

The ClimateCost Project Final Report

Volume 1:
Europe

The Impacts and Economic Costs of Climate Change in Europe and the Costs and Benefits of Adaptation

Summary of Results from the
EC RTD ClimateCost Project

ClimateCost



EUROPEAN COMMISSION
European Research Area

ClimateCost: The Full Costs of Climate Change

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

Introduction and Aims

There is increasing interest in the economics of climate change to:

- Provide important information on the costs of inaction (the economic effects of climate change);
- Inform the policy debate on long-term targets and mitigation policies;
- Assess the costs and benefits of adaptation.

The aim of the FP7 funded ClimateCost project has been to advance the knowledge in all of the three areas above, using detailed sectoral analysis alongside top-down aggregated analysis and modelling. To progress this, the project has undertaken a number of work packages, in line with the key research objectives.

First, the project has identified and developed consistent scenarios for climate change and socio-economic development, including mitigation scenarios.

The project considered a medium-high non-mitigation baseline scenario (A1B) and a mitigation scenario (E1), which stabilises global temperature change at about 2°C above pre-industrial levels.

For each of these scenarios, the project assessed three future time slices, for the years 2011 – 2040 (the 2020s), 2041-2070 (the 2050s) and 2071-2100 (the 2080s) and used recent multi-model projections from the ENSEMBLES project.

Using these scenarios, the project has quantified in physical terms, and valued in monetary values, the economic impacts of future climate change (the 'costs of inaction') for the EU.

This work included a detailed sectoral analysis, using bottom-up models for market and non-market sectors (coasts, health, ecosystems, energy, agriculture and infrastructure). This has considered a large number of sectoral impacts, assessing the impacts (number of people flooded, agricultural production changes, increases in cooling demand, etc.), and then assessing these impacts in monetary terms.

The results show large economic costs arise from climate change in Europe. They also show a strong distributional pattern in the levels of impacts between Member States.

The use of different scenarios demonstrates that these economic costs are significantly lower under the E1 mitigation scenarios, i.e. with mitigation, but only after the year 2040. This highlights the need for both adaptation and mitigation.

The analysis has also quantified and valued the costs and benefits of adaptation in Europe. The results show that adaptation is generally very effective at reducing the impacts of climate change at low cost. However, the study has also considered the uncertainty in the climate models and how these affect the costs of inaction, and adaptation costs and benefits. This highlights the need for robust and resilient adaptation strategies, which work within a framework of decision making under uncertainty.

The study has quantified the improvements in air quality from mitigation policy in Europe (co-benefits) and assessed the economic benefits of these. The size of these co-benefits is found to be very large, and occur directly in Europe. They are therefore very relevant to the policy discussion on the costs and benefits of mitigation.

The project has also explored the risks of major catastrophic events (tipping extremes). While these involve large-scale global effects, the economic analysis shows that they could disproportionately increase the sector impacts above, such as with the effects of major sea level rise in Europe.

Finally, the study has used a number of the global models to look at the European and global costs and benefits of mitigation.

This paper summarises the results of the project, focusing on the European analysis.

Climate Models and Uncertainty

Analysis of the future impacts and economic costs of climate change requires climate models. These models require inputs of future greenhouse gas emissions, based on modelled global socio-economic scenarios, to make projections of future changes in temperature, precipitation and other meteorological variables.

The ClimateCost project has considered three emissions scenarios: a medium-high non-mitigation baseline scenario (A1B); a mitigation scenario (E1), which stabilises global temperature change at about 2°C above pre-industrial levels; and a high-emission scenario (RCP8.5).

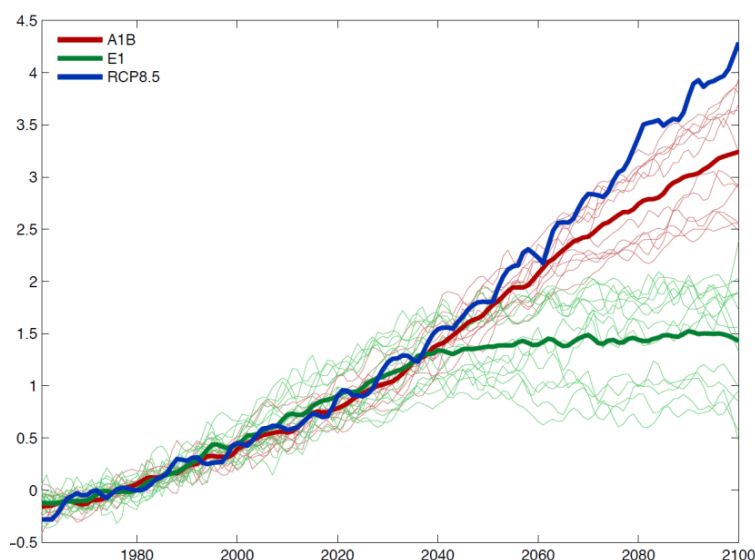
Under a medium-high emission baseline (A1B), with no mitigation, the climate models and results considered in ClimateCost, from the ENSEMBLES project, show that global average temperatures could rise by between 1.6°C and 2.3°C by 2041-2070, and 2.4°C and 3.4°C by 2071-2100, relative to the modelled baseline period used in the project (1961-1990). However, the models project much larger temperature increases for Europe in summer, and strong regional differences across countries: for example, the Iberian Peninsula has a mean projected increase of up to 5°C by 2071-2100.

The differences in the precipitation projections between the models are much greater and the distributional patterns across Europe are more pronounced than for temperature. Nonetheless, there are some robust patterns of change. There are wetter winters projected for Western and Northern Europe. By contrast, there are drier conditions projected all year for Southern Europe, where summer precipitation could be reduced by 50% by the end of the century. In other parts of Europe, the changes are more uncertain, and the models even project differences in the direction of change (i.e. whether increases or decreases will occur).

Under an E1 stabilisation scenario, broadly equivalent to the EU 2 degrees global target, all changes are significantly reduced. Average global temperatures are projected to increase by about 1.5°C by 2071-2100 compared with the 1961-1990 baseline. In Europe, summer temperatures are projected to increase by more than 2°C and possibly in excess of 3°C by 2071-2100 relative to the 1961-1990 baseline even under this mitigation scenario. Under this mitigation scenario, the stronger wetter signal in Northern Europe and the drier summer signal in

Southern Europe are both considerably reduced, though there are still major variations across different models.

The study has also considered the new RCP8.5 'high' scenario. This reaches a global warming of about 3.5°C by 2071-2100 relative to the 1961-1990 baseline. The uncertainty cannot be estimated for this scenario, as only one simulation was available to the project.



Projected change in global mean temperature (°C) with respect to the 1961-1990 baseline for the A1B (red) and E1 (green) and RCP 8.5 emissions scenarios.

Results from the ENSEMBLES project GCM runs. Blue line shows the EC-Earth RCP8.5 model run, thin lines show individual models, and thick red and green lines show ensemble mean.

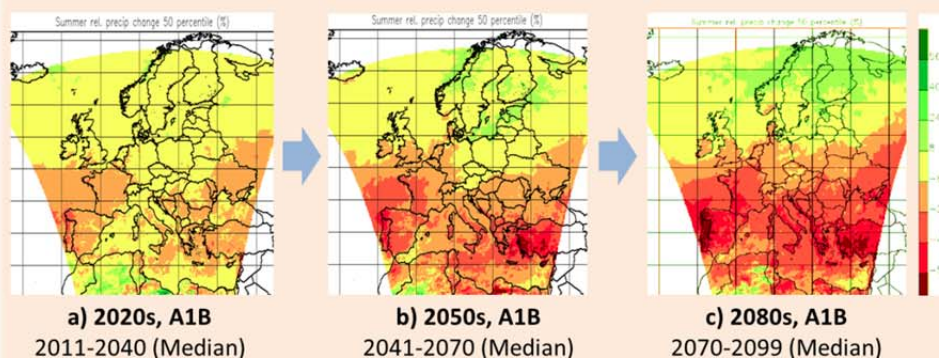
It is highlighted that the E1 (mitigation) projections only diverge significantly from A1B after 2040 (i.e. the differences only emerge in the latter part of the century). Mean global temperature is projected to increase by about 1°C by 2011-2040 relative to the 1961-1990 baseline, irrespective of the emission pathway. This highlights the need for adaptation and mitigation.

As has been found by other studies, projections of future climate change, particularly for precipitation, are uncertain. This is shown in the figure below, which shows the projections of summer precipitation in Europe.

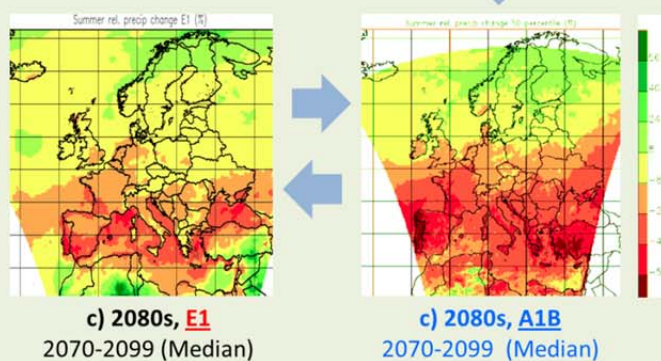
It is essential to recognise and to try to quantify this uncertainty, not to ignore it. In ClimateCost, this has been addressed with the use of multi-model analysis. It also leads to the need to plan robust strategies to prepare for uncertain futures and not to use uncertainty as a reason for inaction.

Relative change in **summer precipitation** (%) for summer (June, July and August) in 11 RCM simulations from the ENSEMBLES archive

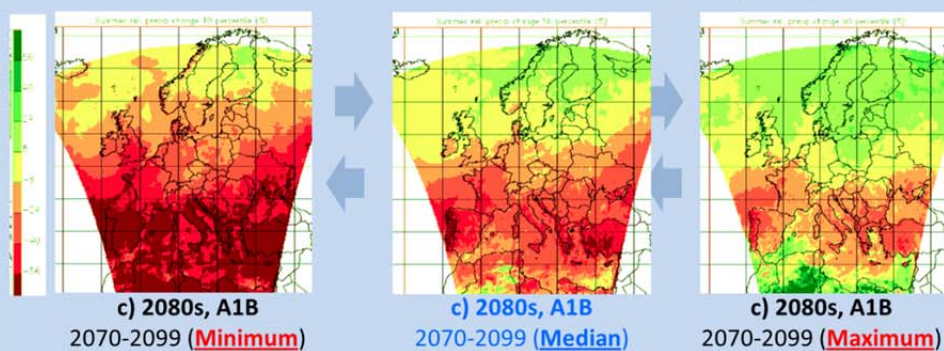
1. Change over the three time periods, for one emission scenario (A1B)



2. Difference between mitigation (E1) and reference (A1B) scenarios (2080s)



3. Range across model projections for the same emission scenario (A1B) and same time period (2080s)



In 1) the '**Change over the three time periods**', the relative precipitation signal can be seen for 2011-2040, 2041-2070 and 2071-2100 – with the red colour scale indicating a decrease and the green an increase in seasonal precipitation. There are strong differences in the precipitation changes over time for Europe with increasing amplitude through the three time periods. There is also a strong spatial pattern of change across Europe, which is similar in all periods.

In 2) the '**Difference between the reference and mitigation scenario**', the relative change for two alternative scenarios (i.e. A1B and E1) are shown for the time period 2071-2100. These reveal there are important end-of-century differences. Indeed, the projections for the E1 2080s are similar to the projections for A1B for the 2050s.

In 3) the '**Range across the model projections**', the low – mid – high range across the 11 models for the A1B scenario in 2071-2100 are shown, revealing the very wide range of results from the models. In many areas, even the direction of the change is different across the range of model projections. **This uncertainty is critical for the consideration of adaptation.**

Sea-Level Rise and Coastal Zones

Coastal zones contain high population densities, significant economic activities and provide important 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.

An estimated 55,000 additional people will be directly affected by coastal flooding each year by the 2050s (A1B scenario), with expected annual damage costs of €11 billion/yr.

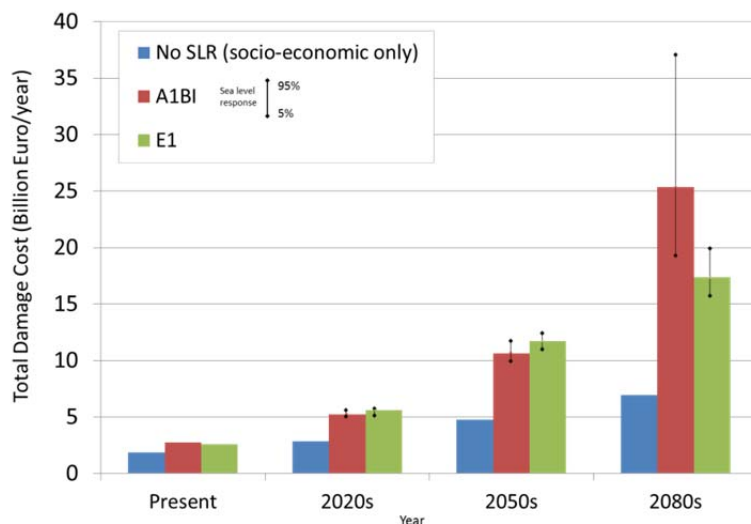
The ClimateCost study has assessed the potential impacts and economic costs of sea-level rise in Europe, and the costs and benefits of adaptation. The analysis used the DIVA Model, and considered future climate and socio-economic change. As floods are probabilistic events, the results are presented as expected annual damage (EAD) costs (undiscounted).

For Europe, the mid-range projections for a medium-to-high emissions scenario (A1B(I)) suggest 37cm 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 26cm 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, the 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), shown in the figure below. 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.

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.



Total damage cost (current 2005 prices, undiscounted) for the EU for the A1B(I) and E1 scenarios and no sea-level rise 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.

In addition, sea-level rise will affect coastal ecosystems. Wetlands act as natural flood barriers and feeding grounds, and 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 metre 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 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) scenario.

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 cost of adaptation has been estimated at €1.5 billion per year 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.

River Floods

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

An estimated 290,000 additional people will be directly affected by river flooding each year by the 2050s (A1B scenario), with expected annual damage costs of €46 billion/yr.

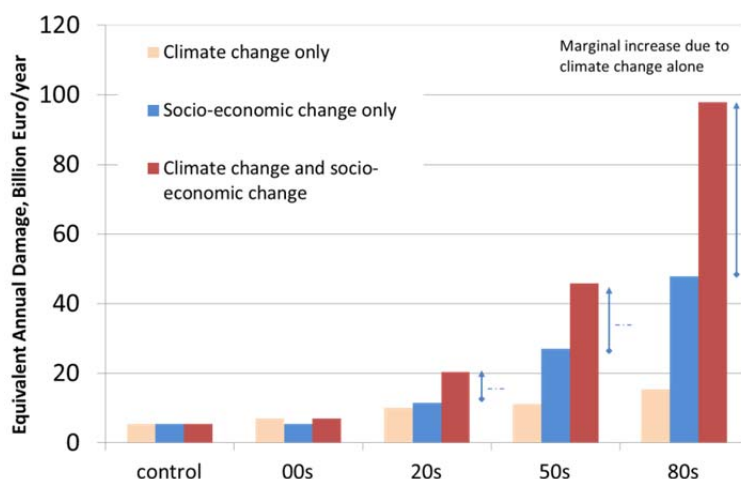
The ClimateCost study has assessed the potential impacts of climate change on river flood damage in Europe, and the costs and benefits of adaptation. The analysis used the LISFLOOD model, and considered future climate and socio-economic change. As floods are probabilistic events, the results are presented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

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

The economic damages from flooding on the residential and other sectors were then assessed. The EAD in the baseline climate period (with current socio-economic conditions) is estimated at around €5.5 billion in the EU27. The analysis then looked at the increase in the number of people and the EAD from future climate change, considering three future time

periods (averaged in thirty year periods), for a medium-high emission and mitigation scenario.

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



EU27 Annual Damage from floods in billions of Euros

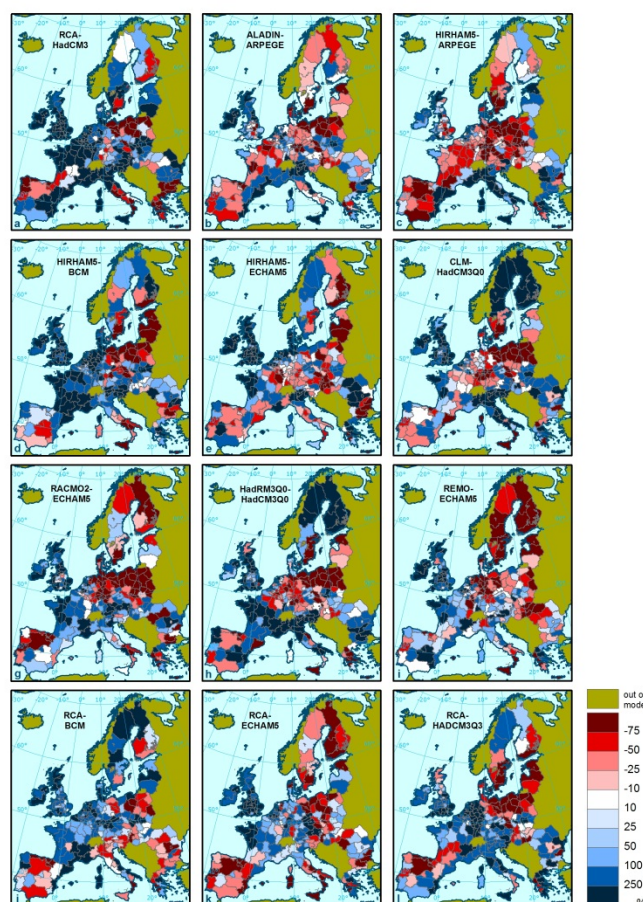
For baseline period (1961-1990), 2000s (1981-2010), 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) for the A1B scenario based on LISFLOOD simulations driven by 12 regional climate models. Values in constant 2006 prices, undiscounted, assuming no adaptation.

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

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

There is a very wide range around these central (mean) estimates, representing the range of results from different climate models. The study considered 12 alternative climate outputs (GCM-RCM combinations). These reveal that the potential costs vary by a factor of two (higher or lower).

These differences are even more significant at the country level, with some models even reporting differences in the effects of climate change (i.e. some models project relative reductions in future flood risk from climate change for some areas, as shown in the figure below). This highlights the need to consider this variability (uncertainty) in formulating adaptation strategies.



Change in Expected annual damage between the 2080s (2071-2100) and baseline period (1961-1990) for the A1B scenario based on LISFLOOD simulations driven by various regional climate models. Each plate represents the results for one of the 12 model combinations

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

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

The socio-economic uncertainty and climate-model variability make a large difference to the actual adaptation response at a country level. The need to recognise and work with uncertainty – as part of integrated and sustainable policies – requires an iterative and flexible approach. A number of implications arise from the analysis, the most important of which is to start including these issues in policy across Europe.

Energy

Temperature is already a major driver of energy demand in Europe for the domestic and service sectors, driving winter heating and summer cooling. Climate change will have positive and negative effects on these demand levels, reducing winter heating demand but increasing summer cooling demand. However, these changes need to be seen in the context of other socio-economic drivers and future energy and mitigation scenarios. Climate change may also have other effects on energy supply technologies,

notably on hydro electricity generation, but also potentially on other supply technologies.

The costs of additional electricity consumption for air conditioning (cooling) are estimated to rise to around \$ 130 billion/year in EU27 by 2100 (A1B scenario).

The ClimateCost study has assessed the potential impacts and economic costs of climate change on energy supply and demand in Europe. The analysis used the POLES model, and considered future climate and socio-economic change, as well as future climate change. This takes account of energy growth, but also mitigation policy and the effects on the energy mix

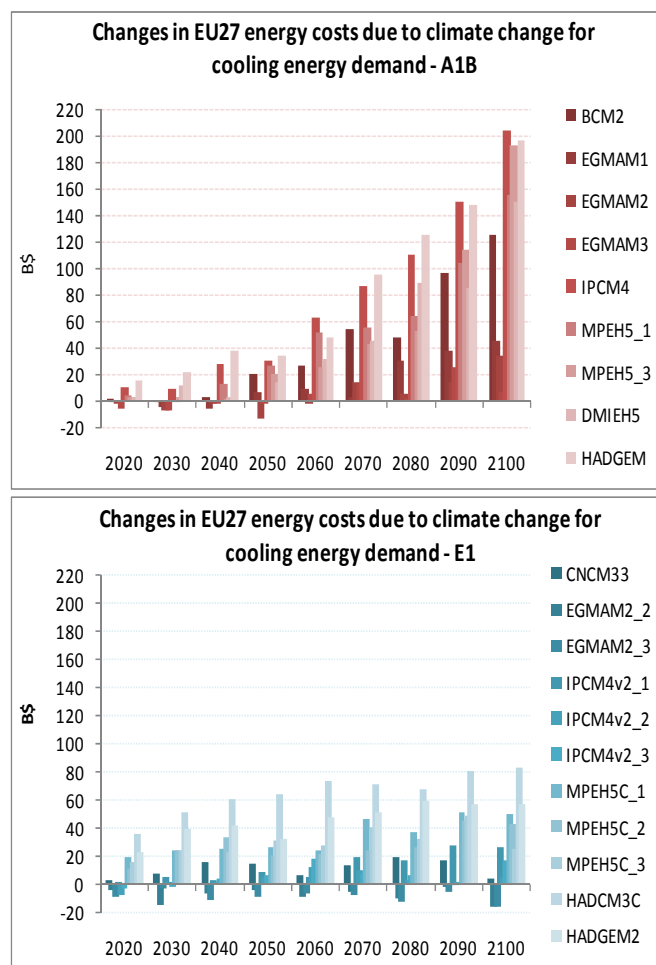
The study has first assessed the decrease in heating demand in Europe from climate change for two scenarios. A medium-high emission scenario (A1B) and a low emission (mitigation scenario, E1), the latter consistent with the 2 degrees stabilisation target. The POLES simulations for the A1B and E1 scenarios, incorporating climate change, show reduced demand, of -9 % by 2050 to -22% by 2100 for the A1B scenario and from -6 to -9% for E1 scenario. The results in the service sector are more important in absolute figures, but similar in relative terms. There are also large differences by region of Europe (and country) with the largest reductions in Western Europe. When considered in economic terms, this reduction in heating demand is estimated at \$ 140 billion/year in the EU27 by 2100 under the A1B scenario (as the reduction in heating expenditures), corresponding to around -0.17% of projected EU27 GDP in 2100.

The study has also assessed the increase in cooling demand in Europe. Under the A1B scenario EU27 electricity use for space cooling is projected to increase by around 3% a year during the century. With climate change, the analysis estimates an increase in the domestic sector from 22% to 127% for the 2050s for the A1B scenario and 83% for the service sector. There is a strong distributional effect across Europe, with much higher increases in Southern Europe.

The costs of additional electricity consumption for air conditioning in residential and service sector have been estimated rise to around \$ 130 billion/year in EU27 by 2100 under the A1B scenario. Note there is a considerable range around these values, as shown in the figure below, which reflects the warming signal from different climate models. However, this cost only includes the energy costs. To consider the full costs of cooling, it is also necessary to add the investment

costs for new air conditioners. Taking this new capacity into account increases the costs significantly, by \$23 billion by 2100.

These costs are reduced significantly under the E1 mitigation scenario, as shown in the figure below.



EU27 cooling consumption, estimated energy costs in the A1B scenario (top), additional investment costs and energy costs in the E1 scenario (bottom). Variations presented for alternative climate models, set against socio-economic baseline.

Source POLES model.

The study has also looked at the potential for low and very low efficiency houses in response to the cooling trends above, a planned adaptation response to additional cooling demand.

The study has also considered energy supply effects. Hydropower plants are potentially affected by climate change. The impacts of climate change on hydro generation varies strongly according to the climate models, due to the fact that different models predict very different levels of precipitation change.

Nonetheless, the A1B scenario results show a decrease of European hydro generation due to climate

change of around -3% in 2050 and -8% in 2100, compared to the case without climate change. The impacts are lower for E1 scenario at respectively around -2 and -3%.

The values vary according to the region. Results indicate decreasing discharge volumes for southern and east-central Europe, by more than 20% in some countries, whilst the projected rises in discharge volumes for northern European countries may at times exceed 20%. Note that this analysis does not take annual variability into account.

In addition, higher temperatures affect power plant cooling influence efficiency. This effect has been also considered in POLES. The efficiency decrease was derived and implemented for all types of thermal power plants (nuclear and fossil) and the results estimate that thermal and nuclear power generation could be constrained respectively 2-3% and 4-5% per year, which would mean less 150 TWh per year due to changes in CDD in A1B scenarios.

The total supply side analysis implies annual European energy costs could be as high as \$ 95 billion in 2100.

Health

There are a large number of potential health impacts that could arise from climate change, directly or indirectly, including heat-related mortality and morbidity, food safety and vector-borne diseases, outdoor air pollution, deaths, injuries and wider well-being from flooding, though there are also some potential benefits. There are also risks to health infrastructure and other critical infrastructure (water and power supplies) from extreme weather events.

The ClimateCost study has assessed the potential impacts and economic costs of health impacts in Europe, focusing on four impacts: heat related mortality, food borne disease, coastal flooding and labour productivity. This has considered future climate and socio-economic change. The latter is important in taking into account age specific changes in population, particularly Europe's aging population.

An estimated 90 thousand additional heat related deaths are projected each year by the 2050s (under the A1B scenario), with an expected welfare cost of €30 billion/year.

The study has first focused on heat related mortality. Under a medium to high emission (A1B) scenario,

with no mitigation or adaptation, the study estimates that there could be an additional 26 thousand deaths/year from heat by the 2020s (2011-2040), rising to 88 thousand/year by the 2050s (2041-2070) and 126 thousand/year by the 2080s (2071-2100). These values reflect the changes from climate change alone. While heat-related mortality in Europe is projected to increase in all regions, there are relatively higher levels of climate change attributable heat deaths in Southern Europe. The cost of these impacts depends very significantly on the valuation method used for changes in the risk of fatality, specifically whether a Value of a Life Year Lost (VOLY) or a Value of a Statistical Life (VSL) is used. Using the latter, the estimated welfare costs are €30 billion/year by the 2020s (2011-2040), €102 billion/year by the 2050s (2041-2070) and €146 billion/year by the 2080s (2071-2100). but these values fall by over an order of magnitude if the VOLY approach is used.

Under an E1 stabilisation scenario, broadly equivalent to the EU 2 degrees target, these impacts are reduced significantly (after 2040), falling to 74 thousand deaths/year by the 2050s (2041-2070) and remaining broadly similar in the 2080s (2071-2100). The equivalent economic costs are €87 billion/year by the 2050s (2041-2070) if the VSL approach is used.

However, including physiological (autonomous) acclimatisation in the analysis reduces these impacts significantly. With acclimatisation, the estimated number of heat related deaths fall to 13 thousand/year in the 2020s) 44 thousand/year in the 2050s and 40 thousand per year in the 2080s under the A1B scenario. The equivalent figures for the E1 scenario are 31 thousand/year in the 2050s and 15 thousand per year in the 2080s. The welfare costs fall in line with these estimates, though they are still very significant if the higher VSL estimate is used.

The analysis has also assessed the impacts of climate change on food borne disease. Salmonellosis is a leading cause of food borne illness in Europe and is sensitivity to ambient temperature. The estimates suggest that under the A1B scenario, climate change (alone) could lead to an additional 7 thousand cases/year of salmonellosis in EU27 by 2020s, rising to 13 thousand by the 2050s and 17 thousand by the 2080s, if the incidence remains at current levels, but with 5.5, 8.8 and 9.3 thousand cases/year if a baseline decline in incidence is assumed. Under the E1 scenario, these fall to around 6-7 thousand cases per year (2050s/2080s, baseline decline). The economic costs of these additional food borne illnesses has also been estimated. The welfare costs are estimated at €36 million/year in the 2020s (A1B, current baseline),

rising to €68 and €89 million/year in the 2050s and 2080s respectively (€30, 46 and 49 million/year if a baseline decline in incidence is included).

Coastal flooding is associated with direct health impacts including fatalities. The study has assessed the impacts of climate change (sea level rise and storm surge). Climate and socio-economic change is estimated to lead to 130 deaths/year in the EU by the 2050s and 650 deaths/year in the EU by the 2080s (A1B) with two thirds of these arising in Western Europe. The associated welfare costs are estimated at €151/year in the 2050s and €750 million/year by the 2080s. These fall significantly under the E1 mitigation scenario to 100 (2050s) and 185 (2080s) fatalities/year, with welfare costs of €117/year (2050s) and €214 million/year (2080s).

Finally, the study has assessed the effects of higher temperatures from climate change on outdoor productivity, using well-established physiological limits for active individuals. Climate change is likely to cause negative impacts on labour productivity in some regions. Under the A1B scenario, Southern Europe is estimated to incur a mean loss of productivity – measured here as days lost - of 0.4% to 0.9% by the 2080s (with the range reflecting different future labour structures). Total productivity losses for Europe are estimated at €300 - 740 million/ in 2080s (A1B). These are significantly reduced under the E1 mitigation scenario to €60 - 150 million per year in 2080s.

While these cover many of the major health impacts of climate change, there are other important potential effects, and the analysis above is only partial. As well as health outcomes, these also include the costs of adapting health systems infrastructure, which could be high. There are also future research priorities to assess the effectiveness of specific interventions.

It is stressed that there is a wide range of uncertainty around all these estimates – for all four health categories above - reflecting the underlying uncertainty in emissions scenario and temperature outcomes. The need to recognise and work with this uncertainty – as part of integrated and sustainable health policies – requires an iterative and flexible approach.

The study has also reviewed the information available on the costs of adaptation. The study finds that heat-alert systems are a low cost response for addressing heat related mortality. However, additional case study work in ClimateCost reveals that there are additional resource costs involved with such schemes, and the operating costs rise sharply with future climate change

(as more events are triggered). The analysis also shows that future measures beyond heat alert systems are likely to involve more technical cross-sectoral options through cooling, building design or spatial planning.

For coastal flood risks, other parts of the ClimateCost study (see earlier sea level rise section) have considered technical adaptation (dikes). These show that such adaptation can reduce risks significantly; down to less than 10 deaths per year in 2080 (from 650 without adaptation), reducing residual impacts to around €5 million/year (A1B).

There is much less information on the costs of adaptation for other risks. The limited information available suggests that many early public health based adaptation measures are relatively cost-effective, and/or have high benefit to cost ratios. However, some options (e.g. large-scale vaccination programmes, infrastructure such as cool rooms, new water treatment) increase costs significantly. As impacts evolve over time, and risks become more cross-sectoral in nature, the cost of adaptation may also rise significantly, due to the need for larger capital investment.

Agriculture

Agriculture is a highly climate sensitive sector and the ClimateCost study has investigated the potential impacts and economic costs of climate change, and also the potential benefits of agricultural adaptation in Europe and globally.

The study has developed existing models and data into a ClimateCrop model, which addresses climate change impacts in agriculture as well as adaptation responses. The model integrates land and water spatial analysis, agricultural models (including crop models), and policy analysis. This allows analysis of changes in agro-climatic regions, crop productivity, and crop management (deliberate adjustments of the crop calendar, nitrogen fertilizer, and amount of irrigation water, in order to optimize productivity in each scenario). The economic valuation is conducted using the global GTAP general equilibrium model: the global scale is important because of international agricultural trade.

The study has first assessed the changes to crop productivity with climate change. Crop yield changes include the direct positive effects of CO₂ on the crops, as well as temperature and rainfall. The analysis also assumes some level of baseline (autonomous) farm

level adaptation, including changes in crop distribution due to modified crop suitability under a warmer climate, but do not include planned or structural adaptation.

The results show that agroclimatic regions will change significantly in Europe, as a result of climate change. It also finds large differences between European regions, with strong distributional differences (positive and negative).

In general, there are yield improvements projected for Northern Europe due to a longer growing season (and frost-free period), while crop productivity decreases in Southern Europe. As with other sectoral assessments, the agricultural analysis has considered the full suite of ENSEMBLES GCM runs, and this shows that for Central Europe, the yield changes depend strongly on the particular climate scenario and model output.

At the aggregated level, the net changes in the EU under the A1B scenario are modest by the 2080s: at the global level, however, there is a more marked decrease in crop productivity. However, the variability in the climate model output significantly changes the pattern and level of impacts projected, not least due to the variation in precipitation (see climate model discussion earlier).

The analysis has then considered adaptation. This is incorporated into the results by assessing country or regional potential for reaching optimal crop yield (in the face of climate change), with an without constraints on water application, fertilizer inputs, and management. Three scenarios have been assessed which compare different fertilizer, irrigation and environmental scenarios (and the conflicts between these). The analysis also takes current irrigation efficiency into account.

The results show that different scenarios lead to very different results, but importantly, adaptation seems to reduce the effects of climate change, especially under the E1 mitigation scenario. Indeed, under the E1 scenario, with adaptation, Europe overall would be unlikely to experience yield reductions, though there would be exceptions at the regional level. However, these adaptation policies have implications for water availability and environmental pollution. They also raise concerns for the Mediterranean region, particularly because of water availability, highlighting key cross sectoral resource issues.

In practice, increased water use requires a coordinated series of actions in terms of awareness and education, investment in conservation, maintenance and

improvement of facilities, establishment of rules for exchanging water rights and increasing the flexibility of the operation of the water resource system.

Air Quality Co-Benefits

The study has quantified the improvements in air quality with mitigation (co-benefits) in Europe and assessed these in terms of physical and economic benefits.

The results show very large co-benefits arise with mitigation, which lead to local and immediate benefits. In the EU27, the air quality benefits of mitigation by 2050 are estimated at €48 to €99 billion per year.

Mitigation policy has a beneficial effect in reducing greenhouse gas (GHG) emissions, because it introduces cleaner fuels and improves energy efficiency. These mitigation measures also reduce emissions of air pollutants such as oxides of nitrogen (NO_x), sulphur dioxide (SO₂) and fine particles (PM), and as a result, they improve air quality.

Despite large improvements in Europe in recent decades, current air quality (air pollution) levels are responsible for adverse health and environmental impacts, including a significant shortening of life expectancy. These impacts have large economic costs. The air quality improvements from mitigation policy will reduce these costs, and therefore lead to economic co-benefits.

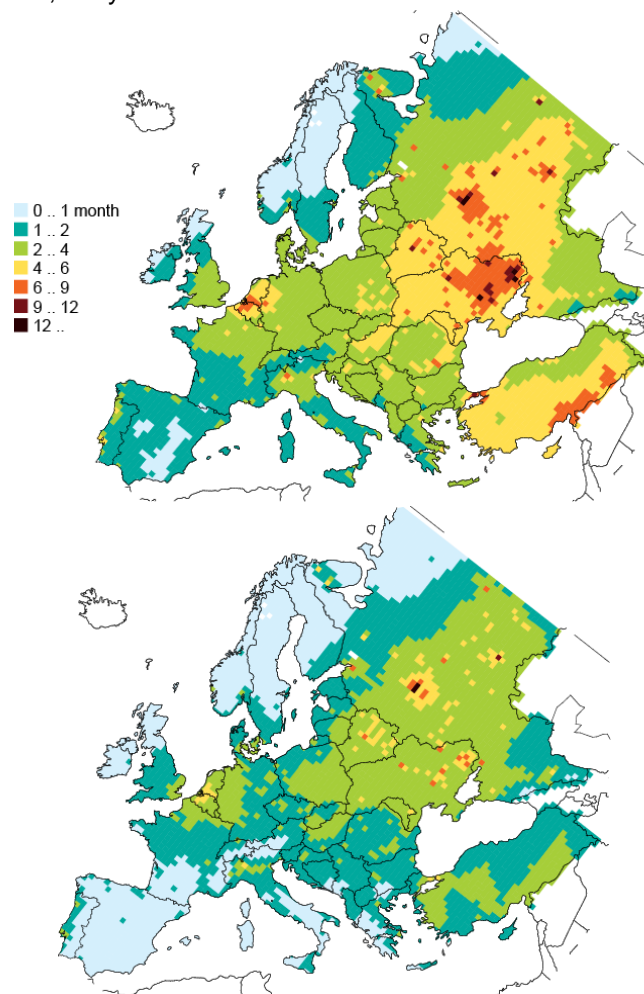
These ancillary co-benefits are important when comparing the costs and benefits of mitigation. Whilst the full benefit of European GHG reductions may only be experienced by future generations and occur at the global level, the ancillary benefits of air quality improvements occur in the short-term and lead to direct (local) benefits in Europe.

The ClimateCost study has assessed the health, environmental and economic air quality benefits of mitigation policy. The analysis used the GAINS and ALPHA models to assess a mitigation policy scenario that is consistent with the EC's 2 degrees target, and compared this to a baseline medium-high emissions scenario.

The estimated benefits of the 2 degrees stabilisation (mitigation) scenario, over and above the baseline scenario, are substantial.

Under the mitigation scenario, there are large reductions in EU air pollutant emissions, with a 60% reduction in sulphur dioxide (SO₂) and a 46% reduction in oxides of nitrogen (NO_x) when compared to the baseline in 2050. There is also a 19% reduction in emissions of particulate matter (PM).

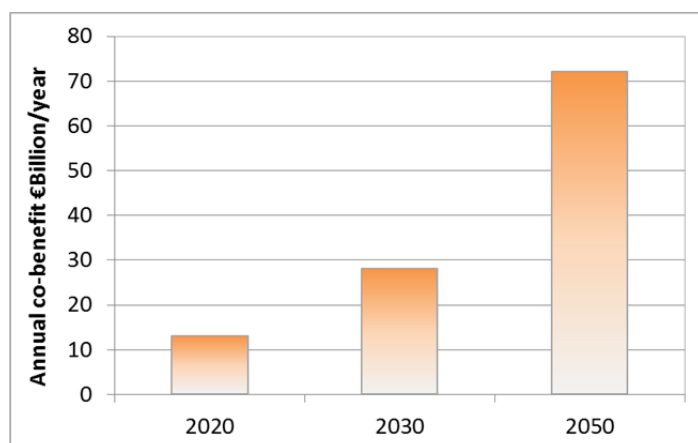
These emission reductions, and the associated improvement in air quality, lead to large health benefits. Under the mitigation scenario, average life expectancy in Europe (EU27) is extended by 1 month of life by 2050: equivalent to an annual benefit of 890,000 years of life.



Statistical loss of life expectancy in Europe due to anthropogenic PM_{2.5} for the Baseline (top panel) and Mitigation (bottom panel) scenarios in 2050; month. (Source GAINS, Rafaj et al, 2011).

In addition, the mitigation scenario reduces the number of ozone related deaths in the EU27 by 2800 fatalities a year by 2050, as well as reducing the annual number of cases of chronic bronchitis and hospital admissions by 36,000 and 23,000 respectively. It also leads to an estimated reduction of 150 million minor symptom days each year by 2050.

The economic benefits of these health improvements are estimated at €44 billion per year in 2050 in the EU27 (current prices, undiscounted), based on a value of life years lost approach for the change in mortality risk. Using an alternative valuation metric of the value of a statistical life, the benefits of the mitigation scenario increase to €98 billion per year by 2050. Additional benefits from avoided material and crop damage increase these slightly.



EU Annual Health Co-benefits (Net benefit of the Mitigation Scenario relative to the Baseline) (source ALPHA). All figures in €Billions/year (current prices, undiscounted, VOLY estimate).

When expressed against the CO₂ reductions achieved, the air quality co-benefits of the mitigation scenario are around €25 for each tonne of CO₂ reduced.

GHG mitigation policies also reduce the need to implement air quality pollution measures and equipment required by legislation. These avoided costs have also been considered in ClimateCost, using the GAINS model. Under the mitigation scenario, the regulatory air quality costs in the EU27 are reduced by €36 billion per year by 2050, mostly due to avoided costs of NO_x and PM control in the transport sector.

The mitigation scenario also leads to important co-benefits for managed and unmanaged ecosystems, reducing acidification and eutrophication. Under the mitigation scenario, the area of forest in the EU27 that exceeds the critical loads for acid deposition is reduced by 42 thousand km² by 2050, a 15% reduction on the baseline. The area of ecosystems in the EU27 that exceeds the critical load for nitrogen deposition and eutrophication is reduced by 144 thousand km² by 2050.

The study has also considered the air quality benefits of global mitigation policy in other world regions using the GAINS model, which reveals even larger health

benefits. Under the mitigation scenario, the average life expectancy gain is estimated at 19 months in China and nearly 30 months in India by 2050, compared to the baseline, and would also reduce ozone related mortality by more than 75 thousand cases per year across the two countries.

The magnitude of the co-benefits above demonstrates they are very relevant to the policy discussion on the costs and benefits of mitigation. It also emphasises the importance of exploiting synergies in the fields of climate and air pollution.

Other Effects

Ecosystems

ClimateCost has used the Lund-Potsdam-Jena (LPJ) Dynamic Global Vegetation Model, to simulate the impacts of climate change on natural and managed vegetation, linking this to consider forestry with the Global Forest Model (G4M) and the partial equilibrium land use model GLOBIOM.

One of the findings is that biomes will shift further northwards/to higher altitudes. This may lead to a replacement of productive forest ecosystems by lower productive shrublands and to a change in the structure of the landscape. Changes will also occur in carbon storage, with decreases in southern and Central Europe and increase in regions presently covered by taiga vegetation. For the forestry sector, the analysis found a strong climate feedback on forest growth and biomass accumulation that could be tackled through species change. However, this needs time to become effective and these adaptation strategies might conflict with mitigation measures in the forestry sector such as biomass maximization.

Windstorms

Windstorms are one of the major sources of insurance related damage in Europe. However, the evidence of the effects of climate change on future storm frequency and intensity is unclear, thus the project adopted a scoping analysis to investigate the potential order of magnitude of future costs.

The analysis incorporated insured losses as well as other economic losses (such as losses from the transport sector and other affected sectors), looking at the potential economic costs in future periods for plausible increases in wind storm.

The study results estimated that a 20 percent increase in the frequency of the top 5 percent of storms' windspeed would increase annual average economic

losses to a total of around 5 billion Euros by the 2050s under the A1 scenario, though 65% (3.5 billion Euro) of this increase arises because of underlying socio-economic growth.

The analysis then considered the effects of low level adaptation (retrofitting of windows, doors and garage doors). Under this scenario, average annual total economic losses were reduced down to 3.6 billion Euros. The payback period (from analysis of adaptation costs and benefits) for these measures was estimated at between 10-20 years. A comparison with a high adaptation scenario (roof anchoring, roof deck upgrades and roof covering upgrades) led to larger reductions in absolute damages, but a similar pay-back time.

Tipping Points

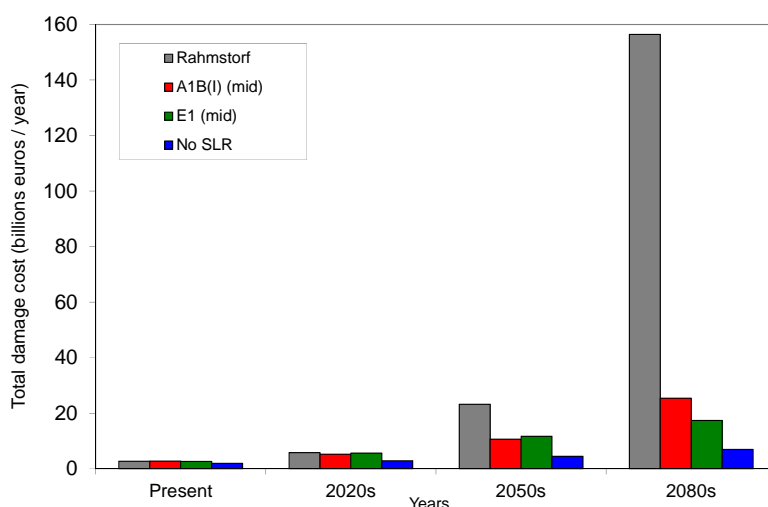
Extreme outcomes – often known as tipping points or tipping elements - refer to the near-catastrophic events and processes that would push the climate system into very undesirable states. While highly uncertain, these tipping elements of this nature are poorly represented in most assessments of the economics of climate change, but as many commentators have highlighted, they are key to the justification for mitigation action.

ClimateCost has updated the literature on the bio-physical tipping extremes. This concludes that a number could have major consequences: melting of the Greenland and West Antarctic ice caps and the Hindu-Kush-Himalaya-Tibetan glaciers; changes in the Atlantic thermohaline circulation and El Nino/Southern Oscillation (ENSO); drought in the Amazon; and shifts in the Indian summer monsoon and rainfall in southwestern North America.

The project has then undertaken a major case study to explore the economic costs of these types of major events, looking at European and global extreme sea level rise. Over 600 million people currently live in the low elevation coastal zone, i.e. at less than 10m elevation and economic activity in this at-risk is over \$2,000 trillion GDP.

Under high emissions scenarios, there is an increased risk of extreme sea-level rise, with some projections estimating over 1 metre by 2100. The study has estimated the potential damage costs from such a scenario using the DIVA model and compared this to the IPCC scenarios used in the earlier coastal assessment. The study finds that these upper sea level rise scenarios lead to non-linear increases in impacts.

For Europe, a rise of 1.4 metres by 2100 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 for only around two times the level of SLR, as shown in the figure below.



Total damage cost with extreme SLR

(present values, undiscounted) for the EU for relative sea-level rise of Rahmstorf (2007), A1B(I) Mid, E1 Mid scenarios and no sea-level rise 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.

At the global level, the changes are even more dramatic. The global population occupying coastal zones subject to inundation (including storm surges) for the high-end scenario is nearly double the population affected A1B-range scenarios. By the 2080s, nearly 25 million people per year would be affected. People choosing to live outside at-risk coastal regions, i.e. SLR-induced migration, is estimated to reach a cumulative total of over 250 million people by the 2080s (from 1990). The vast majority of this population at-risk is from low and middle income countries.

The global economic cost of high-end sea level rise (not including the cost of adaptation) rises to Euro 900 billion per year in the 2080s. This is four times greater than a moderate scenario. In contrast to the population affected, damages costs are more evenly distributed across middle and upper income countries. Low income countries, although highly vulnerable in terms of the proportion of the GDP that might be affected, have relatively low costs compared to the global total. Asia and the Asia-Pacific account for the majority of the population-at-risk and a third of the global GDP at-

risk, but Europe has amongst the highest economic risks.

The study has also extended the consideration of the major effects to consider socially contingent extremes, i.e. large scale issues associated with conflict, migration, etc. The study has considered possible drivers, and overlaid state fragility and potential adverse climate change to highlight over 100 countries at risk of significant negative knock-on socio-political effects. However, there are major challenges in validating 'hot spot' maps of future climate vulnerability to capture the instability of extreme outcomes. A case study for South Asia in the study has illustrated the many security, conflict and physical impacts of climate change could contribute to a socially contingent tipping point.

Integrated Assessment Models and Global Economic Analysis

Finally, ClimateCost has updated and developed a number of top-down models.

It has linked the results from the previous sectoral assessments into a number of Computable General Equilibrium (CGE) models, to look at the wider economic costs of climate change, looking in detail for Europe and at the global level. These models allow the consideration of indirect costs, and also autonomous market based adaptation to impacts.

The study has also funded the development of a new global economic Integrated Assessment Models (IAMs), PAGE09, as well as running a number of other IAMs, to look at the total global economic costs of climate change over time.

These have been used to look at the aggregated economic costs of climate change, expressed as a % of GDP. The model runs show that the global economic costs of climate change could be significant, particularly towards the end of the century.

The new PAGE09 models shows very significant impacts for Europe, reporting that the total economic costs (including non-market and major catastrophic events) could have annual damages that are equivalent to almost 4% of European GDP (A1B scenario, 2100, unweighted values). It also shows that a scenario consistent with the 2 degree target would reduce these down to between 0.5 – 1% equivalent of GDP (E1, 2100, unweighted values). Importantly, within the model analysis, the mitigation (stabilisation) scenario removes the possibility of very high economic

costs and discontinuities towards the upper end of the probabilistic outcome. However, an inter-comparison with other IAM models shows different results in the relative impacts in different world regions, and in the total values projected.

The models have also been used to estimate the social cost of carbon the global marginal impact caused by the emission of one additional tonne of carbon (or CO₂). The estimation of these metrics involves a number of assumptions or choices, some of which – such as the discount rate – are contentious. To address this, the ClimateCost project has used a range of alternative assumptions, rather than using discrete choices.

The results confirm previous studies, in that all models show low SCC values with high pure rate of time preference rates (the prtp, one of the main components of the discount rate), and very high SCC values with low or near zero prtps. They also vary significantly with the assumptions of equity weighting (i.e. adding up and adjusting values from different world regions). However, when these assumptions are fixed, the different models still show very wide estimates, nonetheless: the new PAGE09 model reports high SCC values > €100/tCO₂ at rates used in typical economic policy appraisal, though the other models considered report much lower values.

Finally, the models have considered the costs and benefits of mitigation. The models give a range of results, varying between the models, again with the assumptions on discounting and equity, and between the models, which lead to conflicting policy conclusions. Nevertheless, a comparison of the costs and benefits of the 2 degree scenario with the new PAGE09 model, does produce net benefits, i.e. under this models the benefits of an aggressive mitigation policy outweigh the costs of mitigation.

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The ClimateCost Project Final Report

Volume 1: **Europe**

Further information

To find out more about ClimateCost, please visit:

www.climatecost.eu

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organisation being the Stockholm Environment Institute
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