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Assessment Agency

COSTS AND BENEFITS OF CLIMATE CHANGE ADAPTATION AND MITIGATION:

An assessment on different regional scales

PBL Policy Brief

Costs and benefits of climate change adaptation and mitigation: An assessment on different regional scales

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Nederlandse samenvatting

Kosten en baten van klimaatadaptatie en -mitigatie

Klimaatverandering kan grote gevolgen hebben, zoals hogere temperaturen en stijging van de zeespiegel. Om die het hoofd te bieden kan worden gekozen voor het aanpassen aan die gevolgen (adapteren) en voor het beperken van de klimaatverandering (mitigeren).
Deze notitie geeft inzicht in de kosten en baten van die klimaatmitigatie en -adaptatie, met als doel strategische beleidsvorming voor klimaatverandering te ondersteunen. Bij mitigatiekosten gaat het om de kosten die worden gemaakt om broeikasgasemissies te reduceren; bijvoorbeeld de extra kosten van hernieuwbare energie ten opzichte van fossiele brandstoffen. Adaptatiekosten zijn de kosten voor het aanpassen aan (toekomstige) klimaatverandering; bijvoorbeeld de constructie van klimaatbestendige gebouwen of het ophogen van dijken.
De baten van mitigatie bestaan uit verminderde schade doordat de aarde minder opwarmt. Bij de baten van adaptatie gaat het om verminderde schade doordat de omgeving is aangepast aan klimaatverandering.
De kosten en baten van mitigatie zijn niet eenduidig vast te stellen. Daarbij spelen timing, onzekerheid en verdeling namelijk een cruciale rol. De baten van mitigatie vinden niet alleen pas decennia na de kosten ervan plaats, maar de baten zijn ook veel onzekerder dan de kosten. Dit komt door de grote onzekerheid in de zogenoemde schadeprojecties: de schattingen voor de totale mondiale gevolgen van 2,5 °C opwarming lopen uiteen van nauwelijks schade tot 3 procent van het mondiaal inkomen. Boven 2,5 °C lopen de schade-inschattingen snel op; voor 5 °C zijn deze 7 tot 25 procent van het mondiaal inkomen.
De schade is ongelijk verdeeld: in de armste landen is de schade het hoogst, terwijl de rijkere landen historisch het meest verantwoordelijk voor klimaatverandering zijn.
Inschattingen van mitigatiekosten voor een 2 °C-pad zijn gemiddeld over de eeuw genomen in de orde van 1 tot 3 procent van het mondiaal inkomen. Op de lange termijn worden de baten van mitigatie hoger geschat dan de kosten.
Mondiale adaptatiekosten worden ingeschat op circa 100 miljard dollar per jaar in de eerste helft van de 21e eeuw. In de tweede helft van de eeuw stijgen naar verwachting zowel de klimaatschade als de adaptatiekosten sterk als er geen mitigatie plaatsvindt.

Er zijn nog weinig studies over de baten van adaptatie; dit ligt deels aan het hanteren van verschillende definities van de term adaptatie. Wel concluderen verschillende studies dat adaptatie maar tot op zekere hoogte de schade kan voorkomen. Dit betekent dat een deel van de schade alleen met mitigatie kan worden voorkomen, hoewel ook hier geldt dat een bepaalde mate van klimaatverandering – en daarmee klimaatschade – onvermijdelijk is.

Op mondiaal niveau kan mitigatie worden gezien als een strategie om risico's te verkleinen: mitigatie verlaagt zowel het risico op onzekere, maar potentieel hoge, klimaatschade als op het falen van optimaal adaptatiebeleid. Dit verklaart ook waarom analyses waarin niet wordt gekeken naar de waarschijnlijke klimaatschade, maar naar de mogelijke risico's gebaseerd op het voorzorgsprincipe, stringent mitigatiebeleid aanbevelen.

Op Europees niveau is er vooral gekeken naar de kosten voor het halen van de reductiedoelstelling van 40 procent minder uitstoot van broeikasgassen in 2030 dan in 1990. Deze variëren van 0,1 tot 0,5 procent van het Europees inkomen in 2030. Bij unilaterale actie worden de kosten zo'n 0,1 procent van het inkomen hoger ingeschat dan bij mondiale actie. De welvaartswinsten van mitigatie zijn erg onzeker, maar kunnen aan het eind van de eeuw oplopen tot 1 procent van het inkomen in Zuid-Europa, bij een relatief droog en warm klimaat. Hierbij zijn echter de risico's als de effecten van verstoringen van handelsstromen, klimaatmigratie en conflicten nog niet meegenomen, noch de (kleinere) kans op grootschalige klimaatrisico's (snellere zeespiegelstijging; verstoring van de Atlantische golfstroom).

Er is nog weinig bekend over de adaptatiekosten op Europees niveau; sommige studies op Europees niveau laten jaarlijkse kosten van 10 miljard dollar zien, maar studies op nationaal niveau suggereren dat de kosten hoger kunnen uitvallen.

Voor Nederland lijken de cumulatieve kosten voor zowel adaptatie als mitigatie tot en met 2050 rond de 70 miljard euro te liggen, verdisconteerd naar huidige waarde. Voor mitigatie is hierbij uitgegaan van een emissiereductie van 80 procent in 2050 ten opzichte van 1990.

De baten van adaptatie zijn grotendeels onbekend. De baten van mitigatie hangen af van de actie van de rest van de wereld. Dit laatste betekent dat een directe vergelijking van mitigatiekosten en -baten niet zinvol is voor een individueel land. Omdat Nederland in een delta ligt en daarmee relatief hoge adaptatiekosten en risico's heeft, lijkt het aantrekkelijk voor Nederland internationaal een actieve rol te spelen bij het overtuigen van het belang van verregaande mitigatie.

Main findings

This policy brief summarises the current knowledge about the costs and benefits of climate change adaptation and mitigation, with the aim to support strategic policymaking on climate change. Mitigation costs are defined as the costs of reducing greenhouse gas emissions; adaptation costs refer to making society more resilient to climate change. The benefits of mitigation consist of the avoided damage due to less climate change, while the benefits of adaptation consist of avoided damage by adjusting to climate change. All costs and benefits were set against those under a scenario without mitigation and adaptation. As this policy brief does not assess specific mitigation policies or measures, but instead provides overall model estimates of the costs and benefits related to such measures, it cannot be regarded as a true cost-benefit analysis. This implies that the policy brief does not discuss how climate policies should be implemented, but it does provide insight into whether and to which degree climate action should be taken.

The policy brief focuses on three regional scales: the world, the EU, and the Netherlands.

Main findings on a global level

- Two crucial aspects about the costs and benefits of mitigation are those of timing and uncertainty. The benefits of mitigation take place decades after the costs are made, and they are much more uncertain than the costs – as this depends on the possible occurrence of catastrophic events.
- Average annual mitigation costs for this century are projected to be 1% to 3% of global GDP (depending on the model), for a medium to likely chance of achieving the maximum temperature increase target of 2 °C.
- Studies show a large range in effects for a global warming of 2.5 °C, from small benefits to damage of 3% of GDP. Beyond 2.5 °C, damage is projected to increase rapidly; indicative figures are 7% to 25% for a warming of 5 °C.
- Costs and benefits are unevenly distributed among countries. In general, the countries that are most responsible for climate change (developed and emerging economies) will not experience the largest impacts (the least developed countries will).
- In the long term, the benefits of mitigation will outweigh the costs.
- In the short term, global adaptation costs will not depend heavily on the level of mitigation and are estimated to be about USD 100 billion, or about 0.14% of current

global GDP. In the second half of this century, without mitigation efforts, adaptation costs are likely to increase sharply and large residual damage will remain unsolved, as adaptation can only reduce them to a certain degree.
- Mitigation can be regarded both as a strategy to reduce risk of uncertain but potentially large damage from climate change, and a failure to adapt to climate change. This is why studies that do not focus on likely damage, but rather on the possible risks according to a precautionary approach, recommend stringent mitigation policy.

Main findings for the EU

- An earlier PBL study (Hof et al., 2012) reports mitigation costs of between 0.25% and 0.4% of GDP by 2030 to achieve a 40% reduction in EU domestic emissions, compared to 1990 levels. The corresponding welfare losses will be about 0.3% in the case of global action and about 0.4% under unilateral action.
- For the same target, the European Commission reports GDP losses due to mitigation costs of between 0.1% and 0.45% by 2030, depending on the policy instruments used.
- Estimations of the welfare benefits of mitigation strongly depend on the climate model used. Mitigation is more important under a relatively hot and dry scenario, especially for the Nordic countries and southern Europe, for which the benefits of mitigation are projected to be over 1% of GDP by the end of this century.
- Climate change risks, such as climate migration and conflict, and their impact on the EU, have not yet been accounted for in the current estimates, nor have the (smaller) probabilities of large-scale events, such as the collapse of the West Antarctic Ice Sheet and a shutdown of the thermohaline circulation.
- Top-down studies project annual adaptation costs of about USD 10 billion for the EU, but national studies indicate that costs could be even higher. Adaptation benefits on EU level are still largely unknown, as there are only a few national studies, which are also difficult to compare because of different definitions of adaptation policies.

Main findings for the Netherlands

- An ECN and SEO study (Daniëls et al., 2012) projects that, in order to achieve an 80% reduction target by 2050, the net present value of mitigation costs would be 70 billion euros. Adaptation costs are of a similar order of magnitude.
- The benefits of mitigation for any particular country depend on the level of global action, not on the mitigation action taken by that country itself. This implies that i) a comparison of mitigation costs and benefits per country is not useful, and ii) with non-cooperative behaviour, every country has an incentive to free-ride within a coalition.
- Estimates of the benefits of adaptation are available for a few specific measures only.
- As the Netherlands is located in a delta, it faces both relatively high adaptation costs and high climate risks. Therefore, for the Netherlands, it makes sense to actively convince other countries of the need for stringent mitigation policies.

1 Motivation, explanation of terms, and scope

Recently, the Dutch Ministry of Infrastructure and the Environment published its climate agenda (K*limaatagenda*, Ministerie van Infrastructuur en Milieu, October 2013), which sketches an approach that combines climate adaptation (i.e. making society robust against climate change) and climate mitigation (i.e. reducing greenhouse gas emissions). To support policy-making on adaptation and mitigation, several research questions have been formulated. In what may be described as a first step on the research agenda, this policy brief summarises the current knowledge about the costs and benefits of climate change adaptation and mitigation. For a better understanding of the meaning of the terms of mitigation and adaptation costs and benefits, Table 1.1 provides their definitions and some examples.

Information about the costs and benefits of climate policies is important as large investments are required for both mitigation and adaptation. Recent studies indicate that the annual global costs of adaptation are of the order of USD 100 billion over the coming decades (UNFCCC, 2007; World Bank, 2010). During the same period, the costs of mitigating global warming to stay within the internationally agreed target of no more than 2 °C temperature increase, compared to pre-industrial levels, are likely to be many times higher. Stern (2006) nevertheless concluded that the benefits of mitigating to 2 °C will outweigh the costs. The Stern review triggered a heated debate about the benefits of mitigation, which focused on discounting and how low-probability – high-impact events should be treated in cost-benefit analyses.
The focus of this policy brief is on the *costs* and *benefits* (see Text box 1 for another view on how to approach the climate problem). The *costs* are either based on macroeconomic models or energy system models. The first type of models calculates macroeconomic costs, expressed as changes in GDP, consumption, or welfare. Energy system models, on the other hand, usually measure costs related to the energy system, which consist of capital costs, fuel costs, and operation and maintenance costs. Carbon prices are another often used measure. However, as carbon prices are a very poor indicator of the total costs of a policy (Paltsev and Capros, 2013) these are not the focus of this policy brief. The *benefits*, which is the avoided damage of climate change, is either based on the expected physical effects of climate change (also called the enumerative method) or on a statistical approach that is based on direct welfare impacts using observations (Tol, 2009). Both methods usually take into account market as well as non-market impacts. For instance, the impact of climate change on ecosystems and human health is often

included, and most studies specifically take into account regional differences in damage (significant damage in developing countries leads to higher global costs). As the focus here is on costs and benefits, the underlying physical impact of climate change is not explicitly discussed– although many of the monetary estimates are based on such effects.

Even though this policy brief focuses on costs and benefits, it is not a formal cost-benefit analysis. Instead, it uses the current literature on costs and benefits, and identifies crucial aspects of this issue. Comparing studies proved difficult as costs and benefits in the various studies are represented in a variety of ways: they present direct mitigation costs or GDP losses or welfare losses, and costs are presented as either annual costs or cumulative costs, discounted or undiscounted. Some studies present absolute costs, others talk about costs as a share of GDP. Most studies, as is the normal practice in cost-benefit analyses, do formulate a business-as-usual scenario (commonly a scenario without mitigation and adaptation) and one or more alternative scenarios (commonly a mitigation scenario with or without adaptation). The scenario with the highest benefit-cost ratio, in terms of present value, is the most attractive scenario. As with climate change, the benefit-cost ratio strongly depends on the discount rate. This policy brief focuses on annual, undiscounted costs and benefits over time.

Table 1.1
Definitions of mitigation and adaptation and examples of the costs and benefits

	Mitigation	Adaptation
Costs	*Definition*: Costs of reducing greenhouse gas emissions *Examples*: – implementing carbon capture and storage (CCS) systems in power plants or industry – replacing fossil fuel by renewable energy, such as solar and wind power – applying insulation measures in buildings	*Definition*: Costs of adapting society to climate change *Examples*: – Building dykes or beach nourishment – Heat warning systems – Construction of climate-proof buildings
Benefits	*Definition*: Avoided climate change damage because of less climate change as a result of mitigation measures *Examples*: – Less coastal damage because of lower sea level rise – Less heat-related mortality because of fewer heatwaves – Less biodiversity loss because of slower climate change	*Definition*: Avoided climate change damage because of adaptation to climate change *Examples*: – Less coastal damage because of dykes – Less heat-related mortality – Less biodiversity loss because of connecting green zones

Finally, co-benefits of mitigation, such as less air pollution and higher energy security are not addressed here, for the sake of maintaining focus. Such co-benefits, however, could be quite substantial: co-benefits of around 40% of mitigation costs have been reported for stringent mitigation scenarios (GEA, 2012; McCollum et al., 2013). On the other hand, several factors may lead to higher mitigation costs than assumed in most studies. One important factor is that most underlying studies on mitigation costs assume a perfect world with complete information, rational actors and one global decision-maker. As this obviously does not reflect reality, and because other factors than costs also play a role in deciding mitigation measures, mitigation costs will be higher, in actual practice. Another factor is that negative side effects of mitigation measures are not accounted for (think of perceived landscape pollution due to wind power). Adaptation and mitigation costs, however, could potentially be reduced if synergies are achieved between adaptation and mitigation measures. This policy brief does not address such synergies, as information on the possible degree of synergy is scant.
Since climate change is a global problem, Chapter 2 first presents an assessment of the costs and benefits for the world as a whole, followed by a discussion on the implications for the EU in Chapter 3, and the Netherlands in Chapter 4.

Text box 1: An alternative to comparing costs and benefits: The precautionary approach

The current policy brief focuses on the costs and benefits of climate change policy. There are alternative considerations on which to base climate policy, one of which being the precautionary principle. This principle is based on considerations such as changes in extreme weather events, the risk of large-scale, perhaps irreversible changes in the climate system, and the loss of biodiversity and food security. An argument for using the precautionary principle is that the uncertainties around climate change are so large that the results from a formal quantitative cost-benefit study would be unreliable (Van den Bergh, 2004). Indeed, Article 2 of the UNFCCC (that is about stabilisation of greenhouse gas concentrations at a level '*that would prevent dangerous anthropogenic interference with the climate system*') suggests that a precautionary approach to climate change may be more appropriate. Studies using a precautionary principle suggest that climate risks could be substantial, even with a global temperature increase of only 1 to 3 °C, compared to pre-industrial levels (Hansen, 2005; Izrael and Semenov, 2006; Mastrandrea and Schneider, 2004; O'Neill and Oppenheimer, 2002).

2 Costs and benefits: A global picture

Mitigation costs of achieving the 2 °C target are projected to be 1% to 3% of GDP

Global studies of the costs and benefits of climate change mitigation make use of Integrated Assessment Models (IAMs). These models cover the cause-and-effect chain of climate change, including the economic activities that cause greenhouse gas emissions, the effect of these emissions on greenhouse gas concentrations in the atmosphere and the oceans, the changes in temperature and other parameters due to the increased concentrations, and the impact of these changes on ecosystems and the economy.

The more detailed IAMs focus especially on mitigation costs, resulting in a considerable amount of literature on this topic. Broadly speaking, two types of such literature can be distinguished: studies projecting the direct mitigation costs based on detailed descriptions of energy and land-use systems (but do not cover the whole economy) and studies projecting welfare costs by focusing on the economy as a whole and the interactions between the various sectors (but with a less detailed representation of the energy system). The results from many of these models have been compared in the intercomparison project of the Energy Modeling Forum (EMF). The latest EMF study, EMF27 (Kriegler et al., 2013), analysed the emission reductions and associated costs related to two different long-term climate targets: i) achieving a 2 °C target with medium probability (a target of 450 ppm CO_2 eq), and ii) achieving a 2 °C target with low (about 30%) probability (a target of 550 ppm CO_2 eq).

For achieving the first target, the energy models project the present value of abatement costs at about 1% of GDP, for the first half of this century, and at about 2% of GDP for the whole century – with wide uncertainty margins (Table 2.1). For the less stringent target, projected costs are about half the above levels. The associated consumption losses as projected by the macroeconomic models are somewhat higher than these direct abatement costs.

The above numbers are based on optimistic assumptions about countries participating in reducing emissions and the availability of abatement technologies. Less optimistic model assumptions may result in higher mitigation costs or may even lead to the 2 °C target becoming infeasible to achieve. For instance, more than half of the models used in the model comparison of the EMF27 study reported that the 450 ppm target would be infeasible without carbon capture and storage (CCS, the process of capturing CO_2 from power plants or industry and depositing it in underground geological formations). Furthermore, figures do not show possible differences in costs between countries. Although the level of regional mitigation costs depends on the distribution of the global effort among countries, studies on effort-sharing show that, in general, oil-exporting countries and carbon-intensive economies are likely to incur relatively high costs (Hof et al., 2009b).

Economic damage of climate change very uncertain, but is estimated to increase rapidly at temperature increases beyond 2.5 °C

Mitigation leads to less climate change and therefore less damage from climate change. These benefits are only observed after a few decades due to inertia in the climate system. There is much less literature available about the benefits of mitigation than the costs of mitigation. The first of such studies were published in the early 1990s as part of cost-benefit analyses of climate change. These studies acknowledge that projecting the economic and non-economic damage in monetary terms is very difficult. Most information is available for the EU and North America, based on which damage for other world regions is estimated using multiplication factors. This damage typically includes the impact on coastal zones (due to sea level rise), agriculture, human health, infrastructure, and leisure activities. Some studies include a rough estimate of the impact of catastrophic events, on the basis of expert judgement.
A recent study summarises the various estimates of the global economic impact of climate change (Tol, 2013). Of the 17 estimates that were summarised, 13 concern a global warming of 2.5 °C or 3 °C. There are hardly any estimates of economic impacts beyond a global warming of 3 °C (and only a few below a warming of 2.5 °C). For a temperature increase of 2.5 °C, the studies show a large range: from small benefits (of about 0.5% of GDP) to a damage of 3% of GDP. As these are global percentages, the damage for individual countries may be different. Especially for least developing countries, the damage is expected to be higher than the global average. For a global warming of 3 °C, the four studies concerned, together, show global economic damage within a range from 1.5% to more than 10% of GDP. For higher temperature increases, estimates can only be provided by extrapolation of the available projections or by expert judgement on whether or not certain tipping points will occur. This is quite difficult, given i) the large uncertainty range in the available estimates, and ii) the fact that the estimates only cover a narrow set of global warming levels. Depending on the

Table 2.1
Global net present value of mitigation costs as % of GDP (abatement costs) and as % of consumption (consumption loss)

	2 °C with medium to likely probability	2 °C with low to medium probability
Energy Models		
Abatement cost, 2010–2050	0.3 - 1.7	0.2 - 0.7
Abatement cost, 2010–2100	0.8 - 2.8	0.4 - 1.0
Macroeconomic models		
Consumption loss, 2010–2050	0.5 - 2.0	0.2 - 1.5
Consumption loss, 2010–2100	0.9 - 3.2	0.7 - 2.1

Source: Based on Kriegler et al. (2013)

method of extrapolation, estimates of economic damage for a 4 °C temperature increase range from 10% to 16% to 31% to 47% of GDP (Tol, 2013). For levels of global warming of less than 2.5 °C, studies tend to find very small or even positive global net impacts. All these percentages are based on the assumption that society will be able to adapt to climate change to a certain degree.

Annual adaptation costs are projected at around USD 100 billion

Over the last few years, several studies were published on the costs of adaptation. Some studies address the national level, but most global studies focus on developing countries. Two studies project adaptation costs on a global scale. The UNFCCC (2007) estimates a wide range for the global adaptation costs, for 2030, of between USD 50 and 170 billion. The size of this range is caused mainly by the uncertainty about the adaptation costs that would be required for new infrastructure. The most recent and comprehensive study on adaptation costs (World Bank, 2010) reports average annual adaptation costs of USD 70 to 100 billion, between 2010 and 2050, depending on the degree of climate change. The most important reason that the range is smaller than that of the UNFCCC study is the more detailed coverage of infrastructure, which reduced the level of uncertainty for this sector.
Estimates of the annual adaptation costs in the studies that focus on developing countries, vary from USD 9 to 41 billion (World Bank, 2006) to USD 50 billion or higher (Oxfam, 2007) to USD 86 billion (UNDP, 2007). Based on all the above studies, it can be concluded that the current state of knowledge indicates that annual global adaptation costs will be of the order of USD 100 billion, or about 0.14% of current global GDP. However, the uncertainty around this figure is large and some studies indicate that costs could be (much) higher than the above estimates. For instance, Parry et al. (2009) concludes that the UNFCCC study significantly underestimates adaptation costs,

potentially by a factor of two or three, or even more if other sectors, such as ecosystem services, are also included. Moreover, sectoral studies also indicate that adaptation costs could be much higher. Markandya and Chiabai (2009) project additional annual health adaptation costs of USD 3.3 to 10.7 billion between 2000 and 2030, while the World Bank 2010 study projects health adaptation costs of about USD 2 billion for the same period.

The few studies that address the benefits of adaptation indicate that these will be about four times the costs

The benefits of mitigation are achieved by adjusting to climate change. As adaptation does not change the level of climate change, it will be more difficult if no mitigation takes place. There is very little information available about the global benefits of adaptation. The likely reason for this is that adaptation measures are very diverse and usually take place on a local level. The studies on the costs of adaptation do not make any statements about the benefits, but instead assume that certain types of impacts should be avoided. They suggest that if society adapts optimally to climate change, the benefits will be about four times the costs (de Bruin et al., 2009; Hof et al., 2009a). Combining this finding with annual adaptation costs of USD 100 billion leads to the indicative amount for the benefits of adaptation of about USD 400 billion, or about 0.56% of current global GDP.

In the long term, mitigation costs will be lower than the avoided damage

Timing and uncertainty are two very important aspects when comparing costs and benefits. The benefits of mitigation will not emerge until a few decades after the costs have been made, and will be much more uncertain than the costs – especially for the upper end of the range. This is depicted in the schematic of Figure 2.1, which compares the mitigation costs of a 2 °C global warming scenario with the avoided damage (or benefits), compared to a scenario without mitigation (leading to a global temperature increase of 3.5 °C by 2100 and 5.4 °C by 2200). The amount of avoided damage is based on Nordhaus and Sztorc (2013) for the lower end of the range, and Weitzman (2012) for the upper end. Mitigation costs will exceed the avoided damage in the short term, but eventually the benefits of reduced climate change will outweigh the mitigation costs. Exactly when this happens is uncertain, due to both uncertainty in mitigation costs and uncertainty in the avoided damage. The figure also clearly shows that the uncertainty about the short-term mitigation costs is much smaller than that of the long-term benefits. As the benefits consist of avoided climate change damage, this can be

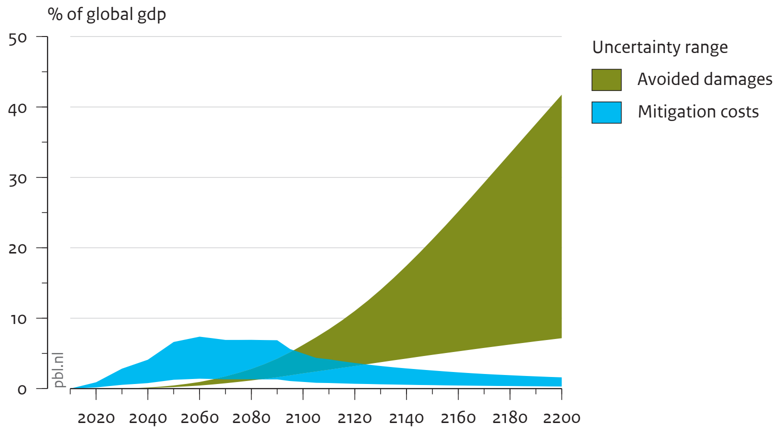
translated into an uncertain, but large amount of future damage in the scenario without mitigation.
Figure 2.1 also shows the importance of discounting. In order to compare short-term costs with long-term benefits, future costs and benefits are discounted to their present values. There are two important reasons why future costs and benefits are valued lower in present terms. The first reason is based on the assumption that one additional euro is worth more to a poor person than to a rich person. As future generations are likely to be richer than they are today, future costs and benefits are valued lower in present terms. The second reason is based on time preference: in general, today's euros are valued higher than those of next year – even if incomes remain the same. Especially this second reason for discounting is heavily debated, and different perspectives between scientists remain. Stern (2006), for instance, applied a time preference discount rate of 0.1%, while Nordhaus and Sztorc (2013) apply one of 1.5%. Such differences largely determine whether the net present value of benefits and costs are positive or negative (Hof et al., 2008).

Another important uncertainty, in addition to that about climate change damage, is the uncertainty about the climate system. The sensitivity of the climate system to changes in greenhouse gas concentrations in the atmosphere is usually expressed as climate sensitivity: the equilibrium change in global mean surface temperature that is caused by a doubling of atmospheric CO_2 concentrations. According to the IPCC (2013), climate sensitivity is likely to be in the range of 1.5 °C to 4.5 °C, extremely unlikely at less than 1 °C, and very unlikely over 6 °C. This uncertainty was not taken into account in Figure 2.1. If it had been, the uncertainty range in avoided damage would even be much larger. For an indication of the total uncertainty, estimates of the Social Cost of Carbon (SCC) can be used. The SCC is defined as the added damage of emitting one additional tonne of CO_2. Tol (2009) calculated a mean SCC value of about USD 30/tCO_2 from 232 different estimates, with a 95 percentile value of about USD 100/tCO_2 and a 99 percentile value of more than USD 400/tCO_2.

Summarising the interactions between mitigation, adaptation, and damage

Figure 2.2 provides an overview of the interactions and orders of magnitude of adaptation and mitigation costs and benefits. The panels of the figure, for different climate mitigation scenarios, each show the residual damage (defined as the damage that remains after adaptation), mitigation costs, adaptation costs, and the added damage if no adaptation takes place. For clarity, uncertainty about the mitigation costs and benefits is not depicted in this figure; the shown costs and damage are similar to the lower end of the range as depicted in Figure 2.1.

Figure 2.1
Annual mitigation costs and avoided damages of a 2 °C scenario

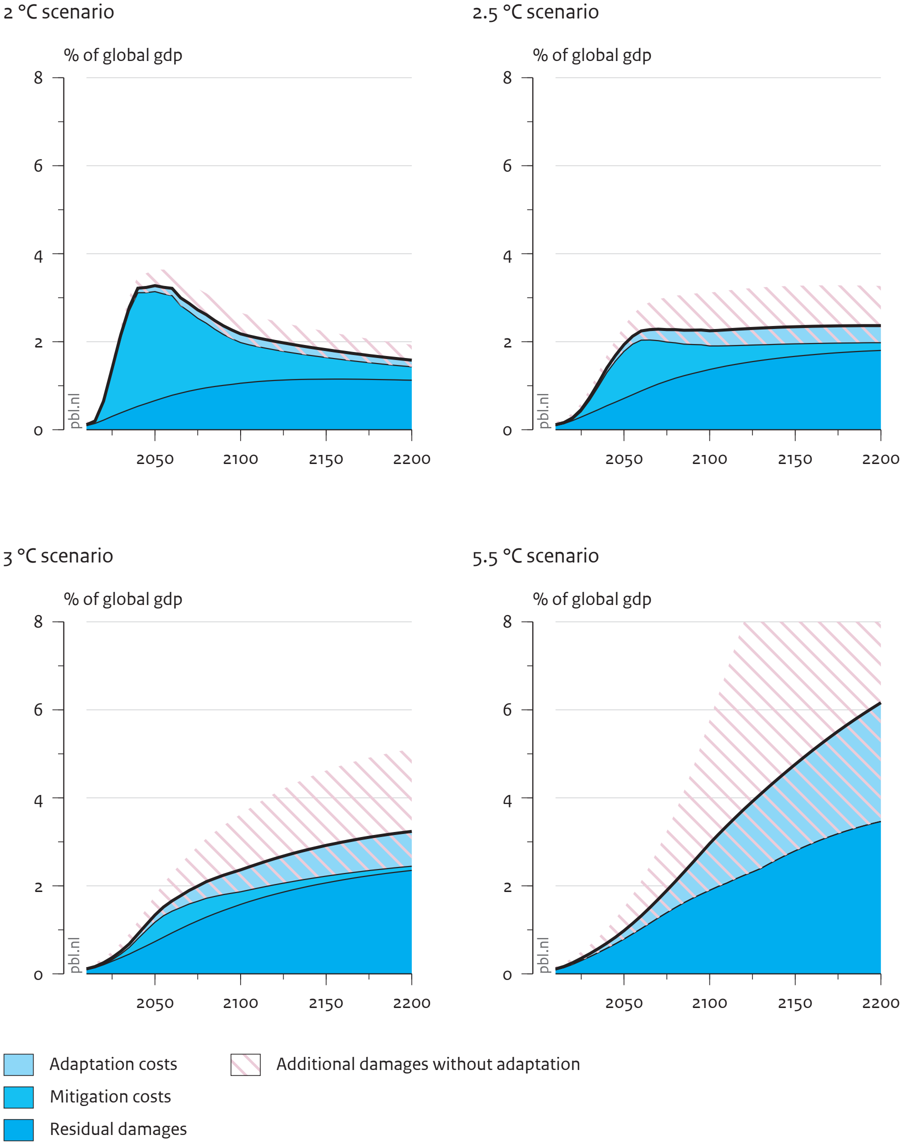


Source: Kriegler et al., 2013; Nordhaus and Sztorc, 2013; Weitzman, 2012; analysis PBL Netherlands Environmental Assessment Agency

The cost range for mitigation is based on the EMF27 study (Kriegler et al., 2013). Mitigation benefits (or avoided damage) are based on the DICE model, version 2013R (Nordhaus and Sztorc, 2013) for the lower end of the range and on Weitzman (2012) for the upper end. The uncertainty range for avoided damage only considers the uncertainty in damage estimates given a certain temperature, but does not account for the uncertainty about the climate system.

The figure shows that, due to inertia in the climate system, the amount of residual damage is similar for all scenarios until about 2040. In the longer term, this damage strongly diverges between the scenarios. At the end of this century, residual damage will outweigh the sum of mitigation and adaptation costs, even for the 2 °C climate target. This does not apply to the first half of the century, as mitigation costs are projected to increase sharply from 2020 onwards and to stabilise around the middle of the century. By the end of the 21st century, mitigation costs as a share of GDP will decline, as by then the transition to a low-carbon economy will have been largely achieved. As with the residual damage, global adaptation costs up to 2040 will be similar between the scenarios. By the end of the century, global adaptation costs without mitigation will be about 5 times higher than under the 2 °C scenario (and the difference will continue to increase, thereafter). The importance of adaptation is also much greater under the scenario without mitigation, as a failure to invest in adaptation measures will lead to much greater additional damage than will be the case under the 2 °C scenario. As such, mitigation can be regarded as a strategy to reduce the risk of uncertain damage, as well as a failure to optimally invest in adaptation.

Figure 2.2
Annual costs of climate change



Source: Hof et al., 2009

Global mitigation and adaptation costs, residual damage, and the additional damage under no adaptation, for different mitigation scenarios. Residual damage is damage that remains after adaptation.

3 Costs and benefits for the EU

Mitigation costs for achieving a 40% domestic EU target by 2030 will be around 0.1% to 0.5% of GDP

The projected global mitigation costs presented in Table 2.1 assume a cost-efficient emission reduction strategy. This means that emission reductions will take place wherever it is cheapest to do so. Such a scenario would lead to relatively high costs for developing regions, which is not in line with Common but Differentiated Responsibilities, one of the main principles of the UNFCCC.

A recent PBL report (Hof et al., 2012) analysed the reductions that would lead to a global 2030 emission level consistent with a 2 °C pathway, while sharing the reductions among countries in such a way that the costs for each country amount to the same share of GDP. The least developed countries were assigned a degree of effort that would correspond to 30% of the costs for the other countries. This would lead to a domestic reduction target for the EU for 2030 of between 45% and 47% below 1990 levels, with associated abatement costs of about 0.6% of GDP by 2030. For a somewhat less ambitious domestic reduction target of 40%, abatement costs were projected at 0.25% to 0.4% of GDP by 2030 – with an associated welfare loss of 0.3% in case of global action and 0.4% in case of unilateral action.

The impact assessment of the European Commission (2014) also analysed the GDP effects of 40% domestic emission reduction by 2030, from 1990 levels, compared to a reference scenario in which emissions are reduced by 32%. The assessment reports GDP losses of 0.1% by 2030 if a carbon tax would be introduced in the non-ETS sector, and a loss of 0.45% without such a carbon tax. In the first case, the revenue from the carbon tax would be used to lower labour costs, thereby improving the competitiveness of the economy. The effect on employment ranges from -0.6% (without a carbon tax in the non-ETS sector) to +0.2% (with a carbon tax).

Welfare benefits of mitigation more than 1% of GDP for some EU regions, depending on the climate's sensitivity to emissions

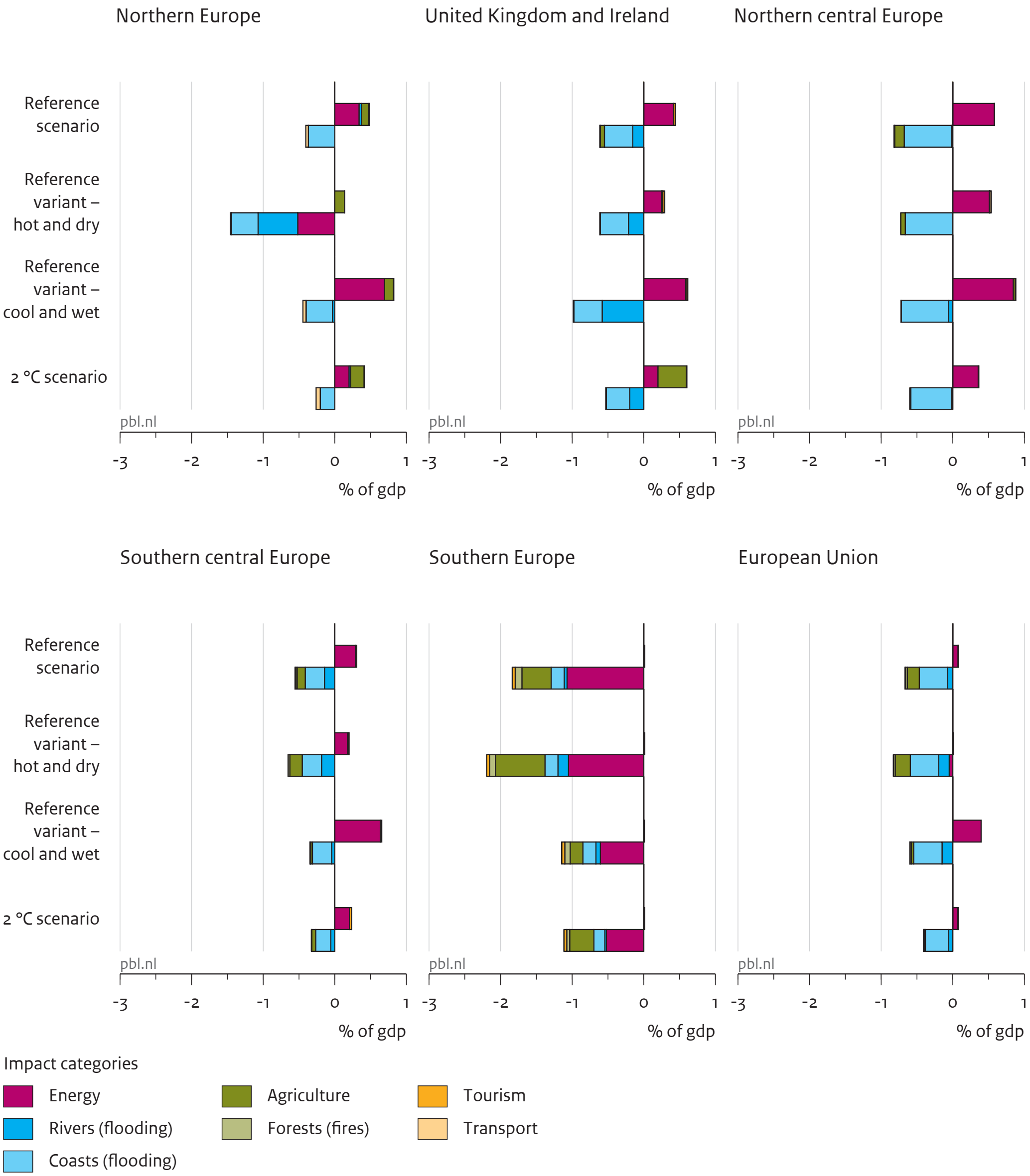
The most recent and comprehensive study of the economic impact of climate change for the EU is the PESETA II project. Preliminary results of this study were used in the Impact Assessment of the European Commission (2013). The PESETA II project provides a projection of welfare impacts for the EU for the end of this century, under global warming scenarios of 2 °C and 4 °C, the latter being the reference scenario. For these projections, a macroeconomic model was used (the GEM-E3 model). The preliminary results are shown in Figure 3.1.
For the reference case, three different climate scenarios were analysed: a default scenario (*Reference*), a relatively warm and dry scenario (*Reference variant hot and dry*) and a relatively cool and wet scenario (*Reference variant cool and wet*). Under the last scenario, the net benefits of mitigation are close to zero or even negative by the end of the 21st century, both for the EU as a whole and for individual EU regions. Under the hot and dry scenario, however, mitigation increases welfare levels by about 0.5% by the end of the century for the EU as a whole, and by more than 1% for southern and northern Europe. Overall, the most negative impacts of climate change are expected to be in southern Europe.
It should be noted that these figures assume no adaptation; with adaptation, especially in the form of dykes and beach nourishment, the benefits of mitigation will be smaller. However, the projections may have underestimated the benefits of mitigation, as not all impacts were considered. For instance, non-market components in welfare losses for the impact categories were not included, nor were the impacts on human health and biodiversity, or the damage caused by catastrophic events. Finally, the study did not include the effects of climate change on the rest of the world and the related impact for the EU. For instance, migration issues or rising agriculture costs on a global level could result in costs or benefits for the EU.

Another EU study estimated the annual benefits of mitigation at about 130 billion euros for the EU, during the 2070–2100 period (Watkiss, 2011). The benefits for southern Europe would mainly consist of less cooling and lower heat-related mortality rate. For western Europe, the main benefits would consist of less damage to coastal zones. A reduction in river flooding will be a relatively important benefit for northern and eastern Europe. However, it should be noted that the coverage of the studies on the cost of Europe-wide damage is limited; the EEA (2010) concluded that such coverage is good only for the coastal zones.

Top-down studies project EU adaptation costs of 0.1% of GDP, bottom-up studies indicate costs may be higher

Information about adaptation costs on EU level may be obtained from global studies with regional detail, European sectoral studies, and national studies.
As mentioned in the previous section, the World Bank report on global adaptation costs (World Bank, 2010) is the most comprehensive study on global-scale adaptation costs. This study has the advantages that it i) considers different climate futures, and ii) projects adaptation costs over time. A disadvantage is that the EU is not an individual region, but is part of the larger regions of Europe and Central Asia. The World Bank study projects that, in absolute terms, annual adaptation costs in Europe and Central Asia will increase from USD 7 billion between 2010 and 2019 to USD 15 billion towards 2050, under a relatively wet climate scenario. Under a relatively dry scenario, average annual adaptation costs over this whole period are estimated to be USD 4 to 5 billion lower. Adaptation costs are projected to stay relatively constant, at 0.12% of GDP, under the wet scenario, and at about 0.08% of GDP under the dry scenario.
Sectoral studies on a European level focus mainly on sea level rise and human health. The first PESETA study (Ciscar, 2009), for instance, estimated annual adaptation costs for sea level rise, for the EU, to be between 0.3 and 1 billion euros over the 2010–2040 period. By the end of this century, this would have increased to between 0.3 and 2.6 billion euros. The given ranges are for different sea level rise scenarios. For human health, Markandya and Chiabai (2009) estimated the additional annual costs of adaptation, in relation to diarrhoea, for the EU to be USD 12 to 260 million, depending on the climate change scenario.
Certain national studies, as were cited by Watkiss and Hunt (2010), indicate that EU adaptation costs may be higher than suggested in the aggregate and sectoral studies. For instance, the UK Foresight study *Flooding and Coastal Defence*, launched in 2004, estimated the total adaptation investment required to address UK flooding (coasts, rivers and 'intra-urban' flooding), for the next 80 years, to be between GBP 22 billion and 75 billion for a portfolio of responses, depending on the scenario, implying average annual costs of up to 1 billion euros. For the Netherlands, the Deltacommissie (2008) estimated that the implementation of a comprehensive set of adaptation measures against flooding – both coastal, due to sea level rise, and river flooding – will cost, annually, between 1.2 and 1.6 billion euros up to 2050 and between 0.9 and 1.5 billion euros over the 2050–2100 period (see the following section). A general problem with comparing adaptation cost studies is the conceptual indistinctness of adaptation policy. For instance, some studies regard adaptation policies as the additional policies needed because of climate change, whereas other countries count all policies targeted at reducing vulnerability to climatic variability as adaptation policies (Dupuis and Biesbroek, 2013).

Figure 3.1
Welfare impacts of climate change in EU regions, 2071 – 2100



Source: Preliminary results of JRC PESETA II project

Welfare impacts of climate change in five EU regions and the EU as a whole. The impacts are shown for three reference scenarios without mitigation and one 2 °C scenario

Estimates of adaptation benefits on an EU level mainly related to sea level rise

On an EU level, there are no comprehensive studies available on adaptation benefits. The studies that cover adaptation benefits mainly address sea level rise (Watkiss and Hunt, 2010). The PESETA study (Ciscar, 2009) found that adaptation to sea level rise would significantly reduce the number of people exposed to flooding and reduce migration instigated by the loss of land. This resulted in estimated annual net economic benefits of adaptation of about 3.5 billion euros in the 2020s and between 9 and 40 billion euros in the 2080s, depending on the sea level rise scenario. The ClimateCost study, using a similar model framework, arrives at similar figures.

On a national level, estimates of adaptation benefits for specific adaptation measures are available for the Netherlands (see the following section) and Germany. For Germany, the Umweltbundesamt published a study on the costs and benefits of 28 adaptation measures in 13 sectors (Tröltzsch et al., 2012). The study shows that uncertainty about the costs and benefits are large: 18 of the 28 measures were surrounded by high or very high uncertainty, and none by a low degree of uncertainty. Measures with the highest net benefits were the prevention of heat-related productivity losses by using air conditioning (annual benefits of 7.4 billion euros by 2050, against costs of 1.1 billion); the prevention of storm damage to buildings (annual benefits of 2.1 to 5.3 billion euros by 2100, against costs of 1.1 to 1.6 billion); the implementation of heat warning systems (annual benefits of 0.4 to 2.5 billion euros, against the very low costs of 5 million); the construction of artificial ski slopes (annual benefits of 0.85 to 1.7 billion euros, against costs of 15 to 30 million); the building of dykes and application of beach nourishment (annual benefits of 270 million euros by 2085, against costs of 110 million); and the use of adapted plant varieties in agriculture (annual benefits of up to 165 million euros, against costs of about a quarter of a million).

Synthesis

A comparison of the costs and benefits of mitigation on an EU level is not easy. Most studies on the benefits focus on the long term, such as the end of the 21st century, whereas studies about mitigation costs usually focus on the next few decades. The reason for the focus on long-term benefits is the fact that there are no short-term benefits of mitigation with regard to reduced climate impacts. The reason for the focus on mitigation costs in the short term, is that it is much more difficult to estimate these costs for longer time horizons – as these largely depend on societal, economic, and technological developments. Moreover, most of the costs of achieving a 2 °C global warming target will be incurred during the next few decades when the transition towards a low-carbon society has to be made.

However, a general conclusion can be that, for the next few decades, the costs of mitigation for the EU very likely will outweigh the benefits. At the end of this century, the reverse is probably true. This is confirmed by Hof et al. (2010a), who used an IAM to compare adaptation and mitigation costs and climate change damage, for a 2 °C and a 3 °C global warming scenario, for different world regions. For western Europe, they hardly found any benefits for mitigating from 3 °C to 2 °C by 2020 and, therefore, the mitigation costs will outweigh the benefits. The costs will still outweigh the benefits up to 2050 (assuming that effects of climate change in the rest of the world do not impact the EU). However, at the end of the century, the benefits in terms of avoided impacts when going from a 3 °C to a 2 °C scenario are estimated at 0.7% of GDP. Moreover, the required adaptation costs will be 0.8% of GDP lower under the 2 °C scenario. Together, by the end of the century, these benefits will outweigh the mitigation costs, which are estimated at about 0.6% to 0.7% of GDP in 2100.

4 Implications for the Netherlands

Present value of net direct mitigation costs of achieving 80% emission reduction by 2050 is about 70 billion euros

In 2012, ECN and SEO (Daniels et al., 2012) published a comprehensive study on cost-effective measures to achieve an 80% reduction in greenhouse gas emissions in the Netherlands, by 2050. The present value of the direct costs of the most cost-effective measures was projected to be almost 150 billion euros (with undiscounted annual costs in 2050 of about 15 billion). These costs are partly offset by the direct benefits of a reduced energy use of almost 70 billion euros and an improved energy security of about 8 billion – which lead to net costs of about 70 billion euros. Total mitigation costs strongly depend on the technology mix: without wind energy and efficiency improvement measures, costs will be much higher.

Mitigation benefits depend on the level of global action

The benefits of mitigation per country strongly depend on the mitigation efforts by the rest of the world. In the theoretical case of the Netherlands unilaterally reducing emissions, there would hardly be an impact on climate and, hence, hardly any mitigation benefits. In a scenario under which the whole world would participate in reducing emissions, Daniels et al. estimate the present value of benefits for the Netherlands to be between 37 and 276 billion euros, on the basis of various projections of global damage caused by CO_2 emissions. Chapter 2 discusses the uncertainties associated with such damage projections.

For the Netherlands, specifically, there are no comprehensive cross-sectoral studies on the economic impacts of climate change. A detailed study of the physical effects of climate change for the Netherlands is provided by PBL (2012). As for the impact on an EU level, hardly any studies have analysed the impact of climate change elsewhere in the world on the Netherlands. Examples of such possible impacts are disruptions in food and trade flows, the import of raw materials, increases in price fluctuations and a possible worsening of international relations (PBL, 2013).

Annual costs of adaptation to flooding projected at 1 to 1.5 billion euros

Similar to studies on adaptation costs and benefits on a global and EU level, those for the Netherlands are also either preliminary or incomplete, or both.
In 2006, the Routeplannerproject compiled a list of 18 adaptation measures with their related costs and benefits (Drunen, 2006). The net present value of the costs of these measures ranged from 0 (lowering the discount rate of investment projects) to 23 billion euros (construction of climate-proof new buildings). The present value of the costs of all measures is estimated at at least 70 billion euros. This indicates that, for the Netherlands, adaptation costs are of a similar order of magnitude as those of mitigation – if these 18 measures would all be implemented. For only 5 of the 18 measures it was possible to indicate the benefits. For 4 of these 5 measures, the benefits were larger than the costs; only for the development of cooling towers for power plants were the benefits (much) lower than the costs.
As mentioned in the previous chapter, the Deltacommissie (2008) projected that a comprehensive set of adaptation measures to sea level rise and river flooding up to 2050 would cost between 1.2 and 1.6 billion euros, annually, and for the 2050–2100 period the annual costs would be 0.9 to 1.5 billion euros. This equals between 28 and 38 billion euros in terms of present value. These measures are based on a risk approach and, therefore, the benefits are not reported in monetary terms but in terms of a reduced risk of flooding.

Synthesis

The usefulness of cost-benefit analyses of climate change mitigation on a national scale is only limited. The reason for this is not that the avoided damage is very uncertain, but that it does not depend on the mitigation efforts of a single country; this is especially true for small countries. This is also an important reason why collaborations between countries are so difficult (see Text box 2). Furthermore, research on the benefits of adaptation, on any scale, is still in its infancy.

Text box 2: Climate coalitions and free-riding

In order to effectively combat climate change, many countries need to participate in mitigation activities. A major challenge hereby is that, in such a large coalition, the individual countries could be tempted to free-ride (Barrett, 1999). This temptation is fed by the fact that the benefits of mitigation depend for the largest part on mitigation actions of other countries. An optimal outcome – all countries participating in taking mitigation action – is therefore difficult to achieve.

Game theory provides several suggestions on how to improve the likelihood of a stable coalition with a high level of participation (Hof et al., 2010b). One is to compensate countries that would lose from joining an agreement by providing them with side payments or by transfer schemes. Several studies have shown that although the likelihood of cooperation may be improved by such side payments, strong free-rider impulses still remain an obstacle to the formation of large coalitions (Eyckmans and Finus, 2007; Finus et al., 2006; Tol, 2001). Another suggestion is to change the design of coalitions from open to exclusive membership, similar to the EU or WTO. But even though a coalition based on exclusive membership may enhance stability, it would be is unlikely to lead to substantial emission reductions (Finus et al., 2005). A more promising route seems to be to form partial coalitions and reach multiple, separate agreements, which may sustain a larger number of cooperating parties than a single global treaty would (Asheim et al., 2006; Carraro, 1999, 2000; Carraro and Siniscalco, 1998).

The above studies all assume non-cooperative behaviour, meaning that, in a stable coalition, no country or region has anything to gain by changing its own strategy, unilaterally. Such an assumption on behaviour may be too pessimistic. Alternative behaviours, such as taking responsibility, taking equity considerations into account, and having a far-sighted view on the future, in principle, could empower self-enforcing coalitions in all regions of the world, provided that a global authoritative institution facilitates world regions to commit to a certain emission reduction target (Lange, 2006; Lise and Tol, 2004). Such regions would not necessarily have to be entire nations, but may also be smaller or different actors, such as enterprises or large cities.

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