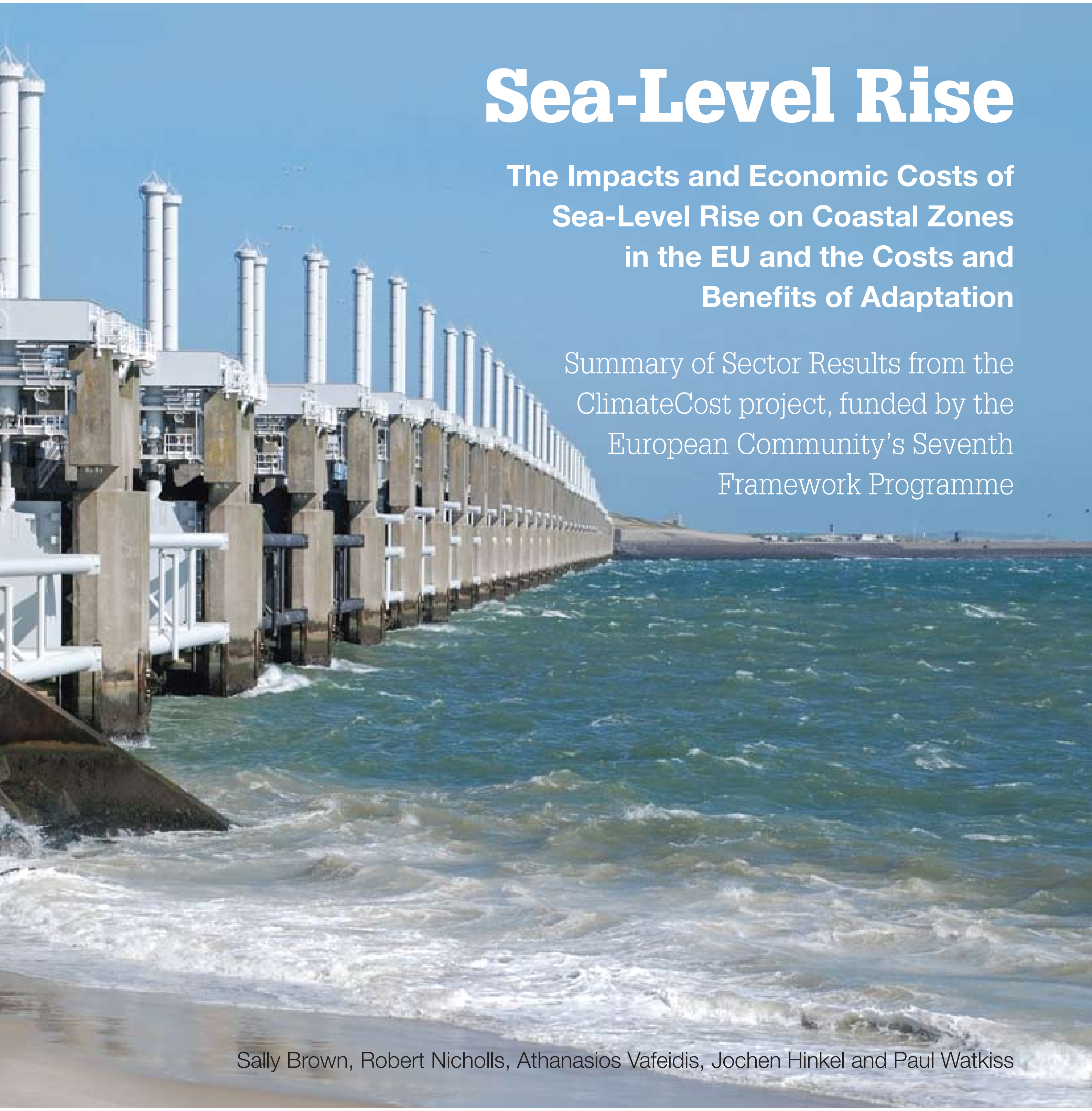
Technical Policy
Briefing Note

02



Sea-Level Rise

The Impacts and Economic Costs of Sea-Level Rise on Coastal Zones in the EU and the Costs and Benefits of Adaptation

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

Sally Brown, Robert Nicholls, Athanasios Vafeidis, Jochen Hinkel and Paul Watkiss

ClimateCost

SEVENTH FRAMEWORK PROGRAMME

EUROPEAN COMMISSION
European Research Area

Key Messages

- Coastal zones contain high population densities, significant economic activities and ecosystem services. These areas are already subject to coastal flooding and climate change has the potential to pose increasing risks to these coastal zones in the future. However, the effects of climate change need to be seen in the context of other socio-economic drivers.

- The ClimateCost study has assessed the potential impacts and economic costs of sea-level rise in Europe, and the costs and benefits of adaptation. The analysis used the Dynamic Interactive Vulnerability Assessment (DIVA) 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).

- For Europe, the mid-range projections for a medium-to-high emissions scenario (A1B(IMAGE)) suggest 37 cm of rise by the 2080s, though sea levels will also continue to rise into the 22nd century and beyond. Under an E1 mitigation scenario (stabilisation), which is broadly consistent with the EC's 2 degrees target, the rate of rise is reduced, with 26 cm projected by the 2080s. However, due to the thermal inertia of the ocean, the two scenarios do not diverge until the 2050s.

- **Under a medium to high emission (A1B(I)) scenario**, with no mitigation or adaptation, this study estimates that, annually, 55,000 people (mid estimate) in the EU could be flooded by the 2050s (the years 2041-2070) and, potentially, over 250,000 people by the 2080s (2071-2100). A further 438,000 people may need to move away from coastal areas because of annual flooding.

- This flooding, along with other impacts of sea-level rise (e.g. erosion), leads to high economic costs. The annual costs in Europe are up to €11 billion (mid estimate) for the 2050s, rising to €25 billion by the 2080s (combined effects of climate and socio-economic change, based on current prices, with no discounting). These costs include direct impacts, salinisation, costs of moving and land loss. Additional unquantified costs will occur due to ecosystem losses and possible knock-on effects of damage on supply chains.

55,000

projected number of people directly affected by coastal flooding each year by the 2050s (under the A1B scenario)

€11bn

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

€1.5bn

estimated annual incremental costs of adaptation for the 2050s (A1B)

- These impacts have a strong distributional pattern. Countries in north-west Europe have the greatest potential damages and costs, although many of these countries are the most prepared for climate change in the European Union.

- In addition, sea-level rise will affect coastal ecosystems. Wetlands act as natural flood barriers and feeding grounds, and have recreational value. The analysis has estimated that, by the 2080s, over 35% of EU wetlands could be lost unless protective measures are undertaken. Where hard defences are also present, coastal squeeze could result.

- It is stressed that there is a wide range of uncertainty around these mid estimates, reflecting the underlying uncertainty in the sea-level response to a given emissions scenario and temperature outcome. As an example, while the mid estimate of the number of people flooded in the 2080s is 250,000, and annual estimated damage costs are €25 billion, the ice melt response range varies between 121,000 and 425,000 people flooded, with annual damage costs of between €19 billion to €37 billion. An even wider range results when the uncertainty in projected temperature is considered. This uncertainty needs to be considered when formulating adaptation strategies.

- Under higher emission scenarios, there is also an increased risk of extreme sea-level rise, with some projections estimating over 1 m by 2100. The study has estimated the potential damage costs from such a scenario, and estimated this would increase the annual damage costs for the EU to €156 billion (undiscounted) by the 2080s – six times higher than that for the A1B scenario.

- **Under a stabilisation scenario broadly equivalent to the EU 2 degrees target**, these impacts are significantly reduced in Europe. Under this scenario, the estimated annual number of people flooded falls to 80,000 and the annual damage costs fall to €17 billion (mid estimates) by the 2080s. This mitigation scenario reduces the chance of extreme sea-level rise, an additional factor in the relative costs and benefits between the A1B and E1 (stabilisation) scenarios.

The study has also assessed **the costs and benefits of adaptation**.

- Hard (dike building) and soft (beach nourishment) adaptation greatly reduces the overall cost of flood damage. The annual cost of adaptation has been estimated at €1.5 billion in the 2050s (EU, current prices, undiscounted), and achieves a benefit-to-cost ratio of 6:1 (A1B(I) mid scenario). The benefit-to-cost ratios increase throughout the 21st century. However, hard defences need ongoing maintenance to operate efficiently and to keep risk at a low or acceptable level. As the stock of dikes grows throughout the 21st century, annual maintenance costs could approach or exceed annual incremental costs.

- 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). Other adaptation options not used in the model may be more costly, but more effective in reducing flood risk. Sea-level rise should be anticipated and planned for in adaptation policies.

- The climate and socio-economic uncertainty makes 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. Climate change is only one aspect of coastal management policy in the EU and adaptation to it needs to be positioned within a broader integrated coastal-zone management policy framework.

- Mitigating for climate change by reducing the rate of sea-level rise is likely to decrease wetland loss, those at risk from flooding, damage costs and subsequent adaptation costs. Mitigation, as opposed to hard adaptation, benefits the natural environment as habitats and ecosystems are allowed a greater time to respond to a challenging environment and climate.

- These results reinforce the message that the most appropriate response to sea-level rise for coastal areas is a combination of adaptation to deal with the inevitable rise and mitigation to limit the long-term rise to a manageable level. More detailed, local-scale assessments are required to assess and reduce risk to vulnerable areas, including adaptation plans.

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 and analysis of adaptation 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 a European-wide assessment of the impacts and economic costs of sea-level rise (SLR) as part of the ClimateCost project, and the analysis of the costs and benefits of adaptation. While coastal floods and flooding around estuaries are covered in this TPBN, inland river flooding is covered in TPBN 3.

1.1 Background

The coastal zones of the European Union[2] (EU) contain large human populations and significant socio-economic activities (Nicholls et al., 2007). They also support diverse ecosystems that provide important habitats and sources of food, and provide other ecosystem services. Many of these habitats are designated under the EU Habitats Directive and other protective legislation.

These areas are already subject to coastal flooding and this will continue to occur in the future even without climate change. However, over the next century and beyond, climate change is expected to bring warmer temperatures and global sea levels are expected to rise, posing increasing risks to coastal zones.

In the European Union, some coastal areas are already well protected against rising sea levels (e.g. the low-lying sections of the North Sea coast such as the Wadden Sea or around the Thames Estuary). However, other coastal zones have far less protection and lower awareness of sea-level rise, such as those of Bulgaria or Romania (Tol et al., 2008).

2. Sea-level rise and socio-economic projections

Sea levels have been changing naturally for thousands of years, from geological changes causing natural subsidence or uplift (in response to the melting of large ice sheets from the last ice age or tectonic changes) and natural climatic variability. However, during the 20th century, global sea levels rose 1.7 ±0.3 mm/year (Church and White, 2006). Between 1993 and 2009, the estimated rate of sea-level rise was 3.2 ±0.4 mm/year from satellite data, and 2.8 ±0.8 mm/year from in-situ measurements such as tide gauges (Church and White, 2011). The Intergovernmental Panel on Climate Change (IPCC, 2007) states that human influences are very likely to have contributed to a rise in sea level during the second half of the 20th century. Thus, there is clear evidence that sea levels have been rising and this continued rise will have implications for natural and human environments.

Climate change, and the associated rise in global mean temperature, is projected to lead to accelerated sea-level rise over the 21st century. This is caused by: the increase in global ocean volume due to thermal expansion from oceanic temperature and salinity changes; and the additional melting of land-based ice caps and glaciers, and the ice sheets of Greenland and Antarctica. In the IPCC Fourth Assessment Report (AR4), sea-level rise of 0.18 m to 0.59 m was projected by the end of the 21st century (for the period 2090-2099 relative to 1980-1999) (Meehl et al., 2007).

While thermal expansion forms the major part of the IPCC standard projections, the IPCC additionally noted a limited understanding of, and modelling capability for, any potential contribution of future accelerated ice-sheet dynamics to sea-level rise. Therefore, this process is not included in

---

[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 Sally Brown and Robert Nicholls from the University of Southampton and the Tyndall Centre for Climate Change Research (UK), Athanasios Vafeidis from the University of Kiel (Germany), Jochen Hinkel from Potsdam Institute for Climate Impact Research and European Climate Forum (Germany) and Paul Watkiss from Paul Watkiss Associates (UK). The citation should be: Brown S, Nicholls RJ, Vafeidis A, Hinkel J, and Watkiss P (2011). The Impacts and Economic Costs of Sea-Level Rise on Coastal Zones in the EU and the Costs and Benefits of Adaptation. Summary of Results from the EC RTD ClimateCost Project. In Watkiss, P (Editor), 2011. The ClimateCost Project. Final Report. Volume 1: Europe. Published by the Stockholm Environment Institute, Sweden, 2011. ISBN 978-91-86125-35-6.

[2] The coastline of the European Union is defined as: Belgium, Bulgaria, Cyprus, Denmark, Estonia, Finland, France, the UK, Germany, Greece, Ireland, Italy, Latvia, Lithuania, Malta, Netherlands, Poland, Portugal, Romania, Slovenia, Spain, Sweden and the United Kingdom (UK). For the UK, only England, Scotland, Wales and Northern Ireland have been considered. France comprises mainland France, and overseas departments (including Guadeloupe, French Guiana, Martinique, Reunion, Mayotte). Denmark excludes Greenland and Faroe Islands. This creates a total coastal length of 68,200km.

its standard projections. However, an illustrative example of how such an additional contribution from ice-sheet melt might scale under global warming is included. This potentially increases the upper end of the IPCC predictions to 0.76 m by the 2090s.

In the assessment of the future damages of climate change, assumptions have to be made about future conditions, which require climate and socio-economic scenarios. In scientific terms, a scenario is a plausible future ('storyline') of environmental and anthropogenic change as informed by expert judgement, but it does not mean that this future will necessarily occur. The most widely used are the emissions scenarios of the IPCC Special Report on Emission Scenarios (the SRES scenarios, Nakicenovic et al., 2000). These define a set of future self-consistent and harmonised socio-economic conditions and emissions 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 a number of 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 global and recent European regional climate modelling studies, notably in the ENSEMBLES study (van der Linden and Mitchell, 2009). For this reason, it was also used in ClimateCost. For sea-level rise, the analysis used the ENSEMBLES A1B(IMAGE) scenario (shortened name in this report to A1B(I)). It reflects a medium-high emissions trajectory and leads to central estimates of global average surface temperatures that are greater than 2°C relative to pre-industrial levels[3].

The second is the ENSEMBLES E1 scenario (van der Linden and Mitchell, 2009: Lowe et al., 2009a), which leads to long-term stabilisation of greenhouse gas concentrations at 450 ppm (assuming a peak of 535 ppm in 2045, stabilising to 450 ppm by 2140). For this scenario, global mean temperatures have a higher probability of remaining below 2°C (compared to pre-industrial levels) than those in A1B(I). It should be noted that temperatures have already risen 0.7°C higher than pre-industrial levels (van der Linden and Mitchell, 2009).

The third is a high sea-level rise scenario, which was undertaken as a sensitivity study to reflect the emergence of literature (post IPCC) that greater increases than reported by Meehl et al., (2007) could be possible. This is based on the trajectories of Rahmstorf (2007).

Further details about the first two scenarios and the associated temperature changes are outlined in TPBN1 'Climate Models'.

2.1 Generating sea-level-rise scenarios

A rise in sea levels due to climate change is normally discussed as a global mean. However, observations indicate that global variations occur and there are some places around the world that experience higher-than-average sea-level rise, whereas others experience a lower-than-average rise. An example of local sea-level trends based on historical data records is shown in Figure 1. Around Europe's seas, trends in changes in mean sea-level anomalies range from 1.4 ±0.4 mm/year to 2.9 ±0.4 mm/year (1992-2010)[4].

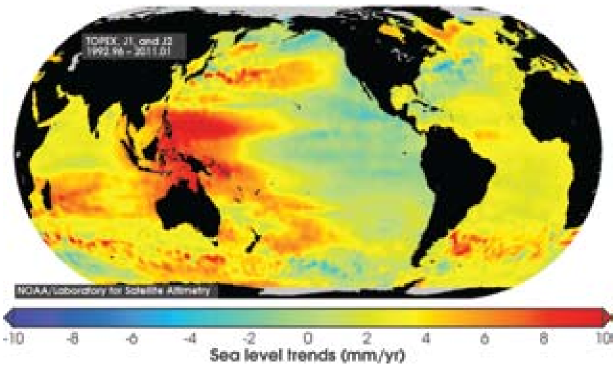
In modelling future climate-change-induced sea-level rise, a 'pattern' of sea-level rise should be used indicating where there are regions of higher and lower rise, rather than a single, global value. Patterns of sea-level rise can change over time and with different scenarios. Impact studies based on patterns of sea-level rise rather than a global mean are therefore more realistic. However, patterns have often not been used in analyses of coastal zone impacts due to the complexity of creating scenarios for impact models. Their use in this study provides a novel aspect to this project. Further details on the methodology used for creating the sea-level rise projections used here are given in Pardaens et al., (2011).

---

[3] The IPCC AR4 (IPCC, 2007) reports that the best estimate of global surface temperature change from the A1B scenario is 2.8°C by 2090 – 2099, relative to 1980-1999, with a likely range of 1.7°C to 4.4°C (noting that that temperatures have increased by about 0.74°C between 1906 and 2005, thus making a similar rise to the ENSEMBLES projection).

[4] Altimetry data provided by the NOAA Laboratory for Satellite Altimetry. See http://ibis.grdl.noaa.gov/SAT/SeaLevelRise/LSA_SLR_maps.php for further details.

Figure 1. Annual global sea-level rise estimated from global trends from satellite altimetry data from 1992 to 2010 (local trends were estimated using data from TOPEX/Poseidon (T/P), Jason-1, and Jason-2). Altimetry data provided by the NOAA Laboratory for Satellite Altimetry. See http://ibis.grdl.noaa.gov/SAT/SeaLevelRise/LSA_SLR_maps.php for further details



In the other sectoral assessments (e.g. for inland floods, energy, agriculture), the ClimateCost study uses the direct climate model outputs from the ENSEMBLES project. However, these models do not include sea-level rise projections. To create sea-level scenarios using the methodology described in the IPCC Fourth Assessment report (Meehl et al., 2007), two outputs from climate models are required (along with other model parameters - see Meehl et al., (2007)):

- Thermal expansion (the increase in water volume (represented in mm) due to rising temperatures).
- Changes in surface air temperature (to calculate the contribution of land-based ice).

While temperature is a common output available in the ENSEMBLES dataset in all models, thermal expansion is not. This has limited the model choice. In the ClimateCost project, patterned sea-level rise scenarios were provided by the UK Met Office Hadley Centre from the multi-model climate experiment from the European Commission ENSEMBLES project (Lowe et al., 2009a). The Hadley Centre's HadGEM-A0 model was used to create the sea-level scenarios.

Sea-level rise at any particular location generally differs from the global mean value, because of an interplay between ocean circulation and subsurface density changes. These differences create a pattern of sea-level rise. Models tend to give a fairly wide range of projected pattern changes, albeit with some common features, giving additional uncertainty in projected local sea-level rise. In this project, the time-evolving projected sea-level rise from one particular model is used.

The other contribution to sea-level rise, based on temperature projections, is that of land-based ice from glacier, ice caps (smaller tongue-shaped ice found mostly in mountainous regions) and ice sheets (the large expanses of ice in Greenland and Antarctica). There is much uncertainty in the magnitude of ice melt during the 21st century because, based on observations throughout the 20th century, scientists are unsure about the rate at which ice will melt. Therefore, a range of uncertainty is used in the treatment of land-based ice melt (Gregory and Huybrechts, 2006; Meehl et al., 2007). For ice melt, a uniform sea-level rise is assumed. However, in reality, there will be areas with higher and lower ice melt compared with the global mean. This is known as glacier isostatic adjustment (GIA) fingerprinting. It is not included in the projections as the scenarios are not yet advanced enough to capture this change. Thermal expansion and ice melt have been combined to create total sea-level rise.

The scenarios generated only indicate a time-mean rise in sea level and do not include any change in storm surges (storminess). Storminess has the potential to occur with climate change. This follows 20th century observations (Menéndez and Woodworth, 2010).

2.2. Future time periods

The assessments here consider the future projected impacts of climate change, set against a modelled baseline between 1980 and 1999. 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, and longer term, more significant, changes that can help inform mitigation. The ClimateCost study has considered three future time-slices to 2100: the 2020s (i.e. 2011-2040)[5]; 2050s (i.e. 2041-2070); and 2080s (i.e. 2071-2100).

---

[5] The climate change signal, particularly for sea-level rise, 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. This means that extreme weather conditions will continue to occur in the short term leading to potential flooding. However, over the medium- to long-term, natural variability combined with sea-level rise will, potentially, make impacts worse.

2.3 Uncertainty

Even for a given future emissions scenario, there is a wide range of possible effects, reflecting the underlying uncertainty in the climate response. The ClimateCost project has ensured that all sector assessments take into account, and report on, this uncertainty. For a given global temperature rise, a range of sea-level rise is possible, which reflects uncertainty in ice melt (see Section 2.1).

For the ClimateCost project, only one temperature profile has been used for projections (the HadGEM-A0 model). The relationship between temperature rise and sea-level rise is complex due to differences in thermal expansion and its pattern, and the melting of land-based ice (Brown et al., in prep). A multi-model impacts assessment with many temperature profiles could potentially increase the range of estimated sea-level rise due to the contribution of land-based ice, and include uncertainties associated with the range of thermal expansion and changes in the sea-level patterns. Therefore, it is stressed that the coastal results reported in this TPBN do not cover the same climate model and temperature spread as for other sectors. These have used alternative global or regional climate model outputs and, therefore, report the uncertainty in projected temperature increases across the multi-model ensemble range. This is important when directly comparing the range reported across sectors. However, a low rise in temperature may not always be associated with a low rise in sea level due to the relative proportions of thermal expansion and land-based ice to sea-level rise (Brown et al., in prep).

This study has used a range of sea-level rise projections, where the upper and lower limits are represented by the 95% and 5% uncertainty levels due to the contribution of land-based ice (following IPCC convention). The mid-point of projections is also reported (Table 1). The A1B(I) scenario is associated with a 3.5°C rise in the 2080s and the E1 scenario a 1.5°C rise by the 2080s. A scenario of no sea-level rise (No SLR) is used as a baseline case. However, in reality, even if emissions stopped today, sea levels would continue to rise due to the heat inertia already present in the ocean system. Sea-level rise projections for the A1B(I) scenario in Table 1 are slightly higher than the equivalent A1B scenario presented in Meehl et al., (2007) because the scenarios are based on different concentrations of greenhouse gases, which affect the rate of temperature rise and, therefore, sea-level rise.

Table 1. Global mean sea-level rise (m) for the scenarios studied for short (2020s), medium (2050s) and long (2080s) timeframes to be explored in ClimateCost

	2020s	2050s	2080s
A1B(I) (95%)	0.12	0.27	0.46
A1B(I) (Mid)	0.10	0.22	0.37
A1B(I) (5%)	0.07	0.17	0.28
E1 (95%)	0.11	0.23	0.33
E1 (Mid)	0.09	0.18	0.26
E1 (5%)	0.07	0.13	0.18
No SLR	0.00	0.00	0.00

A changing climate is not the only driver of sea-level change. Geological changes (e.g. subsidence or tectonic movements) need to be combined with the projected sea-level rise due to climate change to measure the relative sea-level rise (RSLR). Natural subsidence is occurring locally in coastal lowlands such as the Netherlands and the Northern Adriatic Coastal Plain in Italy, and this is considered in the Dynamic Interactive Vulnerability Assessment (DIVA) Model analysis presented below. Additional non-climatic factors may also be important, such as human-induced subsidence (due to groundwater extraction), though these are not considered here due to a lack of consistent global data and models. Generally, these effects are not as important in Europe as they are in other world regions, notably east, south-east and south Asia (Nicholls et al., 2008).

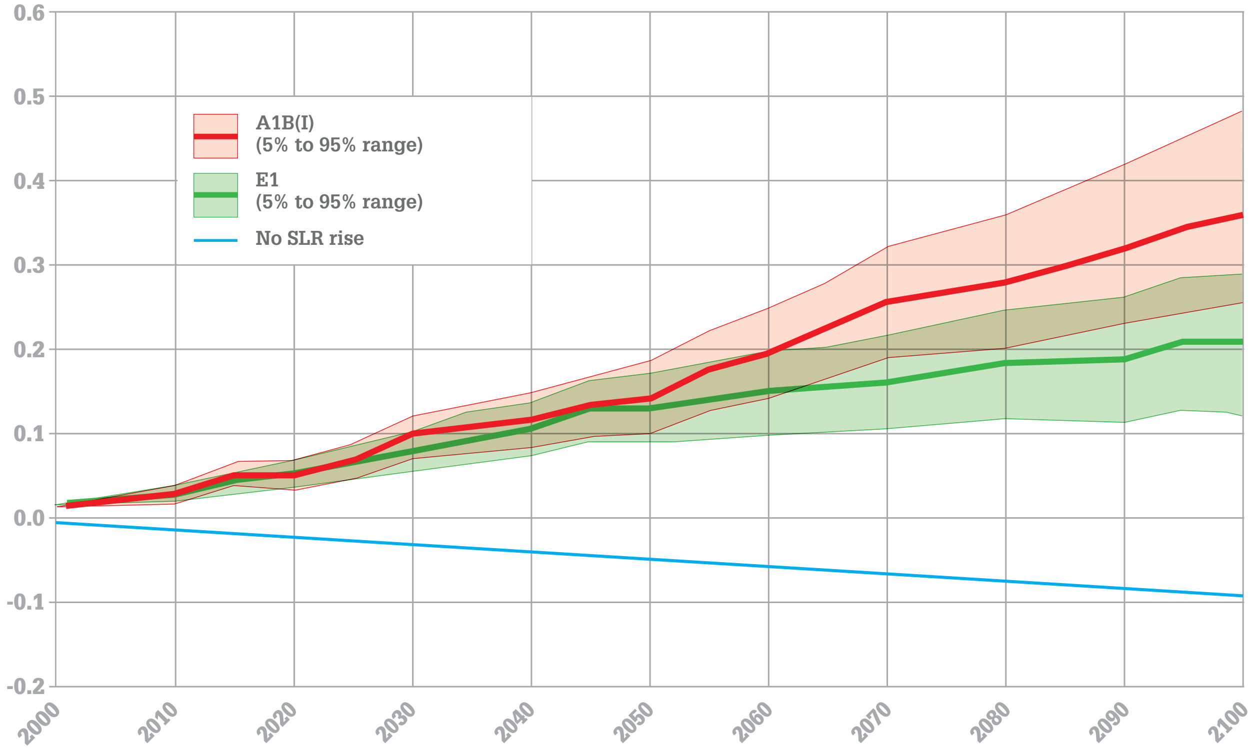
The average RSLR for Europe is presented in Figure 2 (where land-based movements are combined with sea-level rise). For the A1B(I) and E1 scenarios, RSLR is similar until the 2050s and then diverges. By the 2080s, RSLR is projected to be between 0.23 m and 0.40 m for the A1B(I) scenario, and 0.12 m and 0.26 m for the E1 scenario. With the E1 scenario, sea-level rise appears to stabilise, not decelerate, which is consistent with the commitment to sea-level rise and the findings of Nicholls and Lowe (2004). Beyond the 2080s, sea levels are expected to continue to rise independent of subsequent emissions (Nicholls and Lowe, 2004), but this effect is not evaluated further here. For the No SLR scenario (i.e. a baseline scenario of no climate change), it is estimated that relative sea levels would, on an average for geographical Europe, fall by 0.08 m by 2100 due to a net rise in land levels. There are marked variations around this relative value, with land uplifting in northern Scandinavia, but sinking in southern Europe, particularly in deltaic regions. For instance, tide-gauge records over the past century (and more) indicate a decline in relative sea levels in Oulu, Finland at 6.3 mm/year, whereas in Varna, Georgia relative sea levels have been rising at 2.0 mm/year (Proudman Oceanographic Laboratory, 2010). Even for a scenario of No SLR, impacts would still be expected to occur due to local changes in subsidence/uplift and changes in population density.

In comparison with measured tide-gauge and satellite data (with a global average of 1.4 ±0.4 mm/year from tide-gauge measurements from 1990-2009 (Church and White, 2011)), the projections are at the lower end of this range. However, in the last two decades (1993-2009), a higher rise of mean sea level (3.2 ±0.4 mm/year) has been recorded, which is at the upper end of the A1B(I) and E1 range. With spatial variations (see Figure 1) and the need to measure rises in sea level over many decades to a century to better quantify the effects of any unforced variability, short-term measurements cannot be relied upon to fully and accurately represent long-term change.

The magnitude of future sea-level rise is uncertain. There are considerable differences between emissions scenarios, temperature outcomes and the sea-level response

Finally, sea-level rise is only one source of uncertainty. Other sources of uncertainty in the coastal model (e.g. surge heights, topographic model), socio-economic projections (e.g. changes to population, population density and gross national product) and economics (e.g. exchange rates, discount rates) have not been investigated.

Figure 2. Average relative global sea-level rise for the A1B(I), E1 and No SLR climate scenarios. The uncertainty range (5% to 95%) shown in the figure is associated with the ice melt response to a single temperature profile over time. A multi-model climate analysis with a range of temperature profiles (as used in other sectors in ClimateCost) would expand the range of estimated sea-level rise from that shown.



2.4 Socio-economic scenarios and data

In absolute terms, socio-economic change can, potentially, be as important as future climate change in determining impacts and economic damage costs on the costs and benefits of adaptation. While including these effects is challenging, they need to be considered across the timeframes of interest here, otherwise this implies that projected future climates will take place in a world that is similar to today. One of the aims of the ClimateCost project has been to apply consistent climate and socio-economic scenarios across sectors to ensure comparability across the study. Therefore, coastal zone analysis includes projections of socio-economic drivers in the analysis below, including future population and per-capita incomes in Europe.

The primary drivers of modelled socio-economic change include economic growth and demographic change (population). In the socio-economic scenarios, European Union countries are divided into three geographical regions (Organisation for Economic Co-operation and Development (OECD)[6] Europe, Eastern Europe[7] and the former USSR[8] countries). All countries experience gross domestic product (GDP) growth through the 21st century (Table 2). However, regions experience these socio-economic changes at different rates as they are driven by different politics, policies and economies. For the A1B scenario, the population grows until mid century before declining. For the E1 scenario, the population remains stable or experiences a small decline until the 2020s (Eastern Europe), 2040s (former USSR) and 2060s (OECD Europe) before more rapidly declining (Table 3). In terms of physical impacts, previous research (e.g. Nicholls et al., 2010) indicates that, due to the small magnitude of relative population change between these regions, this will probably have a smaller impact than the rate of sea-level rise on a European scale.

Table 2. GDP projections (billions of Euros) of EU countries in the three regions for short (2020s), medium (2050s) and long (2080s) timeframes

	2020s		2050s		2080s	
	A1B	**E1**	**A1B**	**E1**	**A1B**	**E1**
Eastern Europe	1,090	640	3,022	2,346	4,901	4,285
Former USSR	100	53	402	279	837	677
OECD Europe	17,588	14,250	29,566	25,128	48,101	40,883
EU total	18,778	14,943	32,990	27,753	53,838	45,844

Table 3. Population projections for EU countries in the three regions (millions of people) - for short (2020s), medium (2050s) and long (2080s) timeframes

	2020s		2050s		2080s	
	A1B	**E1**	**A1B**	**E1**	**A1B**	**E1**
Eastern Europe	73	70	66	65	56	57
Former USSR	8	8	8	8	7	7
OECD Europe	403	387	403	406	385	397
EU total	484	465	477	479	448	461

---

[6] Organisation for Economic Co-operation and Development. Contains EU countries: Belgium, Cyprus, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Malta, Netherlands, Portugal, Spain, Sweden and the UK.

[7] Bulgaria, Poland, Romania, Slovenia.

[8] Estonia, Latvia, Lithuania.

2.5 Separating climate and socio-economic signals

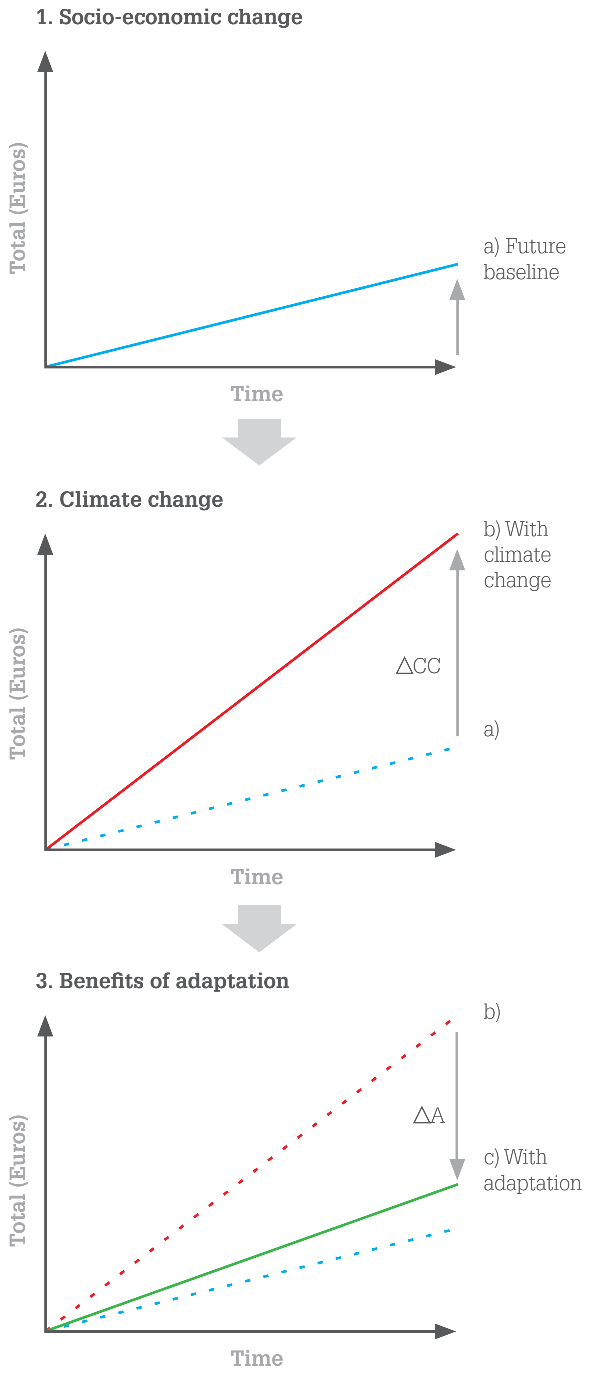
In the ClimateCost project, the analysis has separated the socio-economic and climate components of future impact, to identify the 'net' effects of climate change, rather than reporting the 'gross' impacts of climate and socio-economic change together. It has been done in this way because the future impacts from socio-economic change would have occurred even in the absence of climate change.

For this reason, the analysis in the sections below first considers a scenario of No SLR as a baseline (i.e. which shows the level of change that would occur in the absence of climate change). This is also included in the analysis of adaptation and is important in allowing the 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. The analysis then considers the combined effects of socio-economic and climate change. Strictly speaking, only the marginal (or net) increase above the socio-economic baseline is attributable to climate change, though adaptation is needed to address the combined effects. Finally, the effects of adaptation in reducing future impacts are considered, though noting that there are still residual damages even with adaptation. These three steps are shown in Figure 3.

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

Consistent with all sector-based analysis in ClimateCost, the economic valuation results below are presented in terms of constant 2005 prices in Euros 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 from the DIVA Model in this TPBN refer to the undiscounted equivalent values, not the discounted annualised values. It should also be noted that the model presents annual costs for capital adaptation in a similar format.

Figure 3. Outline and steps of stylised framework relating with socio-economic change, then building on climate change and realising the benefits of adaptation (adapted from Boyd and Hunt, 2006).



1. Socio-economic change

2. Climate change

3. Benefits of adaptation

However, the use of the values in subsequent policy analysis (e.g. in looking at the costs and benefits of adaptation options to reduce these impacts), would need to work with present values (i.e. values that are adjusted and discounted as with standard economic appraisal). This analysis is included in other parts of the ClimateCost study (see Volume 2 of the study results).

A number of other notes on valuation are also highlighted. The analysis applies unit values for the impact categories covered, which evolve with the population and GDP scenarios. The values presented represent direct costs only. They do not consider the wider economic costs associated with damage costs or adaptation, nor do they consider potential feedbacks on price levels and demand, though this analysis is included in the Computable General Equilibrium analysis in ClimateCost (see Volume 2 of the study results). Finally, the analysis does not consider how values may change in cases where there are non-marginal effects (i.e. impacts that are so large that the unit values for land damage are no longer applicable: noting this could be relevant for the high (Rahmstorf, 2007) sea-level rise scenario).

3. Methodology

To establish coastal change from rising sea levels, the DIVA Model (Hinkel, 2005; Vafeidis et al., 2008; Hinkel and Klein, 2009; http://diva-model.net) was used to assess impacts and adaptation to sea-level rise. The DIVA Model comprises 12,148 linear segments and associates about 100 pieces of data with each of these segments. The data provide information on the physical ecological and socio-economic characteristics of the coast. The segments have a variable length (mean average is 45 km), with over 1,500 segments in the EU. The DIVA Model downscales the global sea-level rise scenario using local estimates of natural uplift/subsidence to calculate relative sea-level rise for each segment. This is combined with storm surge data and socio-economic change. Flood and submergence of the coastal zone is calculated, along with their impacts and associated economic costs.

For the sea-level scenarios listed in Table 1, the analysis considered the following parameters:

- The number of people at risk from flooding due to extreme sea levels[9]. This is defined as the expected number of people subject to annual flooding due to submergence and assuming those subjected to a 1-in-1 year flood migrate from the coastal zone (people/year).
- The number of people who would be forced to move due to submergence subjected to a 1-in-1 year flood (cumulative number with respect to 1990 baseline).
- The total annual damage cost in Euros (2005 prices). This includes the number of people forced to move due to erosion and submergence (assuming the cost for people that move is three times the value of their per-capita GDP (Tol, 1995)), land-loss costs (land below the 1-in-1 year flood level) taking into account dikes and direct erosion ignoring nourishment, salinisation costs, and the expected costs of sea floods and river floods.
- The total annual capital adaptation cost in Euros (2005 prices). This includes the sum of sea dikes, river dikes and beach nourishment. Dikes are constructed where population density is greater than 1 person/km^2 and is thereafter based on a demand for safety. Therefore, the higher the population density, the greater the protection.
- Total area of wetland loss expressed as a percentage relative to wetland area in 1990. Wetlands comprise saltmarsh, freshwater marsh, mangroves, low and high unvegetated wetlands (noting some types may only be present in EU territories overseas). The emergence of new wetlands is not taken into account.

While the DIVA Model is fairly comprehensive compared with other models, it does not include all the potential impacts of sea-level rise. A note on the impacts included and not included is shown in Table 4. This is key in interpreting the overall values presented in this TPBN (i.e. to some extent, the reported effects are a sub-total of overall impacts and economic costs). The analysis also does not include any autonomous adaptation.

The results presented, illustrate these impacts for the total relative sea-level rise (i.e. not the climate-change-only component of coastal change). These costs are controlled by the relationship between the magnitude of relative sea-level rise and the changes to the population and GDP.

[9] An extreme sea level that would be expected to occur up to once every 1,000 years. With rising sea levels, extreme water levels would be expected to occur more often.

Table 4. Major coastal impacts and other parameters included and excluded in the analysis

Impacts	Included
Coastal flooding: People at risk from flooding	✓ yes
Coastal flooding: Number of people to move	✓ yes
Coastal flooding costs:	
• Flood damage due to sea and coastal river flooding.	✓ yes
• Land loss (erosion and submergence).	✓ yes
• People to move.	✓ yes
• Salinisation.	✓ yes
Area of wetland and coastal ecosystem loss (including coastal squeeze to intertidal areas)	✓ yes
Health impacts of flooding (direct and indirect including wellbeing)	Included in the health sector
Tourism and culture	✗ no
Port infrastructure and port activities	✗ no
Wider effects on marine environment including fisheries	✗ no
Effect of increased storminess	✗ no scenarios considered
Adaptation costs: Hard defences (dikes)	✓ yes
Adaptation costs: Soft defences (beach nourishment)	✓ yes

The costing procedure follows standard methods described by Hinkel et al., (in preparation) and Tol et al., (in preparation). The costs are presented here in 2005 Euros, with no additional adjustment or discounting. With adaptation, two approaches are used as listed in Table 5.

The results are first presented for the future projections, with no upgrade to protective measures, followed by impacts if defences are upgraded following a cost-benefit analysis, including the economic costs of adaptation.

Table 5. The two approaches of adaptation used in this study.

Approach to adaptation	Description
No upgrade in adaptation measures	Defences are initiated at a 1995 baseline on a demand for safety method and maintained at this level. There is no beach nourishment. Capital costs are zero.
Cost-benefit analysis of adaptation	After initialisation, defences continue to be constructed and increase in height based on a cost-benefit analysis. Defences include capital costs of river and sea dikes, plus beach nourishment.

4. Results – impacts and economic costs of sea-level rise

4.1 People at risk from flooding (assuming no upgrade of protection)

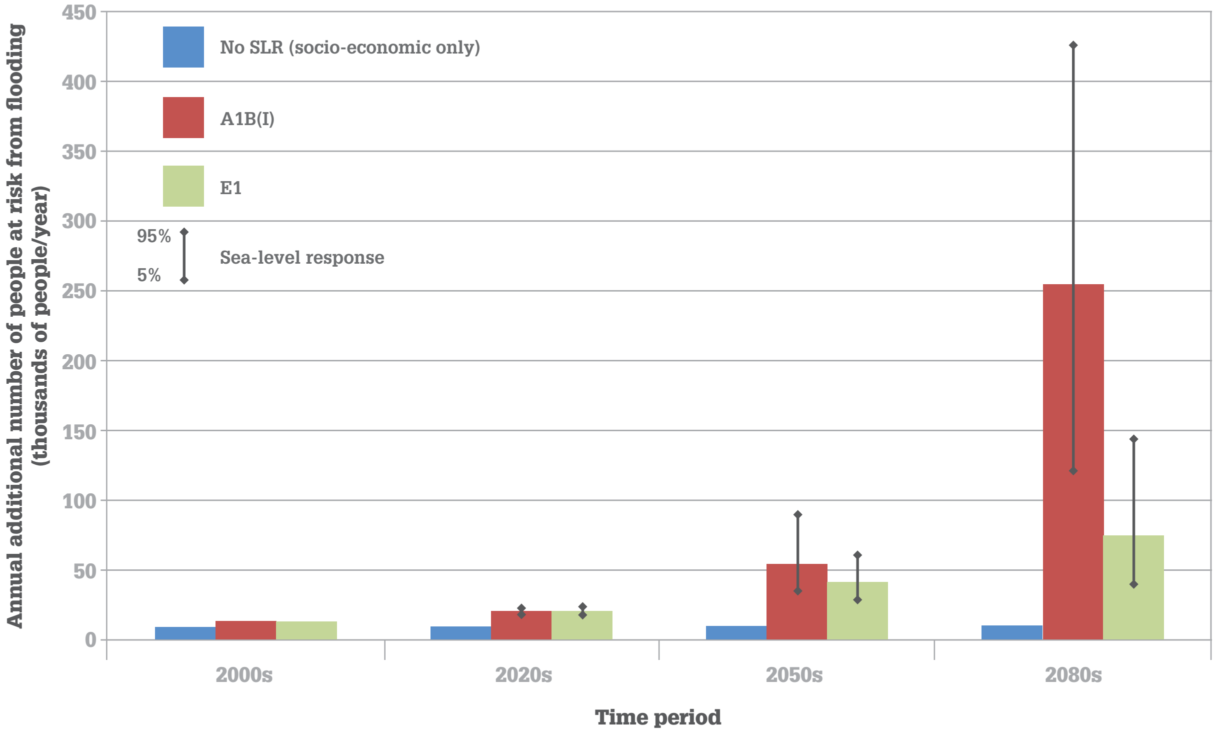
Figure 4 illustrates the average number of additional people at risk from extreme water levels in the EU for the three sea-level rise scenarios (i.e. A1B(I), E1 and No SLR) assuming that protection is not upgraded throughout the 21st century (with respect to 1995 levels). The figure includes the modelled uncertainty, based around sea-level rise projections (see Section 2.3). A No SLR scenario is presented to indicate differences between a climate-change scenario and a no climate-change scenario. As with the climate-change scenarios, the value of the No SLR scenario changes for each time period due to socio-economics.

Under a scenario of No SLR, around 10,000 additional people would be flooded annually for any time period studied (Figure 4). This suggests that the assumed baseline (1995) standards of coastal protection would still be sufficient protection for most of Europe by the end of the 21st century (although spatial variations around the EU would exist).

In the 2020s, the number of people at risk is similar for the A1B(I) and E1 scenarios, with a range of between 18,000 and 24,000 additional people/year. From the 2050s, the difference in the magnitude of sea-level rise between the scenarios diverges. Therefore, so does the number of people at risk. Absolute numbers of people flooded annually increase, despite scenarios of declining population in Europe (see Table 3).

In the 2080s, for the A1B(I) scenario, between 121,000 to 425,000 additional people (to 1990 levels) would be expected to be flooded each year – the vast majority (over 98%) due to climate-change-induced sea-level rise. For the E1 scenario, this falls to between 40,000 to 145,000 additional people each year – with over three quarters of this number due to climate-change-induced sea-level rise. Thus, when comparing the range of scenarios, a climate stabilisation strategy consistent with the EU's 2 degrees target could potentially reduce the number of people flooded annually by 280,000 by the 2080s. However, significant impacts still occur on this mitigation trajectory.

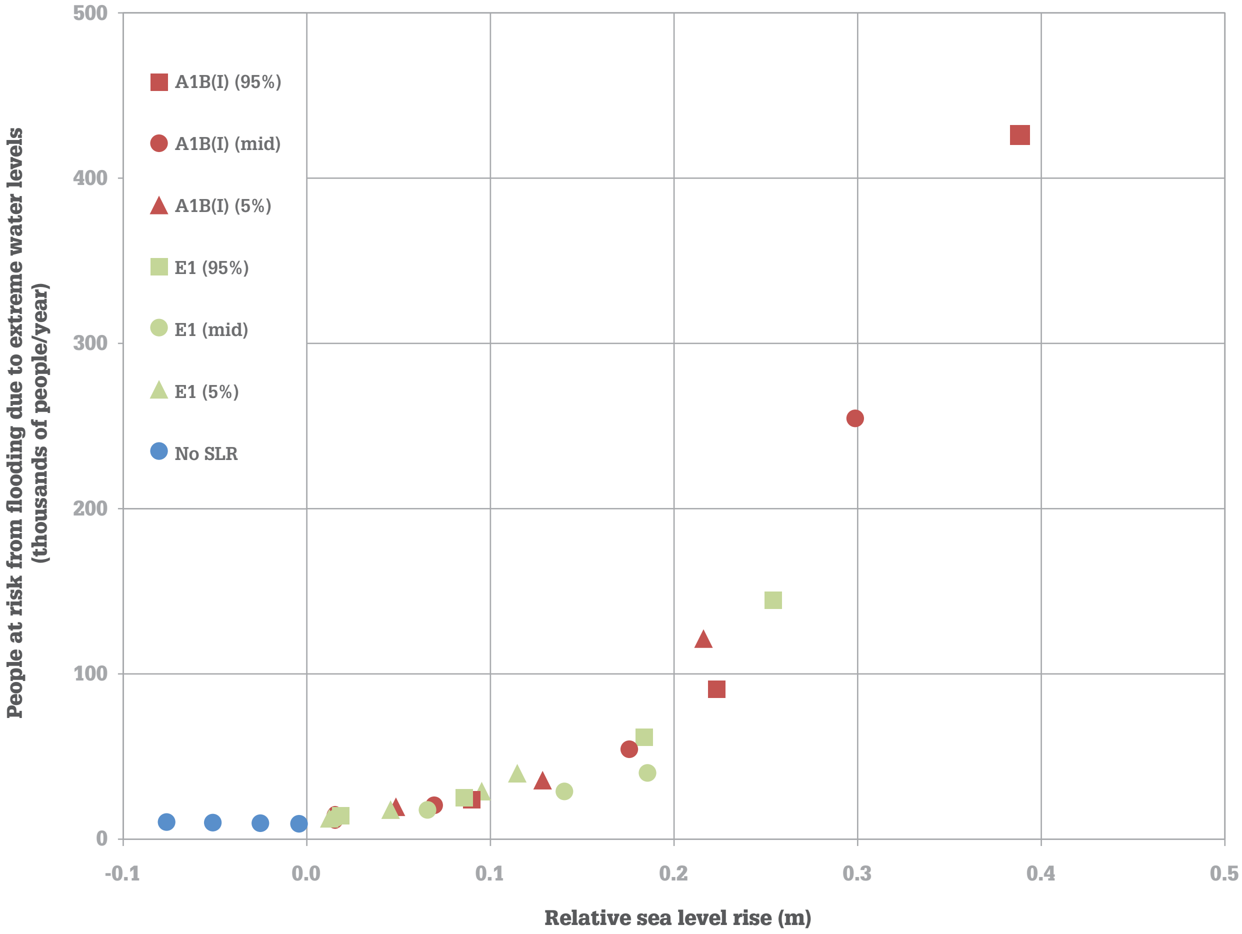
Figure 4. Annual number of additional people at risk (in thousands compared with 1990 levels) from extreme water levels for the EU for the A1B(I), E1 and No SLR scenarios throughout the 21st century (relative to 1995) assuming no upgrade in protection. Numbers reported for A1B(I) and E1 include the combined effects of sea-level rise and socio-economic change. The effects of future socio-economic change (without future climate change) can be seen with the No SLR scenario. The increases above this reflect the marginal economic costs directly attributable to climate change. The uncertainty range (5% to 95%) shown is associated with the ice melt response to a single temperature profile over time. A multi-model climate analysis with a range of temperature profiles would expand the range of estimated sea-level rise from that shown.



The number of additional people at risk from flooding is estimated at 250,000/year in the 2080s under the A1B mid-range value

Figure 5 presents the average annual number of additional people at risk (compared with 1990 levels) from extreme water levels in Europe for the three sea-level rise scenarios (and their associated uncertainty), assuming that protection is not upgraded throughout the 21st century. It differs from Figure 4 as it shows the people at risk as a function of relative sea-level rise rather than time. The figure shows that the number of people at risk from flooding increases exponentially with relative sea-level rise, particularly after 0.2 m (corresponding with the 2050s in Table 1). At this point, a doubling of relative sea-level rise to 0.4 m (time independent) is estimated to potentially increase the exposure more than six-fold, despite a falling population in Europe after 2050. If coastal populations remain stable, the impacts would be higher than reported here.

Figure 5. Annual number of additional people at risk (in thousands compared with 1990 levels) from extreme water levels for the EU for the A1B(I), E1 and No SLR scenarios throughout the 21st century assuming no upgrade in protection, plotted as a function of relative sea-level rise. Numbers reported for A1B(I) and E1 include the combined effects of sea-level rise and socio-economic change. The uncertainty range (5% to 95%) shown is associated with the ice melt response to a single temperature profile over time. A multi-model climate analysis with a range of temperature profiles would expand the range of estimated sea-level rise from that shown.



4.2 People who move due to land submergence and flooding

When people are subject to regular annual flooding (defined as greater than a 1-in-1 year flood), there is an incentive to move away from the coastal zone. These people are classified here as 'people who move'. Figure 6 illustrates the cumulative sum of people who move due to land submergence caused by rising sea levels since the 1990 baseline. Until the 2080s, the number of people who move remains low, at fewer than 10,000 people (since 1995). In the 2080s and as sea levels rise more than about 0.30 m, the number of people who move increases rapidly, despite falling populations (see Table 3). A 0.46 m rise in sea level could potentially cause nearly 440,000 people to move due to regular submergence of the land by the 2080s.

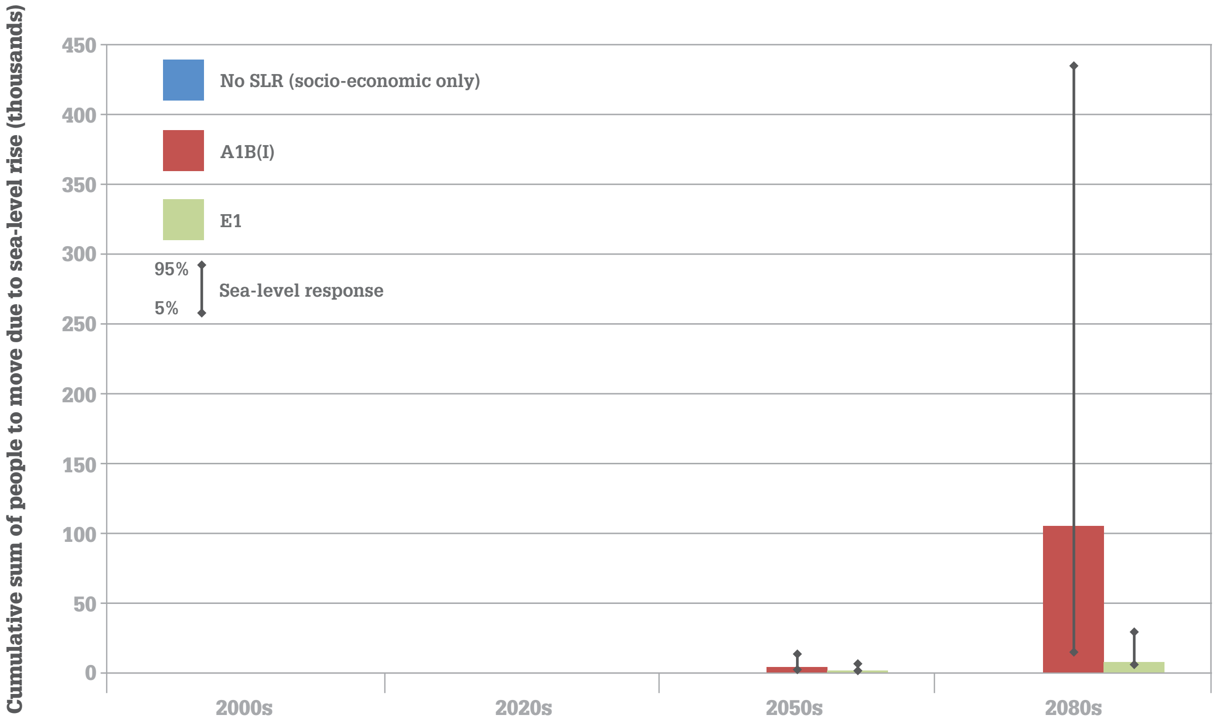
The number of people who move (shown in Figure 6) is in addition to the number of people who are at risk from flooding (Figure 4 and Figure 5), leading to a large number of people affected by rising sea levels. The number of people who move is expected to increase beyond the 21st century.

4.3 Total annual damage with no upgrade in protection (no adaptation)

Figure 7 shows the annual damage costs with adaptation and with no upgrade to protection measures (i.e. with no adaptation from baseline (1995) standards for the A1B(I), E1 and No SLR scenarios). Economic costs are presented as current Euro (2005) over time, without any uplifts or discounting.

Damage and associated economic costs will still occur throughout the 21st century under a scenario of no climate change because flooding is already a problem in many areas and, due to local subsidence, will worsen in some places. Under the 'present' climatic conditions and a baseline scenario of No SLR, annual damage costs are about €1.9 billion. However, by the 2080s, this increases to €7.0 billion/year if defences are not upgraded to cope with changing conditions. This is mainly driven by relative sea-level change (e.g. ground subsidence and economic activities) and socio-economic factors.

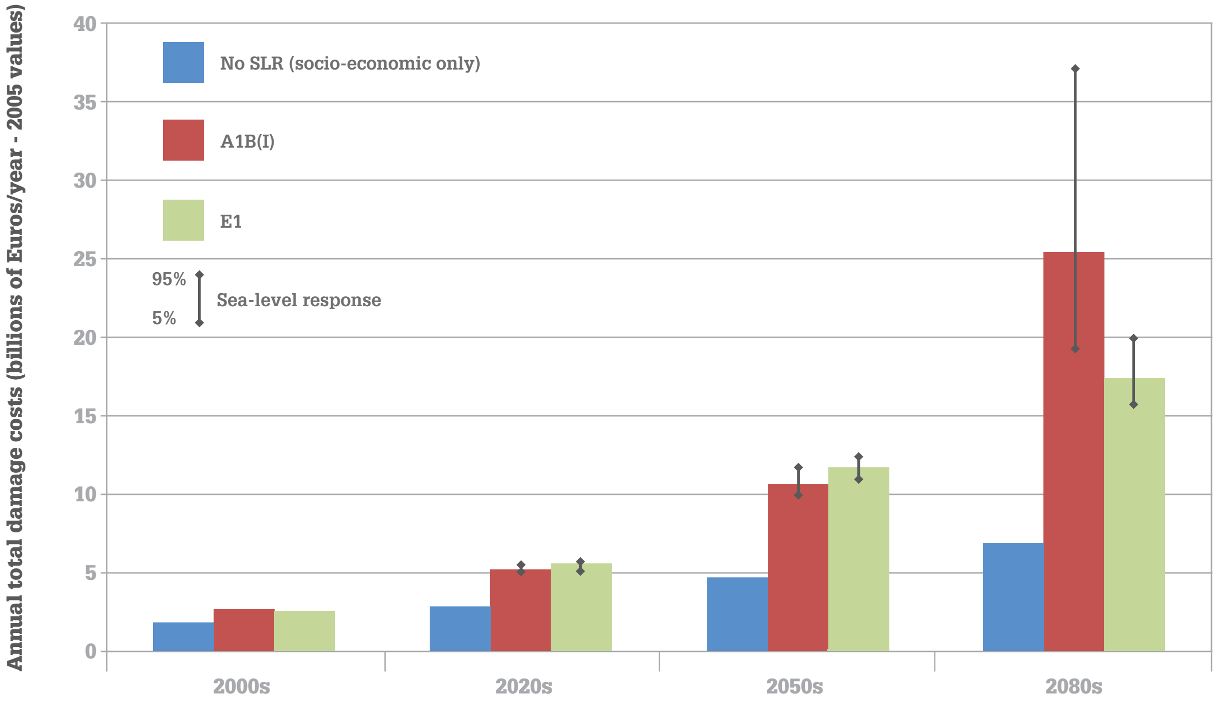
Figure 6. Cumulative number of people to move due to extreme water levels for the EU for the A1B(I), E1 and No SLR scenarios throughout the 21st century assuming no upgrade in protection, plotted as a function of relative sea-level rise. Numbers reported for A1B(I) and E1 include the combined effects of sea-level rise and socio-economic change. The uncertainty range (5% to 95%) shown is associated with the ice melt response to a single temperature profile over time. A multi-model climate analysis with a range of temperature profiles would expand the range of estimated sea-level rise from that shown.



For relative sea-level rise, total projected annual damage costs are estimated at €5.2 billion, €10.6 billion and €25.4 billion for the 2020s, 2050s and 2080s respectively for the A1B(I) scenario (Mid estimate, undiscounted), and €5.6 billion, €11.7 billion, €17.4 billion for the E1 scenario for the 2020s, 2050s and 2080s respectively. This includes the combined effects of climate and socio-economic change. However, even in the short term, differences occur between the A1B(I) and E1 scenarios due to assumptions about socio-economic conditions. For both scenarios, the total damage costs are similar until the 2050s (as they have a similar magnitude of relative sea-level rise), but diverge thereafter, reflecting the magnitude of sea-level rise with respect to topography and population distribution. These scenarios indicate that, at the present timeframe, the climate-induced sea-level rise component of damage costs is 30%, but by the 2080s, it is over 80% of the total damage cost. Therefore, climate change will create an increasing proportion of the damage costs on the coast.

In the short term, policy makers and coastal managers need to be concerned with relatively small levels of damage but, in the medium to long term, investment is required to prepare for and, ideally, reduce damage cost as environmental conditions change. The need for adaptation is planned for decades ahead so that defences may continue to work effectively as environmental conditions change. Land-use planning, such as limiting population growth in coastal zones, may have limited effect as there is already a large investment in infrastructure in the coastal zone. Hence, early investment in defence planning, construction, planning and maintenance is important.

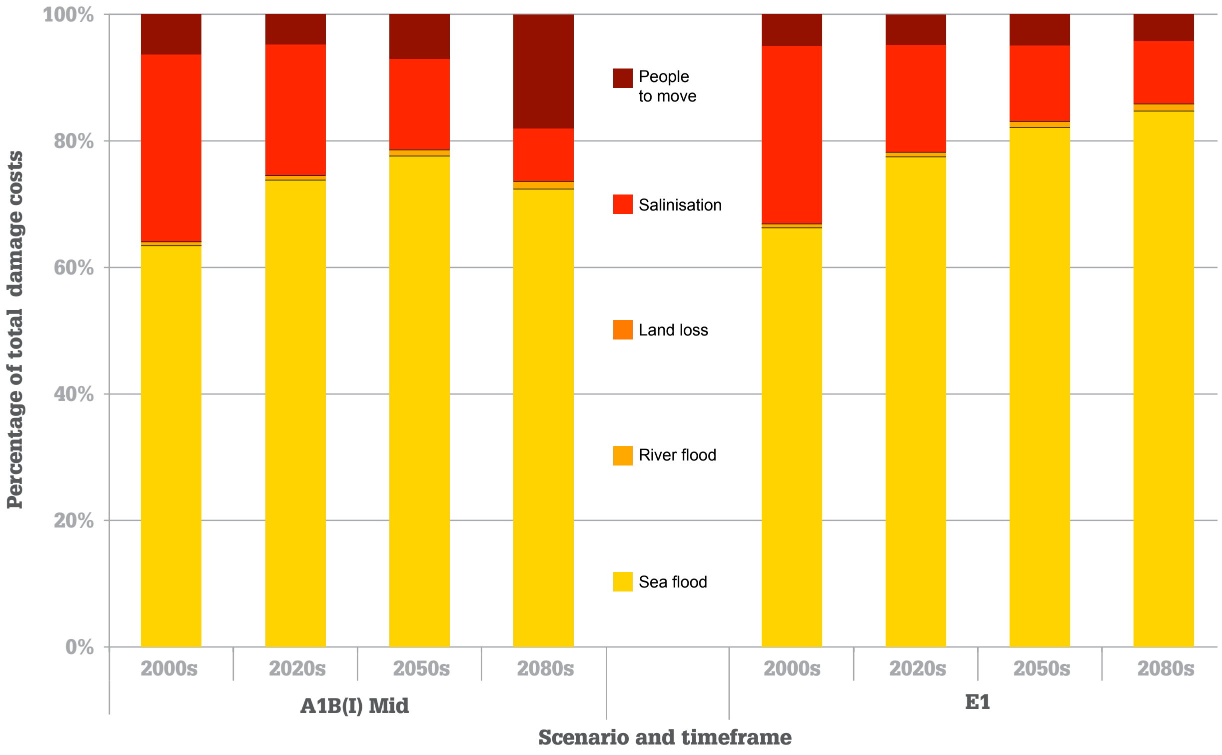
Figure 7. Total damage cost (current 2005 prices, undiscounted) for the EU for the A1B(I), E1 and No SLR scenarios throughout the 21st century assuming no upgrade in protection. Numbers reported for A1B(I) and E1 include the combined effects of sea-level rise and socio-economic change. The effects of future socio-economic change (without future climate change) can be seen with the No SLR scenario. The increases above this reflect the marginal economic costs directly attributable to climate change. The uncertainty range (5% to 95%) shown is associated with the ice melt response to a single temperature profile over time. A multi-model climate analysis with a range of temperature profiles would expand the range of estimated sea-level rise from that shown.



As a result of climate and socio-economic change, the expected annual damage from coastal flooding is projected to grow to around €5 billion by the 2020s, €11 billion by the 2050s and €25 billion by the 2080s for the EU (A1B mid scenario, undiscounted).

Damage costs comprise sea and river floods, land loss, salinisation and people who are forced to move. A breakdown of these costs, as a proportion of total damage costs, is shown in Figure 8. The majority of damage costs (over 60%) is due to sea flood costs. This increases over time as countries become wealthier. The only exception to this is for the A1B(I) Mid scenario in the 2080s due to the very large number of people who are being flooded. This indicates that, by the 2080s, the magnitude of sea-level rise may have an increasing importance on damage costs over socio-economics.

Figure 8. Breakdown of total damage costs for the EU for the A1B(I) Mid and E1 Mid SLR scenarios throughout the 21st century. Damage costs are responding to the combined effects of sea-level rise and socio-economic change



There is also a strong distributional pattern across Europe. Figure 9 shows the damage costs for each member state for the mid estimate for the 2080s under the A1B and E1 (based on relative sea-level rise) and No SLR scenarios (also see Figures A1 and A2 in the Map section in the Appendix at the end of this TPBN). Figure 9 shows that using the results from these models, the low-lying Netherlands would have the greatest annual damage cost in the 2080s. However, in reality, the Dutch coastline is heavily defended, with design standards higher than the rest of Europe (see discussion of adaptation in Section 5.3). Damage costs in France and the UK are also high (greater than €4 billion/year for the A1B(I) scenario) due to their long coastlines. Countries with short coastlines and small island states are low on the list. These results are similar to Hinkel et al., (2010) who studied damage and adaptation costs in the EU under an A2 and B2 scenario[10]. They also identified the same top five countries with the highest potential damages as here. Therefore, even under different scenarios of sea-level rise, a similar trend and ranking among countries with the highest potential impacts emerge. Some of the largest costs are incurred by some of the richest countries.

Dividing the numbers shown in Figure 9 by the total length of a country's coastline helps identify where the most local damage will occur. The top countries are Belgium, the Netherlands, Germany, France and the UK. For these countries, damage costs would be expected to range from €0.3 to €12 million/km. For the remaining countries, damage costs are less than €0.3 million/km. These countries, in particular, need to plan for the long-term damage of their coastline. For the climate-change-only component, the same countries have high damage costs, though they are also joined by Poland.

While small islands and countries with short coastlines have lower absolute costs, the relative impacts on their economies can be higher. The Netherlands, Belgium, Denmark, UK and Portugal are ranked in the top five most costly countries for damage costs relative to GDP. Three of these countries (the Netherlands, Belgium and the UK) are also in the top five for cost per km of coastline. While not in the top five in terms of relative cost to the economy, Malta, Cyprus and Ireland also experience high costs relative to their economies, although absolute costs are generally low.

There are large differences across Europe and some member states are likely to face much higher increases in climate change related coastal flood damages.

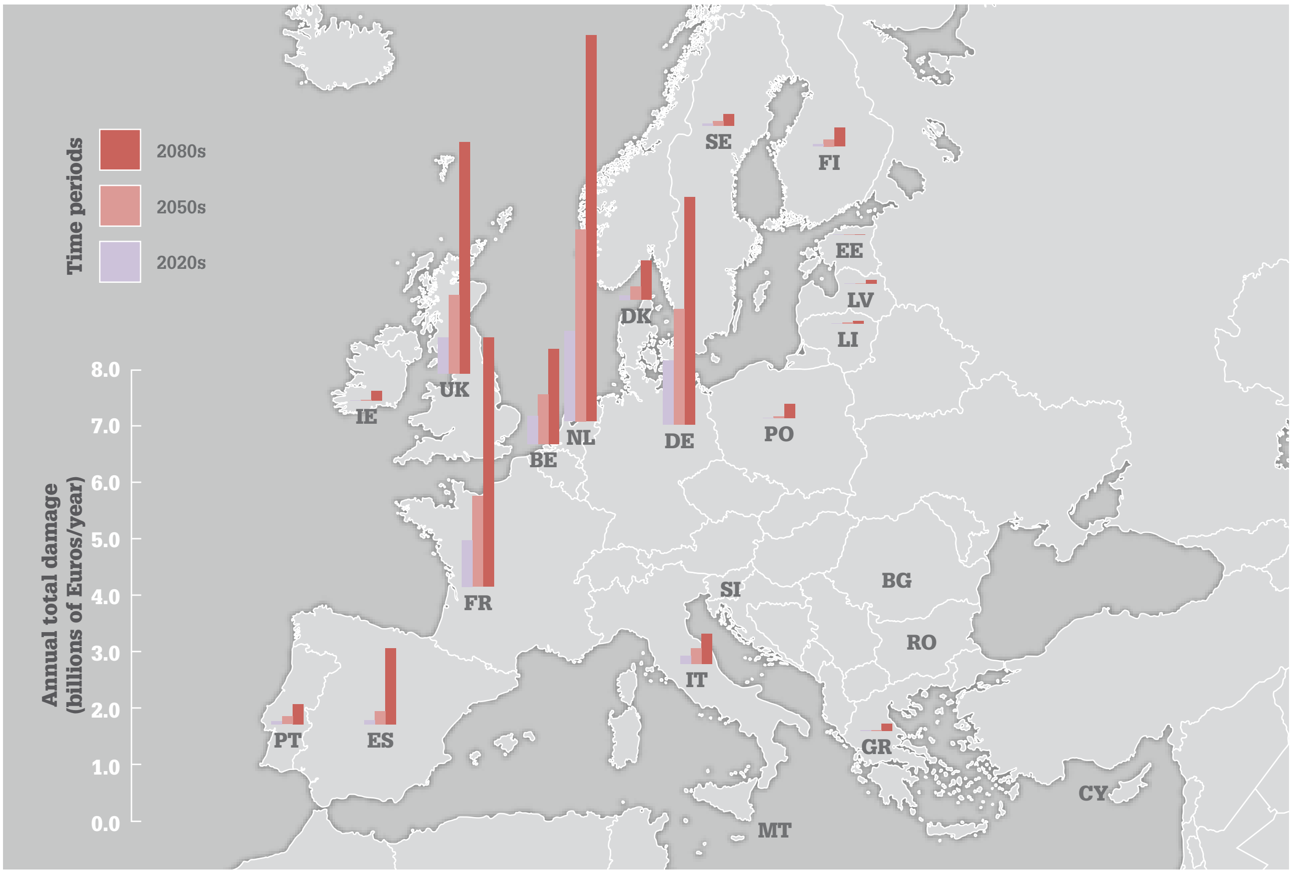
Taking into account the damage cost per km and the size of economy, Belgium, Malta, Netherlands and Slovenia have the highest costs of damage and would be potentially worst hit due to a mixture of topography and small economies, despite having short coastlines.

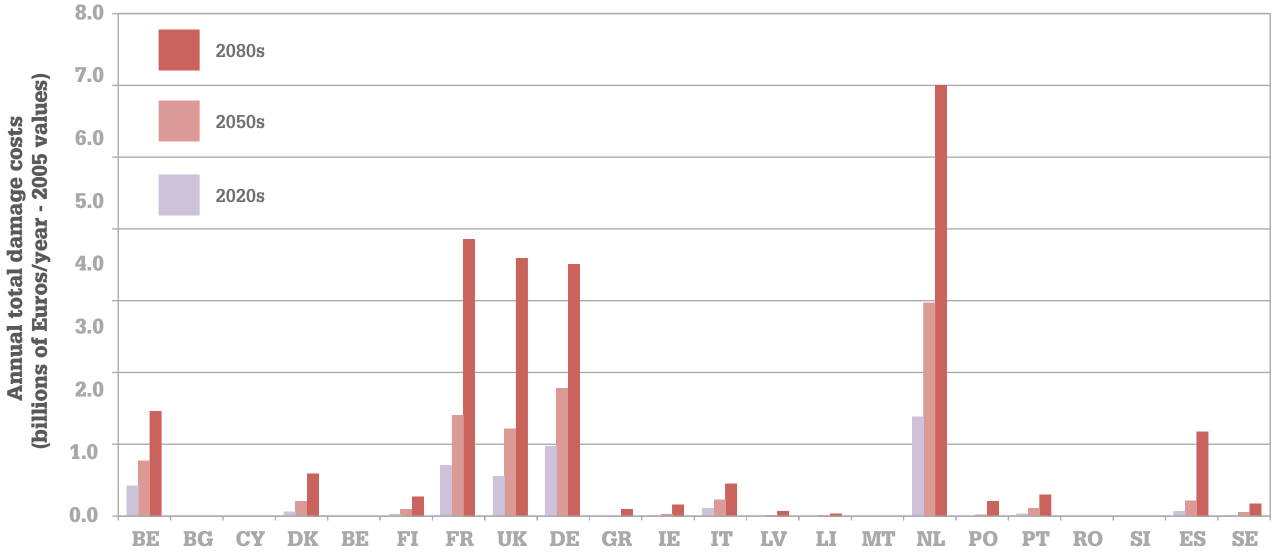
The analysis above can also be used to estimate the economic benefits of mitigation, by comparing the difference between the A1B(I) and the E1 mitigation scenarios. At the EU level, by the 2080s, the annual difference (benefit) is nearly €8 billion (mid scenario). Prior to this, there are very limited benefits of mitigation as global mean sea levels between the scenarios, when combined with socio-economics, are similar. The analysis of these benefits at the country level reveals that Belgium, Italy, the Netherlands, Portugal and Germany have the greatest benefits due to mitigation, mainly due to their large unmitigated damage costs. However, in relative terms, the Netherlands, Denmark, Malta, Spain, Ireland, UK and Cyprus have the highest benefit of mitigation relative to the size of their economies. The two small island states of Europe - Cyprus and Malta - receive some of the greatest benefits.

---

[10] Hinkel et al., (2010, p708) state that 'The A2 storyline assumes a socio-economically heterogeneous world and a continuously increasing global population. Global emissions increase throughout the century. The B1 storyline assumes a socio-economically converging world; global population and emissions peak in 2050 and decline thereafter'. The A2 and B2 scenarios considered project about 0.39 m and 0.30 m of sea-level rise in the 2080s respectively.

Figure 9. Total damage cost (2005 prices, undiscounted) broken down for each EU country. The map at the top shows change over time for member states (A1B). The graph at the bottom shows comparison for the A1B(I), E1 Mid and No SLR scenarios for the 2080s. Numbers reported for A1B(I) and E1 include the combined effects of sea-level rise and socio-economic change.





Note – for an explanation of the abbreviations used in Fig 9, see Table A5 in the Appendix

5. Adaptation

Coastal protection for sea-level rise and other coastal hazards is often a costly, but straightforward, way to overcome many of the adverse impacts of climate change. There are a large number of potential adaptation options to address these risks, particularly for protecting market sectors. Planned adaptation options to rising sea levels are usually presented as one of three generic approaches - retreat, accommodation or protection (Table 6). For example, planned retreat involves pulling back from the coast via appropriate development control, land-use planning and set-back zones. Accommodation involves adjusting human use of the coastal zone (e.g. through early warning and evacuation systems), increasing risk-based hazard insurance and increasing flood resilience (e.g. raising houses). Protection involves controlling risks through soft (e.g. beach nourishment) or hard (e.g. dikes construction) engineering. However, with protection, a residual risk always remains and complete protection cannot be achieved. Hence, managing residual risk is a key element to an overall strategy.

The choice and use of such strategies depend on the nature of the coastal zone, and the type and extent of impacts (i.e. adaptation requires a site and context-specific response). There are also differences when considering wider impacts on coastal ecosystems rather than just on humans; sometimes there can be conflicts when addressing different impacts. For example, fixed coastal defences (protection) might lead to ‘coastal squeeze’ (preventing onshore migration of coastal ecosystems) which is less of an issue for the accommodation and retreat options. There are also differences between technical (hard) and non-technical (soft) options.

Table 6. Impacts of sea-level rise (after Klein et al., 2001; Linham and Nicholls, 2010; Nicholls and Tol, 2006;).

Physical impact of sea-level rise		**Examples of potential adaptation responses**
Direct inundation, flooding and storm damage	**Storm surge (sea)**	• Dikes/surge barriers (P) • Building codes/flood-wise buildings (A) • Land-use planning/hazard delineation (A/R)
	Back water effects (river)	
Erosion (direct and indirect)		• Coastal defences (P) • Nourishment (P) • Building setbacks (R)
Saltwater intrusion	**Surface waters**	• Saltwater intrusion barriers (P) • Change water abstraction (A)
	Ground waters	• Freshwater injection (P) • Change water abstraction (A)
Rising water tables and impeded drainage		• Upgrade drainage systems (P) • Polders (P) • Change land use (A) • Land-use planning/hazard delineation (A/R)
Loss of wetland area (and change)		• Land use planning (A/R) • Managed realignment/forbid hard defences (R) • Nourishment/sediment management (P)
		Note: P – Protection; A – Accommodation R – Retreat

The physical impacts of sea-level rise that have been calculated within the DIVA Model are from direct inundation, erosion, salinisation and wetland loss. In terms of potential adaptation responses, coastal defences (dikes) and nourishment have been calculated within the DIVA Model.

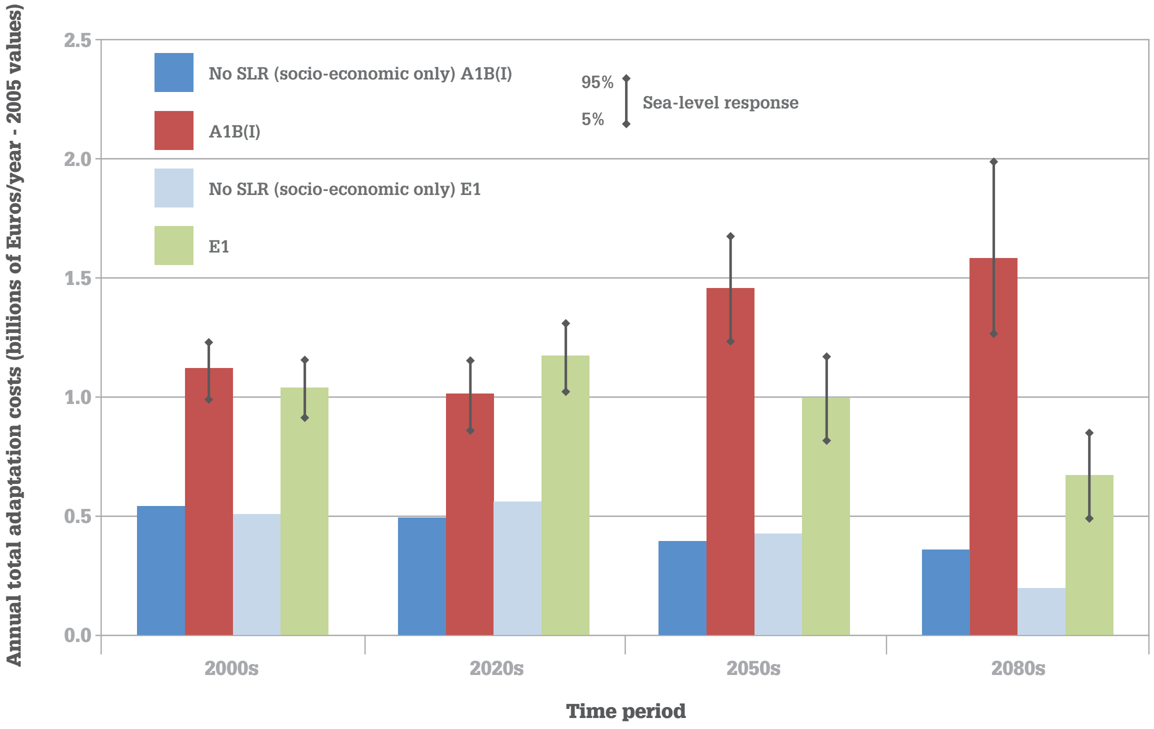
5.1 Costs of adaptation

The ClimateCost project has looked at the potential costs of adaptation in the EU and the damage cost estimates using the DIVA Model.

In the model, different adaptation strategies can be applied. These focus on addressing the two main impacts identified above - flooding and coastal erosion. The planned adaptation options to these being dike building and nourishment of the beach/shore face. These reduce damage costs for flooding and land loss, but not salinisation as alternative technologies are required (e.g. freshwater injection barriers, groundwater pumping (Sorensen et al., 1984)) that are not included in the DIVA Model. Building dikes will only be successful if they continue to be maintained after they are built. This requires additional investment. For dikes, the model uses a demand function for safety and maintaining acceptable levels of risk, with thresholds based on population density (so that highly populated coastal zones are protected). Dike costs are based on the cost per kilometre of defence multiplied by the dike height. For beach nourishment, a cost-benefit analysis is used comparing costs against avoided damages, including tourist benefits where appropriate. Existing protection measures (1995 base year) are assumed and modelled in the DIVA Model, and are based on population density and GDP. Assuming upgrading to adaptation occurs as sea levels rise and population increases (thus creating a greater demand for safety), dikes (for sea coasts and adjacent river estuaries) are newly constructed or increase in height and beaches are nourished. In the DIVA Model, the total capital costs of adaptation (in 2005 Euros) comprise costs for sea and river dikes, and beach-nourishment costs.

Figure 10 illustrates the associated adaptation costs due to a rise in sea levels. By the 2080s, annual adaptation costs are €1.6 billion (A1B(I) Mid scenario), €0.7 billion (E1 Mid scenario) and €0.3 billion for the No SLR scenario. As time progresses, adaptation costs (for relative sea-level rise) increase for the A1B(I) scenario, more than for the E1 and No SLR. This is because the rate of relative sea-level rise for A1B(I) accelerates over time. For the E1 scenario, the rate of relative sea-level change stabilises after the 2050s, so a decrease in annual costs is seen (see Figure 2 and Table 1). It is worth noting that the analysis suggests that adaptation would be required even without climate

Figure 10. Total capital adaptation costs (2005 prices, undiscounted) for the EU for A1B(I), E1 and No SLR scenarios throughout the 21st century. Note that adaptation costs are responding to the combined effects of sea-level rise and socio-economic change. The costs of adaptation to future socio-economic change (without future climate change) can be seen with the No SLR scenario. The increases above this reflect the marginal adaptation costs directly attributable to climate change. The uncertainty range (5% to 95%) shown is associated with the ice melt response to a single temperature profile over time. A multi-model climate analysis with a range of temperature profiles would expand the range of estimated sea-level rise from that shown.



change, as there is already large investment in the coastal zone and this investment is likely to grow. Thus defence levels would need to increase due to just socio-economic reasons as there would be more assets to protect (unless coastal management policies can steer development to less vulnerable locations). Moreover, as the sea level rises, protection will become increasingly cost-effective as the benefit-to-cost ratio increases.

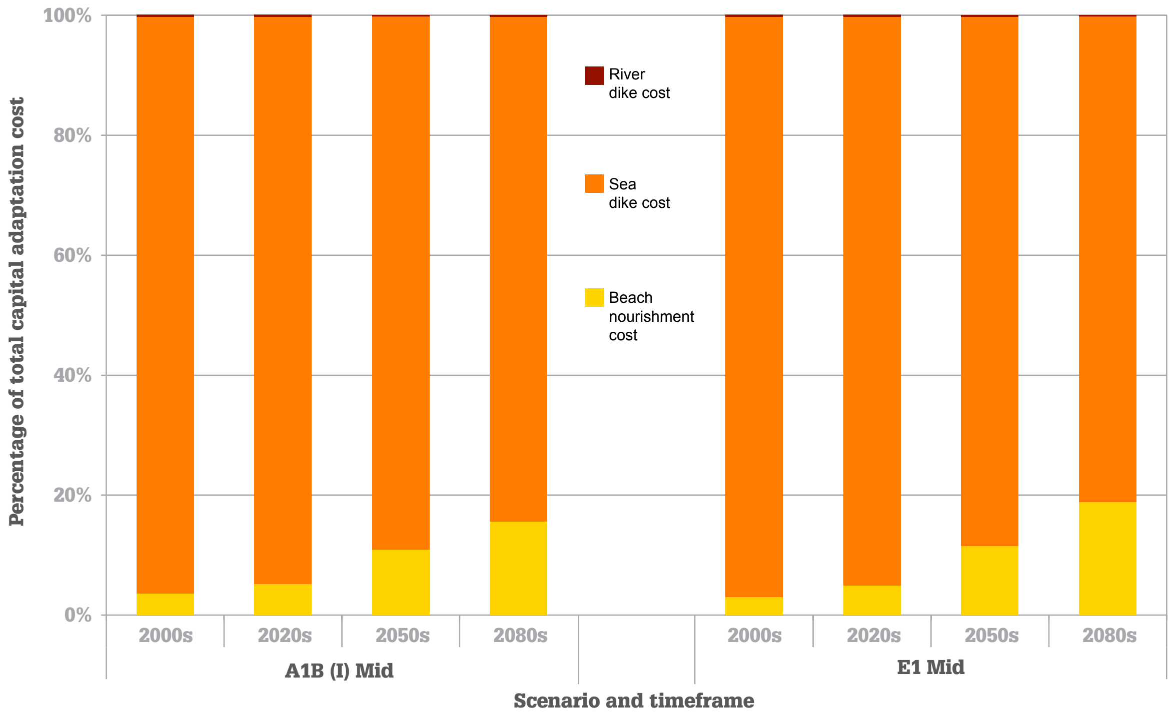
These results indicate slightly lower adaptation costs than presented by Hinkel et al., (2010), who reported on adaptation costs for the EU. While this is due to differences in sea-level rise, and its associated pattern and socio-economic differences, the rate of change of sea-level rise is also important. For example, although the sea-level rise associated with Hinkel et al's., (2010) B2 scenario in the 2080s is of a similar magnitude to the E1 Mid and 95% scenarios, it has a higher annual adaptation cost due to the continual rate of increase of sea-level rise. However, for the E1 scenario, the rate of rise stabilises after the 2050s, thus producing a lower annual cost. Hence, mitigating for climate change is beneficial as long-term adaptation costs may be reduced.

The adaptation capital costs are broken down into costs of hard and soft adaptation. Around the EU, hard adaptation has been the dominant form of protection.

The estimated costs of adaptation for coastal protection are estimated to grow to around €1 billion by the 2020s, rising to €1.5 billion by the 2050s and 2080s (A1B Mid scenario, undiscounted).

Figure 11 illustrates the breakdown in adaptation measures for the A1B(I) Mid and E1 Mid scenarios from the DIVA Model – this shows, for the present timeframe, that 96% of adaptation costs in the model are in the form of sea dikes. However, throughout the 21st century, the model projects a shift towards beach nourishment, which increases to over 15% of the total adaptation costs. River dike costs are small in comparison (less than 1% of the total cost).

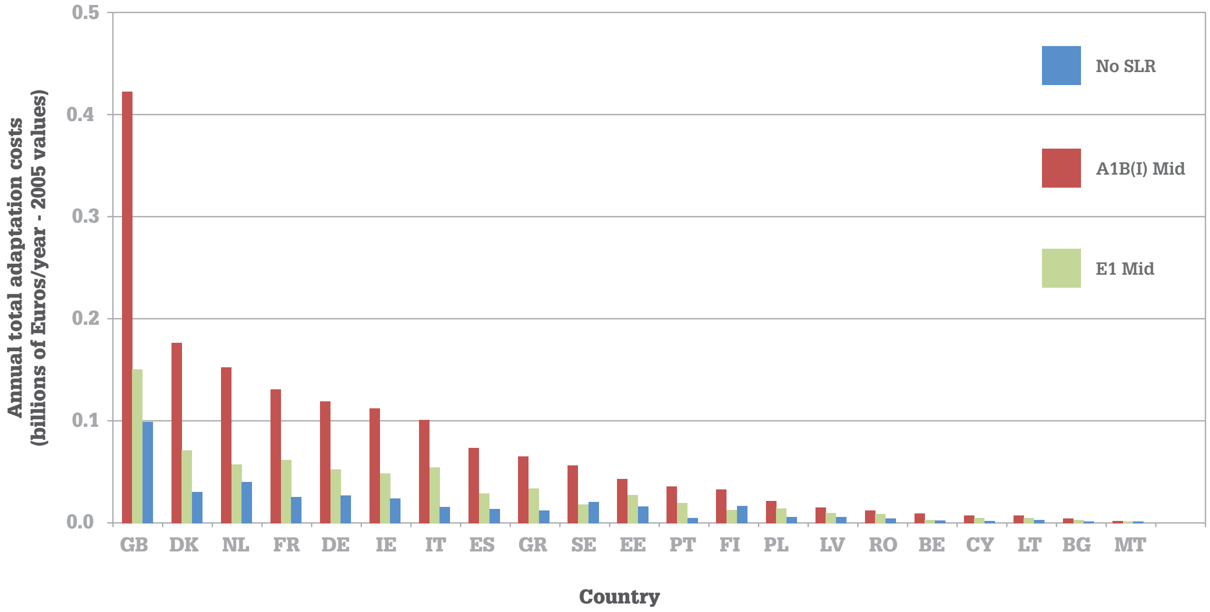
Figure 11. Breakdown of the total capital adaptation costs for the EU for A1B(I) Mid and E1 Mid SLR scenarios throughout the 21st century. Adaptation costs are responding to the combined effects of sea-level rise and socio-economic change.



Sea dikes are the dominant form of protection and will only continue to protect land to a sufficient standard if they are maintained. An assumption, based on developed world literature (see Nicholls et al., 2010 for a review), is that sea dikes cost 1% of their capital cost to maintain. River dikes are subject to lower wave loading compared with sea dikes, so cost 0.5% of their capital cost to maintain. Existing dikes (i.e. pre 1995) also require maintenance. The annual maintenance costs for sea and river dikes are estimated to be in excess of €5 billion (current prices, undiscounted) across all scenarios. 99% of this cost is for sea dikes. Therefore, maintaining this existing large investment in hard defences across Europe has a much greater cost than building new defences. Maintaining existing dikes is essential to retain low levels of flood risk where hard protection is necessary. In calculating these values, the coastal model assumes that all defences are constructed to a high defence level (up to a 1:10,000-year flood) following a cost-benefit analysis linked to population densities. In reality, there will be locations in Europe (e.g. Romania, Bulgaria) that do not have such a high standard of protection (this is often known as an 'adaptation deficit'), so maintenance costs would be expected to be lower than the modelled output. Conversely, higher-than-average levels of maintenance would be expected in countries that are already highly defended, such as those in north-west Europe.

As with damage costs, there is also a strong distributional pattern across the EU. Figure 12 shows the costs of adaptation for each member state, for the mid estimate for the 2080s under the A1B and E1 scenarios (also see Figure A3 in Map section of the Appendix). The top five countries for adaptation costs are the UK, Denmark, the Netherlands, France and Germany - four of these countries are also in the top five for damage costs. When considering costs per kilometre of coast, the Netherlands, Belgium, Germany, Denmark and the UK have the highest adaptation costs. These are also the countries that would benefit most from climate mitigation policies. In terms of the size of their economies, Ireland, Cyprus, Estonia, Denmark and Greece have the highest adaptation costs. For Denmark and Greece this is due to their long coastlines. For Ireland, Cyprus and Estonia it is due to their smaller economies.

Figure 12. Total adaptation cost (current prices, undiscounted) broken down for each EU country for the A1B(I), E1 Mid and No SLR scenarios in the 2080s. Numbers reported for A1B(I) and E1 include the combined effects of sea-level rise and socio-economic change.

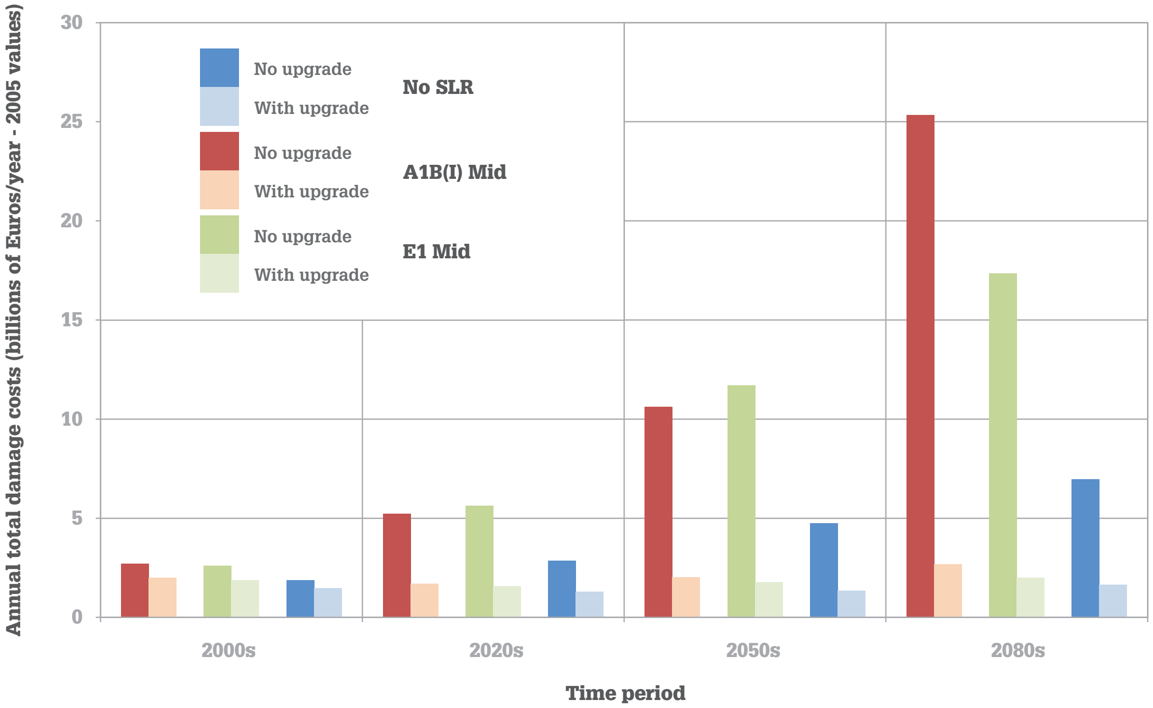


Note – for an explanation of the abbreviations used in Fig 12, see Table A5 in the Appendix

Even when coasts are defended, damage will still occur as not all of the coastline will be protected and a residual risk remains in protected areas. Figure 13 illustrates the damage cost with adaptation measures and no upgrade to protection for the A1B(l) Mid-range, E1 Mid-range and No SLR scenarios for relative sea-level rise (for a country breakdown, see Figure A2 in Map section in the Appendix). The figure shows that adaptation dramatically reduces damage costs, even in a scenario of no climate change. The difference in height between each pair of columns for each timestep indicates the amount saved in damage costs. For instance, by the 2080s for the A1B(l) scenario, adaptation can reduce annual damage costs by a factor of eight to €2.6 billion. The climate change component of relative sea-level rise can take up to 70% off the total damage cost.

The avoided cost of damages increases as time progresses and sea levels rise. When considering the avoided annual costs due to adaptation, they are the highest in the 2080s at €21.1 billion, €14.7 billion and €5.0 billion. Hence, an adaptation policy could greatly reduce overall damage costs. In terms of policy options, wider adaptation measures (e.g. the protection, accommodate and retreat options discussed at the start of Section 5) need to be considered, not just the dike and nourishment options as used in the coastal model.

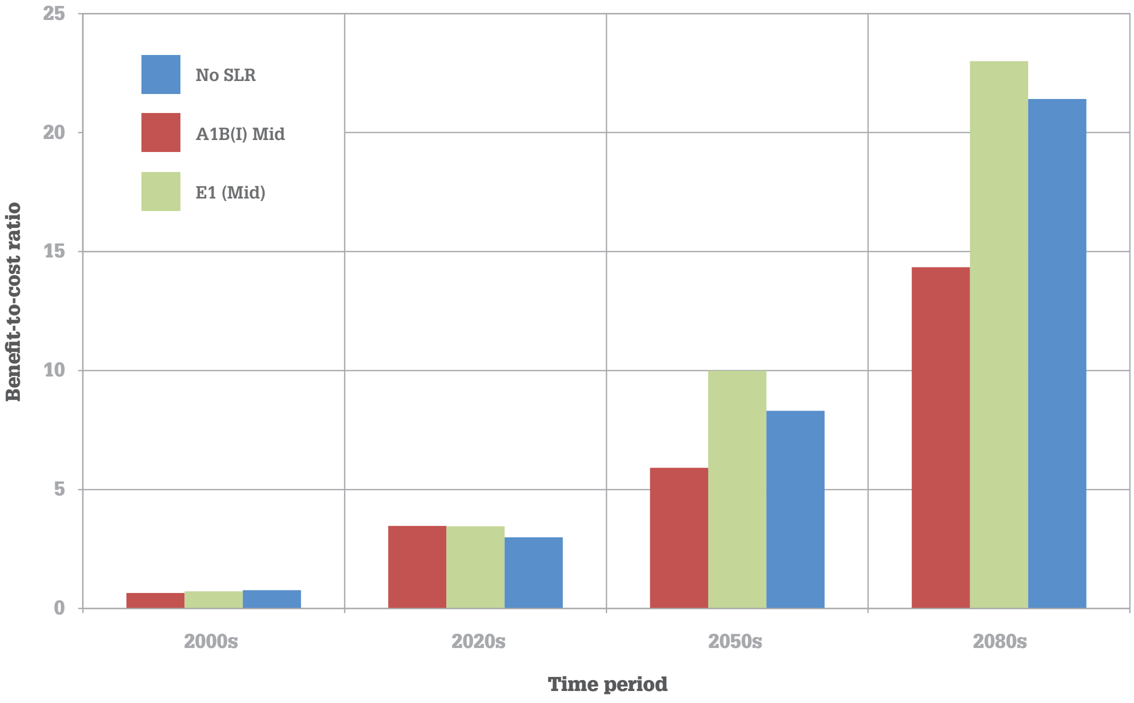
Figure 13. Total damage cost (current prices, undiscounted) for the EU for the mid-range scenarios and No SLR throughout the 21st century for no upgrade in protection and with adaptation. Costs reported are for the combined effects of sea-level rise and socio-economic change. The effects of future socio-economic change (without future climate change) can be seen with the No SLR scenario. The increases above this line reflect the marginal economic costs directly attributable to climate change.



5.2 A comparison of the costs and benefits of adaptation

Using data from Figures 7 and 9, Figure 14 illustrates the benefit-to-cost ratio of adapting to rising sea levels. It should be noted that in the DIVA Model, additional adaptation measures are considered in the same period as benefits, thus is it possible to compare costs and benefits directly[11]. This ratio only considers the costs as described in Section 3 and has not included costs due to the loss of ecosystems (e.g. wetlands). Adaptation becomes more effective throughout the 21st century, even for small rises in sea level. At the present time, for the climate scenarios, the DIVA Model estimates that damage costs are over twice as high as possible adaptation costs (Figure 7 and Figure 10). By the 2080s, for the highest magnitude of sea-level rise (A1B(I) 95% at 0.46 m in the 2080s), the damage costs could be 18 times higher than the possible costs of adaptation, leading to a benefit-to-cost ratio[12] of 17:1 (Figure 14). It is important to note that, even in this case where benefits are high, residual damages will still occur. The benefit-to-cost ratio varies between the scenarios due to the rate of sea-level rise, topography and population distribution according to elevation.

Figure 14. Benefit-to-cost ratio for damage and adaptation costs for EU countries. Note that costs address the combined effects of sea-level rise and socio-economic change



---

[11] This arises because the additional sea dikes and coastal protection involve strengthening existing measures, and beach nourishment is a soft measure. In practice, many new coastal defences and adaptation measures would involve more significant planning in early periods for later impacts. In such cases, benefits are likely to accrue in later time periods, while costs may be incurred earlier, and this will affect the ratio of costs and benefits. Such effects 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, acceptable levels of risk protection for coastal flooding in Europe are often considered in a cost-effectiveness framework.

[12] The benefit–to-cost ratio is the damage cost with upgrade to adaptation – damage cost with adaptation)/adaptation costs, that arise for each specific time period. It is not a standard cost-benefit analysis with discounted present values. For definitions of damage and adaptation costs, see Section 3.

5.3 Discussion of adaptation costs

Adaptation is advantageous as it can reduce the amount of land flooded, the number of people at risk and, thus, the associated costs. There are high benefit-to-cost ratios, which increase as time progresses, so adaptation becomes a more worthwhile investment over the long term. The analysis above provides an estimate of the potential costs of adaptation at the European scale. It provides cost estimates for protection against two of the main impacts - flooding and the movement of people - based on the costs of key technical options. However, in the DIVA Model used to derive these results (see Section 3), uniform responses to damage and adaptation are used. In reality, coastal adaptation will be site and context specific. There is a very wide range of options, which includes soft and hard options, and considers a wider range of impacts including those on coastal ecosystems (Klein et al., 2001; Hinkel et al., 2010). The benefit-to-cost ratio shown in Figure 14 purely provides an economic assessment of the effects of sea-level rise immediately in the coastal zone, but adaptation can have a far more reaching benefit as inland areas also take advantage of the coast (e.g. supply chains, aquaculture products).

There is literature on the potential costs of coastal adaptation in the EU at the member state level, notably in the Netherlands with the Delta Commission (Delta Commissie, 2008) and in the UK (e.g. Evans et al., 2008). These studies report similar conclusions (i.e. that coastal adaptation has high benefit–to-cost and is effective). However, they do imply potentially higher costs than cited above. Coastal flood and erosion budget in the Netherlands was between €410 million and €820 million (2006 prices, 0.1 - 0.2% of GDP) and in England and Wales €880 million (2009/10 prices, 0.05% of GDP) (see Nicholls, 2007). In England, 23% of the budget was spent on erosion, in Wales 12% of the budget was spent on erosion (pers. comm. UK Environment Agency via Iain Shepherd (DG MARE)). The estimated annual costs for future flood protection and flood-risk management in the Netherlands for the implementation of a comprehensive set of adaptation measures could be in excess of €1 billion and these imply higher costs at the European scale than the results above. The Dutch are already anticipating sea-level rise, acting in a proactive manner, constructing defences for a sea-level rise of about 1 m and providing higher standards of protection than elsewhere in the EU. This is because the Dutch are also protecting low-lying land that, in places, is below sea level and are working to generate hydro energy to produce food and allow infrastructure development (e.g. such as roads to be built on top of the flood defences). Similar situations happen with defences in other countries, albeit at a smaller scale. Costs given in other studies can be higher than presented here as they are designed to achieve much higher levels of protection than modelled here (e.g. the Netherlands works towards very stringent levels of acceptable risks for flooding, which leads to much higher costs of adaptation). This highlights that the costs of adaptation are determined by the underlying objectives of coastal policy. They are also influenced by whether protection levels are set on the basis of maintaining or improving current levels of risk or looking to apply strict economic efficiency criteria.

Adaptation can achieve large reductions in damages at low cost. However, these costs vary with the level of protection or acceptable risk and the policy framework (risk versus optimisation).

Similarly, studies at the city level reveal that the costs for some individual projects can be very large. For instance, the Modulo Sperimentale Elettromeccanico barrier in Venice has a capital cost of €4.7 billion (Regione del Veneto, 2010) and the Thames Barrier in London (Environment Agency, 2010) cost £0.5 billion to build (completed in 1982, £1.4 billion at 2007 prices). Both of these projects use moveable barriers across an inlet or estuary.

Looking to the future, the immediate priority is to develop iterative approaches that allow future decisions to be taken that address uncertainty. Projects such as the Thames Estuary 2100 study (Environment Agency, 2009) demonstrate such methods, working within an iterative framework of decision-making under uncertainty and allowing the consideration of portfolios of adaptation strategies that can evolve over time as better information on future risk levels emerges.

6. Wetland losses

EU countries have approximately 26,000 km^2 of wetlands, comprising saltmarsh, freshwater marsh, mangroves, and low and high water unvegetated wetlands (though some types may only be present in EU territories overseas). Wetlands are beneficial as they provide a habitat for wildlife, are used for agriculture, act as pollution filters, absorb greenhouses gases and are a natural wave attenuator, thus protecting the coast. These combined effects are often referred to as ecosystem services and there is great interest in the monetary value of these services.

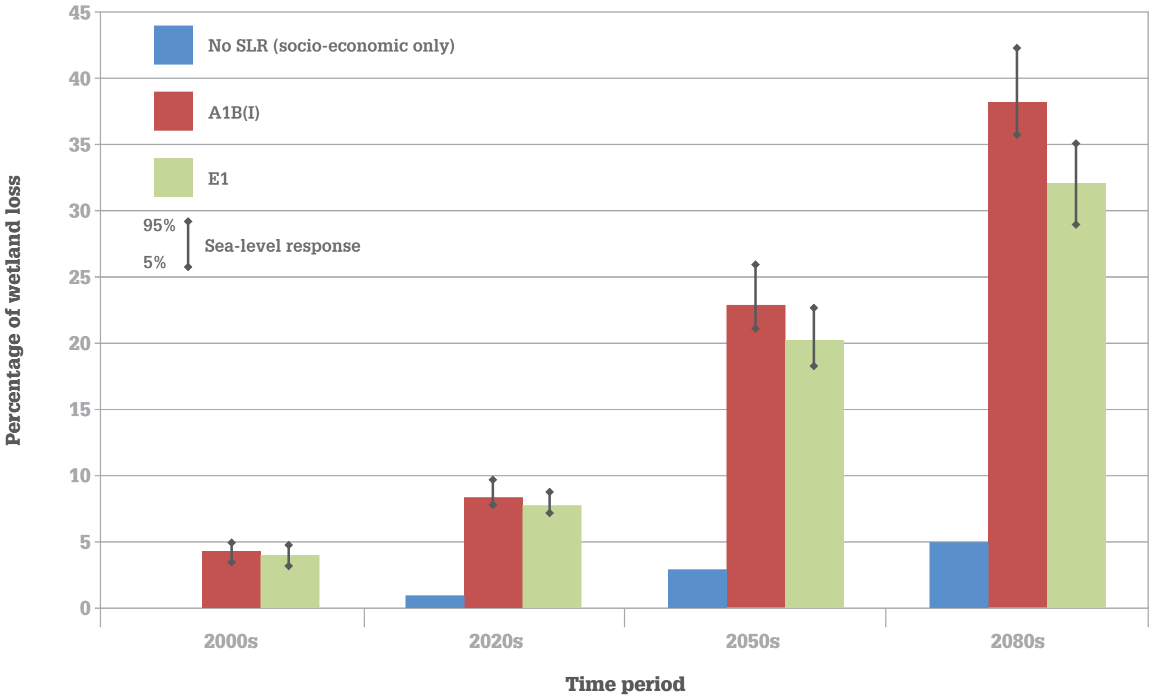
While wetlands can accrete sediment as sea-levels rise, once a threshold of sea-level rise is reached wetlands are effectively drowned and lost to open water. Therefore, they are extremely vulnerable to rises in sea level. Figure 15 shows the percentage of wetlands lost to rising sea levels for the A1B(I), E1 and No SLR scenarios in the EU. Under the present conditions, results indicate that up to about 5% of wetlands have been lost compared with 1995 levels. By the 2020s, this is estimated to increase up to 10%, and to over 35% by the 2080s for A1B(I) and E1 scenarios. The figure illustrates that, due to their low-lying nature, wetlands are sensitive to even small amounts of sea-level rise as large losses are seen for the No SLR and the lower projections of the A1B(I) and E1 scenarios.

The flooding and erosion of wetlands may result in their inland migration (the creation of new wetlands is not reported in the coastal model) unless inhibited to do so by an artificial barrier such as a sea wall. This phenomenon is known as coastal squeeze. Coastal squeeze can result in loss of habitats, and increase pressure on wetlands and the defences/land behind the wetlands, which could potentially lead to increased flooding. Areas most sensitive to change will be those that presently have a low tidal range, such as along the Baltic, Mediterranean and Black Sea coasts as they are less used to coping with extreme conditions.

Wetlands are also under threat from non-climatic influences, such as conversion for agriculture or drainage. Within the EU, the Habitats Directive (92/43/EEC) helps to protect and preserve sites of particularly ecological importance (such as wetlands), and to encourage biodiversity and conservation. When habitat ground is lost, such as through development, compensation ground in the local area is sought (Gardiner et al., 2007; Lee, 2001). Establishing compensation ground can be challenging, not just its physical location, but also ensuring it is the correct type of habitat for the ecosystems that have been lost. Rising sea levels will make this more challenging as coastal squeeze creates increased pressures between the natural and man-made (e.g. coastal defences) environments (Lee, 2001). Envisaging compensation and habitat replacement in a changing climate means planning ahead (for instance over a 50-year time scale) and applying sea-level rise scenarios to predict land-form change. Historical land-use decisions have often restricted habitat replacement. However, spatial planning does allow greater potential and flexibility, for example, by buying land in advance to allow alternative sites to be used. Wetland nourishment (e.g. through dredged spoil) is also a method of reducing wetland loss (Gardiner et al., 2007). Thus, wetlands should be monitored, potential changes envisaged and losses minimised.

In this analysis, the potential loss of these ecosystems services has not been monetised, but they would add to the economic impacts reported above.

Figure 15. Percentage of decrease in EU wetland area due to a relative sea-level rise from the A1B(I), E1 and No SLR scenarios for no upgrade in protection. Numbers reported for A1B(I) and E1 include the combined effects of sea-level rise and socio-economic change. The effects of future socio-economic change (without future climate change) can be seen with the No SLR scenario. The increases above this reflect the marginal economic costs directly attributable to climate change. The uncertainty range (5% to 95%) shown is associated with the ice melt response to a single temperature profile over time. A multi-model climate analysis with a range of temperature profiles would expand the range of estimated sea-level rise from that shown.



7. The potential risks of high sea-level rise

The IPCC AR4 assessment (Meehl et al., 2007) considered that thermal expansion would be the dominant input to global sea-level rise in the 21st century. However, observations around that time suggested that ice melt, such as from the Greenland and Antarctic ice sheets, would play an increasing role. Since the publication of the IPCC AR4 assessment, a number of additional studies have provided possible higher estimates, including Rahmstorf (2007) who projects up to 1.4 m by 2100, Pfeffer et al. (2008) up to 2 m by 2100, and Lowe et al. (2009b)[13] and Vermeer and Rahmstorf (2009) who project upper estimates of up to 1.9 m by 2100. These scenarios were derived from semi-empirical observations and physical-constraint analysis. They are not all associated with a set rise in temperatures or emissions.

These higher estimates are important in considering the full costs of climate change under higher emission scenarios. They are extremely unlikely under the EU's 2 degrees target and this provides an additional benefit from mitigation (i.e. it reduces the risk of these potentially major events (or tipping extremes)).

These extreme sea-level rise scenarios are a potential risk that is relevant when assessing the costs of the A1B scenario and they have relevance in very long-term adaptation planning. Indeed, they have already been included in assessments in the UK and Netherlands (Lowe et al., 2009b; Delta Commissie, 2008).

The ClimateCost study has also used the DIVA Model to assess the potential impacts and economic costs of these high scenarios. It is highlighted that the uncertainty around the use of the model to assess these changes is higher than that for the European analysis in the above sections of this TPBN.

---

[13] Unlike Rahmstorf (2007), Pfeffer et al. (2008) and Vermeer and Rahmstorf (2009), this is a regional sea-level rise scenario for the UK.

The example presented here is for damage costs - assuming no adaptation. The results are shown in Figure 16. This illustrates the relative sea-level rise for the high-level Rahmstorf (2007), A1B(I) Mid and E1 Mid scenarios. Until the 2050s, there are only small differences between the four scenarios. However, by the 2080s, the annual damage costs for the Rahmstorf (2007) are projected to be €156 billion. Damage costs for the Rahmstorf (2007) scenario are six times greater for the A1B(I) Mid scenario and nine times greater than the E1 (Mid) scenario. The analysis shows that these very large rises in sea level produce much larger costs of damage.

8. Limitations on the results

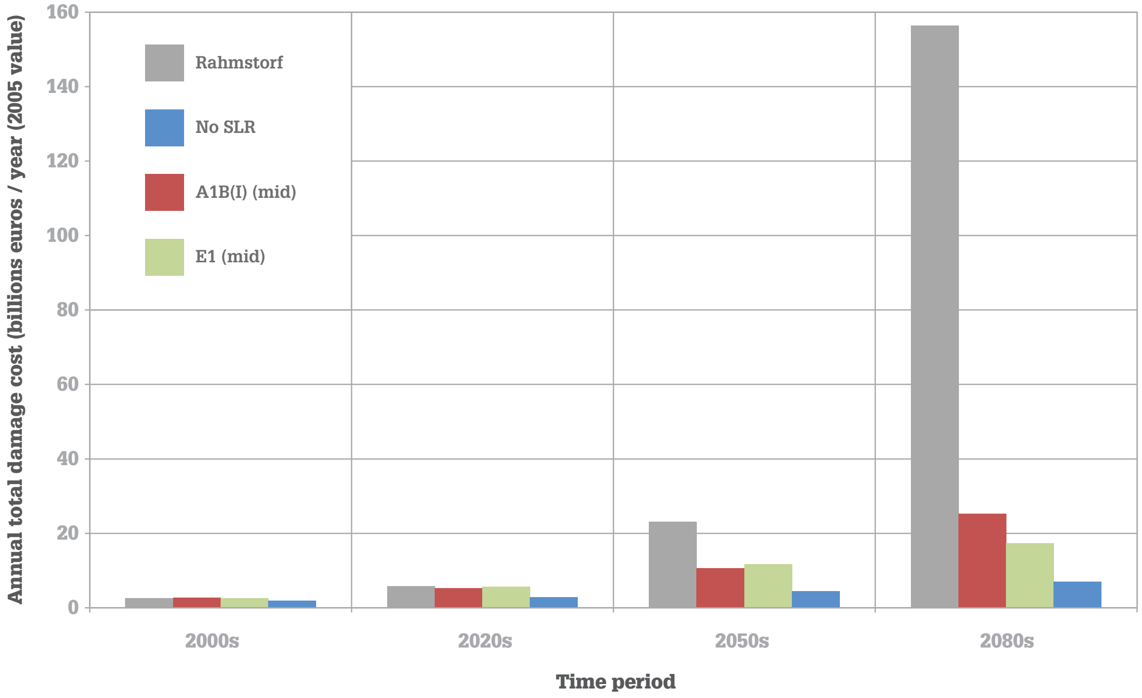
In considering the analysis above, the following points should be noted. The analysis only covers coastal floods (river flooding is covered in a separate analysis and presented in TPBN 3) and only includes the direct effects of coastal flooding and wetland loss (see Table 6), though this typically forms the largest share of flood damage. It does not consider the wider effects from disruptions to physical and economic activities, 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, such as the knock-on effects of energy supply or the transport network.

There are also sources of uncertainty that should be considered when interpreting the results.

First, while the DIVA Model has improved its spatial resolution compared with earlier analyses, coastal data and sea-level scenarios at the European scale still present challenges and, hence, introduce uncertainties (e.g. elevation, rates of localised subsidence and model input parameters in the sea-level scenarios). There are also uncertainties in the underlying impact relationships and cost functions.

Second, the model assumes that adaptation (up to 1:10,000 levels) is in place in the initialisation phase of the model (i.e. 1995). In reality, there is an adaptation deficit

Figure 16. Total damage cost (present values, undiscounted) for the EU for relative sea-level rise of Rahmstorf (2007), A1B(I) Mid, E1 Mid scenarios and No SLR scenarios for no upgrade in protection. Numbers reported for Rahmstorf (2007), A1B(I) and E1 include the combined effects of sea-level rise and socio-economic change. The effects of future socio-economic change (without future climate change) can be seen with the No SLR scenario. The increases above this reflect the marginal economic costs directly attributable to climate change.



(the difference between the modelled adaptation/protection level and the real protection level) and not all places will be defended to the level determined in the model or, in some cases, at all. This is most likely to occur in eastern European countries (see Tol et al., 2008). The limited adaptation options (of no upgrade to protection from 1995 values, and with adaptation comprising dike building and beach nourishment) are a caricature of coastal adaptation. A much wider variety of measures are potentially available, including accommodate or retreat options. However, protection is most likely for densely populated areas, such as the Netherlands, London or Hamburg.

Finally, the adaptation strategies (dikes and nourishment) in the DIVA Model only address flooding and erosional impacts. They do not provide responses to other potential impacts, such as on coastal ecosystems. Nonetheless, these options are well understood and provide a meaningful sense of how adaptation could reduce impacts and the costs. When coastal populations do expand, the dominant assumption in the model is that population density increases uniformly.

9. Implications for European policy

These results reinforce one of the main conclusions on coastal zones and low-lying areas in the IPCC's report that 'the most appropriate response to sea-level rise for coastal areas is a combination of adaptation to deal with the inevitable rise, and mitigation to limit the long-term rise to a manageable level' (Nicholls et al., 2007, p318).

To reinforce this, the main benefit of mitigation is to stop any acceleration in global mean sea-level rise, but even with this, a rise in sea level still occurs in the 21st century, as shown in Figure 2 and Table 1, and this will continue for many centuries into the future (Meehl et al., 2007). This so-called 'commitment to sea-level rise' reflects the strong thermal inertia of the oceans, which means that sea-level rise is the least responsive climate parameter to climate mitigation. As a result, adaptation is required for committed sea-level rise even under quite strident mitigation options. In addition, there is a resulting commitment to adaptation that will increase through the 21st century and beyond. Hence, in addition to promoting climate mitigation (and associated ecosystem benefits such as a reduction in wetland loss), it is vital that the countries in the EU introduce appropriate coastal planning and adaptation at the same time as emissions reduction.

These results investigate only two types of adaptation option - building dikes and nourishing beaches. However, many different types of adaptation are available including protection (e.g. groynes, offshore reefs, moveable barriers and dune nourishment), accommodation (e.g. flood-proofing) and planned retreat (managed realignment, building setbacks) (Linham and Nicholls, 2010). In many cases, these may be preferable to the options considered in DIVA. Furthermore, adaptation needs to be seen in a wider context than that for climate change alone and there are many potential adaptation costs that are not considered here. For instance, defences are often integrated with urban infrastructure, as they are used alongside energy infrastructure and roads. Therefore, total defence costs are likely to be considerably more for some countries than the estimates presented here. Adaptation has large benefits to reduce damage costs and making dual uses of structures could potentially make costs even more efficient.

The distribution of potential impacts across the EU shows these are concentrated in certain regions. Hence, adaptation policies are likely to be heterogeneous - with some combination of retreat, accommodation and protection. It is also likely that portfolios (i.e. combinations or packages) of individual adaptation measures will be most appropriate (Evans et al., 2004). While these results provide a useful European context, more local-scale assessment of adaptation including the best portfolios of measures for different coastal settings is needed. For instance, hard protection with dikes promotes coastal squeeze and intertidal habitat degradation, which is contrary to the Habitats Directive. Hence, protection strategies will have to address human safety while sustaining habitat stocks. Existing EC research investments such as the THESEUS project[14] are addressing this issue.

Local subsidence measurements could also be improved, as this contributes to relative sea-level rise. Assessing and monitoring subsidence is subject to EC-funded research under the SubCoast project[15].

Tol et al. (2008) investigated the awareness of European countries to rising sea levels. They found that many of the countries that had the greatest awareness were in north-west Europe, where most of the most severe impacts are

[14] THESEUS: Innovative technologies for safer European coasts in a changing climate. www.theseusproject.eu/

[15] SubCoast. Assessing and monitoring subsidence hazards in coastal lowland around Europe. www.subcoast.eu

likely to occur. Many of these countries strategically plan for climate change (e.g. Delta Commissie, 2008; Lowe et al., 2009b) and manage their coast. The countries that were least aware of sea-level rise are located around the Black Sea and Scandinavia. Findings from the research for this TPBN (e.g. Figure 9) indicate these countries would experience some of the small damage costs in Europe. However, these countries should not be complacent that they will not be affected by climatic and environmental change; where low-lying land coincides with the built environment and high population densities, the natural and human environment is at risk. National reviews are required to anticipate and plan for climatic change, particularly in 'hotspots' where land, habitat and people are at high risk from flooding and inundation. Such analysis could lead to the formation of long-term strategic coastal protection plans, as advocated in EC-funded Eurosion project[16] (cf Eurosion, 2004).

Finally, climate change is only one aspect of coastal management policy in the EU. Adaptation to climate change needs to be positioned within a broader, integrated, coastal-zone management policy framework that is consistent with wider coastal management and development goals. While this is increasingly recognised, there has been little progress to date, particularly in some regions of Europe (Tol et al., 2008) and this requires long-term effort to achieve a systemic change in many European countries.

10. Conclusions

By the end of the 21st century, increasing temperatures from climate change could lead to sea-level rise of between 0.12 m and 0.46 m for the A1B(I) scenario (for a 3.5°C rise in temperature by the 2080s), and between 0.11 m and 0.33 m for the E1 mitigation scenario (for a 1.5°C rise in temperature by the 2080s). The analysis here indicates that, up to the 2050s, the magnitude of sea–level rise between the A1B(I) scenario and the E1 scenario are similar, after which they diverge, resulting in a larger range of potential impacts.

The number of people at risk from flooding is expected to increase exponentially with time. A mid-range sea-level rise projection indicates that 250,000 additional people will be flooded/year with the A1B(I) scenario (mid-range value) and 75,000 people will be flooded/year for the E1 mitigation scenario (mid-range value) in the 2080s assuming no upgrade in adaptation. Therefore, a mitigation policy could result in 180,000 fewer people flooded annually by the 2080s (based on the mid scenarios). Without upgrading protection, by the 2080s, over 100,000 people would potentially have moved away from the coastal zone due to land submergence. The vast majority of these people would move due to sea-level rise caused by climate change.

Climate change is only one aspect of coastal management policy in the EU. Adaptation to climate change needs to be positioned within a broader, integrated, coastal-zone management policy framework.

Under the 'present' climatic conditions, annual damage costs are estimated to be about €1.9 billion (mid-range value), but could potentially increase in the 2080s to €25.3 billion and €17.4 billion for the A1B(I) and E1 scenarios respectively (mid-range values) if defences are not upgraded to cope with changing conditions. Thus, the net benefits of mitigation are about €7.9 billion/year by the 2080s. Annual damage costs may be reduced by up to 90% by implementing an adaptation policy, estimated here at a cost of €1.6 billion and €0.7 billion (mid-range values) for the 2080s for the A1B(I) and E1 scenarios respectively. Hence, the avoided damage costs due to adaptation in the 2080s are €21.1 billion and €14.7 billion for the A1B(I) and E1 scenarios respectively. The countries where there are the highest costs (and, therefore, benefits of mitigation) are virtually all located in north-west Europe. Subsequently, these countries have a higher awareness of the problems of sea-level rise, with many countries anticipating and planning for future change.

By the 2080s, over 45% of EU wetlands could be lost unless protective measures are undertaken to preserve and protect important areas. Legislation, such as the EU

[16] Eurosion. Living with coastal erosion in Europe: Sediment and space for sustainability. www.eurosion.org

Habitats Directive, will assist this. Wetlands are sensitive to even small magnitudes of sea-level rise, so the risk is greater than that in urban areas.

At the high end, sea-level rise of more than 1 m by the 2080s is possible, and would result in annual damage costs of €156 billion for the EU. This is nine times the cost of the E1 mitigation scenario (consistent with a less than 2°C rise in global temperatures by the end of the 21st century) and would result in a net benefit of €139 billion per year. By adapting to a high-sea-level scenario, model results indicate that annual damages of up to €147 billion may be avoided. The E1 mitigation scenario would reduce the chance of such major sea-level rise (though this has not been evaluated above), an additional factor in the relative costs and benefits between the A1B and E1 (stabilisation) scenarios. This is an important topic for future research.

A summary of the damage cost numbers is presented in the Appendix – showing the values for climate and socio-economic change – and for climate change only (the net effect attributable to climate change alone). The information also provides the uncertainty ranges for the 5%, mid and 95% values.

11. Acknowledgements

Thanks are given to the Met Office Hadley Centre, UK, for the provision of the sea-level rise projections used in this study. Assistance from colleagues from the University of the Aegean, Greece is gratefully acknowledged.

The ENSEMBLES data used in this work was funded by the EU FP6 Integrated Project ENSEMBLES (Contract number 505539) whose support is gratefully acknowledged. We thank the Max-Planck Institute for Meteorology, the Danish Meteorological Institute and the Centre National de Recherches Météorologiques for making their simulation data available for the project.

References

Boyd R and Hunt, A (2004). *Costing the impacts of climate change in the UK: overview of guidelines, UKCIP Technical Report. UKCIP, Oxford, July 2004.*

Brown S, Nicholls RJ, Lowe JA, Hinkel J (in prep) *Spatial variations in sea-level rise and global impacts: An application of DIVA.*

Church JA, White NJ (2006) *A 20th century acceleration in global sea-level rise. Geophysical Research Letters 33 L01602, doi:10.1029/2005GL024826.*

Church JA, White NJ (2011) *Sea-level rise from the late 19th to the early 21st century. Surv Geophy DOI 10.1007/ s10712-011-9119-1.*

Delta Commissie (2008) *Working together with Water. A living land builds for its future. Findings of the Deltacommissie. DeltaCommissie, The Netherlands.* http://www.deltacommissie.com/doc/deltareport_full.pdf Accessed March 2011.

Environment Agency (20010). *The Thames Barrier project pack 2010, Environment Agency.* http://www.environment-agency.gov.uk/static/documents/Leisure/Thames_Barrier_2010_project_pack.pdf Accessed March 2011.

Evans E, Ashley R, Hall J, Penning-Rowsell E, Sayers P, Thorne C, Watkinson A (2004) *Foresight. Future flooding. Scientific summary: Volume 2 – Managing future risks. Office of Science and Technology, London.*

Evans EP, Simm JD, Thorne CR, Arnell NW, Ashley RM, Hess TM, Lane SN, Morris J, Nicholls RJ, Penning-Rowsell EC, Reynard NS, Saul AJ, Tapsell SM, Watkinson AR, Wheater HS (2008) *An update of the Foresight Future Flooding 2004 qualitative risk analysis. Cabinet Office, London.*

Gardiner S, Hanson S, Nicholls R, Zhang Z, Jude S, Jones A, Richards J, Williams A, Spencer T, Cope S, Gorczynska M, Bradbury A, McInnes R, Ingleby A, Dalton H (2007) *The Habitats Directive, coastal habitats and climate change – Case studies from the south coast of the UK. In: McInnes R (ed), 2007. Proceedings of the ICE International Conference on Coastal Management. London, Thomas Telford, 193-202.*

Gregory J, Huybrechts P (2006) *Ice-sheet contributions to future sea-level change. Phil Trans Roy Soc Lon A 364: 1709-1731.*

Hinkel J (2005) *DIVA: An iterative method for building modular integrated models. Adv Geosci 4:45-50.*

Hinkel J, Klein RJT (2009) T*he DINAS-COAST project: Developing a tool for the dynamic and interactive assessment of coastal vulnerability. Global Environ Change 19 (3):384-395.*

Hinkel J, Nicholls RJ, Vafeidis AT, Tol RSJ, Avagianou T (2010) *Assessing risk of and adaptation to sea-level rise in the European Union: An application of DIVA. Mitig Adapt Strateg Glob Change 15:03-719.*

Hinkel, J et al., (in prep) *A global analysis of coastal erosion of beaches due to sea-level rise: an application of DIVA. In preparation.*

IPCC (2007) Climate change 2007: *Synthesis report: Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri RK, Reisinger A (eds)) IPCC, Geneva, Switzerland.*

Klein RJT, Nicholls RJ, Ragoonaden S, Capobianco M, Aston J, Buckley EN, (2001) *Technological options for adaptation to climate change in coastal zones. J Coast Res 17(3):531–543.*

Lee M (2001) *Coastal defence and the Habitats Directive: Predictions of habitat change in England and Wales. Geog J 167(1): 39-56.*

Linham MM and Nicholls RJ (2010) *Technologies for climate change adaptation – coastal erosion and flooding. UNEP report, Denmark.*

Lowe JA, Hewitt CD, van Vuuren DP, Johns TC, Stehfest E, Royer JF, van der Linden PJ (2009a) *New study for climate modeling, analyses, and scenarios. Eos, Trans Am Geophys Union 90(21):181-182.*

Lowe JA, Howard TP, Pardaens A, Tinker J, Holt J, Wakelin S, Milne G, Leake J, Wolf J, Horsburgh K, Reeder T, Jenkins G, Ridley J, Dye S and Bradley S (2009b) *UK Climate projections science report: marine and coastal projections. Exeter, UK: Met Office Hadley Centre. See* http://ukclimateprojections.defra.gov.uk/images/stories/marine_pdfs/UKP09_Marine_report.pdf. Accessed March 2011.

Meehl GA, Stocker TF, Collins WD, Friedlingstein P, Gaye AT, Gregory JM, Kitoh A, Knutti R, Murphy JM, Noda A, Raper SCB, Watterson IG, Weaver AJ, Zhao Z-C (2007) *Global climate projections. In: Solomon S, Qin D, Manning M et al., (eds) Climate change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, pp 433-497.*

Menéndez M, Woodworth PL (2010). *Changes in extreme high water levels based on a quasi-global tide-gauge data set. J Geophy Res 115:C10011.*

Nakicenovic N, Alcamo J, Davis G., de Vries B., Fenhann J, Gaffin S, Gregory K, Grübler A. et al., (2000), *Special Report on Emissions Scenarios, Working Group III, Intergovernmental Panel on Climate Change (IPCC), Cambridge University Press, Cambridge, UK, pp. 595.* http://www.grida.no/climate/ipcc/emission/index.htm Accessed March 2011.

Nicholls RJ (2007). *Adaptation options for coastal areas and infrastructure: An analysis for 2030, Report to the UNFCCC, Bonn, Germany.*

Nicholls RJ, Brown S, Hanson E, Hinkel J (2010) *Economics of coastal zone. Adaptation to climate change. Discussion paper no. 10. The World Bank, Washington, USA.*

Nicholls RJ, Lowe JA (2004). *Benefits of mitigation of climate change for coastal areas. Global Environmental Change Part A: Human and Policy Dimensions. October 2004, pages 229-244 (doi:10.1016/j.gloenvcha.2004.04.005).*

Nicholls RJ, Tol, RSJ (2006). *Impacts and responses to sea-level rise: a global analysis of the SRES scenarios over the twenty-first century, Philos. Trans. R. Soc. Lond. A, 364:1073-1095.*

Nicholls, RJ, Wong, PP, Burkett, VR, Codignotto, JO, Hay, JE, McLean, RF, Ragoonaden, S and Woodroffe, CD (2007). *Coastal systems and low-lying areas. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (Eds), Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK, pp. 315-356.*

Nicholls RJ, Wong PP, Burkett V, Woodroffe CD, Hay J (2008). *Climate change and coastal vulnerability assessment: scenarios for integrated assessment. Sustainability Sci 3(1): 89-102.*

Pardaens AK, Lowe JA, Brown S, Nicholls RJ, de Gusmão D (2011), *Sea-level rise and impacts projections under a future scenario with large greenhouse gas emission reductions, Geophysical Research Letters, 38:L12604.*

Pfeffer W, Harper J, O'Neel S (2008) *Kinematic constraints on glacier contributions to 21st-century sea-level rise. Science 321 (5894), 1340-1343 (DOI:10.1126/science.1159099).*

Proudman Oceanographic Laboratory (2010). *Permanent Service for Mean Sea-level* http://www.psmsl.org/prodcuts/kml_data Accessed June 2010.

Regione del Veneto (2010). *The MOSE Venice* http://www.veneto.to/web/guest Accessed March 2011.

Rahmstorf S (2007). *A Semi-Empirical Approach to Projecting Future Sea-Level Rise. Science, 315, 368-370.*

Sorensen RM, Weisman RN, Lennon GP (1984). *Control of erosion, inundation and salinity intrusion caused by sea level rise. In: Barth MC, Titus JG (eds) Greenhouse effect and sea level rise. A challenge for this generation. Van Nostran Reinhold Company Inc, New York. Pp179-214.*

Tol RSJ (1995), *The Damage Costs of Climate Change Toward More Comprehensive Calculations, Environmental & Resource Economics 5:353-374.*

Tol RSJ, Klein RJT, Nicholls RJ (2008) *Towards successful adaptation to sea level rise along Europe's coasts. J Coast Res 242:432-442.*

Tol RSJ et al., (in prep). *Flooding and sea-level rise: an application of DIVA, in preparation.*

Vafeidis AT, Nicholls RJ, McFadden L, Tol RSJ, Hinkel J, Spencer T, Grashoff PS, Boot G, Klein RJT (2008) *A new global coastal database for impact and vulnerability analysis to sea-level rise. J Coastal Res 24:917-924.*

van der Linden P, Mitchell, JFB (Eds.) (2009). *ENSEMBLES: Climate Change and its Impacts: Summary of research and results from the ENSEMBLES project. Met Office Hadley Centre, FitzRoy Road, Exeter EX1 3PB, UK. 160pp.*

Vermeer M, Rahmstorf S (2009). *Global sea level linked to global temperature. Proc. Natl Acad. Sci. USA 106, 21 527–21 532. (doi:10.1073/pnas.0907765106).*

Appendix

Table A1. Economic damage cost for the effects of sea-level rise, no upgrade to adaptation.

Analysis	Baseline (1990-2000)	2020s (2011-2040)	2050s (2041-2070)	2080s (2071-2100)
Effects of socio-economic change and climate change together				
A1B scenario				
5%	€2.6 billion/year	€5.0 billion/year	€9.9 billion/year	€19.3 billion/year
Mid	**€2.7 billion/year**	**€5.2 billion/year**	**€10.6 billion/year**	**€25.4 billion/year**
95%	€2.8 billion/year	€5.6 billion/year	€11.7 billion/year	€37.2 billion/year
High SLR (1.2 m by 2100)	**€2.6 billion/year**	**€5.8 billion/year**	**€23.2 billion/year**	**€156 billion/year**
A1B No SLR	€1.9 billion/year	€2.8 billion/year	€4.5 billion/year	€7.0 billion/year
E1 scenario				
5%	€2.5 billion/year	€5.2 billion/year	€11.1 billion/year	€15.8 billion/year
Mid	**€2.6 billion/year**	**€5.6 billion/year**	**€11.7 billion/year**	**€17.4 billion/year**
95%	€2.7 billion/year	€5.8 billion/year	€12.5 billion/year	€20.1 billion/year
E1 No SLR	€1.8 billion/year	€2.9 billion/year	€5.0 billion/year	€7.0 billion/year
Marginal effects due to climate change signal only (minus socio-economic counterfactual)				
A1B				
5%	€0.7 billion/year	€2.2 billion/year	€5.5 billion/year	€12.4 billion/year
Mid	**€0.8 billion/year**	**€2.4 billion/year**	**€6.2 billion/year**	**€18.4 billion/year**
95%	€0.8 billion/year	€2.7 billion/year	€7.3 billion/year	€30.2 billion/year
High SLR (1.2 m by 2100)	**€0.7 billion/year**	**€2.9 billion/year**	**€18.7 billion/year**	**€149 billion/year**
A1B No SLR		€2.8 billion/year	€4.5 billion/year	€7.0 billion/year
E1				
5%	€0.7 billion/year	€2.3 billion/year	€6.0 billion/year	€8.9 billion/year
Mid	**€0.8 billion/year**	**€2.8 billion/year**	**€6.7 billion/year**	**€10.4 billion/year**
95%	€0.8 billion/year	€2.9 billion/year	€7.5 billion/year	€13.1 billion/year
E1 No SLR		€2.9 billion/year	€5.0 billion/year	€7.0 billion/year

These values are presented as current prices without discounting or uplifts.

These values assume no additional coastal protection (adaptation).

Impacts covered include: sum of dry-land-loss costs, people to move, salinisation costs, sea-flood costs and river costs. See Table 4.

Impacts exclude the effects of increased storminess, full ecosystem services, fisheries, ports and marine effects (e.g. acidification).

Table A2. Cost of adaptation in Europe due to the effects of sea-level rise.

Analysis	Baseline (1990-2000)	2020s (2011-2040)	2050s (2041-2070)	2080s (2071-2100)
Effects of socio-economic change and climate change together				
A1B				
5%		€0.9 billion/year	€1.2 billion/year	€1.3 billion/year
Mid		**€1.0 billion/year**	**€1.5 billion/year**	**€1.6 billion/year**
95%		€1.2 billion/year	€1.7 billion/year	€2.0 billion/year
A1B No SLR		€0.5 billion/year	€0.4 billion/year	€0.4 billion/year
E1				
5%		€1.0 billion/year	€0.8 billion/year	€0.5 billion/year
Mid		**€1.2 billion/year**	**€1.0 billion/year**	**€0.7 billion/year**
95%		€1.3 billion/year	€1.2 billion/year	€0.8 billion/year
E1 No SLR		€0.6 billion/year	€0.4 billion/year	€0.2 billion/year
Marginal effects due to climate change signal only (minus socio-economic counterfactual)				
A1B				
5%		€0.4 billion/year	€0.9 billion/year	€0.9 billion/year
Mid		**€0.5 billion/year**	**€1.1 billion/year**	**€1.2 billion/year**
95%		€0.7 billion/year	€1.3 billion/year	€1.7 billion/year
A1B No SLR		€0.5 billion/year	€0.4 billion/year	€0.4 billion/year
E1				
5%		€0.5 billion/year	€0.4 billion/year	€0.3 billion/year
Mid		**€0.6 billion/year**	**€0.6 billion/year**	**€0.5 billion/year**
95%		€0.8 billion/year	€0.7 billion/year	€0.7 billion/year
E1 No SLR		€0.6 billion/year	€0.4 billion/year	€0.2 billion/year

The costs are higher under the E1 scenario because the socio-economic data in this scenario are different.

These values are presented as current prices without discounting or uplifts.

Impacts covered include sum of dry-land-loss costs, people to move, salinisation costs, sea-flood costs and river costs.

Impacts exclude the effects of increased storminess, full ecosystem services, fisheries, ports and marine effects (e.g. acidification). See Table 4.

Adaptation options include beach-nourishment costs, and sea and river dike costs.

Table A3. Residual Impacts after adaptation in the EU (Economic damage impacts after adaptation) due to the effects of sea-level rise.

Analysis	Baseline (1990-2000)	2020s (2011-2040)	2050s (2041-2070)	2080s (2071-2100)
Effects of socio-economic change and climate change together				
A1B				
5%		€1.7 billion/year	€1.9 billion/year	€2.5 billion/year
Mid		**€1.7 billion/year**	**€2.0 billion/year**	**€2.7 billion/year**
95%		€1.8 billion/year	€2.2 billion/year	€2.9 billion/year
A1B No SLR		€1.4 billion/year	€1.4 billion/year	€1.8 billion/year
E1				
5%		€1.5 billion/year	€1.7 billion/year	€1.9 billion/year
Mid		**€1.6 billion/year**	**€1.8 billion/year**	**€2.0 billion/year**
95%		€1.7 billion/year	€1.8 billion/year	€2.1 billion/year
E1 No SLR		€1.2 billion/year	€1.3 billion/year	€1.5 billion/year

Marginal effects due to climate change signal only (minus socio-economic counterfactual)				
A1B				
5%		€0.3 billion/year	€0.5 billion/year	€0.8 billion/year
Mid		**€0.3 billion/year**	**€0.6 billion/year**	**€0.9 billion/year**
95%		€0.4 billion/year	€0.8 billion/year	€1.1 billion/year
A1B No SLR				
E1				
5%		€0.3 billion/year	€0.4 billion/year	€0.4 billion/year
Mid		**€0.4 billion/year**	**€0.5 billion/year**	**€0.5 billion/year**
95%		€0.4 billion/year	€0.5 billion/year	€0.6 billion/year
E1 No SLR				

The costs are higher under the E1 scenario because the socio-economic data in this scenario are different.

These values are presented as current prices without discounting or uplifts.

Impacts covered include sum of dry-land-loss costs, people to move, salinisation costs, sea-flood costs and river costs.

Impacts exclude the effects of increased storminess, full ecosystem services, fisheries, ports and marine effects (e.g. acidification). See Table 4.

Adaptation options include beach-nourishment costs, and sea and river dike costs.

Table A4. Benefits of adaptation in the EU due to the effects of sea-level rise.

Analysis	Baseline (1990-2000)	2020s (2011-2040)	2050s (2041-2070)	2080s (2071-2100)
Effects of socio-economic change and climate change together				
A1B				
5%		€2.5 billion/year	€6.8 billion/year	€15.5 billion/year
Mid		**€2.5 billion/year** (ratio benefits: costs = 3.9)	**€7.1 billion/year** (ratio benefits: costs = 5.2)	**€21.1 billion/year** (ratio benefits: costs = 14.2)
95%		€2.6 billion/year	€7.9 billion/year	€32.3 billion/year
A1B No SLR		€1.0 billion/year	€2.7 billion/year	€4.9 billion/year
E1				
5%		€2.6 billion/year	€8.6 billion/year	€13.4 billion/year
Mid		**€2.9 billion/year** ratio benefits: costs = 3.9)	**€8.9 billion/year** (ratio benefits: costs = 10.9)	**€14.7 billion/year** (ratio benefits: costs = 20.9)
95%		€2.8 billion/year	€9.5 billion/year	€17.1 billion/year
E1 No SLR		€1.1 billion/year	€3.3 billion/year	€5.2 billion/year
Marginal effects due to climate change signal only (minus socio-economic counterfactual)				
A1B				
5%		€1.5 billion/year	€4.1 billion/year	€10.7 billion/year
Mid		**€1.5 billion/year** (ratio benefits: costs = 3.9)	**€4.5 billion/year** (ratio benefits: costs = 5.2)	**€16.2 billion/year** (ratio benefits: costs = 14.2)
95%		€1.6 billion/year	€5.2 billion/year	€27.4 billion/year
A1B No SLR		€1.0 billion/year	€2.7 billion/year	€4.9 billion/year
E1				
5%		€1.6 billion/year	€5.3 billion/year	€8.2 billion/year
Mid		**€1.8 billion/year** (ratio benefits: costs = 3.9)	**€5.6 billion/year** (ratio benefits: costs = 10.9)	**€9.4 billion/year** (ratio benefits: costs = 20.9)
95%		€1.7 billion/year	€6.2 billion/year	€11.9 billion/year
E1 No SLR		€1.1 billion/year	€3.3 billion/year	€5.2 billion/year

The costs are higher under the E1 scenario because the socio-economic data in this scenario are different.

These values are presented as current prices without discounting or uplifts.

Impacts covered include sum of dry-land-loss costs, people to move, salinisation costs, sea-flood costs and river costs.

Impacts exclude the effects of increased storminess, full ecosystem services, fisheries, ports and marine effects (e.g. acidification). See Table 4.

Adaptation options include beach-nourishment costs, and sea and river dike costs.

Table A5. Country codes for Figure 9

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

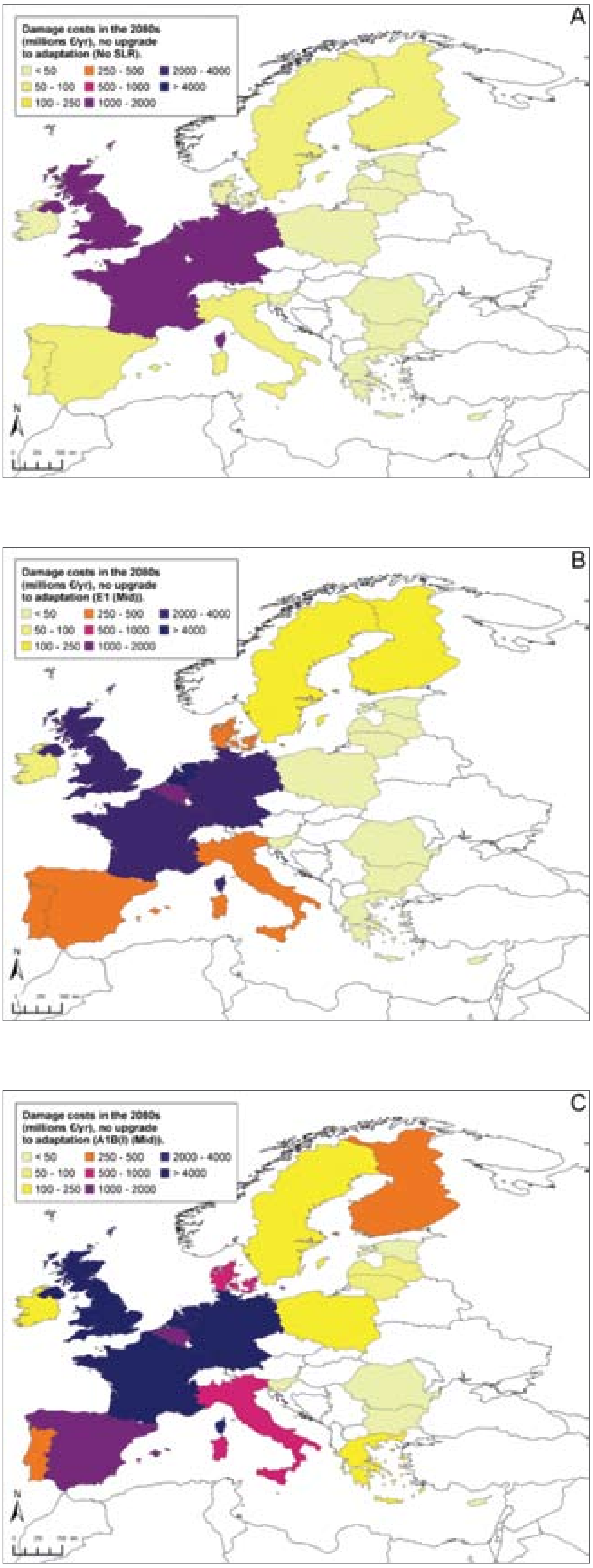


Figure A1. Damage costs (due to people moving, land loss, salinisation, sea flood and river flood costs) for no upgrade in adaptation in the 2080s (millions of Euros/year) for:

A) No sea-level rise

B) E1 (Mid)

C) A1B(I) (Mid)

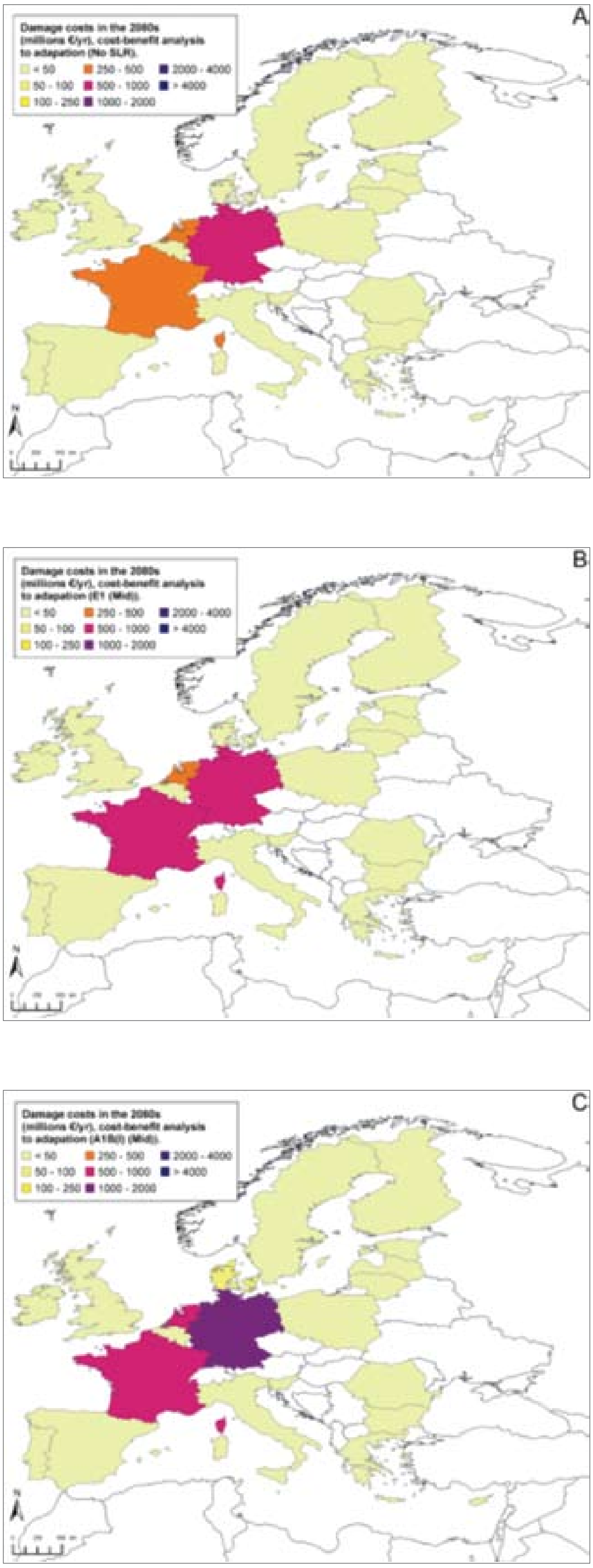


Figure A2. Damage costs (due to people moving, land loss, salinisation, sea flood and river flood costs) using a cost-benefit analysis for adaptation in the 2080s (millions of Euros/year) for:

A) No sea-level rise

B) E1 (Mid)

C) A1B(I) (Mid)

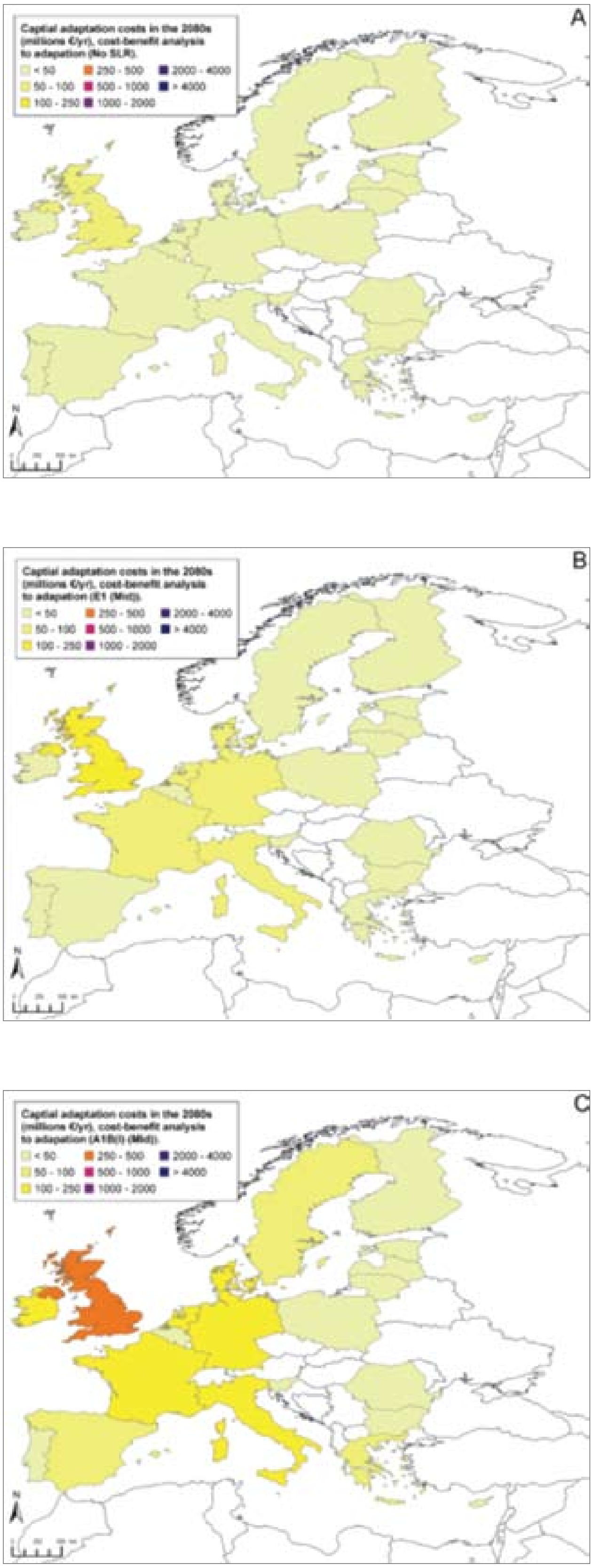


Figure A3. Capital adaptations costs (due to sea dike and river dike building and beach nourishment) using a cost-benefit analysis for adaptation in the 2080s (millions of Euros/year) for:

A) No sea-level rise

B) E1 (Mid)

C) A1B(I) (Mid)

Technical Policy Briefing Note 02

Further information

To find out more about ClimateCost, please visit:
www.climatecost.eu

For further information about ClimateCost, please contact **Paul Watkiss** at:
paul_watkiss@btinternetcom

For further information on the coastal analysis and the DIVA Model, contact **Robert Nicholls** at
r.j.nicholls@soton.ac.uk

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007- 2013) under grant agreement n° 212774. The views expressed in this publication are the sole responsibility of the author(s) and do not necessarily reflect the views of the European Commission. The European Community is not liable for any use made of this information.

First published September 2011

The CimateCost project involved 22 partners, the lead organisation being the Stockholm Environment Institute (Oxford).

SEI STOCKHOLM ENVIRONMENT INSTITUTE

Citation. Brown S, Nicholls RJ, Vafeidis A, Hinkel J, and Watkiss P (2011). The Impacts and Economic Costs of Sea-Level Rise in Europe and the Costs and Benefits of Adaptation. Summary of Results from the EC RTD ClimateCost Project. In Watkiss, P (Editor), 2011. The ClimateCost Project. Final Report. Volume 1: Europe. Published by the Stockholm Environment Institute, Sweden, 2011. ISBN 978-91-86125-35-6.

ClimateCost

SEVENTH FRAMEWORK
PROGRAMME

EUROPEAN COMMISSION
European Research Area