Scenarios as the basis for assessment of mitigation and adaptation

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Summary

The possibilities and need for adaptation and mitigation depend on uncertain future developments with respect to socio-economic factors and the climate system. Scenarios are used to explore the impacts of different strategies under uncertainty. In this chapter, some scenarios are presented that are used in the ADAM project for this purpose. One scenario explores developments with no mitigation, and thus with high temperature increase and high reliance on adaptation (leading to 4 °C increase by 2100 compared to pre-industrial levels). A second scenario explores an ambitious mitigation strategy (leading to 2 °C increase by 2100 compared with pre-industrial levels). In the latter scenario, stringent mitigation strategies effectively reduces the risks of climate change, but based on uncertainties in the climate system a temperature increase of 3 °C or more cannot be excluded. The analysis shows that, in many cases, adaptation and mitigation are not trade-offs but supplements. For example, the number of people exposed to increased water resource stress due to climate change can be substantially reduced in the mitigation scenario, but even then adaptation will be required for the remaining large numbers of people exposed to increased stress. Another example is sea level rise, for which adaptation is more cost-effective than mitigation, but mitigation can help reduce damages and the cost of adaptation. For agriculture, finally, only the scenario based on a combination of adaptation and mitigation is able to avoid serious climate change impacts.

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3.1 Introduction

The future development of many factors that determine climate change and climate change policy is highly uncertain. This uncertainty includes, for instance, future man-made greenhouse gas emissions, the ~~relationship between emissions and actual~~ impacts and ~~socio-economic developments (which determine~~ the capacity of societies to adapt to a changing climate~~)~~. These factors determine both the need and the possibilities for mitigation and adaptation. Scenario analysis has been developed to explore different uncertain developments and their consequences. For example, the scenarios from the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emission Scenarios (SRES) (Nakicenovic *et al.*, 2000) have been used in mitigation, climate analysis, impact and adaptation research, and have provided a means to compare information across the different research communities that are involved in these fields.

Both within the ADAM project and elsewhere in the scientific community, there is an interest in exploring the relationships between adaptation and mitigation based on consistent assumptions. This chapter briefly discusses how scenario analysis can contribute to an assessment of future adaptation and mitigation strategies. It also describes scenarios that are used throughout the ADAM project as a common basis of analysis. These scenarios are based on different combinations of adaptation and mitigation strategies[1] as illustrated conceptually in Fig. 3.1. The first two cases include no mitigation. The first case is a *baseline scenario*, in which we also assume no explicit adaptation. This scenario is useful as an analytical point of reference, ~~as it~~ is rather implausible. The other non-mitigation case assumes an efficient *adaptation strategy*, reducing climate change impacts. A third scenario includes stringent *mitigation action*, and hence less adaptation. While adaptation and mitigation can partly be regarded as substitutes, they are certainly not mutually exclusive. Effective climate policy involves a portfolio of both adaptation and mitigation activities. For example, even with high levels of mitigation, some climate change impacts remain likely and will require considerable adaptation efforts. In contrast, a high degree of climate change could make effective adaptation impossible, which means that there is a need for some minimum level of mitigation.

For the baseline scenario, we assume a continuation of current trends. For this purpose, we developed a scenario consistent with the WETO-H_2 scenario recently published by the European Commission (EC, 2006). As energy use in such a scenario is mostly based on fossil fuels, this scenario will lead to considerable

[1] In this context, mitigation is defined as activity aiming to avoid impacts by constraining the level of climate change, whereas adaptation aims at avoiding, or reducing, adverse impacts (or exploiting opportunities) by adjusting human systems in response to observed or projected climate change.

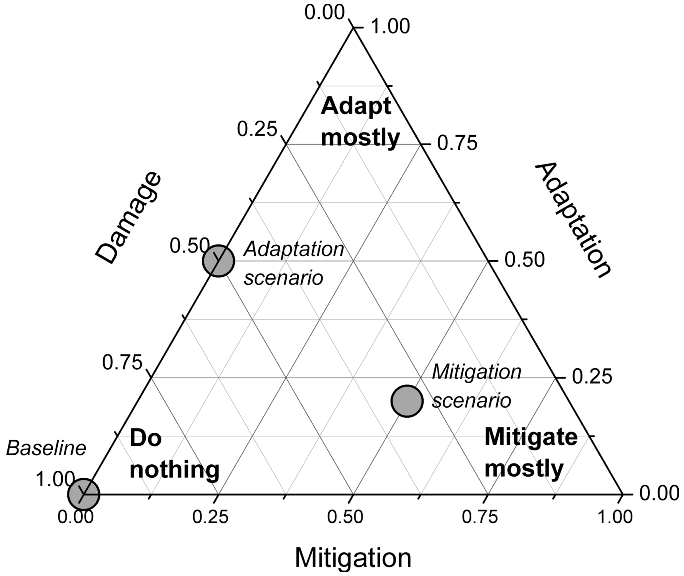

Fig. 3.1. Climate policy leads to different combinations of three types of costs: mitigation costs, adaptation costs and residual damage (illustration). The figure also illustratively indicates the position of the ADAM scenarios. (Source: based on Klein *et al*., 2007).

climate change. For the mitigation scenario we focus on the target of current EU climate policy: a maximum of 2 °C of temperature increase compared with pre-industrial levels. Using the median value for climate sensitivity given by the Intergovernmental Panel on Climate Change (IPCC) of 3 °C (Meehl *et al*., 2007), this translates into a stabilisation level of 450 parts per million (ppm) carbon dioxide equivalent (CO_2e.).

While Fig. 3.1 suggests that the costs and benefits of mitigation, adaptation and residual damages can be weighed against each other, there are several challenges in the appraisal of long-term mitigation and adaptation strategies (see also Section 3.4.8).

S*patial and temporal scales* of proposed action are very important. Both mitigation and adaptation happen at various *spatial s*cales ranging from individual households to the global scale. For mitigation, benefits always occur globally – despite the fact that action is taken at national or local level. A critical factor in limiting mitigation costs is international cooperation (or competition) in technology development. For adaptation, in contrast, both costs and benefits occur at the local scale, though a supportive environment created at a larger spatial scale (e.g. in a multinational entity, such as the European Union) can enhance adaptation at a smaller scale. Mitigation action involves some form of international co-operation, while adaptation is mostly explored at the local scale. From this perspective, Fig. 3.1 is an enormous simplification of the real problem, as costs occur at different points in time and for different actors and stakeholders. The challenge of bringing adaptation issues into scenarios is discussed further in Chapter 4.

The *temporal scale* of mitigation and adaptation also varies over a wide range. Stringent mitigation scenarios typically require strong early reduction of emissions. However, the impacts in these scenarios will in the short term, and will hardly vary from those in scenarios without climate change policy. The impacts in stringent mitigation scenarios typically only diverge from impacts in scenarios without mitigation after a few decades due to the high inertia of the climate system. Adaptation measures can often be implemented over a shorter time scale and become effective immediately, but some important exceptions exist, which may require decades to implement, such as changes in spatial planning or large scale engineering works for flood protection.

Other important factors are *risk and uncertainty.* The cause–effect chain of climate change (see Fig. 3.2) is beset with risks (quantifiable as probability density functions with various, often asymmetrical, forms) and uncertainties. At each main stage of the chain, the uncertainties are due to different factors. Examples of factors affecting the various stages are: (i) emissions, affected by economic development; (ii) the climate system, affected by unknown climate sensitivities; (iii) adaptive capacity, affected by costs of infrastructure; and (iv) mitigation, affected by the wide range of costs of mitigation. Mitigation reduces the uncertainties, since it reduces the originating sources of climate change (Barker, 2003; Piani *et al*., 2005). But mitigation and adaptation may both add to risks. For example, some geo-engineering options may compound risks of climate change by attempting to offset one set of risks (climate) while creating another set of different risks (e.g. ocean

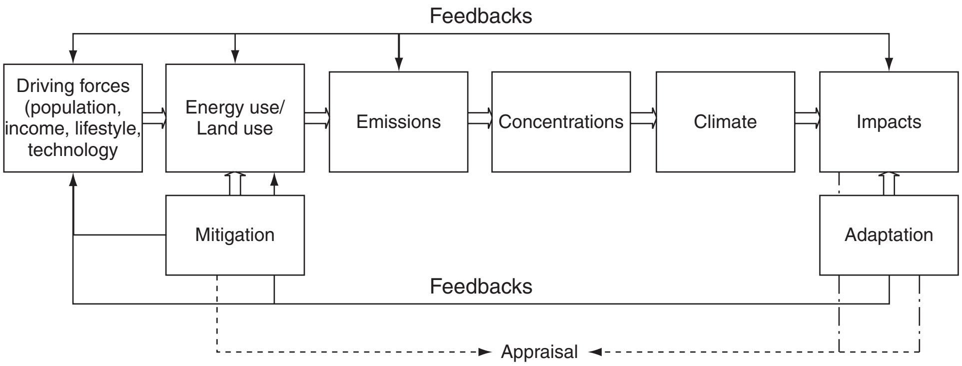

Fig. 3.2. Driving force–pressure–state–impact–response framework for climate change. Thick lines indicate direct linkages. Solid small lines indicate potentials feedback (many of which are not included in current scenarios). The dashed lines indicate categories that are generally used to explore the impact/costs/benefits of different scenarios.

acidification). Exploring uncertainties should be part of a robust decision-making process, but makes appraisal much more difficult. Among other issues, differences in risk perception become relevant. One way of dealing with risks is to include assessments of probabilities. This is often done on the basis of past evidence, extrapolated to cover specific future circumstances. Uncertainties (unknown or unknowable shocks and surprises) are more difficult to represent numerically, but justify precaution and acknowledgement of ignorance. Scenarios can explore the potential for extreme events and the robustness of various policy portfolios to address the problem and to reduce the risks and uncertainties in the system (we come back to this in Section 3.4.2).

In this chapter we discuss the ~~two extreme~~ ADAM scenarios: a baseline scenario in which global mean temperature increases by 4 °C above pre-industrial levels, and a scenario with considerable mitigation efforts in which global mean temperature increase is limited to 2 °C. These scenarios have been developed as a basis of analysis for the whole ADAM project to enhance consistency in the analyses performed by various work packages. We describe the assumptions that have been made and indicate their major outcomes. We also discuss whether the mostly linear approach taken here in scenario development is warranted, given expected impacts, or whether a more integrated approach should be used for future analysis. In our descriptions, we focus on the global level (in view of the limited space). Clearly, adaptation decisions need more detail. Such detail is included in the underlying analysis not presented here; it would also need to come from more country or sector level analysis, for example, as presented in Chapter 8.

3.2 Scenario development

3.2.1 Types of scenarios

Based on the considerations about mitigation and adaptation described in the introduction, different types of scenarios can be defined. *Firstly, we define a* baseline scenario, *as* a trajectory of events assuming no major feedbacks from climate change and no specific policy efforts on either mitigation or adaptation (such scenarios are also sometimes referred to as 'business-as-usual' scenarios). The main purpose of this type of scenario is analytical, serving as a point of reference for other scenarios, and a starting point for both mitigation and adaptation analysis. Secondly, *adaptation scenarios* describe a world responding to climate change impacts. Their purpose is to explore the type of technologies and policies required to adapt to climate change, and the associated costs. Thirdly, *mitigation scenarios* describe a world with policies aiming to limit climate change.

In ADAM, a scenario has been developed with ambitious mitigation policies aiming to reach a 2 °C target (also called low-stabilisation scenarios). Its purpose is to explore the type of technologies and policies required to minimise climate change, and the associated costs of some of these technologies and policies. *In reality, future development may combine some of these elements (and aim for intermediate targets).*

The scenarios can be used in different ways. Firstly, a qualitative description (storylines) and quantitative analysis can be used to describe the kind of conditions associated with certain development trajectories. Secondly, one may explore the implications of these scenarios, either in terms of physical impacts (e.g. change of climate or biodiversity loss) or in terms of costs associated with mitigation, adaptation or (residual) damages. In exploring a preferred mix of mitigation, adaptation and residual damage, two main approaches exist: (i) the risk-based approach that describes potential impacts as function of global mean temperature increase (and thus mitigation), and (ii) cost–benefit analysis that looks at the same impacts, but now in monetary terms. Most studies indicate that mitigation efforts, and associated costs, increase for scenarios aiming at lower greenhouse gas concentrations (Fisher *et al*., 2007). At the same time, assessments of impacts indicate that the magnitude of impacts and adaptation costs (and, in particular, the sum of these two) increases for higher temperatures and concentration levels (see e.g. (Parry *et al*., 2007; Stern, 2006). The result is a virtual trade-off between mitigation, climate change damages and adaptation costs along the concentration line. However, for several reasons outlined in the introduction, such a trade-off cannot really be made. Moreover, uncertainties play a critical role in baseline development, technological development, climate impacts and climate sensitivity.

3.2.2 Further integration

In climate analysis, scenarios are generally developed in a manner consistent with the driver–pressures–state–impacts–responses (DPSIR) framework (Fig. 3.2). Using this approach, the development of scenarios starts by describing changes in economic activities (income, energy use, agriculture, etc.) and estimating the resulting emissions. These emissions become inputs to climate models, whose outputs are estimates of climate impacts (as done for the SRES scenarios mentioned before) or, in case of integrated assessment models (IAMs), to a climate model included in the IAM. Next, changes in climate variables are used to assess possible impacts and, in some cases, adaptation opportunities.

The DPSIR framework is also used to develop scenarios for IPCC reports. Scenarios are developed by Working Group III researchers focusing on development of driving forces, energy system and land use parameters in baseline and mitigation scenarios. Subsequently, they are run by Global Circulation Models in Working Group I analyses to assess climate change. Finally, the scenarios are used for Impact, Adaptation and Vulnerability analyses by Working Group II researchers. In fact, many integrated assessment models are built around a similar approach. This implies that possible feedbacks from climate change on driving forces, energy system or land use are typically not considered in the IPCC assessment, but also that very few models include any of these feedbacks. Ignoring these feedbacks might only be scientifically sound if those feedbacks are not substantial enough to undermine the likelihood of the original scenario. For analytical reasons, there are major advantages to organising scenario development in a linear way along the DPSIR framework. It enables research to focus on elements of the chain, without the complication of interlinkages between the elements, uncertain feedbacks etc. In the context of integrated analysis of both mitigation and adaptation needs and opportunities, this may, however, not be sufficient. Some examples of why an integrated approach might be necessary are as follows.

(i) Climate impacts could be substantial in agriculture. In such cases, estimates of land-use related emissions not taking impacts into account might be wrong, and the mitigation potential of bio-energy could also be affected.
(ii) Climate impacts may be so severe that they undermine the economic assumptions of the original scenario.
(iii) Land areas might be attractive for both mitigation and adaptation purposes.

An interesting question therefore is whether impacts are indeed so severe that a more integrated approach of scenario development should be preferred, or whether the impacts can be handled separately (as they mostly have until now), simplifying the analysis framework. The few available studies that looked at the interrelationships between adaptation and mitigation indicate that, in most sectors, the adaptation implications of any mitigation project are small and, conversely, the emissions generated by most adaptation activities are only small fractions of total emissions (Klein *et al*., 2007). In the scenarios presented here, based on the current state of the art in modeling and scenario development, we also ignore most feedbacks. However, we will discuss the impacts of different strategies, and by the end of the chapter come back to the question of whether more integrated (but also more complex) scenarios need to be developed.

3.2.3 Approaches to scenario development and their use in ADAM

The use of scenarios within ADAM illustrates different approaches to scenario application. One approach is to use scenarios to analyse the same climate goals with different models (parallel approach). In ADAM, this approach is used in Chapter 11, where integrated models covering the overall global energy system have systematically analysed the implication of achieving stringent mitigation targets using the ADAM scenarios. Model assumptions were harmonised on the basis of the ADAM scenarios for income, population and as far as possible the energy system, in the case of the baseline scenario. For the mitigation scenario, modelling teams were free to follow the greenhouse gas emission profile, the cumulative emissions or the concentration target. The use of multiple models, following alternative approaches, provides insight into uncertainty. The results can, in fact, be seen as an improvement of the original scenario by providing alternative pathways for the same storyline.

The second approach deepens the original scenario by using more detailed models (serial approach). The more detailed model uses the default scenario descriptions as boundary conditions, such as annual temperature and precipitation profiles. The interesting aspect of this approach is that disciplinary strengths of many different models are used. This approach was employed here and in subsequent chapters in assessing the expected impacts of the two scenarios. This improves the original scenario by providing in-depth analysis of the consequences of the scenario. The shortcoming of this method is that possible interactions are often difficult to handle (as they require feedbacks and iterations).

In some cases, the coupled scenario development exercise may itself be highly integrated, or can be coupled in a more interactive way to the original scenario. In such a case, the models complement each other, providing an improved assessment by integrating various disciplinary models. To some degree, the coupled analysis within ADAM, assessing mitigation and adaptation of the European energy system, is an example of this. A description of this work is given in Chapter 7.

3.3 The ADAM scenarios

As explained in the introduction, in ADAM, a set of scenarios is used to explore different combinations of mitigation and adaptation. For analytical purpose, we define a baseline scenario without mitigation action leading to a global mean temperature increase of about 4 °C by the end of the century. Two variants of this scenario are used: one without adaptation (and thus high impacts) and one with adaptation. In terms of socio-economic projections the scenarios are considered to be the same (ignoring for analytical reasons some of the feedbacks). Finally, the mitigation scenario is based on a stringent mitigation strategy leading to an increase of about 2 °C above pre-industrial levels by 2100. Here, we briefly discuss the different assumptions and results. Various storylines may lead to these scenarios. Box 3.1 presents two different possibilities for each scenario. The scenarios were used for various purposes in the ADAM project (see Chapters 4,7,8 and 11).

Box 3.1. Storylines for climate policy

The development of emissions strongly depends on the development of international climate policy. In considering international climate policy, one may consider two important factors: (i) the ambition with respect to mitigation and (ii) the degree of international coordination. Together these create four caricature storylines: (i) adapt alone, (ii) sharing the costs, (iii) technology competition, and (iv) Kyoto++. The first two storylines would coincide with the high emission scenario, while the latter two storylines could possibly coincide with the low emission scenario. Table 3.1 provides the main characteristics of each of these storylines. The *adapt alone* scenario does little mitigation action and organises adaptation at the local scale. In the *sharing the costs* scenario international climate policy fails to organise mitigation actions, but is still able to organise international mechanisms to finance adaptation costs (complying to responsibility and/or the polluters-pays-principle). The *technology competition* scenario starts from local, technology-focused mitigation policies without binding international commitments (an important challenge here is whether countries voluntarily invest enough in new technologies in the next one to two decades). Whether such a scenario may reduce emissions enough to limit global mean temperature increase to 2 °C is an open question. Finally the *Kyoto++* storyline emphasises a development pathway based on co-ordinated international climate policy with binding commitments. The fact that more than one storyline could lead to similar emission scenarios (as emphasised earlier by (Nakicenovic *et al*., 2000)) implies that even with a set target, various policy options exists. That does not mean that all pathways are equally likely to lead to similar outcomes. For instance, the stringent mitigation scenario described in this chapter will require early participation of developing countries in order to achieve the global emission reduction as described. Such an ambitious reduction is arguably more likely to be achieved under an international co-ordination framework than under a more locally orientated, more fragmented regime such as the *technology competition* case.

3.3.1 Population development and economic growth.

The ADAM baseline scenario uses the 2004 revision of world population projections (UN, 2005) up to 2050, and the UN's long-range medium projections over the period 2050–2100 (Fig. 3.3). The projections are based on the medium-fertility variant with global populations steadily increasing to reach a total of almost 9.1 billion people by 2050, leveling off and stabilising at about 9.2 billion people over the subsequent 50 years up to 2100. According to the UN's definition, medium-fertility rests on the assumption that total fertility in all countries converge towards a level of 1.85 children per woman (though not all countries reach this level by 2050).

The population growth patterns that are used in the ADAM baseline scenario take a middle ground within the range of population forecasting. This is because the UN

Table 3.1. *Four storylines for international climate policy*

	Adapt alone	Sharing the costs	Technology competition	Kyoto++
Focus of climate policy	Adaptation	Adaptation	Stringent mitigation and adaptation	Stringent mitigation and adaptation
International cooperation	Autonomous	Coordinated	Autonomous	Coordinated
Characteristics of climate policy	Government policy to ensure access to cheap energy; abandonment of Kyoto-style approaches; Adaptation at local scale	No agreements on emission reductions leads to failure of mitigation; but developing countries are able to get an UNFCCC type agreement on sharing adaptation costs.	High technology orientation, but little international institutional arrangements; dedicated technology fixes; both cooperation and competitive relationships across different regions;	High level of mitigation based on high level of international coordination. Universal and effective governance structure. Adaptation mostly at local level.
Outcome	High level of climate change	High level of climate change	Low level of climate change	Low level of climate change

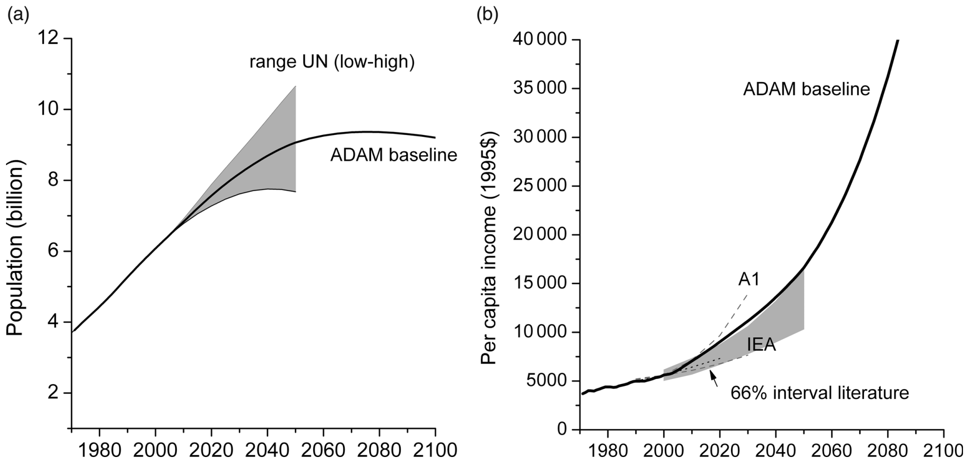

Fig. 3.3. (a) Population development and (b) economic growth in the ADAM scenario compared with recently published scenarios (for economic growth the database of scenarios as compiled for IPCC (Fisher *et al*., 2007) was used).

indicates both low and high-fertility variants with projections varying from 7.8 billion (low series) to 10.6 billion (high series) by 2050 (Fisher *et al*., 2007). The extent of uncertainties are illustrated by the wide range of projections available in the literature. For example the IPCC in its SRES report displays a range from just above 6 billion to over 15 billion of people to inhabit the planet by 2100. Higher or lower population numbers will impact on both the demand-side through changes in consumption, and on the supply-side by affecting the availability of labour supply. These both in turn affect future growth prospects.

It should be noted that the economic growth projections presented in the ADAM baseline are only partially linked to the UN population projections. There is no direct feedback between the expected economic growth and changes in fertility, life expectancy rates and international migration flows, other than those taken into account in the UN's calculation of future population increases. Nevertheless, long-term growth rates underpinning the ADAM baseline do draw partly on population developments, particularly on likely future urban–rural migration flows across major economies. That is, the greater the availability of under-utilised labour resources and the higher the scope for rural–urban migration, the greater the perspectives for long-term sustained growth, as growth processes are arguably concentrated and dominating in large urban areas and city centres

In terms of economic growth, Fig. 3.3 shows the baseline scenario to be a high economic growth scenario, which is mainly the result of optimistic growth assumptions for China and India (*cf*. Fisher *et al*., 2007). Outside these regions, ADAM assumptions are comparable to other more medium projections. The high income (western) economies are project to remain the richest in per capita terms. In terms of total economic activity, however, the importance of developing regions grows rapidly, especially in much of Asia, particularly China and India, and in Latin America. In terms of gross domestic product (GDP) per capita, growth is between zero and two percent per annum in Africa, the Middle East and Latin America. In Asia, it falls steeply from the current seven percent per annum to four percent per annum between 2010 and 2030 and to less than three percent per annum by 2050. This largely reflects the end of the rapid catch-up process currently experienced by Asian economies and the economic slowdown as consequence of the ageing population in China.

3.3.2 Energy use and greenhouse gas emissions

Baseline scenario

Energy use in the ADAM baseline scenario is based on the baseline published earlier by the European Commission (EC, 2006). The scenario shows energy intensity of the world economy in 2050 falls to about half of the 2001 value, and

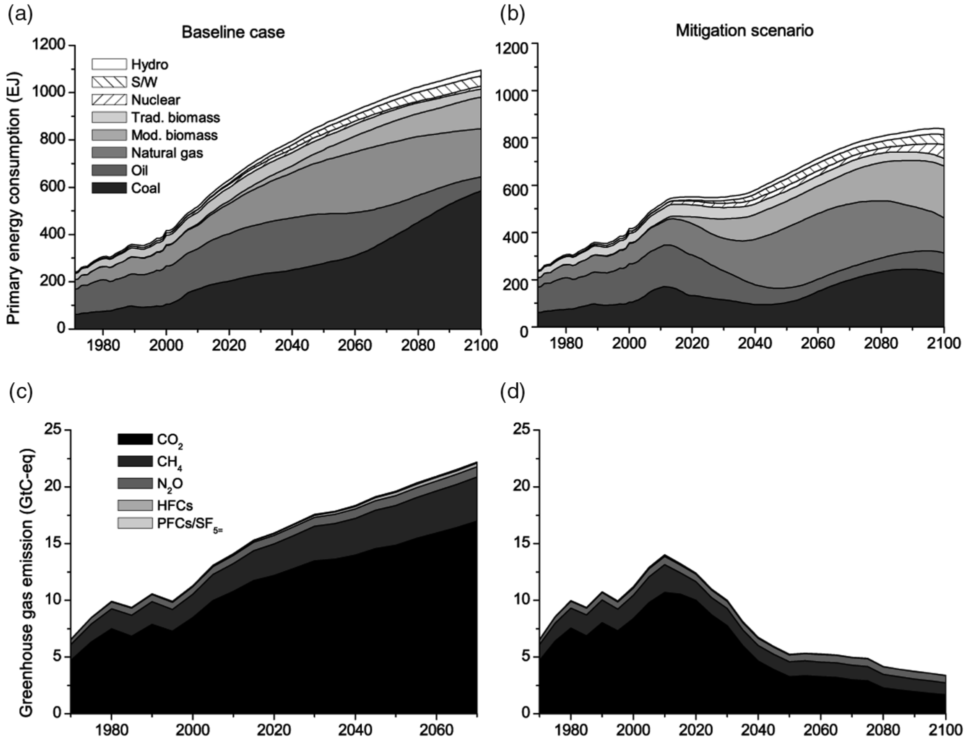

Fig. 3.4. (a) Global primary energy use for the baseline scenario and (b) the 450 ppm scenario (right). (c) Global CO_2e. emissions for the baseline scenario and (d) the 450 ppm scenario (right). (Source: TIMER model). (See colour plate section.)

by 2100 it is halved again (Fig. 3.4). World energy consumption however, more than doubles in the 2000–2050 period and increases by another 25% in the 2050–2100 period. Over the whole century, energy supply remains dominated by fossil fuels. At about 2040, conventional oil production peaks. Production of unconventional oil increases to compensate for reduced conventional oil production, so that total oil production does not decrease significantly before 2060. The peak of natural gas production occurs considerably later (around 2070). With an increase in coal use, the contribution of non-fossil energy sources to total primary production does not decrease significantly. The high degree of coal use (almost half of all energy used in 2100) reflects the relative abundance of coal, for which resource scarcity is not expected to play a role in limiting production or significantly increasing cost in any foreseeable future. The amount of non-fossil energy production also increases substantially. Nuclear energy use increases by a factor of two to three to 76 EJ over the period until 2100, the use of biomass increases strongly, while hydroelectricity production increases by about 60 to 80%. All these resources grow further after 2050. The largest relative increase is that of wind and solar energy;

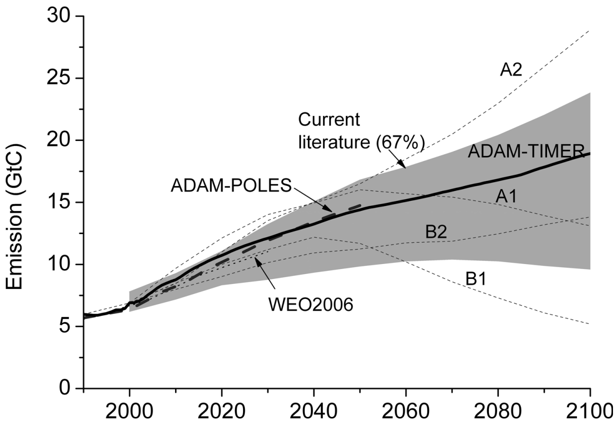

Fig. 3.5. World carbon dioxide emissions from energy production and use in the baseline scenario compared to emissions according to other scenarios.

this rises from less than one percent of all non-fossil energy to between 10 and 14 percent in 2050. Between 2050 and 2100, wind and solar energy double again. Total renewable energy use in 2050 is 120 to 140 EJ, and 190 EJ in 2100.

As a result of the trends described above, emissions of carbon dioxide from energy activities more than double until 2050, and rise by a third again between 2050 and 2100 (see Fig. 3.5). This scenario is consistent with a large range of other scenarios in scientific literature (Fisher *et al.*, 2007).

Land-use-related emissions of greenhouse gases other than carbon dioxide (in particular methane) increase steadily in the period 2000 to 2050 (driven by increasing agricultural production), but at a slower rate than energy-related carbon dioxide. In the second half of the century, a stabilising population also leads to a stabilisation of agricultural emissions. The ADAM baseline scenario lies at the low end of the range of similar scenarios that have recently been published (Rose *et al.*, 2008). Carbon dioxide emissions from land-use fall back to zero during the first half of the century.

Mitigation scenario

The ADAM mitigation scenario corresponds to the ambition of the EU to limit global mean temperature increase to maximum 2 °C compared to pre-industrial levels (using a best-guess value for climate sensitivity). This scenario aims at stabilising greenhouse gases at around 450 ppm CO_2e after an initial overshoot to about 510 ppm CO_2e (den Elzen and Van Vuuren, 2007).

The emission reduction is achieved in various ways. One element is to increase energy efficiency, which reduces the total amount of energy use. By 2050, energy is reduced by more than 20% in this scenario compared to the baseline (see Fig. 3.4).

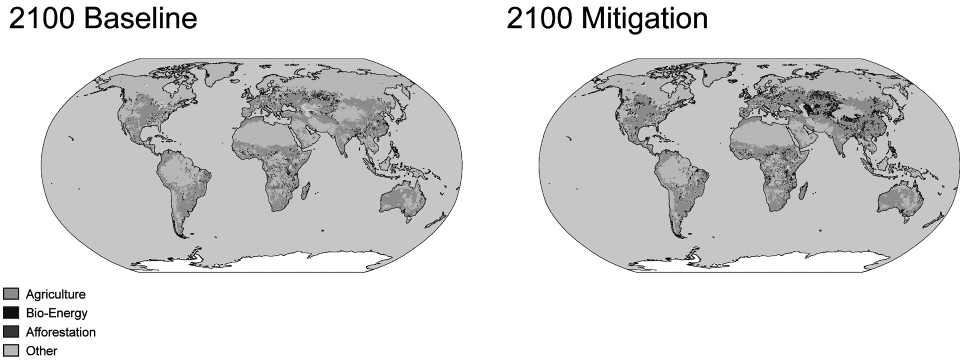

Fig. 3.6. Land use in the different scenarios. Geographic details are for illustration only. The figure shows the visible impact of land-use related mitigation options on future global land use. (See colour plate section.)

Another measure seen in this scenario is a switch away from coal to natural gas, especially during the first half of the century, when other technologies for emission reduction are still underdeveloped. Oil use is also reduced, so that ‘peak oil’ due to depletion is not reached, as in the baseline scenario, and unconventional oil resources are minimally exploited. The scenario also shows an increasing use of energy from non-fossil sources, which account for most of the growth in total energy use. Non-fossil energy use increases from about 15% of total primary energy use in 2010 to more than 30 percent in 2050 and is over 40% of the total by the end of the century. Most of this growth is due to an increase in bio-energy use. Finally, carbon capture and storage is applied in most remaining stationary uses of fossil fuels. In addition, also non-carbon dioxide greenhouse gas emissions are reduced. As a result, global emissions peak around 2020, and reduce further with time. By 2050, emissions are reduced by more than 70% compared to the baseline and more than 80 percent by 2100 .The consequences of the mitigation policies are not only obvious for energy, but also for global land use. Substantial land areas are used for afforestation and bio-energy (see Fig. 3.6).

3.3.3 Climate change

The atmospheric greenhouse gas concentration, in CO_2e, resulting from the emissions of the two scenarios is shown in Fig. 3.7. There is some uncertainty in the concentration levels, because of uncertainties in the carbon cycle. The figure also shows the global temperature change and the solid lines indicate the outcome for best-guess assumptions (such as a climate sensitivity of 3 °C). The shaded area indicates the uncertainty due to carbon cycle and climate sensitivity. Global mean temperature under the baseline case increases almost linearly to 2.1 °C above the

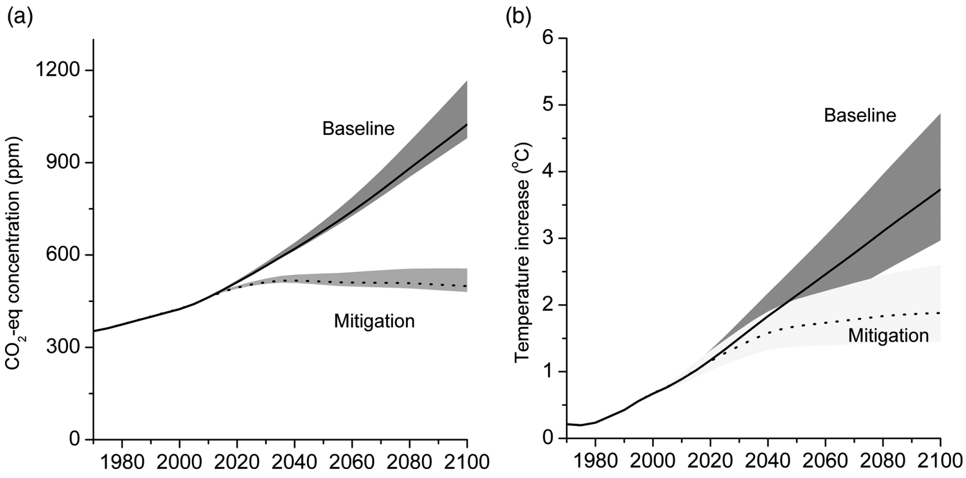

Fig. 3.7. Atmospheric carbon dioxide equivalent concentration (taking into account the Kyoto gases) (a) for the baseline scenario (4 °C, no climate policy) and mitigation scenario (2 °C) (left) and (b) global temperature change (since the pre-industrial age) for the same two scenarios (right). Ranges are based on van Vuuren *et al*., 2008.

pre-industrial levels in 2050 and to 3.7 °C in 2100. The uncertainty in these values, however, ranges from 3 to 5 °C. In the mitigation scenario, the global mean temperature increase by 2100 reduces to 1.9 °C for the best-guess assumptions. Again, there is considerable uncertainty, and in fact, during the first decades the temperature range of the baseline case and the mitigation scenario strongly overlap. By the end of the century, however, there is a clear difference. Even so, Fig. 3.7 indicates that the mitigation case could also lead to a temperature increase of 2.6 °C compared with pre-industrial levels.

The mitigation scenario presented here is among the most stringent in scientific literature, and two important conclusions can be drawn. Firstly, global warming can be mitigated but not be stopped; the most stringent scenarios still lead to an increase of about 2 °C above pre-industrial levels, whilst assuming there is global co-operation to reduce emissions from about 2015/2020 onwards. Secondly, because this stringent scenario could also lead to considerably greater climate change, adaptation policies could be hedged against the higher numbers. For example, such policies may be to ‘aim for 2 °C, but prepare for 3 °C’. In the assessment of impacts below, we focus on the central climate change projections.

Models agree that the level of temperature and precipitation change will not be the same at different locations. The patterns of change are, however, very different across the models. Some general trends can be observed; for example, the change in annual mean temperature is larger at high latitudes than at low latitudes. In terms of precipitation, however, differences across models are even greater; there are only a

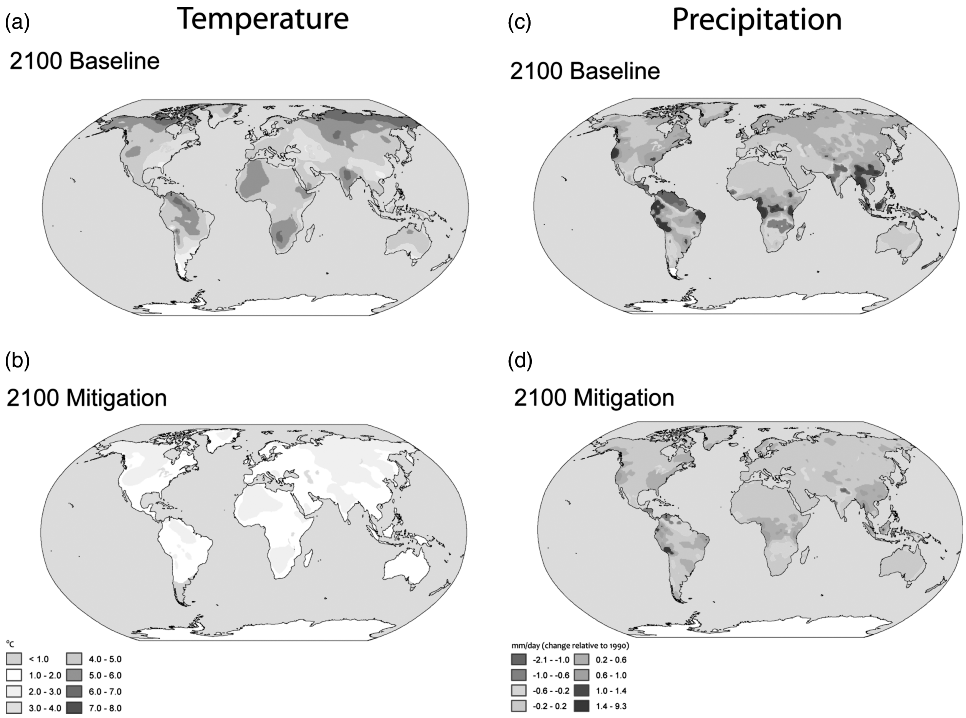

Fig. 3.8. Map of change of annual mean temperature and precipitation in 2100 relative to 1990; (a) temperature; scenario: baseline (leading to 4 °C warming in 2100); (b) temperature; scenario: mitigation (2 °C); (c) precipitation; scenario: baseline (leading to 4 °C warming in 2100); (d) precipitation; scenario: mitigation (2 °C). (See colour plate section.)

few places where the majority of models agree on whether there is an increase or decrease (e.g. all models expect Southern Europe to be become drier). The patterns used for the ADAM scenarios are shown in Fig. 3.8.

3.4 Impacts and adaptation in the different scenarios

3.4.1 Introduction

The Synthesis Report of the IPCC Fourth Assessment Report (IPCC, 2007) gives an overview of impacts associated with climate change. Some of these impacts result from changes in climate averages, but other impacts (and arguably more severe ones) may result from changes in extreme events. Table 3.2 summarises some of the main impacts. There are six broad categories of important impacts: health, agriculture, water availability, coastal flooding, urban areas and energy system, and large-scale disruptions of the climate system. In this section, we sketch some impacts and adaptation requirements under the two main ADAM scenarios (baseline and

Table 3.2. *Possible impacts of climate change*

	Impacts associated with global average temperature change	*Impacts due to changes in extreme events*
Health	Increasing burden from malnutrition, diarrhoeal, cardio-respiratory and infectious diseases. This will affect particularly populations with low adaptive capacity	1. Reduced mortality from cold exposure, increased risk of heat related morbidity and mortality (heat waves) 2. Risks related to heavy precipitation events (deathes, injuries and diseases) 3. Food and water shortage and increased risk of water- and food- borne diseases as a result of drought 4. Risks related to floods Population migration with associated health risks due to droughts, floods, increased incidence of extreme high sea level
Food	Negative impacts on vulnerable groups. Region specific changes (both positive and negative) in cereal crop productivity.	1. Changed yields in agriculture (due to extreme temperatures, droughts, heavy precipitation) 2. Land erosion and degradation (due to heavy precipitation events, droughts) Increased livestock deaths (due to drought)
Water	Increased availability in some areas, decreased availability and increasing drought and water stress in other areas. Effects are both through changes in rainfall + evapotranspiration and through changes in snow and ice melt. This will affect agriculture.	1. Effects on water resources relying on snowmelt and glaciers (due to changed extreme temperatures) 2. Effects on water supplies (due to changed extreme temperatures, changed seasonality, droughts, heavy precipitation events) 3. Increased water demand (due to heat waves, droughts) 4. Changed (reduced or increased) hydropower generation potentials due to changing droughts
Coasts	Increased damage from floods and storms due to sea level rise. This will affect low-lying coastal systems.	Increased risk and costs of coastal protection from extreme weather events.

Table 3.2. (*cont.*)

	Impacts associated with global average temperature change	*Impacts due to changes in extreme events*
Industry, settlements and society	Affected by impacts in all of the above categories, compounding pressures associated with rapid urbanisation, industrialisation and aging in some societies. The most vulnerable are generally those in flood plains, those whose economies are closely linked with climate-sensitive resources and the poor.	Affected by impacts in all of the above categories. Specific impacts include: 1. Changes in energy demand for space conditioning 2. Reduced quality of life due to heat waves for people without appropriate housing, 3. Disruption due to flooding caused by heavy precipitation 4. Water shortages due to drought 5. Disruption due to cyclones 6. Increased costs of coastal protection from extreme high sea level
Large-scale disruption	1. Partial loss of ice sheets on polar land implies metres of sea level rise. Rapid sea level rise on century time scales cannot be excluded. 2. Large-scale and persistent changes in the meridional overturning circulation (MOC) of the Atlantic Ocean could cause various changes to ocean behaviour.	

mitigation) within these categories. The descriptions are not intended to be exhaustive, but instead provide some indication of the magnitude of impacts and adaptation challenges. We also use the results to discuss the possibilities and the need to develop more integrated scenarios.

3.4.2 Human health: temperature-related mortality and malaria

Climate change influences human health in various ways. It is likely, however, to remain a relatively minor factor compared to other drivers that impact human health (such as life-style related factors) (Hilderink *et al*., 2008). We focus here on climate change impacts on temperature related mortality and malaria.

Temperature related mortality

The effect of heat, in the form of heatwaves, on mortality has been described in various studies. The strongest physiological evidence for additional mortality levels is available for cardiovascular disease. The impact of climate change may occur via changes in extreme temperatures, changes in average temperatures or in seasonal variation of temperature and the literature shows varying results. McMichael *et al.* (1996) made an estimation of temperature-related mortality using relative risk ratios, showing that there is an optimum temperature at which the death rate is lowest (also know as the U-shaped dose-response relation) (McMichael *et al.*, 1996). This study also shows that for higher temperatures heat stress-related mortality increases, whereas cold-related mortality decreases. Tol (2002) concluded that, in monetary terms, the reduction in cold-related mortality due to climate change will outnumber the increase in heat-related mortality. This conclusion is, however, strongly influenced by the approach used to value a life and also subject to the large uncertainties in the relationships between temperature and health. Adaptation may occur both by the adjustment of the human physiology to higher temperatures (McMichael *et al.*, 1996) and an increase of air conditioning use (Kinney *et al.*, 2008). Given the complexities in using dose–response relationships between temperature and mortality, we have not directly related them to the two ADAM scenarios.

Malaria

Annually more than one million people, mostly African children, die from malaria, a vector-born infectious disease. Malaria vectors spreading the infection, i.e. the anopheles mosquitoes, can only survive in climates with high average temperatures, no frost and sufficient precipitation. The MARA/ARMA malaria suitability model (Craig *et al.*, 1999) incorporates these factors to determine climatically suitable areas – which was run for the ADAM scenarios (Fig. 3.9) (see Appendix for details).

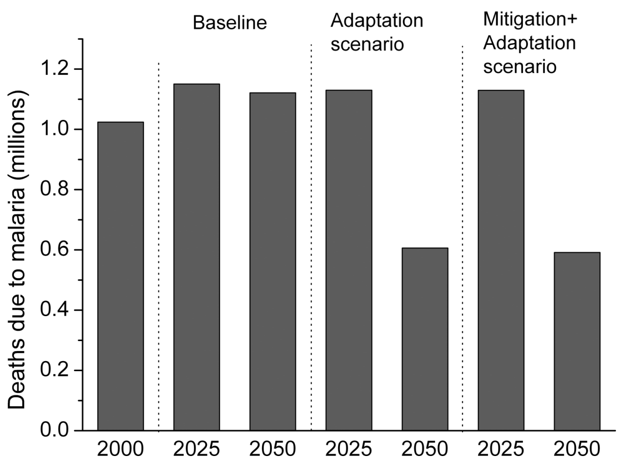

Fig. 3.9. Death due to malaria in the baseline scenario and in the mitigation scenario. ~~The ‘no GDP growth’ scenario has been added to illustrate the importance of socio-economic development on malaria deaths.~~

The number of deaths from malaria are predominantly influenced by factors such as access to preventative measures, such as insecticide-treated bed nets, and access to health care, both of which are linked to income and urbanisation. This is demonstrated by comparing a hypothetical scenario without GDP growth and the baseline scenario: the assumed income growth reduces malaria deaths by around 50 percent and suggests that adaptation strategies might be similarly effective. The difference between the mitigation scenario and the baseline case however, is much smaller; mitigation reduces malarial health risks by about 2 percent.

3.4.3 Agriculture: Impacts on yields

For the IPCC, Easterling *et al*. (2007) have synthesised a large amount of research on the impacts on crops of incremental temperature change, with or without adaptation. Their information represents an overview of the best knowledge currently available on the impact of climate change on crop yields (both with and without adaptation) and therefore we have compared their results to our scenarios. Easterling *et al*. (2007) have summarised the results using best-fit polynomials of the percentage yield change as a function of mean local temperature change[2]. These results can be used to estimate the potential global impacts of the ADAM baseline and mitigation scenarios, with and without adaptation, for maize, wheat and rice. Figure 3.10 shows the yield change according to Easterling *et al*. (2007) at low latitudes (tropics) and at mid to high latitudes (temperate zones) at temperature

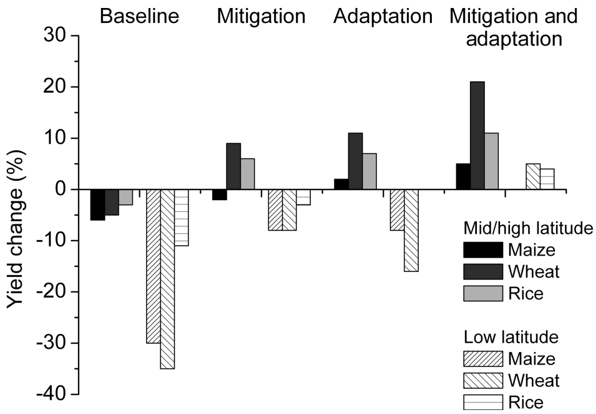

Fig. 3.10. Indicative results for the sensitivity of maize, wheat and rice yield change at low and mid- to high-latitudes to climate change for each of four scenarios (following Easterling *et al*. (2007)

[2] We have in each case taken the global mean temperature change for a scenario and used that as an indication of the average local temperature change to be expected.

changes equal to the global mean temperature change in 2100 according to the ADAM scenarios. Although the results are highly uncertain, some preliminary conclusions seem to be possible from this figure. Firstly, the baseline scenario, with high climate change and no adaptation, causes a very substantial decrease in yields for all cases shown., Climate impacts. especially in the tropics, may reduce yields by 10 to 35 percent for the crops studied. Secondly, engaging in either mitigation or adaptation limits the decrease in yields and, in some cases, may enable an increase in yields. In the tropics, impacts remain negative and typically in the order of a 10 percent loss. Thirdly, the mitigation scenario with adaptation may result in an improvement from today's situation.

The importance of mitigation is illustrated by the analysis of Tubiello and Fischer (2007), who found that when comparing a non-mitigated scenario with a mitigation scenario, global costs of climate change in agriculture were reduced by 75% to 100% with mitigation, and the number of additional people at risk of malnutrition was reduced by 80 to 95%. The importance of adaptation may be seen in the work of the same authors (Fischer *et al*., 2007) on climate change impacts on water irrigation requirements, where they found that mitigation reduced the impacts of climate change on agricultural water requirements by about 40%, This leaves 60% of the effects of climate change on irrigation requiring adaptation.

These results underline the need to look at both mitigation and adaptation. While mitigation limits the damages of climate change, adaptation is still necessary, since even with 2 °C mean climate change, impacts can be significant.

3.4.4 Water resources: potential water availability

The effects of the two ADAM scenarios on water resources are assessed using a global-scale water resources impact model (Arnell, 2003)[3]. Figure 3.11 shows the percentage change in average annual runoff by 2100 (relative to the 1961–1990 mean) under the baseline scenario and the mitigation scenario. The differences between the scenarios in change in runoff are similar to, but slightly larger than, the relative difference in change in global average temperature under the two scenarios. For example, the change in temperature by 2050 is approximately 20 percent smaller under the mitigation than the baseline scenario (1.7 °C compared to 2.2 °C), and the change in runoff is generally between 20 and 25% smaller.

The human implications of the difference between the baseline and mitigation scenarios can be assessed by examining changes in runoff in watersheds exposed to water resource stress (here defined to have runoff less than 1000 m^3/capita/year). The results show quite substantial differences in exposure to increased water

[3] We used pattern-scaling to obtained maps of temperature and rainfall change, on the basis of the HadCM2 run.

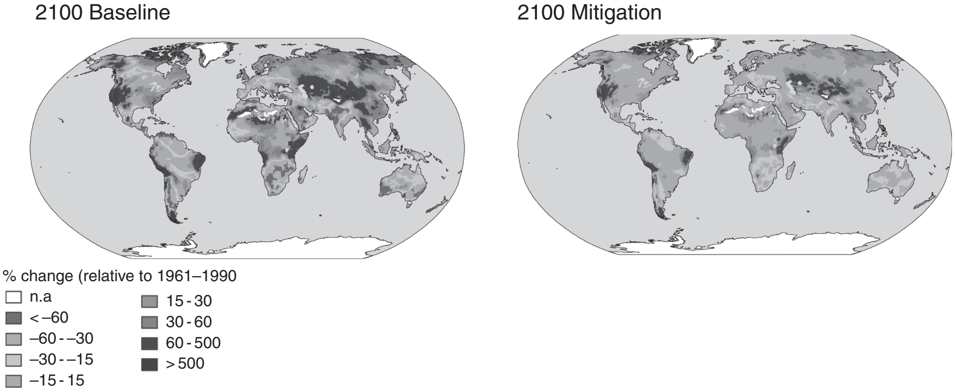

Fig. 3.11. Change in runoff by 2100s. The figure shows the percentage change in average annual runoff by the 2050s, relative to 1961–1990, under the baseline and mitigation scenario. (See colour plate section.)

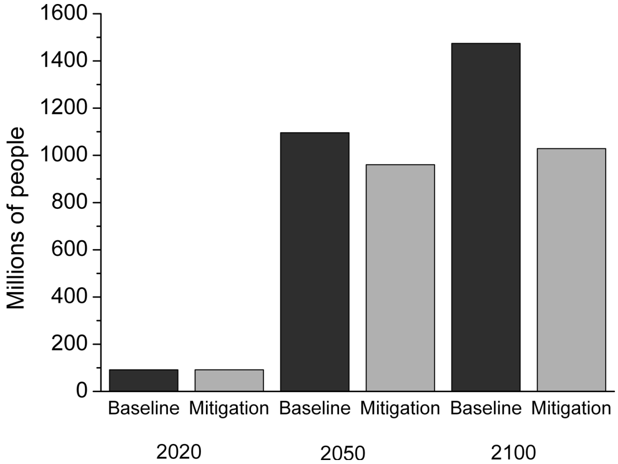

Fig. 3.12. Numbers of people exposed to increase in water resource stress due to climate change, under the baseline and mitigation scenarios. The simulations are based on the HadCM2 climate model pattern.

resource stress in 2050, 2080 and 2100 between the mitigation and baseline scenarios. There is no difference, however, in 2020 because there is little difference in runoff between the two scenarios. Figure 3.12 shows the numbers of people exposed to an increase in water resource stress due to climate change under the two scenarios; the mitigation scenario reduces the numbers exposed by 135 million, 281 million and 457 million in 2050, 2080 and 2100, respectively (the numbers are sensitive to the assumed pattern of climate change). Mitigation, however, does not eliminate the impact of climate change, and adaptation will clearly be required for the remaining billion people exposed to a situation of water resource stress due to climate change. Underlying results show that the effects of mitigation are regionally variable, and in some circumstances, mitigation appears to increase the numbers of people exposed to increased stress. This occurs because of the non-linear response of runoff in some circumstances to gradually changing rainfall and temperature.

The indicator used is a measure of exposure to water resource stress, and does not represent the actual water stress (which is determined by water management structures and practices). In a sense, it can be viewed as an index of 'adaptation demand', defining adaptation as the introduction of management practices to reduce the increased exposure to water resource stress. Adaptation may include measures to increase water storage, transport of water, or reduction of water demand by increasing efficiency. Another way of characterising adaptation is to assume that the aim of adaptation is to eliminate water resource stress. The effect of climate change on this demand for adaptation is indexed by the difference in exposure with and without climate change.

3.4.5 Coasts: sea level rise

Another important impact of climate change results from increasing sea levels. For this we used the DIVA model (version 2.0.3; see model appendix) to explore the vulnerability of coastal zones to sea level rise. The expected global sea level rise in 2025 is 19 cm (since the pre-industrial age) in both scenarios. In later years the scenarios start to diverge, with sea level rise in 2050 being 31 cm in the mitigation scenario and 35 cm in the baseline scenario, and in 2100 the rise is 49 cm and 71 cm, respectively.

The model simulates costs of damage caused by sea level rise and associated storm surges as well as costs of adaptation in terms of dike building and nourishing beaches, assuming (i) no adaptation, or alternatively (ii) optimal adaptation (DINAS-COAST Consortium, 2006; Hinkel and Klein, 2007) . Figure 3.13 shows that the sum of damages and adaptation costs are highest for the baseline case and lowest for the mitigation scenario with adaptation. The figure also shows that adaptation reduces overall costs rather effectively. The necessity of engaging in adaptation even under an ambitious mitigation effort is underlined by the fact that costs in the mitigation-only scenario, are much larger than the costs in the adaptation-only scenario. For sea level rise, more damages can be avoided through an adaptation-only strategy than through a mitigation-only strategy, although the combination of the two has the strongest positive impact. The causes of the increasing costs over time are the gradually rising sea level and rising GDP. While the costs involve substantial investment flows (10s of billions of US$ worldwide), they are a relatively small fraction of global GDP, even for sea level rise at the level

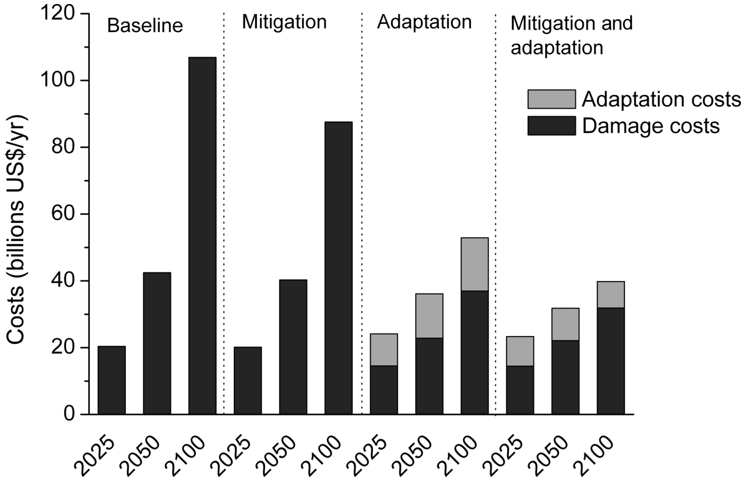

Fig. 3.13. Global total annual adaptation costs and damages up to 2100 as a result of sea level rise, as modelled in the DIVA model using the ADAM scenarios.

of the baseline scenario,. However, for individual countries or regions (particularly small island states) these costs can be a much larger fraction of income.

3.4.6 Industry, settlements and society: Heating and cooling demand

Since the demand for space cooling and heating is linked to climate, it is expected to be influenced by climate change. We have used some simple relationships to describe heating and air conditioning demand in the residential sector, and explore the impacts of climate change on this simulated energy demand (Isaac and van Vuuren, 2009). It should be noted that changes in population and income are projected to lead to a considerable growth in the energy demand for heating and air conditioning in the coming century (see Fig. 3.14, no climate change case). Changes in cooling and heating practices are examples of that part of adaptation to climate change which is expected to occur 'autonomously' (i.e. without policy intervention). As a result, we do not have a separate adaptation scenario, but include adaptation in all scenarios. This is not perfect adaptation, however, since the extent to which a population is able to fulfill demand for space conditioning depends on income. Unfulfilled demand for heating and cooling can lead to health impacts (as described in Section 3.4.2) and to loss of labour productivity. In addition to these effects, which can be costed in a relatively straightforward way, there is reduced comfort when indoor temperatures are not optimal.

Figure 3.14 shows that globally the increase in energy demand with time is much larger than the difference between the energy demand in the baseline scenario, the

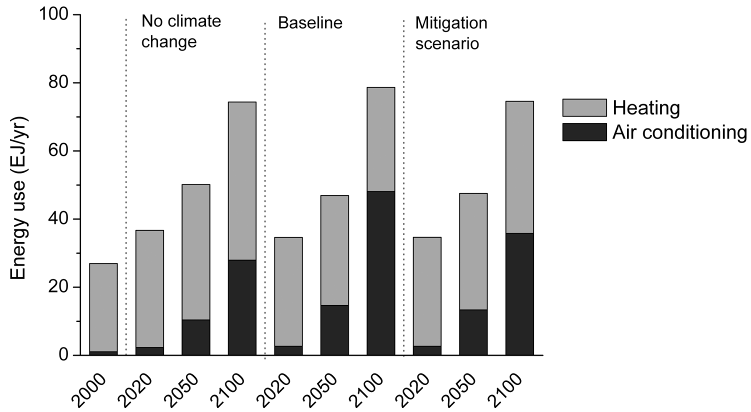

Fig. 3.14. Global annual energy demand for heating and air conditioning in the residential sector in the year 2000 and during the coming century for two scenarios (baseline and mitigation) and if no climate change at all is assumed (TIMER model).

mitigation scenario, and the values calculated without taking climate change into account. The effect of climate change on the combined energy demand is also smaller than the effect on heating and air conditioning individually, since increases in air conditioning compensate decreases in heating. On the regional and country level, impacts can be far more substantial: for example, India, where a large increase in energy demand is due to increased cooling, and Western Europe and the USA where there is a substantial decrease in energy demand due to reduced heating.

3.4.7 Changes in extreme weather events

Climate change is expected to include changes in frequency and intensity of some weather-related extreme events. Extremes like floods, droughts, storm surges and 'warm' extremes are projected to become more frequent, widespread, and intense, while cold-extremes, such as cold spells, are likely to become less frequent and weaker. Assessing risks on the basis of changes in average conditions runs the risks that changes in extreme event risks are averaged out over temporal and spatial scales. A more risk-based, geographically explicit method is therefore preferable (see Chapter 8, Mechler *et al.*). Substantial progress has yet to be made, however, as comprehensive knowledge on disaster impacts and risks is limited and heterogeneous in nature, and uncertainties, particularly for future projections, are very large. For example, climate models do not always agree whether precipitation increases or decreases. Furthermore, flood risk analysis is hampered by a lack of modelled variability in precipitation events and coarse resolution of events, often only allowing assessments in terms of sensitivity analyses.

There was no global assessment of extreme events in the ADAM project, but we provide here a few examples of other work in the context of the ADAM scenarios. The global average number of people affected by flooding each year is about 50 million. Hirabayashi and Kanae (2008) and Kundzewicz *et al*. (2009) compared changes in the number of people affected by floods for different degrees of global warming. For 2 °C warming above pre-industrial levels the number is projected to be 211 million, while for 4 °C warming it rises to 544 million. Impacts of flood disasters on human welfare are likely to occur disproportionately in countries with low adaptation capacity. Projected flooded area in Bangladesh, the most flood-vulnerable country in the world, is expected to increase by at least 23 to 29% with a global temperature rise of 2 °C (Mirza *et al*., 2003). However, the uncertainty of socio-economic factors and adaptation still leads to a wide range of estimates for the costs of future flood damage. With respect to drought, the projections for the 2090s made by Burke *et al*. (2006), using scenarios comparable to our baseline case, show a net overall global drying trend. The proportion of the global land surface suffering from extreme drought is predicted to increase by a factor of 10 to 30; from one to three percent for the present day to about 30 percent by the 2090s. The number of extreme drought events per 100 years and mean drought duration are likely to increase by factors of two and six, respectively, by the 2090s.

Rising costs due to weather-related extreme events are already increasing the need for effective economic and financial risk management. The costs of major events are expected to range from several percent of annual regional GDP and income in very large regions with very strong economies, to more than 25 percent in smaller areas. (Parry *et al*., 2007).

3.4.8 Economic evaluation of impacts

Cost–benefit analysis (CBA) can be used to express the costs and benefits of climate change of different strategies (see Section 3.1) in terms of a common monetary unit. These costs are discounted into net present value calculations. The costs include: (i) real, measurable, economic costs (so-called market costs); and (ii) other impacts expressed in monetary terms on the basis of an 'assumed' value, such as the loss of biodiversity cost based on the willingness-to-pay concept. In the past, damage functions have been published as part of work on various integrated assessment models (see Hof *et al*., 2008). More recently, damage estimates for the DICE model were extended with explicit adaptation cost estimates (De Bruin *et al*., 2007). We have used the FAIR model (see model appendix) to develop economic costs estimates under these scenarios, especially to assess the impact of relevant uncertainties (Hof *et al*., 2009; Hof *et al*., 2008). Some important observations are that most models typically assess the costs of mitigation to be between zero and three percent of GDP, for optimal implementation of 450 ppm CO_2e stabilisation scenarios at a global scale (Fisher *et al*., 2007). Regional costs can be considerably higher, for example, greater than 10% for oil-exporting countries. A few models report net economic gains even for very stringent stabilisation targets such as in the case of Barker *et al*. (2006; 2008). At the same time, estimates of the costs of impacts of climate change vary over a very wide range. While the damage curves for a baseline scenario included in most models typically lead to costs in the order of a few per cent of GDP, under extreme assumptions, these costs may be up to 25% or higher. Finally, adaptation investments are mostly assessed to be smaller than mitigation investments and residual damages. However, they are very important in limiting residual damages. While uncertainties imply that CBA cannot be used to provide quantitative results on optimal mitigation and adaptation levels, the outcomes can very well be used to explore the impacts of different assumptions.

Under default settings of the FAIR model, the discounted costs as share of GDP due to climate change impacts for the period 2005–2200 at 2.5% discount rate amount to nearly 4.5% in the baseline (Fig. 3.15). These costs rise sharply over time, reaching 17% in 2200. Adaptation or mitigation reduces these costs substantially to around 2.5%. The adaptation scenario results in relatively low costs due to discounting, as in the long-run this scenario still leads to 8% costs of GDP in 2200. By comparison, the mitigation scenario leads to less than 2% costs of GDP in 2200, but follows a completely different time profile, with mitigation costs early in the century. The combination of mitigation and adaptation leads to the lowest discounted costs, namely 2%.

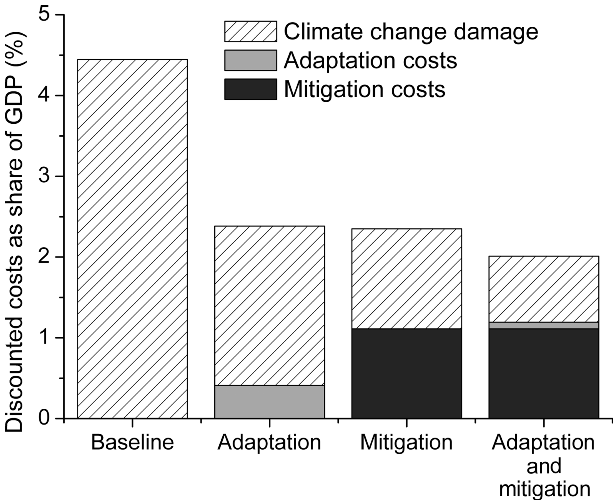

Fig. 3.15. Mitigation costs, adaptation costs, and residual damages due to climate change as share of GDP according to the FAIR model (Hof *et al*., 2009).

A crucial caveat needs mentioning at this point with regard to the economic evaluation of climate change impacts. First of all, calculations cannot be regarded as reliable for the extreme tails of risks (i.e. low probability, high impact events). As a subjective assessment on how to handle such risks is involved, Weitzman (2008) questioned the usefulness of CBA for policy makers. Secondly, the value of the discount rate to account for time preference and risk is currently heavily debated, with arguments relating to subjective time preference and risk perception (Nordhaus, 2008; Price, 2005; Stern, 2006). Finally, irreversible changes, for example a warming of the oceans leading to the loss of coral reefs, need subjective quantification of damages (Ackerman and Heinzerling, 2004).

3.4.9 Uncertainties in climate change, impacts and adaptation

There are many sources of uncertainty in projections of future climate change and its impacts. Uncertainties are associated with every step in the causal chain shown in Figure 3.2: emissions, climatic drivers (e.g. the carbon cycle), climate (mainly climate sensitivity and pattern of climate change), and impacts (including adaptive capacity). The initial uncertainty, relating to future human development, is considerably amplified along this chain This is illustrated by the fact that, under the same emission scenario, different models give rise to different impacts, due to model differences in the later steps in the chain. This difference is often larger than that arising in one model with different emission scenarios. For example, for precipitation changes until the end of the twenty-first century, the multi-model ensemble mean exceeds the inter-model standard deviation only at high latitudes (Kundzewicz *et al*., 2007). Uncertainties in climate change projections increase with the length of the time horizon. In the near term (e.g. the 2020s), climate model uncertainties play the most important role; while over longer time horizons (e.g. the 2090s), uncertainties due to the selection of emissions scenario become increasingly significant (Jenkins and Lowe, 2003).

The impact of future climate change on extreme events is particularly uncertain. This is partly due to a mismatch between the larger spatial and temporal scale of coarse-resolution climate models, and the local occurrence and short life of some weather extremes (e.g. cloudburst precipitation and flash floods). Impacts and adaptation are most relevant at the local scale, as people experience events in a particular time and place. Resolving the mismatches at both the spatial and the temporal scale requires downscaling, giving rise to another source of uncertainty, no matter which method of downscaling is used.

Uncertainty has implications for adaptation. The large range of projections observed in different climate model-based scenarios (*cf.* ENSEMBLES Project of the EU) suggests that planning for adaptation should not be based on a limited number of scenarios, since the range of simulations obtained might not represent the full range possible. Robust adaptation procedures, which do not rely on precise projections of changes, therefore need to be developed.

3.5 Conclusion

In this chapter, we have discussed how scenario analysis may contribute to the assessment of mitigation and adaptation strategies. We have also presented two scenarios used in the ADAM project as a starting point for analysis. We specified impacts in those scenarios for a selected number of parameters, focusing mainly on mean climate changes. Further improvements can be made by focusing on extreme events and by exploring the implications of various risk levels. Both the IPCC (Parry *et al*., 2007) and the Stern Review (Stern, 2006) made a more comprehensive overview of impacts as a function of global mean temperature rise, but did not couple impacts to specific scenarios. Figure 3.16 shows the impacts as assessed by the Stern review, indicating the position of the two ADAM scenarios on the climate change axis.

(i) *We described two sets of possible climate change trajectories for the world for analysis of mitigation, adaptation and impacts*. The first set, including the so-called baseline and adaptation scenario without climate policies, is expected to lead to a global mean temperature increase by the end of the century of around 4 °C (for the most likely values for climate parameters, and current economic trends). This scenario has high adaptation needs as explicitly described in the adaptation scenario. The second scenario assumes stringent mitigation and limits global mean temperature change to 2 °C, with a probability of 50%, using known techniques and costing one to two percent of GDP. Even under this scenario, adaptation measures will still be needed.

(ii) *While it is possible to explore different consequences of scenarios (including uncertainties) it is not practical to scientifically determine an optimal mix between mitigation, adaptation and residual damages*. As discussed in this chapter, the weighing of the consequences of climate change and the various policy responses is complicated by large differences in scale, space and time; large uncertainties; and clear differences in interest between individual actors. As a result, subjective interpretation of risks will always play an important role.

(iii) *Effective climate policy includes both adaptation and mitigation*. Even the most stringent climate policy scenarios can still result in a global mean temperature increase of more than 2.5 °C and at best a temperature increase of 1.5 °C. The need for a combination of mitigation and adaptation has been shown for most of the impacts explored in this chapter. For example, adaptation can be more effective than mitigation in dealing with sea level rise, but mitigation still has a role to play in reducing damages and costs of adaptation. Agriculture presents an example where adaptation and mitigation are both clearly necessary. Crop yields in agriculture are projected to be negatively

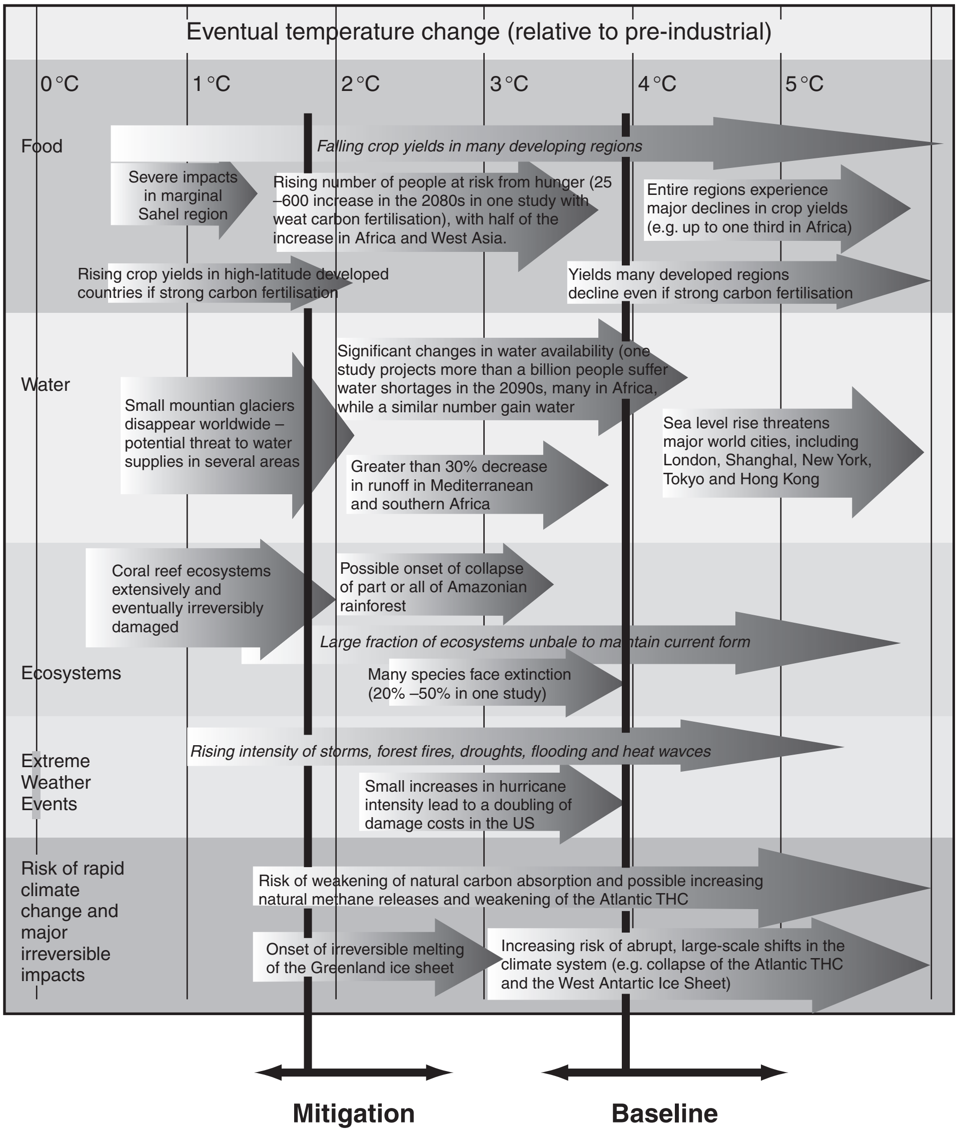

Fig. 3.16. Stabilisation levels and probability ranges for temperature increases (Stern, 2006), with lines marking the temperature change for the baseline and mitigation scenarios.

impacted by climate change in the absence of both adaptation and mitigation action. Without stringent mitigation, adaptation could limit negative impacts, but not remove them.

(iv) *While impacts of climate change can be severe and, depending on subjective choices, may warrant stringent climate policy, these impacts are not necessarily of the order of magnitude that significantly undermine assumptions of population and economic* *growth at a global scale*. Current 'middle-of-the-road' estimates of mitigation costs and climate damage are likely to be in the order of a few percent of GDP. While climate change may have an impact on millions of people, other challenges are likely to influence global population growth more significantly. It should be noted, however, that the impacts of climate damages might be too low. Mitigation studies are often optimistic in assuming global participation, while studies on damages are almost exclusively focused on changes in average climate. In an analytical context, the severity of impacts is relevant; although there might be merit in improved integration of impacts and adaptation, low costs negate the need for global analysis to include all feedbacks on main drivers based on the consistency of the storylines. Clearly, at the local scale, the situation is likely to be very different; impacts for individual countries can be far more substantial than at the global scale.

(v) *Impacts may differ very much between locations*. Sea level rise is very important for some low-lying island states and countries. These countries could be significantly affected, or even destroyed, by large adaptation costs and/or damages. For agriculture, positive and negative impacts are projected to occur in different places and at different times, with low-income countries often experiencing greater negative impacts. The wealthier north, where agriculture is currently temperature-limited, would benefit.

(vi) *Important focus areas for further analysis include variability and extreme events and the role of governance*. In our work, we focus on changes in mean values. There is strong evidence that changes in probability of extreme events may be of more relevance than mean values, but information on this is still scarce. The role of different actors is another issue; some forms of adaptation require active governmental involvement; other measures, such as installation of space cooling systems, are likely to be implemented by private investors. The differences between these two adaptation protagonists are relevant for scenario development.

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