Growing within Limits

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A Report to the Global Assembly 2009 of the Club of Rome

Netherlands Environmental Assessment Agency

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The Netherlands Environmental Assessment Agency (PBL) is the national institute for strategic policy analysis in the field of environment, nature and spatial planning. We contribute to improving the quality of political and administrative decision-making by conducting outlook studies, analyses and evaluations in which an integrated approach is considered paramount. Policy relevance is the prime concern in all our studies. We conduct solicited and unsolicited research that is both independent and always scientifically sound.

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Preface

In May this year the Netherlands' Minister of Housing, Spatial Planning and the Environment invited the Netherlands Environmental Assessment Agency (PBL) to analyse current trends with respect to global environmental problems, in the context of the findings of the so-called "Limits to Growth" publications to the Club of Rome published since 1972. The Minister wanted, above all, to get a better insight in available measures to control risks that might endanger sustainable development. The report was to be presented at the conference celebrating the 40th anniversary of the Club of Rome in October 2009 in Amsterdam.

PBL could deliver to this request in time by building upon ongoing and available research in this area. In the study, we contrast two scenarios: a current 'trend scenario' (depicting trends without major policy changes) and a 'challenge scenario' (depicting the options for change). The focus of the report is on the two clusters energy supply and climate change ánd agriculture and biodiversity loss. The two clusters are considered to key issues in addressing sustainable development. The report looks also into the interactions between these, and their relationship with the ambition to reduce poverty.

The report shows there is a large potential for a more efficient energy and food supply system. The true challenge now is one of finding the governance regimes that might deliver on this task. This integrated assessment may help facilitate timely action. Here we have to bear in mind that, while the 1972 report 'Limits to Growth' was highly influential, the ecological dilemma facing society is still with us today. Paradoxically, the current credit crisis seems to create a window of opportunity for a serious discussion on the basic values underpinning our economic system.

For the Netherlands Environmental Assessment Agency this report is one out of a series of three reports. The second report, called "Getting in the Right Lane for 2050", focuses on the policies the European Commission might consider to arrive at a Low Carbon Economy during the next decades. It will also be published in the Fall of 2009. The third report, addressing the options to further the search for a sustainable development of the Netherlands, is due early next year.

Prof. Dr. Maarten Hajer
Director of the Netherlands Environmental Assessment Agency

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Summary 'Growing within Limits'

- Current and projected future trends indicate an unprecedented increase in average human welfare – but at a cost of a further degradation of the global environment. Two key challenges with respect to the global environment are to ensure sustainable energy supply while avoiding climate change, and to ensure food security while preventing dramatic biodiversity loss. Business-as-usual leads to an expected increase of global mean temperature increase of 4°C by 2100 and a further worldwide loss of biodiversity of 15% by 2050.

- The risks of the 'Business-as-usual' are now well understood and could severely threaten the sustainability of human society. However, there is sufficient potential to correct current trends. Climate change and biodiversity loss can be limited by implementing policy packages aiming at zero-carbon energy options, energy efficiency, ecosystem conservation, higher agricultural yields and lifestyle changes. The economic impacts are expected to be modest, despite considerable investment needs.

- The most significant challenge is to create the appropriate institutional conditions to spur off the shift to innovation and fundamental transitions that will help bring about a 'green' economy. Here, an integrated approach is crucial, given important trade-offs and synergies between climate change mitigation and biodiversity protection and other important considerations, including the achievement of the Millennium Development Goals. Effective policies in this context require long-term targets and strict regulations to reach these. The current economic crisis might serve as an opportunity to foster this process of change.

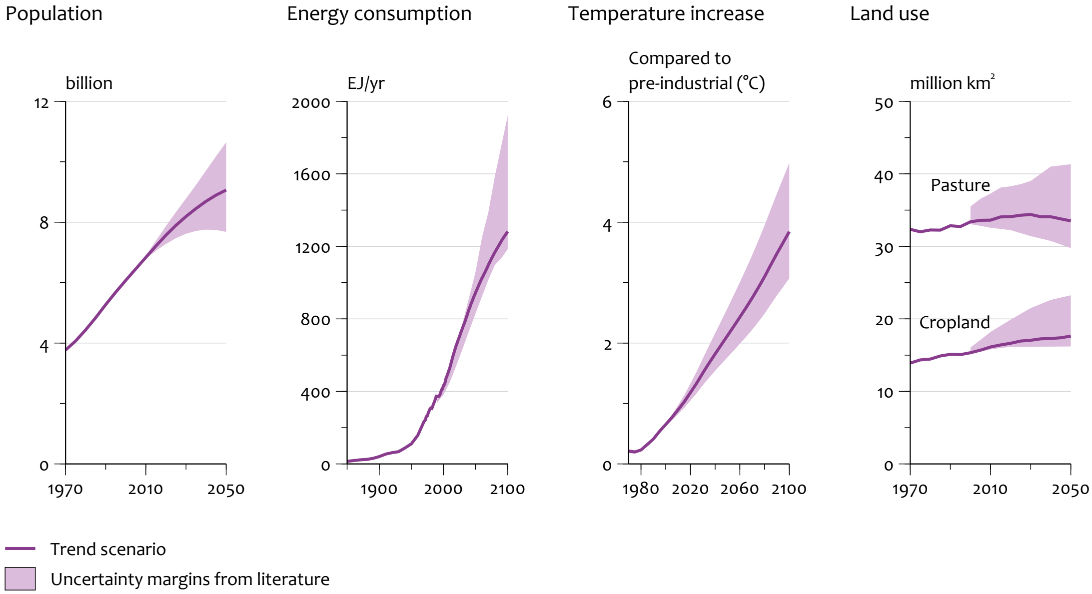
What is the problem?

Human society will face severe problems when global bio-physical trends in climate change and biodiversity loss continue

Since the publication of 'The Limits to Growth' for the Club of Rome in 1972, it has become increasingly clear that the current trends in the consumption of fossil fuel and other resources, use of land, and pressure on the Earth's capacity to deal with pollution lead to serious environmental risks. In numerous global environmental assessments published since 1972, more detailed analyses have been made in terms of analysis of specific environmental problems and their magnitude. These studies also show that should historic trends continue in the coming decades, then the world will run into an increasing range of environmental and social tensions (*Figure S.1*). Two top priorities can be derived:

1. ensuring a sustainable energy supply while avoiding climate change, and
2. preventing terrestrial biodiversity losses while ensuring food security – also in light of possible threats to human development, including poverty.

Global trends in human consumption and environment degradation **Figure S.1**



Trends in population, energy consumption temperature change and land use.

Other important environmental issues, such as preserving marine biodiversity, ensuring a sustainable water supply or avoiding a further unbalance in the global nitrogen cycle are therefore outside the scope of this report. If unchecked, anthropogenic greenhouse gas emissions are likely to cause an increase in average global temperature of 4 °C, by the end of the century. This would lead to serious climate risks, including the loss of valuable ecosystems, impacts on the global food supply and large-scale disturbances of the current climate system and related social disruptions. Global biodiversity is endangered through increasing pressure on land use for food production, biofuels and urbanisation, which could result in losses of genetic capital and disturbance of global biogeochemical cycles. This could, in turn, affect the climate system as well, specifically when deforestation limits the sequestration of carbon dioxide from the atmosphere.

What are the limits?

A maximum increase in average global temperature of 2 °C has been proposed as a reasonable limit to manage climate risks

The causal chain from human activities to climate change impacts is beset with large uncertainties, with a likely presence of thresholds and irreversibilities. Moreover, there is a large disconnection in time and space between the cause of climate change and the impacts. The ambition to avoid 'dangerous anthropogenic interference with the climate system' has been translated in environmental policies of a large number of countries into the target of a maximum increase of global mean temperature of 2 °C (as a political trade-off between risks and achievable emission reduction targets). This limit implies a maximum long-run greenhouse gas concentration level of 400 to 450 ppmv CO_2 equivalents, compared to present levels of around 400 ppmv and pre-industrial levels of 280 ppmv. In order to achieve this, global greenhouse gas emissions need to be reduced by around 50% in 2050, compared to 2000. Depending on international agreements on burden sharing, this is likely to imply a much higher reduction of 80-90% for high-income countries.

The preservation of biodiversity calls for a more stringent political approach. However, so far, no concrete limits to biodiversity loss have been internationally agreed on.

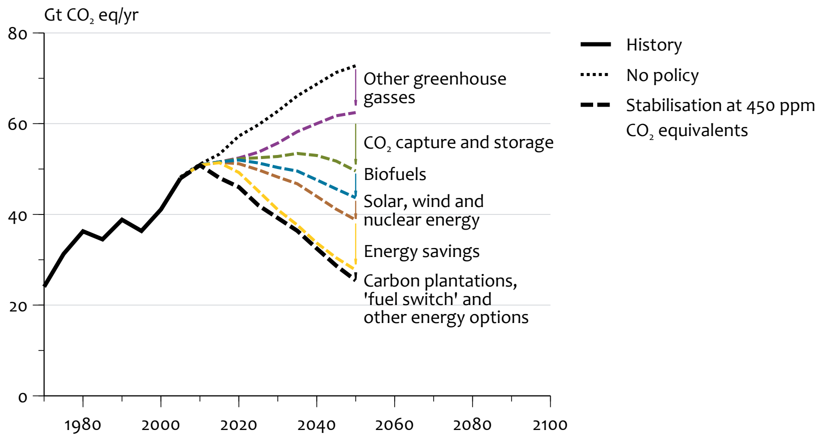
The Convention on Biological Diversity (CBD), agreed upon by nearly all countries, has the objective to conserve global biodiversity, but the Convention does not specify at what level. The limits to biodiversity loss, in terms of upholding the ecological services they provide, are difficult to ascertain scientifically and thus need to be based also on subjective factors such as risk management and valuation of the intrinsic value of biodiversity. The Convention advocates a precautionary approach. The effectiveness of international biodiversity policy could be enhanced by a more concrete approach of biodiversity protection, on the basis of an overall target, priority areas for biodiversity protection. Several criteria have been proposed to prioritise conservation areas, including hot spot areas for biodiversity, wilderness areas and/or areas important for the ecological services they provide To some degree, synergies can be found: areas that are high on biodiversity and have a large natural carbon storage capacity can be found in the tropical forests of the Amazon, Central Africa and Indonesia. Identifying priority areas for biodiversity protection eventually requires choice based on above mentioned criteria. Studies have indicated that the value of protecting these ecosystems could be several percentage points of GDP.

What can be done?

Global greenhouse gas emission reductions require, above all, a rapid increase in energy efficiency as well as a decarbonisation of the power supply

The ambition to reduce greenhouse gas emissions by around 50% by 2050 implies that, for the energy system, the annual rate of decarbonisation needs to be increased to 5%, up from the historic average of 2%. The assessment shows that it is possible to achieve such a reduction by rapidly increasing energy efficiency, replacing fossil-fuel technologies by zero-carbon technologies, and by introducing carbon-capture-and-storage (CCS) techniques. In addition, greenhouse gas emissions from agriculture and deforestation can be reduced (*Figure S.2*). The potential for increasing energy efficiency is considerable, but its realisation requires ambitious standards for appliances, vehicles and new houses, with respect to energy consumption, and retrofitting buildings with improved insulation. There is also a large scope to reduce greenhouse gas emissions from power generation. Development of a connecting super grid on a continental scale combined with a smart grid at local scale would facilitate penetration of large-scale renewable power production, but also allow for a combination with decentralised power generation (by accommodating the variations in power production due to weather variation). This also

Contribution by reduction options to stabilise global greenhouse gas emissions **Figure S.2**



Indication of how reduction measures can be combined to achieve the required emission reductions.

requires storage systems and assurance of grid access. The important role of CCS in a shift towards a low-carbon society, even only as a 'transition technology', calls for experiments with this technology in the short term. Combined policies to abate air pollution and climate change will reduce costs and lead to considerable gains in life-expectancy, especially in low-income countries.

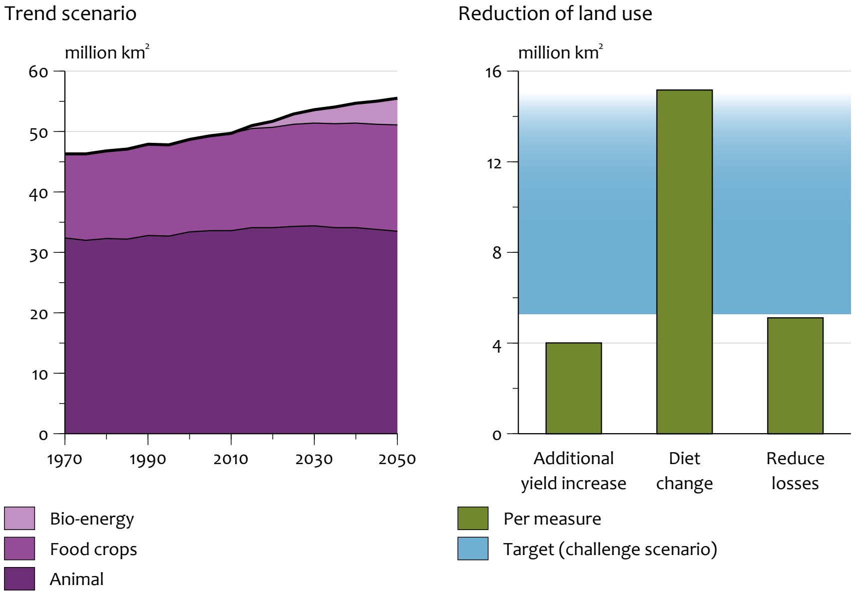
Large emerging economies need to be involved in a global climate coalition

A credible international coalition will be needed to address the issues at stake. Without involvement of at least all of today's high-income countries (OECD) and the BRIC countries (Brazil, Russia, India and China), the 2 °C target cannot be reached. While high-income countries will be faced with substantial absolute emission reductions, low-income countries will need to adjust and restructure their development paths towards a much less carbon-intensive economy.. Technology transfers and investment funds could facilitate such a transformation of growth. Such funds might be financed through revenues from a climate fund, generated by a global greenhouse gas tax or trading system, or contributions from high-income countries.

Protecting biodiversity requires adequate protection regimes for ecosystems and nature reserves

In order to be able to stop the loss of biodiversity, it is crucial to decrease pressure on ecosystems and nature reserves from competing demands for land use. An effective international conservation strategy would be greatly facilitated by the setting of a credible long-term target, intermediate targets and priority areas for biodiversity protection. This requires important decisions on what to protect and on the roles of various stakeholders involved. Priority areas can be identified on their role in preserving biodiversity and upholding ecological services. In many cases, a clearer definition of land ownership, responsibilities and systems of com-

Figure S.3 **Measures for land use reduction**



The left figure illustrates trends without policy change. Halting biodiversity loss requires agricultural land to, at least, stabilise from 2020. The right figure illustrates the contribution of various measures that can reduce the land claim for agriculture. Given uncertainties, the numbers are mostly illustrative.

pensation will be needed to stop deforestation and ecosystem destruction. A key challenge here is to develop the international institutional setting to value the protection and maintenance of natural areas and biodiversity hot spots and to develop means of financing biodiversity protection in low-income countries in a way that benefits local resource users.

Halting biodiversity loss clearly requires a decrease in land-use pressure from agriculture.

Given the increase in global population and expected dietary changes, food production will inevitably need to increase in the coming decades. Around 3 billion more people will not only eat more food per person, but will also include more meat in their diet. In order to avoid expansion of agricultural areas, a significant increase in agricultural productivity will be needed to simultaneously provide enough food and decrease pressure on natural ecosystems. Assessments show that further increases in yield, dietary changes and reduction of post-harvest losses can lead to the required reduction in the land claim from agriculture (*Figure S.3*). Meat, and especially beef, consumption is responsible for the lion's share in global agricultural land (80%). Given the fact that, on average, meat consumption in high-income countries is above what is assumed to be a healthy level, a transition towards more healthy but less meat-intensive diets would be an effective way of reducing demand for land. Reducing post-harvest losses (estimated to be around 30%) is another way to reduce pressure on land. Reforestation can also reduce the costs of climate policies considerably.

Investments to achieve climate and biodiversity targets amount to about 2% of GDP in 2050

A considerable and global effort is required to reduce greenhouse gas emission by 50% by 2050. Although costs estimates are highly uncertain, available literature provides an idea of the order of magnitude. Additional global investment needs for climate policy are estimated to average around 1,200 billion USD per year (with a wide uncertainty range) in the 2005-2050 period, which is, on average, about 1.4% of global GDP (these costs do not distinguish between public and private finance – but are economy-wide estimates). In addition, estimated average costs for climate adaptation range between 50 and 160 billion USD per year. Increasing agricultural yields, worldwide, up to a level that will provide all of humanity with basic food supply without a further expansion of agricultural land areas, requires probably less than 50 billion USD per year. To put these figures into perspective, the sum amounts to annual expenditure of about 2% of GDP in 2050, which is similar to current spending on environmental protection (1-2%) and is lower than expenditure on the energy system (around 3-4% of GDP).

Estimates on macro-economic impacts of such policies cover a wide range; typical values of around 0.1% reduction of economic growth are reported for ambitious climate policy scenarios. To put this in perspective, world GDP would increase in the 2005-2050 period not by 240% but by 225%. It should be noted that the costs are expected to be unevenly distributed across countries and sectors. High carbon-intensive and fossil-fuel exporting regions are expected to bear higher costs. The benefits from reduced climate change are not taken into account here. They are uncertain, too, although, in the long run, they will most likely surpass the cost levels mentioned above. Their valuation, however, depends on choices in the system of financial discounting.

Policies will need to be strengthened to reduce hunger and increase access to energy in order to achieve the Millennium Development Goals

The Millennium Development Goals (MDGs) are a meaningful institutional translation of the ambition to reduce absolute poverty. Current policies and development trends are not leading to the realisation of the so-called Millennium Development Goals (MDGs) to reduce absolute poverty by 2015. Yet, to achieve the agreed upon MDGs, policies will need to be reconsidered and strengthened. Such significant improvements in the lives of hundreds of millions of people will have only minor environmental consequences: enhanced access to energy implies a 1% increase in greenhouse gas emissions and realising an adequate food supply for all increases food demand by 2%. Moreover, successful implementation of these goals will avoid some of the environmental long-term risks for human development associated with a business-as-usual future.

What are the policy implications?

The policies that are currently proposed will fall seriously short of achieving the policy targets for climate change and biodiversity

Several countries have pledged emission reduction targets as part of the international negotiations on climate policy and/or have formulated national targets. Also, countries and regions have formulated biodiversity action plans. However, in both areas, current plans do not add up to achieving the long-term sustainability targets. While to delimit climate change to the 2 degree target, greenhouse gas emissions need to be stabilised around 2020 to 2025, currently proposed policies would still lead to a serious increase in emissions by that time. For biodiversity protection, the 2010 target to significantly reduce the rate of biodiversity loss will not be met.

The most significant challenge is not to know more about the natural environment but to politically decide on a joint commitment to a sustainable future

The fact that the 'Limits to Growth' assessments for the Club of Rome (1972, 1992, 2004) retain their value (in terms of the overall message) over time, illustrates that in order to deflect trends in reducing environmental pressure, the world community now has to move from signalling and identifying the main global environmental problems, to the joint decision and subsequent implementation of concrete measures. A low-carbon economy, as well as adequate biodiversity protection, can be achieved with currently identifiable technologies and at moderate economic costs without damaging opportunities for human development. Clearly other barriers exists: a key challenge is to achieve the right policy conditions and institutional settings to further more sustainable investments, stimulate innovation and bring environmental concerns to the core of political decision-making. A joint decision on a 'politics of limits' might create the shared legitimacy to create these institutional conditions. Innovative thinking is called for. It seems clear that the first step is to define the targets to which the world community will have to work. These may then work as the basis for policies that work towards these targets. On the global scale, the strengthening, integration and proper alignment of multilateral and bilateral environmental agreements could provide an effective starting point for improving environmental governance. On the national scale, long-term and strictly enforced environmental policies could ensure the framework for other actors to articulate innovative search for solutions in the desired direction. Citizens could take up the challenge at a local and personal level, triggered by the notion that lifestyle changes in dietary patterns, energy use and transport patterns can contribute very significantly to decrease environmental pressure. Generally, integration between the various sustainability themes could greatly enhance the success of any environmental strategy, reducing costs and taking co-benefits into maximum account.

Integrated policies are needed, if societies would like to achieve both climate and biodiversity goals

This assessment presents the interconnections between the energy/climate cluster and the land use/terrestrial biodiversity only. Yet even within that restriction it is obvious that a portfolio of measures is needed to achieve the targets that are discussed. Single policy measures will not achieve these targets. In addition, there are important relationships between these clusters. Some of these represent synergies, while others are important trade-offs. Crucial synergies between climate policy and protecting biodiversity include measures that avoid expansion of agricultural areas or that would even lead to reforestation, increased energy efficiency and use of most zero-carbon energy options, and reduction in meat consumption. Other synergies exist, for instance, between climate policy and air pollution control. There are, however, also possible trade-offs. An important trade-off may exist for bio-energy, depending, among other things, on development of new technologies; this warrants a careful approach with respect to bio-energy targets. Other important trade-offs to consider are between positive impacts of increased yields (less agricultural area) and the negative impacts (possibly increased use of water, pesticides and nutrients) and the material implications of some new energy technologies. Together, this implies that integrated approaches towards environmental policy are required.

It seems that effective environmental policies require long-term targets, and need to be strictly enforced and predictable

Long-term targets help to create predictable policies that work towards these targets. A robust commitment to standards that will be strictly guarded, defines the level playing field for creative and innovative stakeholders, to exploit the new possibilities of the sustainability challenge. A key condition for any policy strategy is to acknowledge the interrelations between environmental themes, but also between the environment and meeting basic human needs.

The current economic crisis could serve as a moment of reflection to better take into account environmental issues and equitable human development in further plans for development

Meeting the challenges of climate change, biodiversity loss and basic human development comes at relatively moderate (overall) economic cost. Moreover, a fundamentally restructured economy may well be able to accommodate workers in new and greener sectors, replacing sectors from the fossil-fuel economy. However, the global environmental crisis will require drastic institutional measures on all levels of governance. In the light of the economic crisis, governments worldwide intervened massively in markets to a degree that, by most, would previously have been considered impossible. The crisis, therefore, may provide a window of opportunity to seriously consider such a fundamental transition of the global economy, which credibly accounts for the global commons.

1

Global Environmental Challenges and the Limits to Growth

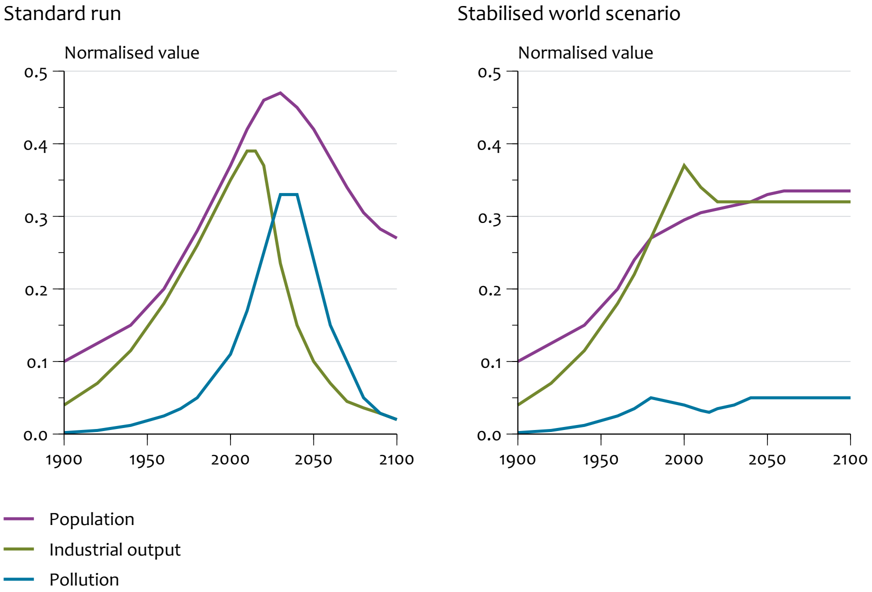
In 1972, the publication *The Limits to Growth* pointed to the non-sustainable direction of various socio-economic trends for the future (Meadows *et al.*, 1972). The purpose of *The Limits to Growth* was not to make specific predictions, but to explore how exponential growth interacts with finite resources. The model calculations in the report highlighted its main message: if resources would be extracted at a rate beyond their regeneration capacity, this would ultimately lead to a collapse of the socio-economic and ecological systems. Since its publication, the report has been subject to considerable debate and criticism, but it has remained a keystone in the discussions on the systemic nature of environmental issues, which has influenced many environmental policies worldwide.

Public debate about the report has always focused on the doomsday character of the business-as-usual scenario. Alternative, more sustainable, projections in the report, were noticed less. Now more than ever, there is a need to focus on the elements of a more sustainable future. What would such a sustainable scenario look like, if applied to the current challenges for the global environment? Which technological and non-technological means are available? What investments would be required in the coming decades?

In 1991, *Beyond the Limits* was published as an update of the original report to the Club of Rome, concluding that the main trends had not changed: business-as-usual development would still lead to overshoot and collapse (Meadows *et al.*, 1991). And again it was emphasised that an alternative pathway towards sustainable management of natural resources could be achieved, provided political action would be taken soon (*Figure 1.1*).

The notion of serious environmental degradation, and the huge challenge of combining human aspirations and needs with the carrying capacity of our planet has been widely recognised in various global environmental studies, such as the Millennium Ecosystem Assessment (2005), the fourth Global Environment Outlook (UNEP, 2007), and the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007b). Compared to descriptions in earlier analyses in the 1970s, environmental problems such as climate change, depletion of fossil fuels,

'Limits to Growth' scenarios **Figure 1.1**



The development of world population, industrial output and pollution according to the standard run and the stabilised world scenario. Source: Meadows *et al.*, 1972).

water scarcity and loss of biodiversity, could now be described in much more detail, and the potential of technological solutions and instruments to stimulate behavioural change could be made more explicit.

Two prominent and recurrent issues can be derived as key challenges from a range of global environmental assessment studies:

1. Increased use of fossil fuels has major impact on climate change, air pollution and risks to energy supply. A comprehensive solution would require a low-carbon society, including a fundamental restructuring of the energy system.
2. Increased use of land for food production and bio-energy is causing loss of natural land, forests and biodiversity, affecting the global carbon and nitrogen cycles. A comprehensive solution for the world food supply, increasing demand for biofuels, and the protection of ecosystems, could consist of a mixture of nature protection, more efficient agricultural production, as well as behavioural changes, such as low-protein diets.

Some studies have argued that the solution to the climate crisis, the energy security crisis, the food crisis, and the biodiversity crisis, could effectively contribute to the solution to the current economic crisis. A range of actors in the global arena have advocated a *Global Green New Deal*. The OECD, for instance, sees the economic crisis as an unique opportunity to develop a stronger, cleaner and more equitable economy (OECD, 2009c). UNEP argues that a green new deal that aims at realising the millennium development targets, at reducing carbon dependency, and protecting ecosystems could stimulate the economy, create jobs and help to protect vulnerable groups in society (Barbier, 2009).

This report looks into the possible developments in the climate and energy system on the one hand, and biodiversity and land use on the other hand. Obviously, also other important global environmental problems exist, but these are outside the scope of this report. The report presents two scenarios: a baseline, business-as-usual scenario (*Trend* scenario) explores the risks of climate change and biodiversity loss, while the *Challenge* scenario explores the pathway and required actions to bring about a more environmentally sustainable future (*Chapter 2*). This chapter also briefly assesses whether the threat of overshoot and collapse, as identified in *The Limits to Growth,* is still valid and which 'safe' constraints could be defined that characterise a sustainable development.*Chapter 3* focuses further on the issue of climate change, exploring the requirements for a low-carbon society, by 2050, compared with the *Trend* scenario. What would the energy mix in such a future look like? What crucial technological choices are there to be made? Which combinations of technological and non-technological solutions are possible? *Chapter 4* focuses on the issues of land use and biodiversity loss. Could agricultural productivity be increased to such an extent that it is possible to use less land for food production and more land for bio-energy? What can be the contribution of dietary changes?

This report takes an explicitly global perspective, but occasionally lower levels are included to do justice to the multi-level complexity of the issues at stake. The concluding *Chapter 5* looks at a range of strategies and measures on global, regional and national levels, including their institutional prerequisites. Moreover, behav-

Two prominent and recurrent clusters of global environmental change are; climate change and energy(left) and land use and biodiversity (right).

iour and consumption is addressed to be included in taking up the environmental challenges.

It should be noted that, in presenting these strategies and measures, this report does not provide a recipe for sustainable development, but rather offers a range of scientifically rooted options that address the environmental challenges. These options indicate the challenges and offer ways of deflecting from environmentally damaging business-as-usual pathways towards more environmentally sustainable development.

While using the 1972 limits to growth publication as starting point, the findings of this report ar not always equal to those of Meadows *et al*. (1972).

2

Environmental Challenges for the 21st Century

2.1 Limits to growth

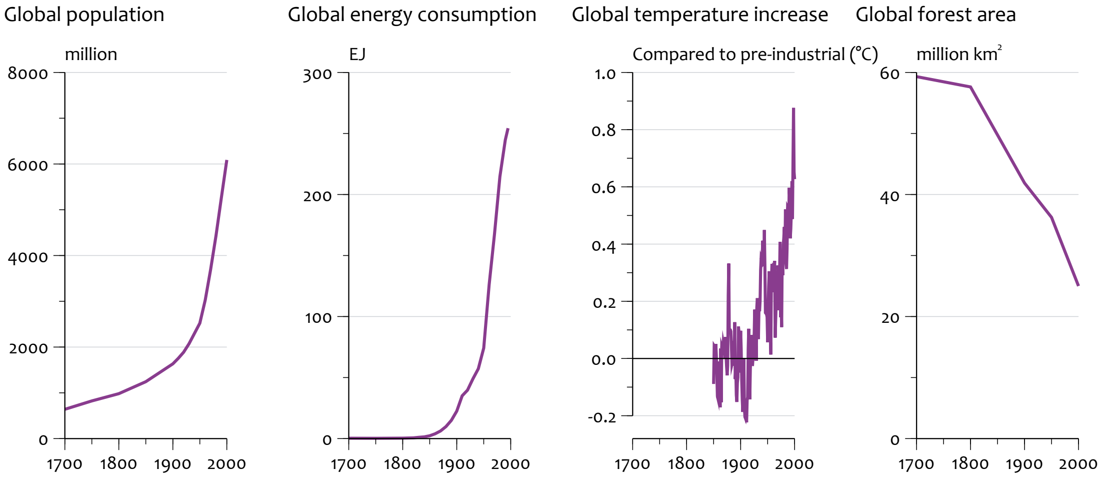
Since the Industrial Revolution, human welfare has increased in an unprecedented way, but at the cost of an equally unprecedented environmental degradation

The Industrial Revolution stands at the basis of major transitions within human society, over the last centuries. The world population has grown more than sixfold (see *Figure 2.1*). Average life expectancy has increased from 26 years in 1800, to 66 years today, while average global income has grown by a factor 13 (Maddison, 2007). Since 1950, malnutrition has more than halved and child mortality in developing countries has decreased, from 1 in every 5 children, to 1 in 18.

Technological developments have played a crucial role in these transitions, allowing humans to overcome resource scarcity of land, energy and labour. Replacing traditional energy forms, such as wood and peat, with coal, oil and natural gas, provided access to more easily extractable forms of energy, allowing human labour to be replaced by all forms of mechanised production. Just as important was the discovery of artificial fertiliser in 1908, through the process of nitrogen fixation, which caused substantial increases in agricultural yields. However, while these technological developments stretched the boundaries of human activities, they also introduced new ones. Natural resources are being extracted at an ever increasing rate, while the environment's capability to absorb society's waste products is tested at an increasing rate. Such a situation entails risks, as environmental factors have played an important role in the decline of human civilisations in the past (De Vries and Goudsblom, 2002; Diamond, 2004). Over recent times, human behaviour has been affecting the natural cycles of carbon, nitrogen and phosphorus to such an extent that consequences are clearly visible on a global scale, specifically, in the form of increasing CO_2 concentration levels, large-scale eutrophication and biodiversity loss.

Moreover, the improvements in welfare have not spread equally across the globe. Globally, 1.4 billion people live on less than USD 1.25 per day (Chen and Ravallion, 2008). Furthermore, 923 million people are undernourished, almost 2.9 billion people are dependent on traditional fuels for cooking, such as wood and coal,

Human development and environmental quality **Figure 2.1**



Global increase in population, energy use, average global temperature and global forest area (1700-2000). Source: Klein Goldewijk and Van Drent (2006); Jones *et al.* (2009).

around 900 million people have no access to safe drinking water, and 2.5 billion people lack basic sanitation (UN, 2009). In 2007, the global mortality rate for children under five years old was 67 deaths per 1,000 live births (UN, 2009), with approximately 55% of the deaths being related to these largely preventable or treatable causes (PBL, 2009a). One of the reasons for this situation is the dramatic inequality across countries and regions (Bourguignon and Morisson, 2002). Nevertheless, since the 1950s, several developing countries have experienced some level of economic development; a number of them with growth rates of over 5% for 20 consecutive years. Most African countries, however, have had zero growth over the last 30 years and have only recently began showing improvement.

There are significant environmental challenges ahead

Given these historic trends, the question is how these parameters, including the stresses on the environment, will develop in the future. Many scenario studies project further increases in energy consumption, emission of urban air pollutants, land use, and resource consumption, if no measures are taken. Economies of high-income countries are still expanding, countries such as China and India have experienced very rapid growth rates over the past decades, and several developing countries are aspiring to do so as well, in the near future. The global, human population has increased rapidly over the last decades, but will even out at a projected nine billion people, by 2050. Obviously, this will have consequences for increasing scarcity of resources and environmental stress.

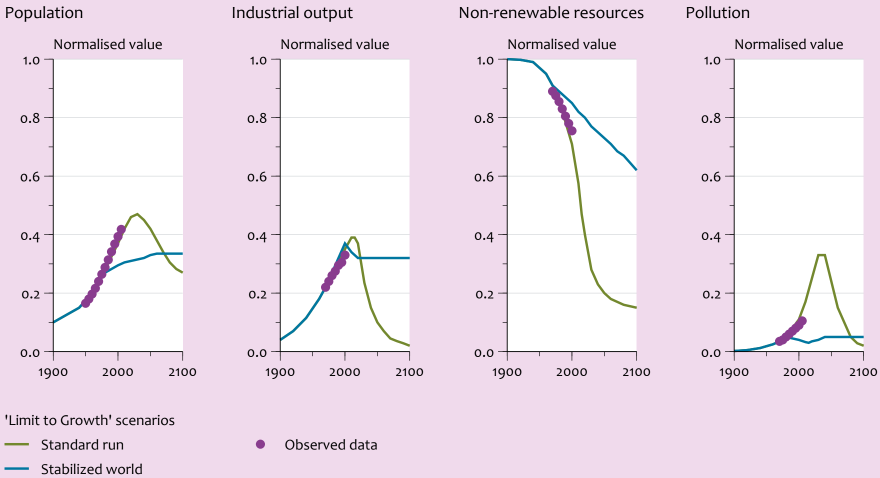
Text box 2.1 Comparing *Limits to Growth* to 1970-2000 trends

The Limits to Growth publications received praise, but they have also been criticised, among other things with respect to representation of technology, the aggregated representation of resources and environmental factors, and the misinterpretation of estimated reserves. In that context, it is often claimed that history has proved those projections to be incorrect, which is specifically based on the popular believe that Limits to Growth predicted resource depletion and associated economic collapse by the end of the 20th century (Hall and Day, 2009). In reality, the 'standard' scenario (without policy changes) in the publication showed global collapse in the middle of the 21st century. Almost four decades since the publication of Limits to Growth in 1972, Turner (2008) compared the historic trends with the original projections.

This comparison showed the 'standard' scenario to be very close to the actual trends for many variables, such as total population levels, birth and death rates, industrial output, and per-capita food consumption. For more complicated indices, such as resource depletion and persistent pollution, the results were more difficult to check. Using data on energy resources and CO_2 *concentration for comparison, Turner concluded that, also for these variables, the Limits to Growth projections reflected past trends reasonable well. For instance, the report indicated an increase in global* CO_2 *concentrations, from 320 ppm in 1970 to 380 ppm in 2000; in reality the concentration in 2000 was 369 ppm. In contrast, alternative scenarios presented in Limits to Growth showed emission projections that lie below the actually observed trend.*

Figure 2.2

Comparing 'Limit to Growth' scenarios to observed global data



Important environmental challenges named in the report are: energy production, CO_2 emissions, urban heat islands, radioactive waste, eutrophication, heavy metals and pesticides, air quality, and depletion of fish stocks. Many of these were still prioritised in recent global assessments, but several other have been solved or decreased over the course of the past decades. On certain specific issues, such as the reserves of several non-renewable resources, the wording in the report is often considered to have been too negative.

The aggregated variables the Limit to Growth projections are not invalidated, but this does not automatically mean that the predicted system collapse is likely to eventuate, an issue that is discussed in some more detail for the subjects of climate change and biodiversity loss, further on in the underlying report.

The 1972, publication of *Limits to Growth* explored the tensions between exponential growth in population and income on the one hand, and resource and environmental limitations on the other. This was done with a computer model simulating the dynamics of the 'world system'. Several scenarios were made, with the default one – indicating an overshoot and collapse in the first quarter of the 21st century – drawing most and worldwide attention (see *Text box 2.1*). Updates of this analysis in 1992 and 2004 more or less confirmed the original conclusions, which were clearly formulated thus in Meadows *et al.* (1991):

- Human use of many essential resources and generation of many kinds of pollutants have already *surpassed rates that are physically sustainable*. Without significant reductions in material and energy flows, there will be an uncontrolled decline in per capita food output, energy use, and industrial production in the coming decades.
- *This decline is not inevitable*. To avoid it, two changes are necessary. The first is a comprehensive revision of policies and practices that perpetuate growth in material consumption and in population. The second is a rapid, drastic increase in the efficiency with which materials and energy are used.
- A sustainable society is technically and economically possible, but the transition to a sustainable society requires a careful balance between long-term and short-term goals and an *emphasis on sufficiency, equity, and quality of life rather than on quantity of output.* It requires more than productivity and more than technology; it also requires maturity, compassion, and wisdom.

By now, information exists to address these issues in more detail. A crucial question is whether the human 'footprint' on this planet has reached a level that could lead to irreversible and undesired environmental change (see also Rockström *et al.*, 2009).

2.2 The challenges ahead

2.2.1 Main global environmental problems

Biodiversity loss and climate change stand out as key global environmental challenges

The global environmental assessment and system analysis methodology have become common practice in the monitoring of environmental and sustainability trends on a global scale (see *Text box 2.2*). Prime examples of such assessments include UNEP's Global Environment Outlook (GEO), IPCC's fourth Assessment Report on Climate Change, the Millennium Ecosystem Assessment (MA), OECD's Environmental Outlook and the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD). Together, these assessments indicated that there are significant sustainability problems associated with current trends (PBL, 2008).

First of all, the increasing human food demand already seriously depleted many natural terrestrial and aquatic resources, while putting strong pressure on the remaining biodiversity in the world. Increased land use for agricultural production and demand for wood products will put increased pressure on ecosystem preservation, due to deforestation and forest degradation, specifically in tropical and subtropical areas. Deforestation could reduce the ability of ecosystems to provide ecological services, and may have serious effects on human societies around the world. Moreover, carbon storage capacity has been severely reduced, and nitrogen leaching to sea could further reduce marine carbon absorption capacity, while reducing biodiversity in coastal areas through enhanced fertilisation. Protection of forests and terrestrial and marine ecosystems, therefore, is crucial to sustain global biochemical cycles. Demand for fish has led to serious overexploitation of most of world's fish resources, with a serious risk of the collapse of major fish stocks. At the same time, overexploitation of soil and water resources is leading to serious soil degradation in arid and semi-arid regions of the world. Also, the availability of phosphorus could become a serious global concern; although its resource base could be sufficient for at least 200 more years of current agricultural practice, its possible depletion is a concern, as there are no real substitutes for phosphorus.

Second, climate change represents a very serious risk for the coming century. While the exact impacts are uncertain, projections indicate the possible risks to global yields, collapse of sensitive ecosystems, sea level rise, and increasing occurrence of weather extremes. Projections also show the main driver of climate change, fossil-fuel use, to further increase in the future if business remains as usual. This could also lead to increasing problems for energy security, as easily accessible oil and gas reserves will become depleted. Moreover, fossil-fuel use also plays a role in urban and regional air pollution, which leads to major health losses, especially in developing regions.

The overall conclusion emerges that by considering the main impacts related to fossil-fuel use (depletion, climate change, air pollution) and agricultural production (deforestation, biodiversity loss, soil degradation), the major part of the world's sustainable development challenges has been covered. Of course, there are other concerns: water scarcity; depletion of fish stocks; acidification of the seas; risks associated with new technologies, such as nanoparticles and genetically modified organisms; and nuclear energy, among several others. However, addressing the main issues of fossil-fuel use and agricultural production is a credible starting point for a strategy to the most important environmental challenges of today.

Text box 2.2 Global Environmental Assessments

In the last decade, several global environmental assessments were published. Each of these reports approached the world's environmental challenges from a different perspective. A few of the most noteworthy assessments were used for this report and are summarised below. An overview is provided bij PBL 2008.

UNEP's Global Environment Outlooks (GEO)

Since 1997, UNEP has published four Global Environment Outlooks, evaluating the status of the global environment, often paying considerable attention to the regional dimensions. The Global Environment Outlooks enable identification of the main problems that threaten sustainable development. The fourth Outlook especially emphasised the need for a healthy environment, both for development and for combating poverty.

Millennium Ecosystem Assessment

In 2000, the Secretary-General of the United Nations requested a Millennium Ecosystem Assessment, to assess the consequences of ecosystem change for human well-being, and to establish the scientific basis for actions needed to enhance the conservation and sustainable use of ecosystems and their contribution to human well-being. The Millennium Ecosystem Assessment's 'Ecosystems and Human Well-being' connects ecosystem services to constituents of human well-being (security, basic ingredients for a good life, good social relations, health, and freedom of choice and action) (Millennium Ecosystem Assessment, 2005). The assessment concluded that approximately 60% of the ecosystem services examined were being degraded or used unsustainably.

The International Assessment of Agricultural Science and Technology Development (IAASTD)

The report of the IAASTD, published in 2008, was supported by various governments and the World Bank, and assessed development in agriculture in relation to policy goals, such as reducing hunger and poverty, while preserving the quality of the environment and biodiversity.

IPCC's Assessment Reports

The Intergovernmental Panel on Climate Change (IPCC), on a regular basis, publishes assessment reports on the current knowledge about climate change. These reports address climate problems, their consequences and possible solutions.

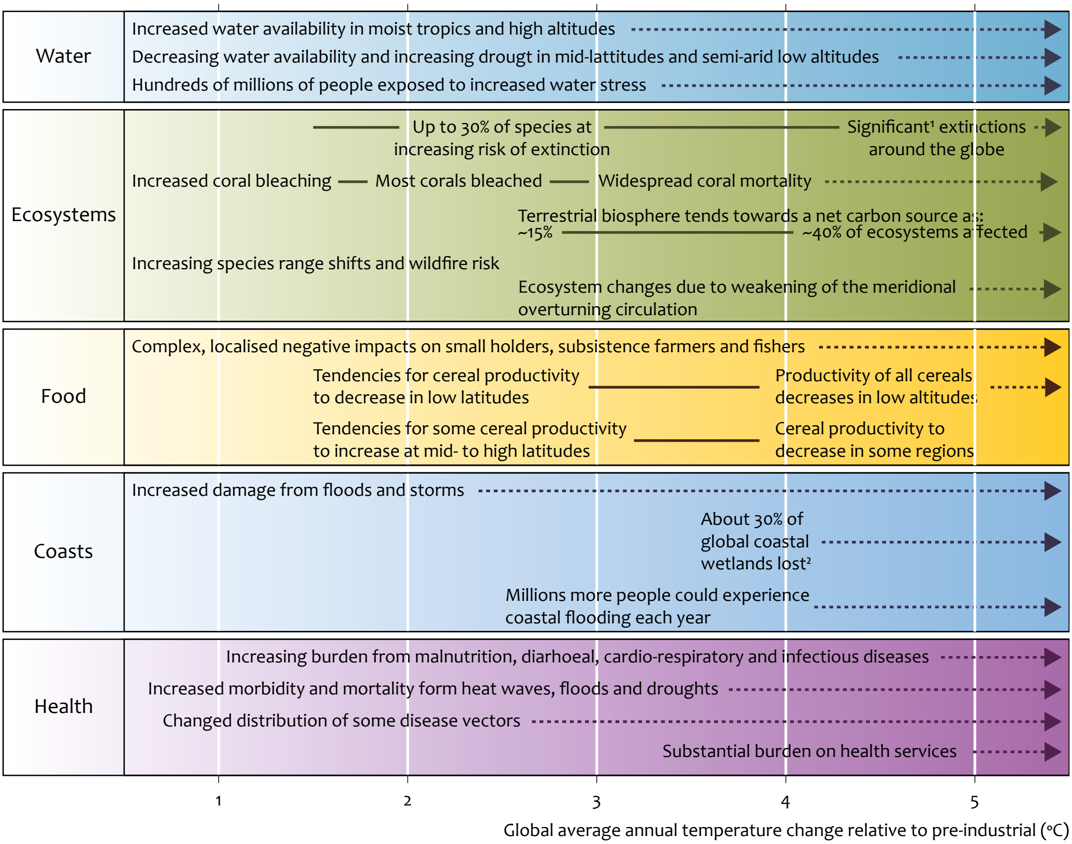
Unabated climate change is likely to lead to more extreme weather events

2.2.2 The challenge of climate change

Policymakers have set a climate target of a maximum temperature increase of 2°C
According to the fourth Assessment Report of the IPCC, climate change is almost certainly caused by greenhouse gases and other radiative substances, emitted through human activities related to fossil-fuel combustion and land-use changes (IPCC, 2007c). The report also indicates that impacts of climate change are already visible, and that further climate change may have serious consequences – for instance, for sensitive ecosystems, agriculture, water availability, and the occurrence of extreme weather events. Studies show that the effects of climate change will increase if the temperature continues to rise (*Figure 2.3*). Although there are still considerable uncertainties, it is expected that changes will initially concern sensitive ecosystems, such as coral reefs, and have local effects (for example, from the increase in extreme weather events). Further climate change increases the risks of more radical (and large-scale) effects, such as the melting of Arctic ice and parts of the Greenland ice sheet, with related impacts on sea levels, and negative effects on food production, or the collapse of the thermohaline circulation. For the 21st century, unabated climate change may lead to a sea level rise of between 50 centimetres to over 1 metre; in the long-run, it may even lead to an increase of more than 6 meters. The greatest effects of climate change are expected to take place in developing countries; they are also the most vulnerable because of their considerable dependence on climate-sensitive economic sectors.

In response to earlier IPCC reports, nearly all countries in the world agreed to aim for the prevention of dangerous anthropogenic interferences with the climate system (UNFCCC, 1992). However, it is not possible to unambiguously determine how much global warming could be tolerated without destroying human and

Examples of impacts associated with global average temperature change **Figure 2.3**



[1] Significant is defined here as more than 40%

[2] Based on average rate of sea level rise of 4.2mm/year from 2000 to 2080

The risks of climate change on a global scale. Impacts will vary by extent of adaption, rate of temperature change and socio-economic pathway. Source: IPCC (2007a).

natural systems. This is partly due to uncertainties in the climate system, but also because of differences of opinion on what should be protected and how much risk could be accepted, which involves an interpretation of the actual risks, the ability to cope with climate change, and the weight attributed to sensitive ecosystems. Currently, many countries have agreed to the objective of limiting the average global temperature rise to a maximum of 2°C compared to pre-industrial levels. Such a maximum level is considered to control the most severe risks of climate change, although it will still lead to considerable climate impacts.

Recently, the G8 Summit also adopted the 2°C target as a guideline for international climate policy (MEF, 2009). This target may be seen as a compromise between the risks of climate change and the required efforts to reduce greenhouse gas emissions. Some experts argue for a lower targets (Hansen *et al.*, 2007), while others state that a cost-optimal climate policy allows for the acceptance of higher temperature changes (Nordhaus, 2008). In this report, the 2°C limit is taken as a starting point to analyse the required policy strategy.

2.2.3 The challenge of stopping biodiversity loss

Limits to global biodiversity loss involves critical thresholds, that are hard to determine before they are exceeded

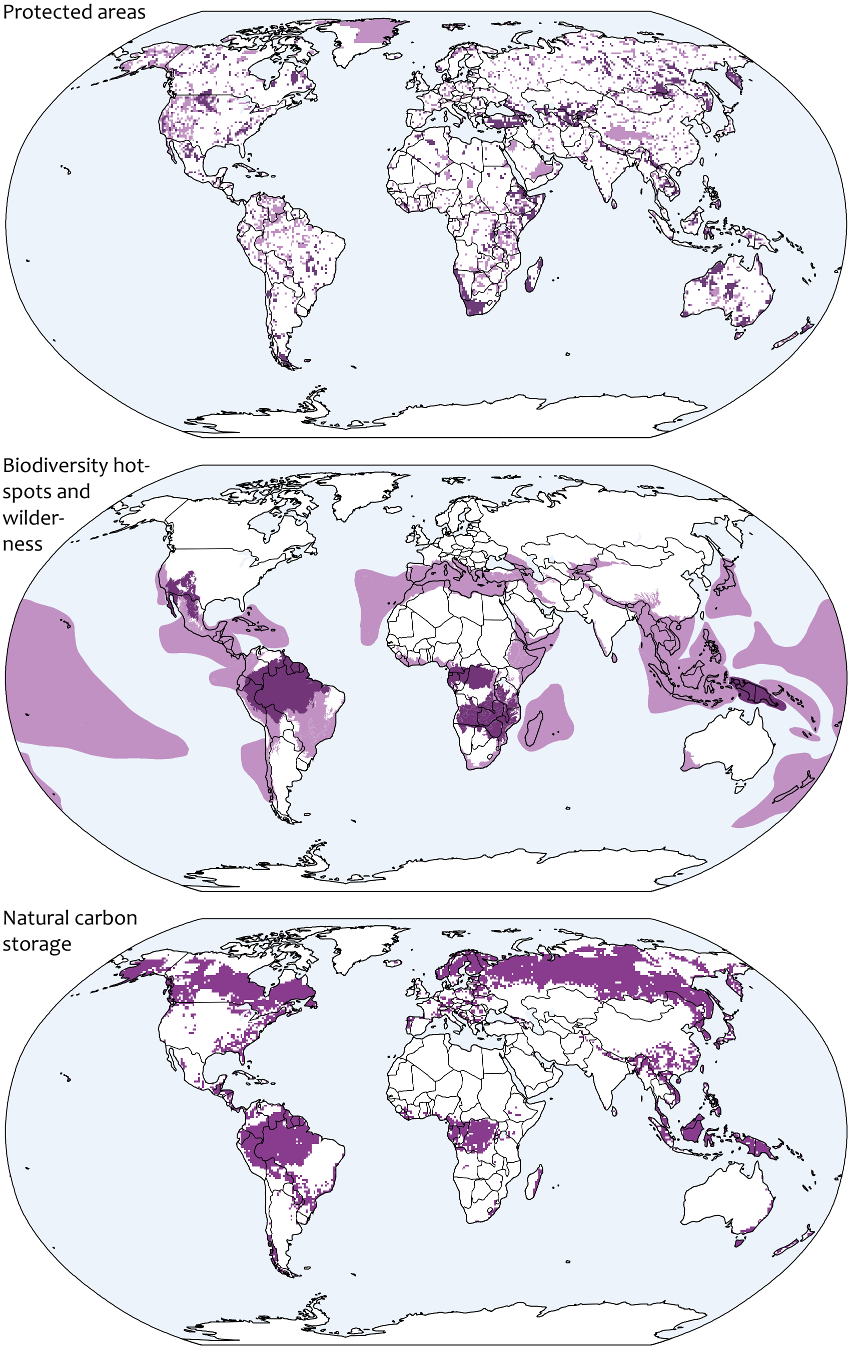
The area of forest and wilderness, as well as the terrestrial, freshwater and marine diversity of species, has declined over the past centuries. Today, the rate of extinction of species is estimated to be 100 to 1000 times higher than what would be considered a natural rate of loss (MA, 2005). In 1992, many countries in the world committed themselves to protecting biodiversity under the Convention on Biological Diversity (CBD). The Convention aims to conserve biological diversity, including its sustainable use and the fair sharing of its benefits. As part of the 1992 strategic plan, countries agreed on a significant reduction in the current rate of biodiversity loss on global, regional and national levels, by 2010. For the European Union, the goal was to even halt further biodiversity loss by 2010. Discussions on a comprehensive framework for long-term targets have been continuing for over a decade now, both on international and European levels. Policy documents mostly use general and unspecific terminology when it comes to goals for biodiversity.

The complexity of biodiversity makes it unclear which elements should be protected and to which level. While it is well known that ecosystems play a crucial role in upholding all kind of ecosystem goods and services, there is no indication on the variety, disparity and diversity of ecosystems and species needed to functionally maintain their provision. Moreover, it is unclear what crucial ecosystems or ecosystem services could be at stake in the case of considerable loss of species. In general, an ecosystem is more resilient to shocks when its diversity of species is larger, but collapse thresholds are impossible to determine before they are exceeded.

As maintaining ecological services and the global cycles of carbon, nitrogen and water, are a major part of the definition of sustainable development on the global scale, several scientists have argued to be wary of further biodiversity loss and apply the precautionary principle (MA, 2005). Next to a functional view on ecosystems and their biodiversity, the ethical approach is an important argument for protection,although it remains difficult to assess the intrinsic value of biodiversity, which depends on cultural, ethical and individual values. Although it is accepted that a rich mix of species underpins the resilience of ecosystems, little is known of the level of biodiversity losses that will lead to irreversible erosion of this resilience (Rockström *et al.*, 2009).

A controversial issue is the use of cost-benefits arguments in setting biodiversity targets. A recent report (TEEB, 2008) estimates the value of possible biodiversity loss in the 2000-2050 period at 7% of world GDP, but such numbers are highly contested. When trying to determine which ecosystems should be protected, various criteria can be applied (*Figure 2.4*). Ecologists have defined biodiversity hotspots on the basis of the number of unique ecosystems and endemic species. One could also focus on

Perspectives on preserving biodiversity — Figure 2.4



Different perspectives on preserving biodiversity: a) protection of 20% of each biome, b) biodiversity hotspots and c) protection of areas with specific ecological services (carbon storage).

threatened ecosystems or high value nature areas as already protected under different forms of legislation (for instance, in Europe, the Natura 2000 areas and areas protected by the Birds and Habitats Directives). In the second approach, areas are identified also according to their high value in ecosystems services, such as their role in the carbon cycle (global level), or in supplying freshwater services (catchment level). A third method is to focus on wilderness areas, that are considered to hold important biodiversity values. In any way, the policy process would benefit from deciding on inspirational targets in protecting biodiversity in the long term.

A crucial difference to climate change mitigation is that the biodiversity problem and, therefore, also the solutions, are not so much global, but simply occurring everywhere. As decisions will always be made on national or even regional levels, all approaches can and will be used. Choices are inevitable, because of the different trade-offs between elements of biodiversity. For instance, when forest areas increase through afforestation, the areas of open human-altered landscape will decline, and so will elements of agro-biodiversity. In many parts of the world the landscape tells the histor of cultivation going back centuries. These landscapes constitute a form of biodiversity which has a value by itselfFinding a balance between wilderness nature, where human influence is kept to a minimum, and half-natural cultural dependant nature requires the ability to choose and set priorities.

Based on these considerations, this reports explores the impacts of halting significant biodiversity loss from 2020 onwards by not allowing further expansion of agricultural area. Alternatively, targets could be set, for instance in terms of the rate of species loss (Rockström *et al.*, 2009). As there are other factors leading to biodiversity loss, arguably some increase in natural areas would be needed to reach a net zero result.

2.2.4 The challenge to human development

Meeting human development conditions crucial for any sustainable development strategy

There are strong relationships between climate change, biodiversity and human development. On the one hand, both climate change and biodiversity loss lead to serious erosion of the ecological capital on which human development is based. As such, climate and biodiversity protection are important conditions for development. On the other hand, economic development often leads to increased energy use and to increased carbon emissions and deforestation. For low-income countries, local development will often have a priority over protecting the global commons, setting the agenda for global cooperation in order to ensure that low-income countries can contribute to the ambitions of protecting climate and biodiversity.

Child mortality in developing countries is largely related to inadequate access to food, water and energy; something which may be prevented at relatively low costs. Increasing access to food, safe drinking water, sanitation, and improved energy sources for the poorest people, therefore, is be at the top of the international development agenda. As a consequence of environmental degradation, provision of these ecosystem goods and services is under increased pressure. Policies

Increasing access to food, safe drinking water, sanitation and modern energy sources is at the top at the international development agenda.

addressing access to food, water and energy have to take these environmental issues into account. Population policies have been suggested to address both human development issues and environmental problems, but they only have effect in the very long term (see *Text box 2.3*).

In order to specifically address the issue of human development, 192 nations and various international organisations agreed on a set of development goals, known as the Millennium Development Goals (MDGs) (see *Figure 2.5*). These quantitative and time-bound goals are directed to reducing extreme poverty and hunger, to improving basic circumstances such as people's health and education, to ensure environmental sustainability, and to create a global partnership to enable the realisation of these goals. Addressing these objectives is an essential element of any sustainable development strategy, reinforcing its ability of ensuring a global environmental quality

2.3 Scenario analysis as a tool to explore uncertain futures

Uncertainties play a key role in exploring possible future trends

The future development of many parameters that determine future climate change and biodiversity loss is highly uncertain. This includes uncertainty in economic development patterns, technology development and lifestyle preferences. Relevant systems (energy, agriculture, climate and ecosystems) are determined by a complex interplay of many different factors. Such systems are often characterised by the presence of *tipping points* – non-linearities and thresholds beyond which large, rapid and often catastrophic changes take place that are difficult to reverse (Lenton *et al.*, 2008; Scheffer *et al.*, 2001). Such thresholds are difficult or impossible to identify, as they present themselves only after they have been crossed. Thus, designing a sustainability strategy means having to take into account sudden and potentially irreversible changes (UNEP, 2007), and making it robust enough to deal

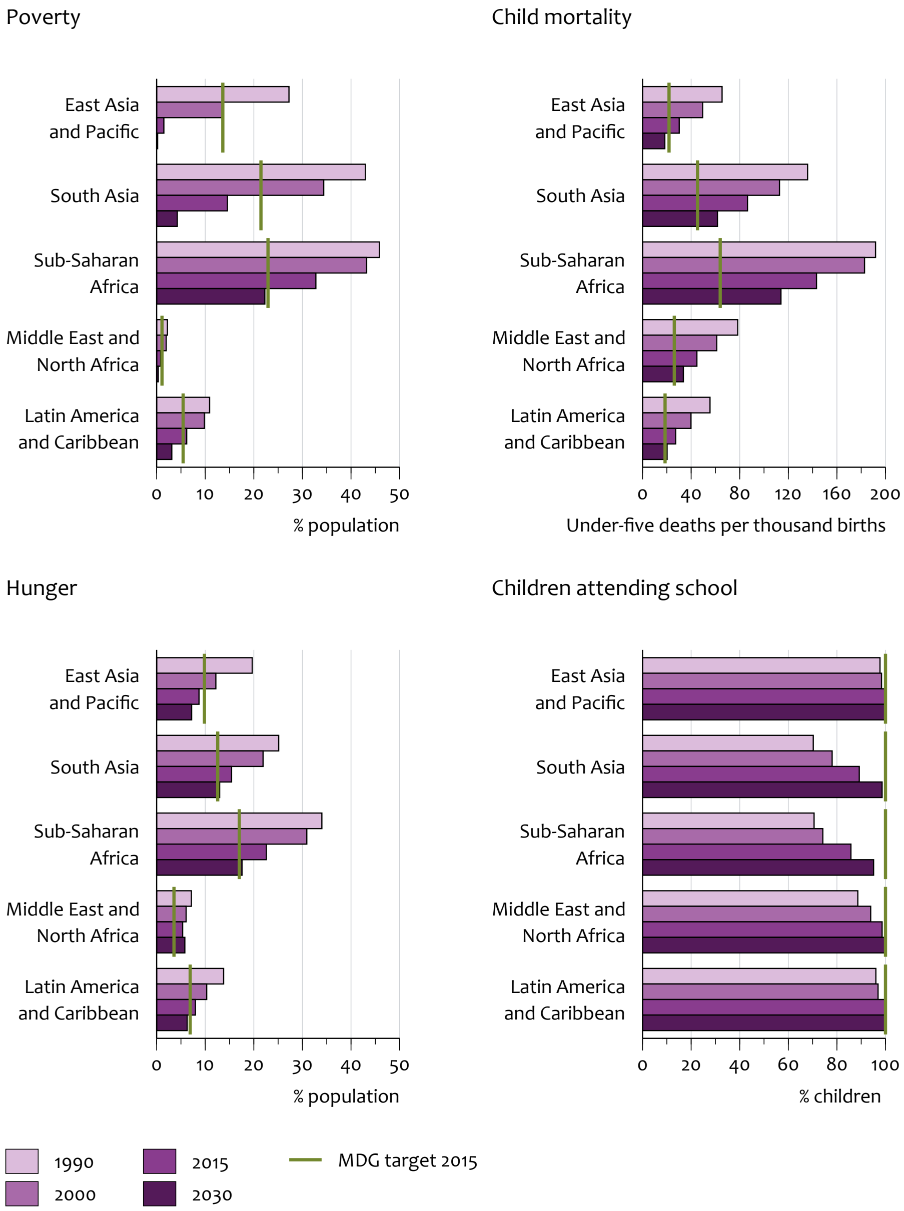
Text box 2.3 Population policy and population growth

The rapid population growth of the last century has led to large pressures on the environmental system. As a result of a declining fertility rate, the growth rate of the world population is decreasing: the 1.2% increase of 2009 was the lowest of the last 50 years. In absolute terms, this means an annual addition to the world population of about 80 million people. In the coming decades, fertility will continue to decline and is expected to drop below the replacement level of 2.1 children per woman, in about 25 years. However, due to the so-called population momentum, the overall population growth will continue until at least 2050, when the human world population is expected to reach 9.1 billion (UN, 2008).

Reinforcing the fertility transition through population policies in order to reduce environmental pressure was an important theme in Limits to Growth. *India and China are striking examples of effective family-planning programs which reduced fertility levels but were also criticised on ethical grounds. A more indirect way of affecting fertility rates would be to improve people's socio-economic status, for example, by stimulating education (especially of girls), offering them better personal control over the number of children they have. The effects of this would be noticeable with a time lag of at least 10 to 20 years – the time it takes to educate people and influence their fertility. As such a measure would also be likely to stimulate economic growth, any positive impact on environmental pressure would be less straightforward.*

In the low variant of the UN population prospects, fertility is assumed to decline much faster than in the medium variant, to 1.5 instead of 2.0 children per woman, by 2050. However, due to the population momentum, the effect on population size would be relativity small in the shorter term: 300 million less people by 2025, but this would increase again in the longer term, to a population size that would be 1.2 billion less than in the medium variant, by 2050.

Population policies can have a substantial effect, but only in the long to very long term. More vigorous policies, such as those seen in history, do have an immediate effect, but also have considerable negative side effects, in terms of social human welfare. Population policy included in general development policies aimed at educating people, might be a preferable option. Not only would this help people to choose the (family) life they would want, but a better education would also have a positive effect on human health and productivity.



Projected developments on four key indicators of the Millennium Development Goals (GISMO 1.0 calculations; Source PBL, 2009b).

with surprises and uncertainties in complex systems (Walker and Salt, 2006). Unfortunately, given the uncertainties involved, these non-linearities and thresholds are poorly captured by models and, therefore, often described in terms of increasing risks.

Another key characteristic of complex systems is the so-called *lock-in,* which results from the interaction between different parameters – such as enabling infrastructure and end-use technologies. The disadvantages of lock-in situations are that they may occur in more costly technologies and cause a loss in flexibility. Agricultural practice, for example, is increasingly based on a small number of high-yielding crop varieties and livestock breeds. The consequential loss of agricultural biodiversity – both across and within species – increases vulnerability to diseases and can have massive impacts on food security (Heal *et al.*, 2004). With regard to energy, diversity helps to increase security of supply, as it reduces the vulnerability to disruptions in a single-supply chain.

Scenario analysis has been developed as a tool to explore different uncertain developments and their future consequences. Scenarios can be described as plausible projections of future developments, based on coherent and internally consistent sets of assumptions on key driving forces and relationships. Given the uncertainties and complexities that are involved, they are projections rather than predictions – as they critically depend on a set of key assumptions. Computer models often represent an important tool in scenario analysis, because they allow users to explore key interactions between the various scenario parameters.

Model-based scenario analysis as the basis of this report

The method of model-based scenario analysis was used to explore how different trends may work out in the future. The models used for this purpose are the so-called integrated assessment models. The World-3 model from Meadows *et al.* (1972) is a computer model used for studying the overall trends and dynamics of overshoot and collapse, on a global scale. Many models have since been developed, with much more regional detail and with much more specific insight on environmental problems. In this report, result of the PBL IMAGE modelling framework are used, which describe the chain of global environmental change for both climate and land use. The framework includes world energy use and food production, as well as the planet's biochemical cycles, climate impacts and land cover (see *Text box 2.4*).

Two alternative projections for the future: *Trend* and *Challenge*

Following main uncertainties, such as international cooperation or tensions, lifestyle developments, or technology surprises, may determine the very different ways in which the world could develop over the coming decades. In scenario literature of recent years, a set of standard characterisations of future trends has emerged, describing global trends, either on the basis of exploring trends with a strong economic focus or particularly focusing on achieving environmental objectives.The analysis in this report uses two major scenarios, each corresponding to a crucial question with respect to the sustainability ambitions:

1. The *Trend* scenario: what happens if we continue along the current pathway?
2. The *Challenge* scenario: what is needed to address the two key environmental challenges, and what are the costs and benefits of such a strategy?

Text box 2.4 The IMAGE modelling framework

IMAGE (Integrated Model to Assess the Global Environment) is an integrated assessment modelling framework that consists of a set of linked and integrated models that, together, describe important elements of the long-term dynamics of global environmental change, such as air pollution, climate change, and land-use change. The global energy model that forms part of this framework, TIMER, describes the demand for, and production of, primary and secondary energy and related greenhouse gas emissions and regional air pollutants. The land modules of IMAGE describe the dynamics of agriculture and natural vegetation. Both are connected to a climate model that describes resulting climate change and impacts. The other model in the modelling framework, FAIR, is used for analysing cost implications of climate policy (MNP, 2006).

TIMER is an energy-system model that simulates the choice of different energy supply options, on the basis of the assumption that the lowest cost options will get the largest market share. The main objective of the model is to analyse the long-term trends in energy-related greenhouse gas emissions. The model particularly focuses on several dynamic relationships within the energy system, such as inertia, learning-by-doing, depletion, substitution processes, and trade between the different regions. A sub-model of TIMER determines the demand for fuel and electricity in 5 sectors (industry, transport, residential, services, and other) based on structural change, autonomous and price-induced change in energy intensity ('energy conservation'), and price-based fuel substitution. The demand for electricity is met by fossil fuel or bio-energy-based thermal power, hydropower, nuclear power, and solar or wind.

The agricultural module of IMAGE describes the productivity of seven groups of crops and pasture which are used by five animal categories. Scenarios of agricultural demand, trade and production, are either obtained from an agricultural economy model linked to IMAGE, or included from other studies. The land area (cropland and pasture) needed for meeting regional production depends not only on production levels, but also on changes in crop and pasture productivity. The regional production of agricultural goods in the model is distributed spatially (at a 0.5 x 0.5 grid) on the basis of a set of allocation rules, such as high productivity, proximity to existing agricultural areas, and proximity to water (Alcamo et al., 1998). IMAGE 2.4 uses a land-cover map based on satellite data and statistical information on the distribution of agricultural land. For the historical period, agricultural land cover was calibrated with data from FAO (2007).

IMAGE estimates both the greenhouse gas emissions (CO_2, CH_4, N_2O) and air polluting emissions associated with energy consumption, land-use change, and agriculture.

The FAIR model can be used for exploring the impacts of different climate policies, such as the required reductions to meet different climate targets, the consequences of different proposals for regional contribution, emission trading, and the potential for adaptation strategies.

The consequences of these scenarios will be explored for climate change and biodiversity loss in Chapters 3 and 4, respectively. The main assumptions are described below. The scenarios are constructed on the basis of earlier analysis, mostly from Van Vuuren *et al.* (2007) for climate change and IAASTD (2008) for land use.

Trend scenario

In the *Trend* scenario, it is assumed that the world continues to develop in a business-as-usual (BAU) pattern, which serves as a reference scenario by extrapolating trends for the main parameters of the last decades. In this scenario, there are no explicit policies to address main environmental challenges. The *Trend* scenario is in line with the so-called A-worlds in earlier scenario work (IPCC, 2000). These A-worlds feature a strengthening of corporate capitalism and market mechanism, after the proclaimed 'End of History', rapid globalisation of goods and financial markets, a new technological wave in the form of ICT, and the rapid economic growth in some major world regions, notably China. The *Trend* scenario projects a continuing increase in material goods and services, driven by the same entrepreneurial and market dynamics which the world has experienced over the last decades. At individual levels, this has provided an increase in material welfare for billions of people in OECD countries, as well as outside the OECD – and provided hope to the poor of catching up with the rich. A plethora of high-tech products entered the global market place, satisfying demand from the rich and the poor. Meanwhile, there a huge and partly unsatisfied demand for low-tech elementary goods and services remains.

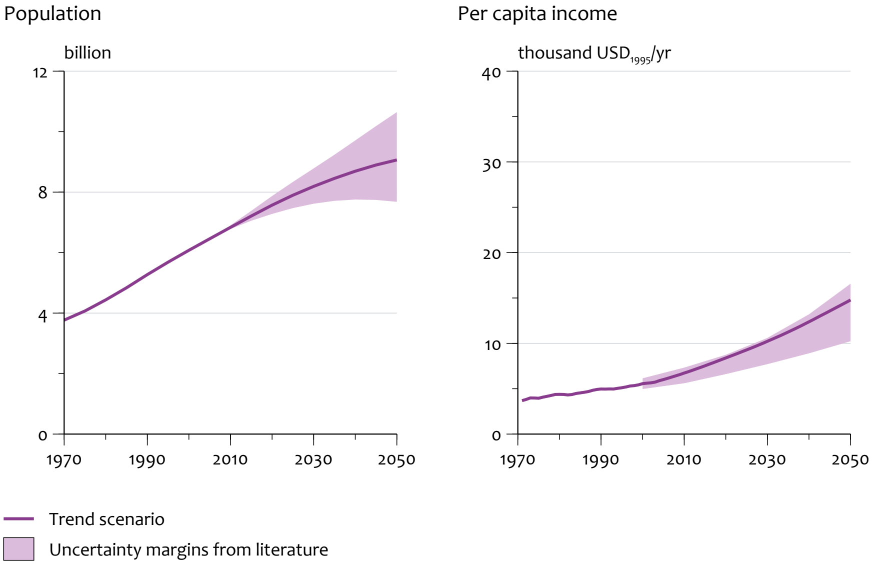
Population size dynamics in the *Trend* scenario follows the UN medium scenario, increasing to 9 billion around 2050, and slowly declining to around 8 billion by 2100 (*Figure 2.6*). This projection lies within the uncertainty range of published projections over the last few years. In terms of economic growth, current expectations are followed: economic growth, in general, will be higher in low-income countries than in high-income countries, but this will not result in income convergence. Based on population dynamics (ageing of the population) and declining total factor productivity (TFP) improvement, economic growth in high-income countries is expected to slow down – but, on a global scale, this is compensated by an increasing share of faster growing low-income countries. The key question with respect to the *Trend* scenario is whether the growth in material flows could remain within the limits for climate change and biodiversity loss. In other words: is the collective outcome of such a world indeed a continuing smooth increase in quality of life for the average person, or will it meet its limits?

For analytical reasons, feedbacks between the assumptions on population and the economy and the changes in climate and biodiversity loss were not taken into account (in contrast to, for instance, the *Limits to Growth* model).

Challenge scenario

The *Challenge* scenario explores the result of policies developed to meet the climate and biodiversity objectives. This scenario is based on two normative choices:

Global population and income Figure 2.6



Population and income growth in the Trend scenario. Source: Van Vuuren *et al.* (2009).

- Greenhouse gases will be reduced in order to limit average global temperature increase to a maximum of 2°C.
- Expansion of agricultural land will be limited in order to avoid further loss of biodiversity, from 2020 onwards.

The main objective of the *Challenge* scenario is to find out what kind of changes in the world's energy and land-use systems would be required to meet the objectives for climate change and biodiversity loss (see Chapters 3 and 4). Given the enormous momentum behind the drivers in the *Trend* scenario, the force to deflect such trends to meet environmental targets is not a trivial task. As no feedback on population and economic growth was taken into account for the *Trend* scenario, population and economic growth in the *Challenge* scenario is assumed to equal that of the *Trend* scenario.

There is more than one way to Rome

There is no silver bullet to achieve the 2°C climate target, or to prevent biodiversity loss. Various options available, several of which requiring a choice in support or implementation of technological response and lifestyle change. Therefore, an integrated strategy will be needed, nurturing some level of *diversity* to increase resilience.

In the past, several analyses were carried out to explore the relationships between sustainable development and world view (PBL, 2008; RIVM, 2004; Rotmans and De Vries, 1997; UNEP, 2007; Vries and Petersen, 2009), which shows different perspec-

This reports contrast 2 scenarios: trend and challenge. The challenge scenario indicates different options that would allow to decrease environmental pressure

tives on overall environmental targets, but also on the type of policy responses. Different world views lead to different preferences for decentralised or centralised power systems, use of market-based instruments, nuclear power etc. In the *Challenge* scenario it is indicated how certain targets could be achieved, mostly to illustrate which efforts would be required, rather than providing a blueprint. As such, it does not present one single scenario, but describes various options. Robustness and attractiveness of specific choices under different circumstances is indicated were appropriate.

Towards a Low-carbon Economy

3

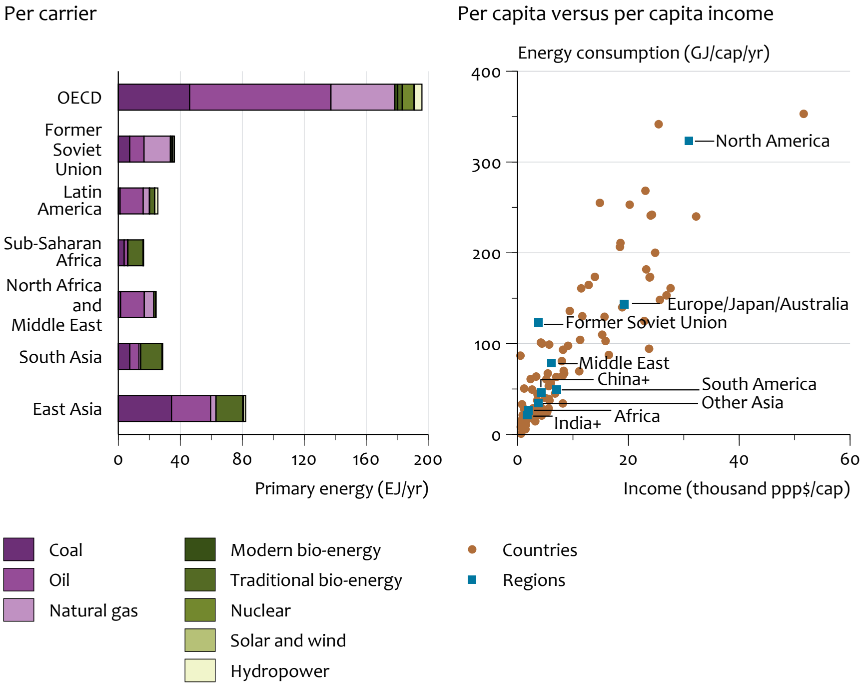
3.1 Where does business-as-usual takes us?

Energy plays a crucial role in ensuring a more sustainable development pattern

The consumption of energy is a necessary condition for human activities and economic welfare, but the present ways of energy production and consumption are associated with large environmental impacts and issues of energy security. Above all, fossil-fuel combustion is the single most important cause of anthropogenic climate change. Reducing greenhouse gas emissions will arguably be the greatest challenge facing the energy system today. In addition, various other environmental problems are also associated with the production of energy, such as air pollution on various scales (regional, urban and local), landscape disturbance, generation of waste, and the risks of nuclear accidents. Moreover, energy resources are limited and unevenly distributed across the world. This leads to the question of whether energy security can be maintained in the long run, especially for resource-poor regions.

Energy plays a key role in many environmental problems.

Primary energy consumption, 2000 **Figure 3.1**



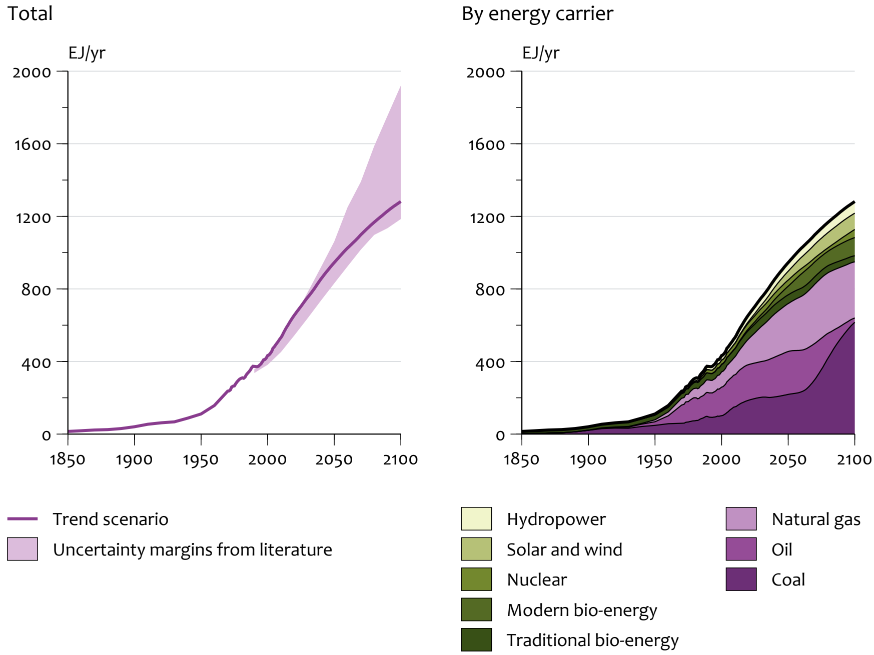
Regional energy use in 2000 – and historic relationship between income and per-capita energy consumption. Source: IEA (2006).

Present energy consumption patterns differ widely, from an average of more than 100 GJ per capita, per year, in high-income regions (OECD countries and the Former Soviet Union), to less than 40 GJ per capita, per year, in low-income regions, such as Africa and parts of Asia and Latin America (*Figure 3.1*). In the low-income regions, presently, about 1.6 billion people have no access to electricity, and nearly 2.4 billion people mainly depend on traditional bio-energy (Modi *et al.*, 2006). Providing sufficient energy to those presently deprived of it, is, on the one hand, an essential condition for human development in low-income regions, but, on the other hand, could complicate the global environmental problems and energy security issues (see *Section 5.2.2*).

With business as usual, fossil-fuel use will increase globally, over the next decades, to meet energy demand for human development

Energy consumption is expected to continue to grow worldwide, mainly driven by increasing demand in low-income regions. A typical projection of world energy consumption shows an increase by a factor of 2 to 3, over the 21st century (*Figure 3.2*). In the *Trend* projection for this report, energy consumption doubles over the next 50 years and increases by about 25% in the subsequent 50 years. Assuming no change in current policies, fossil fuels keep a large market share in this scenario, as their

Figure 3.2 **Global energy consumption, Trend scenario**



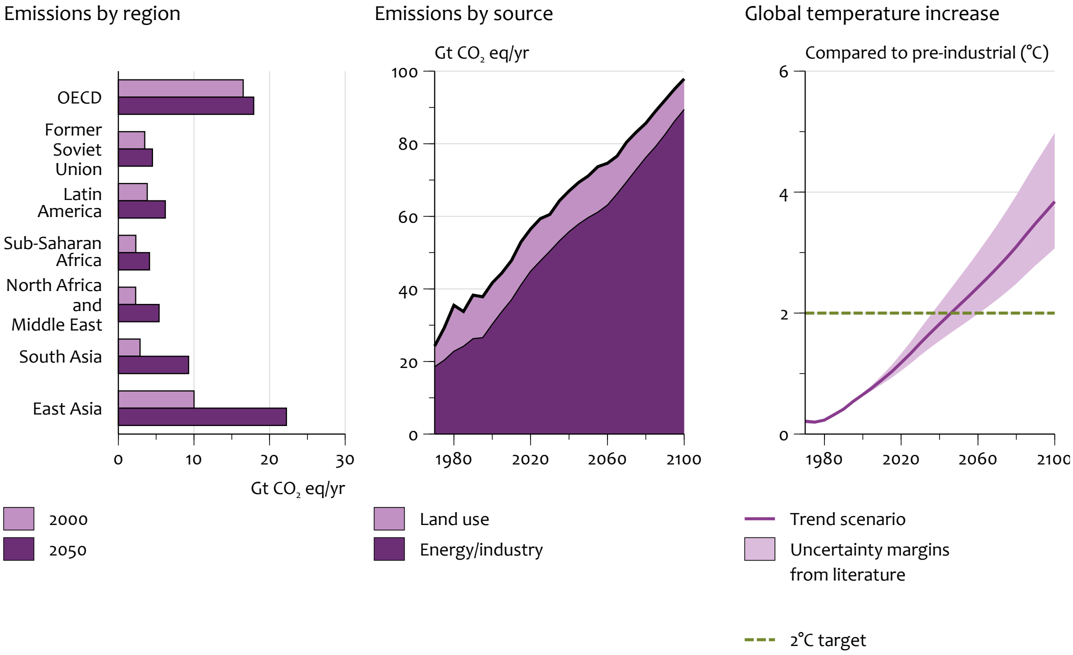
Projections of future energy consumption under the Trend scenario. Source: Van Vuuren *et al.* (2009) and IPCC (2007c).

average prices remain lower than those of alternative fuels. Annual growth rates are projected to be in the order of 1% (oil) and over 2% (coal and natural gas). For oil and natural gas, depletion and resulting price increases around the middle of the 21st century are expected to lead to stabilisation or even a peak in production, with production concentrated in only a few resource-rich regions. For coal, however, resource scarcity is not expected to limit production or cause cost increases, in the foreseeable future. As a result, it is likely that coal use will strongly increase. At the same time, non-fossil energy production will increase substantially, also under the *Trend* scenario, including nuclear, biomass and other renewables.

Business as usual according to the Trend scenario will lead to increases in greenhouse gas emissions. Temperature increase will likely pass the 2°C target

Increasing fossil-fuel use implies increasing emissions of greenhouse gases. At this moment, most greenhouse gas emissions can be attributed to fossil-fuel combustion and industrial emissions. Land-use change and agriculture cause about a third of the total in emissions. While this emission category will also grow, its share is likely to drop to about 10% in 2100 (mostly due to a decrease in emissions from deforestation) (*Figure 3.3*). In total, under the *Trend* scenario, greenhouse gas emissions are expected to more or less double. Although most of this increase occurs in low-income countries, per-capita emissions remain highest in the OECD countries.

Greenhouse gas emissions and temperature change, Trend scenario **Figure 3.3**



Greenhouse gas emissions under the Trend scenario and associated climate change. Source: van Vuuren *et al.* (2008a and 2009b).

Scientific knowledge leaves little doubt that a consequence of the increase in atmospheric greenhouse gas concentration is a steady increase in global mean temperature (*Figure 3.3*). Although there is considerable uncertainty about the exact level of temperature increase, the 2 °C target discussed in Chapter 2 is likely to be exceeded by the middle of this century in the *Trend* scenario. Based on the uncertainty is the relationship between greenhouse gas concentration and temperature increase (the so-called climate sensitivity), near the end of the century, the temperature increase may be 3 to 5 °C, relative to pre-industrial levels, although uncertainty ranges do not exclude even higher values.

Business as usual leads to severe climate impacts

There are considerable risks associated with such temperature increases (*Figure 2.3*). For the *Trend* scenario, the most likely projection is an increase in global mean temperature of 4 °C, with likely negative impacts on agricultural yields in most parts of the world. Moreover, sensitive systems, such as coral reefs, part of mountain ecosystems, Arctic sea ice, and part of the world's glaciers, are likely to be lost. Forests would be more vulnerable to wildfires and there would be a serious risk of an increase in extreme weather events. The world sea level could rise by up to 1.2 metres, by the end of the century. Moreover, there is considerable risk of passing critical thresholds for the functioning of the Amazon, the release of methane from tundra/permafrost, and for the stability of the Greenland and west Antarctic ice sheets (Alley *et al.*, 2002; Oppenheimer and Alley, 2004, 2005). There is also a significant threat (5-15% change) of a warming by more than 6 °C, in 2100 (Schneider, 2009), which would clearly have even more serious impacts on ecosystems and human conditions.

Access to modern energy services will improve – but not enough; energy security will decline

While economic development under the *Trend* scenario will improve access to modern energy such as electricity and LPG for many, significant parts the world population are expected to still be deprived of modern energy services. In fact, the expected increase in fossil-fuel prices, as a result of depletion, would make access to energy more expensive for the poor. For oil and natural gas, the scenario shows a further concentration of supply in only a small number of supply countries, leading to a decrease in energy security.

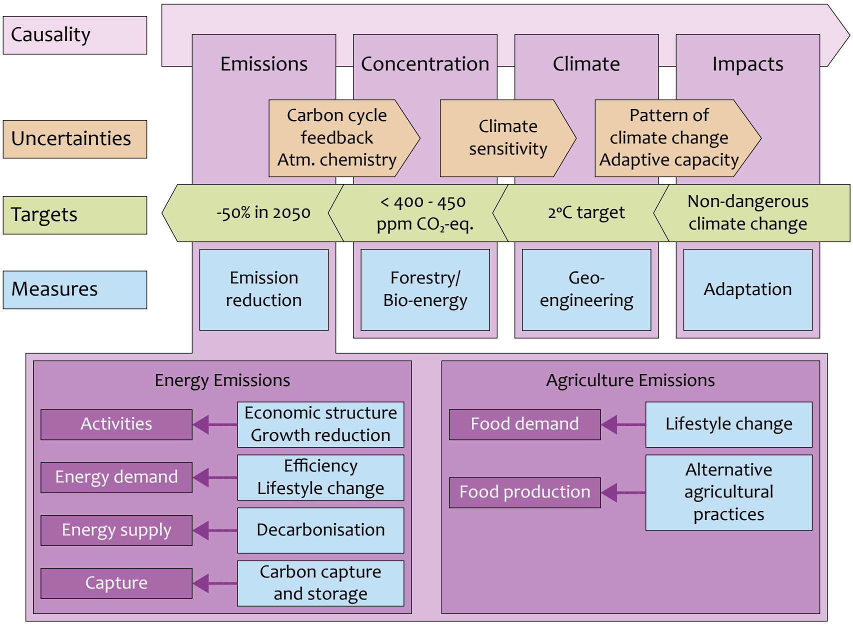
3.2 What is needed to reduce climate risks?

A sustainable energy system requires urgent action: global emissions need to peak in just one to two decades and be reduced by around 50% by 2050.

The causal chain of climate change runs from emissions to greenhouse concentration, to climate change and, finally, to impacts (*Figure 3.4*). The overall goal of international climate policy is to avoid 'dangerous anthropogenic interference in the climate system' (UN Climate Convention). This can be interpreted as a maximum global temperature increase of 2 °C (see *Chapter 2*). In translating this target to implications for emissions, it is important to account for the uncertainties that play an important role in the causal chain, specifically the response of the terrestrial biosphere to climate change, and the so-called 'sensitivity' of the climate system to greenhouse gas concentrations. For the first factor, normally, the terrestrial biosphere is expected to absorb some of the carbon dioxide in the atmosphere, thus limiting climate change. However, increased droughts could actually cause a net carbon release. In such as situation, the climate system could show significant feedbacks that could further worsen the situation. The second factor, climate sensitivity, is defined as the warming that will occur at a doubling of greenhouse gases in the atmosphere, for which likely values range from 2 ºC to as much as 4.5 ºC.

As a result of these uncertainties, policy goals should be formulated in terms of risks. For example, for a climate sensitivity of 2 °C, the 2 °C target requires a long-term greenhouse gas concentration of 560 ppm CO_2 eq; for a climate sensitivity of 4.5 °C, the concentration needs to stay below 380 ppm CO_2 eq. For the average value of climate sensitivity, a maximum greenhouse gas stabilisation level of 450 ppm CO_2 equivalents would be required, thus providing a 50% chance of staying below the 2 °C temperature increase. Stabilising below 400 ppm CO_2 equivalents could increase this chance to over 70%, but obviously would also require more stringent emission cuts. Tighter targets would be even harder to achieve in the light of present concentration levels of about 390 ppm (in CO_2 alone) or somewhere around 410 ppm if measured in CO_2 equivalents (including other greenhouse gases). A target range of 450 to 400 ppm CO_2 equivalents already implies significant emis-

Causality, targets and measures of climate change **Figure 3.4**



Relationships between elements of the causality change of climate change, uncertainties (red), targets (green) and policy measures (blue).

sion reductions, in the short term (*Figure 3.5*). Emissions need to have been reduced by around 50%, by 2050, compared to 2000, for both a 450 and a 400 ppm target, with a peak in global emissions within only one to two decades. Again, other values have also been proposed. The *Challenge* scenario presented here explores the effort required to reach such a profile (see chapter 2)

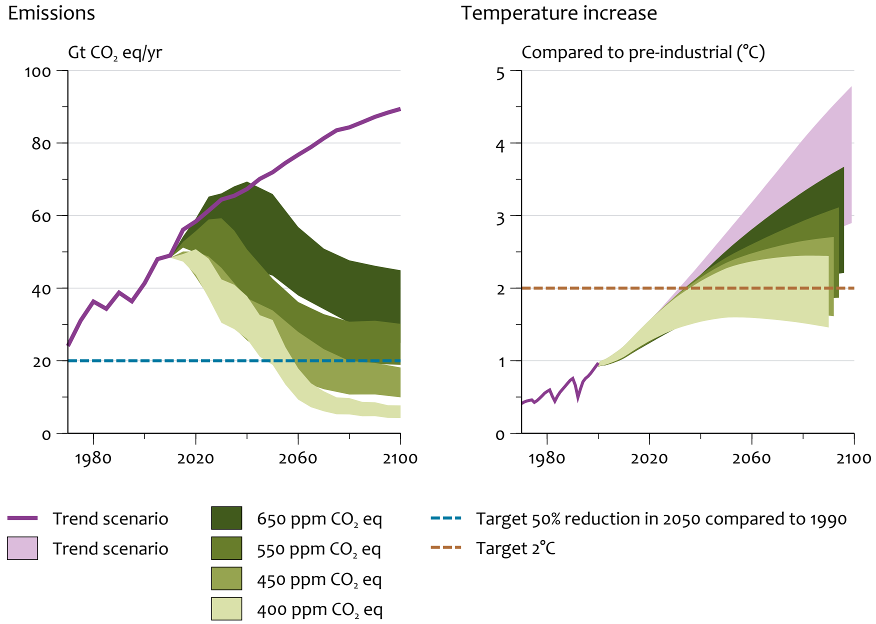
There are several options for responding to climate change (see text in blue boxes in *Figure 3.4*). Leverage points in the system include:

- limiting climate change effects through adaptation measures,
- introducing geo-engineering measures to break the link between greenhouse gas concentrations and temperature,
- measures to remove CO_2 from the atmosphere (e.g. by increasing forest cover),
- reducing greenhouse gas emissions.

Adaptation and mitigation both need to be included in a successful climate change policy

Even a limited global temperature increase of 2 °C would require considerable adaptation measures to climate change. In such a projection, for instance, sea levels could still rise by around 0.5 metres by 2100, requiring significant measures of coastal protection, specifically in densely populated areas. Adaptation is even more important, because the uncertainty in the climate system implies that a concentra-

Figure 3.5 **Global emissions and temperature increase for various concentration levels**

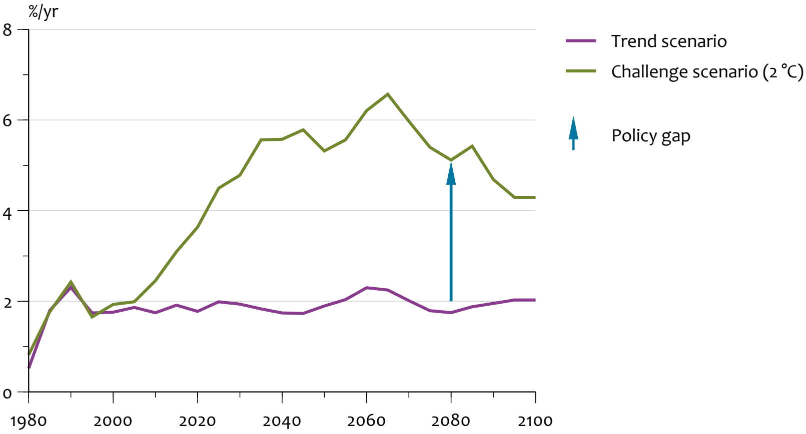


Indication of emission profiles and temperature outcomes for different stabilisation targets. Sources: MAGICC calculations from Van Vuuren *et al.*, 2008a.

tion level of 450 ppm CO_2 equivalents could also lead to a temperature increase of around 3.5 °C, if climate sensitivity is higher than presently considered to be most likely. Adaptation and mitigation measures are not trade-offs, but two strategies of an integrated and effective climate policy.

Major areas of adaptation would include: 1) coastal protection, 2) ensuring adequate water supply with projected changes in precipitation and evaporation, 3) making agriculture less vulnerable to climate change, 4) adapt urban infrastructure and building design, 5) more cooling equipment, and 6) adjust biodiversity protection strategies (see next chapter). This list is far from exhaustive; many other measures would be needed. Global investment costs for adaptation measures are estimated at between USD 40 and 170 billion, in 2030 (UNFCCC, 2007), or cumulative at USD 2000 billion for the period from 2000 to 2050 (Hof *et al.*, 2009a). A recent study by Parry (2009) indicated that adaptation costs could be three times higher. These costs, however, are lower than mitigation costs and projected overall damages (see further) but are still very substantial. It would be crucial to make 'adaptation to climate change' an essential part of any investment decision, including, for instance, infrastructure projects and development assistance.

Rate of improvement of ration between greenhouse gasses and GDP **Figure 3.6**



Decarbonisation rate under the Trend scenario and the Challenge scenario.

A strategy for achieving the 2 °C target requires both energy efficiency improvement and a transition to low-carbon and zero-carbon energy options

Figure 3.4 indicates that a reduction of greenhouse gas emissions requires various measures for energy-related and agriculture-related emissions. The task ahead can also be expressed in terms of implication for the so-called 'rate of greenhouse gas intensity decrease', that is the change in the ratio between greenhouse gas emissions and income (GDP). Achieving the goal of a 50% emission reduction by 2050, outlined in the previous section, would require the decrease rate in 'greenhouse gas intensity' to be around 5% per year instead of the historic value of around 2%. (*Figure 3.6*). The ambitious '5% rate' would need to be sustained for many decades. In order to achieve such decarbonisation rates, a wide range of technology options need to be implemented.

Increased participation in an international mitigation regime is a key condition for meeting climate change stabilisation targets

Emission pathways that comply with a 2 °C target are extremely challenging for climate policy, in general, and for restructuring of the world energy system, in particular. All scenarios that lead to low greenhouse gas concentrations show a peak in global emissions within one to two decades. It is clear that the ambitious global emission reductions needed to comply with the 2 °C target could only be reached if emission reductions would take place in all major emitting countries, including large emerging economies. Given large differences between countries in per-capita emissions, development stage, ability to reduce emissions and interpretation of fairness, it has proven to be far from easy to allocate responsibility for emission reductions to different parts of the world. This is discussed further in *Section 3.4*.

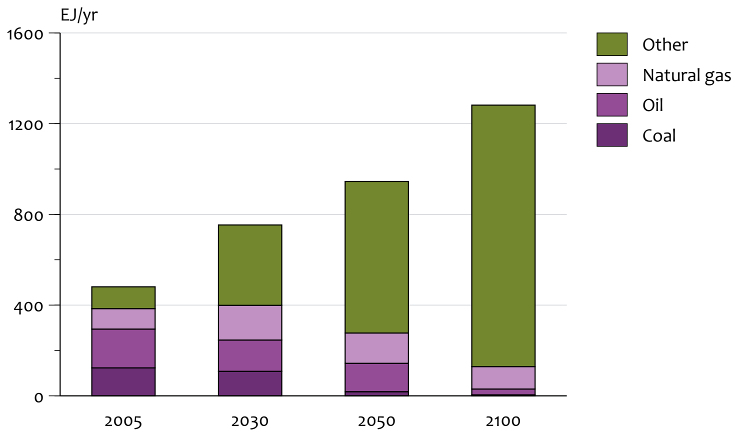
A robust energy system includes a broad portfolio of options such as bio-energy and fossil fuels (when combined with CCS).

At this point it is not possible to determine with certainty the optimal technology mix that would bring about the required emission reductions, but some robust strategies can be defined

Given uncertainty in technology development rates and different valuation of the (co)benefits and trade-offs of different technologies, it is not possible to determine the optimal technology mix, per sector, that would bring about the required low emissions levels for 2050. In fact, historically, many examples exist of long-term visions on energy systems that turned out to be completely misguided, for example, when energy policies in several industrialised countries the 1970s were guided by the projected nuclear domination of the energy system in 2000. However, currently, we do know some of the key conditions for a 2050 energy system, such as an emission reduction of around 50%, compared to 2000 levels (assuming targets are not loosened or tightened in light of new evidence). Therefore, a robust energy strategy would require to:

1. clearly set the long-term *conditions* for any future energy system (e.g. 50% emission reduction worldwide, by 2050),
2. determine the *robust elements* of desired energy systems, and make sure that these are developed, and
3. allow for *resilient* energy/climate policy measures.

Global energy consumption, Challenge scenario **Figure 3.7**



Energy system under the Challenge scenario (based on Van Vuuren et al., 2009b).

Although various pathways to a low-carbon society may exist, any credible long-term climate policy would need to take these conditions into account.

3.3 A strategy of a post-carbon society

The combined potential of measures could make climate goals achievable

In the energy sector, there are four ways of reducing greenhouse gas emissions (similar measures could be taken in the agriculture sector) (*Figure 3.4*):

1. changing economic structure / less economic growth,
2. increasing energy efficiency (using technology or life-style changes),
3. changing energy supply (using zero-carbon energy options),
4. implementing end-off pipe measures (carbon capture and storage).

Various assessments of the emission reduction potential have been made. The assessment in this report was partly based on model calculations, and partly on considerations that are not generally captured by models. How measures are used partly depends on expected costs and technical factors, but also, for instance, on their public acceptance and possible competition between measures. It is obvious that the challenge of reaching a low temperature target would require using most of the available options; there is no silver bullet.

The objective of reducing greenhouse gas emissions by 50% can be translated in terms of the overall character of the world energy system in the *Challenge* scenario (*Figure 3.7*). While the *Trend* scenario is dominated by fossil fuels, the *Challenge* scenario – over time – phases out unabated coal and oil use. The use of natural gas is phased out more slowly, given its lower emissions per unit of energy. Most energy will need to come from zero-carbon options (including efficiency), already

Table 3.1 Important technologies for decreasing greenhouse gas emissions

	Important emission reduction technologies and measures that are now commercially available	Important emission reduction technologies and measures expected to be commercially available by 2030
Energy production	Improved efficiency in production and distribution; switching from coal to gas; nuclear energy; renewable heat and electricity (water, sun, wind, geothermal and bio-energy); Combined Heat & Power units; first applications of carbon capture and storage	Carbon capture and storage for electricity generation from gas, biomass and coal; advanced nuclear energy; advanced renewable energy, including tidal and wave energy, concentrated solar energy and photovoltaics
Transport	More efficient vehicles; hybrid vehicles; clean diesel; biofuels; 'modal shift' to rail and public transport and to non-motorised transport; improved spatial planning and transport planning	Second generation biofuels, high-efficiency aircraft; advanced electric and hybrid vehicles
Buildings	Efficient lighting, appliances and heating and cooling; improved boilers and insulation, passive and active applications of solar energy for heating and cooling; alternative refrigerants and recycling of conventional refrigerants	Integrated design of utility buildings with intelligent energy management; integrated photovoltaics
Industry	Efficient electrical devices, heat and electricity recovery, recycling and replacement of materials, management of greenhouse gases other than carbon dioxide, various process technologies	Advanced energy saving; carbon capture and storage in cement, ammonia and steel production, inert electrodes for aluminium production

Source: IPCC (2007b)

encompassing about two thirds of the total in energy consumption in 2050. Various technologies contribute to this part of the energy system (*Table 3.1*).

Reaching the emission reduction targets to achieve the 2 °C temperature target (*Challenge* scenario) would require a broad portfolio of reduction measures, because the potential contribution from each individual option is limited, due to technical or other reasons. In addition, in some cases, technologies only apply to specific sectors and regions. A broad portfolio approach has some drawbacks, in terms of the diffusion of research investments, but there are also clear advantages. It would lead to a more resilient policy, in case some technologies achieve less than promised, or cannot be implemented at all. Excluding certain options can lead to additional costs and/or the inability to reach the 2 °C target. Van Vuuren *et al.* (2007) provided an indication of how the *Challenge* scenario could diverge from the *Trend* scenario, as indicated in *Figure 3.8*. The use of bio-energy may have consequences for biodiversity (see Chapter 4 and 5). Its use therefore needs to be carefully monitored and the available potential needs to be used as efficiently as possible.

Energy efficiency improvement is robust under all scenarios

Saving energy is an important element in all climate policy strategies. Studies show that, compared to the current situation, saving energy over the next century could achieve substantial emission reductions, although the effect decreases after the first decades of this century. On average, across different scenarios, saving energy can achieve a 25% reduction in emissions over the next 30 years, compared to a scenario witout climate policy. Saving energy is an attractive option because it has many other advantages: it reduces the dependence on energy imports, it reduces the sensitivity to energy price variations, and it helps to improve the competitiveness of companies or whole sectors. Substantial acceleration in the rate of energy-efficiency improvement is, however, not easy to implement by policy, due to the wide range of sectors and applications, and the large number of actors involved.

Contribution by reduction options to stabilise global greenhouse gas emissions **Figure 3.8**

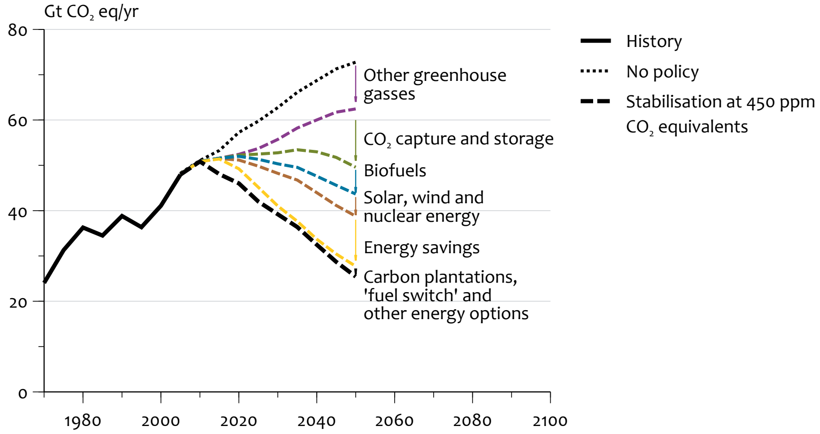


Illustration of contribution of various reduction options. Source: Van Vuuren *et al.*, 2007.

This is particularly valid for options concerning households and the transport sector. Moreover there are unknown rebound effects.

Large-scale and centralised power generation provides very significant emission reduction potential

One of the most attractive forms of climate policy, in terms of low costs and ease of implementation, is to decarbonise the central power system. This can be done by using large-scale renewable power production, such as wind power, hydro power or concentrated solar power (CSP), bio-energy, nuclear power and/or fossil-fuel fired plants in combination with carbon capture and storage (CCS). This makes it attractive to promote transformation to electricity as the primary mode of energy for end use ('all-electric energy system'), with electricity being produced – at least partly – in centralised units and distributed through a well-developed grid. For personal transport, a transition to electric vehicles charged from grid power points fits such a strategy. At the same time, transport modes for which electric motorisation would probably be more problematic, such as trucks, aeroplanes and ships, could be run either on biofuels or oil-based fuels. Most domestic functions, such as heating and cooking, could also be based on electricity. Space heating, for instance, could easily be based on efficient heat pumps or solar boiler systems.

An essential part of such a transformation of the energy system is an extensive investment in expansion of power grids at a continental scale (super grid). Such super grids would more easily facilitate penetration of large-scale renewable energy plants, reducing problems of intermittency. It would also provide the option of transporting electricity on an even larger scale across continents (such as from North Africa into Europe). This strategy of increased investments in grids, and a phase in of large 'non-carbon emitting' plants could start in high-income countries and be followed by a similar strategy in low-income countries. A crucial element in an electricity-based energy system is the development of electricity storage capacity, either in large-scale facilities using pumped hydropower or compressed air, or on a generally smaller scale, using batteries.

The use of fossil fuel in the energy system could fit within this strategy in combination with CCS. Although this technology has not been tested on a large scale, yet, nearly all model studies indicate that this could be attractive in terms of costs and relative ease of implementation. Large-scale penetration would require further experimentation, in the near future, followed by the development of a transport and storage infrastructure for carbon dioxide. In the longer-run bio-energy combined with CCS might be an essential technology as it allows to create net negative emissions, required to reach the lowest targets (Van Vuuren *et al.*, 2007).

Small-scale energy production by end-users reduces energy dependency, but requires development of smart distribution grids

The use of cleaner technologies would lead to an increase in electricity prices of about 20%, thus providing some stimulus for increased efficiency and small-scale power generation by households, companies and industries. This would partly reduce the demand for large-scale power plants. The main technologies here are solar photovoltaic (PV) systems and small-scale wind turbines, distributed geother-

The use of fossil fuels could fit in the Challenge scenario in combination with CCS.

mal heating and cooling, and biogas-based micro combined heat and power (micro CHP). Including such technologies in the energy system would need an evolution of distribution grids, and require significant elaboration of coordination and grid control mechanisms and development of so-called smart grids. Large-scale local power production would require deployment of additional production capacity, which could compromise the overall environmental effect, somewhat, if storage or back-up capacity is limited (Faber and Ros, 2009). Since both centralised and decentralised power systems offer significant potential for inclusion of renewable power production and CO_2 emission reduction, there is a good argument for maintaining both, as a hybrid option in any future sustainable energy system.

High-income countriescan take the lead

Technologies implemented in high-income countries are often also implemented in low-income countries with only limited delay. This is especially the case for technologies that are sold at a global scale, such as in cars, technologies associated with lead-free petrol and desulphurisation equipment in power plants. On the basis of financial and innovative capability and expected outcomes of climate policy negotiations (see Section 3.4), high-income countries are likely to take the lead in implementation of low-carbon energy systems. In a recent study (PBL, 2009b), the option of an 80% emission reduction in the European Union was explored, showing that such an emission target could be achieved (*Figure 3.9*). The currently proposed policies of high income countries as part of the post-Kyoto negotiations, however, are not in line with a 2°C target (PBL, 2009c).

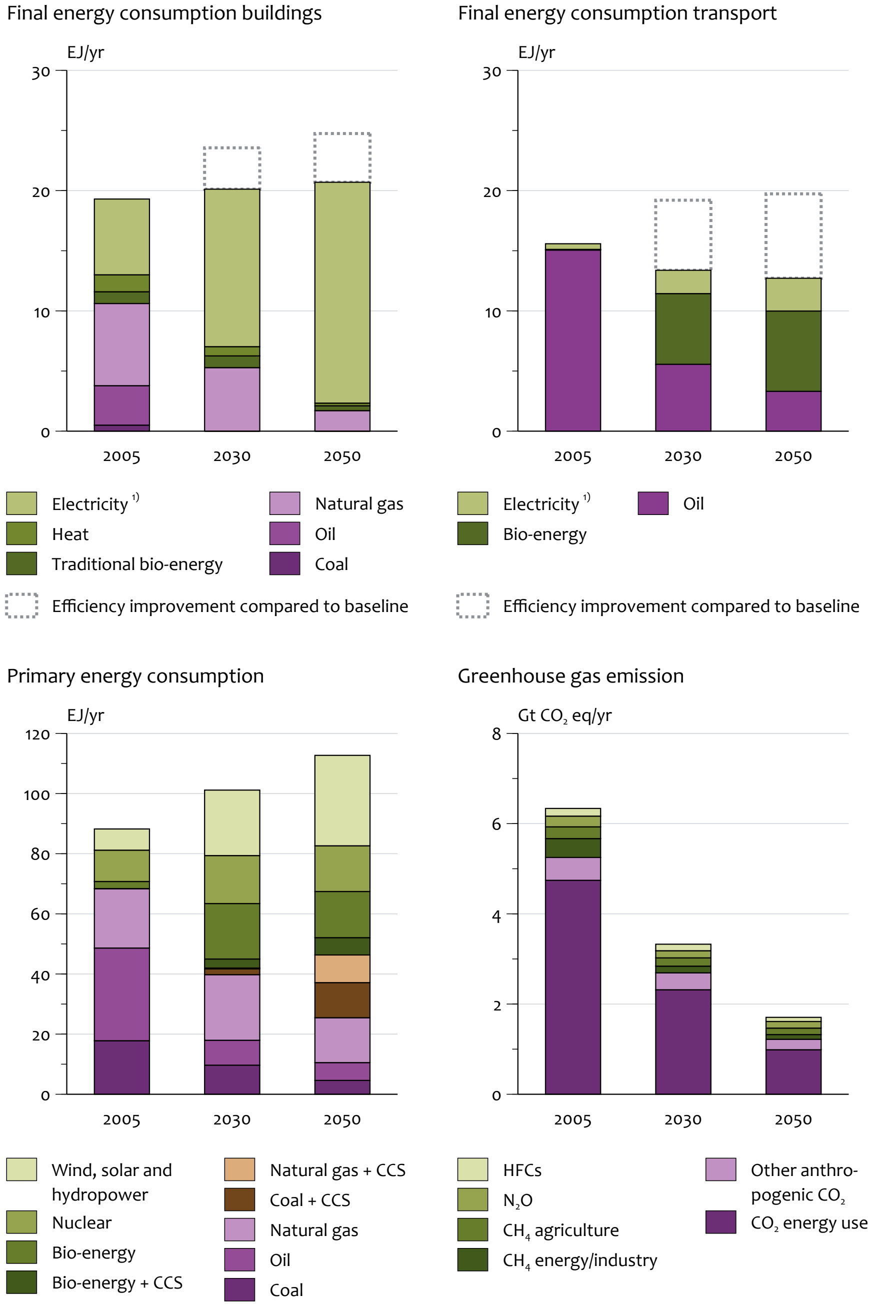
Reducing non-CO_2 greenhouse gas emissions would contribute significantly to the countering of climate change at relatively low costs, but could be difficult to organise, in practice

Non-CO_2 greenhouse gas emissions currently account for about a quarter of all greenhouse gas emissions. This includes methane emissions from animals, rice cultivation, waste management and fossil-fuel operations, nitrous oxide emissions from fertiliser use, and animals and adipic and nitric acid production, and emission of fluorinated substances. A substantial number of these emissions could be avoided at relatively low costs (Lucas *et al*., 2007), such as most fugitive emissions from energy production, emissions associated with waste management, industrial emissions, and part of the agricultural emissions. A challenge with respect to reducing these last emissions is that a significant part originates from activities of a very large number of farmers in low-income countries, making implementation of reduction measures more difficult. Still, studies indicate that, by 2050, at least half of the non-CO_2 emissions could be avoided (Van Vuuren *et al*. 2007).

Deforestation and afforestation

Currently, between 10 to 20% of emissions are associated with deforestation. Partly, the costs of reducing deforestation rates are relatively low compared to other mitigation options, while benefits would not only be the reduced greenhouse gas emission, but also biodiversity protection. Kindermann *et al*. (2008) estimate that especially in the tropics costs of avoided deforestation could be as low as 10 or 20 USD per ton of CO_2. They estimate that reducing deforestation emissions by 50% would reduce global emissions by around 2 Gt CO_2. In addition, afforestation activities could contribute to managing climate change, although estimates of its

Figure 3.9 **Towards a low-carbon EU energy system, vision**



1) Alternatively, the carbon-free carrier could be hydrogen

Illustration of the EU energy system under the vision for 2050. Transport (upper right) and buildings (upper left) final energy consumption, total primary energy (lower left) and greenhouse gas emissions (lower right). Results from the TIMER model. Source: PBL (2009b).

potential range widely (IPCC, 2007b): from more than 20% of present greenhouse gas emissions to more modest and probably more likely figures of at maximum 5% of current emissions per year (Strengers *et al*., 2008). Implementation of afforestation and reduced deforestation measures is far from trivial. It often involves many stakeholders, and, in countries where these measures can be implemented, often, institutional reform would be required.

3.4 Elements of effective climate policy

An effective transition towards a post-carbon society depends strongly on a coherent set of policies across different sectors and regions. A key point is the setting of clear long-term targets with short-term policies gearing up to this target (see *Chapter 5*). The focus here would be on specific features of the energy system.

Considerable investments in low-carbon societies are required

The cost and pace of any response to climate change will depend critically on the cost, performance and availability of technologies that can lower emissions in the future (IPCC, 2007). Investments in the energy system, in the next 50 years, in any way will be considerable, with or without climate policy.

Even under the *Trend* scenario (that is, in the absence of climate policy), the world would need to spend between 25,000 and 30,000 billion USD on energy supply, up to 2030, to meet global energy demand. This figure amounts to about 1.5% of cumulative GDP over this period (IEA, 2008, Rao, 2009, Van Vuuren *et al*., 2009b). In the period from 2030 to 2050, another 30,000 billion USD in investments would need to be spent on energy supply (Van Vuuren *et al*., 2009b; Rao,2009). This implies an average in the 2008-2050 period of 1400 billion USD per year. Expenditures on the demand side (equipment for energy-transformation and efficiency) are more difficult to determine as a result of system boundaries, but they are estimated to be at least of the same order of magnitude, bringing the expected total energy expenditures globally at the level of 4% of GDP.

The transition to a low-carbon economy would require a shift in existing investments, next to considerable additional investments. Based on information on abatement costs, IPCC published estimates of additional annual expenditures of climate policy for reaching low greenhouse gas concentration levels of 17,000 to 68,000 billion USD in the period up to 2030, which would amount to around 0.5 to 2% of cumulative GDP in that same period [IPCC, 2007]. Other studies showed similar orders of magnitude with equally large ranges (*Table 3.2*) (Van Vuuren *et al*., 2007, IEA, 2008, Stern, 2007, Rao, 2009). To conclude, on average, global climate policy costs of the coming decades are estimated at around 50,000 billion USD, or around 1.4% of cumulative world GDP. This implies on average about 1200 USD billion per year. Assuming regular energy investments to be 4% of cumulative world GDP, this would imply a 30 to 40% increase in the aggregate investment in the energy sector compared to the *Trend Scenario*.

The above figures indicate a significant re-direction of investments. Most of the *additional* aggregate investments would be in energy efficiency, even though these

Table 3.2 **Investments in the energy system (2000-2050)**

	Cumulative investment 2005-2050 estimates (billion USD)	Investment estimates (billion per year)
Trend scenario	Supply: 26,000 (IEA, 2008) (only until 2030) Supply: Around 60,000 (Rao, 2009; Van Vuuren *et al.*, 2009b) *Demand: pm*	~ 1400
Challenge scenario (additional)	17,000-68,000 (IPCC) 25,000-80,000 (Van Vuuren *et al.*, 2007) -10,000-48,000 (Stern) (less reduction) 45,000-90,000 (IEA) 15,000 (Rao, 2009)	~ 400-1600
Adaptation costs	2,000-7,000	~ 50-160
Grid expansion for MDGs	200	

Sources: IEA, 2008; Rao, 2009; Van Vuuren, 2009b; IPCC, 2007b; Stern, 2006 and Van Vuuren, *2007*.

are generally very cost-effective for each individual measure. While, in energy supply, there would be a shift towards more expensive options, this would be – at least partly – offset by reduced energy demand. For energy supply, there would be a major redirection of investments, from producing fossil fuels to low-carbon options. The macro-economic impacts of the changes in investments are more uncertain. Estimates on the total macro-economic impacts vary widely due to large uncertainties. While most studies showed a limited reduction in economic growth, a small number of studies showed a more rapid growth as a result of increased investment in research and development and high employment rates (see Stern, 2006; IPCC, 2007b). Limited by enough available data, the IPCC did not provide an average impact in the literature, but only a maximum GDP loss of 5.5% by 2050 (IPCC, 2007b). Lower losses (2-3%) would be conceivable when larger technological progress is taken into account (Knopf *et al*, 2009). It needs to be noted that economic costs are not equally distributed. Costs are higher in countries with a high carbon intensity and in energy-exporting countries.

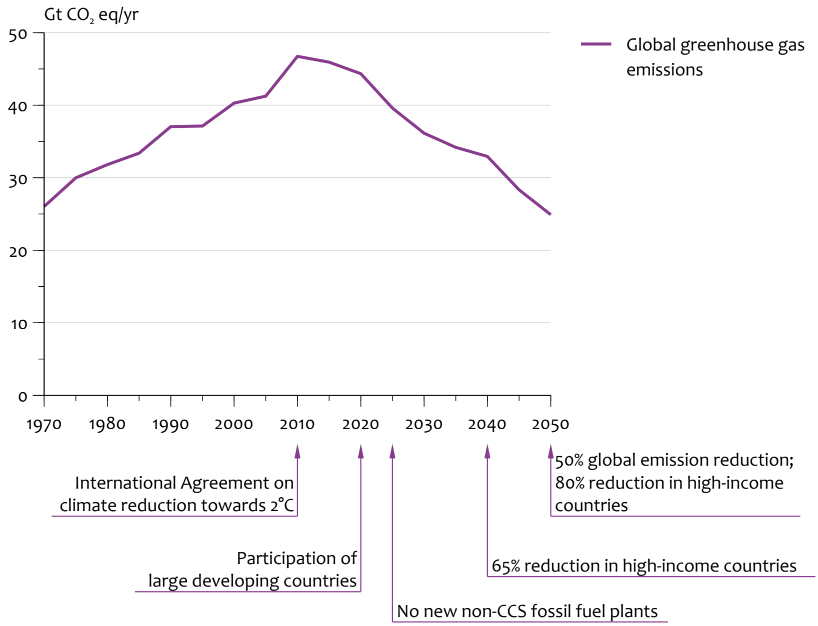
To a large degree, climate policy needs to be integrated into other policy areas, such as energy, transport, infrastructure development, spatial planning, and agriculture. In this context, it should be noted that some of the current subsidies on the use and production of energy frustrate climate policy (see *Chapter 5*).

Investing in clean technology development and deployment offers opportunity for a lock-in with a low-carbon energy system

Given the long lifetimes of capacity in the energy system, decisions today will have considerable impact for decades to come. Investment decisions taken over the next decade, thus, will too some degree determine the CO_2 emissions for the next 40 to 50 years (IEA, 2008). An important reason is formed by the long lifetimes of energy technologies, which determine their turnover rate. For example, a car's lifespan is around 15 years, but industrial facilities and power plants that are built today are likely to be still running in 2050. In the building sector, lifetimes could even be longer (realizing that there is some scope for retrofit).

Global pathway towards Challenge scenario

Figure 3.10



Possible pathway for targets and decisions that are needed to reach a low-carbon energy system by 2050.

Without agreement on long-term goals, no clear signals are provided on where emissions should be heading for. But at the same time, if one wants to achieve targets for 2050 it will be require to identify what needs to happen when in order to meet such a target. A strategy therefore needs to be long-term. Strategies need to identify the costs-and-benefits of the timing of taking measures, but even more so determine whether there are points of no return, that should not be crossed in order to bring targets out-of-reach. *Figure 3.10* indicates some elements of timing towards a 2050 50% reduction target. In the power sector, regulation could help to make sure that a clear target is set for phase-out of non-CCS fossil-fuel plants. Such regulation would need to include minimum requirements for the technical installations and – directly or indirectly – a phase-out calendar for the construction of fossil-fuel based electricity plants without CCS.

Infrastructure development and adjustment is crucial to enable the incorporation of large-scale renewable production capacity

Large-scale penetration of renewable energy sources requires a differently structured high- voltage power grid. A very important issue is a high degree of interconnection to cope with intermittency and exploit the cheapest potentials. High-voltage direct current (HVDC) power lines are often considered necessary for connecting large-scale sustainable energy production, and a prerequisite for connecting different, non-synchronous power systems (super grid). In Europe and other regions with developed power grids, considerable investments would be required, in the coming decades, to update the grids in order to facilitate large shares of power from renewable sources.

At the same time, the incorporation of local domestic power production in the wider energy system would requires the integration of energy and information flows, often referred to as smart grids. Smart grids essentially enable the organisation of a real-time balance between supply and demand, generally, in a system with distributed power production. The development of smart grids would require tackling a number of institutional barriers, including agreement on standards, pricing and regulating systems (Faber and Ros, 2009). A robust investment option would be one that makes sure that current grids are further developed, in terms of ability to transfer power across long-distances, while increasing flexibility.

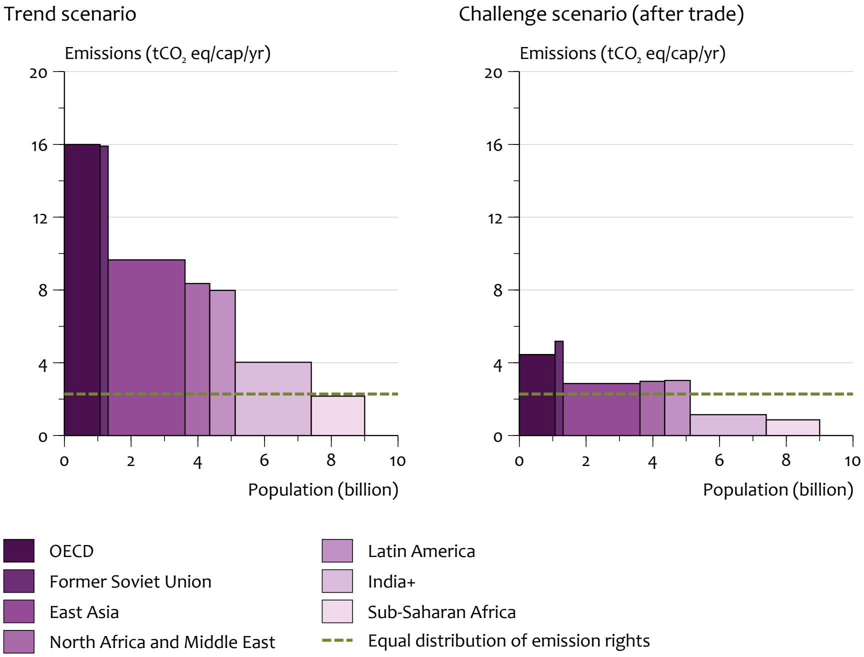
International cooperation is essential to achieve the 2 °C target

The 2 °C target will not be achievable without meaningful participation of large emerging economies, such as those of Brazil, China and India, in the next one to two decades. Still, the role of the various regions could be different, as was acknowledged as 'common, but differentiated commitments' in the Climate Change framework convention (UNFCCC, 1992). These different roles would reflect differences in the development agenda, mitigation capability and historic responsibility. Still, the large absolute contribution from several large low-income countries does not permit them to withhold their cooperation in taking up the climate change challenge. Moreover, aggregate financial consequences are lower and effective reduction levels are higher under more extensive global coalitions (Hof *et al*., 2009; Clarke *et al*., 2009; Van Vliet *et al*., 2009).

Different proposals are still being discussed on how to derive regional emission reduction targets (before trade). In negotiations, it is important that there is a common interest in reaching a 50% emission reduction, worldwide, most cost-effectively. For illustrative purposes, *Figure 3.11* shows the emissions in 2050, assuming a situation wherein all burden-sharing is based on a convergence of per-capita emissions. In such a case, the emission reduction target for high-income regions would be 80 to 90% by 2050, while emission reductions for low-income regions would be around substantially less (*Figure 3.11*). Such agreements would, for many regions, lead to comparable cost levels. Den Elzen *et al.* (2008) evaluated a large number of different proposals, and found the numbers quoted above as being more or less representative.

A system with binding targets which allows flexible mechanisms (taking credit for emission reduction elsewhere or on a different point in time) is likely to be one of the most effective means of achieving ambitious climate targets, certainly in the long term. It would achieve reduction at the lowest costs, but within the boundaries of some form of obligation. It is, however, not easy to strike a deal that would be considered fair enough to encourage participation of all countries, specifically, due to the large differences in their historic and present contributions to the problem, their current levels of economic development, their expected emission trends, and regional impacts of climate change. Moreover, as low stabilisation targets can only be achieved under successful international climate policy, negotia-

Global greenhouse gas emissions, 2050 Figure 3.11



Per-capita emissions in 2040, and emission caps based on equal per-capita distribution on an emissions convergence path to 2050 (reaching 2 °C target). Analyses: TIMER/FAIR

tions are complicated and suffer from free-riders. Agreement on fair burden-sharing rules is also being complicated by different perceptions of fairness among countries (Den Elzen *et al*., 2008). In the long run, fairness principles could be based on factors of responsibility, and capability to reduce emissions and costs. It would be hard to imagine that, ultimately, allocation of commitments would not increasingly consider an approach of per-capita convergence.

Carbon markets can be an important means for achieving ambitious goals at the lowest costs

It should be noted that allocation of reduction targets can be very different from the actual emission reductions per region. The flexibility instruments introduced in international climate policy, specifically emission trading, at least in theory, allow taking action wherever this is most cost-effective. This provides an argument for broadening participation, as it would reduce costs globally, while financial instruments would still allow emission reductions in low-income countries to be partly financed by high-income countries. In Chapter 5 we compare different financial instruments (i.e. carbon tax and cap-and-trade) – indicating the strengths and weaknesses of both approaches. The emergence of a global carbon market (cap-and-trade) depends on well-governed markets and transparent monitoring systems. Over time, regional carbon markets could enlarge and eventually be

Table 3.3 Interaction between measures to promote sustainable energy supply

	Effect on climate change	Effect on air pollution	Effect on security of energy supply	Effect on access to clean energy services
Climate change		Often positive, for example, less use of fossil fuels due to energy saving and renewable energy sources. Exceptions - some local biomass applications (NO_x and emissions of particulate matter)	Often positive (especially with a stringent climate policy) - energy savings, renewable energy, for biomass only by diversifying sources; negative - switching to gas, reduction in coal use (without carbon capture and storage)	The energy system could become more expensive; restrictive effect on electrification based on fossil fuels
Air pollution	Often little effect, because of many 'end of pipe' measures; sometimes positive, but can also be negative, such as decrease in aerosols, diminishing the regional cooling effect that partially counteracts global warming		Often little effect; limited negative effect, as a result of less use of coal and more of gas	Restrictive for electrification on the basis of fossil fuels
Security of supply	Negative - use of coal and exploitation of unconventional oil and gas sources; positive - biomass	Possibly negative - use of coal, less use of clean fossil fuels; positive - renewable energy		Slight
Access to clean energy services	Limited negative - electrification based on fossil fuels; neutral/positive if based on renewable energy	Positive, if renewable energy is used to replace traditional biomass; negative, if based on fossil fuels	Negative, if based on fossil fuels; positive, if based on local energy sources and renewable energy	

coupled with carbon markets in other regions, possibly supported by agreements on application of different technologies and sectoral targets.

3.5 Co-benefits and trade-offs: implications for energy security, air pollution and land use

Many technical measures in the energy sector have an effect on various other environmental themes. Synergetic relationships provide opportunities for harvesting co-benefits and for avoiding negative trade-offs between climate change measures and other environmental or social issues (*Table 3.3*). Especially measures such as energy efficiency, renewables, nuclear power, and, to some degree, CCS can have important synergies.

Climate policy can improve global security of energy supply through reduced oil dependency, although dependency on natural gas may increase

Without climate policy, under the *Trend* scenario oil production is expected to be concentrated further in the Middle East (while similar trends occur for natural gas). As climate policy is expected to lead to lower oil use, for net energy importing regions, such as the United States, Western Europe, India and China, it will lead to a reduction in oil imports and thus improve energy security. In contrast, global natural gas trade may, in fact, increase under a climate policy regime, as it is a relatively clean alternative to coal. The net result would be that climate policy is likely to improve energy security in countries with low coal use and high oil consumption, but worsen energy security in countries with high coal use.

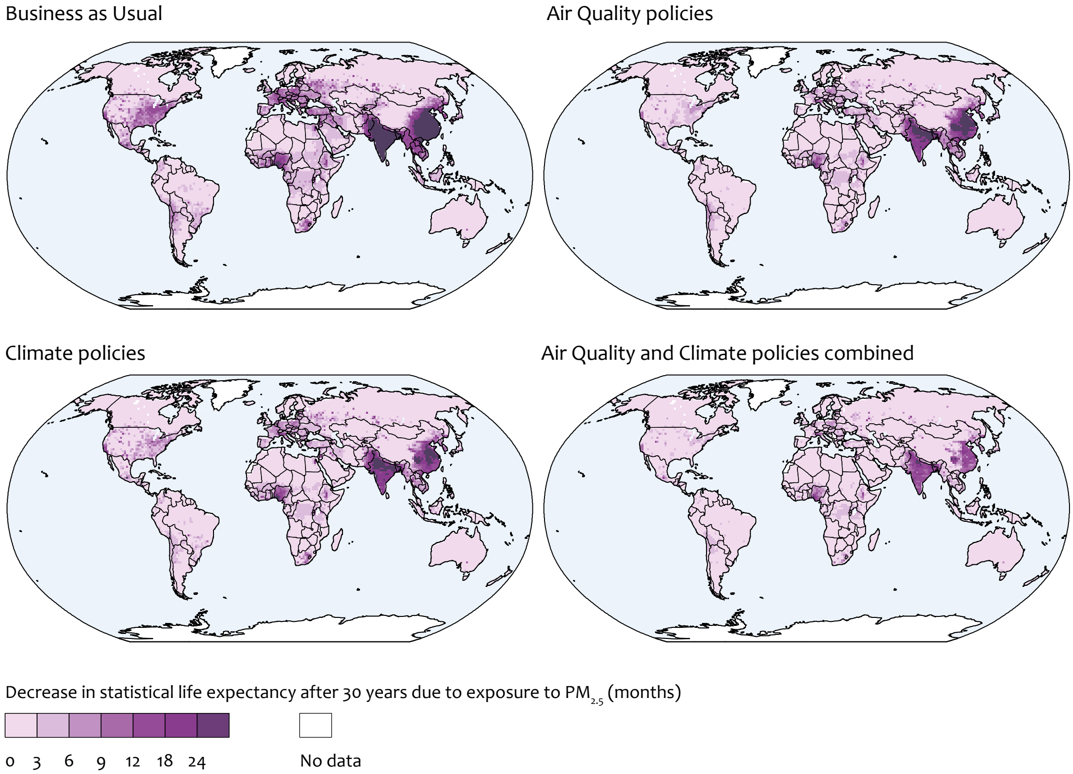
Climate policies can contribute significantly to the reduction of air pollution, specifically in low-income countries

Greenhouse gas emissions and emission of air pollutants, such as sulphur dioxide, nitrous oxides, and particulate matter, largely originate from the same activities. This implies that there could be important links between these two policy fields. Co-benefits of air quality and climate policies depend on the type of technologies that are introduced. In transport, for instance, introduction of hydrogen and electricity would reduce the emission of air pollutants to virtually zero. Use of bio-energy, however, would only have a limited effect on nitrous oxide and particulate matter emissions. In the power sector, most climate options reduce a range of emissions, but some important exceptions exist, such as carbon capture, which leads to an increase in nitrous oxide emissions as a result of efficiency loss, and the earlier mentioned bio-energy. Overall, however, the co-benefits of air quality and climate policies are significant. This is illustrated in *Figure 3.12* that shows the health impacts of particulate matter pollution under scenarios with air pollution and climate policy that are similar to the scenarios presented here. The combination is able to reduce health impacts much further than air pollution control alone, especially in South and East Asia.

These co-benefits could be important especially in low-income countries. Reducing local air pollution in these countries often has a much higher priority, from a health perspective, than reducing greenhouse gas emissions. The benefits from reduced

Climate policies can contribute significantly to the reduction of air pollution.

Figure 3.12 **Health impact of global climate and air quality policies for 2050**



Co-benefits of climate policy and air quality policy. Source: Van Dingenes and Dentener, 2009.

air pollution due to climate policy are felt mainly at the local level and in the short term, which would give them a higher priority for many developing countries.

The co-benefits of air quality and climate change are not harvested by default. The traditional way of reducing emissions of air pollutants by means of end-of-pipe measures hardly leads to co-benefits. There is, in fact, one important trade-off: sulphur-based aerosols have a cooling effect, therefore, reducing sulphur emissions is likely to lead to increased warming

Energy access is a crucial condition to improve human development indicators

Under the *Trend* scenario, a substantial part of the world population will still have no access to modern energy. Improved access to energy is a necessary condition for raising the standard of living for 1-2 billion people, especially in rural areas. Although there is no formal Millennium Development Goal (MDG) formulated for energy, it has been shown that other MDGs cannot be achieved without increasing access to modern energy (Modi et al, 2006). Use of traditional energy does not only limit economic prospects, but has a negative impact on human health (as traditional energy is associated with high emissions of particulate matter) and even climate change (so-called black carbon emissions are thought to be important for an additional increase of temperature in Asia).

Provision of electricity is of crucial importance to improve human development indicators for the poor. Globally such a number would be substantially lower. If emissions from traditional biomass and the influence of black carbon emissions are also accounted for, this policy would in fact reduce greenhouse gas emissions. Thus, to support development increasing access to electricity in the rural areas of low-income countries is necessary. Rural electrification levels are lowest in sub-saharan Africa, South-Asia and South-East Asia. Connecting a household to electricity for the first time costs and estimated USD 1000. Therefore, to connect the world's 1.6 billion people without access to electricity would cost about USD 400 billion, assuming on average about four people per household. To be effective, this kind of investment would have to be enhanced by providing a certain level of affordable energy for the poorest (Von Winterfeldt and Nakicenovic, 2009).

What does this imply for greenhouse gas emissions?

Presently, many people in developing countries only have access to traditional biomass such as wood and charcoal. This has considerable effects on local biodiversity, indoor air pollution and associated respiratory diseases. It also contributes to climate change by generating black carbon emissions and in case wood and charcoal are extracted in a non-renewable way. A switch of fuels to as well as an improvement of stoves with (much) higher efficiencies could contribute greatly to improve health, while also reducing pressure on land and with possibly even positive effect on climate change. A recent study looked into the question of what would be the impact of increasing access to modern energy in India. The calculations show that a shift in final energy use from fuel wood to oil and LPG in fact decrease total residential energy use as a result of the higher efficiency. As a result, there would be an increase of only 4% of Indian greenhouse gas emissions from providing full access to modern energy use (base level) by modern forms of energy. Globally, introducing modern energy to 325 million households worldwide, would lead to about 3 EJ/yr of additional LPG use (less than 1% of global energy consumption), but saves more than 17 EJ/yr of fuel wood. Such a fuel switch would require about USD 285 billion (mostly fuel cost). A switch to renewable energy (solar) sources rather than LPG is attractive for projects of power supply, but long term involvement and finance is required (PBL, 2009a).

Implication for land-use require a careful approach to bio-energy.

Bio-energy could be an important factor in climate policy, based on its relatively low costs and ease of implementation. In the *Challenge* scenario, bio-energy use in 2050 would be in the order of 100 EJ. Many studies on climate mitigation identified bioenergy as important to reduce greenhouse gas emissions and at the same an important economic chance to reduce poverty in developing countries. Also based on energy security considerations, policy-makers have in particular focussed on stimulating the use of biofuels in the transport sector. This overwhelming push for biofuels caused a scientific and political debate whether biofuels in practice are indeed a sustainable solution. Especially, the risk of biodiversity loss and the increase in food prices have dominated recent debates on biofuels, while the sustainability effects of so-called second generation biofuels (based on cellulosic material) is still largely uncertain (Eickhout *et al.*, 2008). In order to avoid negative impacts, it seems useful to be careful with setting ambitious bio-energy or biofuel targets. For second generation bio-energy, risks of negative biodiversity impacts or impacts on hunger seem to be much less severe. Still it would be important to monitor impacts and adjust policies accordingly.

3.6 Conclusions

The *Trend* scenario (picturing possible development if there is no major change in existing policies and measures) is likely to lead to an increase in average global temperature of 4 °C above pre-industrial levels, by the end of the century. This implies that the climate policy target of 2 °C (chosen as an interpretation of preventing non-dangerous climate change) would not be met. Such a degree of global warming is likely to lead to serious climate change. The scenario shows that greenhouse gas emissions will have more or less doubled, by 2050. Assuming that policymakers would like to limit the probability of overshooting the 2 °C target to less than 50%, or even 25%, emissions need would need to peak in about one to two decades, and be reduced by around 50% by the middle of the century. For achieving this, the energy production system should be very different from that under the *Trend* scenario. Moreover, all major developing countries, including China and Brazil, would have to participate in international climate policy, from 2020 onwards.

As shown in the *Challenge* scenario, a low-carbon economy could be achieved with currently identifiable technologies. The first steps would be to improve energy savings, increase use of renewable energy and carbon capture and storage, reduce deforestation, and reduce non-CO_2 emissions. An attractive route is based on a further electrification of energy use. In that sense, considerable investments in the power grid would be needed. In the transport sector, energy efficiency could reduce emissions, in the short term. In the long term, however, a dramatic shift towards electric (or hydrogen) vehicles is required.

Investments in the energy system (supply-side only) are estimated to be around 60,000 billion USD between 2000 and 2050 (i.e. around 1400 billion per year or 1.5% of GDP). Achieving the *Challenge* scenario could lead to a doubling of these costs. The macro-economic impacts of these costs are significantly smaller. However, economic and technical barriers are not the main obstacles to achieving the *Challenge* scenario. A shared sense of urgency and an international response is critically important. Given the need for reducing global emissions within one to two decades, emissions must be reduced substantially in both high- and low-income countries. The current proposals stated by OECD countries and low-income countries as part of the international climate policy negotiations clearly would not be enough to implement a 2 °C scenario. Significant delays in the negotiations would bring the 2 °C target out of reach.

4 Towards Efficient Land Use and Biodiversity Preservation

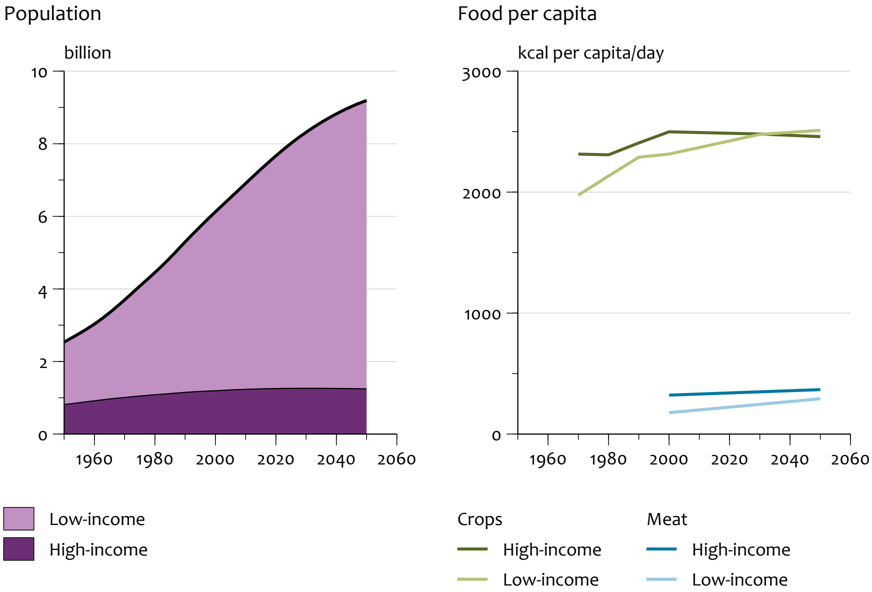
4.1 Where does business-as-usual take us?

Land is a crucial resource for life on earth, for both humans and natural systems

The human production of food, feed and fibres has increased significantly over the last centuries, requiring vast amounts of land. Today, the total agricultural area amounts to about 5 billion hectare, i.e. nearly 40% of the world's terrestrial surface area. The consequence of this trend is a loss of natural ecosystems. Yet, natural ecosystems play an important role in the provisioning of all kinds of ecosystem services (see *Chapter 2*), e.g. in balancing the earth's geochemical cycles. Trade-offs – at local and global level – between the production functions imposed on the land and the ecosystem services it can provide are becoming increasingly obvious. Managing these trade-offs is crucial for life on earth.

The land for production of food and feed has ben increasing over time leading to a loss of natural ecosystems.

Drivers of global food demand, Trend scenario **Figure 4.1**

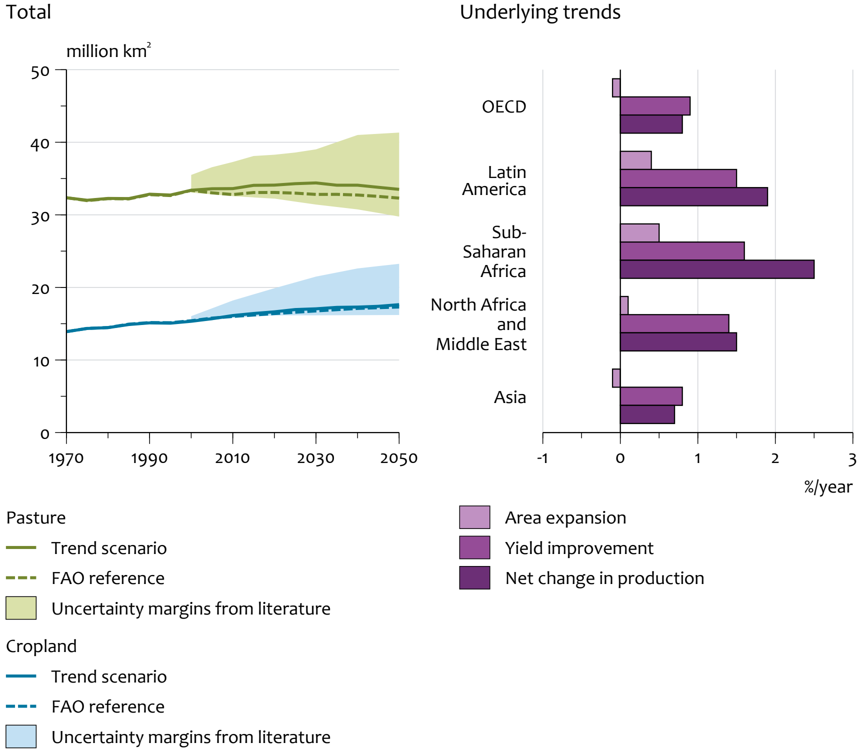


Source: UN (2006), FAO (2006), IAASTD (2008).

More people need more food

Driven by population growth and changes in diet, global food production is projected to increase. Projections without major policy changes show growth numbers of between 50 and 65%, compared to 2000, in the period up to 2030 and beyond (FAO, 2006; IAASTD, 2008; Van Vuuren *et al.*, 2008b). Consistent with the range in the literature, global food production increases steadily under the *Trend* scenario used to indicate the changes without new policies in this report (see *Figure 4.1*). The increase in production is somewhat slower than in the past, as a result of a slowdown in population growth. Diets are projected to become more meat intensive, with annual per-capita meat consumption increasing, on average, from 90 kg per person per year to over 100 kg between 2000 and 2050, in high-income countries, and from around 25 to nearly 45 kg per person per year, in low-income countries during the same period (*Figure 4.1*). This trend is relevant for land use, since animal products require much more land than crops. On average, the production of beef protein requires several times the amount of land than the production of vegetable proteins, such as cereals (MNP, 2008; Stehfest *et al.*, 2009). While meat currently represents only 15% of the total global human diet, approximately 80% of all the agricultural land is used for animal ranging or the production of feed and fodder for animals (FAO, 2006). It should be noted that this includes extensive grasslands in areas where other forms of agriculture are hardly feasible.

Figure 4.2 **Global land use, Trend scenario**



Land use for food and feed production. Source: FAO (2006), IAASTD (2008), Van Vuuren *et al.* (2008b).

Increased food demand is likely to lead to an increase in land use

Increased food production can be achieved through improvement of yields and by expansion of agricultural land. In the last decades, yield improvements have been the most important factor, but at the same time agricultural areas expanded by about 5% since 1970. Under the *Trend* scenario, this trend of improving yields, but even faster increase in food demand, is expected to continue (*Figure 4.2*) (IAASTD, 2008). About 70% of the production growth would come from yield increase, but cropland would still expand from 1.5 billion hectares today to more than 1.6 billion hectares, by 2050. This would be mostly due to a net expansion of cropland in Africa, Latin America and Southeast Asia. During the same period, there would also be some decrease in agricultural areas in temperate zones. In *Figure 4.2*, for comparison also the FAO outlook (FAO, 2006) has been added, showing very similar trends as the *Trend* scenario.

For grassland areas, projections are somewhat different. The increase in meat consumption is expected to lead to a significant increase in the number of animals. Whether this leads to an expansion of grass area, however, depends on the rate of transition between different types of production systems. Worldwide, there is a gradual shift from very extensive animal husbandry to more intensive forms of animal keeping. This trend mitigates the expansion of pasture areas, but inserts negative trade-offs, such as increasing use of nutrients and pesticides. Under the *Trend* scenario, some net expansion of pasture areas still occurs, but it levels off soon after 2025, consistent with the projections found in literature. Again, the trends are comparable to the IMAGE model implementation (see *Chapter 2*) of the FAO outlook (2006). For agricultural land in total, this implies a further expansion in area, with available productive land becoming more-and-more constraining.

Most of these projections account only in a limited way for the impacts of climate change on agriculture. In case climate impacts turn out to be severe, this could lead significant losses in yield – increasing the amount of land that would be needed (See *Text Box 4.1*).

Production of bio-energy is expected to increase

Another potentially large demand for agricultural areas, in the future, is the large-scale production of biofuels. In the short term, relatively moderate biofuel targets, such as proposed in the EU and United States, are expected to lead to considerable land use. The EU's 10% biofuel target, for instance, would require 0.2 to 0.3 million km^2 of land (Eickhout *et al*., 2008). Many scenarios with ambitious climate change mitigation policies project a strong increase in bio-energy consumption. For 2050, numbers vary over a range from rather modest numbers (e.g. 20 EJ) to around 100 EJ and even 400 EJ, annually (Van Vuuren *et al.*, 2009c). The impact in terms of land required for production obviously varies in a similar way. The exact consequences depend not only on the consumption level itself, but also on the type of crops used, the yields, and the efficiency of the conversion processes. In general, it is expected that so-called second-generation biofuels (that is, fuels based on woody or grass crops, and/or residues) require less land per unit of energy produced and can be produced on other areas than currently used for food crops, which helps to reduce impact on food prices, but not necessarily on biodiversity losses. A similar argument holds for use of woody bio-energy for electricity production. Under the *Trend* scenario, a modest expansion of the global area used for bio-energy of up to 2 million km^2 is assumed for 2050, which would account for around 10 to 15% of the total crop area. It should, however, be noted that projections for 2050 range widely. Fisher (2009), for instance, provided numbers of less than 0.6 million km^2. Finally, at this moment around 40 EJ of total energy supply comes from traditional bio-energy (e.g. fuel wood, charcoal and dung). Also the consumption of these energy sources does provide a substantial pressure on local biodiversity. Providing access to modern energy sources is also important for health reasons (see also *Chapter 3*).

Biodiversity loss continues under the *Trend* scenario, and therefore this scenario would not achieve the target for biodiversity proposed in Chapter 2

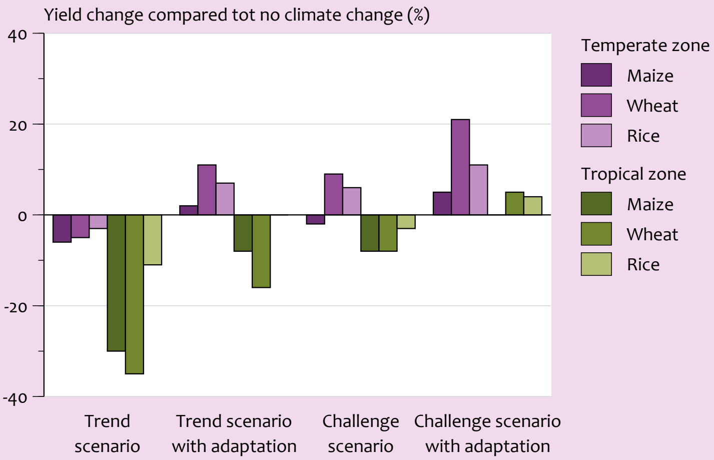
Important drivers of biodiversity loss include loss of habitat due to agricultural expansion, climate change, nitrogen deposition, infrastructure expansion, fragmentation, introduction of alien species and timber production. Expansion of agricultural areas has been the most important driver of biodiversity loss, as the conversion of natural habitats to cropland and other uses typically entails the replacement of systems rich in biodiversity with monocultures or other systems poor in biodi-

Text Box 4.1 Agriculture and climate change

Agriculture is not only a key contributor to greenhouse gas emissions, but also a sector that could be severely impacted by climate change. The IPCC estimated the potential global impacts of climate change on maize, wheat and rice production, by synthesising a large amount of research on the impacts on crops. These results can be used to estimate the potential global impacts of climate change, under scenarios with and without adaptation and mitigation policies (Figure 4.3). Climate impacts on yields were reported for low latitudes regions (tropics) and mid to high latitudes regions (temperate zones) (Easterling et al. ,2007).

Although the results are highly uncertain, some preliminary conclusions can be drawn from this figure. First, if no adaptation is account for the Trend scenario, with high climate change, would causes a very substantial negative climate impact on yields of 10 to 35%, for all crops at all latitudes (the numbers presented here are compared to the situation in which climate change is not accounted). It should be noted that the Figure reports impacts for very aggregated regions – hiding that impacts in underlying countries and regions are more diverse and can in fact be positive. Second, engaging in either mitigation or adaptation alone, would limit the decrease in yields and, in some cases, may enable an increase, but this would not be enough in the tropics (still experiencing a reduction in yields of around 10%). Only under the Challenge scenario, based on a combination of mitigation and adaptation, negative impacts would be avoided, which could even result in an improvement from the situation without climate change.

Figure 4.3 **Sensitivity yield change to climate change**



Source: Easterling *et al.* (2007).

versity (MA, 2005). In fact, agriculture does also contribute to biodiversity loss via other factors than area expansion (*Text Box 4.2*). The overall loss of biodiversity, estimated in terms of the mean-species-abundance (MSA), is about 25% since 1700, (*Figure 4.5*). Alkemade *et al.* (2009) estimated agricultural expansion to contribute to about half this total value.

The increase in agricultural areas under the *Trend* scenario is projected to lead to a further loss of biodiversity. Moreover, other factors, such as climate change and infrastructure expansion are expected to increasingly contribute to biodiversity loss. As a result, the contribution from agricultural expansion is estimated to decline to between 20 and 25% of the total – with infrastructure expansion and climate change taking playing a similar role (Alkemade *et al*., 2009). It should be noted that trends in loss of biodiversity are not equally distributed across the world. The trend in *Figure 4.5* combines an increase in (regrowing) natural areas in temperate zones with a decrease in forest areas in the tropics.

The MSA biodiversity indicator measures the current state of ecosystems relatively to the natural state (given equal value to each ecosystem). The indicator has been used in several international assessments. Van Vuuren *et al*. (2007b) show that under a similar scenario a considerable share of terrestrial vascular plants could be threatened with extinction.

The regulating and supporting ecosystem services associated with natural area are slowly replaced by production services for human needs

Ecosystem services can be divided into regulating, supporting, production and cultural services. The loss of natural areas, as depicted under the *Trend* scenario, implies that the regulating and supporting ecosystem services associated with natural areas (such as regulation of the carbon and nitrogen cycles, flood control, water management, resilience to disturbances in human-dominated ecosystems, and support of soil fertility) are decreasing, due to the increasing pressure from systems that produce services for human needs (most notably food production).

The Millennium Development Goal for reducing hunger is not met

As was indicated in Chapter 2, the environmental goals that are the main focus of this report need to be evaluated simultaneously with the goal of achieving a more

Text Box 4.2 Agricultural and environmental pressures other than land use change

Agricultural pressure on ecosystems goes beyond mere land-use competition. Other environmental pressures include the disturbance of the nitrogen and phosphorous cycles through use of fertilisers, manure, water and pesticides. The presence of excess nutrients (N, P) in water can lead to eutrophication (Bennett et al., 2001; Galloway and Cowling, 2002), ground water pollution and air pollution. The agricultural sector also contributes to climate change, with methane and nitrous oxide emissions; as well as with CO_2 emissions, particularly in case of deforestation.

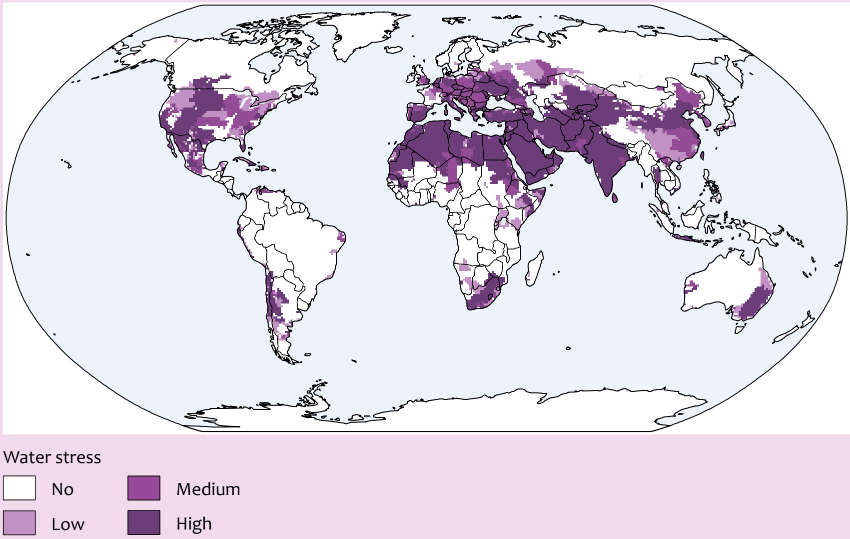
Text Box 4.3 Water is scarce and needs careful management, especially in vulnerable areas

Although the earth holds large amounts of water, only around 2.5% of it is fresh water and two thirds of that is trapped in glaciers and ice caps. As fresh water is devided around the world unequally, it is in scarce supply in many locations. Agriculture is responsible for around 70% of water use worldwide. The growing world population carries a growing demand for food, water and energy. Even without the effects of climate change, obtaining adequate, clean drinking water is a major challenge in many parts of the world. Projections show water stress, i.e. an unfavourable ratio between water supply and demand, to become worse in several regions (see Figure 4.4).

Climate change causes changes in the hydrologic cycle and in several regions, reduced precipitation will add to existing water scarcity. Especially parts of Africa and Asia are vulnerable, such as already arid regions of the Sahel. Water scarcity can also occur outside Africa and Asia, for instance, in the Mediterranean and the Western USA. Increasing drought caused by climate change means increased risk to the economy and to poverty alleviation.

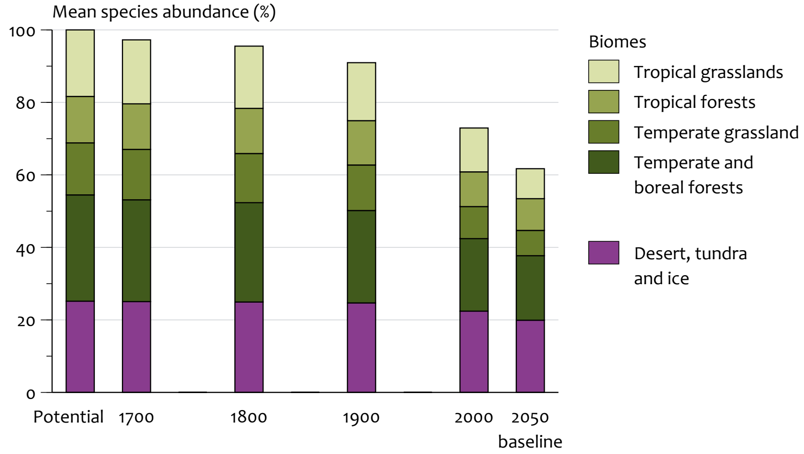
As water becomes more scarce, it becomes increasingly difficult to reach a balance in the needs for water between humans, agriculture and nature. This balancing act takes place particularly at regional and local levels, but, through global food chains, developed countries also contribute to water scarcity around local food production in developing countries.

Figure 4.4 **Water stress, 2030 baseline**



Water stress in 2030 in the major river basins Source Bakkes et al., 2008.

Global biodiversity — Figure 4.5



Historic and future development of original biodiversity. Source: Bakkes *et al*. (2008).

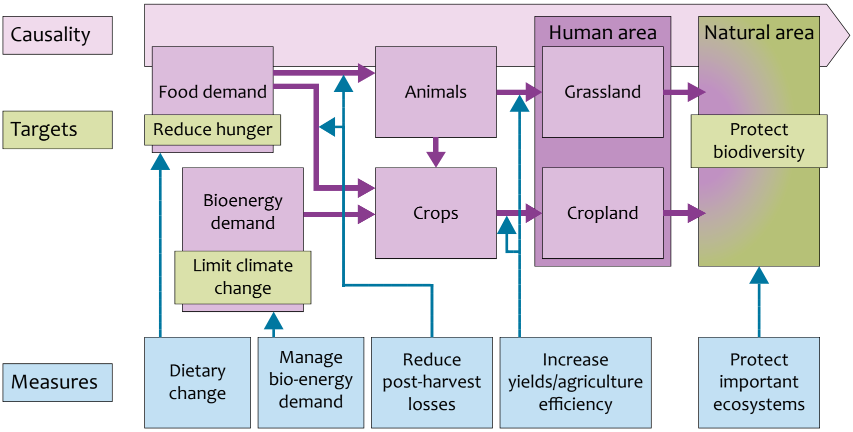
sustainable development, worldwide, among other things by reducing absolute poverty. Currently, almost one billion people are living in hunger (Nellemann *et al.*, 2009). While policy goals (Millennium Development Goals) aim to half the number of people suffering from hunger by 2015, this target will not be met under current policies in the target year, nor in the decades to come (PBL, 2009a). It is important to note that food security is not an issue of food production, but rather relates to poverty, distribution of food, post-harvest losses, food prices and access to markets (Nellemann *et al.*, 2009). However, increasing land scarcity plays a critical role in securing both food production and food prices. While food prices were historically low at the beginning of this century, they spiked in 2008, just before the economic recession, and are (on average) expected to remain above 2000 levels, in the next decades (OECD-FAO, 2008; IAASTD, 2008).

4.2 What is needed to stop biodiversity loss?

Chapter 2 presented the ambition to halt biodiversity loss from around 2020 onwards and to preserve around 50% of the world's natural areas to protect global biodiversity in the long term. There are different important measures that could be taken to achieve this (*Figure 4.6*):

- Protect valuable ecosystems and their goods and services;
- Increase agricultural yields;
- Reduce post-harvest losses;
- Promote dietary change, away from animal products;
- Manage bio-energy demand.

Figure 4.6 **Causality, targets and measures of biodiversity protection**



Causality, Targets and measures of biodiversity protection

Also slowing down population growth could contribute to a lower pressure on land, as discussed in Chapter 2. Management of bio-energy demand is elaborated in Chapter 5, where it integrates strategies for tackling both the energy system challenge and the reduction of land use required to meet bio-energy demand. The other options are discussed below, including some of the implications of trends in the agricultural system for reducing hunger.

4.3 Towards a strategy for reducing biodiversity loss

4.3.1 Protection of valuable ecosystems

Formulation of international biodiversity strategy needed

One way to preserve biodiversity is by direct conservation of valuable ecosystems. Presently, about 108,000 official protected areas in the world cover about 12 per cent of the total land mass (Dowie, 2009). While it is clear that a conservation strategy by itself would be insufficient, it can constitute an important element within a larger strategy, by providing guidance and vision.

At the global scale, the Convention on Biological Diversity (CBD) provides context for a biodiversity conservation strategy. So far, policymakers have had little success in translating the aims of the Convention into a concrete set of long-term and short-term targets, with the exception of the 2010 target to slow down the rate of biodiversity loss. An issue is that countries are sometimes reluctant to accept interference in the decisions they make about land use. Another factor is that among policymakers and scientists, there are different visions on which conservation strategies would work best and what would be the most important ecosystems to preserve. Scientists have made different proposals for areas that should be protected based for instance on areas with a high biodiversity value (e.g. hotspots), the provision of ecological goods and services, wilderness area or even vulnerability (see also *Chapter 2*).

However, there also seems to be consensus on some key regions that should be protected, such as the Cape Floral Region, and part of the rain forest regions. It seems that a consensus could be reached on protected areas. The Natura 2000 programme in Europe could serve as a good example here. Creating such a strategy would require taking some bold steps in dealing with uncertainty and finding consensus on important conservation areas. A key condition in any protection strategy would be to have a clear definition of property rights, as well as credible involvement of local populations.

Protect biodiversity outside conservation areas

There is no clear-cut difference between the value of biodiversity inside and outside conservation areas. In fact, research has shown that very little nature exists that is not intertwined with the surrounding human context. It may therefore be useful to accept that humans have fundamentally altered form, process, and biodiversity of most ecosystems. Much of the world's land mass can be classified in terms of a continuum based on the level of human impact going from urban settlements to populated forests and ultimately real wilderness (Ellis and Ramankutty, 2008; Ellis *et al*., 2009). In this perspective, nature reserves are not to be seen as pristine islands, but as ecosystems that interact heavily with human and natural surroundings. This perspective argues to involve local populations in conservation programmes, using possible contributions to local economies (Wittemyer *et al.*, 2008).

The quality of biodiversity inside and outside conservation areas is heavily influenced by external factors, for example, air pollution and climate change. This is another reason why, in addition to establishing protection areas, it would be just as important to develop strategies for the areas outside conservation areas. This not only includes natural areas, but also the biodiversity in agricultural areas (so-called agro-ecosystems). Especially low-intensity agricultural areas can still be important for their contribution to biodiversity. Protection of this biodiversity would imply that a clear strategy is made for prime areas for agricultural intensification (thus with a low-biodiversity value) vis-à-vis areas where protecting biodiversity represents another function (in addition to the food production function).

An international strategy should include agreements on financial compensation.

At the local level, a greatly improved framework of property rights is a key issue in ensuring the protection of areas that would otherwise be strongly affected by the 'tragedy of the commons'. Unclear property rights and legal enforcements often generate perverse effects, in terms of inappropriate management of land, including slash-and-burn activities and urban sprawl (Nelleman *et al*., 2009). Such legal systems would require updates that take efficient land use into much better account. At the international level, the agreements on carbon storage in the Kyoto Protocol could possibly be adapted as an instrument to ensure biodiversity protection by preventing deforestation and improving forest management (PBL, 2008).

A payment system for ecosystem services and international compensation mechanisms might be used, to provide a long lasting incentive for protection. Ideas for this are inspired by similar instruments in the protection against climate change and forest loss (financial support in 'reducing deforestation and degradation' (REDD)). In fact, the establishment of an international biodiversity strategy might allow for a part combination of the two policy goals, and provide additional credits for REDD use within biodiversity conservation areas. Compared to other climate measures, REDD is in general relatively cheap. For vast areas, avoiding deforestation costs may be in the order of 20 USD/ton CO_2 (Kindermann *et al.*, 2008)

There are, however, many practical limitations to such a scheme, for instance, that of how to weight different forms of biodiversity. The costs of protecting biodiversity differ greatly, with reported costs of tens and hundreds of euros per hectare per year. Studies have tried to value also the ecosystem services, resulting in different values, as well. A recent study for the Amazon forest found different services being valued at between 200 and 400 USD/ha per year. This compares to the returns on beef and soy, the main Amazonian products imported by Europe. Soy generates profits of 230 to 470 USD/ha, annually, and for cattle breeding this is 40 to 115 USD/ha (Verweij *et al*., 2009). Globally the value of biodiversity loss in the 2000-2050 period is estimated at 7% of world GDP (TEEB, 2008), but such values are highly contested.

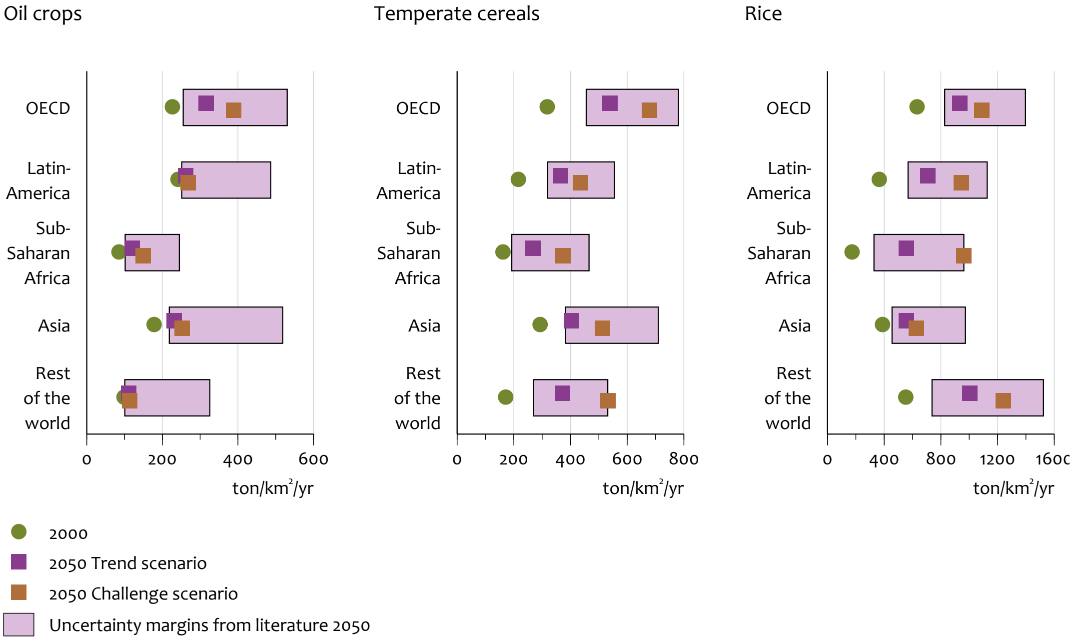
4.3.2 Agricultural yield increases

Increase agricultural yields where possible

Increasing agricultural production is a key factor in bridging the conflict between food supply goals and biodiversity goals. Since 1970, agricultural yields have been increasing by about 1% per year. The current yield levels, however, are not equally distributed across the world (*Figure 4.7)*. Relatively high yields have been achieved in many high-income countries and in Asia and parts of South America. In other areas of the world, yields are often considerably lower. The difference between potential yields (i.e. based on biophysical factors alone) and actual yields is referred to as the yield gap. Reasons for large yield gaps in, for example, Sub-Saharan Africa, are due to factors like lower agricultural inputs, less use of technology and inappropriate management practices. These factors, on their turn, are often caused by social and institutional barriers, such as lack of good governance, lack of co-ordination between different stakeholders, poor access to credit and markets, and other market failures (often at the local level) implying that agricultural technologies and management are not fully used. Obviously, also potential yields differ between regions.

In order to limit the expansion of agricultural areas, the increase in food demand (described earlier) needs to be balanced by strong increases in yields. Unfortunately, the growth rates of crop yields (especially for cereals) have been falling since the so-called "green revolution". However, even to make sure than land expansion does not go beyond the *Trend* scenario (as depicted in *Figure 4.2*) the realisation of considerable yield improvements would be necessary. Crucial questions are whether yields in developing countries can be increased – and secondly, whether in general yield increases are reaching some kind of plateau, or whether there are still sources for further improvement, either on the shelf or in the research pipeline (Fisher, 2009).

Regional yields **Figure 4.7**

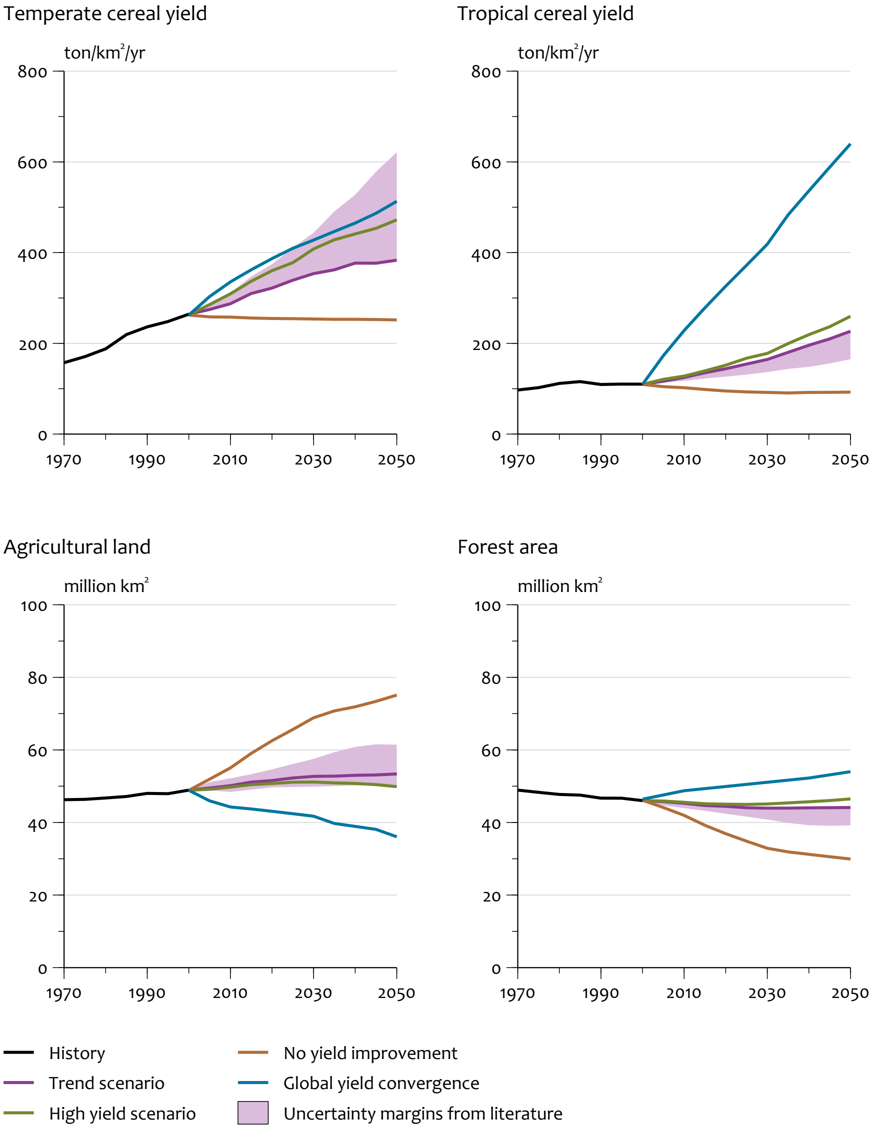


Source: IAASTD (2008), various assessments.

To illustrate the importance of agricultural productivity increase, we used two hypothetical scenarios: 1) yields remain constant from 2010 onwards, and 2) the so-called yield gap in low-income countries is closed completely until 2050. These scenarios are shown in *Figure 4.7* as the situation of no improvement, versus that of yield convergence. In the first scenario, a very large part of available productive land will have to be brought into cultivation by 2050. Cultivated land area will need to increase by nearly 36% by 2050, compared to 2010 (*Figure 4.8*). The consequence is a dramatic loss of biodiversity, including a 25% reduction in forest cover – with the loss mostly being in tropical countries. The second hypothetical case, in which the current yield gap is closed completely, forms a sharp contrast. Here, 19% of the global agricultural area can be taken out of production by 2050, compared to 2010, thus releasing land for other purposes. The result for biodiversity is expressed in forest area surface, which gains nearly 20%. The analysis shows that outcomes for global land use are very sensitive for yield assumptions – and that high yields can prevent an extension of agricultural area.

A key question is what yield improvements can be achieved realistically. There are substantially different views on this. It is clear however, that the main challenge is not a lack of technologies to realise the yield improvements. For example, Fisher *et al*. (2009) reviewed existing information on the potential to improve cereal yields drastically, finding that there is ample scope for improvement. They emphasize the large economically exploitable yield gaps that exist at many places, the improved

Figure 4.8 **Yields and associated land use**



Source: IAASTD (2008), various assessments

technologies on the shelf, the improving policy context in some developing countries and the gains made by breeders in improving theoretical yields (including application of genetic modification). The FAO identified the following ways for reducing yield gaps (FAO, 2004):

- extension of improved land-use practices to small-holder farmers, including integrated crop management

- using new techniques, including genetically modified organisms (GMOs),
- reducing harvest losses,
- turning the outcome of agricultural research into practical methods for farmers,
- providing efficient government support and infrastructure that promotes access to markets (FAO, 2004).

Useful technologies for agricultural production improvements in low-income countries are already available. The key challenge is to ensure the relevance and appropriate use of these technologies, which requires investments in enabling conditions, including infrastructures, such as roads, irrigation systems, water supply, and ICT, as well as in capacity building through knowledge transfer and education. Policies for ensuring the use of technology would also need to improve the access to markets. Better connections (both physically and through communication) between producers and the market, would provide price incentives to farmers. Access to markets also increases the possibility to purchase inputs and may provide incentives to intensify production. The impact of trade-liberalisation is more controversial (see *Text Box 4.4*). All-in-all, the different options discussed above should not be seen as a menu: they should be used as an integrated package in order to avoid the weakest link determining the final outcome.

Next to education of farmers, (public) investments in R&D are also crucial for development of technologies to close the yield gap and to increase potential yields. The International Assessment of Agricultural Science and Technology Development (IAASTD, 2008) estimated that a more aggressive policy to support agricultural R&D and agricultural knowledge extension programmes may lead to a 40% increase in the yield improvement rate. In combination with supporting policies to improve irrigation, drinking-water supply and education, it may be possible to increase the yield improvement rate by 60%. As the yield improvements induced by these invest-

Textbox 4.4 Liberalisation of agricultural trade is likely to lead to more use of land, in the short term

There are widely diverging views on the importance of agricultural trade liberalisation. Some studies emphasise the importance of trade liberalisation, as, through connecting markets, it would provide additional income for many countries, reduce food prices and lead to more efficient use of resources. However, other studies emphasise that, in the short term, trade liberalisation could have negative impacts on small farmers in developing countries, who would suffer even more from cheap food imports (partly depending on the strategy of high-income countries. Most studies agree that trade liberalisation will in the short term, at the global scale, lead to more land use. As production would increase in low-income countries, the lower land costs than those in high income countries would imply that more land would be taken into production. This would lead to further biodiversity loss, also because the biodiversity gains in areas with reduced agricultural production would be small. Countervailing policies are thus required to ensure that further liberalisation of world trade would not be at the expense of nature areas and biodiversity.

ments also lead to lower food prices than the *Trend* scenario, the study expects an increase in food demand.

The scenario with these yield improvements diverges in important ways from the *Trend* scenario (*Figure 4.7*). The global agricultural area decreases rather than increases, while the opposite trend is noted for forest areas. The scenario shows that it is possible to reverse the centuries-long decline of forest areas. Simultaneously, it does make food more affordable for the poor, which leads to an accelerated decline in the number of malnourished children in developing countries.

It should be noted that there are also important reasons to be cautious with optimism regarding further yield improvement. First of all, climate change may, in the long run, have net negative impacts on yields, if not countered by mitigation policies. Secondly, some of the yield improvements in the past have been based on using unrenewable resources, especially with respect to energy, fertiliser and ground water. These resources are expected to become more scarce. This implies that focus should also be on improving resource efficiency.

Intensification is useful in some areas – low-input agriculture is more appropriate in others

The above scenarios provide a rather optimistic view. However, it is important to note that intensification comes at a price: it generally requires more inputs, such as fertilisers and water. The adoption of integrated crop management by farmers could mitigate some of these impacts by adapting management to the given natural conditions and to use ecosystem services (such as N provision, management of green water, or functional agro-biodiversity). However, existing agricultural areas and their surroundings have a biodiversity value. When these areas become more productive (are intensified), biodiversity may be threatened. A strategy for sustainable yield increase, therefore, would identify where intensification is possible without severe negative environmental impacts, and where a more extensive form land use is preferable. This should include considering the side-effects of intensified agriculture (water and soil pollution). Also, technologies can be developed and used that at a local scale can combine the ambition of biodiversity protection and agricultural production functions.

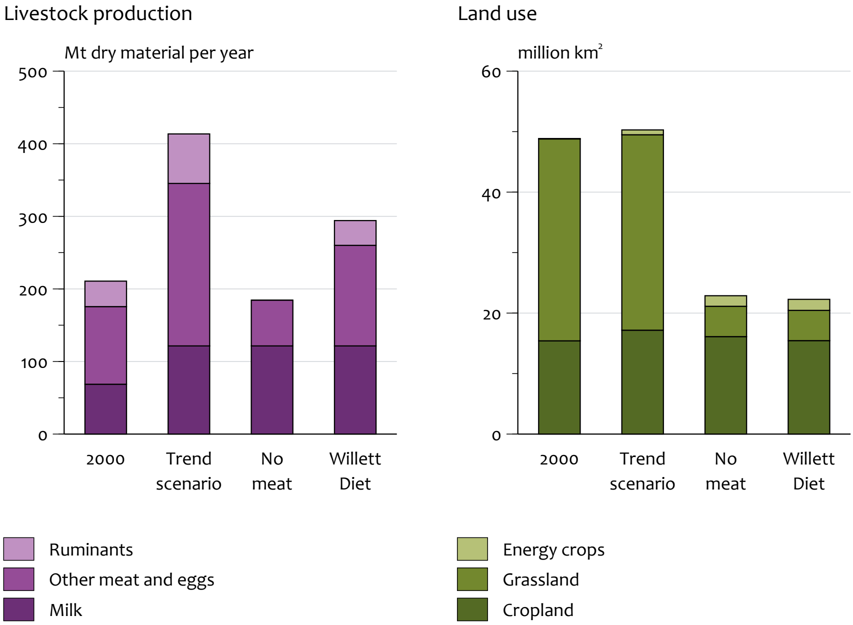
4.3.3 Dietary change to low meat consumption

Shifting towards a low-meat diet can decrease the global agricultural area

Meat production currently uses 80% of the agricultural land, but accounts only for 15% of caloric intake. The most land intensive form of meat production is that for beef. Reduced meat (or specifically beef) consumption can contribute substantially to decreasing land use pressure. In order to illustrate the potential impact of reduced meat consumption, Stehfest *et al.* (2009) evaluated the consequences of an illustrative case in which meat consumption was replaced by a vegetarian diet based on crops (using pulses and soy to replace protein intake). In such a case, agricultural land use was reduced by more than 50% (mostly grasslands).

Studies also show that in current diets in rich countries, red meat consumption is in fact too high for health reasons. Based on this, Stehfest *et al.* (2009) looked at a

Global livestock production and land use, 2050 — Figure 4.9

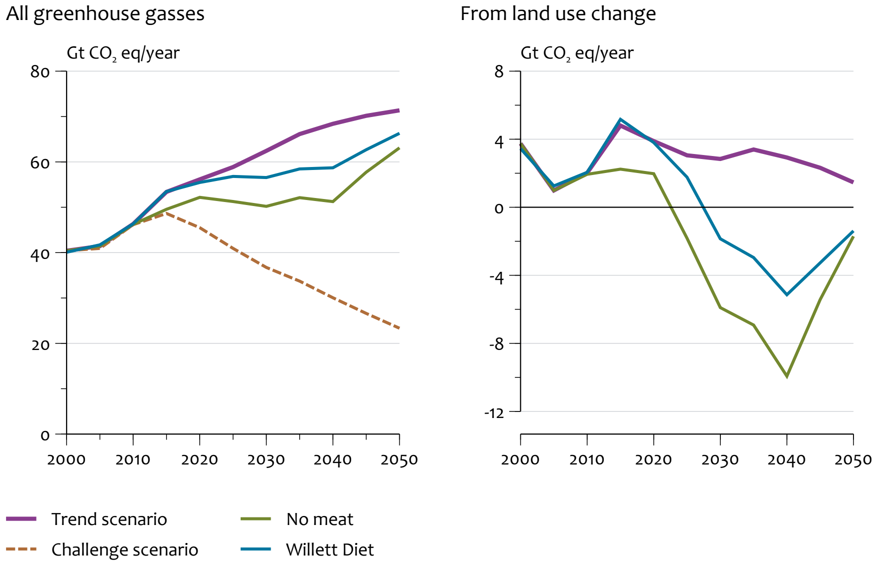


Source: Stehfest *et al.* (2009).

second illustrative case, implementing a healthy diet worldwide (in fact leading to an increase of consumption that currently have a lower meat consumption). Such a transition would also be attractive for health reasons and would not completely move away from meat consumption. The diet looked at is the so-called Willett diet, advocated by the Harvard School, which is based on an average daily consumption of around 10g of beef, 10g of pork, 47g of chicken and eggs, and 23g of fish. This case reduced the need for cropland by 10 per cent, and the area for grass land by 40 per cent (*Figure 4.9*). This was mostly due to a sharp reduction in the number of cattle. As a result, global biodiversity loss, up to 2050, would be around 8 per cent instead of around 10 per cent.

Arguably more realistic dietary changes that assume less dramatic shifts, in principle, could achieve similar results (although proportionally scaled down). Similarly, scenarios that would simply substitute some of the beef consumption by pork or chicken would also reduce agricultural land use (although cropland areas would increase for feed production, this is compensated by a larger reduction in pastures). In this context, the impact of low-meat (or beef) diets depends on the substitutes: the environmental benefits from going from meat consumption to artificial 'meat-like' substitutes (milk-based), for instance, would provide substantially less gain. Substitution of meat with fish is even undesirable, as a majority of fishing grounds is currently overexploited. The question remains whether these lifestyle changes could be achieved. Financial stimuli (such as a meat tax) could have some effect,

Figure 4.10 Impact of diet on emissions greenhouse gasses



Impact of diet on greenhouse gas emissions. Source: Stehfest *et al.* (2009).

but considerable societal resistance can be expected. Consumer preferences with respect to meat consumption have shown to be hard to change (see also *Chapter 5*). It should also be noted that for these changes, a substantial transformation of the world agricultural system would be required.

Dietary changes also decrease the costs of climate policy

The same dietary changes that reduce land use would also substantially decrease the greenhouse gas emissions associated with agriculture. In part, directly, by reducing the methane and nitrous oxide emissions associated with animal husbandry, but, more importantly, also indirectly by the regrowth of natural vegetation on abandoned agricultural land. Model calculations showed (*Figure 4.10*) that the adoption of the two illustrative cases, described in the previous section, theoretically, could achieve as much as 20 to 30% of the emissions reduction required to realise the 2 °C target (Stehfest *et al.*, 2009). In reality, the effect may be somewhat lower than is shown here, as regrowth of forests might be slower than modelled and reduced land scarcity could also lead to a slower improvement of crop yields (less price incentives for both farmers and seed companies). Nevertheless, there remains a substantial effect, which would decrease the costs of more traditional measures to reduce greenhouse gas emissions described in the previous chapter.

4.3.4 Reduction in post-harvest losses

After produce is grown, it is harvested, transported, stored, retailed and made ready for consumption. In all of these steps, losses occur. Data on post-harvest losses are hard to obtain and only a few surveys have been published. Estimates of losses vary between 2 and 23% from production to retail sites, for developed countries depending on the commodity. For developing countries, the ranges have been estimated to be even larger; up to 50%. In contrast, food losses by consumers are estimated to be higher in developed countries than in developing countries (Kader, 2005): in the United States, these losses have been estimated at around 25% of edible food available (Kantor *et al.*, 1997). In the Netherlands, estimates range from 13 to 25%, of which about 50% is unavoidable, such as losses in peelings (Milieu Centraal, 2007). Expectations are that losses will increase due to the consumption of more perishable commodities in the future. Thus, there is much scope to improve the efficiency of the total food chain.

Options for reducing post-harvest losses are to:
- enhance knowledge of farmers on timing of harvests and improvement of storage practices;
- improve the infrastructure from field to market;
- increase awareness of the problems of spoiled food in those preparing the food for consumers;
- support (e.g. by credit) local storage facilities.

4.4 Scope to halt biodiversity loss

Required investments for halting biodiversity loss are difficult to assess, but those required for agricultural yield improvements do not seem to be excessive

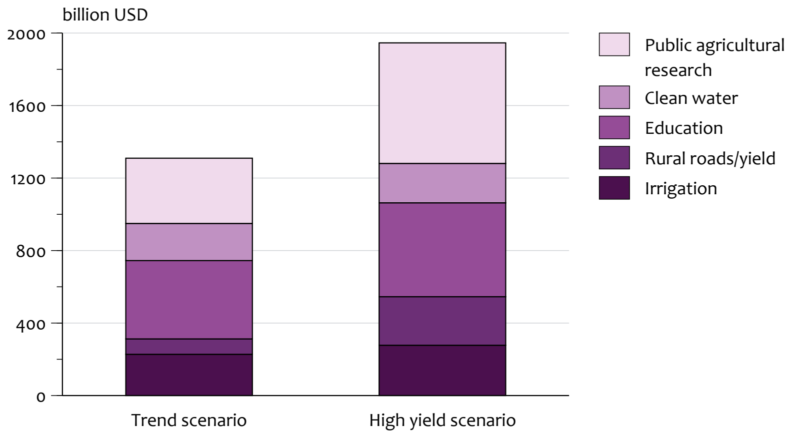
Although other factors also play a role, lack of investment in agriculture has been identified as an important factor for continuing low productivity, in many developing countries (Schmidhuber, 2009). Also, the slowing down in yield improvement, historically, has been attributed to lack of (public) investments into agricultural R&D. For most of the policy measures discussed above, it is difficult to assess the investment needs – and available information is somewhat scattered. According to Schmidhuber (2009), the cumulative gross investment requirements for low-income countries in the period up to 2050 would be of the order of 9000 billion USD on average up to 2050 (*Table 4.1*). Most of this amount (85 billion USD per year) would be for so-called downstream needs (processing, transportation, storage) outside the main agricultural sector. For the agricultural sector itself, the single largest investment is for mechanisation. One of the limitation in the massive use of is the fact that investments in R&D (especially publicly funded) have lacked behind the growth of agricultural production.

In the context of the IAASTD, the IMPACT model was used to assess additional investment for yield change in the *Challenge* scenario, compared to the *Trend* scenario. The required investments do not capture those in agricultural production itself, but only those in supporting factors (public agricultural research, irrigation, rural roads, education, and access to clean drinking water). For the *Trend* scenario, investment costs would be 1310 billion USD (not including investments in production) (*Figure 4.11*). For the Challenge scenario, these investment levels would need to increase to around 2000 billion USD. The additional investments are relative small. In the five key policy areas, additional investments would be around 640 billion USD. Schmidhuber estimates the need for additional investments of around

Table 4.1 **Investments in the energy system (2000-2050)**

	Cumulative investment estimates (billion USD)	Average investment per year
Trend scenario	9000 (total agriculture sector developing countries; Schmidhuber) 1300 (specifically for food production, IAASTD)	200
Challenge scenario	640 (additional investments for high yield scenario, IAASTD) 1200 (addition investments for higher yields, Schmidhuber)	30 ~ 15-30
MDGs	300	30

Figure 4.11 **Global investment requirements for agricultural yield scenarios, 2050**



Investment requirements in various scenarios. Source: IAASTD, 2008.

1200 billion USD, to significantly increase yields in developing countries. Finally, FAO has estimated the potential costs of achieving the MDG target for reducing/ eradicating hunger. They estimated costs to be nearly 300 billion USD (cumulative), over a 12 year period, mostly for infrastructure development and natural resource management.

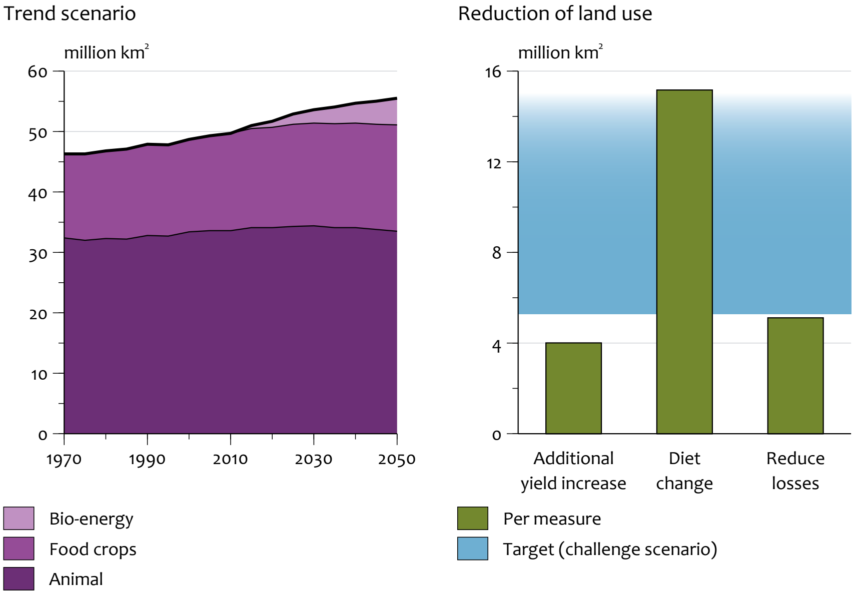
Together these numbers suggest baseline investments in the food sector in developing countries of around 10,000 billion USD, between 2000 and 2050. About half of these investments would be related to agriculture. The additional investments for further yield improvement were estimated at around 1000 billion USD. Although these numbers make up only between 0.1 and 0.5% of world GDP, the capacity of developing countries to make these investments would be limited.

A combination of options could, at least theoretically, bring about the required changes to halt biodiversity loss

The key question is whether the measures discussed above, together, would be sufficient to halt biodiversity loss. In the previous sections, we discussed various options that would reduce the loss of biodiversity. Taking a simplified approach in looking at the potential in the various options one-by-one and not accounting for

Measures for land use reduction

Figure 4.12



Comparing policy goals and options.

agro-economic considerations, *Figure 4.12* compares the required policy effort and the potential of the options.

The left-hand figure shows the land-use implications of the *Trend* scenario – including the proposed target of stabilising the area of agricultural land. Assuming that halting biodiversity loss by 2020 is accepted as a policy goal, the question is what does this imply for agricultural land use? As discussed in Section 4.1, expansion of agricultural area has historically been the main driver of biodiversity loss. In the future, however, the role of this factor is expected to decline, with both climate change and infrastructure expansion becoming increasingly important. This implies that for biodiversity protection it will also be important to mitigate the impact of these factors. Some loss due to both climate change and infrastructure expansion is inevitable. As indicated in the previous chapter, limiting global mean temperature increase to a maximum of 2°C is a very ambitious goal, but will still lead to negative biodiversity impacts. Therefore, halting biodiversity loss might require an ambition to reduce agricultural area further, below the 2020 level, which is indicated in *Figure 4.11* by showing uncertainty in the actual target.

The right-hand figure compares the potential for the various options discussed earlier. For yield improvement we use the differences indicated for the *Trend* scenario and the high yield scenario of the IAASTD (assuming also increased production and improved food security), for dietary change we show the potential of implementing a healthy (less meat-intensive) diet globally, and for reducing losses

Improving food security is a key condition for any sustainable development

we assume that losses are reduced from 30% to 20% globally. The figure shows that, theoretically, a combination of these measures (or even individual options) could certainly bring about the changes required for meeting a cropland stabilisation goal. Also, more ambitious goals could theoretically be achieved.

However, none of these options could be implemented easily – or would come without trade-offs. For instance, the dietary changes and reduced losses would require substantial lifestyle changes. For increasing agricultural yields, many actors are involved (e.g. small-holder farmers), making implementation relatively difficult. Failure to improve yields in many regions in the past, has been clear proof of this. Increasing agricultural yields also comes at the cost of other increased environmental pressures. For each of these options, it is therefore likely that they cannot be implemented too their full extent, but at the same time, the figure shows that considerable potential for improvement exists.

4.4.1 Improving food security is a key condition for any sustainable development

As indicated in Chapter 2, in addition to limiting ecological risks, another global challenge is that of reducing poverty. Under the *Trend* scenario, the Millennium Development Goal formulated for reducing hunger, that is, halving the number of people suffering from hunger by 2015, will not be achieved. Food security means that all people have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and preferences, for living an active and healthy life (FAO, 1996). The definition makes clear that food production does not equal food security. Food security involves four dimensions: availability, stability, accessibility ad utilisation. Most malnutrition, by far, occurs in rural farming households . Poor farmers often lack the land or resources they need to grow enough or the right kind of food. Over time, they are hit by both economic and environmental factors.

The changes discussed in the *Challenge* scenario, that is, increasing yields by increasing agricultural knowledge, science, and technology, will all contribute to achieve environmental sustainability, but also to reduce hunger (IAASTD, 2008). Other measures include price regulation on commodities and larger cereal stocks should be created as a buffer against tight markets of food commodities and the subsequent risks of market speculation (Nelleman *et al.*, 2009). Opening markets to international competition could offer economic benefits for some, but would initially require a strengthening of regional markets and improved access to credit for small-holder farmers (IAASTD, 2008). Finally, important measures include improved education, improvement of sanitation and hygiene practices (including ensuring access to clean drinking water), and treatment of infectious diseases, including diarrhoea and malaria.

A relevant policy question is whether there is a trade-off between reducing absolute hunger and the ambition to prevent an increase in agriculture areas. The answer is that reducing global hunger completely to zero by increasing agricultural production would lead to an increase in global food production of less than 2.5%. In other words, there is no real trade-off, here.

4.5 Conclusions

1. This chapter shows that there is a need to reduce the impact of the human footprint on biodiversity. It seems possible to do this by a coherent set of policies that include conservation, yield improvement, reduction of food losses, and possibly lifestyle changes. Realising a world that provides enough food for 9 billion people, provides other ecosystem goods and services, and still contains large nature areas, will, however, require ambitious action at different levels of scale and different policies in different areas. Where to increase the yield to the maximum? Where to combine higher production with more biodiversity? And which areas to protect?
2. An important element of biodiversity policy would be to accelerated productivity gains. Studies indicate this is possible – and with limited costs. To increase the global productivity, investments in agricultural research and development and extension should be brought back on track. Increased investments, in the next fifty years, could reduce food insecurity and reduce impact on biodiversity. The major challenge is to enhance governance practices that favour sustainable use of resources, such as land and water.
3. Just as importantly, however, is to develop a clear international strategy for biodiversity protection – including protection of hot-spots of biodiversity. In the unprotected areas, elements of biodiversity can be integrated into the management system of land and landscapes. The right balance between intensive and extensive (biological) agricultural practices needs to be found.

5 Strategy and policies

5.1 The *Trend* and *Challenge* scenarios

The *Trend* scenario carries substantial environmental and human risks for the long term

The previous chapters indicated pathways without policy reform for various variables: population, income, energy use, food demand, carbon emissions and others. This *Trend* reference scenario is presumed to be a smooth and business-as-usual continuation of past trends (see *Chapter 2*). At the individual level, these developments have provided an increase in material welfare for billions of people across the world. At the same time, considerable segments of the world population remain deprived of basic needs. In the *Trend* scenario, these recent historic trends are projected to continue into the future, driven by entrepreneurial and market dynamics. An important issue in the *Trend* scenario is the gradual transfer of activities from the public sphere to the market, including food supply and security, energy, public transport and various other, formerly public, services.

Chapters 3 and 4 have shown that the *Trend* scenario involves substantial environmental and human risks for the long run, specifically, with respect to large and irreversible climate change, severe loss of biodiversity and further marginalisation of hundreds of millions of people in the world. If unchecked, anthropogenic greenhouse gas emissions are likely to lead to a increase of global mean temperature of 4°C by the end of the century. This would lead to serious risks, including extreme weather events, loss of valuable ecosystems, impacts on global food supply and serious impact for vulnerable systems including coastal and arid areas. Global biodiversity is endangered through increasing pressure on land use for food production and urbanisation, which could lead to losses of genetic capital and disturbance of global biogeochemical cycles. This could in turn affect the climate system as well, specifically when deforestation limits the sequestration of carbon dioxide from the atmosphere.

It is important to note that these are not separate issues, but that they are interrelated and in many cases mutually reinforcing. Unless the baseline in the *Trend* scenario is deflected from the causative underlying dynamics, there is a serious risk of a future compromised by environmental crisis and degradation.

The *Challenge* scenario fundamentally deflects from the *Trend* pathway

Given the enormous momentum behind developments in the *Trend* scenario, any policy trying to deflect from the business-as-usual pathway should engage its strengths. Within the context of clear and long-term environmental goals, efficiency and innovation are important strengths in the *Trend* scenario, that could provide a useful contribution to reach these goals. However, to ensure a fundamental deflection from the baseline, rigorous policy interventions, widespread engagement, and public involvement from the sustainable *Challenge* scenario will be required to meet the challenges and uncertainties addressed in the previous chapters. Moreover, the *Challenge* scenario introduces additional policy criteria, most importantly the issues of equity and fundamental care for the (global) commons.

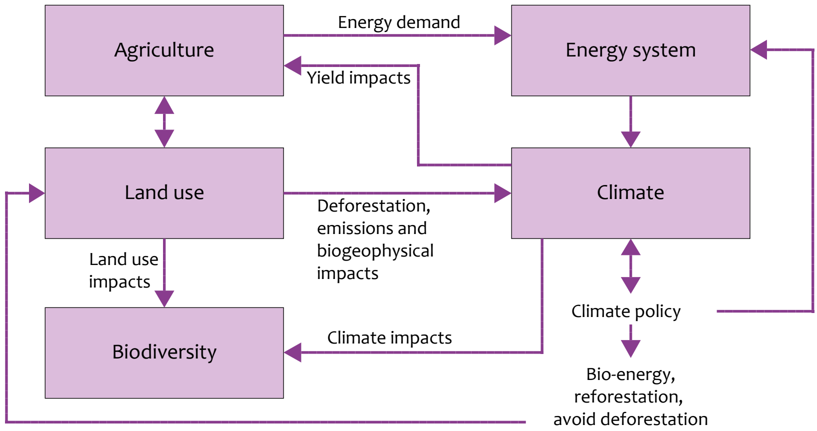
Following the view that the old system no longer fits the solutions required for present-day problems, the global multiple environmental crises provide ample reasons for addressing these challenges in a coordinated way. Where a crisis offers chances for breaking away from old trends, and for changing old routines, it makes strategic sense to align worldwide measures for tackling the current economic contraction, thus, providing opportunities for sustainable, long-term, environmentally-friendly growth in the future (OECD, 2009b). Some general conditions need to be taken into account when developing a policy strategy for meeting climate and biodiversity challenges and deflecting from the path of the *Trend* scenario towards the more sustainable *Challenge* scenario. Such a strategy would involve a long-term perspective and a balance between market-based and regulatory instruments, and between top-down and bottom-up strategies, also taking into account the conflict of multiple (national) interests and thematic interlinkages. These notions will all be explored throughout this chapter.

5.2 Thematic interlinkages: dilemmas, co-benefits and trade-offs

Interlinkages between climate system, land use, agriculture, energy and biodiversity, make it important to consider co-benefits and trade-offs: integrated approaches are required

There are important relationships between climate policy and strategies to protect biodiversity, making it important to consider co-benefits and trade-offs. Several interlinkages can be identified, implying several trade-offs and co-benefits for climate policy and biodiversity policy (*Figure 5.1*). First of all, land use plays a crucial role, both in the protection of biodiversity and in ensuring stability of the climate system through biogeophysical cycles. Several climate change mitigation strategies, most noteworthy bio-energy and reforestation policies, require land, thus, potentially further increasing competition over land. Second, climate change also affects global agriculture, considerably decreasing yields in tropical areas, while in temperate areas yields may increase with relatively moderate temperature increases of up to about 2°C. However, increasingly severe negative impacts are expected from larger temperature increases (IPCC, 2007a). In a reverse relation, agriculture also contributes to climate change, by causing deforestation and by being a major source of non-CO_2 greenhouse gas. Third, climate change will also directly leads to biodiversity loss, even at a medium level of temperature increase (Biggs *et al.*, 2008; Sala *et al.*, 2000). Specifically vulnerable ecosystems, such as coral reefs and mountain areas, would be severely affected.

Figure 5.1 **Thematic relationships**



Thematic trade-offs and interlinkages.

Implications for land use require a careful approach to bio-energy

Bio-energy could be an important factor in climate policy, based on its relatively low costs and ease of implementation. In the recent past, many studies on climate mitigation identified bio-energy as important for reducing greenhouse gas emissions, simultaneously offering an important economic chance for reducing poverty in low-income countries. In addition, and based on energy security considerations, policymakers have focussed particularly on stimulating the use of biofuels in the transport sector. This overwhelming push for biofuels caused a scientific and political debate on whether biofuels indeed would be a sustainable solution, in actual practice. Especially, the risk of biodiversity loss and the increase in food prices have dominated recent debates on biofuels, while the sustainability effects of so-called second-generation biofuels (based on cellulosic material) is still largely uncertain (Eickhout *et al.*, 2008). In order to avoid negative impacts, it seems prudent to be cautious about setting ambitious bio-energy or biofuel targets. For second-generation bio-energy, risks of negative impacts on biodiversity or on human food supply, seem to be much less severe. Nevertheless, monitoring impacts and adjusting policies accordingly, remains important. In 2050, about 50-150 EJ/yr might be used without severe impacts on biodiversity, conditional of production restricted to abandoned agricultural land, some of the natural grassland areas and with additional biodiversity constraints, and including agricultural and forest residues. However, such numbers are very uncertain.

Preserving natural forests helps to protect biodiversity and limits climate change

For climate mitigation policies, preserving natural ecosystems and restoring degraded ecosystems, is essential, because they play a key role in the global carbon cycle and are crucial in adapting to climate change. Ecosystems tend to be carbon dense and biologically more diverse in their natural state, so degradation of many ecosystems significantly reduces their carbon storage and sequestration capacity (CBD, 2009; Millennium Ecosystem Assessment, 2005). *Figure 2.4* illustrates this,

Implications for land use require a careful approach to bio-energy

by comparing areas worthwhile to protect for biodiversity reasons to areas with a high carbon density. Many land-use management activities could contribute to the synergy between the policy areas of climate change and biodiversity. Some relevant examples are protection of natural forests and peatland carbon stocks, sustainable management of forests, the use of native forest species in restoration activities on degraded lands, sustainable wetland management, and sustainable agricultural practices.

Specifically, the design of mechanisms for Reducing Emissions from Deforestation and Forest Degradation (REDD) will have key implications for the associated effects on biodiversity. The identification of areas both rich in carbon and in biodiversity value helps to focus the REDD implementation. Reducing forest degradation and stimulating both reforestation and afforestation could, potentially, provide co-benefits, if knowledge on biodiversity is adequately integrated in the overall design.

Furthermore, the use and implementation of different sources of bio-energy should take both carbon and biodiversity into account. A correct balance must be achieved between local biodiversity loss in the short term, and reducing greenhouse gas emissions in the longer term (Eickhout *et al.*, 2008). This requires a clear international strategy with regard to protecting biodiversity, so that areas with a high-biodiversity value can be prioritised in REDD action. Costs of REDD action seems to be comparatively low compared to other climate measures (see *Chapter 3*).

Synergies can be analysed by looking at delivered ecosystem goods and services. However, there are a number of issues that need to be resolved in such a valuation system. The value and costs of protecting biodiversity, and the value of delivered ecosystem services diverges greatly and includes many uncertainties. These uncertainties are both conceptual and quantitative. First, different elements of the broad concept biodiversity are hard to weigh in relation to each other. Putting numbers on services also delivers greatly varying results, depending on the methods used for upscaling local marginal local values to the whole regional or even global biome level, the so-called benefit transfer functions. Next to that, there is the conceptual problem of putting a value on non-marketed services, such as clean air or an attractive landscape (Ten Brink *et al.*, 2009).

Intensification of agriculture requires consideration of possible trade-offs

Chapter 4 has shown that a significant increase of agricultural yields is required, in order to avoid deforestation and to prevent further biodiversity loss as well as climate change. Nevertheless, the consequences of intensification need to be taken into account as well. First of all, higher yields may imply increased use of energy (mechanisation) and fertilisers. The latter may lead to higher N_2O emissions from agriculture, contributing to climate change. In Chapter 3 it is indicated that specific measures and integrated approaches exists to cut agricultural N_2O emissions from agriculture by half. Another trade-off with respect to increased yields concerns the potentially higher consumption rate of phosphor fertilisers. Van Vuuren *et al.* (2009d) show that the risk of phosphor depletion is not immediate, but given the fact that phosphor is a non-renewable resource it is important to improve the efficiency of human phosphor use. There still is considerable scope to do so.

A less meat-intensive diet helps to avoid climate change and to protect biodiversity

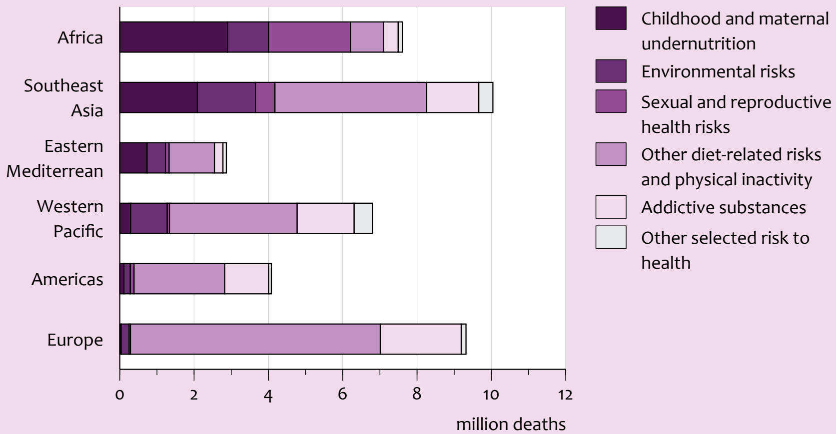
In Chapter 4 it was shown that meat consumption is responsible for about 80% of current agricultural land use, while it only contributes to about 15% of the total caloric value of consumption. Changing consumption to a less meat-intensive diets (and especially less beef) therefore helps to reduce the pressure on land considerably. As shown in Chapter 4, this helps both to protect biodiversity and to reduce greenhouse gas emissions , but also implies significant health impacts (see *Text Box 5.1*). The latter is due to a direct reduction of greenhouse gas emissions related to animal husbandry and by freeing-up land for reforestation. It should be noted the effectiveness of dietary changes does depend on substitution. While substitution to crop-based products does lead to significant less land-use, milk-based alternatives may also be land-intensive. Substitution to more fish-based diets is likely to be unsustainable given to current state of world fish stocks.

Text Box 5.1 Relationships between diet, environment and health

Environmental policies can have important consequences for health. The World Health Organization (WHO, 2002) has made an assessment of the health loss attributable to the most important health risk factors (see Figure 5.2; future changes, such as an increase in climate change, are not accounted for). The relevance of these factors varies among the different regions. In developing regions, mortality is primarily a function of risk factors, such as malnutrition, environmental risks (e.g. unsafe drinking water and air pollution), and unsafe sexual behaviour. Improving food security and reducing air pollution, therefore, can create important health gains. In the developed regions, these risks have been mostly eliminated, but are gradually substituted by the more lifestyle-related health risks. Next to health risks from addictive substances, such as tobacco and alcohol, a major cluster of diet-related risks related to obesity and a high level of meat consumption can be distinguished. A too low fruit and vegetable intake, which is most directly related to a changing diet, is globally associated with 2.7 million annual deaths, while obesity adds another 2.6 million deaths. Most of the these deaths occur in high income countries. However, even in South-East Asia the setting in of these 'modern' risks can already be seen, while they are still also suffering considerable health losses from traditional health risks. Estimating what the effect of healthier diets could be is rather complex, since these health risks interact and eliminating one risk can make room for another. Nevertheless, a healthier lifestyle – including a shift to a less meat-intesive diet - could create substantial health gains.

Attributable Mortality by Risk Factor

Figure 5.2



Mortality by cause in different regions. Source: WHO (2002).

Access to energy is a crucial precondition for improving human development

Under the *Trend* scenario, several of the Millennium Development Goal (MDGs) will not be met by 2015 (see *Text box 5.2*), including access to modern energy. Improved access to energy is a necessary precondition for raising the standard of living for up to two billion people. Although there is no formal Millennium Development Goal (MDG) formulated for energy, it has been shown that other MDGs cannot be achieved without increasing access to modern energy (Modi *et al.*, 2006). The use of traditional energy does not only limit economic prospects, but also has a negative impact on human health (as traditional energy is associated with high emissions of particulate matter), and even on climate change (so-called black carbon emissions are thought to be responsible for an additional temperature increase in Asia).

Provision of electricity to the poor is of crucial importance to improve human development , contributing to health improvements as well as to the ability to grasp business and education opportunities. To be effective, this energy needs to be affordable, also to the poorest people (Von Winterfeldt and Nakicenovic, 2009). Presently, many people in developing countries only have access to traditional biomass fuel, such as wood and charcoal, the latter of which is often harvested through slash and burn practices and combusted on traditional stoves. This has considerable effect on local biodiversity and climate change, and causes indoor air pollution and associated respiratory diseases. Improving stoves with (much) higher efficiencies

Text Box 5.2 Long-term development and the Millennium Development Goals

Analyses with the GISMO1.0 model show that progress on many of the Millennium Development Goals (MDGs) can be expected in the coming decades, but progress might not be sufficient to achieve all goals in all regions, and some goals may not even be achieved by 2030 (PBL, 2009a). Poverty will remain concentrated in Sub-saharan Africa and South Asia. Reducing child mortality by two thirds will probably be the most difficult MDG to achieve, even with high economic growth and greatly improved agricultural productivity. By 2030, environmental health risks, related to food, water and energy, would still account for 45% of all child mortality in developing countries, although most of these risks are preventable at relatively low costs.

Without additional policies, global environmental change puts further pressure on the natural resource base of the poor, and adversely affects the quality and quantity of the vital ecosystem goods and services in already stressed areas. Increasing access to food, safe drinking water, basic sanitation, and improved energy sources for the poorest people, are of key importance for the international development agenda. Health risks and environmental degradation will continue to be major concerns.

Future policies for poverty reduction, including a post-MDG development agenda, should take into account the increased pressures of global environmental change and clearly distinguish between medium-term and long-term objectives.

Access to modern energy is a crucial precondition for improving human development

or switching fuels to LPG would greatly improve human health, and reduce climate change effects and land-use pressure.

This would lead to an additional LPG use of about 3 EJ/yr, but it would save more than 17 EJ/yr in fuel wood. Global energy consumption would increase by only about 1%. Such a fuel switch would cost about 285 billion USD, 16 billion USD of which would be capital investment and 269 billion USD would be fuel cost. A switch to renewable energy sources (solar), rather than LPG requires long-term involvement, and financing of installation as well as for maintenance (PBL, 2009a).

Raising food production to eradicate hunger would only marginally increase land use

For agriculture, a relevant policy question is whether there is a trade-off between reducing absolute hunger and the ambition to prevent an increase in agriculture area. Food security is not only a function of food production, but also of physical and economic access to sufficient, safe and nutritious food that meets dietary needs (FAO, 1996). The added policies in the *Challenge* scenario (see Chapter 4) – specifically those to increase yields by increasing agricultural knowledge, science and technology – will contribute to not only achieve environmental sustainability, but also to reduce hunger (IAASTD, 2008).

Raising global food production to a level that meets food demand from the entire human population, would lead to an increase in global food production of less than 2.5%. At least as important would be the regulation of commodity prices and stocks to buffer the market against speculation and sharp price changes, which could severely affect farmers' livelihoods (Nelleman *et al*., 2009). Opening markets to international competition could offer economic benefits for some, but would first require strengthening of regional markets and improving access to credit for small-holder farmers (IAASTD, 2008). Market operations could be significantly enhanced by measures that support an 'enabling environment', including education, support of improved nutritional practices, sanitation and hygiene, access to safe drinking water and improved infrastructures.

5.3 Policy: vision, targets and measures

5.3.1 Long term vision and targets

Short-term decision-making requires long-term visions and associated targets to avoid lock-in and endorse fundamental changes

Many of the choices made over the coming years will have their impact far into the future. Many of the main infrastructures take a significant amount of time to design and deploy and, subsequently, determine the pace of development for decades to follow. Power stations and buildings that are designed and built today, are likely to still be standing in 2050. This means that restructuring the energy and agricultural systems by the middle of the 21st century, would require strong political action in the short term.

Visions for a sustainable future can be used to develop binding and compelling targets for the long-term, addressing both climate change and biodiversity loss. Long-term targets and vision can help to ensure timely technological development as well as the necessary changes in institutional arrangements, lifestyles and values (PBL, 2009b). However, reaching such long-term targets will not be a straight-forward process, but rather one of learning-by-doing, innovative research, and tackling unexpected obstacles along the way. It is important to note that solutions identified today, might not necessarily show the pathways to long-term sustainable development. Many innovations build on previous techniques and solutions, while radical innovations often deal with substitution processes, replacing one technology and its social incorporation with another (Mokyr, 1990). Technological systems, thus, have a tendency to 'lock-in', precluding other options and raising the costs of shifting to alternatives. This is particular relevant for developing countries where, currently, large investments are being made in infrastructure.

Since it is not possible to prescribe what would be the optimal technological configuration of the economic system in general, or of the energy system in particular, a sound long-term policy would indicate the general direction, invest in robust measures, and preclude unwanted outcomes, while keeping options open for a variety of technical and political solutions. It is particularly important to realise that, although interim solutions may appear to form a bridge to fundamental restructuring in 2050, they may sometimes prove to be a dead end. For example, energy security considerations for the 2020-2030 period, when taken in isolation, could easily lead to investment in coal-based technology that would be long-lived and incompatible with the vision for a low-carbon economy, by 2050. The degree of freedom, however, is not unlimited, and excluding specific options could make achieving the targets increasingly difficult. Clearly, there are trade-offs between efficiency and diversity, but strategic policy-making would strike a balance between the short-term competitive need for efficiency and the long-term need to maintain diversity for dealing with unexpected events (PBL, 2009b; Van den Bergh *et al.*, 2007).

Recognition of useful solutions may be enhanced by developing a (long-term) strategy, to anticipate on windows of opportunity (Sartorius and Zundel, 2005). Moreover, any future vision would be greatly enhanced by an attractive guiding narrative, to mobilise people and politicians for the challenges ahead. Such a narrative would need to be attuned to opportunities as identified in this and other reports, rather than to crisis rhetoric.

5.3.2 Instruments: markets versus regulation

A balance between market-based and regulatory instruments incorporates environmental effectiveness, as well as some of the fundamental driving forces of human dynamics

Various policy instruments are available in the policymaker's toolbox, for example, public procurement, tax measures, standards and regulation, and mobilisation of the private sector through subsidies or engagement in public-private partnerships. A balance between market-based and regulatory instruments is needed to incorporate some of the fundamental driving forces of human dynamics, while ensuring maximum environmental effectiveness, institutional feasibility and equitable sharing of benefits and burdens (*Table 5.1*). A number of instruments will be further explored in this section, without being exhaustive.

While policy choices in the past have alternately favoured any of these instruments, their combined effect could harvest 'the best of both worlds', when applied in a sensible way. Progressive environmental standards for a broad range of products, for example ,the emission criteria for cars and televisions in the EU, could significantly help clearing the market of products that do not meet these standards (PBL, 2009b). Strict and long-term standards would set the limits in the economic playing field and ensure distributional equity, while market forces would help to ensure that these conditions are met with maximum efficiency, and with innovative creativity within this playing field. Such a strategy would encourage experimentation, learning and innovation, not by 'picking (technological) winners', but by setting strict standards or targets, and by leaving solutions to creativity in the market and civil society. Nevertheless, it will be important to provide public support for some technologies and infrastructures, or for institutions that provide significant contributions to a sustainable strategy. In many cases, the balance between market instruments and regulatory settings will be a matter of regional policy and preference, although it will be useful to ensure international coherence for the protection of the global commons.

Directly influencing consumption patterns by means of consumer quota is in most countries a more sensitive issue (PBL, 2009b), but it could help to break through regular routines and bring about fundamental changes rather than incremental improvements. Governments can also increase their spending on public procure-

Table 5.1 **Overview and evaluation of national policy instruments, with a focus on climate policy**

Instrument	Criteria			
	Environmental effectiveness	**Cost-effectiveness**	**Sharing benefits and burdens**	**Institutional feasibility**
Regulation and standards	Emission levels are directly influenced; depends on exceptions and maintenance	Depends on design; uniform application often leads to better enforcement	Depends on a 'level playing field'; smaller, as well as new players are sometimes disadvantaged	Depends on the technical capacity of institutions
Charges and fiscal measures	Only if the level of the charge leads to changes in behaviour	Better if broadly applied; higher administrative costs if institutions are weak	Can be improved by recycling income	Often politically unpopular; difficult to introduce where the institutions are underdeveloped
Tradable rights	Depends on the emission ceiling, participation and enforcement	Less where participation is limited, or if applied to limited sectors	Depends on allocation; can cause problems for small participants	Requires well-functioning markets and institutions
Voluntary agreements	Depends on design (objectives, references) and independent control	Depends on the flexibility and size of government stimuli, rewards and penalties	Only participants benefit	Often politically popular; requires relatively limited administration
Subsidies and other financial incentives	Depends on design; more uncertain than regulation	Depends on design; can distort markets	Advantages for participants; sometimes for those who do not need them	Popular among participants; difficult to abolish later
Research and development	Depends on consistent financing; long-term benefits are possible	Depends on the design of the support and the amount of risk	Advantage primarily for participants; probability of bad funding allocation	Requires many different decisions; depends on research and development capacity and long-term financing
Information provision	Depends on acceptance by users; most effective in combination with other measures	Potential for low costs, but this depends on design	Can be less effective for particular groups that have no access to information (such as those on low incomes)	Depends on cooperation with the business community and social actors

Source: (IPCC, 2007b)

ment, that is, on items that show up directly on their balance sheets, such as government buildings and infrastructure. To make such spending part of a green recovery package, priority can be given to measures which bring about direct or indirect climate benefits or reduction of land use, such as investments in public transport, power grids and energy efficiency (Edendorfer and Stern, 2009)

Cap-and-trade systems are a key example of integrating market instruments with regulatory settings (see *Text box 5.3*). While a strict cap ensures that meaningful emission reductions can be achieved, the trading systems ensures that these reductions are achieved in a cost-effective way. However, while such a system is very feasible for reducing emissions, the non-tradeability of ecosystems requires a different instrumental outline for their protection. It can be useful to ensure that ecosystems are valued economically, but when this value is smaller than other land use alternatives, or when property rights are unclear, it will be difficult to provide the same environmental effectiveness as strict regulatory protection measures.

5.3.3 Conditional measures and generic instruments

Removing perverse subsidies provides room for a sustainable development strategy

Many perverse subsidies for fossil-fuel use and for resource depletion through mining, forestry and fishing, are embedded in national policy architectures. Examples of this situation are tax exemptions for aeroplane kerosene or state support systems for fishing fleets. It has been estimated that annual global costs of public subsidies in the energy and industry sectors amounted to about 520 billion euros in the 1990s, accounting for 2% of world GDP. Close to half this amount went to the energy sector, mostly targeting production in industrialised countries, while supporting consumption in low-income countries (Van Beers and De Moor, 2001). A critical area supported by perverse subsidies is that of fossil fuels, inhibiting the growth of renewables. Currently, price and production subsidies for fossil fuels amount to over 200 billion USD per year, globally (UNEP, 2009b). For a global sustainability agenda, such subsidies clearly require reform to fully take into account the global commons.

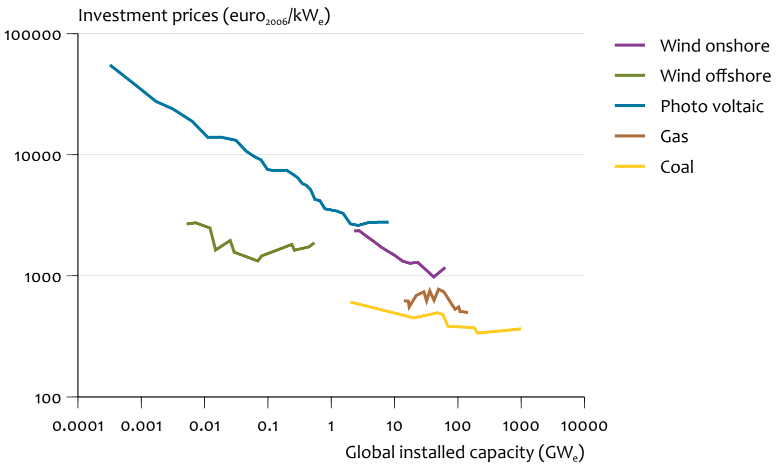
R&D investments help to support and direct technology development

As was concluded in Chapter 3, there is considerable potential to decrease greenhouse gas emissions through the application of a range of technologies that are already known and available, but the rate of implementation has to be stepped up considerably if important pilot technologies are to play a significant role in 2050. This, in turn, requires extensive effort in up-scaling, training, decisions on test locations, and, last but not least, gaining public acceptance for new technologies to ensure their wide application (PBL, 2009b).

Text Box 5.3 Cap-and-trade schemes versus international carbon taxes

Market based instruments, such as carbon taxes and cap-and-trade systems, have been advocated as cost-effective instruments for reducing emissions. In principle, both instruments allow involved stakeholders to identify options for reduction at the lowest costs possible. The effort sharing is independent of the instrument chosen. With a tax system, it is the redistribution of tax revenues that determines the costs for stakeholders; in a cap-and-trade system the allocation of emission rights is crucial. There are some differences, however. Carbon taxes provide more certainty about the mitigation costs, and caps are a better guarantee for a specific emission outcome (Newell and Pizer, 2003; Van Vuuren et al., 2009a). Both systems have passionate advocates and opponents, depending on the preference for more certain economic outcomes or more certain environmental outcomes. In the short term, it makes sense to build on already existing systems, most notably the cap-and-trade systems in the EU and the United States. In future arrangements, more hybrid systems may be considered, for instance, a cap-and-trade system that allows for banking of emissions, or a trading system with minimum and maximum emission permit prices as safety valves (Jacoby and Ellerman,2004).

Figure 5.2 **Experience curves of energy supply technologies**



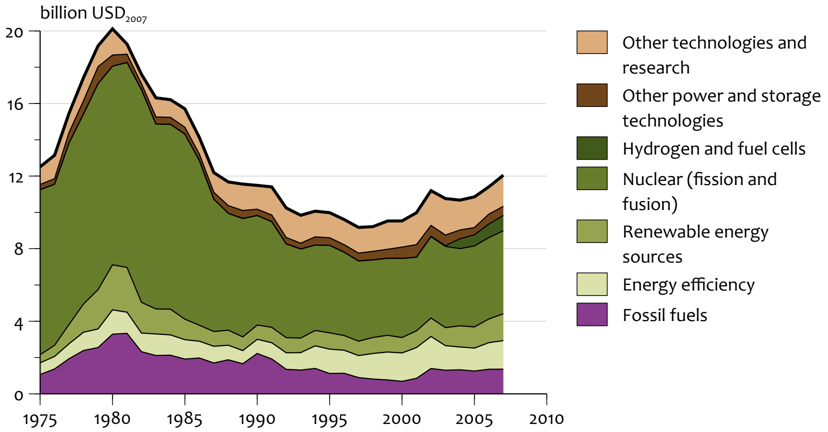
Experience curves of energy supply technologies. Source: Junginger *et al.* (2008)

Many renewable technologies are presently still relatively expensive, but show generally fast learning rates (*Figure 5.2*). Learning curves allow an investigation of the necessity for learning investments, i.e. the expenditures required to bridge the gap between the electricity production costs of the new technology and the baseline costs of the incumbent technology until a competitive break-even point is reached. Although there is no proof of policy accelerating technology learning processes through public R&D investments, financial policy measures could stimulate extra market volume, which in turn drives down production costs (Junginger *et al.*, 2008). Depending on consistency of finance and regulatory context, long-term environmental benefits of R&D programmes are possible. Moreover, R&D investment, most probably, is a *conditio sine qua non* for technological progress. However, while general R&D levels in OECD countries have slowly increased over the last decades, public investments in energy R&D have decreased for more than two decades, only modestly recovering in the last years (*Figure 5.3*). Over the years, only a minor share of energy research investments has been spent on renewable power innovations. In addition, much of the private spending on energy R&D is increasingly focused on projects with short-term pay-offs.

Today, many clean-energy entrepreneurs still largely depend on the availability of credits and loans, but in a more mature market they are likely to be a major source of future economic growth. Although the immediate economic and environmental effectiveness of major public investments in green technologies has been disputed, the sheltering of immature renewable technologies from the harsh effects of market forces could well prove to be a benefit of immense importance, in the long run (see Technology Review, 2009a for a discussion). Rather than through direct public investments, the private sector may also be mobilised through loans or guarantees, which could help to engage public-private partnerships.

Public research and development energy investments

Figure 5.3



Public energy R&D investments in IEA countries. Source: IIASA, based on IEA database.

With respect to food production, it is assumed that 70% of future food demand can be met through yield enhancements, thus, requiring a more extensive distribution of various agricultural technologies (see Chapter 4). Yet, agricultural research has stagnated or declined over the years, for many regions, in terms of GDP share, particularly after the 1990s. Moreover, in many developed regions, the focus of research has shifted to reflect consumer preferences in processes, organic and products and animal welfare, while the diffusion of yield enhancing technology in developing countries has slowed. This argues in favour of dedicating more funds to technology diffusion and developing countries research programmes to meet growing food needs (Msangi *et al.*, 2009).

Large investments in energy infrastructure will be required in the future, in any case, providing a window of opportunity for including renewable energy technologies

In Europe and other regions with developed power grids, considerable investments will be required, in the coming decades, to update the grids in order to meet renewable targets. IEA estimated global investments for development and replacement of energy infrastructure between 2001 and 2030 at 8200 billion euros (IEA, 2003), and at 9900 billion euros up to 2050 (IEA, 2008). Extending and updating the energy grid infrastructure provides considerable opportunity for considering the requirements of sustainable energy production. A key issue, in this respect, is the large and hard-to-control fluctuation in power production, which requires additional storage and grid capacity or back-up production facilities. Therefore, overall investments in sustainable energy systems are generally higher than those in 'regular' grid improvements (Roland Berger Strategy Consultants, 2008). Moreover, additional investments would be required to combine scenarios to, thus, maintain flexibility for developing future options and to avoid lock-in. Because investors in clean energy technologies need to be sure that they will get a return on their investments, long-term regulation and reliable governments are essential for the development of the EU power system.

On a local scale, small-scale power generation by individual households, companies and industries requires the development of so-called smart grids. Incorporating decentralised power production in the energy infrastructure is not only a technological issue, but rather an institutional challenge to allow for electricity feedback mechanisms, and to elaborate coordination and grid control mechanisms (Faber and Ros, 2009). In Germany, an advanced feedback system for renewable energy production has been institutionalised, including pre-determined tariffs that are secured for the long term, and the gearing down of regular production facilities at times when sustainable power production is high.

In Europe, ideas have risen for the development of a pan-continental 'supergrid' to connect large-scale centres of sustainable energy production, such as windparks, large solar power farms, and geothermal power plants. In July 2009, a consortium of mainly German companies adopted the idea of developing large-scale CSP plants in the Sahara, to meet at least 15% of European energy demand by 2050. Development of many square kilometres of parabolic mirrors, in combination with an extensive transmission grid, was estimated to cost around 400 billion euros (Desertec Foundation, 2009). In the United States, the main location for development of solar and wind farms is the Midwest, incidentally also the area with the least-developed grid connections (Technology Review, 2009b). Considering the potential for developing such a sustainable energy system, the United States Stimulus Bill acknowledged the opportunity for investment in modernisation and extension of the power grid.

For low-income countries with poorly developed power infrastructures, many renewable power technologies offer opportunities for stand-alone systems or for developing local grids in a bottom-up fashion. Since both centralised and decentralised power systems offer significant opportunities for inclusion of renewable power production and CO_2 emission reduction, there is a good argument for maintaining both as a hybrid option in any future sustainable energy system.

Ensure room for experiments

Today, many technologies that could contribute to long-term environmental emission reductions are still in a developmental phase, with many uncertainties in terms of future market demand, social gains and the need for change at different levels of organisation, technology, infrastructure and the wider social and institutional context. The step from developmental phase to full commercial application, therefore, is a difficult one for any technology, and the provision of market niches and room for experiments could be crucial to allow competitive development of these technologies (Kemp *et al.*, 1998; Schot and Geels, 2007). By definition, this provision takes place on a relatively small scale, sheltered from competition with already well-developed, fossil-fuel technologies. Regions, small countries or cities could provide such room for experiments (see *Text box 5.4*). Strategic niche management could be a useful domestic policy strategy to allow technologies that are promising from an environmental perspective to mature, before they enter the market. In practice, such an approach would allow an experimental period for technologies in development, possibly followed by guarantees for, for example, grid placement or feedback tariffs. Often, such experiments require regulatory exemptions, for example, regarding standards for buildings or transport.

Text Box 5.4 Sustainable cities

Many issues of sustainability clusters in urban settings, following high demand for resources and direct environmental rebound effects, in terms of health and quality of life. From this perspective, cities and towns could provide room for sustainability experiments at a local scale. In a multi-disciplinary stakeholder dialogue, in the Netherlands, a future vision on the energy system of a sustainable city in 2040 was developed to meet the challenges of urban sustainability.

The sustainable city in 2040 aims, first, to significantly reduce energy use and increase efficiency and, second, to use only renewable and preferably locally generated energy. In this city, new houses will be build according to principles of 'passive housing', recapturing all heat and cold, while the efficiency of existing buildings is improved through retrofit insulation measures. Heat exchange takes place between residential, industrial and utility buildings. Greenhouses provide food, as well as heat for the city, and the transport system is multimodal and electrically powered. Different transport systems have converged, and transferring or connecting while travelling by car, train or bicycle is effortless. Slow transport (walking, cycling) or public transport are the main urban travel modes. With respect to local power generation, residents are shareholders in new coalitions for energy production, which renders a more 'bottom-up' energy system, also contributing to social cohesion. A smart grid provides the electricity distribution. When local generation cannot meet (peak) demand, power is supplied from large-scale renewable production, for instance, by wind farms in the North Sea. Technological innovation is not the biggest challenge, as many technologies are already available or under development. Large-scale implementation of these measures through institutional reform is the biggest challenge. This reform should provoke and facilitate behavioural change, for example, through the implementation of new financial constructions, new regulations or formation of new coalitions.

Assessment of this vision showed that the sustainable city would not be able to meet more than one third of its total energy demand within the next 30 to 40 years. The city could supply a maximum of 50 percent of the energy required by its own transport sector and built environment. Increasing this amount would require the use of otherwise open spaces within city boundaries, which may conflict with other functions of (public) urban spaces. Therefore, much of the remaining energy will still come from power production outside the city.

In a relatively condensed city lay-out, energy demand could be reduced by about 15% (compared to an urban sprawl scenario) through lower intra-urban transport requirements. Additional policy could also direct a shift to a more efficient transport system, specifically with well-developed urban–public transport systems and efficient electric vehicles. For any city or town, such a shift would require considerable investments as well as spatial-planning efforts.

Table 5.2 **Estimated investment needs to address the main sustainability issues**

Strategy	Ranges of estimated additional cumulative investment needs (USD)	Ranges of annual estimated additional investment needs (USD)
Climate mitigation	20,000-70,000 billion	400-1600 billion
Climate adaptation	2000-7000 billion	50-160 billion
Increasing agricultural yields	600-1200 billion	15-30 billion

5.3.4 A window of opportunity for investments

Investments directed to climate and biodiversity goals, and to the tackling of human development issues, are less than 1.5% of cumulative world GDP up to 2050

As discussed in Chapter 3, a low-carbon economy can be achieved with currently identifiable technologies, although many technologies still require considerable R&D efforts before being economically available. Cumulative additional costs of climate policy, in the period up to 2050, are estimated to average out at about 50,000 billion USD, with a range of between 20,000 billion and 70,000 billion USD, due to uncertainties, energy intensity, and variations in targets. This accounts for around 1.4% of cumulative world GDP over this period. Assuming overall investments in the energy system of 4 to 5% of GDP, which need to be made anyway, this would more or less imply a 30% increase of the investment in the energy sector for the period up to 2050 (see *Table 5.2*). These investment estimates are taken from a range of individual studies and should be interpreted as indicative.

In Chapter 4 was indicated that increasing agricultural yields requires investments in public agricultural research, rural roads, education, irrigation and access to water, aggregately amounting to 1,310 billion USD. Although outcomes could be significantly improved for land use and food security in developing countries, at a relatively modest additional investment of 263 to 636 billion USD, depending on the scenario used. In the highest investment scenario, this would be the equivalent of about 3.7% of present world GDP, but spread over time to around 2025, this would come to about 0.2% of world GDP.

Targeted investments from donated funds could be very helpful to tackle extreme poverty. A simple calculation shows that about 125 billion USD per year would be needed to supply the 1.1 billion extremely poor people in the world with their basic needs (Sachs, 2005), but additional investments will most probably be needed to make a structural difference. Tackling climate change and halting biodiversity loss could generate additional benefits for further development of the very poor, specifically in reducing vulnerability patterns. Given the major benefits and relatively small investment requirements of poverty eradication, it is clear that tackling extreme poverty should not compete with finance for reducting climate change and halting of biodiversity loss (see also Lomborg, 2004).

Although these aggregate costs and investments are relatively modest on a macro-economic scale, it is important to note the underlying assumption that all enabling conditions are in place, such as global cooperation in climate policy, increasing agricultural yields, the implementation of emission reduction measures at the lowest

Large investment in energy infrastructure will provide a window of opportunity for including reneweble energy technologies

cost in all sectors and regions, and no market or policy failures. Clearly, these are the main challenges for tackling the global environmental problems.

Even if the global costs of action are considered to be high, in the long run, they still would not outweigh the expected costs of inaction (Hof *et al.*, 2008; Stern, 2007). If unchecked changes in any of the ecological subsystems trigger catastrophic tipping points, the costs of inaction would certainly become even much higher. The exact weighing of costs and benefits of climate policy also depends on distribution of risks and on how the future is valued and discounted. The 2°C target has been proposed as a possible interpretation of how to weigh these factors (see *Chapter 2*).

The present economic crisis may well be a window of opportunity for breaking away from current trends

The present economic recession not only features a downturn in worldwide economic activity, but also has strong environmental impacts (see *Text Box 5.5*). The current global environmental challenges are enhanced by the present global economic recession, which provides a rationale to develop an integrated, holistic approach as the core of a credible sustainability strategy. The current economic recession, therefore, could provide a unique opportunity for developing a coherent strategic response to the most prominent environmental challenges, as has been recognised in various recent studies and reports (Bowen *et al.*, 2009; Edendorfer and Stern, 2009; OECD, 2009a, b; PBL, 2009b; Robins *et al.*, 2009; UNEP, 2009; Worldwatch Institute, 2009). The recession could be used for breaking away from old trends and to align present worldwide measures for tackling the current economic contraction, with opportunities for sustainable long-term environmentally friendly growth (OECD, 2009b). Many measures proposed in recent economic recovery packages involve sustainability issues and 'green investments'. In South Korea, about two thirds of the proposed economic recovery package is explicitly targeted as 'green investment'. The United States recovery plans cover about 100 billion USD in the next two years, to be spent on public infrastructure, public building retrofits, smart grid electricity systems, and development and installation of various renewable energy technologies (Bowen *et al.*, 2009). In China, development of six 10 GW wind parks are foreseen in the Gobi desert, which will make up a large share of global wind power, and create a very significant industry.

Developing a green sector could create a range of economic opportunities

Specifically investments in improvement and extension of infrastructures are estimated to provide significant overall benefits of spillover and multiplier effects (Edendorfer and Stern, 2009), but the net impact is subject to debate. Some studies point out that renewable energy industries appear to be more labour intensive than the existing energy sector, particularly in initial construction, manufacture and installation (Bowen *et al.*, 2009). It has been suggested tha a strong renewable energy policy in the coming years could create a net average effect of over 400,000 additional jobs, as well as about 0.24% GDP in the EU by 2020, in addition to a present sectoral workforce of 1.4 million and 0.6% EU GDP (EmployRES, 2009). Including all supplying sectors would increase this figure considerably; up to 1.8 million people in Germany alone, which equals an increase of more than 5% in industrial production (Edendorfer and Stern, 2009). Increased production of low-emission vehicles could create 3.8 million jobs directly in the production process itself, and up to 19 million ancillary jobs, globally (UNEP, 2009).

It should be pointed out, however, that several studies emphasising the creation of green jobs show a partial analysis, excluding job losses in traditional industries or in other regions. It should be noted that economic restructuration could well imply job losses elsewhere, thus leading to a shift in employment, rather than creating new jobs as such. From this perspective, it might be safer to conclude that macro-economic impacts of 'green investments' are modest.

Stimulus measures to tackle the economic crisis and recover a more sustainable economy

From the perspective of response to an economic crisis, stimulus measures have to be timely, targeted and time-limited, in order to achieve maximum impact without generating adverse lock-in effects, or crowding out private spending in the recovery (Edendorfer and Stern, 2009). While effectiveness and cost-effectiveness are traditional *criteria* to assess environmental policy instruments, also criteria such as flexibility, technological innovation, secondary benefits, sustainability issues, and institutional embedding, should be included in long-term assessments (see e.g. Hoen *et al.*, 2009). The investments in climate policy measures and agricultural yields would fit such criteria, given the expected long-term benefits. Specifically energy efficiency improvements have a double long-term benefit, as they reduce emissions and energy costs simultaneously. In times of economic crisis, this offers good opportunities for restoring sustainable trajectory of development in the long term, while providing an effective stimulus for economic restoration, in the short term (Edendorfer and Stern, 2009).

A key domestic policy strategy for high-income countries would be to reduce their energy demand. Improvement of energy efficiency is a 'no regret' option in many respects, as it can be implemented quickly, shows high multiplier effects, improves energy security and generates large cost savings. Moreover, in the context of the present economic crisis, it has been proposed to promote sectoral fiscal stimuli on energy efficient buildings, sustainable transport, and sustainable energy, as these provide particular opportunities, in terms of their economic, environmental and employment benefits (UNEP, 2009b). Especially retrofitting of buildings is considered a highly effective measure: globally, energy used by buildings could be reduced by almost 30%, by 2030, at zero net cost effects, in the long term (Edendorfer and Stern, 2009), and the application of current building technology could cut energy use by around 80%, compared to traditional designs (UNEP, 2009b). For the transport sector, regular CO_2 legislation is associated with incremental improvements, which runs the risk of limiting innovative incentives. Therefore, a proper and robust long-term strategy would be required to significantly reduce greenhouse gas emissions from transport, and to avoid lock-in effects and loss of flexibility (Hoen *et*

Text Box 5.5 Environmental effects of economic crisis

The present economic recession not only features a downturn in worldwide economic activity, but also has strong environmental impacts. Emissions in high-income regions have declined, while emission increases in most low-income regions were smaller than originally projected. Most notably, demand for many commodities dropped worldwide, in 2008 and 2009, reducing demand for fuels and materials, and as a result, also reducing many emissions. Between 2007 and 2010, a 5 to 10 percent reduction in greenhouse gas emissions, and a 5 to 20 percent reduction in polluting emissions of NO_x, NH_3, volatile organic compounds, and particulate matter, is estimated for the Netherlands (PBL, 2009c). However, it is expected that if the economy recovers, greenhouse gas emissions will rise again. As such, the crisis mainly translates to a 2 to 3 year delay in emission, on a global scale.

Investment in any abatement measure is also severely hampered by the credit crunch, which dries up funding for environmental purposes. Worldwide, in 2008, about 111 billion euros was invested in renewable energy; a modest annual rise of 5%, compared to annual growth rates of over 50 percent in previous years (Science for Environmental Policy, 2009). Investments in greenhouse gas emission reduction in sectors within the European Emission Trading Scheme (EU ETS) are also likely to decline due to very significant drops in CO_2 prices. Prices dropped from pre-crisis levels of about 30 euro/tonne to less than 10 euro/tonne, by the end of 2008 (PBL, 2009c). Since companies within the EU ETS are allowed to transfer excess emission rights to the next budget period after 2012 ('banking'), it may be assumed that CO_2 prices will not easily recover and will remain low at an estimated 20 euro/tonne, for several years to come (Ecofys, 2009).

Overall, the economic crisis helps to make short-term targets easier to achieve, but reduced investments could make it more difficult to achieve emission reductions, in the long term.

al., 2009). Measures for improving general vehicle energy efficiency (aerodynamics, weight reduction) and to address travel behaviour (awareness, pricing measures), are 'no-regret' options for reducing emissions from the transport sector.

5.4 The institutional dimension: conflicts of multiple interests

5.4.1 International governance issues

A credible allocation regime to share the burden of climate change policy action is crucial for the Copenhagen negotiations

Climate change follows from worldwide anthropogenic greenhouse gas emissions, and it affects humans and ecosystems on a global scale. Therefore, any policy to tackle climate change is a global and shared responsibility. Several studies have shown that international climate policy can only be effective and cost-efficient if all major emitting countries at some point participate in reducing greenhouse gas emission; even if emissions of all OECD countries would be reduced to zero over the next few decades, the more ambitious greenhouse gas concentration targets could not be reached (Den Elzen and Höhne, 2008). Various schemes for burden sharing among countries have been proposed in the course of the international negotiations, all with specific qualities of equitability, effectiveness, efficiency and ethics (see *Section 3.4*). It will be a key challenge to the post-Kyoto negotiations to find an allocation principle that does justice to responsibility for both historic and future greenhouse emissions. In some sectors, it is expected that leadership of high-income countries will automatically make the transition in low-income countries easier, for instance, in transport where there are clear examples of technology transfer. Low-income countries could then follow with some delay. In other sectors, transition in low-income countries could occur with support of high-income countries (for example, with a trading scheme). In some cases, low-income countries may even benefit from leap-frogging, such as for new grid design.

Sharing the responsibility for biodiversity loss needs more elaborate finance and aid mechanisms

Biodiversity losses are often considered to be a national matter, although global effects arise through disturbances of global biogeochemical cycles and losses of global gene pools. Given the global character of these environmental problems, the protection of the global commons is also an international and shared responsibility (see also *Section 4.3.1*). There are two general pathways to effectuate this responsibility. A first option is by financing the protection of important biodiversity reserves. Various constructions can be elaborated here, either in the context of public investment related to Clean Development mechanism (CDM) or development assistance funds, or as targeted private investments, often in the context of charity funds. For instance, the REDD mechanism can serve multiple benefits, preserving global biodiversity, among other things. Generally, financial transfer systems still need to be further elaborated to take local as well as global benefits into proper account.

Assuring regional food security as an international challenge

Since food is a basic requirement for all, assurance of food security has always been a key element of any political agenda. It has been argued that food security can be articulated globally, as was suggested at the start of the Uruguay Round negotiations in 1986: 'The idea that developing countries should feed themselves is an anachronism from a bygone era. They could better ensure their food security by relying on US agricultural products, which are available, in most cases at much lower cost.' (quoted in Bello, 2002: p. 53). While costs for such a framework may indeed be lower, vulnerability to price and harvest fluctuations would probably significantly affect food security, as well as destabilise the large agricultural sectors in many countries. Securing basic food supply, therefore, is essentially a national or regional responsibility. At the same time, the existance of a global food market implies that the agricultural policies of nations are linked. Technology transfer has played a significant role, for several decades, and will be needed in the future as well, to ensure increased food production.

While the importance of technology is generally recognised, it should be noted that the biggest challenges are in the dimension of institutions and governance practices (IAASTD, 2008). Hunger, poverty and food supply are mainly questions of distribution. A key question is whether trade liberalisation could contribute to improve a more equitable global distribution of food stuffs and thereby relieve hunger and poverty. Generally, the liberalisation of world trade leads to greater prosperity on a global level, creating winners (including farmers in Latin America and Australia) and losers (farmers in the EU, the United States and Sub-Saharan Africa, and urban populations in developing countries in general) (PBL, 2008). On the one hand, liberalisation of world trade may stimulate a more efficient use of natural resources and connect many regions to world markets (OECD, 2008), but, on the other hand, temporary protection of developing countries may be required to prevent small farmers from suffering because of cheap food imports (IAASTD, 2008). Moreover, countervailing policies are considered necessary to ensure that further liberalisation of world trade is not at the expense of nature areas and biodiversity (OECD, 2008). A key challenge to improve food security in low-income countries is to ensure access to markets, for example, through improved infrastructure and information and knowledge on prices and technologies.

Institutional issues are at the heart of international environmental policy-making, aligning national interests and including bottom-up initiatives in global challenges

Since any effective protection of the global commons would require some kind of a supra-national policy framework, international governance issues are at the heart of the challenge to align conflicts of multiple national interests in the international environmental policy arena. National interests relate to resources and vested interests, while international power positions of key players in the global arena are of crucial importance to coordinate these interests for the global good. A better representation of low-income countries in international organisations on behalf of development and the environment has been suggested for a more equitable involvement in the decision-making process, the setting of the international agenda, the resolve of disagreements and the making of rules of enforcement (Stiglitz, 2006).

Strong domestic and international institutions and regulations are required to ensure a proper care for the global commons. Moreover, good governance and effective institutions are key to accomplish a full deployment of necessary technologies at acceptable costs, a stringent level of biodiversity protection, and overall fundamental solutions rather than incremental improvements. This, however, is no triviality for either local actions or global regulations. Bottom-up approaches include decentralised, community-based and cooperative initiatives, based on local practices. Top-down approaches include centralised, generic and governed practices, often including regulations such as cap and trade, taxation, trade regulations and direct regulations. Such global, top-down practices face the pitfalls of overlooking local requirements and involvement, of engaging in bureaucratic organisations, or of ineffectiveness due to the generality of their highly aggregated approach. It has therefore been argued to better balance top-down coordinated strategies with bottom-up, hands-on initiatives (ISDR, 2009). The integration of domestic national policies in an international playing field, therefore, is a key condition for aligning strategies that address global environmental challenges.

Making use of comparative national advantages provides opportunity for a broader, integrated regional strategy

Geography, infrastructure and vested interests are key aspects that characterise comparative national advantages. Consider energy: in Europe, France has a long history and associated cumulative knowledge of nuclear energy, Germany and Denmark have accumulated a similar position with respect to wind energy, and the Rotterdam harbour in the Netherlands serves as the geographical jetty for bulk goods, LNG and non-refined oil. The industrial, energy and environmental policies of the various countries could be geared to each other to make use of such comparative differences, nurturing the diversity in technologies that contribute to the climate change target in a broader European perspective. However, it is important to note that much of the decisive power in European energy production has been transferred from policymakers to energy companies, which operate within the European Emission Trading Scheme (EU ETS).

These notions suggest to integrate national policies in to a broader regional context, in order to make full use of comparative advantages. For example, for the Netherlands, the large port of Rotterdam, together with some of the smaller harbours could provide an argument in favour of relating the energy system to bulk fuels, such as coal and biomass, including carbon storage in abandoned natural gas fields. On the other hand, the very extensive natural gas infrastructure could be an argument for investing and reinforcing the natural gas system – possibly as a stepping stone to a future hydrogen economy. The Dutch, relatively advanced, distributed power production by means of co-heating technology provides opportunity for exploring the elaboration of, and investment in, distributed power systems. Generally, flagship projects could be initiated within large-scale technology projects, most notably on carbon capture and storage, concentrated solar power, gasification of cellulosic biomass, power storage, and hydrogen systems (Edendorfer and Stern, 2009).

Improvement of international cooperation and the institutional framework for sustainable development

In response to the global character of many environmental problems, an international policy architecture with respect to sustainable development has been developed over the last decades, shaped in treaties, coordinated efforts, international organisations, multinational legal frameworks, and many good intentions. Key

Upscaling production of new technologies provides an opportunity for cost reduction

challenges are those of working towards global cooperation to reach agreement about the goals and ways of distributing the costs and benefits of policy, and of strengthening the international governance structures into a more comprehensive framework to deal with issues of climate change and biodiversity loss (PBL, 2008; UNEP, 2009b).

Because of increased economic globalisation and the importance of trade, a key issue in ensuring international cooperation is the alignment between WTO trade treaties and multilateral environmental agreements (MEAs). Conflicts between these frameworks arise in several ways (Verhaak, 2003). First, some MEAs include explicit trade restrictions, for example, the CITES treaty on trade in protected species. Second, the precautionary principle is an important element in several MEAs, but its application is often disputed in the context of the WTO trade agreement. Third, there are conflicts between WTO agreements and restrictive national or European policy standards, which may lead to import bans on some products. High national environmental standards may then be considered as trade barriers. Fourth, there may be conflicts about production processes (rather than on the product itself) being considered unacceptable by individual countries, based on environmental considerations. In most cases of conflict, WTO agreements prevail over international environmental agreements, because of the WTO effective dispute settlement regime.

A sanctionary regime, the feasibility of exerting political pressure, and the right of initiative for new international environmental agreements, are key conditions for improving effectiveness of and compliance with global environmental governance, either within a new institutional framework, or within the context of present or new environmental agreements. Several models of institutional re-design have been proposed to better address environmental problems, on a global scale (Vellinga *et al.*, 2002). First, an authoritative World Environment Organisation (WEO) has been proposed, alongside other major institutions in the present UN and Bretton Woods systems (Biermann, 2000), but this would require considerable sovereignty concessions from nation states. Second, a settlement to harmonise existing international policies and agreements in the environmental area, and the development of a common dispute settlement and reporting mechanism, could ensure that duplication and contradiction are avoided, improving effectiveness of the aggregate sum of treaties (Sampford, 2002). Third, a system beyond the present UN framework could enable the involvement not only of nation-states, but also of other actors from civil society, industry and interest groups.

Recently, many global environmental issues have been tackled in coalitions of convenience, in semi-formal networks such as the G8 and G20. These activities offer the opportunity of making quick progress and settling bilateral progressive deals outside of formal institutions, but they also bear the risk of marginalising formal institutions and, thereby, losing involvement and support of nations outside the network. Progressive agreement among nations could serve as a future vision, challenging others to follow. A more formal global cooperation that addresses climate change and biodiversity protection would require the establishment of global alliances, including OECD countries, rapidly emerging countries such as Brazil, Russia, India and China (BRIC countries), and the low-income developing countries. Formal agreements have the advantage that they can establish a framework for a long-term perspective, creating a level playing field and a compliance regime for stakeholders involved.

5.4.2 Beyond policy: changes in consumption and production

Environmental governance goes beyond top-down control and involves other stakeholders

On a national scale, addressing environmental issues has traditionally been a national command-and-control type of policy, but the scale of environmental problems has now extended the power of individual governments. Governmental activity in relation to environmental issues is increasingly located within a distributed network of governance, in which representative government plays an important role, but without the ability to control the full scale of a particular policy problem (Hajer, 2003; 2009). Moreover, as market parties are increasingly involved in the articulation of global governance, citizens lose direct influence in governing processes, but gain influence in their role as consumer.

Corporate social responsibility can contribute to decrease environmental pressures, but is presently still limited to frontrunner companies

Environmental pressure is traditionally related to industrial production processes. Frontrunner companies involve corporate social responsibility (CSR) measures, which go beyond regulative measures and requirements, thus contributing to environmental improvements on a voluntary basis. Specifically small and medium-sized enterprises are reluctant to take CSR measures, which are often associated with profit losses and reduced operational room for manoeuvre. However, in practice, many CSR measures not only decrease environmental pressure and social disruption, but also contribute to efficiency increases in operational management, saving of natural resources and opening of new markets. (Aalbers *et al.*, 2007).

Corporate responsibility for extensive production chains is often hard to organise and deals with many national differences in legislation and interpretation. Verification schemes are often helpful to ensure that environmental requirements are met, although national regulation is often required to ensure local compliance. A promising way to improve the sustainability of production chains, currently applied in some of them, is by international agreements between companies, NGOs and governments to set criteria for sustainability of these production chains.

Citizens can contribute to very significant decreases in environmental pressure through changing their consumption patterns, political involvement and personal lifestyle

Behaviour and lifestyle are key determinants of human pressure on most natural systems. This pressure largely relates to consumption patterns in high-income countries, which have contributed to high CO_2 emissions per capita, as well as to high pressure on land use for food production. This provides ample opportunity for citizens to personally contribute to the tackling of environmental challenges. For example, in many cases, energy efficiency measures for buildings are cost efficient within a few years, and replacing car transport by other modes of transport has immediate effects on greenhouse gas emissions and air quality. Moreover, environmental considerations with respect to food could greatly reduce greenhouse gas emissions and land use, throughout the production chain. In addition, citizens have significant political power to exert. Anyone can get politically involved, influence politicians to consider environmental issues on their behalf, or use his or her voting power in times of election (Brown, 2008).

One clear example of how lifestyle changes can contribute to achieving multiple sustainability targets is through mitigation of meat consumption. For example, removing meat from the daily diet once a week would reduce associated impacts by about 15%. Using dairy alternatives and fish from sustainable aquacultures on the remaining days could further reduce the impact on global biodiversity and greenhouse gas emissions (PBL, 2009c). However, lifestyle changes associated with basic

Reforestation projects could contribute to address both climate change and biodiversity loss.

routines are not easy to establish, and consumers in high-income countries do not respond strongly to pricing measures for meat consumption (Aalbers *et al.*, 2007).

Intrinsic change requires awareness and acceptance of the urgency of problems

While it has often been argued that resource users will never self-organise to maintain their resources, and that governments must impose solutions, it has become increasingly clear that some government policies accelerate resource destruction, whereas resource users have invested their time and effort in achieving sustainability (Ostrom, 2009). Behavioural change is not necessarily a top-down governmental strategy, but rather also a intrinsically motivated, personal change of lifestyle (Jones, 2008). Awareness, recognition and acceptance of the urgency of the problems at hand, are crucial pre-conditions for fundamentally changing lifestyle and individual consumer behaviour. In order to keep challenges on the agenda, the availability of solutions is crucially important. Entrepreneurs in policy and innovation are needed to connect problems to potential solutions, which ensures keeping the challenges on the political and social agenda (Giddens, 2009).

5.5 A politics of limits

A politics of limits requires environmental problems to be taken seriously, followed by an integrated strategy of setting long-term targets and strict standards

The paradoxical reality of today seems to be that the world manages to discuss both the solution to the economic crisis facing us today as well as the question what to do about the very real threats implicated in a further environmental erosion. This historical moment is one in which we could envisage a new 'politics of limits' bearing fruit. Such a politics of limits can be based on present scientific consensus on the relevant facts as well as on the integrated assessments of distinct scenarios exploring particular courses of action. A politics of limits would accept that there needs to be a firm role for government in both correcting or creating markets. It would start with a clearly and unmistakenly uttered joint commitment to address climate change. While the implications of such a global commitment are considerable, this study shows that it is not a commitment leading to hardship, demise and decline. Far from it: there is a true opportunity to fundamentally restructure economies towards a a more sustainable configuration, at relatively moderate structural expenditures of around 1.5% of global GDP. What is more, a well articulated set of limits may spark off a societal dynamics that could help achieve the necessary environmental goals. The present economic crisis may prove to be a window of opportunity to seriously consider such a fundamental transition of the global economy, to fully take into account the required care for the global commons.

A politics of limits requires all stakeholders, governments, businesses and citizens to realise and accept that the thrust of policy making will be one of tough and probably tougher standards aiming at reaching ambitious but necessary goals. These clearly marked joint political choices would have to translate in regulation which would be the sign for many to invent their businesses anew, reconsider choices and demands. While much will depend on environmental policy standards in the strict sense, it is conceivable that this politics of limits will have another effect as well. A joint politics of limits may spark off a creative competition to invent the technologies, planning arrangements and the like which will help achieve these goals. A politics of limits creates, in this sense, a level playing field in time which allows firms and countries to compete for finding solutions that help achieve climate goals.

It is important to note that a politics of limits is not a single-issue matter, as many synergies, co-benefits and trade-offs exist among climate policy, biodiversity protection and human development themes (see *Section 5.2*). Moreover, basic human development could significantly contribute to ensuring environmental sustainability. This calls for an integrated policy strategy, addressing each issue in the context of others. There is the possibility of a 'triple gain' where CO_2 reductions go hand-in-hand with reducing international dependency relations in the sphere of energy needs, as well as in the creation of jobs in the green manufacturing industries (which will both be highly skilled as well as basic construction such as in the making of off shore wind infra and a new electricity grid). In addition, a politics of limits will need to be based on a further enhancement of North-South relations. Much will depend, however, on the clarity with which these joint commitments to such a sustainable future are uttered, as well as to the creativity in finding ways to make these commitments enduring and firm in the years to come.

Abbreviations

BRIC
Brazil, Russia, India and China

CBD
Convention on Biological Diversity

CCS
Carbon Capture and Storage

CDM
Clean Development Mechanism

CH_4
Methane

CO_2
Carbon dioxide

CO_2-eq.
Carbon dioxide equivalents

CSP
Concentrated Solar Power

CSR
Corporate Social Responsibility

EJ
Exajoule = 10^{18} Joules

ETS
Emission Trading Scheme

EU
European Union

FAO
Food and Agriculture Organisation of the United Nations

FAIR
Framework to Assess International Regimes (model)

GDP
Gross domestic product

GEO
Global Environmental Outlook

GISMO
Global Integrated Sustainability MOdel (model)

GMO
Genetically Modified Organism

IAASTD
International Assessment of Agricultural Knowledge, Science and Technology for Development

ICT
Information and Communication Technologies

IEA
International Energy Agency

IMAGE
Integrated Model to Assess the Global Environment

IPCC
Intergovernmental Panel on Climate Change

LPG
Liquified Petroleum Gas

MA
Millennium (Ecosystem) Assessment

MDGs
Millennium Development Goals

N_2O
Nitrous oxide; dinitrogen oxide

NGO
Non-governmental organisation

OECD
Organisation for Economic Co-operation and Development

ODA
Official Development Assistance

PBL
Netherlands Environmental Assessment Agency

PV
Solar Photovoltaic

R&D
Research and Development

REDD
Reducing Emissions from Deforestation in Developing Countries

RIVM
National Institute for Public Health and the Environment (Netherlands)

TEEB
The Economics of Ecosystems and Biodiversity

TFP
Total Factor Productivity

TIMER
Targets/Image Energy Regional Model (model)

TWh
Terawatt hour = 10^{12} Wh

UN
United Nations

UNEP
United Nations Environment Programme

UNFCCC
United Nations Framework Convention on Climate Change

USD
United States dollars (US$)

WHO
World Health Organization

WTO
World Trade Organization

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