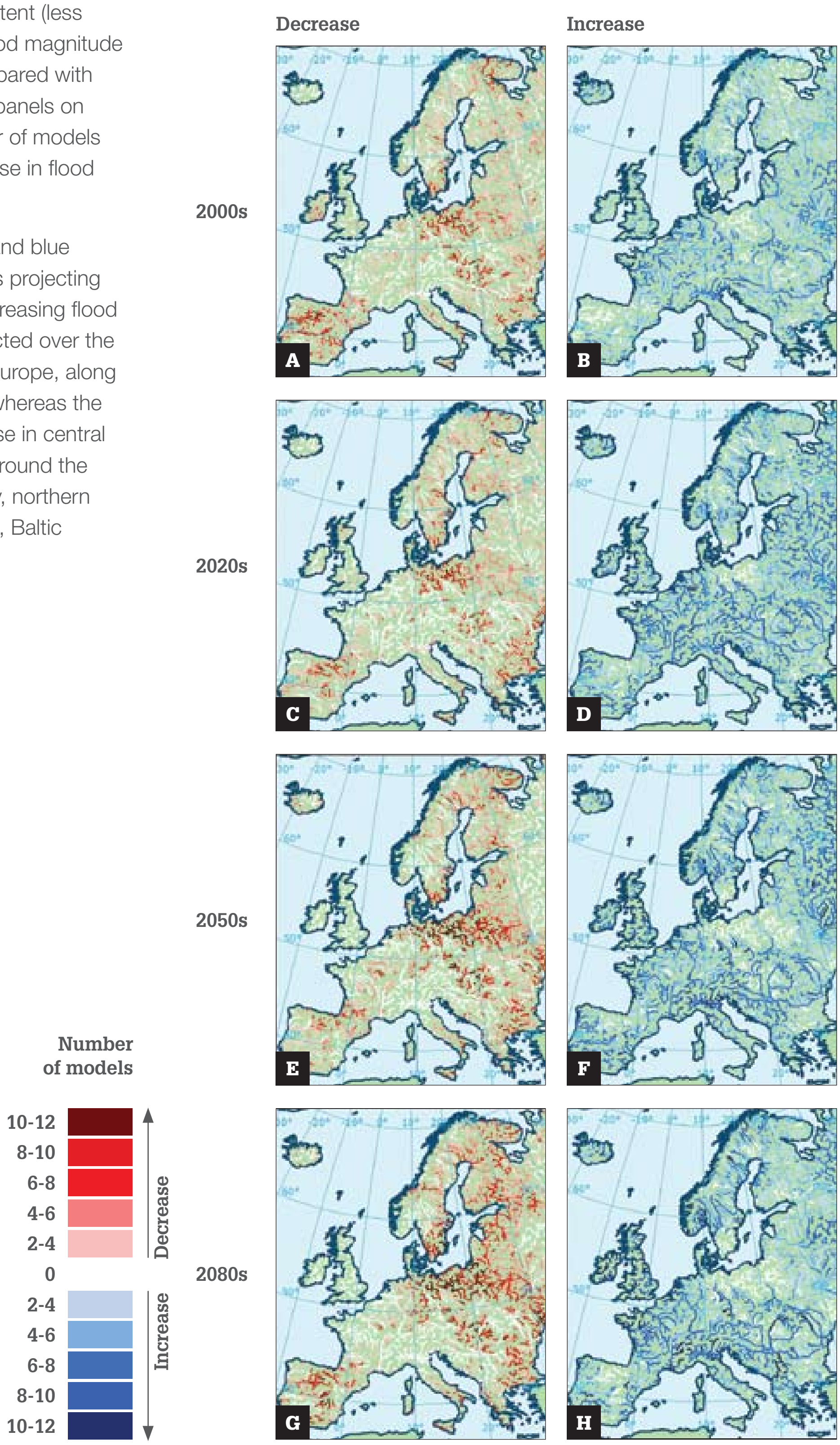


Figure 1. Consistency of changes in the 100-year flood magnitude for the 12 climate models for the A1B scenario used to drive LISFLOOD. These panels show the number of hydrological simulations that showed a considerable (more than 5% with respect to the period 1961-1990) decrease (first column) or increase (second column) for the four time periods analysed.

2.4 Socio-economic scenarios and data

The socio-economic emission scenarios are derived from a wide range of other determinants that are important in influencing future impacts. These include important primary drivers including economic growth and demographic change (population). Previous work has shown that these socio-economic drivers are as important, in determining the size of future impacts and economic costs (Evans et al, 2004), as the change in frequency or intensity of extreme events from climate change. While including these effects is challenging, they need to be considered across the time frames of interest here, otherwise this implies that projected future climates will take place in a world similar to that of today.

The ClimateCost project applied consistent climate and socio-economic scenarios, across sectors, to ensure comparability across the study.

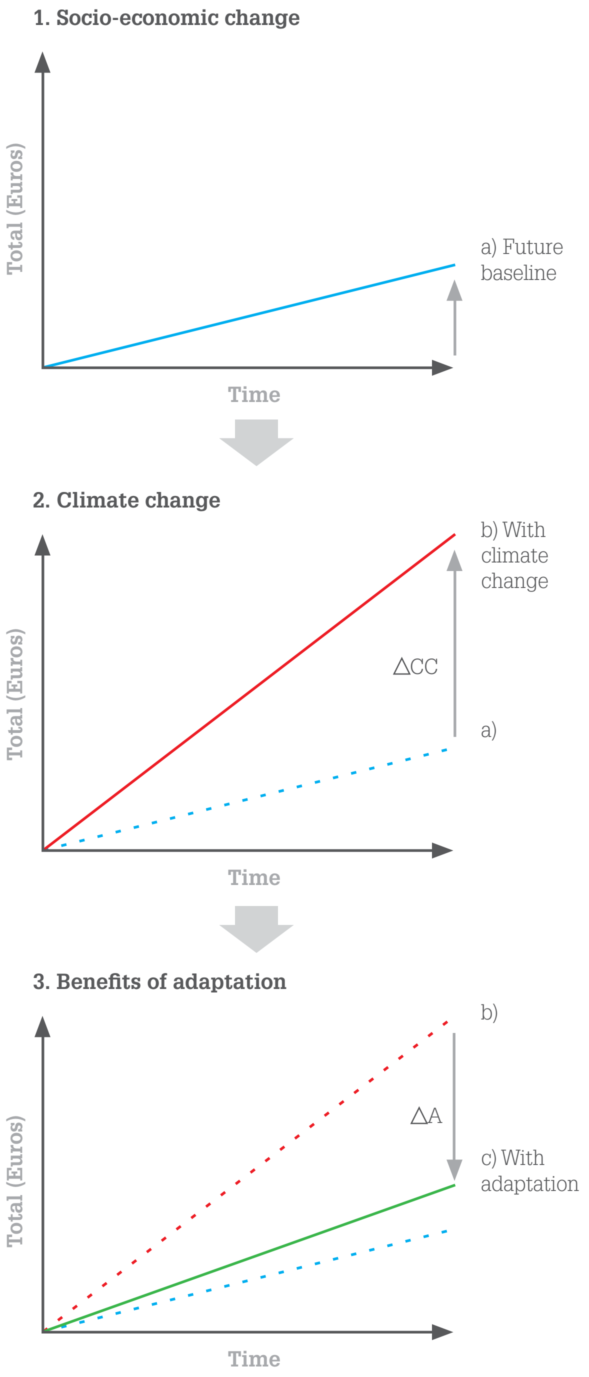
The flooding results reported in this TPBN are based on static land use. Projections of socio-economic drivers relate only to changes in future population and per-capita incomes in Europe. Land-use changes, such as increased urbanisation/industrialisation in flood-prone areas and floodplain development, are likely to further increase the impacts of floods. On the other hand, spatial planning aimed at restoring the natural retention capacity of catchments may have beneficial effects on flood risk in Europe.

2.5 Separating climate and socio-economic drivers

There is a need to consider socio-economic factors when assessing the future risks of climate change. It is also important to split out the socio-economic component to identify the impacts attributable to climate change only, rather than reporting the combined impacts of climate and socio-economic change together - because the impacts from socio-economic change would have occurred even in the absence of climate change. It should be noted that, in many cases, there are also effects of climate and socio-economic change acting together.

For this reason, the analysis shown in Figure 2 first considers a scenario of no climate change as a baseline scenario (i.e. which shows the level of change in flood damage that would occur in the absence of climate change, and that is attributable to the projected changes in population and gross domestic product (GDP) only). This is also included in the analysis of adaptation and is important in allowing attribution of the marginal effects of climate change, while noting that adaptation policy will need to address the combined future effects of climate and socio-economic change acting together. Strictly speaking, only the marginal (or net) increase above the socio-economic baseline is attributable to climate change, though adaptation needs to address the combined effects. Finally, the effects of adaptation in reducing future impacts are considered, but it should be noted that there are still residual damages even with adaptation in place. The steps are shown below.

Figure 2. Outline and steps of stylised framework



Source: Adapted from Boyd and Hunt (2006)

It is stressed that the observed upward trend in flood damage in recent years is primarily attributed to socio-economic factors, such as the increase in population and wealth in flood-prone areas and to changes in the terrestrial system (e.g. from urbanisation, deforestation and loss of natural floodplain storage).

2.6. The reporting of economic values (including adjustments and discounting)

Consistent with all sector-based analysis in ClimateCost, the economic valuation results in this TPBN are presented in terms of constant 2006 prices for the three time periods considered (i.e. the 2020s, 2050s and 2080s) without any adjustments or discounting. **The results are presented in this way to facilitate direct comparison** over time and between sectors. It should be noted that the 'expected annual damages' reported are undiscounted equivalent value, not discounted equivalent annualised value.

However, the use of the values in subsequent policy analyses, for example in looking at the costs and benefits of adaptation options, would need to work with present values (i.e. values that are adjusted and discounted as with standard economic appraisal)

A number of other technical issues are also highlighted. The analysis applies unit values for the impact categories covered. These values do not differ between the socio-economic scenarios covered here (e.g. between A1B and E1) or consider non-marginal changes. The values reported represent direct costs only. They do not consider the wider economic costs associated with damage costs or adaptation, or the potential feedback on price levels and demand. The analysis of these wider economic effects is included in the Computable General Equilibrium analysis in ClimateCost, reported in Volume 2.

3. Methodology

The formation of floods is a highly non-linear process that depends on factors such as the intensity, volume and timing of precipitation, conditions of the river basin (e.g. soil wetness, snow or ice cover), river morphology, land use and flood control measures (e.g. reservoirs and dikes).

ClimateCost used a hydrological model, **LISFLOOD**, to simulate the spatial and temporal patterns of water flow in large river basins in Europe, as a function of spatial information on topography, soils and land cover.

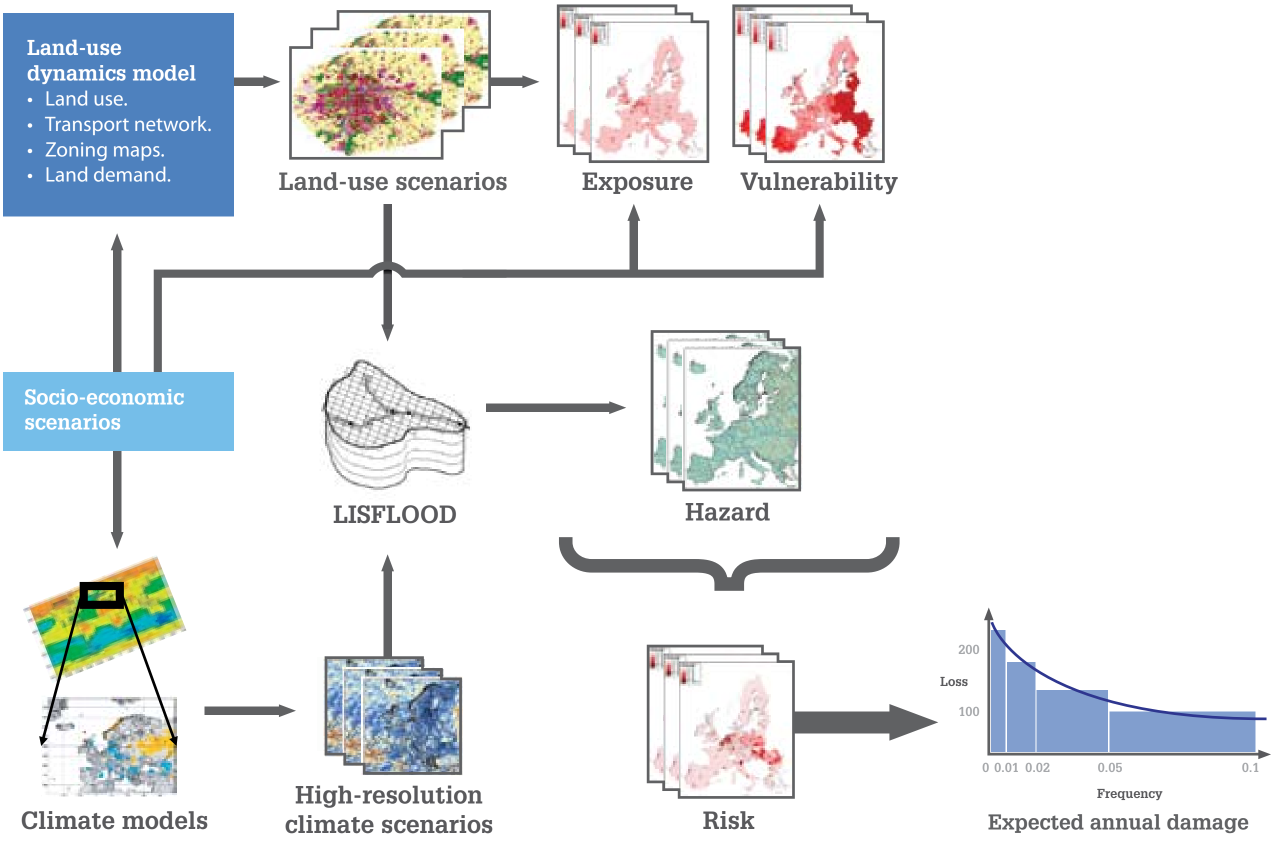
This model was developed for operational flood forecasting at the European scale and is a combination of a grid-based water balance model and a one-dimensional hydrodynamic channel flow routing model. Since it is spatially distributed, the model can take account of the spatial variation in land use, soil properties and climatic variables (van der Knijff et al., 2010).

The hydrological model calculates the changes in flood frequency and water level statistics, which provide an assessment of the expected changes in flood hazard. The model expresses these as a change in the discharge of a flood with a certain (e.g. 100 years) return period (change in intensity) or a change in the return period of a certain event (change in recurrence) under a changed climate. The high-resolution digital elevation data can allow this information to be translated into flooded areas and flood (inundation) water depths. The analysis then uses water-depth damage functions and land-use classifications from CORINE datasets to estimate the direct damage from each flood event, by land-use class. Losses are then accumulated over the frequency distributions to get an overall estimate of the changes in losses. An overall schematic of the modelling framework and the estimation of the damage function are shown in Figure 3 opposite.

Since the work in the PESETA project (Feyen et al., 2006: 2010), considerable development has gone into the model, allowing it to move to a full European-level analysis.

Compared with other sectoral assessments in the ClimateCost project (e.g. health, energy), the analysis of flood damages requires much more complicated climate model outputs, particularly in relation to extreme events. While climate models have considerably advanced in reproducing regional and local climate, they are known to feature systematic errors. These can be a particular issue when projecting extreme flood events. Therefore, climate-model simulations that are not corrected for biases tend to produce inaccurate probabilities for such extreme events. To address this issue, the ClimateCost floods analysis applied bias correction to the precipitation and temperature fields for the different climate-model combinations. This aims to correct the climate simulated by the climate model during a reference period to reflect the spatio-temporal patterns of the observed climate and, subsequently, to use the 'transfer function' between climate observations and simulations obtained to correct future climate simulations. The LISFLOOD simulations with the bias-corrected input fields show a strong improvement in reproducing historical records compared with the runs driven by the uncorrected fields (see Rojas et al., 2011).

Figure 3. The LISFLOOD modelling framework and the damage-probability function for expected annual damage.



For each set of climate data, a series of assessments are made that allow the analysis of climate and socio-economic change.

First, LISFLOOD was run for the period 1961-2100 driven by climate simulations from each regional climate model. Based on extreme value analysis, changes in flood frequency and magnitude were then derived for the current and future climate. For each time period, the resulting flood extent data were combined with country-specific, depth-damage functions and land-use information to calculate direct flood damages. This assumes current socio-economic conditions (static exposure) (i.e. current population and economic asset levels are maintained through future time periods). The current 100-year discharge return level is assumed for flood protection across Europe.

Second, the analysis was undertaken with future socio-economic drivers alone included (i.e. with no future climate change included). This assesses the effects of a rising population and GDP under a static climate.

Third, the future climate and socio-economic changes were run together. This shows the total future burden for adaptation. However, it should be noted that it is the difference between this run and the second run (with socio-economic change only) that provides the marginal economic costs due to climate change.

3.1 What is included and excluded in the analysis?

When considering the results in this TPBN, it is important to be explicit about what is included or excluded and on the areas of uncertainty covered. The analysis only considers river flooding and not intra-urban flooding. Coastal flooding is included in TPBN 2.

The results here only account for the change in population and wealth in flood-prone areas, and are based on changes in population and GDP at the country level. Changes in land use, which may increase or decrease flood risk in the future, are not accounted for.

The results in this TPBN only include the direct costs (losses) associated with river flood damage on residential properties, agriculture, transport, commerce and industry. This type of damage covers all varieties of harm that relate to the immediate physical contact with floodwater. The potential effects of flooding on health (direct fatalities and injuries), and indirect damage to health and wellbeing, are discussed in the health study TPBN. Potential impacts on biodiversity and ecosystem services, and wider multiplier effects from flooding, are not assessed in the analysis here.

In this TPBN a range is often shown from the multi-model ensemble. It is stressed that this range reflects the climate model variability only. Hydrological uncertainty is not accounted for, though several studies (e.g. Wilby, 2005) have shown this is generally much lower than that for climate inputs. However, there is a much wider range of uncertainty across the impacts and valuation assessment.

4. Results – impacts and economic costs of climate change in Europe

4.1 A1B scenario (business as usual)

The ClimateCost results are presented first for the A1B scenario for the EU27. As floods are probabilistic events, results are presented as expected annual values, assuming no adaptation.

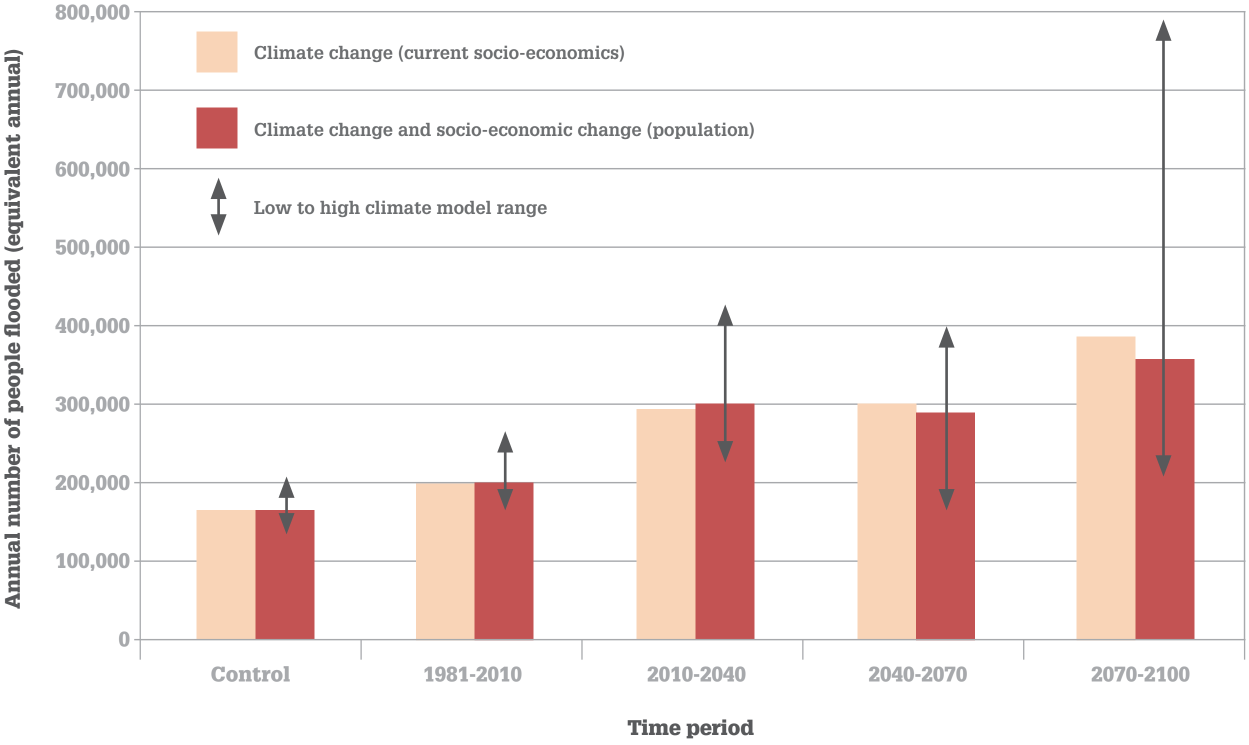
The results in Table 1 are first reported in terms of the EAP affected by flooding, which is currently around 167,000 in the EU27. The analysis shows that this number is projected to rise to 300,000 by the 2020s (2011-2040), 291,000 by the 2050s (2041-2070) and 359,000 by the 2080s (2071-2100), as a result of climate and socio-economic change (row c). The lower values in the 2050s, and the lower rate of increase in later years, reflects the projected decline in Europe’s population in the second half of this century. This offsets the increase in people flooded due to climate change. The marginal impact of climate change (row d) is an additional 130,000 people/year flooded by the 2020s and 2050s, and an additional 210,000/year more by the end of the century. It is stressed that there is a considerable variation across the climate models: the values in Table 1 are

Table 1. EU27 EAP affected by floods for baseline period (1961-1990), 2000s (1981-2010), 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) for the **A1B scenario** (ensemble mean) based on LISFLOOD simulations driven by 12 regional climate models.

EAP for EU27, A1B scenario					
	Baseline (1961-1990)	**Current (1981-2010)**	**2020s (2011-2040)**	**2050s (2041-2070)**	**2080s (2071-2100)**
a) Climate change only (static socio-economics)	167,400	202,300	298,000	301,900	387,400
b) Socio-economic change only (no climate)	167,400	167,400	168,200	160,900	149,400
c) Climate and socio-economic change	167,400	202,300	300,200	291,100	359,300
d) Marginal climate change impact (c-b)		34,900	131,900	130,200	209,800

Note that row c) is not the sum of rows a) and b), but is instead the cumulative effects of climate and socio-economics acting together.

Figure 4. EU27 EAP affected by floods for baseline period (1961-1990), 2000s (1981-2010), 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) for the **A1B scenario** (ensemble mean) based on LISFLOOD simulations driven by 12 regional climate models (columns), with the low and high range across the 12 alternative models, assuming no adaptation.



for the central mean value only, while Figure 4 presents the low and high values from the 12 alternative climate models considered, as well as the mean.

The next results are the expected annual damages (EAD).

Table 2 and Figure 5 show, for the **A1B** scenario, the estimated direct flood damages in recent years and for future time periods in the EU27. The numbers, presented in constant 2006 prices (no future adjustments or discounting), reflect the mean ensemble results across the 12 models. Damages are first calculated for all CORINE land-use classes and then aggregated in five classes (i.e. residential properties, agriculture, transport, commerce and industry).

The estimated EAD for the baseline (1961-1990) is about €5.5 billion. This is similar to the €5.5-7 billion (US$8-10 billion) reported by the Association of British Insurers (ABI, 2005) for present-day average annual losses from flooding in Europe. The analysis also includes an estimate for the current period (1981–2010), including modelled changes since the baseline period, which shows slightly higher EAD values of around €7 billion.

Looking to future periods, for the combined effects of climate and socio-economic change (row c), the EAD is projected to increase to €20.4 billion by the 2020s (2011-2040), €45.9 billion by the 2050s (2041-2070) and €97.9 billion by the 2080s (2071-2100), assuming no adaptation. It should be noted that row b shows that socio-economic growth has a significant impact on flood damage in future years, even without climate change. Notwithstanding this, the marginal effect of climate change (row d) is projected to increase from around €9 billion in the 2020s to €50 billion by the end of this century. All values are presented in current values, undiscounted. The analysis also shows that future socio-economic change is as important as climate change in the level of future damages. Even without climate change, there are still likely to be large increase in flood damages.

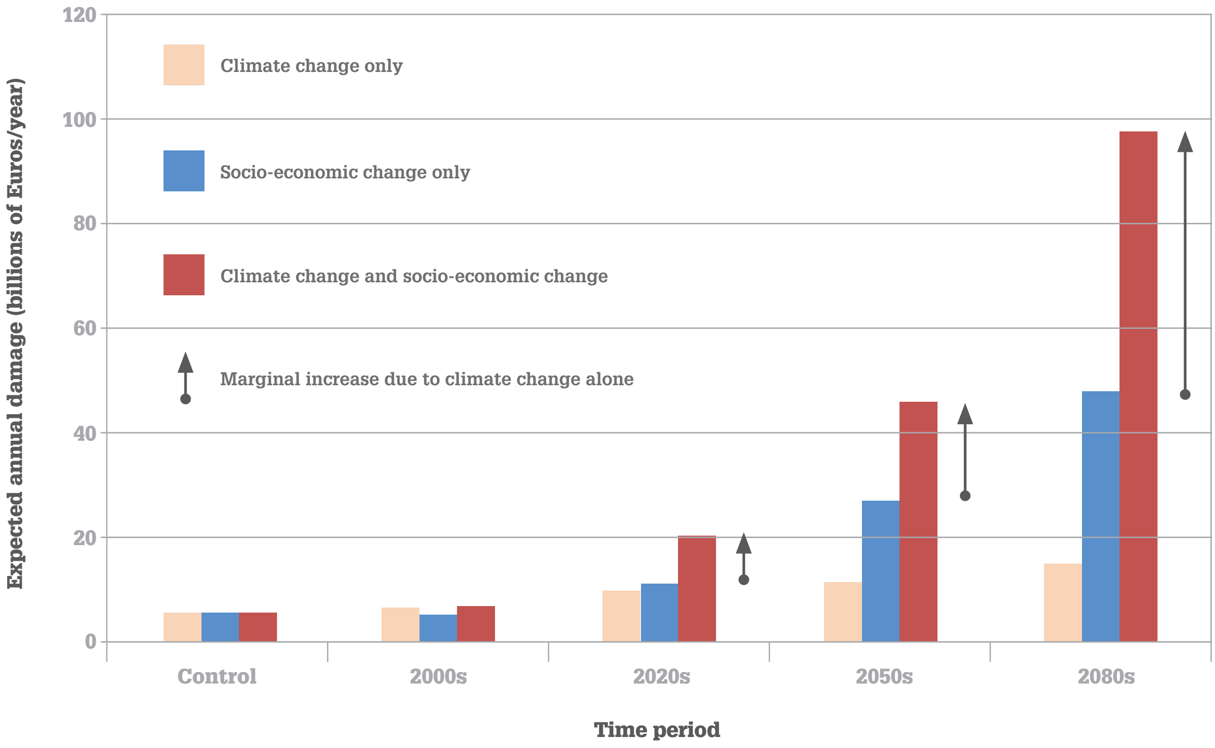
Table 2. EU27 EAD from floods in billions of Euros for baseline period (1961-1990), 2000s (1981-2010), 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) for the **A1B scenario** based on LISFLOOD simulations driven by 12 regional climate models (all numbers in constant 2006 prices, undiscounted), assuming no adaptation.

EAD for EU27 (billions of Euros per year), A1B scenario (undiscounted)

	Baseline (1961-1990)	Current (1981-2010)	2020s (2011-2040)	2050s (2041-2070)	2080s (2071-2100)
a) Climate change only (static socio-economics)	5.5	7.0	10.1	11.2	15.3
b) Socio-economic change only (no climate)	5.5	5.5	11.5	27.0	47.8
c) Climate and socio-economic change	5.5	7.0	20.4	45.9	97.9
d) Marginal climate change impact (c-b)		1.5	9.0	18.9	50.1

For notes, see Figure 5. Note that row c) is not the sum of rows a) and b), but is instead the cumulative effects of climate and socio-economics acting together.

Figure 5. EU27 EAD from floods in billions of Euros for baseline period (1961-1990), 2000s (1981-2010), 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) for the **A1B scenario** based on LISFLOOD simulations driven by 12 regional climate models (all numbers in constant 2006 prices, undiscounted), assuming no adaptation. The entries per time period relate to the first three rows in Table 2, the marginal change represents the final row.



Notes: These values are presented as current prices without adjusting future unit economic values or discounting. No adaptation is included. Impacts covered include river flood damages on residential properties, agriculture, transport, commerce and industry (aggregate). Excluded impacts include intra-urban flooding, health effects of flooding (direct fatalities and injuries, and indirect damage to health and wellbeing), biodiversity and ecosystem services. It also excludes wider multiplier effects from flooding.

Damage caused by floods also leads to other impacts not assessed here, such as those on ecosystems services, additional indirect effects (e.g. the subsequent effects on health and wellbeing) and wider macro-economic effects. These would increase the overall costs further.

Figure 6 shows the distribution of these flood losses for residential properties, agriculture, transport, commerce and industry. About 82% of the losses relate to residential areas, 7% to industry, 5% to commerce, just under 5% to agriculture and 1% to transport. As static land use and economic structure is assumed in the analysis, the distribution of losses over the sectors remains fairly constant over time in the analysis. In practice, there will be potentially important changes in the split over time with the underlying socio-economic change.

It is **essential** to note that the results are strongly dependent on the combination of individual regional/global climate models on which the simulations are based, as models show large variability in the temporal and spatial distribution of future average and extreme precipitation patterns. As a consequence, the uncertainty in the damage estimates is high.

As a result of climate and socio-economic change, the expected annual damage from flooding is projected to grow from about €6 billion currently to €20 billion by the 2020s, €46 billion by the 2050s and almost €100 billion per year (undiscounted) by the 2080s without adaptation.

The EADs shown in Figure 5 reflect the ensemble mean from the 12 climate model outputs. Figure 7 shows the spread in EU27 EAD across the 12 different climate model combinations, without adaptation. This highlights the variation according to the model projections for the A1B scenario. At the upper end of the range, the values are higher than the mean by over a factor of two.

Figure 6. Split (%) of the EU27 EAD from floods for the baseline period (1961-1990) for the **A1B scenario** based on LISFLOOD simulations driven by 12 regional climate models.

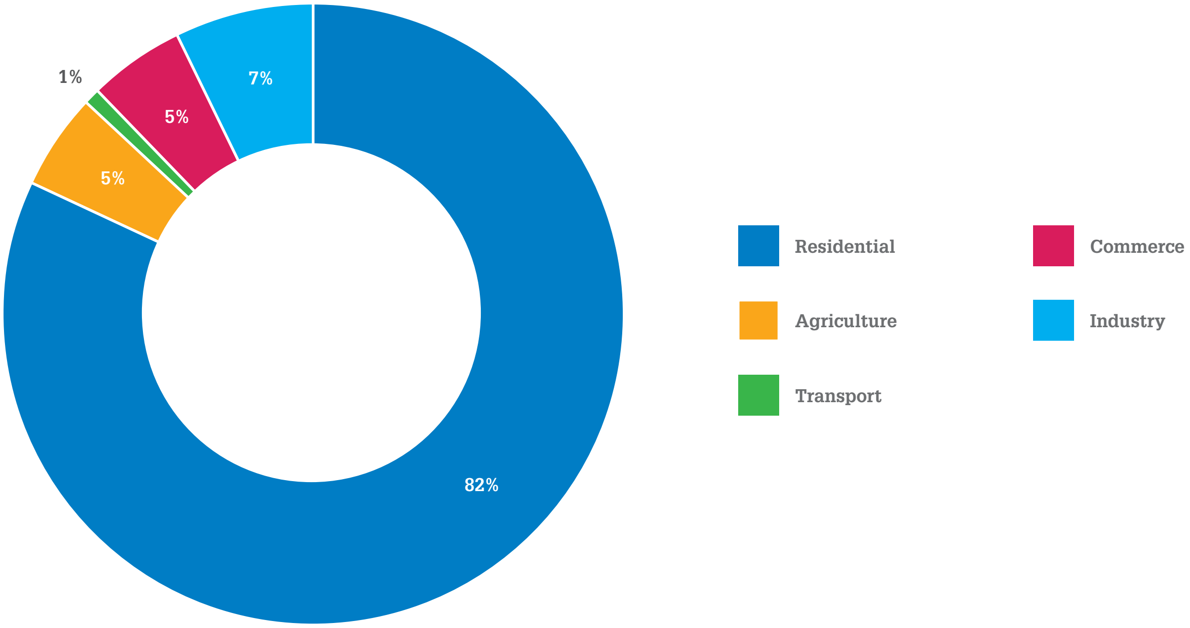
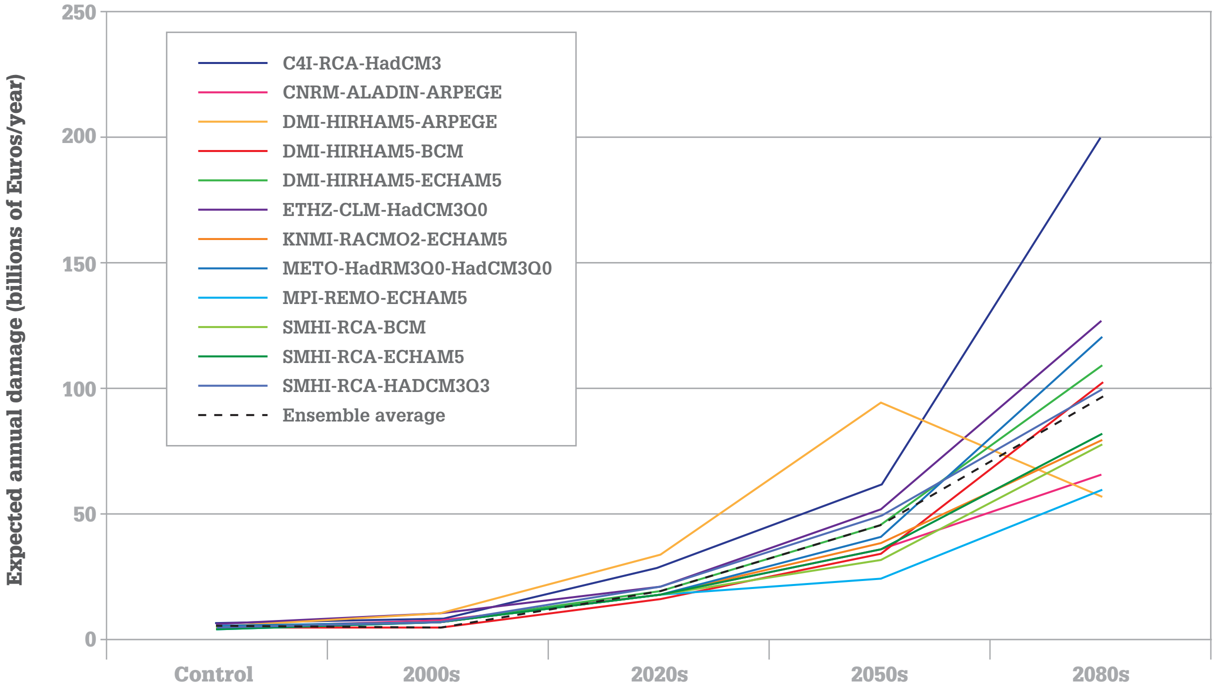


Figure 7. EU27 EAD from floods in billions of Euros for baseline period (1961-1990), 2000s (1980 -2011) 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) for the **A1B scenario** based on LISFLOOD simulations driven by various regional climate models (all numbers in constant 2006 prices, undiscounted). Values shown are for combined effects of climate and socio-economic change, without adaptation. See Figure 5 for notes.



As there are large differences across Europe, some member states are likely to face much higher increases in flood damage related to climate change.

Additional insights on this variation can be gained by looking at differences at the member-state level, shown in Figure 8 opposite. The relative change in direct flood damage due to climate change only (static exposure – no socio-economic change) is shown for the (A) current (B) 2020s (C) 2050s and (D) 2080s relative to the baseline period.

The EAD values for each member state are shown in Figure 9 (combined effect of climate and socio-economic change). All countries will see an increase in flood damage due to these effects. In several eastern European countries (e.g. Hungary and the Czech Republic), the high projected increase in flood damage relates, to a large extent, to the more pronounced increase in exposure (as these countries are expected to have higher rates of GDP growth). However, the greatest increases in the value of flood damage related to climate change (over and above socio-economic change) are seen in the UK, Italy, Slovenia, Belgium and the Netherlands. This is due to a significant increase in the frequency of floods (e.g. 100-year floods may occur every 10 or 20 years by the end of this century).

Figure 8. EU27 relative change in direct flood damage from floods due to climate change only (no socio-economic change) for (A) current (1981-2010), (B) 2020s (2011-2040), (C) 2050s (2041-2070) and (D) 2080s (2071-2100) relative to the baseline period (1961-1990), for the **A1B scenario** on LISFLOOD simulations driven by 12 regional climate models.

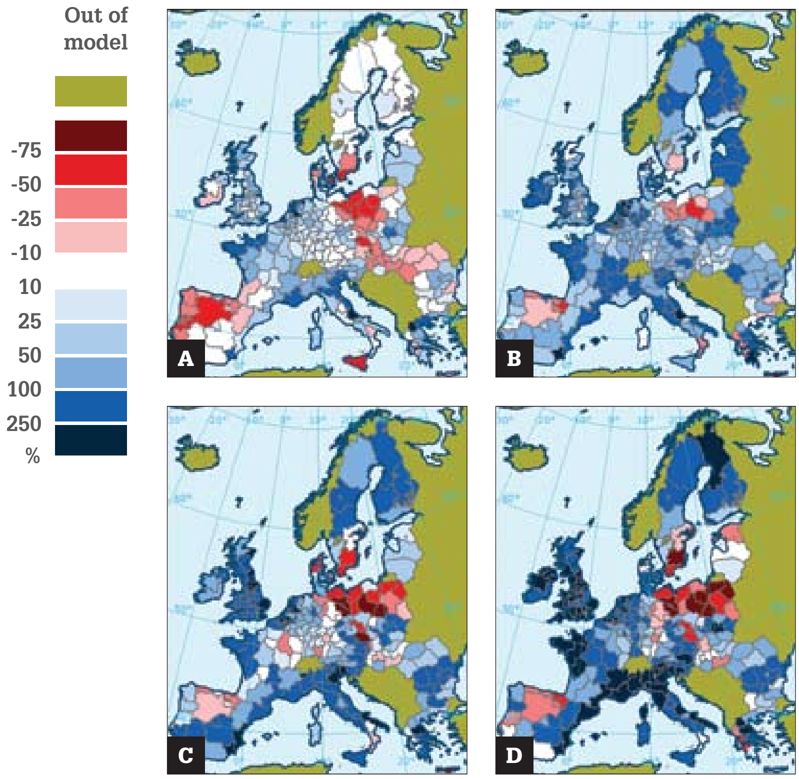
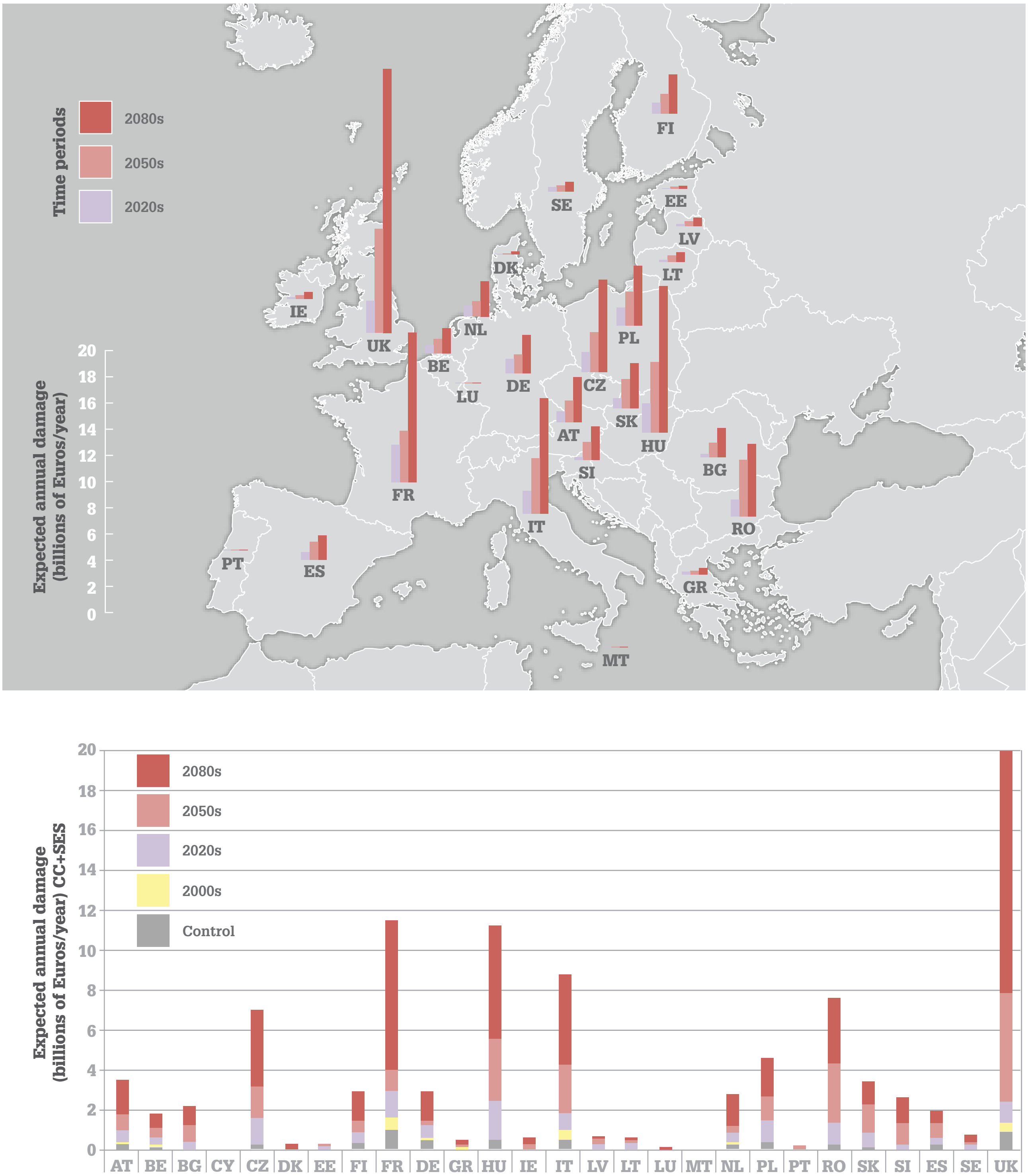


Figure 9. EU27 EAD from floods by member state. for the **A1B scenario** (ensemble mean) based on LISFLOOD simulations driven by 12 regional climate models (all numbers in constant 2006 prices, undiscounted), with no adaptation. Values shown are for combined effects of climate and socio-economic change. The map at the **Top** shows billions of Euros for the 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100). The graph at the **Bottom** shows cumulative annual damages in billions of Euros for the baseline period (1961-1990), 2000s (1981-2010), 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) See Figure 5 for notes.



Note - for an explanation of the abbreviations used in Figure 9, see Appendix 2.

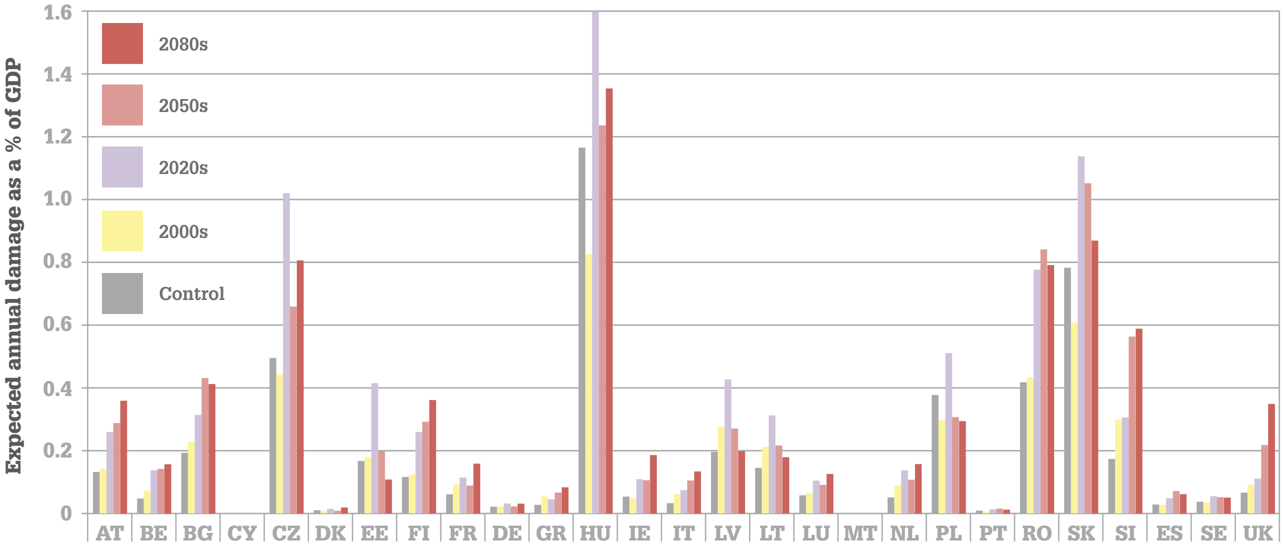
However, when accounting for climate change only, some regions (e.g. the Vistula and Odra catchments in Poland) are likely to see a reduction in floods and flood damage in the spring caused by melting snow. This is because, with the higher winter temperatures, less precipitation will fall as snow, so accumulations will be less. However, there is likely to be an increase in summer flooding in these regions because of warmer, wetter summers due to climate change.

These damages are a relatively low proportion of GDP, equivalent to around 0.1% – 0.2% at the European level over current to future time periods. However, for some countries, these relative impacts are much more important. This can be seen in Figure 10, where the flood damages are scaled by country GDP – noting that this is GDP in the respective future time period.

When moving to the country level, the variations across the models become even more important. These reflect the potentially large differences between model outputs, which can even indicate a reversal of the effects of climate change. Figure 11 shows the variability in the changes of the EAD (between 2080s and baseline period) spatially across the 12 A1B model runs. While some countries, such as the UK, show fairly constant changes, many other countries show increases or decreases for at least some of the model outputs.

There are major uncertainties in the pattern and even the direction of change of future flood damages at the country to local level. It is important to recognise these uncertainties when planning adaptation

Figure 10. EU27 EAD from floods as a percentage of GDP (in the respective future time period) for baseline period (1961-1990), 2000s (1981-2010), 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) for the **A1B scenario** (ensemble mean) based on LISFLOOD simulations driven by 12 regional climate models (all numbers in constant 2006 prices, undiscounted, without adaptation). Values shown are for combined effects of climate and socio-economic change. See Figure 5 for notes.



Note - for an explanation of the abbreviations used in Figure 10, see Appendix 2.

Figure 11. Change in EAD between the 2080s (2071-2100) and baseline period (1961-1990) for the **A1B scenario** based on LISFLOOD simulations driven by various regional climate models. Each plate represents the results for one of the 12 model combinations listed in Appendix 1. See Figure 5 for notes.

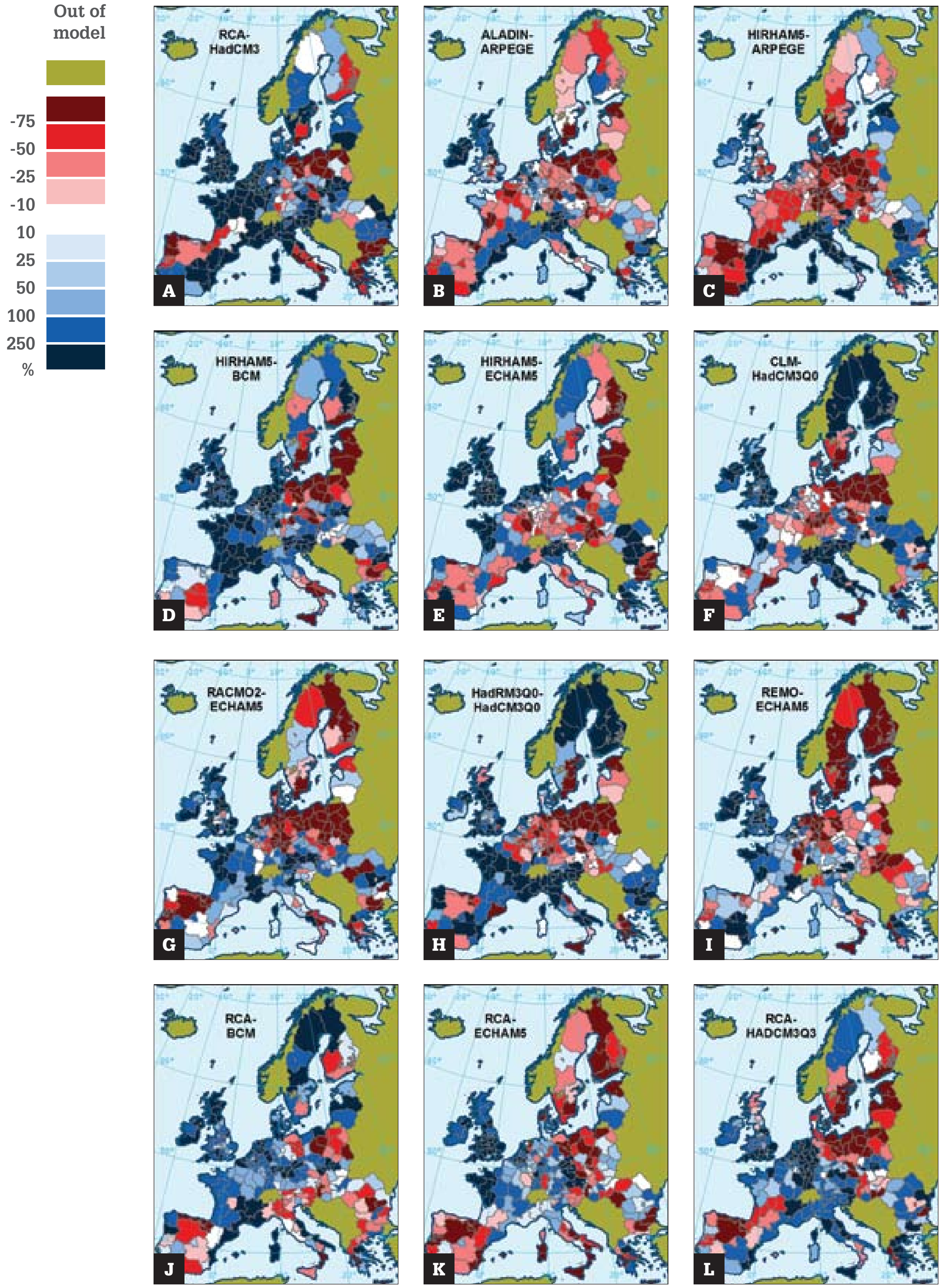


Table 3. EU27 EAD from floods in billions of Euros for the baseline period (1961-1990), 2000s (1981-2010) 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) for the **E1 scenario** based on LISFLOOD simulations driven by three different climate experiments with the MPI-REMO regional climate model (all numbers in constant 2006 prices, undiscounted, with no adaptation).

EU27 EAD in billions of Euros per year, E1 Scenario (undiscounted)

	Baseline (1961-1990)	Current (1981-2010)	2020s (2011-2040)	2050s (2041-2070)	2080s (2071-2100)
a) Climate change only (static socio-economics)	5.0	5.1	8.2	9.6	9.0
b) Socio-economic change only (no climate)	5.0	5.0	9.2	21.4	37.6
c) Climate and socio-economic change	5.0	5.1	14.6	41.7	68.2
d) Marginal climate change impact (c-b)	0.0	0.1	5.4	20.3	30.6

4.2 E1 mitigation scenario (2 degrees target)

Table 3 and Figure 12 show the estimated direct flood damages between the end of the 20th century and future time periods in the EU27 for the **E1** mitigation scenario, which is consistent with the EU 2 degrees target (from pre-industrial levels). This would be expected to lead to reduced flooding costs from future climate change.

The current EAD (about €5 billion) for the baseline period is projected to increase to €14.6 billion by the 2020s (2011-2040), €41.7 billion by the 2050s (2041-2070) and €68.2 billion by the 2080s (2071-2100), as a result of climate and socio-economic changes (row c), with no adaptation included. The marginal impact from climate change (row d) under the E1 scenario increases from about €5 billion in the 2020s to €30 billion by the 2080s. This is considerably lower towards the end of this century than the ensemble mean results of the A1B scenario – and the difference can be considered the marginal benefit of mitigation (relative to the medium-high A1B scenario). However, it is important to note that for the E1 scenario **only three** climate data sets were available. Moreover, they all originate from the MPI-REMO regional climate model, but are driven by three different ECHAM5 runs as boundary conditions. Hence, while the results suggest significant mitigation benefits, a definitive conclusion that there will be a strong reduction in flood damage (especially by the end of this century) under the mitigation scenario cannot be made.

While the results suggest significant mitigation benefits, a definitive conclusion that there will be a strong reduction in flood damage (especially by the end of this century) under the mitigation scenario cannot be made.

Figure 12. EU27 EAD from floods in billions of Euros for baseline period (1961-1990), 2000s (1981-2010), 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) for the **E1 scenario** (ensemble mean) based on LISFLOOD simulations driven by three different climate experiments with the MPI-REMO regional climate model (all numbers in constant 2006 prices, undiscounted, with no adaptation). See Figure 5 for notes.

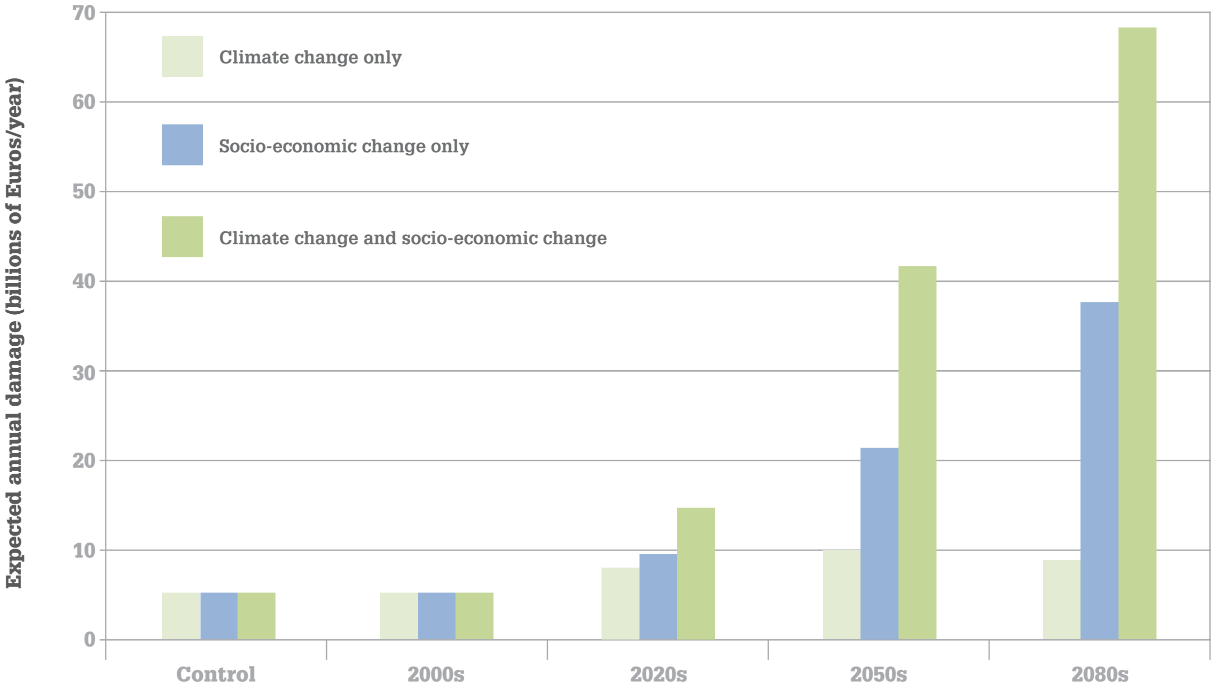
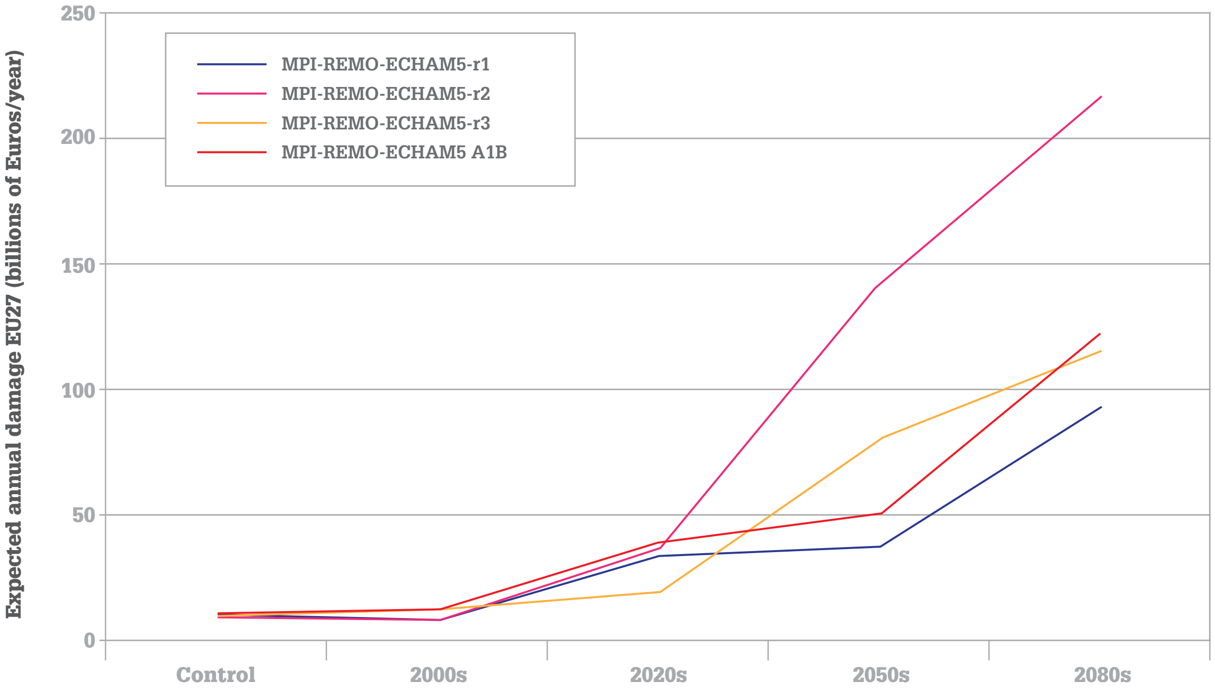


Figure 13. EU27 EAD from floods in billions of Euros for the baseline period (1961-1990), 2000s (1981-2010), 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) for the **E1 scenario** based on LISFLOOD simulations driven by three different climate experiments with the MPI-REMO regional climate model (all numbers in constant 2006 prices, undiscounted, with no adaptation). Also shown is the outcome of the A1B experiment with an identical climate model combination. Values shown are for combined effects of climate and socio-economic change. See Figure 5 for notes.



Indeed, the comparison of the results for the three individual E1 mitigation runs with the A1B run for the same climate model combination (MPI-REMO-ECHAM5) (shown in Figure 13) suggests that the lower average flood damages for E1 is more likely to be linked with the climate models used. The analysis of a larger ensemble of future E1 regional runs (as they become available) is considered a priority.

Alongside the European-scale analysis, the ClimateCost study undertook primary valuation work and work at a higher spatial resolution in Prague in the Czech Republic (see case study).

A case study from the Czech Republic

How do house prices vary with flood risk? A hedonic price study on flooding in Prague.

The main ClimateCost floods analysis, using the LISFLOOD model, uses relationships of flood-depth damage to estimate the value of damages due to river flooding. The results capture the direct costs of flooding. To complement this analysis and to start investigating analysis at the local level, the project has undertaken a primary valuation study of flood risks in Prague by carrying out a hedonic price study on river flood risks. This work was undertaken by Jan Melichar and Milan Ščasnýny from Charles University Environment Center, Prague, Czech Republic.

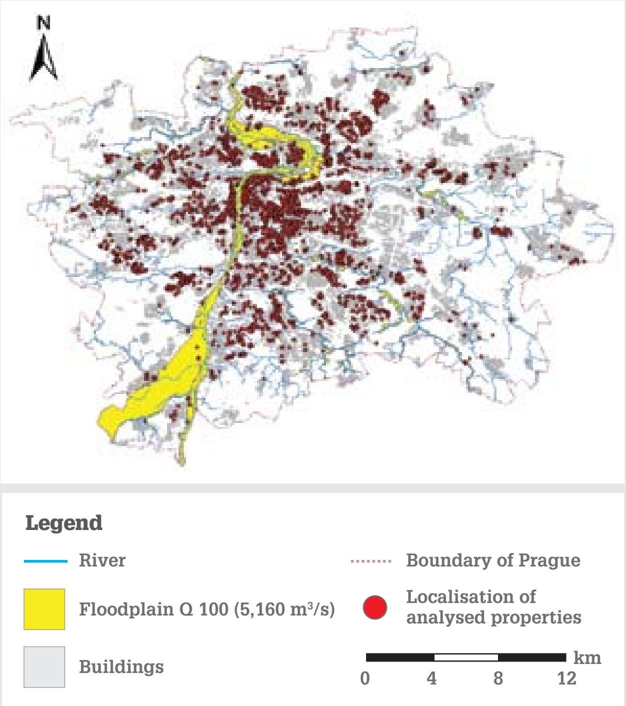
These studies have been widely used in environmental economics. They look at the price that individuals are willing to pay for certain marketed goods/services (e.g. property or labour). As an example, hedonic price methods have been used to look at noise issues (e.g. studying how much more individuals are willing to pay for a house in a quiet area than for an identical house in a noisy area). The approach uses regression analysis to examine the contribution of specific environmental attributes to property prices. In this case, the environmental attribute is flood risk.

Review work as part of the project considered previous hedonic studies of flood risks. These indicate that the relative change in price for houses in the 100-year flood plain is –4.8% on average, but can be as high as -12%.

The study assessed the properties at risk in Prague using flood-risk maps and geographical information systems (GIS). This revealed a large number of properties at risk of a 1 in 100-year event. It used information on the price of real estate in the city to estimate the parameters for the hedonic price regression model and to determine how much flood risks influence house prices by looking at the average price difference between houses inside and outside of the flood-risk zone (adjusting for a range of other factors that influence property prices).

The econometric analysis considered several models (alternative functional forms and variables) and the implicit value for an additional unit of the flood-risk attribute was estimated. The results reveal a central value of -8.5% (i.e. that flood risks have a significant effect in reducing property values in the city). The work is progressing to investigate the change in the flood-risk plain with climate change and estimate possible changes using the hedonic price results.

Figure 14. Prague Floodplain of a 100-year flood based on flood culmination in 2002, August.



5. Adaptation

Historically, protection against flooding has been a costly, but straightforward, way to overcome many of the adverse impacts. Several potential adaptation options to address these risks have evolved in recent years. These adaptation strategies have historically used protection or accommodation to reduce risks. Protection involves the control of risks with defences (e.g. physical barriers to flooding), whereas accommodation involves adjusting human use of the flood zones (e.g. through forecasting and early warning systems, insurance, increased flood resilience). These measures include a mixture of so called ‘hard’ (engineering) and ‘soft’ (non-technical) measures. Increasingly, such options are being seen as part of integrated portfolios. However, a residual risk always remains and complete protection cannot be achieved. Thus, managing floods involves an element of strategy. In recent years, the focus of flood management policy has shifted from technical measures (especially protection with defences) to spatial solutions that aim to create ‘room for the river’, as with recent examples in the Netherlands. The new policy approach tries to take account of long-term developments and risks, such as those presented by climate change.

This study has assessed the potential European costs of adaptation. The local implementation of adaptation measures depends on site-specific hydro-morphological and land-use characteristics, and socio-economic conditions (e.g. risk-perception, availability of funding). Given the variety of these factors across Europe, it is very challenging to model the wide range of adaptation strategies at a pan-European scale. Therefore, rather than evaluating costs and benefits of specific adaptation options, this study has considered an alternative approach. This is done by assessing the benefits of introducing and maintaining flood protection in future time periods to levels of acceptable risk, and then looking at the potential costs of obtaining these standards.

For the assessment in ClimateCost, this study considered minimum protection levels across Europe to a 1 in 100-year event. It estimated the benefits of such protection levels and the costs of adaptation to maintain these levels against future climate change (a future 100-year event may correspond to a current 150-year event, in which case, future protection is against a current 150-year event). The cost of adaptation includes capital costs as well as operation and maintenance (O&M) costs. For the scenario including socio-economic growth, it is assumed that the operating and maintenance costs grow linearly with GDP.

The benefits (i.e. the reduction in EAD with adaptation) are shown for the **A1B medium-high emission scenario** in Table 4. The benefits for the EU27 for the A1B scenario are estimated at €8 billion by the 2020s (2011-2040), €19 billion by the 2050s (2041-2070) and €50 billion by the 2080s (2071-2100) for the mean ensemble results (EU, current values, undiscounted). These can be compared against the flood damages without adaptation, shown in Table 2. The table also shows the residual damages (EAD) after adaptation.

It is stressed that the benefits vary with the climate model output. Thus, in cases where higher flood damages are projected, the benefits will be correspondingly higher.

Table 4. Benefits of adaptation, and residual damages after adaptation, in billions of Euros per year, from maintaining 1 in 100-year levels of flood protection in 2000s (1981-2010), 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) for the **A1B scenario** based on LISFLOOD simulations driven by 12 regional climate models (all numbers in constant 2006 prices, undiscounted). See Figure 5 for notes.

Benefits of adaptation – billions of Euros per year in EU27, A1B scenario (undiscounted)

	Baseline (1960-1990)	Current (1980-2010)	2020s (2011-2040)	2050s (2041-2070)	2080s (2071-2100)
Benefits for adapting to climate change only (static socio-economics)		1.3	4.2	5.4	9.4
Residual impacts after adaptation (climate change only)		5.7	5.9	5.8	5.9
Benefits for adapting to climate and socio-economic change		1.3	8.3	19.0	49.7
Residual impacts after adaptation (climate change and socio-economic change)		5.7	12.1	26.9	48.2

It is also highlighted that there are still residual damages even after adaptation. Under the climate-only scenario, these are kept similar to current damage levels (i.e. around 6 billion Euro/year (EAD)). However, in the scenario of future climate and socio-economic change, the residual damages are much higher because damages would rise even if minimum protection levels are maintained due to socio-economic development. This suggests that higher levels of protection will be justified (and needed) in the future (i.e. that in cost-benefit terms, higher levels of protection would be closer to the optimal strategy).

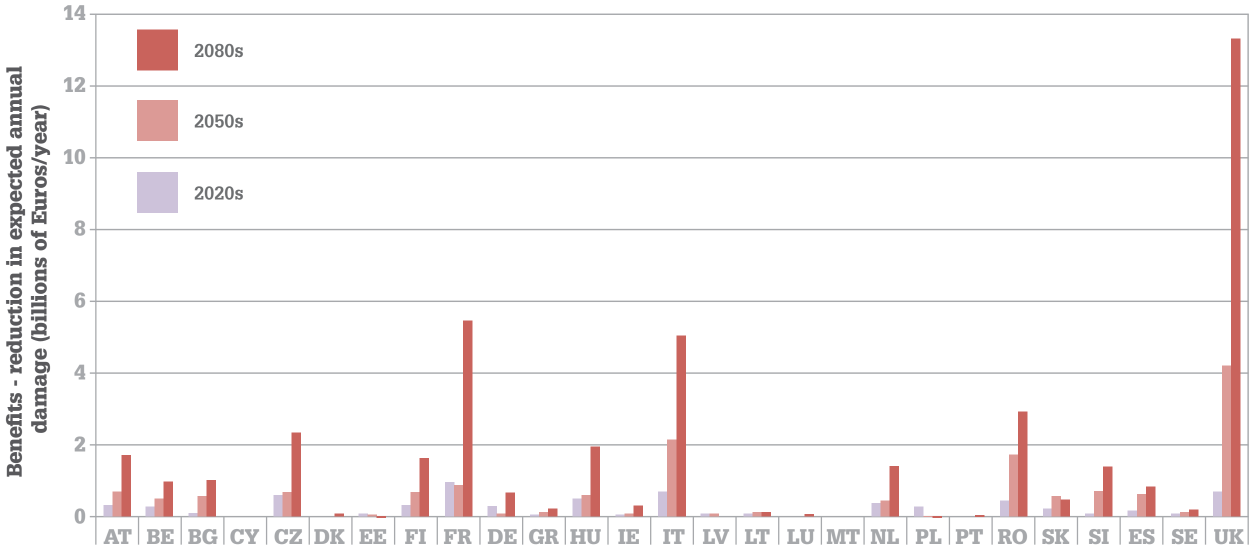
The split by country is shown in Figure 15.

This study then assessed the costs of achieving these protection levels.

The approach used existing literature on the potential costs and benefits of adaptation in Europe at the member-state level in, for example, the UK, the Netherlands, Germany, France, Slovakia and Belgium (e.g. Evans et al., 2004[3]: EA, 2009[4]: EEA, 2007[5], Broekx et al., 2011; Lamothe et al., 2005).

Notwithstanding the difficulty in assessing the costs (capital, operation, maintenance) and benefits (avoided direct and indirect damages, environmental benefits) of flood protection measures, this study indicates that the costs of adaptation in Europe to address future climate (and socio-economic risks) could be relatively large (i.e. billions of Euro per year), even though most options typically have high benefits when compared with costs. Based on these studies, which encompass a wide portfolio of measures, an average benefit-to-cost ratio across the European studies of 4 to 1 was found. This ratio was combined with the avoided damages (benefits) above from adapting to future flood magnitudes (to keep the same level of acceptable risk (i.e. protection to a 100-year flood event)) to derive the costs of adaptation. It is noted that, at the local basin scale, other benefit-to-cost ratios will apply depending on site-specific characteristics and the types of measure (and this approach is not applicable for local or even country-level analysis). It should also be noted that this transfer approach has a number of limitations. Nonetheless, it does provide an exploratory analysis to estimate likely cost at the EU level.

Figure 15. Benefits of adaptation, in billions of Euros per year, to maintain 1 in 100-year levels of flood protection in 2000s (1981-2010), 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) for the **A1B scenario** (ensemble mean) based on LISFLOOD simulations driven by 12 regional climate models (all numbers in constant 2006 prices, undiscounted). See Figure 4 for notes.



Note - for an explanation of the abbreviations used in Figure 15, see Appendix 2.

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[3] Estimated at a total investment over the next 80 years of £22 billion and £75 billion (about €25 and €85 billion at spring 2011 exchange rates)– noting this covers coastal as well as river flooding, and only covers engineering (technical) costs.

[4] This reports that an increase in investment of around £1 billion a year, , is needed to maintain current protection levels through to 2035, i.e. for building and maintaining new and existing flood defences. It should be noted that this includes coastal and river floods, and includes multiple drivers as well as climate change.

[5] An approximate cost of adaptation to climate change for flood defence along the river Rhine was made on the basis of a study of the Netherlands Bureau of Economic Policy Analysis and simplifying assumptions. This found flood defence investments would reduce climate-induced flood damage from €39.9 billion to €1.1 billion over the 21st century at a relatively modest cost of around €1.5 billion.

The analysis shows (see Table 5 and Figure 16) that, under the A1B scenario, the expected annual costs of adaptation – for the combined effects of climate and socio-economic change - rise to €1.7 billion by the 2020s (2011-2040), €3.4 billion by the 2050s (2041-2070) and €7.9 billion by the 2080s (2071-2100). For the E1 scenario, the expected annual costs of adaptation amount to €1.2 billion by the 2020s (2011-2040), €3.3 billion by the 2050s (2041-2070) and €4.7 billion by the 2080s (2071-2100). It is stressed that the lower adaptation costs for the E1 scenario, especially by the end of this century, is more likely to be related to the choice of climate model rather than to climate change mitigation.

Figure 17 shows that there is a large variation in the cost of adaptation by country. These mirror the range of damage costs above. Thus, countries with higher estimated damages, such as the UK, have higher adaptation costs.

The relationship between the climate model uncertainty and the costs of adaptation also needs to be considered. Using the methodological approach above, the costs will vary with the level of future flood risks (i.e. across the full range of climate model outputs shown in Figure 7). This is because greater or lesser amounts of adaptation are required to maintain the same level of protection in the face of different levels of future flooding. However, in practice, some costs would be fixed (e.g. the costs of early warning systems and many other ‘soft’ (i.e. non-technical) measures, as well as some of the components of ‘hard’ (i.e. engineered) measures). Thus, the costs will involve more variation across future outcomes. This also leads to two additional issues.

> **Adaptation leads to significant economic benefits and can potentially reduce direct damages at low cost.**

Table 5. Potential costs of adaptation, in billions of Euros per year, to maintain 1 in 100-year levels of flood protection in the 2000s (1981-2010), 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) for the **A1B scenario** (ensemble mean) based on LISFLOOD simulations driven by 12 regional climate models, and the **E1 scenario** for 3 models (all numbers in constant 2006 prices, undiscounted).

Costs of adaptation – billions of Euros per year in EU27, A1B scenario (undiscounted)

	Baseline (1960-1990)	Current (1981-2010)	2020s (2011-2040)	2050s (2041-2070)	2080s (2071-2100)
Adaptation to climate change only (static socio-economics)	-	0.5	1.1	1.4	2.4
Adaptation to climate and socio-economic change	-	0.5	1.7	3.4	7.9

Costs of adaptation – billions of Euros per year in EU27, E1 scenario (undiscounted)

	Baseline (1960-1990)	Current (1981-2010)	2020s (2011-2040)	2050s (2041-2070)	2080s (2071-2100)
Adaptation to climate change only (static socio-economics)	-	0.2	0.8	1.1	1.1
Adaptation to climate and socio-economic change	-	0.2	1.2	3.2	4.7

Figure 16. Potential costs of adaptation, in billions of Euros per year to maintain 1 in 100-year levels of flood protection in 2000s (1981-2010), 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) for the **A1B scenario** (ensemble mean) based on LISFLOOD simulations driven by 12 regional climate models and **E1 scenario** (driven by 3 RCMs) (all numbers in constant 2006 prices, undiscounted). Data shown for climate change only (static socio-economics), and climate and socio-economic change combined.

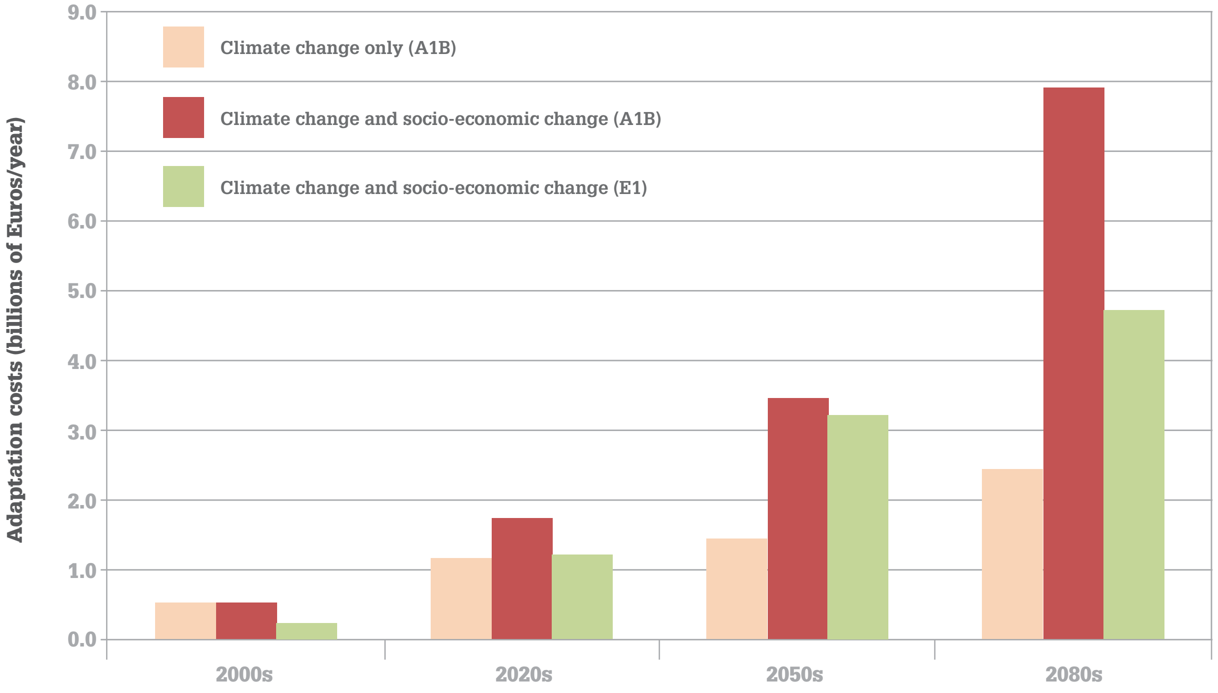
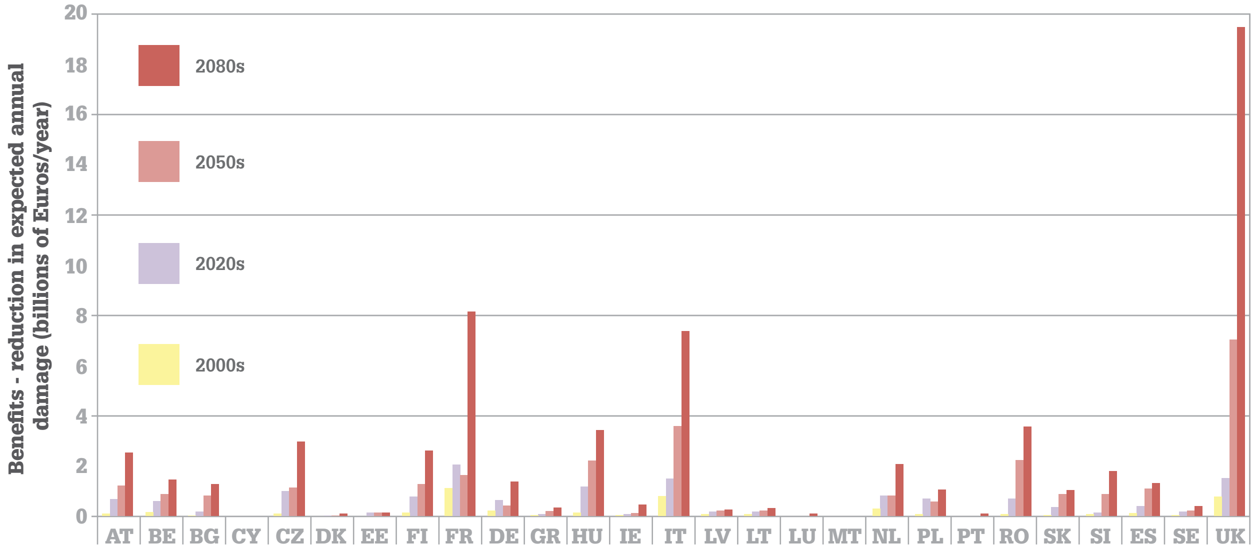


Figure 17. Costs of adaptation for member states, in billions of Euros per year, to maintain 1 in 100-year levels of flood protection in 2000s (1981-2010), 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) for the **A1B scenario** based on LISFLOOD simulations driven by 12 regional climate models (all numbers in constant 2006 prices, undiscounted). Values shown are for adapting to the combined effects of climate and socio-economic change.



Note - for an explanation of the abbreviations used in Figure 17, see Appendix 2

First, the costs and benefits of adaptation are determined by the policy objectives and framework. Thus, there are very different levels of adaptation according to whether an economic efficiency criterion (optimal protection to the point where benefits and costs are equal) or an acceptable level of protection (risk-based protection) is assumed. For the latter, the costs are very strongly determined by the level of risk protection (i.e. by the acceptable level of flood risk), which involves important social as well as economic drivers. There are no minimum levels of risk protection in Europe and levels of acceptable risk vary between, and even in, member states. Countries or areas that seek to achieve higher levels of risk protection will incur higher adaptation costs. Further, strategies that aim to reduce risk to very low levels are, invariably, more costly. This raises important issues for policy.

Second, the consideration of climate model variability also makes a large difference to the actual adaptation response at a country level. The framework used in this study - and the benefits and costs above - assumes that future damage costs are known or can be predicted with confidence. At present, there is very large uncertainty around the outcomes. The future socio-economic scenario is not yet known (e.g. whether we are on a business-as-usual or a mitigation pathway globally) and, for any given pathway, there is then a very wide range of variability on the level of flood risk.

This means there is the potential for mal-adaptation (over-designing versus failing to provide adequate protection). This is particularly important because benefits are likely to accrue in later time periods, while costs may be incurred earlier, and this will affect the cost-to-benefit ratio[6].

Therefore, recognising and adapting to this uncertainty requires a change in the approach for adaptation (i.e. looking at iterative approaches that allow future decisions to be taken that address uncertainty). This involves implementing options that are more robust, providing flexibility and keeping future options open - as part of integrated and sustainable policies. These are often implemented through a process of adaptive management and with portfolios of strategies.

The costs of adaptation vary with the level of protection or acceptable risk. They also vary with the policy framework (risk levels versus optimisation).

Such approaches involve a mix of soft and hard measures, and capacity building. They involve consideration of wider environmental and social aspects, not just protection of physical assets. They invariably involve integrated flood management responses and land management. The move to the implementation of such approaches, and the choice and use of exact strategies, depends on the nature of the flood zone and the type and extent of impacts (i.e. adaptation requires a site- and context-specific response).

6. Notes and limitations on the results

In considering the results above, the following notes and limitations should be considered. The assessment only considers river floods, it does not include intra-urban flooding; coastal flooding is considered in TPBN 2. The assessment only reflects direct tangible damages due to contact with floodwaters, though this typically forms the largest share of flood damage. It does not consider the wider effects from disruptions to physical and economic activities or other damages from adverse social and environmental effects, including wider effects on health and wellbeing or biodiversity and ecosystem services. It also does not consider wider economic costs.

The estimates of flood damage presented are based on static land use. If land use developments, such as increased urbanisation and flood-plain development are not reversed, flood damages are likely to be higher than those reported. On the other hand, spatial planning aimed at restoring natural retention capacities in catchments may reduce future flood risk.

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[6] Note that such an analysis can be considered through a standard cost-benefit analysis, using the calculation of present values (discounted costs and benefits of the life of the project). The results here have not been discounted and assessed in this framework, though this is being undertaken in other ClimateCost tasks. However, it should be noted that acceptable levels of risk protection are usually considered in a cost-effectiveness framework.

The approach adopted in ClimateCost is to sample across the climate model outputs. This leads to large differences in flood-damage assessments. In addition to climate model uncertainty, there are other limitations that should be considered when interpreting the results. While the climate and hydrological models, and hydro-morphological datasets have greatly improved spatial resolution, a large-scale approach at the European scale still presents challenges and, hence, introduces uncertainties. These include inaccuracies in the derivation of flood inundation extents, extrapolation errors in deriving flood return levels for high recurrence intervals based on limited time series, and uncertainties in the underlying impact relationships and cost functions.

While these results provide useful European context, more local-scale assessment of adaptation, including the best portfolios of measures for different settings, is needed. Improvements are also needed to quantify the damage caused by floods, in the costs/benefits of structural (hard) and non-structural (soft) options for adaptation, and in the monetary evaluation of environmental and social benefits.

Notwithstanding these issues, the numbers presented provide an indication of potential future developments in flood risk in a changing climate.

7. Implications for European policy

The results show that rising flood risks could be one of the main impacts of climate change in Europe. They show that, in the medium term, these are likely to have very significant implications for current flood management (i.e. that they require an increased response from the business-as–usual scenario). A key conclusion is that current procedures for designing flood-control infrastructures across Europe should be revised to consider the projected changes in extreme river flows and the existing uncertainties.

The analysis also shows that future socio-economic change is as important as climate change in the level of future damages – even without climate change, there are still likely to be large increases in flood damages. This provides an even stronger justification for action, but it also highlights that any response needs to consider these socio-economic factors and future climate change in the analysis and the responses.

The results also show that these impacts can be reduced significantly through adaptation at relatively low cost. Such action will be needed even under a mitigation scenario. Hence, in addition to promoting climate mitigation, it is important that the countries in Europe introduce appropriate adaptation. However, there will be residual impacts after adaptation and the analysis shows that higher protection levels are likely to be justified in future years because of the increase in underlying socio-economic development.

In addition, the analysis highlights the uncertainty in the future projections of flood risks, especially at the disaggregated scale, reflecting the variation across the models. This leads to a potentially greater focus on robustness and flexibility for adaptation (i.e. through adaptive management). This may involve a greater use of soft, non-structural measures that have the potential to be more flexible and more sustainable than hard measures (though technical measures will be indispensable in certain circumstances). Policy might try to stimulate water managers to move to site-specific mixes of measures, which may be altered or are robust to changing conditions.

The results also show a very strong distributional pattern of increased floods across Europe (i.e. with different risks between member states). It is clear that these future impacts will be more important for some countries or regions. This leads to the question of how these costs could be shared (e.g. through solidarity funds) and issues relating to the role of insurance markets.

There is also an issue of how best to respond to these risks given river catchments are often across national boundaries. This will require co-ordinated responses between countries and regions to avoid mal-adaptation by shifting potential impacts upstream or downstream.

There is also a significant potential for learning. Although transferability of best practices may be limited because of location-specific characteristics, the exchange of information by practitioners in different basins is valuable, not least since pressures such as climate change and land-use dynamics are common to most basins, and present similar challenges for flood-risk management.

Finally, climate change is only one aspect of land and flood-risk management policy in Europe, and adaptation to climate change needs to be positioned in a broader, integrated, management policy framework (e.g. agriculture, spatial planning, transport, energy) that is consistent with wider management and development goals.

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Appendix 1

Table A1. List of regional-global climate model combinations used to produce average damage estimates reported.

Acronym	Regional Climate Model	Global Climate Model	Scenario
C4I-RCA-HadCM3	RCA	HadCM3	A1B
CNRM-ALADIN-ARPEGE	ALADIN	ARPEGE	A1B
DMI-HIRHAM5-ARPEGE	HIRHAM5	ARPEGE	A1B
DMI-HIRHAM5-BCM	HIRHAM5	BCM	A1B
DMI-HIRHAM5_ECHAM5	HIRHAM5	ECHAM5	A1B
ETHZ-CLM-HadCM3Q0	CLM	HadCM3Q0	A1B
KNMI-RACMO2-ECHAM5	RACMO2	ECHAM5	A1B
METO-HadRM3Q0-HadCM3Q0	HadRM3Q0	HadCM3Q0	A1B
MPI-REMO-ECHAM5	REMO	ECHAM5	A1B
SMHI-RCA-BCM	RCA	BCM	A1B
SMHI-RCA-ECHAM5	RCA	ECHAM5	A1B
SMHI-RCA-HADCM3Q3	RCA	HADCM3Q3	A1B
MPI-REMO-ECHAM5-r1	REMO	ECHAM5 - r1 BC	E1
MPI-REMO-ECHAM5-r2	REMO	ECHAM5 - r2 BC	E1
MPI-REMO-ECHAM5-r3	REMO	ECHAM5 - r3 BC	E1

Appendix 2

Table A2. Country codes

AT	Austria
BE	Belgium
BG	Bulgaria
CY	Cyprus
CZ	Czech Republic
DK	Denmark
EE	Estonia
FI	Finland
FR	France
DE	Germany
GR	Greece
HU	Hungary
IE	Ireland
IT	Italy
LV	Latvia
LT	Lithuania
LU	Luxembourg
MT	Malta
NL	Netherlands
PL	Poland
PT	Portugal
RO	Romania
SK	Slovakia
SI	Slovenia
ES	Spain
SE	Sweden
UK	United Kingdom

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Further information

To find out more about ClimateCost, please visit:
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