PBL Netherlands Environmental Assessment Agency

Roads from Rio+20

Pathways to achieve global sustainability goals by 2050

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with contributions from

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Foreword

This report was written in the run-up to Rio+20, the UN conference that will revisit the outcomes of its 1992 precursor. Rio+20 aims to set the agenda for sustainable development policies in the coming decade, with its focus on a next generation of sustainable development goals, a green economy and the reform of the institutional framework for sustainable development.

In 1992, governments agreed to work towards eliminating poverty while keeping global environmental problems within acceptable limits. Although progress has been made in certain areas, overall, the conclusion must be that we have failed to realise the vision that resulted from the 1992 Rio conference.

Could that vision still be achieved? This report analyses possible pathways to achieve a set of internationally agreed sustainable development goals for food, land and biodiversity, as well as for energy and climate. It explores how environmental and development objectives could be reconciled, in actual practice. Furthermore, it shows the level of effort that would be required to meet these goals, the possible pathways along which that could be achieved, as well as the synergies, trade-offs, and possible directions for policy-making.

However, the world has changed, enormously, since 1992. The lack of progress, so far, in combination with the level of subsequent effort that would be needed to meet sustainable development goals, the current economic crises and the difficulties of coming to effective multilateral solutions may result in a sense of pessimism about what could be achieved in the future.

The urgency for progress towards a more sustainable development in view of human well-being and planetary stewardship requires prompt action. This leaves us with no alternative other than a pragmatic search for ways to go forward. We suggest a pragmatic approach that could be further developed into 'roads' that lead us from the Rio conference into the future. This approach builds on the observation that many sustainability initiatives are being developed within civil society and by business community, and that a scale up of such initiatives, in itself, could be worthwhile. In this report, we look for new connections between policy, societal initiatives and learning. Our pragmatic approach includes converging on a shared vision for 2050, combined with short-term targets, making sustainable development the new ‘normalcy of society’ and finding complementary ways of achieving international collaboration.

This report builds on previous PBL assessments of global sustainability problems and the contributions we have made to assessments by international organisations, such as UNEP and OECD, and links to our trend report *The Energetic Society* (2011). Following the Rio+20 conference, PBL intends to publish its assessment of the implications of the Green Economy concept for the Dutch economy.

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Summary

In 1992, governments worldwide agreed to work towards a more sustainable development that would eradicate poverty, halt climate change and conserve ecosystems. Although progress has been made in some areas, actions have not been able to bend the trend in other, critical areas of sustainable development – areas such as those providing access to sufficient food and modern forms of energy, preventing dangerous climate change, conserving biodiversity and controlling air pollution. Without additional effort, these sustainability objectives also will not be achieved by 2050.

This report analyses how combinations of technological measures and changes in consumption patterns could contribute to achieving a set of sustainability objectives, taking into account the interlinkages between them. The potential exists for achieving all of the objectives. The fundamental question here relates to the type of governance structures that could bring about the transformative changes required to meet the sustainable development objectives. We suggest a pragmatic governance approach that consists of a shared vision for 2050, strengthened short-term targets, and strong policy actions by governments, building on the strength of civil society and business.

1 Identifying the problem

Although the 1992 Rio Conference resulted in many activities aimed at sustainable development, historical trends have not been reversed in key areas
Moreover, projections indicate that, without new policy initiatives, sustainable development goals will not be achieved in the coming decades, either. The world has

seen improvements in welfare, reductions in poverty as well as local environmental problems. In two important spheres – *food, land and biodiversity* and *energy and climate* – policies have not led to a reversal of historical, unsustainable trends. Moreover, projections suggest that long-term sustainability objectives will not be achieved unless a significant new policy effort is made.

The number of people without sufficient food has remained almost constant, at around 800 to 900 million people, since 1992. Although economic growth is projected to lead to improvement, it is not likely to be enough to fully eradicate hunger by 2050. Around 1 billion people lack access to electricity, and almost 3 billion people still rely mostly on solid fuels for cooking and heating. This has negative impacts on their health and hampers economic development. Up to 2050, this is expected to improve only to a limited extent.

Since 1992, biodiversity has declined significantly and this is expected to continue. In addition, greenhouse gas emissions have increased rapidly and are projected to increase even further. To achieve the 2 °C target, however, emissions would need to be halved by 2050, compared to 1990 levels. Finally, air pollution levels in many parts of the world are projected to remain high and in some places may even increase, leading to serious health losses.

2 Could a set of ambitious sustainable development objectives be achieved?

There are alternative pathways along which the sustainable development goals could be achieved

Using a backcasting approach with the integrated assessment model IMAGE, this study analyses effort levels and measures required to achieve a set of sustainable development goals. These goals are all derived from existing international agreements (e.g. the Millennium Development Goals, UNFCCC and UN CBD). The focus is on: 1) eradicating hunger and maintaining a stable and sufficient food production, while conserving biodiversity; and 2) ensuring access to modern energy sources for all, while limiting global climate change and air pollution. The analysis explores different combinations of technological measures and consumption changes. It shows that each pathway could be successful, but would also encounter particular problems, such as the environmental impacts of intensive agriculture or the difficulty of influencing consumption patterns. Although not all combinations are possible, combining elements of the pathways could make the response strategy more robust. This would also do justice to the pluriformity in society as different elements are appealing to different actors.

Eradicating hunger and maintaining a stable and sufficient food supply while conserving biodiversity

In order to feed a growing and overall wealthier population, food production needs to increase by around 60% in the 2010–2050 period. However, a slowdown of the increase in agricultural productivity, increasing demands for bio-energy and wood products, as

well as climate change, will result in increasing competition over land. This, in turn, could result in higher and more volatile food prices and increasing pressures on biodiversity and ecosystem services.
In this situation, substantial effort is needed on multiple fronts to meet sustainable development goals, including improved yields (especially in areas with relatively low yields compared to their potential), waste reduction, climate change mitigation, better land management policies and the expansion of protected areas. Lifestyle changes towards less resource-intensive consumption patterns may also contribute significantly to the achievement of these targets. Finally, to eradicate hunger, it will be necessary to increase access to food for the poorest households.

To implement these actions, four fundamental short-term policy priorities can be defined: 1) create conditions to accelerate sustainable agricultural intensification, 2) ensure a more robust food system to reduce hunger, 3) mainstream biodiversity considerations in land-use planning and management, and 4) promote changes, such as in consumption patterns. Clearly, these priorities are likely to differ across countries, depending on their income levels.

Ensuring access to modern energy sources for all, while limiting global climate change and air pollution
As is the case for food, energy production also is expected to increase by around 60% over the next four decades. However, greenhouse gas emissions would need to be halved in order to achieve the 2 °C target to limit climate change.

The analysis shows that access to modern energy could be improved by financial instruments to lower the cost of modern fuels and stoves, distribution programmes for improved stoves, and ambitious electrification programmes, all targeted at the poorest households. The development and health benefits of such a transition are substantial. In order to reduce greenhouse gas emissions, improved energy efficiency must form an essential part of the response strategy. Standards and financial tools (e.g. taxation) could be effective policy instruments to unlock existing potential. In addition, further electrification in the transport and household sectors could ensure more flexibility in reducing emissions. On the supply side, by 2050, around 60% of all energy would need to come from non-CO_2 emitting energy sources, such as renewables, bio-energy, nuclear power, and fossil fuel combined with CO_2 capture (the current share of these technologies is 20%). Reducing non-CO_2 greenhouse gas emissions is also part of an effective strategy, because of low costs and co-benefits, although the long-term mitigating potential is limited.

To implement these long-term changes, the main focus for the energy sector for the next ten years would be in the following areas: 1) substantially increasing efforts to ensure modern energy for all; 2) peaking global greenhouse gas emissions around 2020; 3) introducing appropriate pricing instruments; and 4) ensuring sufficient financing and reform of international climate policy, including R&D efforts. Again, priorities in these areas are dependent, among other things, on income level.

There is no fundamental trade-off between eradicating hunger as well as providing full access to modern energy, on the one hand, and achieving environmental sustainability, on the other

Eradicating hunger and providing access to modern energy for all (beyond production increases that result from population and economic growth) would not necessarily negatively affect global biodiversity or climate change. Even if access to modern fuels for cooking and heating for the poor is achieved with fossil-fuel-based products, this would result in only a small increase in CO_2 emissions, (partly) compensated by reduced emissions from deforestation and of black carbon. Furthermore, the additional increase in food production required to eradicate hunger would be small compared to current production levels and the overall increase to keep up with population growth and economic development. If hunger eradication would be facilitated by a redistribution of current consumption levels, the required increase in production would be even less.

For both of the above thematic areas (land and energy), marginal improvements will not suffice; large, transformative changes are needed to realise sustainable development

Although, technically, environmental and development goals could be achieved, this would require rather bold, systemic changes. Decoupling of CO_2 emissions from economic growth needs to take place at 4% to 6% a year, over the next decades, to meet the climate target of a 2 °C maximum temperature increase by 2100. This is to be compared to the historical rate of 1% to 2%. In agriculture, an average productivity increase of around 1% a year would be needed to provide sufficient food for all, while limiting biodiversity loss. This rate is comparable to historical improvement rates, but will be more difficult to achieve in the future.

3 How to implement transformations?

A new, more effective approach to sustainable development is needed

The outcomes of this study are consistent with earlier studies that focused on specific problems of sustainability; all show that there is sufficient technical potential to meet sustainability objectives. However, it has to be concluded that the approaches used to unlock this potential of achieving the internationally agreed ambition, so far, has not been very successful. Moreover, the geo-political and societal context has changed substantially since 1992. It is therefore paramount to reflect critically on the current governance structures in order to pave roads that more effectively lead from Rio to a sustainable 2050.

This report suggests a governance approach that is based on a shared vision with long-term goals and consistent short-term targets, combining strengthened government actions with the numerous civil and corporate initiatives worldwide
Adaptations to the current approach would consist of an increased focus on creating a long-term vision, combined with stimulating learning and innovation. Incentive structures should match these long-term goals. The best way to go about this could be to start pragmatically by taking many small steps in the right direction, building more strongly on the innovative capacity of citizens and businesses worldwide. By exploring best practices, diffusing technologies and making incremental improvements, support and understanding may be created for the more radical changes that are required. Such an approach could be based on the following key elements:

1. Develop a consistent vision with long-term goals and short-term targets, integrating various areas of sustainable development;
2. Ensure that the rules and regulations which govern day-to-day decision-making are adapted to create the right incentive structure for transformative changes;
3. Increase coherence between relevant decision-making processes;
4. Reform policy-making at an international level.

These elements are explored further below. Clearly, there is a certain tension between the bold changes required to realise sustainable development and the pragmatic policy approach suggested above, the effectiveness of which is yet unknown. However, the current approach does not have the required track record. Given difficulties of agreeing, upfront and on the highest level, on a policy package, it seems important to consider alternative options that implement ambitious elements of a sustainable development trajectory, strengthen social and institutional learning and thus aim to avoid the costs of inaction.

Develop a consistent vision with long-term goals and short-term targets, integrating various areas of sustainable development
Currently, an overall vision on sustainable development is lacking. Although visions are sometimes regarded as soft tools, they may have a serious effect if they mark the clear choice for a sustainable future. Converging towards consensus at international and national levels on an overall vision may help to provide direction in policy-making. Such a vision would link sustainable development issues and involve formulating and agreeing on priorities for different types of countries.

One element here could be to agree on a set of sustainable development goals and targets. Past experience (e.g. the Millennium Development Goals (MDGs) and some environmental policies) has shown that goal-setting could aid effective decision-making. In a similar way, sustainable development goals could form a coherent framework highlighting sustainability issues. Possible targets may include food security, biodiversity conservation and sustainable use, access to modern energy, climate change, and air pollution control.

Formulating and developing these goals will require time and careful consideration. Scenario projections, such as those in this report, could provide useful insights to link long-term ambitions to meaningful values for these new Sustainable Development Goals. Any agreement on goals, however, can only be effective if the governance rules of the game are also changed.

Ensure that the rules and regulations which govern day-to-day decision-making are adapted to create the right incentive structure for transformative changes
Society has an enormous capacity for innovation and learning (in the report, this is referred to as the *energetic society*). It is important to channel this capacity towards sustainable development, by ensuring that sustainable development considerations become part of the day-to-day decision-making process. Our analysis also showed that there is no single and simple solution for the transformation; consequently, changing the incentive structures and allowing for flexibility in societal responses seems a more promising strategy than focusing on specific response options that would steer society along a single, preset path.

The following policy actions and instruments could change the current incentive structure (addressing several market and coordination failures):
- abolish perverse incentives (e.g. environmentally harmful subsidies);
- define natural resource access and tenure rights and ensure that green policies and investments also focus on poverty reduction;
- strengthen the capacity for institutional learning;
- introduce dynamic regulation, stimulating continuous improvement, reinforced by extensive public procurement commitments;
- include sustainable development goals in the indicators used to measure progress;
- include environmental factors in current pricing systems (e.g. green taxation and payments for ecosystem services);
- develop enabling infrastructure, such as smart grids and sustainable city design;
- strengthen monitoring and feedback mechanisms, such as smart metering.

Increase coherence between relevant decision-making processes
The challenges posed by sustainable development are not only influenced by specific environmental and development policies, but also by other policy areas, such as trade, finance and energy. Therefore, it is crucial to increase the coherence between policy domains, long- and short-term goals and levels of decision-making, all focused at sustainability as the overarching target. This would, for example, imply that sustainable development consequences are taken into account in energy security decisions.

For an increase in coherence, it is important to consider synergies and trade-offs. Some examples are:
- sustainable access to food, safe drinking water, and modern energy sources improves health and saves considerable time and effort in water and fuel collecting;

- sound ecosystem management results in cleaner drinking water, higher carbon uptakes and improved soil quality, sustaining a higher agricultural production;
- an integrated approach towards achieving climate, air pollution and energy security targets may lead to significant cost reductions;
- bio-energy can help to reach the climate goal, but complicates achieving those for biodiversity and food. Regulation and monitoring are needed to keep negative impacts within acceptable boundaries;
- certain air pollution measures may improve health, reduce climate change and prevent ecosystem damage.

Reform policy-making at an international level

Multilateral decision-making processes are needed to find effective and fair solutions. However, the current processes seem unable to stimulate the necessary transformative changes in time. As part of a pragmatic response, the focus could be on three complementary strategies. First, progress may result from new coalitions of the willing, consisting of both state and non-state actors, such as municipalities, businesses, NGOs and local citizen organisations. Through their cooperation, they could contribute to a scale up of local solutions. Second, sustainability actions could be reframed, finding new and more appealing concepts and narratives to mobilise citizens, businesses and governments around the world. Examples include concepts, such as the green economy, resource efficiency, energy security and human health. These framings are based on the aspirations, primary concerns and interests of societal actors. Third, institutions that deal with sustainability at international level could be reformed. This would include a strengthening of sustainable development within the United Nations, ensuring a better science–policy interface, and giving businesses and non-governmental organisations a stronger role within the international system.

1 Introduction

Today's challenges and the challenges that lie ahead ask for a more effective approach to sustainable development

In 1992, the world agreed to strive for sustainable development by adopting the Rio Declaration, Agenda 21 and the Rio-conventions. There is a general consensus that sustainable development is about improving human development (i.e. satisfying human needs and aspirations) while ensuring environmental sustainability (i.e. staying within the carrying capacity of the planet). Since 1992, the world has seen improvements in welfare, and reductions in both poverty and local environmental problems. However, in two priority areas – *food, land and biodiversity* and *energy and climate* – policies have not led to a reversal of historical, unsustainable trends. In this context, the main message of this report is that there is a clear need to strengthen current policy efforts and to search for more effective ways of sustainable development governance. There are four important reasons for this: 1) the slow progress, so far; 2) the changed geo-political, economic and societal context; 3) the expected consequences if current trends continue; and 4) the radical changes needed to achieve sustainable development goals. These factors will be explored further in the following sections.

Since 1992, the geo-political, economic and societal context has changed considerably

One reason for adapting the current governance approach is the changed geopolitical, economic and society context. In 1992, differences were clear between country groupings, in terms of economic developments and their contribution to environmental problems, and related to this, the responsibilities of these groups. However, economic and geopolitical developments since then have resulted in a far more diverging picture. This clearly has consequences for policy-making. Also, civil society has become much more actively involved in governance processes. An important factor here is that new media are able to spread information and opinions much more rapidly and effectively than ever before. The context has also changed due to the significant advancement of the science that underpins many sustainable development issues since 1992 (most noteworthy that of climate change). And then there are the current economic and financial crises, which imply that several countries may need to reconsider their economic model, while at the same time there are less public funds available for resolving sustainability problems. Finally, there is widespread concern about the political willingness and institutional capacity to build a strong multilateral system that is capable of dealing with sustainability problems.

This report explores the efforts needed to achieve a set of ambitious long-term sustainable development goals, consistent with existing international agreements

The main purpose of this report was to provide an assessment of the efforts needed to achieve a set of sustainable development goals. For this assessment, we used model-based scenario analysis as well as an analysis of governance issues to explore elements for a more effective governance approach. We looked into the question of how a set of long-term sustainable development goals could be achieved. The set of sustainable development goals has been based, as much as possible, on the ambitions expressed in existing international agreements. For human development goals, we concentrated mostly on the development aspects that are directly related to the environment, that is, the access to natural resources and the influence of environmental factors on health.

The report focuses on two key clusters of sustainable development issues: 1) food, land and biodiversity loss, and 2) energy, air pollution and climate change
Several reports have studied the current situation with respect to environmental and development issues and possible future developments, including the Millennium Ecosystem Assessment (2005), the OECD Environmental Outlook to 2050 (2012) and the Global Environmental Outlook to 2030 (2007). From these reports, the conclusion can be drawn that two clusters of issues play a critical role in the sustainable development debate: 1) ensuring sufficient food supply while conserving biodiversity, and 2) ensuring a modern energy access for all while limiting global climate change and air pollution. This report elaborates pathways that will achieve sustainable development goals by 2050, for these key clusters. In addition, the impacts of reaching these goals on water use, nutrient balances and human health were analysed. Although the pathways share many common elements, they differ in the emphasis that they place on the role of global technologies, decentralised solutions and necessary consumption changes.

The analysis focused on the following questions:
- *What could be sustainable development goals for 2050, for energy, climate, food and biodiversity? (Section 2)*
- *What are the historical and expected future trends related to these goals? (Section 3)*
- *Which barriers have prevented goals from being achieved (Sections 3 and 4).*
- *Which efforts would be needed to bend current trends, in order to achieve the sustainable development goals? What are the key dilemmas, synergies and trade-offs with respect to this effort? (Section 4)*
- *Which policies are needed to achieve these goals and what are the consequences for governance? (Section 5)*

The analysis is intended to contribute to the development of a vision on sustainable development. The methodology applied is described in Box 1.

The report distinguishes between *objectives*, *goals* and *targets*. *Objectives* refer to visions, such as free people from poverty, halt biodiversity loss, and avoid dangerous anthropogenic interference with the climate system. *Goals* are more generic and often more long term, such as the 2 °C target (Copenhagen Agreement) and the ambition to eradicate poverty and hunger (Millennium Development Goal 1). *Targets*, finally, are more specific and short term, such as the Kyoto targets for the 2008–2012 period and the MDG target to halve, between 1990 and 2015, the proportion of people who suffer from hunger.

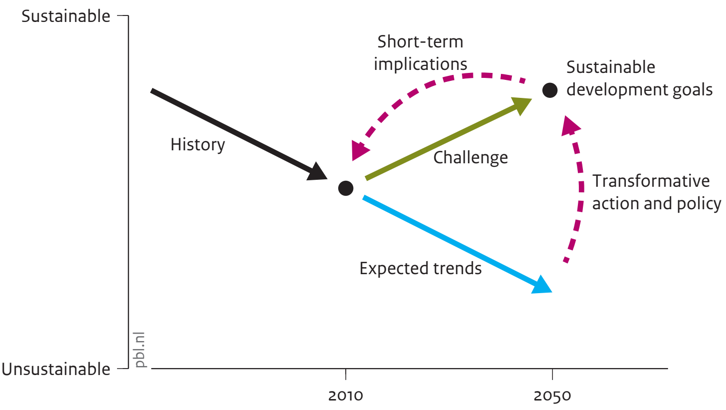
Box 1 Methodology applied in the report

The analysis is based on a model-based backcasting approach combined with analysis of governance issues

For this report, a backcasting approach was used, meaning that pathways were designed that would achieve the sustainability goals to explore the level of effort involved (taking into account technical feasibility constraints). Earlier assessments have focused specifically on separate issues (e.g. on climate), whereas, for this report, we considered the challenge of achieving a comprehensive set of goals, within the same time frame, for different issues. It is clear that there are important linkages between these issues; integrated assessment models can be used to explore these issues. We used the PBL integrated assessment model IMAGE in combination with related models for biodiversity, human health and climate policy (GLOBIO, GISMO and FAIR, respectively). These models provide a global overview, while differentiating between world regions. They have been used in many global and regional assessments, including for the IPCC, the OECD Environmental Outlooks, the UNEP's Global Environment Outlooks, and the Millennium Ecosystem Assessment.

Figure 1

Backcasting analysis, working back from a sustainable end point to determine actions for today



Source: PBL

Indicative representation of the analytical set up of this report. The Trend scenario depicts the possible trends in the absence of strengthened policies. The Challenge pathways explore how to achieve a set of sustainable development goals.

In total, four scenarios or pathways were analysed. The *Trend* scenario is designed to describe possible trends in the absence of strengthened policies. Three *Challenge* pathways were designed to achieve a comprehensive set of sustainability goals. The different measures (technology, consumption changes) included in these pathways and the policy instruments that could bring us from the *Trend* scenario to the *Challenge* pathways in order to achieve the goals are referred to as transformative action and policy. This approach is illustrated in Figure 1.

The scenario analysis concentrates on the physical changes required to achieve a particular set of sustainability goals. The models took into account, as much as was possible, the limitations in terms of physical and economic feasibility (e.g. potential for improving yields and the capital turnover rate in the energy system). Political and societal feasibility (i.e. whether such changes could actually be implemented based on an assessment of the current political situation) were not accounted for in the scenario analysis. Instead, we used the scenario outcomes to assess some of the policy consequences.

2 Long-term vision and goals for food, biodiversity, energy and climate

It is important to develop a consistent vision with long-term goals and short-term targets that integrate different sustainable development themes
At the moment, an overall vision on sustainable development seems to be lacking. The formulation of goals and targets in various agreements is often unrelated, uses different time frames, is based on different degrees of concreteness, and are sometimes even missing. Given the large number of interactions between various sustainable development issues, a clearer vision on sustainable development, including long-term goals and short-term targets could be an important building block for a worldwide effort on sustainable development. Such an approach has shown to be effective for the Millennium Development Goals (MDGs), and, in preparation of the Rio+20 conference, proposals have been made to take a similar approach for sustainable development.

In our analyses of the pathways to achieve a set of environmental and development goals and targets, wherever possible, we derived these goals and targets from international agreements. In some cases, these agreements include formulations of quantifiable targets. In other cases, we interpreted existing qualitative formulations based on the scientific literature. The selected goals are summarised in Box 2.

For *human development*, international agreements have mostly concentrated on minimum conditions for a decent life for each individual. The main overarching international agreement is that of the Millennium Development Goals (MDGs). For the *environmental dimension*, a large number of international agreements have been formulated to prevent further degradation or even reverse the historical processes. The most relevant agreements to our analysis were the UN Framework Convention on Climate Change (UNFCCC) and the Convention on Biodiversity (CBD).

Box 2 The development and environmental goals analysed in this study

The sustainable development goals analysed in this study were derived from existing agreements. The goals explored in this report are those related to the principles of the Rio declaration, in particular Principle 5 (eradicate poverty) and Principle 6 (conserve the Earth's ecosystem).

Goals for food, land and biodiversity loss:

- Halve, between 1990 and 2015 , the proportion of people who suffer from hunger; halve this again by 2030, and fully eradicate hunger by 2050;
- Halve the rate of loss of biodiversity by 2020 and maintain biodiversity at the 2020/2030 level by 2050 (depending on region).

Goals for energy, air pollution and climate:

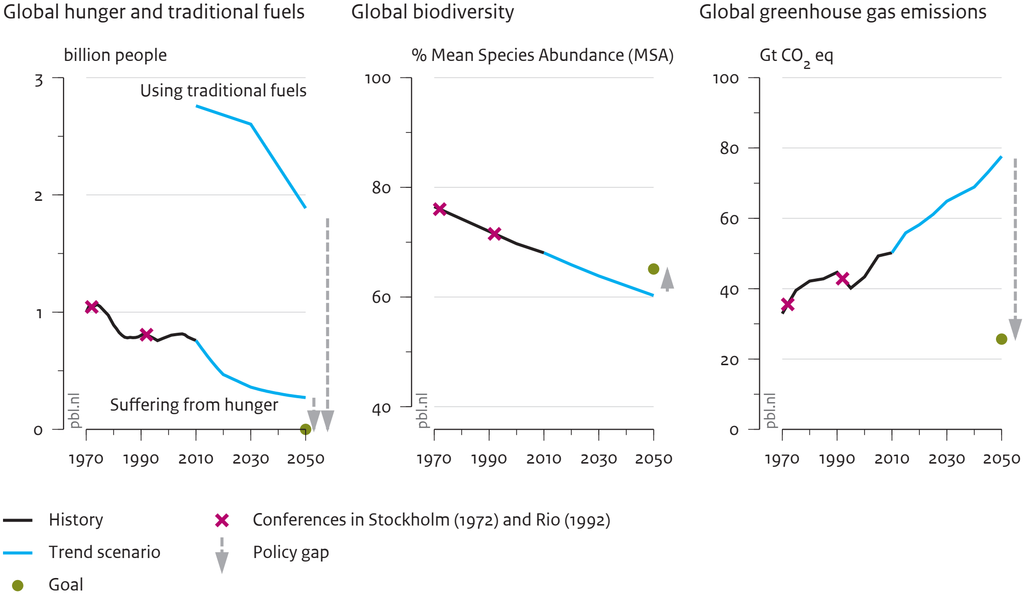
- Achieve universal access to electricity and modern cooking fuels by 2030;
- Avoid temperature increases above 2 °C keep atmospheric greenhouse gas concentrations below 450 ppm CO_2 equivalent;
- Keep annual $PM_{2.5}$ concentrations below 35 µg/m^3 by 2030.

3 What are the historical and expected future trends related to sustainable development goals?

Although the outcomes of the UNCED conference have been the basis for many activities aiming towards more sustainable development, these have not been able to bend the trend in some critical areas of sustainable development

The 1972 Stockholm Conference and the 1992 Rio Conference have led to many new institutional arrangements and activities aimed at achieving a more sustainable development. In some areas, also clear progress has been made, such as reducing absolute poverty and improving access to safe drinking water; as both MDG targets are likely to be achieved by 2015. In other, critical areas of sustainable development actions have not been able to bend the trend, such as for providing access to sufficient food and

Figure 2
Key indicators of sustainability in the Trend scenario



Source: PBL

Historical and projected trend for key indicators, in a situation without new policies. The sustainable development goals analysed in this study and the policy gap are also indicated. There are various indicators for biodiversity. Here, we use MSA (mean species abundance). This indicator is related to naturalness.

modern forms of energy, preventing dangerous climate change, conserving biodiversity and controlling air pollution. Figure 2 shows this for a number of key indicators addressed in this report:

- *Number of people suffering from hunger*: the absolute number of people suffering from hunger has remained almost constant since 1992. While some progress was made to reduce hunger up to the mid-2000s, increasing food prices have led to more people without sufficient access to food, especially in sub-Saharan Africa and South Asia.
- *Access to modern energy*: almost one billion people currently have no access to electricity and almost three billion people still use solid fuels for heating and cooking. This has clear negative impacts on human health and development prospects.
- *Decline in biodiversity*: biodiversity, as measured in mean species abundance (MSA)[1], has continuously declined since 1992, mostly due to habitat loss, but also to increasing environmental pressures and disturbance. The extent of natural area decreased by some 4.6 million km² since 1970.

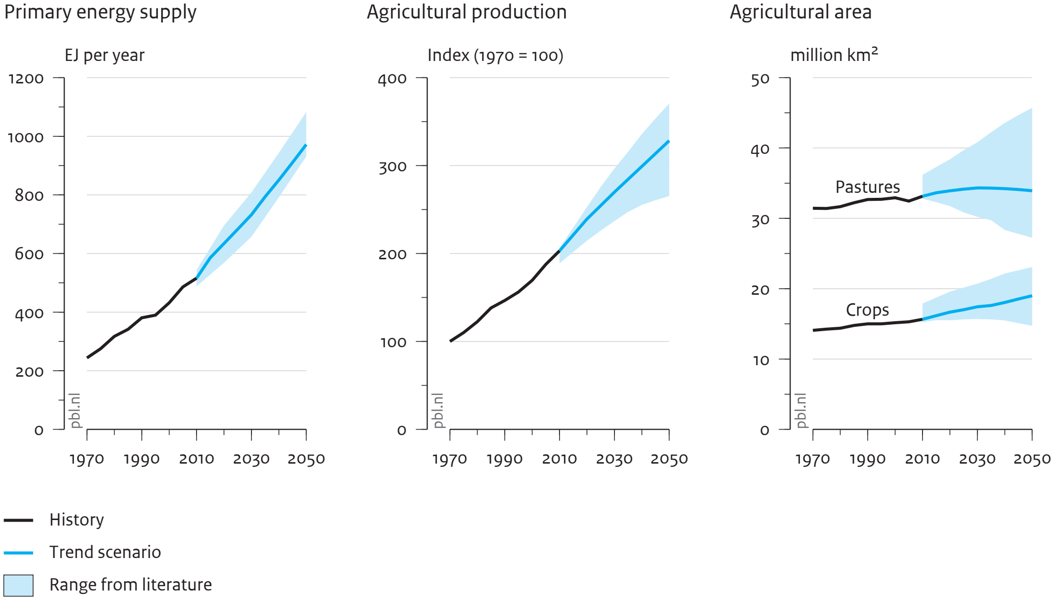
- *Climate change*: greenhouse gas emissions increased by around 30% over the 1992–2010 period.
- *Air pollution* (not shown): Although air pollution was reduced in OECD countries and some developing countries, it has increased in the cities of many other developing countries.

Several barriers have prevented sustainable development targets from being achieved
A number of generic barriers are mentioned in the literature, which, together, could explain why current sustainable development goals have not been achieved:
- *Short-term interests* tend to be *prioritised over long-term concerns*.
- There are many different interests; some actors will win and others will lose in the transition towards sustainable development. *Vested interests cause resistance to the required changes*.
- *Lack of connection between the environment and development*. Energy and land-use policy-making is often *fragmented* and sustainable development concerns are often not integrated into processes of general, economic decision-making (mainstreaming).
- This problem is amplified because of the *lack of a strong institutional framework* to handle global problems at international level.
- *Incentive structures are not conducive to sustainable development*. Current economic incentives often award private benefits at the cost of public interests. Incorporation of environmental and social costs is lacking in many areas.
- The *inability to address absolute poverty, especially in Africa*, is also visible in the insufficient progress made with respect to ensuring access to modern energy and food security.

Population and income growth are projected to lead to strong growth in the demand for food and energy by 2050
In the *Trend* scenario, the world population is projected to continue to grow from around 7 billion people in 2010 to 9 billion by 2050. This growth mostly occurs in sub-Saharan Africa and South Asia. At the same time, economic projection (based on the OECD Environmental Outlook to 2050 (2012)) shows a further increase in per-capita GDP in all world regions. Most economic growth is expected in developing countries. Towards 2040, the highest growth rates are projected for Asia. After 2040, the highest per capita growth rates are projected for Africa, although it will remain the continent with the lowest per capita income levels.

As a consequence of these trends, a strong increase in the demand for energy and agricultural products and related land use is projected (Figure 3). Figure 4 shows in more detail how the demand for agricultural products is driven by both population and income growth (they carry a more or less equal weight over the 2010–2050 period). In agriculture, historically, most of the additional demand was met through an increase in productivity per hectare; about 20% of the increase in agricultural production was generated by expanding the total agricultural area. This practice is expected to continue, leading to some further expansion of agricultural areas (in particular for crops)

Figure 3
Global energy supply, agricultural production and agricultural area in the Trend scenario



Source: PBL/LEI

Energy production, food production and agricultural area, under the Trend scenario. The blue areas indicate the range of projections in the literature.

and to a further loss of natural areas. Nevertheless, as global population growth will slow down around 2050, global land-use expansion is projected to stabilise near the end of the scenario period. Energy demand is expected to grow by 60% to 80% over the 2010–2050 period, with few signs of stabilisation. Most of the demand under this scenario is expected to be met by fossil fuels.

The sustainable development goals will not be achieved under the *Trend* scenario
In the *Trend* scenario, the following developments are foreseen with respect to the sustainable development goals (Figure 2):

- As far as global hunger is concerned, the *Trend* scenario shows some clear improvement, in contrast to the last few decades. This improvement is a consequence of a rapid income growth in low-income regions and levelling-off of population growth.
- For biodiversity, a further decline is projected – at an almost linear rate. Although, historically, habitat loss has been the most important driver of biodiversity loss, for the future, climate change, forestry and infrastructure development are projected to become important factors, as well.

- Greenhouse gas emissions are projected to grow by another 60%. Global mean temperature, therefore, is projected to surpass the 2 °C goal well before 2050 and to continue to rapidly increase. By the end of the century, a global mean temperature increase of more than 4 °C is then likely.
- Access to modern energy sources is projected to improve, largely driven by the relatively high economic growth in developing countries. However, due to population growth, persistent poverty and inequality, and increasing energy prices, around two billion people will still rely on solid fuels for heating and cooking by 2050.
- Finally, air pollution levels are expected to decrease in high-income countries, in line with the historical trend. In most developing countries, however, increasing energy production is projected to be associated with more air pollution.

Many of the developments depicted above will lead to considerable costs. Persistent hunger and lack of access to modern energy sources imply that the development opportunities for a large number of people would still be seriously hampered. Further degradation of ecosystems will also come at a cost. For instance, climate change could lead to considerable costs related to sea level rise, crop yield decreases and higher risks of extreme weather events. Air pollution will lead to costs in terms of health damage and reduced crop growth. Biodiversity loss, in turn, is shown to negatively affect ecological goods and services.

4 Which efforts would be needed to bend current trends, in order to achieve the sustainable development goals?

Three alternative pathways that combine different assumptions on the use of technology and consumption changes were used to explore how sustainable development goals could be achieved
We do not imply that these are the preferred development trajectories, nor that they are the only pathways possible. The pathways differ in their emphasis on changing consumption patterns, the role of large-scale technology and the focus on global versus local approaches.

Table 1
Characterisation of analysed pathways

Pathway	Main assumption
Global Technology	Achieves the 2050 targets, with a focus on large-scale technologically optimal solutions, such as intensive agriculture and a high level of international coordination; for instance, though trade liberalisation
Decentralised Solutions	Achieves the 2050 targets, with a focus on decentralised solutions, such as local energy production, agriculture that is interwoven with natural corridors and national policies that regulate equitable access to food
Consumption Change	Achieves the 2050 targets, with a focus on changes in human consumption patterns, most notably by limiting meat intake per capita, by ambitious efforts to reduce waste in the agricultural production chain and through the choice of a less energy-intensive lifestyle

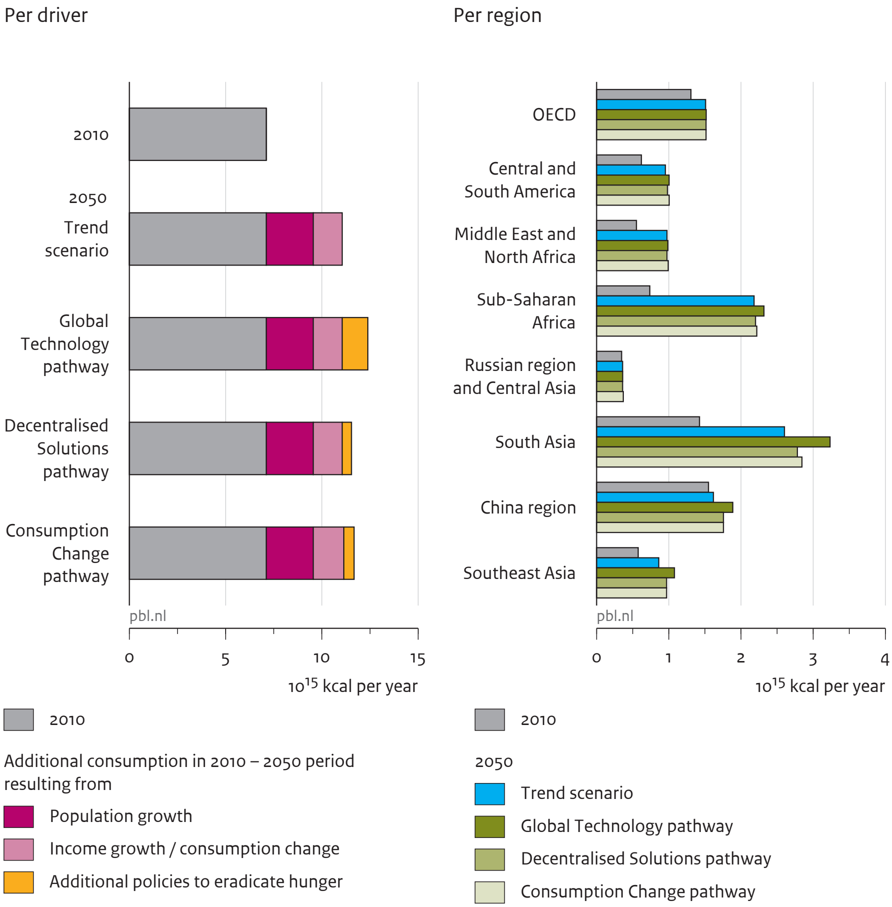
4.1 Food, land use and biodiversity

Fundamental policy issues need to be addressed, in the coming decade, to ensure progress in achieving the sustainable development goals related to food, land use and biodiversity
One overarching goal can be formulated with respect to the biodiversity and food cluster: eradicate hunger and maintain a stable and sufficient food production by 2050 while conserving biodiversity and ecosystems. The analysed biodiversity target was derived from the CBD's long-term vision to *conserve, value, restore and wisely use biodiversity*. The target to eradicate hunger was derived from MDG1 and extrapolated to 2050.

Several trends influence the efforts to reach these goals. With an estimated 925 million people undernourished in 2010, food insecurity continues to hamper development and keeps people trapped in poverty. The ambition to improve their circumstances, however, has to be realised against a backdrop of an increasing demand for food, feed and fuels, which requires agricultural production to increase by 60% to 70% in less than four decades. Over the last decade, however, we have seen a slowdown in the growth in agricultural productivity and climate change is expected to negatively affect crop production in tropical regions. These factors, together, are likely to lead to an increase in competing land claims, which, in turn, could lead to higher and more volatile food prices and loss of biodiversity. In addition, increasing fragmentation, pollution and climate change also will lead to the degradation and loss of ecosystem services.

Over the last decades, several barriers have slowed down progress towards achieving sustainable development goals, in particular: 1) persistent low incomes limit access to food, certainly if higher and more volatile food prices become a new reality; 2) many smallholder farmers have limited opportunities to increase production; 3) low levels of public investment in agricultural research and development; 4) natural capital and ecological goods and services are undervalued in public policy and planning; 5) a lack of consideration for biodiversity concerns in other policy areas; and 6) many countries

Figure 4
Global calorie consumption



Source: PBL/LEI

The lion's share of the growth in food demand until 2050 will be driven by population and income growth in developing countries. The pathways differ in total caloric consumption, based on assumptions on how to ensure access to food for the poor, on reducing waste within the food chain, and on dietary change.

have a limited financial, technical and administrative capacity to manage natural capital. These need to be addressed if sustainable development goals are to be achieved.

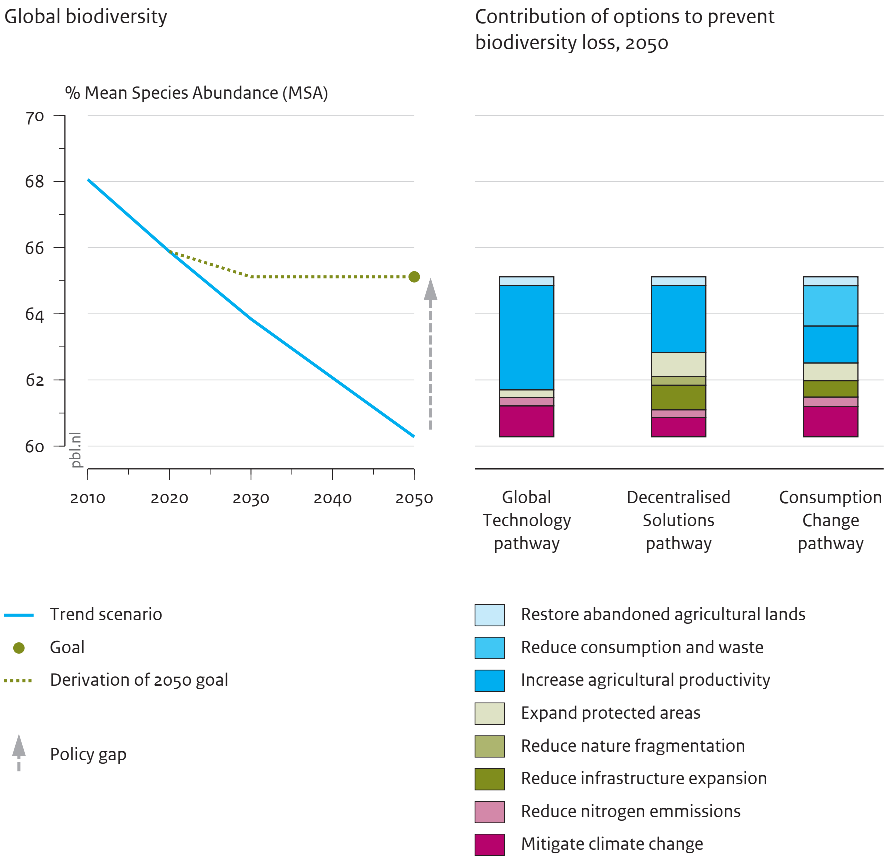
The additional amount of food required to eradicate hunger is only small, compared to the autonomous growth in demand

Figure 4 shows the total caloric consumption level in each region, as well as the relative importance of the drivers of increased demand; that is, population growth and income growth leading to dietary changes. Ensuring that the food system will be able to supply this additional demand presents a formidable challenge, and most of this additional demand will be in developing regions. The sustainable development goal adopted in the pathways is that of eradicating hunger by 2050 through different combinations of global or local agricultural production increases and more equitable access to food (representing national policies targeting the poorest groups within society). Compared to total production levels, this additional amount of food to eradicate hunger is only small. In other words, providing full access to food does not need to represent a serious trade-off with the conservation of habitats and biodiversity.

Each pathway would prevent over half of the projected future biodiversity loss and would stabilise the extent of natural areas, but differ fundamentally in their approach
There is a significant loss of biodiversity projected under the *Trend* scenario up to 2050. The pathways all show that it would be possible to arrive at the 2050 biodiversity target, which was set at the biodiversity level of 2020/2030 of the *Trend* scenario (Figure 5). In fact, this would imply that the net extent of natural area would be maintained at the 2010 level. However, the three pathways use very different combinations of measures to achieve this goal. Under the *Global Technology* pathway the most important contribution by far comes from increasing agricultural productivity on highly productive lands. Under the *Consumption Change* pathway, significant reduction in the consumption of meat and eggs as well as reduced wastage means that less agricultural production would be required, thus, reducing the associated biodiversity loss. Under the *Decentralised Solutions* pathway, a major contribution would come from avoided fragmentation, more ecological farming and reduced infrastructure expansion. Under all scenarios, climate change mitigation, the expansion of protected areas and the recovery of abandoned lands also significantly contribute to reducing biodiversity loss.

All pathways require a substantial increase in agricultural productivity to ensure that sustainable development goals are achieved
Under the *Trend* scenario, the annual growth in agricultural productivity is projected to decline further in line with the trend over the past 15 years (see Figure 6 for cereals). An important reason for this fact is that, in different parts of the world, yields are getting closer to potential maximum achievable levels; the easiest measures have already been implemented and public investment in agricultural research and development has been slowing down, in relative terms. In the pathways, however, a much higher productivity growth would be needed to achieve the goals. The required increase in productivity would be the highest under the *Global Technology pathway*, which is twice that of the *Trend* scenario (1.3% annual increase versus 0.6%). In the other two pathways, however, productivity improvements would also need to be above the *Trend* scenario level. Analysis has shown that several technological options exist for increasing yields sustainably, could be applied in the various farming systems around the globe. The relatively low yields achieved in some developing countries, in particular in sub-Saharan Africa, provide significant potential for improvement, although, to date, socio-economic

Figure 5
Global biodiversity and options to prevent biodiversity loss



Source: PBL

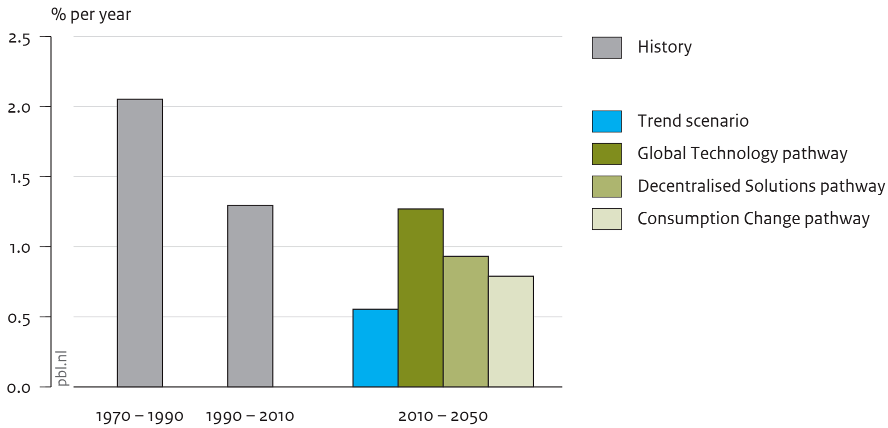
There is a range of options available to achieve the goal on biodiversity. The three pathways each have a different emphasis, but all make clear that global biodiversity conservation requires efforts on many fronts.

factors have acted as barriers, in this respect. Clearly, a massive effort would be needed to improve yields in developing and developed countries.

The consumption of fewer animal products and reductions in food losses would considerably reduce the need to increase yields

The *Consumption Change* pathway shows that not only technical measures may help to ensure the achievement of sustainable development goals; limiting consumption of meat and dairy products and reducing food losses would also be especially effective for achieving the goals. The production of livestock products demands large tracts of land

Figure 6
Increase in global cereal productivity



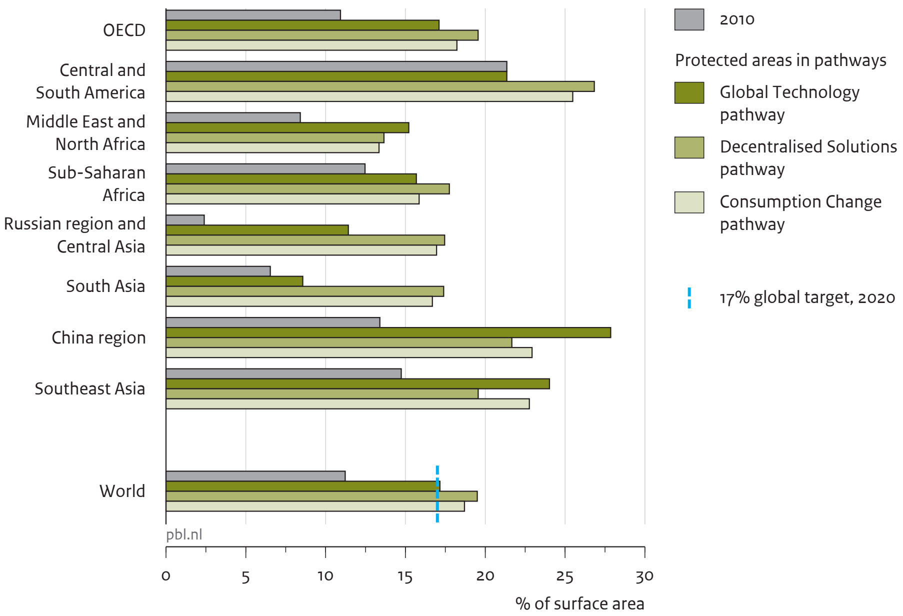
Source: PBL / LEI
The Trend *scenario projects the decreasing trend of cereal productivity growth to continue. In the pathways, a reversal would be needed in order to satisfy increased demand and limit expansion of agriculture area.*

for grazing and feed production, because of the inefficiencies in converting feed into meat and dairy produce. Moreover, estimated food losses stand at one-third of agricultural production.

Mono-functional and multifunctional landscapes both have significant scope for increased and more sustainable production, but require improved land-use planning for optimal use

Multifunctional landscapes may offer areas of agriculture that are highly interwoven with nature areas, improving local ecosystems and connectivity between natural areas. It is likely that such an approach would lead to somewhat lower production intensities compared to mono-functional landscapes. Mono-functional landscapes, however, may lead to more local biodiversity loss. Clearly, both systems have considerable scope for a more sustainable and higher productivity. In mono-functional landscapes, low external environmental impacts may be achieved by a strong emphasis on resource efficiency using cutting edge technological refinements, agronomic optimisation of the farm environment and new animal breeds and crop varieties that perform best under these optimised conditions. In multifunctional landscapes, high yields may be achieved by combining technological advances with the services provided by natural processes. The differences between these systems may become smaller due to the current direction of agricultural research, allowing for improved production in agro-ecological systems and reduced impacts in intensive systems.

Figure 7
Globally protected areas per region



Source: PBL

The pathways employ different rules to allocate new areas to be protected – effectively protecting 17% of the global terrestrial area.

International cooperation on protected areas will be needed

Biodiversity hotspots and other protection targets are often unevenly distributed across the different continents. In the pathways, we assumed different allocation schemes to protect on average 17% of the terrestrial areas. Still, in all pathways, Central and South America, China and Southeast Asia would be required to protect more than 17%, due to the ecological value of their ecosystems (Figure 7). Especially in developing regions, establishing effective protection in current and future protected areas is challenging. Internationally, however, costs would seem to be modest, especially considering the benefits that protected areas may bring; for instance, via ecosystem service management and tourism. Mechanisms to facilitate and scale up international financing of protected areas are essential.

Box 3 Key issues for the coming ten years to eradicate hunger and maintain a stable and sufficient food production by 2050 while limiting biodiversity loss

Accelerate the sustainable intensification of agriculture
As shown, relatively high rates of agricultural productivity improvement would be required during the 2010–2050 period. Improvement rates would need to be scaled up in the near future, in order to avoid requiring even higher improvement rates in the more distant future. Most of the technologies required for sustainable intensification are already being used by best performers or are in an advanced stage of development. Scaling up these improvements is key. A first step would be to better enable farmers to make long-term investments; for instance, by improving market transparency, price stability and secure land tenure. Concurrent action will be needed to address externalities; for example, by removing distorting subsidies, implementing regulation to discourage land conversion and/or creating income opportunities from preserving nature and ecosystem goods and services. Reversing the trend in public investment in agricultural research and development, particularly in developing countries, is also a priority.

Create a more robust food system
The effects of extreme or unexpected food price volatility on farmers and consumers can be mitigated by improved stock management, creating more transparent and well-functioning market mechanisms and investing in more climate-resilient agricultural systems. Putting domestic safety nets in place to mitigate the impacts of high and volatile prices on the poorest consumers is also important. Another important measure is to monitor the land used for bio-energy and to act in case of excessive land claims.

Integrate biodiversity and ecosystem services into land-use planning and management
Integrated land-use planning requires the ability to assess the different demands and uses for land, and to have the administrative capacity to translate these into policies and action on the ground. For this to work, financial, technical and administrative capacities must be developed. The consideration of ecosystem services in land-use planning could lead to better-informed decisions and more optimal allocation of land to different uses.

Initiate a shift towards alternative consumption patterns
Reducing the consumption of animal products emerges as a robust measure to mitigate climate change and limit biodiversity loss. This would imply a more forceful steering of consumption patterns. Potential instruments include regulation, economic incentives, and information campaigns. It might be that a focus on health benefits of reduced meat consumption could be the best avenue to initiate a shift towards alternative consumption patterns.

4.2 Energy and climate

Key challenges in the energy sector include: provide sufficient energy for the rapidly increasing global demand for energy services, ensure access to modern energy for all, reduce the environmental impacts of the energy system and improve energy security

This report concentrates specifically on the question of how to provide access to modern energy for all, while substantially reducing greenhouse gas emissions as well as air pollution. Historically, there have been several barriers that have slowed down progress in responding to energy challenges. In addition to the generic barriers mentioned in Section 3, the following extra barriers apply: 1) pervasive doubt about the extent and seriousness of climate change; 2) large and conflicting interests in the energy system; 3) lock-in dynamics and subsidising of fossil fuels; 4) uncertainty regarding energy prices; 5) a bias towards supply-side investments over those on the demand side; and 6) a lack of commitment to address the energy needs of the poorest segments of the population.

Universal access to electricity and clean fuels for cooking and heating has large development benefits and can be achieved at relatively low costs

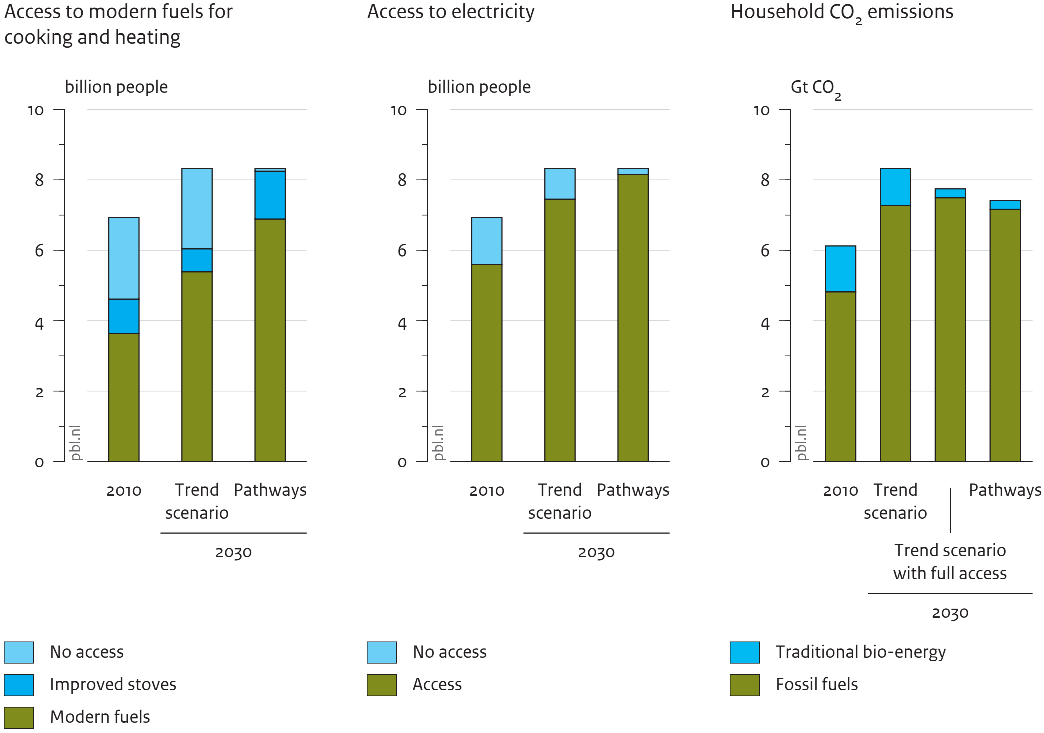
Analysis has shown that ensuring access to modern energy sources for heating and cooking as well as electricity may lead to multiple benefits. It reduces health damages from air pollution, improves development opportunities through electrification and a reduction in the time spent collecting firewood, and decreases deforestation. However, a large number of people still have only limited access to modern energy. Despite some level of improvement, under the *Trend* scenario, for one to two billion people a lack of such access is projected to continue.

Our analysis shows that it is possible to increase access to modern fuels for cooking and heating through well-targeted subsidies of cleaner fuels, such as LPG and kerosene, combined with grants or micro-lending facilities to improve the affordability of the required stoves (Figure 8). Additional programmes are likely to be needed in areas where poverty remains high, such as the distribution of improved biomass-fuelled cooking stoves. These stoves are more efficient and less polluting than conventional ones. Improving access to electricity requires a combination of grid expansion, decentralised mini-grids and off-grid systems. The cost of achieving universal access to modern energy sources is estimated at around USD 70 billion, for the 2010–2030 period. The economic benefits of improving health and providing development opportunities are likely to far outweigh these costs.

Ensuring universal access to modern energy leads to only a small increase in fossil-fuel related greenhouse gas emissions, and, overall, may even lead to a decrease

One of the main results from our analysis consists of the indication that providing access to modern energy sources would only have a small impact on greenhouse gas emission levels, even if the programme would focus on providing fossil fuels (in order to limit

Figure 8
Global household access to modern fuels and CO_2 emissions



Source: PBL

Providing access to modern energy would lead to only a small increase in fossil-fuel-related emissions and, overall, possibly even a decrease. Here, it is assumed that traditional bio-energy is not fully carbon-neutral.

costs). The net result may even be a reduction in greenhouse gas emissions. The reasons are that the per capita energy consumption of the people involved would (initially) be low. In addition, the same energy services could be provided much more efficiently when using modern fuels. Moreover, by increasing modern energy use, the emissions associated with the traditional use of biofuels would be reduced, including CO_2 emissions from deforestation and black carbon emissions from poor combustion. In other words, providing access to modern energy and climate mitigation do not necessarily present a trade-off. However, one should note that climate policies that increase fossil-fuel prices could potentially make the transition to modern energy sources and services more difficult; climate policy should thus be designed in a way that negative impacts on poor households are avoided.

Achieving air pollution and especially climate targets would require fundamental changes to the energy sector, compared with current trends

Greenhouse gas emissions are projected to grow by 60% under the *Trend* scenario. However, to reach the 2 °C target, global emissions would need to be reduced by around 40% to 50 % by 2050. Various pathways for such a transition have been published in the literature, each with a different emphasis on technologies and behavioural changes. One way to illustrate the fundamental shift is to use the decarbonisation rate of the global economy (Figure 9). This is the reduction in the ratio between CO_2 emissions and GDP. Historically, the highest improvement (over a five-year period) occurred during the 1980s at around 2% annually, driven by the high energy prices of the late 1970s and early 1980s and subsequent government response programmes. Under the *Trend* scenario, the historical annual rate of 1% to 2% is projected to continue. To achieve the 2 °C target, however, the decarbonisation rate would need to reach a level of around 4.5%, on average, over the 2010–2050 period. In the pathways, this rate is projected to slowly increase from 2010 onwards, based on all kinds of inertia, and implies an annual improvement rate of 5% to 6% around 2030. Rapid reductions would also be required to avoid overshooting the 2 °C target. After 2030, emission reduction could slow down somewhat, given the dynamics of the climate system and the depletion of low-cost mitigation options. The required improvement rate of 4.5% to 6 % is around three to four times the historical rate.

Energy efficiency improvement and decarbonisation of the energy supply both play a major role in reducing emissions

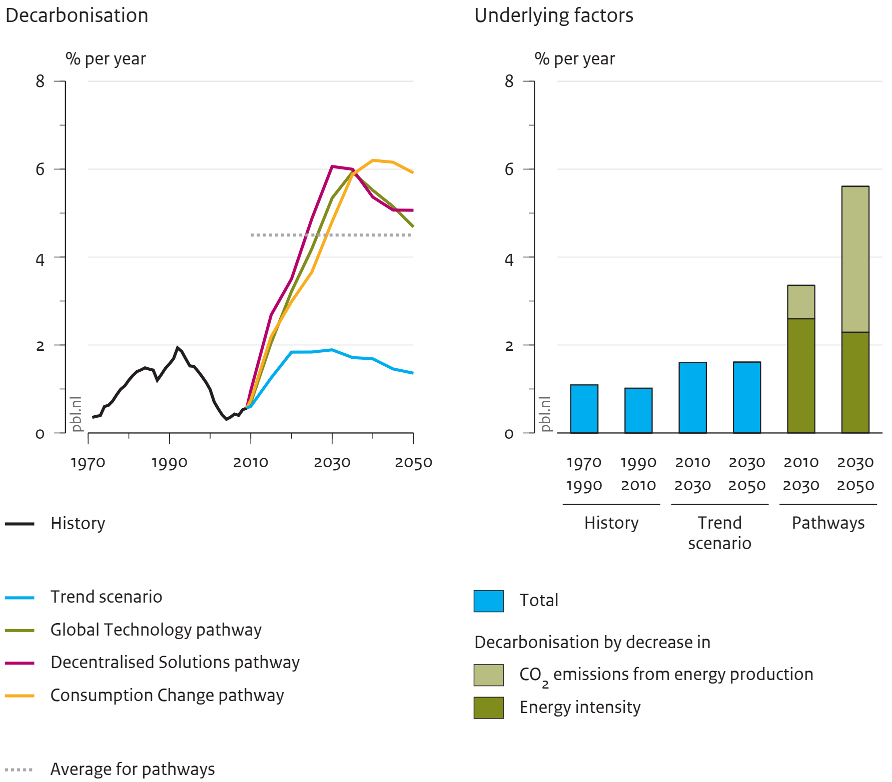
Decarbonisation may be achieved both through energy-efficiency improvements and rapid changes on the supply side. The change over time, for these factors, is shown in the right panel in Figure 9. As shown in various studies, it would be technically possible to reach such decarbonisation rates. However, it remains debatable whether this would still be possible if other factors are accounted for, such as societal inertia and the time it would take to govern this transition. Some key energy technologies have experienced rapid expansion in the past, such as natural gas infrastructure in some countries during the 1960s and 1970s, and, more recently, the use of combined cycle technology in the power sector. However, clearly, such rates are only possible if supported by focused government programmes and sufficient societal backing.

The energy transition would rely on several technologies. The changes required in the energy system are fundamentally different from current trends

Figure 10 shows how different mitigation measures contribute to the emission reductions required to achieve the 2 °C target. Table 2 summarises the consequences for the energy system in terms of key technologies in energy supply, both on the basis of the pathways of this report and of existing literature. Some important measures are discussed below.

Reducing other greenhouse gases, such as cutting gas flaring and industrial N_2O emissions and the recovery of CH_4 from landfills, are relatively inexpensive. An important

Figure 9
Global decarbonisation rate



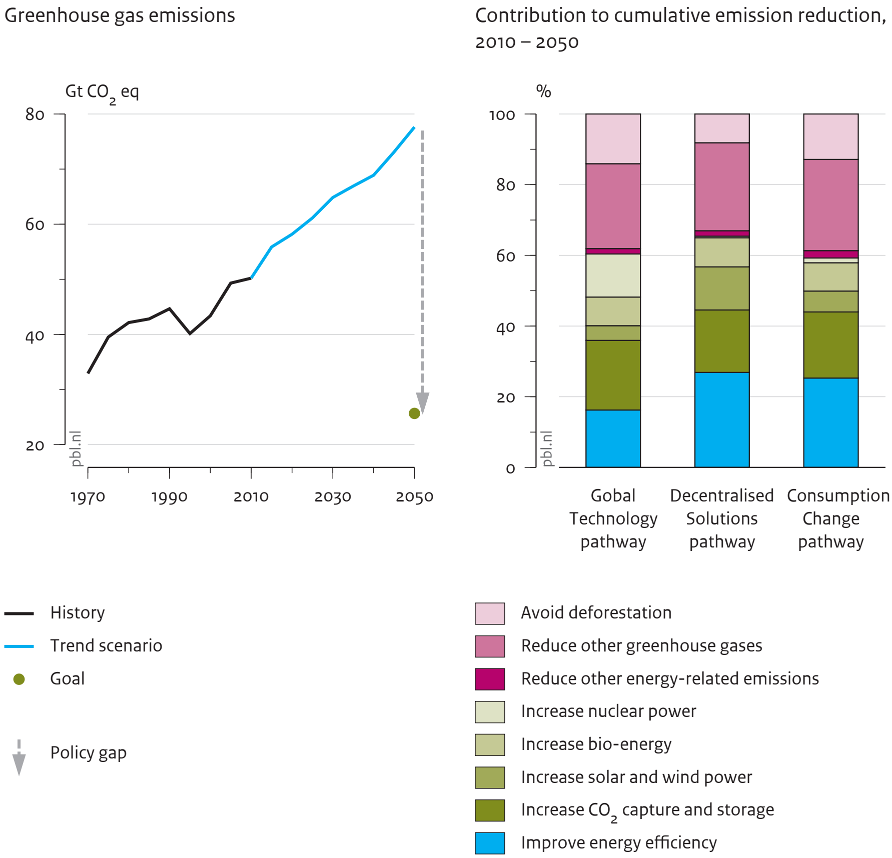
Source: PBL

Under the Challenge pathways, improvement of the carbon intensity would need to be considerably higher than the historical level.

consideration with respect to some non-CO_2 gases are the co-benefits: reducing CH_4 and black carbon emissions would lead to relatively quick gains for climate change and immediate gains in reducing ozone levels and avoiding damage to human health. It should be noted, however, that the potential for reductions in non-CO_2 greenhouse gas emissions is only limited, as emissions from some sources are very difficult to reduce to zero (e.g. N_2O emissions from fertiliser use and CH_4 emissions from ruminant livestock). *Energy efficiency improvements* play a key role. In fact, to reach the targets, energy-efficiency improvements need to occur at double the historical rate. There is considerable scope within the building, transport and industrial sectors, although progress in this area has proven to be difficult in the past. However, there is evidence of standards (e.g. related to appliances or construction) and financial instruments (also to

Figure 10

Global greenhouse gas emissions and options to reduce emissions



Source: PBL

Contribution of different mitigation measures to reductions in greenhouse gas emissions, in the different pathways (note that, although the pathways in this report all use carbon capture and storage, the literature also provides scenarios with less CCS use).

address possible rebound effects) being effective in this field. Potential exists in various sectors. For instance, some improvements could be made in transport by increased efficiency. Many more reductions, however, may be achieved through further electrification or the introduction of hydrogen vehicles, allowing the sector to benefit from the ability to produce electricity and hydrogen, using low- and zero-carbon technologies. In the building sector, considerable potential exists for achieving rapid improvements in the thermal integrity of buildings, by establishing standards for new construction and retrofitting, along with improved appliances and innovative business

Table 2
Share of different technology categories, trend versus alternative pathways

	2000	2050								
		Trend			Alternative pathways					
		This report	EMF22		This report			EMF22		
			Avg	Range	GT	CC	DS	Avg	Range	
Fossil fuel	81	80	79	[68–95]	40	42	40	35	[13–48]
Fossil fuel +CCS	0	0	0	[0–0]	12	20	17	20	[0–31]
Bio-energy	9	6	9	[0–13]	13	14	16	15	[0–28]
Nuclear energy	6	4	3	[1–6]	22	6	2	14	[3–37]
Other renewables	5	10	9	[2–14]	14	18	25	16	[8–24]

Source: PBL/EMF22

NB: GT, CC and DS represent the three pathways considered in this report (Global Technology, Consumption Change and Decentralised Solutions). For comparison, the results from a model comparison study (EMF22) are added for both the Trend scenario and a 2 °C scenario.

models (e.g. energy service companies). Finally, in the industrial sector, energy demand may be reduced, substantially, by the widespread adoption of the best available technology, the retrofit of existing plants, optimisation of material flows and increased recycling.

On the supply side, *low- and zero-carbon energy* would need to provide 50% to 90% of the world's primary energy by 2050 (see Table 2). This could be in the form of non-combustible renewables, bio-energy, carbon capture and storage (CCS) and/or nuclear energy. Many of these options come with their own challenges with respect to implementation and/or sustainability issues, as for bio-energy. In any case, their implementation would require the further development of storage, conversion and end-use technologies and infrastructures, such as smart grids and super grids, and, in general, the rapid decarbonisation of energy systems. It is most likely that financial instruments – such as emission trading schemes, taxation and, first and foremost, the removal of subsidies on fossil fuels – could be successful to stimulate a transition. In addition, governments could also consider specific policies that aim to decrease the costs of clean-energy technologies (risking temporary additional costs).

The transition towards a low-carbon economy will require substantial investments. This could be especially challenging in developing countries
Estimates of the required level of investment in the energy system, over the 2010–2050 period, are substantial, even without a transition towards a more sustainable energy

Box 4 Key policy actions within the next 10 years

Modern fuels need to be made accessible and affordable to achieve universal access
The most important barrier to access is a lack of financing. Well-designed subsidy schemes for clean fuels for poor customers have proven to be successful. However, once incomes reach the level on which households will have the ability to pay, these subsidies need to be phased out.

For the 2 °C target, global emissions need to peak within the next 10 years
Scenario analyses tend to show that emissions need to peak soon, in order not to overshoot the emission budget consistent with the 2 °C target. Further delays could make climate policy very costly. In this context, government should consider phasing out the construction of coal power plants that do not use CCS, before 2020. This situation may be achieved through appropriate pricing, but also through more direct government policies aimed towards utilities.

For international climate policy, seek progress based on pragmatic approaches
It seems attractive to seek progress along different strategies (see also Section 5.4). Develop a consistent multilateral framework that supports energy transition if possible, but also work along alternative strategies that are based on the identification of co-benefits and the connection of 'coalitions of the willing' for energy transition. Clear long-term targets form part of such an approach.

Remove current national energy policy inconsistencies
Energy policies address a large number of different targets, both short term and long term. In order to meet long-term targets, it is important that these are also considered in short-term decisions. For instance, although constructing coal-fired power plants might be the cheapest option to respond to energy security risks, taking a higher cost solution that is more consistent with the long-term targets could in the end be more cost-efficient.

Consider policies that address energy-intensive consumption patterns
The analysis shows that consumer changes may help to ensure sustainability goals are achieved. It is important to stimulate the debate on less energy-intensive consumption patterns, but also to use financial instruments, such as a carbon tax to promote energy efficiency.

Arrange public and private financing for energy transition infrastructures
Ensure that public money is set aside for infrastructures for new energy technologies and for infrastructures that provide access to energy for the poorest people in developing countries. Seek cooperation with business where possible and appropriate; for example, to blend public and private investments.

system. Estimates are of the order of 4% of GDP, for the 2010–2050 period, or about 4% of GDP, if demand-side investment are included. Meeting the sustainable development targets would first of all lead investments in a different direction. Moreover, additional investments would be needed, certainly in the short term. Most estimates of additional investments to reduce greenhouse gas emissions are of the order of 1% to 2% of GDP. Many reduction options tend to be capital-intensive and also more expensive than fossil-fuel-based alternatives. In the long term, however, technology development is likely to reduce the additional costs. It will be necessary to raise the required level of investment to finance the transition, both in developed and developing countries.

Preparing adaptation strategies for climate change would be sensible
The emission reductions assumed in the Challenge pathways would likely lead to an increase in global mean temperature of less than 2 °C. Uncertainties in the climate system, however, imply that warming may also be 3 °C or more, even if emission reductions are successful. There is also the risk of not achieving the emission targets. In other words, countries will need to adapt to climate change and prepare for the impacts of a 2 °C warming, and possibly more than that. It should be noted that part of the adaptation measures to climate change can be introduced at relatively short notice and therefore do not need long-term planning. However, other adaptation measures are slow, such as the raising of dykes and adapting urban planning.

4.3 Related challenges

The land–biodiversity and energy–climate challenges are directly related to other sustainable development issues, such as preventing water scarcity, reducing the imbalances in the Earth's nutrient cycles and preventing damage to human health. These challenges are briefly discussed below, in relation to the critical linkages. Mostly the implications of the food and energy policies are being addressed, but we have also briefly looked into the effectiveness of additional measures.

Water stress is likely to remain an important issue in 2050, even in the Challenge pathways
Many regions worldwide are seriously affected by an imbalance between availability and withdrawal of water (water stress). Agriculture is the main user of water, while water use is increasing most rapidly in the industrial and energy sectors. Water demands are projected to increase strongly, under the *Trend* scenario, and this is projected to result in a doubling of the number of people living under conditions of severe water stress. In the Challenge pathways, water demand is lower, as a result of changes in agricultural production and the impacts of climate policy on the energy system (mainly by reducing demand for thermal cooling). In addition, more efficient water-using equipment would also reduce water stress. The reduction in the number of people living under severe water stress, however, is only limited.

There are various policy instruments to reduce water scarcity, including integrated water resource management, comprising water pricing, regulated access to resources, investing in infrastructure. These and other policy instruments reflecting water scarcity are called upon to adapt to widespread and persistent water shortages. Water pollution prevention and waste-water treatment facilities, also in connection with enhanced sanitation schemes, will improve water quality, thereby enhancing the opportunities for the re-use of water.

Improving access to safe drinking water and basic sanitation requires significant investments in infrastructure expansion. The related additional demand for fresh water would be small compared to total demand and, therefore, would not significantly exacerbate the water scarcity situation. Furthermore, the befits of increased access are high, mainly due to reduced collection time and less health loss from waterborne diseases.

Increasing global food production, involving increases in crop yields, inevitably will push up phosphorus and nitrogen use, which may be mitigated by consumption changes and recycling
Globally, nitrogen and phosphorus fertiliser use inevitably will increase, in order to sustain increasing food production. This increase will be particularly strong in developing countries. Under each of the three pathways, the required additional large increases in crop yields would increase this fertiliser use even further. This effect could only be mitigated by consumption measures, including significant improvements in crop and livestock production, recycling of human excreta and a better integration of animal manure in crop production systems. Strategies for recycling phosphorus (human phosphorus, livestock phosphorus) seem to be most effective, particularly in industrialised countries. Applying these strategies could reduce annual phosphorus fertiliser use from primary sources by 26%, from 26 to 19 million tonnes of phosphorus by 2050. Nevertheless, although the pathways show that agricultural nutrient use may be reduced, compared to the *Trend* scenario, there would still be an increase from today's levels, primarily in transitional and developing countries.

Providing full access to food, water, sanitation and energy could avoid more than 800,000 child deaths, per year, by 2050
Increasing the access to sufficient food, safe drinking water, basic sanitation and modern sources of energy would yield important improvements in the global health situation, by reducing the impacts of infectious diseases, such as diarrhoea and respiratory infections. Providing full access to these basic goods and services would avoid more than 30% or roughly 800,000 child deaths, annually, by 2050, compared to the situation under the *Trend* scenario. Although this would be a significant improvement, globally, the MDG target on child mortality will not be achieved before 2030, mainly due to persistent high child mortality rates in sub-Saharan Africa and South Asia. To achieve the MDG target, policies that address access to food, water and energy also would need to include certain quality aspects of this access, such as those

related to nutrition and water. Furthermore, the broader socio-economic setting would need to be improved, as well, including health services and health education, with a specific focus on female education.

It is important to note that, although reducing the impact of infectious diseases would lead to many health life years gained, the disease burden of chronic diseases would increase, especially at advanced ages. By 2030, the two most dominant chronic diseases (cardiovascular disease and cancers) are projected to make up around 50% of all global deaths. Several environmental factors connected to food consumption, energy emissions, climate change, and a poor quality of the physical environment, are risk factors with respect to these diseases (e.g. through physical inactivity, unfavourable diets, obesity, urban air pollution, heat and cold stress-related mortality). Reducing these risks, as is part of the goals for 2050 as described in this report, thus would have a significantly favourable impact on population health.

4.4 Synergies and trade-offs

The analysis has indicated different pathways for reaching sustainable development goals, but combining certain elements of these pathways may be more effective
The analysis has shown that each pathway is ambitious and faces specific trade-offs. Given the urgency of the problems analysed, a more robust strategy would be to combine certain elements from different pathways; for instance, consumption changes and technological changes focused on large-scale supply-side change and more decentralised solutions. The additional advantage of such an approach would be that different options appeal to different actors; a broad strategy would do more justice to pluriformity in society, and would mobilise its energy. Obviously, combinations would have to be coherent, and the scope for choosing combinations varies depending on the subject. Some choices must be made at the national or supranational level (e.g. emission trading schemes), others could be made at subnational level (e.g. indication of regions dedicated to intensive agriculture, versus regions where agriculture and nature are intertwined), or even at an individual level.

Important synergies and trade-offs exists, which implies that integrated responses would be required
Reducing air pollution, for instance, would lead to important synergies for climate change mitigation (depending on the type of air pollution), improve access to food and protect biodiversity. These benefits would be immediate, which could raise the appraisal of these measures. Important linkages (both synergies and trade-offs) also exist between increased food production and climate change. Table 3 identifies some of the main linkages between the different sustainable development goals considered in this report. It shows that many synergies exist, but there are also some important trade-offs. Policies would have to take account of both, for example:

- Sustainable access to enough food, safe drinking water, improved sanitation and modern energy sources would improve health, significantly – especially for small

children. It would also create wealth, both directly and indirectly; for example, by freeing up time to be used for activities other than the collection of water and firewood.
- Sound ecosystem management and restoration of degraded ecosystems may result in cleaner and more reliable water sources, higher carbon uptakes by natural areas, and improved soils that would sustain a higher agricultural production.
- In the energy field, an integrated approach to achieving climate, air pollution and energy security targets could lead to significant cost reductions.
- Changing dietary patterns may also have important co-benefits. It would not only help to reduce biodiversity loss, but it would also contribute to achieving the climate goal.
- A major trade-off involves bio-energy. This could help to achieve the climate goal, but would complicate achieving those for biodiversity and food. Here, sustainability criteria and monitoring would be needed to keep the negative impacts within acceptable bounds.
- Certain air pollution measures, such as reducing black carbon emissions and ozone precursor emissions, may lead to improved health, reduce climate change and prevent ecosystem damage.

5 Transforming global governance for sustainable development

The previous sections identified important gaps between our *Trend* scenario and the sustainable development goals. However, they also showed that there is a clear potential for achieving these goals, and indicated key policy actions for the coming 10 years. Obviously, the barriers identified in Sections 3 and 4 would form major obstacles to progress.

This report suggests a governance approach that is based on a shared vision with long-term goals and consistent short-term targets, combining strengthened government actions with the numerous civil and corporate initiatives, worldwide
Adaptations to the current approach would consist of an increased focus on creating a reliable long-term vision, combined with stimulating learning and innovation. Incentive structures should match these long-term goals. However, it may be sensible to start, pragmatically, by taking many small steps in the right direction, building more strongly on the innovative capacity of citizens and businesses, worldwide. By exploring best practices, diffusing technologies and making incremental improvements, support and understanding may be created for the more radical changes that are required. Such an approach could be based on the following key elements (as elaborated in Sections 5.1 to 5.4):

1. develop a consistent vision with long-term goals and short-term targets, integrating various areas of sustainable development;

2. ensure that the rules and regulations which govern day-to-day decision-making are adapted to create the right incentive structure for transformative changes;
3. increase coherence between relevant decision-making processes;
4. reform policy-making at an international level, based on three complementary strategies.

A key aspect of this approach is the focus on learning and innovation
Transformative changes are required to reach the sustainability goals, both in terms of human activities and their underlying systems. In many cases, it is difficult to see exactly how such changes could be implemented – and therefore exploring different routes and experimentation with policy instruments is required. This learning process is sometimes characterised as 'radical incrementalism'. Changes would need to be radical, in order to shift them in the direction of true alternatives, rather than seeking small efficiency gains along current routes. However, there are no blueprints for achieving targets, and big changes are difficult to implement. Therefore, decision-making would need to be a 'step-wise' process of acting and learning.

5.1 Develop a consistent vision with long-term goals and short-term targets, integrating various areas of sustainable development

A global consensus on a long-term vision and goals and related short-term targets could act as a guiding star for sustainable development policies
Currently, an overall vision on sustainable development is lacking. Although visions are sometimes regarded as soft tools, they may have a serious effect if they mark the clear choice for a sustainable future. An agreement on a sustainable development goal-setting framework could be an important step towards a more integrated approach to tackling global problems, by providing direction for a green and inclusive economy. Experience with international environmental agreements and the MDGs has shown that such goals could help decision-making as a 'guiding star'. Long-term vision and short-term targets would need to address important sustainable development themes, such as food, energy and water and include the economic, social and environmental domains of sustainable development.

Sustainable development goals must be relevant for all countries
Generally, the MDGs have put forward a set of positive targets that need to be achieved if poor people are to escape poverty. The sustainable development agenda, however, is quite different. For many sustainable development issues different opinions exists, causing goals to be more contested, thus complicating the negotiations. Integrated development and environmental goal-setting would need to focus on poverty reduction for the poorest in the world, but also guide sustainable development pathways and sustainable production and consumption for middle-income and industrialised countries. There is a risk of diverging the MDG into the more politically difficult territory of sustainable development, which could weaken international effort on extreme poverty. However, if successful, they would contribute to the kind of results-based

system and accountability that is currently often lacking in important areas of sustainable development.

This implies that the process of developing a set of meaningful sustainable development goals would need to be carefully designed. These goals, in addition to being meaningful in terms of reaching long-term sustainable development goals, also would need to enable politically feasible targets to be set for the shorter term. Clearly, a fair number of issues may arise during elaborations on such goals. These elaborations would require political decisions to be made on issues related to the areas to be covered and to whom they would apply. In addition, decisions would need to be made about the character of the agreement itself. Addressing these issues would be a highly political process. Therefore, it would be important to organise a balanced, inclusive and fair process that would lead to genuine consensus. One way of achieving this would be to initiate a strong process, running between the Rio+20 conference and the expiry of the MDGs in 2015, involving experts and stakeholders, to come up with a post-2015 set of sustainable development goals that combine development and environmental goals.

5.2 Ensure that the rules and regulations which govern day-to-day decision-making are adapted to create the right incentive structure for transformative changes

Transitions may build on the many existing initiatives within society
Society has an enormous capacity for innovation and learning (in this report, referred to as the energetic society). It is important to ensure that this capacity is channelled towards sustainable development, by ensuring that sustainable development considerations become part of the decision-making process. It is important to recognise that a large number of initiatives are already being undertaken to realise more sustainable development, worldwide. Exactly these initiatives could prove to be the seeds of possible transitions. Public policies need to better capitalise on the numerous civil society, consumer and business initiatives regarding sustainable development, which have been created thanks to or in spite of government policies. A key step for society would be to create convergence on a shared vision and policy objectives (formulated in a positive way, 'the future we want', instead of a negative formulation, 'action that is needed'). Sustainable development goal-setting, as discussed in the previous section, will be important in this regard. By approaching sustainability issues from a societal perspective, governments may gain effectiveness and legitimacy if they view society as producers and allow scope for further cooperation between public organisations, businesses and citizens.

In using the innovation capacity of society, it would important to weigh sustainable development objectives in day-to-day decision-making
Sustainable development considerations would need to be accounted for in public and private decision-making, and to channel the energy in businesses and civil society into the right direction. New rules could be introduced; for instance, in accounting systems

or risk insurance. This could also be done by providing a physical and institutional infrastructure that fosters more sustainable consumption patterns, influencing citizens' choices by changing the default (e.g. by providing smart grids, or by making vegetarian diets the standard) and by strengthening monitoring and feedback mechanisms (e.g. information on energy use and smart metering). Other examples may include voluntary certification schemes, extended producer responsibility and green procurement by governments.

In order to support the vision, there is a need for criteria by which to evaluate the various suggested solutions to achieve corresponding goals. An agreement on the adjustment of key progress indicators (such as the 'Beyond GDP agenda') would be key.

The general approach is to stimulate innovation through a combination of push and pull policies. Possible policy instruments include:

- abolish perverse incentives (e.g. environmentally harmful subsidies);
- define natural resource access and tenure rights and ensure that green policies and investments also focus on poverty reduction;
- strengthen the capacity for institutional learning;
- introduce dynamic regulation stimulating continuous improvement, reinforced by extensive public procurement commitments;
- include sustainable development goals in the indicators used to measure progress;
- include environmental factors in current pricing systems (e.g. green taxation and payments for ecosystem services);
- develop enabling infrastructure, such as smart grids and sustainable city design;
- strengthen monitoring and feedback mechanisms, such as smart metering.

5.3 Increase coherence between relevant decision-making processes

Policy coherence is important: integrated responses may reap important benefits
The challenges posed by sustainable development are not only influenced by specific environmental and development policies, but also by other policy areas, such as trade, finance and energy. Therefore, it is crucial to increase the coherency between policy domains, long- and short-term goals and levels of decision-making, all focused on sustainability as the overarching target. There are important synergies and trade-offs along the pathways towards achieving the sustainability goals. Several factors contribute to achieving multiple goals, such as efficiency improvements, consumption changes and reduced fossil-fuel use. Other factors may achieve one goal but have negative consequences for others, such as bio-energy and desalinisation. These connections are due to physical linkages between the different relevant variables, but they are not usually dealt with in an integrated manner in the related policy domains. Focusing on synergies may make it easier for agreements to be reached.

Linkages between sustainable development goals and the green economy – focus on innovation
This report demonstrates pathways towards achieving sustainability goals and greening the economy and contributing to poverty reduction. Economic growth that does not take into account the natural resource base cannot be sustained in the future. 'In its simplest expression, a green economy can be thought of as one which is low carbon, resource efficient and socially inclusive'. Agreeing on new sustainable development goals is of little value if there is no subsequent change to the rules of the game for a green and inclusive economy.

5.4 Reform policy-making at an international level, based on three complementary strategies

International collaboration will remain a key element of policies that aim to meet sustainable development goals. There are important advantages to this strategy, in terms of efficiency, cost-effectiveness and trust-building. So far, however, the diversity of interests between countries has meant that the multilateral level has been far less successful than hoped. However, action at international level, ineffective as it may be, could serve important legitimation and institutionalisation purposes for more effective action on other levels or within the private sector.

Three complementary strategies for international collaboration are suggested that together may be better able to kick-start and push the transition:
- realise international sustainability goals and the greening of the economy by forming new coalitions of the willing;
- reframe sustainability action to find new concepts and narratives that could mobilise citizens, businesses and governments;
- reform the current multilateral system for sustainability.

None of these strategies are new, but they are not usually considered in combination. In practice, a balance would need to be found between bottom-up initiatives within societies, on the one hand, and top-down steering by providing vision, regulation and enabling frameworks, on the other.

Strategy 1: Build on societal initiatives to form new coalitions of the willing
In this strategy, public policies would be aimed to better capitalise on the numerous civil society, consumer and business initiatives for sustainable development that are being undertaken, worldwide, thanks to or in spite of government policies. For some issues, focus on a small number of multinational companies that dominate the market could make a large difference, also sectoral or regional approaches may work better. Traditional state powers can play a key role in 'unleashing' these societal energies. To be part of a global transition towards sustainability, safeguards that ensure the legitimacy and accountability of non-state actors would also need to be put in place.

Strategy 2: Reframe sustainable development to find new mobilising concepts and narratives

There are ways to reformulate sustainable development issues in order to make them easier to implement. Some of these frames, for instance, prioritise more direct gains – combining these with improving the system in the long term (e.g. energy security or air pollution). It will be important to emphasise those sustainable development strategies that provide clear benefits to the countries involved; in other words, these strategies would need to relate to the aspirations and primary concerns of countries, civil society and businesses. Applying market mechanisms to the logic of the transition towards a green and inclusive economy at least would help this transition to be considered as something that may be co-produced by the players in the current system. The idea of a 'shared development agenda' for a safe and fair operating space does provide a frame that may bring development and the environment together. It is, for example, also conceivable that a greening of the economy will be furthered through an 'Earth Race', as Thomas Friedman called it – a competition between national societies and companies which, from their perceptions of their own strategic interests, choose to green their futures. In this frame, the role of government will be to create a level playing field. There may also be major concerns amongst developing countries that they might lose out, something which also needs to be taken into account. Nevertheless, this is a powerful discourse that helps to understand what is happening in many developing and developed countries, worldwide.

Strategy 3: Reform the current multilateral system for sustainability

Last but not least, through a number of reforms, the multilateral system for sustainability also needs to be strengthened to further many of the necessary policies and actions identified, so far. Shortcomings in the institutional architecture of sustainable development need to be remedied. First of all, the lack of integration of economic, social and environmental policies in the UN system towards stronger policy coherence for sustainability needs to be addressed. One option currently being discussed is the creation of a high-level UN Sustainable Development Council that would replace the UN Commission on Sustainable Development. Secondly, institutional fragmentation could be addressed by upgrading the UN Environment Programme to a full-fledged international organisation that is more on a par with other international organisations. Thirdly, a stronger role could be given to non-governmental organisations, which is also relevant as a link to the strategies presented in this report. Fourthly, in order to integrate knowledge, it seems important to consider creating a global assessment facility that could provide policymakers with accurate and uncontroversial information and analysis. Instead of a new institute, it could be a network of existing organisations currently working in this area. Fifthly, in the implementation of policies for specific issues, such as land use, water and energy, more attention should be given to policy coherence.

6 To conclude: will a pragmatic approach be enough to meet sustainable development goals?

As we have shown, historical experience does not bode well for meeting sustainable development goals. It has often been argued that, given the magnitude of change, this would best be addressed through a large-scale, systemic, preferably internationally coordinated effort. However, recent experiences with multilateral action also have shown the limitations of such an approach. In looking for politically feasible actions, therefore, we looked for approaches that would be multi-scale in nature and stimulate innovation, recognising interdependencies between levels and policy domains. Within this approach, we suggest to look for small steps to be taken into the right direction and to ensure that no decisions are taken that would lead into the wrong direction. It is important especially to build on the many initiatives emerging within society, because at this level most innovation processes take place. Policies could help to ensure that, instead of going in different directions, these processes actually move society as a whole towards achieving the sustainable development goals.

The question remains whether these initiatives will be enough to realise transformative changes and to implement large-scale technologies, as this would probably require a strong enabling and regulatory role of governments. This report provides a discussion on some of the key elements of such a pragmatic approach. There is a certain amount of tension between the transformative changes required to realise sustainable development and the pragmatic policy approach, if changes cannot be made in time. However it seems that, currently, there are few other options. Not meeting sustainability challenges will involve serious costs, and the most vulnerable within society, worldwide, will be the first to pay that price.

Table 3

Interactions between interventions to accomplish goals

Effects on / Action to	Eradication of hunger	Universal access to safe drinking water	Universal access to modern energy	Ensuring clean air	Climate change mitigation	Halting biodiversity loss
Eradicate hunger		ns	ns	ns	More GHG emissions from increased production (fertilisers; land expansion, tractors)1)	More impact of agriculture on ecosystems
Universal access to safe drinking water	Access to safe drinking water helps to prepare safe food Competition as well as synergy between water for residential use and in agriculture		ns	ns	ns	ns
Universal access to modern energy	Allows making use of income opportunities when less time is spent on collecting fuels, and health improved through less indoor air pollution	Water required for power generation Modern energy helps to improve access to safe water (e.g. pumps)		Less pollution from traditional energy sources (charcoal, firewood)	Less deforestation vs more fossil-fuel use, but modern energy more efficient than traditional energy systems	Less disturbance of natural ecosystems from wood collection for fuel or charcoal
Ensuring clean air	Less impact of air pollution on crop yields and quality	Less contamination from the deposition of airborne pollutants	ns		Depends on the choice of air pollutants to be targeted (BC/CH_4)	Lower deposition of atmospheric pollutants on ecosystems

Effects on / Action to	Eradication of hunger	Universal access to safe drinking water	Universal access to modern energy	Ensuring clean air	Climate change mitigation	Halting biodiversity loss
Mitigate climate change	Less risk of disruption of vital ecosystem services Bio-energy competes with food and feed and may spur scrambles for land; but also opportunities for poor in rural areas	Effects of climate change on precipitation patterns and potential evapo-transpiration	Higher energy price	Less pollution thanks to a reduced use of fossil fuels, particularly oil and coal		Less impact of climate change on biodiversity Effects of GHGs and climate change on crop yields Additional land required for bio-energy crops
Halt biodiversity loss	Less land used for food production Preservation of ecosystem services helps safeguard long-term sustainable food supply	A more gradual / uniform flow and cleaner water to rivers and aquifers Increased water use by permanent vegetation	ns	More intact ecosystems contribute to air quality	Fewer CO_2 emissions from land conversion and agriculture Restoration of degraded land creates new CO_2 sinks	

Type of interaction: positive; negative; mix of positive and negative; ns: no significant interactions expected (until 2050).

FULL RESULTS

Introduction: the transition towards sustainable development

In 1992, the world agreed to strive for sustainable development by adopting the Rio Declaration on Environment and Development and Agenda 21. Although the tenets of sustainable development have since become clear and progress has been made in some areas, overall its realisation is lagging behind as is evident from continued environmental degradation and persistent poverty. In this report, we analyse possible pathways towards achieving a set of internationally agreed sustainable development goals and explore how development and environment objectives could be reconciled in practice. The aim is to show the necessary level of effort as well as the possible pathways along which these goals may be achieved, the synergies and trade-offs, and the directions for policy-making.

1.1 The twin challenge of sustainable development

In 1992 the world committed itself to sustainable development.
In 1992, world leaders convened in Rio de Janeiro to discuss the objective of sustainable development at the United Nations Conference on Environment and Development (UNCED), and adopted the Rio Declaration on Environment and Development (UNCED, 1992). This declaration contains a number of important principles aiming at achieving sustainable development, among which:
- people are at the centre of concerns about sustainable development, they are entitled to a healthy and productive life (Principle 1);
- countries have the sovereign right to exploit their own resources and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other countries or to areas beyond the limits of national jurisdiction (Principle 2);

- the right to development must be upheld so as to equitably meet developmental and environmental needs of present and future generations (Principle 3);
- to achieve sustainable development, environmental protection shall constitute an integral part of the development process (Principle 4);
- all countries and all people shall cooperate in the essential task of eradicating poverty as an indispensable requirement for sustainable development (Principle 5);
- the special needs and situation of developing countries, particularly the least developed and those most environmentally vulnerable, shall be given special priority (Principle 6);
- countries shall cooperate to conserve, protect and restore the health and integrity of the Earth's ecosystem. In view of the different contributions to global environmental degradation, countries have common but differentiated responsibilities (Principle 7);
- countries should reduce and eliminate unsustainable patterns of production and consumption and promote appropriate demographic policies (Principle 8).

Furthermore, global conventions to combat climate change, biodiversity loss and desertification, as well as an agenda for action (Agenda 21) were agreed upon at the same conference. Since then, many more goals have been agreed on internationally, including freeing people from extreme poverty and multiple deprivations (Millennium Development Goals), the 2 °C target as a maximum level of climate change to prevent dangerous anthropogenic interference with the climate system (UNFCCC) and halting biodiversity loss (CBD). Box 1.1 provides an overview of the major UN environment and sustainable development policy processes.

Sustainable development is the twin challenge of combining human needs and aspirations with the carrying capacity of the planet

Sustainable development was originally formulated by the Brundtland Commission as 'a development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED, 1987). The former part of the definition refers to realising a decent life for each individual. The latter part refers to conserving natural resources and the environment at such a level to ensures that also the needs of future generations can be met. There has been lively scientific debate on the definition of sustainable development, with a large number of different definitions being proposed (Pezzey, 1992; Lélé, 1991). Despite diverging opinions, there seem to be several common elements in each of the definitions (MNP, 2008):

- Sustainable development covers economic, social and environmental objectives; the main objective is to find an acceptable balance between them.
- Sustainable development clearly refers to linking short-term local interests to consequences elsewhere and for the long-term and for different social groups (equity).
- Both strong and weak sustainability definitions have been proposed. Where the first emphasise 'absolute' limits to environmental degradation in order to avoid environmental and ecological risks, the second type of definitions emphasise finding a balance between different objectives.

From this, we conclude that the core of the sustainable development ambition is the twin challenge of combining human needs and aspirations with the carrying capacity of our planet; in short, improving human development while ensuring environmental sustainability (see also Principles 1, 3, 5 and 7 of the Rio Declaration).

Improving human development…

Human development is the process of enlarging people's choices by expanding human capabilities and functioning (Alkire and Santos, 2010; Alkire, 2010). For development goals, international agreements have mostly concentrated on minimum conditions, a social floor, for a decent life for each individual (e.g. 1996 World Food Summit target; 1990 World Declaration on Education for All; 2002 Johannesburg Plan of Implementation). Currently, the main overarching international agreement – that incorporates several of the earlier agreements – is the Millennium Development Goals (MDGs), a set of broadly supported, comprehensive and mostly quantitative development and poverty-reduction goals and targets. They address the needs of the poorest people around a common definition of basic, minimum conditions for a decent life. The MDGs cover a broad range of development issues, including reducing extreme poverty and hunger, improving basic services for people such as health, education and a healthy environment, and creating a global partnership to enable these goals to be achieved.

… while ensuring environmental sustainability

Ecological systems provide a basis for life on Earth. International assessments (IPCC, 2007a; Millennium Ecosystem Assessment, 2005; UNEP, 2007) over the last decades have indicated that many ecological systems are degraded and concerns have been raised regarding the sustainability of these systems. Several international conventions have been formulated to prevent further degradation – or even to reverse the processes. Examples include the UN Framework Convention on Climate Change (UNFCCC) and the Convention on Biodiversity (CBD), which have different types of objectives. The MDGs also include a goal for ensuring environmental sustainability.

Development within a safe and fair operating space

To address this major challenge, this report identifies a set of development and environmental goals, which together define a 'safe and fair operating space', and explores alternative development pathways to achieve these goals. Obviously, the aspiration to increase human well-being leads to a wish for further economic development beyond the 'social floor'. Therefore, development must be focused on improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities.

1.2 The context: 40 years after Stockholm, 20 years after the Rio Summit

Average human well-being increased rapidly during the twentieth century, but at the cost of the environment. Moreover, many people still live in extreme poverty and without access to sufficient food, modern energy or safe drinking water
Over the last few decades, the world has experienced a rapid increase in population and average income. The global population grew from 2.5 billion in 1950 to over 7 billion today, and their average life expectancy increased from 48 to nearly 70, today (UNDESA, 2011). In the same period, average incomes grew even faster; from around USD 2,400/cap in 1960 to USD 6,000/cap in 2010 (World Bank, 2011c). One of the key factors behind these impressive achievements has been technological innovation, allowing humans to overcome resource scarcity and enjoy a healthier life (e.g. vaccination, pasteurisation, refrigeration). However, technological developments have also introduced new problems. Environmental assessments have repeatedly called attention to the degradation of key global environmental resources such as water and fertile land and the risks associated with climate change and biodiversity loss. Natural resources are being extracted at an increasing rate, giving rise to new concerns about resource scarcity. Furthermore, the acquired wealth is far from equally distributed. Globally, 1.3 billion people still live on less than USD 1.25 a day (Chen and Ravallion, 2010). Furthermore, around 900 million people are undernourished (FAO, 2010), almost 2.8 billion people are dependent on traditional fuels such as wood and charcoal for cooking (IEA, 2010a), around 750 million people have no access to safe drinking water and 2.5 billion people lack basic sanitation (UNICEF and WHO, 2012) see also Chapter 3).

Several international agreements have been formulated to respond to these trends. However, for key areas these agreements have not been able to bend existing, unsustainable trends
The sustainable development challenges identified in 1992 are by and large still with us. Although there has been marked progress in some regions of the world in terms of human development and environmental conditions, there are also a number of persistent problems that have not yet been solved, such as extreme poverty, and some that have even become more pressing, such as climate change, excessive nitrogen deposition in developed countries and water scarcity. The provision of food, water and energy will become more difficult if natural resources are not properly managed or are degraded as a result of environmental change (IPCC, 2007a; Millennium Ecosystem Assessment, 2005; UNEP, 2007). Providing enough food, water and modern energy for a growing and wealthier population, will put further pressure on increasingly scarce natural resources (PBL, 2011b). Furthermore, the provisioning of these services in conventional ways further exacerbates global environmental changes such as climate change and biodiversity loss. As these environmental changes mostly become apparent in the longer term, this may increasingly trap people in poverty or backlash on progress

already made. This again illustrates the need to look at developmental and environmental policies in an integrated manner

Governments will reconvene in 2012 in Rio de Janeiro to renew their commitment to sustainable development

In June 2012, 20 years after the first Rio Summit, the world will again gather in Rio to secure renewed political commitment for sustainable development. The goals of this meeting are assessing the progress to date regarding sustainable development, identifying the remaining gaps in the implementation of the outcomes of earlier commitments and addressing new and emerging challenges for future international sustainability policies. Rio+20 will address three themes: (a) assessing progress; (b) establishing a green economy in the context of sustainable development and poverty eradication; and (c) reforming the institutional framework for sustainable development.

The social, political and environmental context has changed considerably since 1992

The world in which we live has changed considerably since 1992. Although many in the 1990s anticipated that the end of communism would lead to a world dominated by convergence (e.g. 'End of History' (Fukuyama, 1992)), instead a multi-polar political situation has arisen that is far from stable. Although the world is increasingly connected and integrated through commerce, travel and the quick dissemination of images and ideas, there is also a growing emphasis on national interests, as reflected in ethnic-cultural and political tensions and a proliferation of government interventions limiting cross-border activities (Ghemawat, 2011). Traditional distinctions between north and south have become blurred; for example, with the growing middle class in developing countries and the increase in poverty in the North. The rise of the emerging economies including China, India, Brazil and South Africa has become evident in an economic sense, but also in a political sense. These countries have, for instance, become an important factor in the international negotiations on climate change. At the same time, the affluent market-oriented economies of the United States and the European Union are facing serious difficulties reflected by and as a consequence of the ongoing economic and financial crises. In this context, the notion of common but differentiated responsibilities between nations for solving global problems will acquire new meaning (Schrijver, 2010).

It is often said that the institutional framework for sustainable development has not been able to keep pace with the sustainable development challenges and, therefore, requires reform. New governance arrangements are needed that build on the recognition that nation-states alone can no longer determine the fate of global public goods. Rather, a variety of non-state actors such as business corporations, civil society and sub-national authorities such as cities or provinces begin to play their role and will have an impact. Governance arrangements will need to be improved in terms of effectiveness, legitimacy, transparency, accountability and participation (Hajer, 2011).

However, the scientific evidence of man-made environmental change has increased. For instance, in 1992 information about climate change was still scarce. Since then, subsequent IPCC reports have shown that climate change is indeed taking place and that anthropogenic activities are the most likely cause of most of these changes. The implications of climate change for the development agenda have been further elaborated, for example, in the 2007 Human Development Report (UNDP, 2007). Similarly, more convincing evidence has also become available in other areas, such as trends in biodiversity.

Sustainable development requires a shift in current development and environmental trends. The 2012 Rio Conference can contribute to such a shift
The period between the present and 2015 offers a new opportunity for bringing together the two worlds of environment and development. A number of political deadlines coincide in 2015, including the expiry of the Millennium Development Goals and the agreement made at the last Conference of the Parties to the UNFCCC in Durban to negotiate a new climate deal for 2020. The Rio Summit in June 2012 may also set a 2015 deadline for the agreement on 'Sustainable Development Goals', which would put more pressure on actions for sustainable development to fully incorporate development and environment.

Achieving sustainable development will require considerable action
Since UNCED in 1992, the international community, in a variety of international fora, has formulated goals and targets for a more sustainable development. Progress in translating these goals into real action has, however, been considerably less successful. Current progress towards any of these goals is mixed at best. Achieving them will require considerable action on the part of societal actors and governments, and a higher sense of urgency and level of commitment in order to manage the reorientation of investments and behaviour and the associated political risks.

Studies have shown that effective response strategies can be formulated for most sustainability problems. Many of these strategies have the following elements in common:
- targeted policies to support poor people to meet minimum human development conditions;
- changes in technology towards less energy- and material-intensive processes and products, including 'closing the loop';
- changes in the volume and nature of consumer goods and services, including shifts in dietary and mobility patterns;
- changes in the incentive structures for private and public actors to encourage behaviour that is consistent with sustainable development goals; for example, price instruments and standards.

Box 1.1 A brief history of major UN environment and sustainable development conferences

The United Nations Conference on the Human Environment was held in Stockholm in 1972. This was the first major UN conference on the environment and marked a starting point in the development of international environmental policy. The conference also led to the creation of the United Nations Environment Programme (UNEP).

In 1983, the United Nations convened the World Commission on Environment and Development (WCED). Its report, Our Common Future (WCED, 1987), emphasised the link between environment and development issues and coined the term 'sustainable development'. The report indicated the need for stronger environmental protection and emphasised that development processes also had to be accelerated to address the needs of the billions of people without access to safe drinking water, sanitation and sufficient food.

The WCED laid the groundwork for the 1992 United Nations Conference on Environment and Development in Rio de Janeiro. This conference put sustainable development as a top priority on the agenda of the United Nations and the international community. The Earth Summit resulted in the Rio Declaration (27 key principles on sustainable development) and Agenda 21 (a comprehensive blueprint of action to be taken globally, nationally and locally). Moreover, three important legally binding agreements were opened for signature: the Convention on Biological Diversity (CBD), the Convention on Combating Desertification (CCD) and the Framework Convention on Climate Change (UNFCCC).

World leaders met at the Millennium Summit in New York in September 2000 to discuss the role of the United Nations at the turn of the twenty-first century. Here they agreed upon the United Nations Millennium Declaration which focused on various global developmental issues, such as poverty reduction and how to share the benefits of globalisation more fairly. The Millennium Development Goals (MDGs) (UN, 2000) were the main outcome of the Millennium Summit. These are a set of eight goals to encourage development by improving social and economic conditions in the world's poorest countries.

The next landmark was the World Summit on Sustainable Development in Johannesburg ten years after the 1992 Earth Summit. Here, the Johannesburg Plan of Implementation (JPoI) (UN, 2002) was agreed upon. The plan affirmed UN commitment to sustainable development and outlined action for the 'full implementation' of Agenda 21. It also affirmed commitment to achieving the Millennium Development Goals and other international agreements.

The need for a polycentric approach to governance with an increasing role for non-state actors

Lack of progress in resolving sustainability problems has resulted in state-centric approaches in global governance being reconsidered; new ideas are emerging for more effective approaches. At the global level, the increased participation of non-state actors such as businesses and civil society has given rise to new forms of governance beyond the more traditional system in which international environmental policy focuses on legally binding agreements negotiated by governments. In fact, for issues such as climate change, biodiversity and development, a broad range of new governance mechanisms through markets and networks has emerged and proliferated since the early 1990s. This implies that we now need to find ways to complement the state-centric world of international negotiations with the multi-centric world of non-state actors in ways that increases the effectiveness of achieving sustainable development goals (Rosenau, 1990).

In fact, it is not the sheer numbers of non-state actors that make the difference, but rather the capacity that these actors have gained to form transboundary social institu¬tions to address transna¬tional political problems. An in-depth analysis has shown that established actors in world politics, from non-governmental organisations (NGOs) to multinational corporations (MNCs), are taking on new roles and responsibilities beyond lobbying and influencing governments, both nationally and internationally. These roles include agenda-setting, norm- and standard-setting, verification, monitoring and implementation (Pattberg et al., 2011).

An important insight is that different global public goods can be realised through different kinds of collaborative efforts that do not necessarily require the involvement of all stakeholders. In other words, smaller coalitions of different actors can also be effective, depending on the type of problem (Barrett, 2007). Ostrom (Ostrom, 2010; Ostrom and Cox, 2010) makes the case for polycentric governance for collective action. This can be understood as a pragmatic approach, a multi-level effort, involving various activities by relevant actors in society. Polycentric approaches facilitate achieving benefits at multiple scales as well as experimentation and learning from experience with diverse policies. A variety of emerging solutions will jointly contribute to the global response to sustainability problems. Importantly, such approaches would do justice to the plurality of views in society regarding how to resolve sustainability problems (see also Verweij and Thompson, 2011).

1.3 Study objective, research questions and approach

Objective and research questions

Until now, studies mostly focused on analysing possible pathways to achieve individual goals, with little attention paid to the required effort of achieving a much larger set of sustainability goals. *This study addresses that lack of information. Its main question is: What* *would be needed to achieve a set of ambitious sustainable development goals by 2050?* To evaluate what would be needed, the report presents pathways consisting of technological and behavioural changes for achieving a set of goals – derived from existing international agreements and policy and scientific literature – and discuss policy strategies to realise these pathways. We also address the international institutional framework and governance mechanisms required to get these policies in place. The main question is subdivided into the following sub-questions:

- *What could be sustainable development goals for 2050, for energy, climate, food and biodiversity?*
- *What are the historical and expected future trends related to these goals?*
- *Which barriers have prevented goals from being achieved?*
- *Which efforts would be needed to bend current trends, in order to achieve the sustainable development goals? What are the key dilemmas, synergies and trade-offs with respect to this effort?*
- *Which policies are needed to achieve these goals and what are the consequences for governance?*

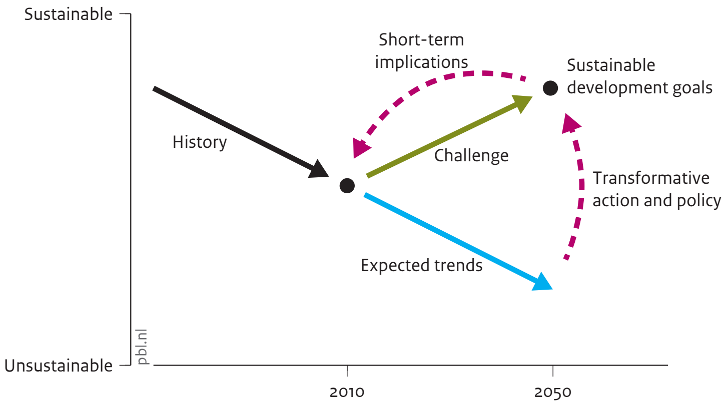
Focus on two broad clusters of sustainable development issues: food, land and biodiversity and energy, air pollution and climate
Sustainable development refers to a wide range of objectives. Several assessments have focused on current environmental and development trends and the importance of looking at them together. For instance, Rockström et al. (2009) show that for three environmental topics the planetary boundaries have already been exceeded: climate change, maintaining the nitrogen cycle and biodiversity loss. The Millennium Ecosystem Assessment (Millennium Ecosystem Assessment, 2005) emphasised the importance of ecosystems to human well-being and identified several key issues: land-use change, overexploitation, invasive alien species, pollution and climate change. The GEO-4 report 'Environment for development' (UNEP, 2007) stressed the importance of the environment to poverty reduction and mentions land-use change and climate change as two main causes of environmental degradation.

This report therefore focuses on two areas: 1) eradicating hunger and maintaining a stable and sufficient food production, while conserving biodiversity; and 2) providing access to modern energy sources for all, while limiting global climate change and air pollution. It should be noted that these focal areas are mainly used as a way to present the outcomes of this study. The underlying scenario analysis takes an integrative approach in answering the above-mentioned research questions for land and energy issues. In addition, we also analyse the implications for water, nutrient balances and human health.

The study's approach is that of identifying strategies to bridge the gap between conventional development and achieving sustainability goals
Given the aim to evaluate what would be needed to achieve a set of ambitious sustainable development goals by 2050, we used quantitative scenario tools as well as qualitative governance analysis. The analysis consisted of four interrelated steps:

a. a set of key sustainable development goals were derived on the basis of international agreements;

Figure 1.1
Backcasting analysis, working back from a sustainable end point to determine actions for today



Source: PBL

The Trend scenario depicts the possible trends in the absence of strengthened policies. The Challenge pathways explore how a set of sustainable development goals may be achieved.

b. a *Trend* scenario was created containing future developments without major policy shifts that would be plausible in the light of existing and expected trends;
c. different options were combined into three alternative scenarios that would achieve the set of goals (Challenge pathways);
d. an assessment was made of the governance mechanisms and institutional framework that would support these transitions in the pathways towards sustainable development – particularly the short-term agenda in light of the long-term goals.

As previously indicated, the sustainable development goals analysed in this report were derived from international agreements. In some agreements, long-term goals are explicitly mentioned. However, in most cases, the agreements include more abstract descriptions of long-term goals. As our model analysis required more explicit goals, we derived them from other, relevant documents and/or extrapolated existing short-term targets. This is explained further in Chapter 2. Backcasting was applied to construct pathways that would achieve the goals and to identify near-term priorities and critical junctions that will be encountered in the coming decade, on route to 2050. Figure 1.1 sketches the idea of the analysis, involving the *Trend* scenario and Challenge pathways. The *Trend* scenario is further presented in Chapter 3, and Chapter 4 presents the Challenge pathways which are quantitatively assessed in the successive chapters.

Scenario analysis as a tool to explore alternative futures

The future development of many parameters relevant to the questions raised in this report is highly uncertain. This includes, for instance, uncertainty in economic development patterns, technology development and consumption preferences. Also, the evolution of environmental systems themselves (e.g. climate and ecosystems) is determined by a complex interplay of many different factors. Scenario analysis is used as a tool to explore different uncertain developments and their future consequences. Scenarios (and pathways) are projections of future developments, based on coherent and internally consistent sets of assumptions on key driving forces and relationships. Given the uncertainties and complexities involved, they are projections and certainly not predictions – as they critically depend on a set of key assumptions. Integrated assessment models are an important tool in scenario analysis because they provide certain forms of rigour and logic to the qualitative storylines and logic and allow users to explore key interactions between the various scenario parameters with respect to a broad range of issues. We use the PBL IMAGE modelling framework in this report; this is described in detail in Appendix A.

The analysis in this report uses two major types of scenarios, each corresponding to a crucial question with respect to the sustainability ambitions (cf. Figure 1.1):

- The *Trend* scenario: what happens if we continue along the current pathway?
- Three challenge pathways: what options are needed to bend the expected trends towards the desired goals?

The *Challenge* pathways

The *Challenge* pathways are constructed using backcasting as they explore pathways to achieve the set of goals. A major characteristic of backcasting analysis is that it is 'not about the future that is likely to happen, but about how a desirable future could be attained'. It is thus explicitly normative, involving working backwards from a particular desirable future end-point to the present in order to determine the physical feasibility of that future and what policy measures would be required to reach such a point (Robinson, 1990; Dreborg, 1996). Rather than presenting the outcomes of alternative scenarios and using this to forecast the possible outcomes of these scenarios, backcasting analyses backwards from desired end points to see what actions and conditions are crucial at various points in time (Andersson et al., 2001). An important step in backcasting involves the analysis of the social, political and institutional implications of alternative scenarios. These deeper societal implications are often, as in forecasting, left largely unattended. This risks making simplified assumptions about policy input and missing how policies develop and interact over the long term (Nilsson et al., 2011). In practice the distinction between forecasting and backcasting is not so clear-cut. In this study, backcasting helps to identify indispensable options to achieve the goals for 2050 and helps to inform on the necessity and possibilities for more radical change and strategies to make that happen.

Strategies for transformative action and policy

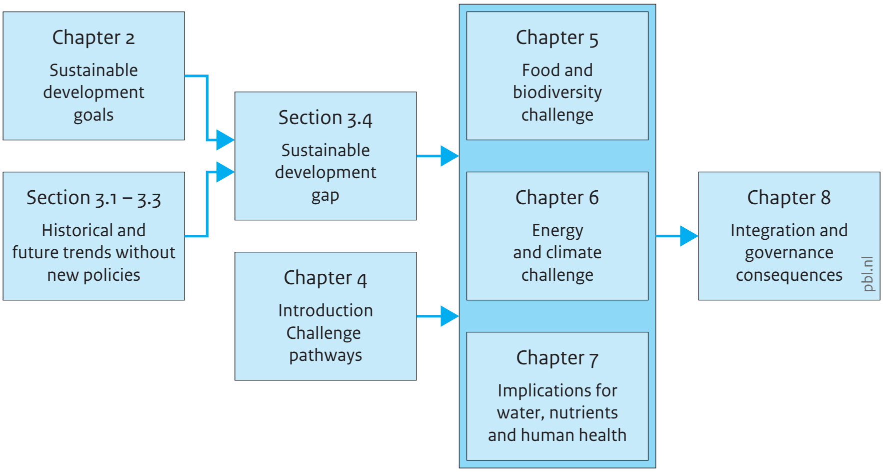
This report also looks at strategies to achieve the goals and targets, from a 'transitional' or 'transformative change' perspective: What is needed to bring about the fundamental systemic changes identified in the scenarios to achieve the long-term goals? The thematic chapters analyse key issues identified through a normative scenario approach and suggest possible policy strategies for the coming decade to deal with the most pressing issues. In considering transformative change, it is useful to distinguish between three different levels at which changes may occur (De Vries et al., 1993; Meadows, 1999). First of all, changes need to occur in the physical world in which human consumption and environmental degradation take place. For instance, to reduce greenhouse gas emissions changes will need to take place in the energy system. Similarly, physical changes will be required to ensure universal access to modern energy. Changes in the physical systems are usually guided by decisions, and the rules that guide these decisions form the second system (financial incentives, rules, prices etc.). The pricing of ecological services may for instance encourage more environmentally friendly behaviour. Finally, the third level is formed by world views and aspirations. As these determine many of the rules at the second level, more lasting transformative changes will need to build on changes at this level as well.

What does this study add to the existing literature?

This study is innovative in three respects: 1) it explicitly looks at achieving a set of long-term goals; 2) it takes a broad set of goals into account that are relevant to sustainable development, combines development and environment and focuses on the inter-linkages between different issues; and 3) it combines scenario analyses with an analysis of governance approaches.

1. With respect to the first point, many scenarios until now have explored future development patterns based on a given set of assumptions (what happens if the world develops like this?). Here, instead, we started with a set of sustainability goals and analysed the required effort to achieve these goals (backcasting).
2. With respect to the second point, it should be noted that the sustainable development agenda is not about achieving individual energy, development or environmental goals: it is about a development that would achieve all of them. Internationally, for each of these issues agreements exist, such as the MDGs, UNFCCC and CBD. In looking at achieving different goals simultaneously we have to take an integrated approach. The study therefore puts the nexus between land and energy to the fore, while also including relevant other themes, such as water and health. We build on the information in more sectoral studies such as the Global Energy Assessment and work by the FAO on agriculture.
3. Finally, this study focuses on what achieving long-term goals would imply for near-term policy priorities, and which institutional framework and governance mechanism would be needed to achieve the goals. As indicated, the role of governance is often lacking in existing scenario work.

Figure 1.2
Organisation of this report



Source: PBL

1.4 Organisation of this report

This report is organised around the different elements presented in Figure 1.2. Chapter 2 first discusses the sustainable development goals and targets analysed in the report. Chapter 3 then presents the historical trends and those expected in a situation without new policies. Together, these two elements define the sustainable development gap: the difference between desired and expected future trends. Chapter 4, subsequently introduces three fundamentally different pathways containing transformative actions and policies. The three subsequent chapters elaborate these pathways for the land-related issues, energy and climate, as well as for the related issues of water, nutrients and human health. Finally, the lessons learned are synthesised in Chapter 8, on the basis of which lessons are drawn for international policies.

Challenges for sustainable development towards 2050

A number of international agreements exist that specify long-term ambitions related to the intentions of the Rio Declaration of 1992. This chapter starts by outlining how long-term development and environmental objectives are currently operationalised. Next, the goals selected for this study are presented. This set of goals has been formulated around the 'twin challenge' of meeting both human development and environmental objectives. At the end of the chapter we show the inter-linkages between different goals and highlight the need for an integrated approach.

2.1 Operationalising long-term goals

A number of international agreements exist that specify some long-term objectives that relate to the intentions of the Rio Declaration. In the report, we distinguish between objectives, goals and targets. Objectives specify a vision such as 'free people from poverty', 'halt biodiversity loss', and 'avoid dangerous anthropogenic interference with the climate'. Goals are more generic and often more long-term such as the 2oC target (Copenhagen Agreement) and 'Eradicate extreme poverty and hunger'(Millennium Development Goal 1). Targets, finally, are more specific and short term, such as the Kyoto targets for the 2008-2012 period and the MDG target to 'reduce by half the proportion of people who suffer from hunger in 2015'. Below, we briefly discuss some of the agreements.

Human development goals
One part of sustainable development relates to improving human living conditions. The ambition has been most focally formulated in the UN Millennium Declaration (UN, 2000). Part of this declaration is the ambition to abolish extreme poverty. This ambition is made operational in the medium term in the form of the Millennium Development

Goals (MDGs). These MDGs formulate goals and targets for development, including halving the number of people living on less than USD 1.25 a day, reducing the number of women who die in childbirth by three-quarters, reducing child mortality by two-thirds and ensuring all children go to school.

It is claimed that the MDGs have contributed to more effective poverty-reduction on the ground, but it should also be noted that this is hard to estimate as some of the MDGs were set in line with on-going trends (so it is hard to know how much credit the MDGs can take for the continuation of those trends). The MDGs are likely to having had an impact on the willingness of donors to increase aid budgets, to have contributed to better monitoring, and in some countries to have had an impact on both civil society advocacy and on the government prioritisation of social spending and social outcomes (Sumner and Tiwari, 2009).

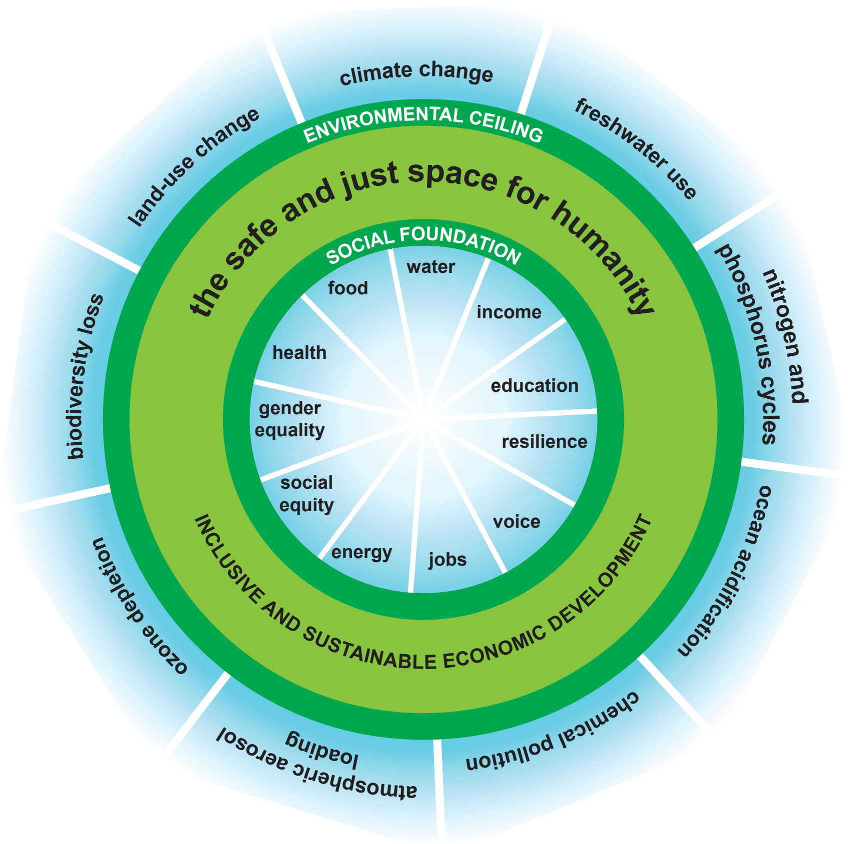
The current MDG targets will come to an end in 2015, by which time many of them, though not all, will have been met at a global level but with large differences at the regional and national level. It is likely that some global framework will replace the MDGs, and debates are currently underway as to what this should look like. It is probable that new goals will include more economic as well as social progress – ideas have been proposed for goals on economic growth, on energy, or on infrastructure. This would offer an opportunity to integrate social with environmental goals, and there is the risk of establishing conflicting or competing goals at the national level if this opportunity is not taken.

Environmental goals

There are several reasons for preventing environmental degradation. First of all, ecosystems deliver all kinds of ecological services and goods. These include both production functions (e.g. food and fibre) as well as regulatory functions (e.g. balancing the carbon and water cycles). Environmental degradation may reduce the ability of ecosystems to deliver these goods and services. In some cases this will be a gradual process. In other cases, however, there might be thresholds (sometimes referred to as tipping points) that, if passed, would lead to large and rapid changes that are difficult to reverse. Such thresholds have been identified in small ecosystems, and have also been hypothesised at the planetary scale (Scheffer, 2009; Lenton et al., 2008). However, they are difficult to identify empirically. The uncertain response of environmental systems to degradation is often seen as a reason for precaution in itself. Finally, the importance of ecosystems to cultural and social services may also mean that the decision is made to protect environmental systems in their own right.

This implies that environmental goals are formulated on the basis of both scientific information (on the potential impacts of environmental degradation) and normative societal choices. Ultimately, it is up to society to decide where the trade-off lies between the desired quality of an environmental resource on the one hand and the risk of irreversible loss of its services on the other (see Box 2.1).

Figure 2.1
The safe and just space for humanity



Source: Raworth (2011)

Combining human development and environmental goals and targets

Recently, a set of key Earth System processes and associated boundary levels have been proposed under the heading 'planetary boundaries' that attempt to define the most important interferences of humans with environmental systems, based on the scientific assessment of the stability of ecosystems (Rockström et al., 2009). This has been extended with social development goals (Raworth, 2011). Here, these social goals are seen as the social foundation. Important goals emphasised by Raworth include access to sufficient food, water and modern energy, health security, social equity, gender equality, job security, access to sufficient income and job security, freedom of speech, access to education and sufficient levels of resilience. By combining planetary boundaries and social goals 'the safe and just space for humanity' would be defined as a policy space in which to find a balance between different types of goals and explore alternative development pathways (see Figure 2.1).

Box 2.1 Can a 'safe and just operating space for humanity' be defined?
A key question in the environmental debate is that of which goals and targets to strive for, and several approaches have been taken in the past. The 'planetary boundaries', recently proposed as a method to derive long-term environmental goals and targets (Rockström et al., 2009), are based on a knowledge of Earth system behaviour that identifies key ecological processes that ensure the current stability of the Earth system. The method proposes threshold values for each of these processes that should not be exceeded, to prevent a collapse of the earth system. The exact values of the planetary boundaries have been derived based on the planet's biophysical conditions during the Holocene – a period that can be regarded as relatively stable and therefore providing a safe operating space. Thresholds for nine key Earth system processes have now been defined (see outer circle, Figure 2.1), and it has been suggested that boundaries have already been surpassed for biodiversity loss, climate change and interference with the nitrogen cycle. For a few others, the boundaries are close to being reached.

It should be noted that the question of whether it is possible to derive meaningful targets on the basis of ecological or Earth system considerations alone has been a subject of debate for some time. This has also been translated into the definitions of 'strong' versus 'weak' sustainability; where the former emphasises that there are clear limits to environmental pressure, the second approach sees targets as an optimal social trade-off between various environmental, social and economic objectives. The complexity of the Earth system and the associated uncertainties, as well as the subjective views on risk acceptance and ecosystem values, mean that it is not really possible to find a correct answer in this debate. In fact, the 'Limits to Growth' publication (Meadows et al., 1972) and its critiques can also be read in the context of the different views on 'strong' and 'weak' sustainability. From a weak sustainability perspective, there are also many questions that could be raised regarding planetary boundaries. What will happen if the thresholds are surpassed? Why are these risks unacceptable? If there is no certainty about collapse, is goal-setting not an inherently societal and political process? In most cases, it is not possible to identify absolute thresholds. At the same time, however, there is a broad consensus that certain levels of environmental degradation should clearly be avoided (precautionary principle) and that not all risks are acceptable. The Planetary Boundary concept has found much support as a formal method to underpin the goal-setting debate from an environmental perspective.

International agreements often lack clear and quantified targets. Formulation of such targets might make these agreements more effective

Although international agreements address important ambitions, several limitations mean they cannot be directly applied to formulate long-term sustainability goals and targets:

- The targets agreed upon are not always quantitative, which makes it difficult to assess progress.
- Even with respect to targets that are selected, they are not always well-defined. For instance, even for the 2oC target adopted by the international community (UNFCCC, 2010), the formulation is still ambiguous: the uncertainty in climate sensitivity implies that statements on achieving the 2oC target need to be combined with a probability statement.
- Many agreements only include short-term targets or a long-term ambition, such as the MDGs aim to halve extreme poverty by 2015, which implies that many people will still be living in deprived circumstances. Similarly, although the CBD (2010a) includes targets for 2020, no clear longer term goals are included.

In our view, clear positioning by governments will help achieve sustainable development. In our view, this could be shaped, for example, by formulating a vision and by internationally agreed goal-setting (see Chapter 8 for more details). This would be particularly useful as sustainable development deals with long-term issues and short-term decision-making, includes strong economic, social and environmental domains, brings together various economic sectors and actors in society and involves decision-making at all levels, therefore resulting in very different societal transformation processes. Sustainable development goals may help guide and direct these processes (Hajer, 2011).

There is substantial empirical evidence to suggest that simple, long-term and mutually agreed policy principles and goals (both legally binding and non-legally binding) can influence the political process. This is surely the case for the quantitative agreements provided for under international legally binding agreements, such as the detailed phase-out scheduled under the Montreal Protocol on Substances that Deplete the Ozone Layer, or the precise World Trade Organization agreements, which have the added force of a legally binding dispute resolution mechanism to ensure compliance. The current slow negotiation process under the UN Framework Convention on Climate Change about the legal status of the future global agreement planned for 2020 shows how difficult it can be to reach agreement in the current international political context. However, it is also evidence of the relevance of international law in these areas. The time horizon that needs to be chosen varies. Long-term, ambitious goals are important for issues that require long-term planning and investment decisions. But even in such situations, short-term, more modest targets are important as benchmarks and as agreed goals for the immediate policy cycle. Obviously, targets are only useful if data for these targets is actually collected (see Box 2.2.)

Box 2.2 The need for quantitative goals and targets and monitoring
Objectives often tend to be formulated in qualitative terms in international agreements. As we have argued in this chapter, and further elaborate in Chapter 8, formulating quantitative targets can help focus policy-making and keep up a sense of urgency. Obviously, this also requires good monitoring systems. In many areas good data on progress are simply lacking. For example, as shown in the next chapter, no systematic data exist on access to modern energy sources. It is therefore important that the international community continues to focus on setting up networks that can create sufficient and solid data and perform regular assessments of the progress and expected trends.

Non-legally binding goals can also inspire political processes at international and national levels. They can form the basis for norm-development processes that can lead, over time, to the evolution of hard law and the incorporation of these standards in international treaties. In addition, widely agreed goals such as the Millennium Development Goals, though not formally legally binding, do have the power to serve as a guidance and mutually agreed benchmark for policy-making at national and international levels.

2.2 Goals selected for this study

Analysis based on internationally agreed goals
This report makes use, as far as possible, of the existing goals formulated in international agreements on environmental and development topics. In some cases, these are directly formulated as quantified goals. In other cases, only more qualitative formulations are available. In those cases, we used quantitative interpretations of these goals, as discussed in the scientific literature. Clearly, in interpreting some of the existing agreements in terms of the targets used for our analysis, some normative choices had to be made (see below). See also UNEP's fifth Global Environment Outlook for an assessment of global long-term goals and targets (UNEP, 2012).

Selection of goals and targets for development and environment
Taking the international agreements as a starting point, extended with proposed goals and targets from high-level UN advisory groups and insights from the scientific literature, we chose a set of relevant goals and targets for the 2030–2050 period (see Table 2.1). For this, we focused on the two key themes of this study: 1) food and biodiversity, and 2) energy and climate. The goals have been categorised into two groups: main goals (goals which the analysis focuses on in full) and monitoring goals (goals without fully fledged targets, which are mainly addressed in relation to the main goals). The monitoring goals were set for themes that are strongly related to the two main clusters, but for which this report provides a less extensive analysis: water scarcity,

interference with the phosphorous and nitrogen cycles and human health (see Table 2.2).

For the human development goals, the UN Millennium Declaration (UN, 2000) and the derived MDGs are the main source. The declaration states that it aims to 'free our fellow men, women and children from the abject and dehumanising conditions of extreme poverty'. Although the MDGs cover a broad set of themes, including poverty, education and health, here we focus on the issues most closely related to the environment: access to food and water (safe drinking water and basic sanitation). For the MDGs, quantitative targets were formulated for 2015; for example, to halve, between 1990 and 2015, the proportion of people who suffer from hunger and the proportion of people without sustainable access to safe drinking water and basic sanitation. We extended these targets to a further halving between 2015 and 2030 and full access by 2050. Energy is not part of the MDG framework, although access to modern energy services is generally regarded as being crucial to human development and to the achievement of the MDGs (Modi et al., 2006; AGECC, 2010). Therefore, we adopted the AGECC target of ensuring universal access to modern energy services by 2030 (AGECC, 2010). Finally, for human health, the most relevant goal is the MDG4, which is to reduce by two-thirds the under-five mortality rate between 1990 and 2015, and strongly relates to hunger, access to safe drinking water and basic sanitation, and the use of traditional energy.

The environmental objectives are formulated in various environmental conventions. The Convention on Long-Range Transboundary Air Pollution (CLTRAP, 1979) states 'to limit and, as far as possible, gradually reduce and prevent air pollution including long-range transboundary air pollution'. It does not however state quantitative or time-bound targets, nor is it global. WHO (2006) has formulated air quality guidelines and interim targets for particulate matter. We have selected Interim Target-1 (annual mean $PM_{2.5}$ concentration below 35 µg/m^3) as our global target.

The United Nations Framework Convention on Climate Change (UNFCCC, 1992) states 'stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system'. The EU and several countries have interpreted this objective in terms of a target not to exceed 2 °C compared to pre-industrial levels. More recently, also in the context of the UNFCCC this 2 °C target was accepted at COP16 in Cancun as a starting point for the negotiations (UNFCCC, 2010). We assume that this target has a high probability of being met; this implies that atmospheric greenhouse gas concentrations should be held below 450 ppm CO_2 equivalents (Meinshausen et al., 2006).

For biodiversity, the Strategic Plan of the Convention on Biological Diversity (CBD, 2010a) states that 'by 2050, biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people'. Several short-term targets also have been formulated. At the COP 10 meeting in Nagoya, Japan, the CBD Conference of the Parties adopted a revised

Table 2.1
Main goals and targets

Themes	Goals	Targets	Reference
Human development	Eradicate hunger	Halve, by 2015, the proportion of people who suffer from hunger; *further halve by 2030 and fully eradicate hunger by 2050*	UN (2001) MDG1, Target 1c
	Ensure universal access to safe drinking water and improved sanitation	Halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation; *further halve by 2030 and ensure full access by 2050*	JPoI-25 JPoI-7a UN (2001) MDG7, Target 7c
	Ensure universal access to modern energy	*Achieve universal access to electricity and modern cooking fuels by 2030*	JPoI-Para 9(a) *UNSG (2011) AGECC (2010)*
Air pollution	Reduce air pollution	*Keep annual mean $PM_{2.5}$ concentration below 35 µg/m³ by 2030*	*WHO (2006)*
Climate change	Prevent dangerous anthropogenic interference with the climate system	Avoid temperature increase above 2 °C in 2100 with a high probability. *Keep atmospheric GHG concentration below 450 ppm CO_2 equivalent*	UNFCCC (1992) – Art. 2 UNFCCC (2010) *Meinshausen (2006)*
Terrestrial biodiversity loss	By 2050, biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people	By 2020 the extinction of known threatened species has been prevented and their conservation status, particularly of those most in decline, has been improved and sustained	CBD (2010a) Target 5, 11 and 12
		By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced	
		Halve the rate of loss of biodiversity loss in 2020 and stabilise biodiversity at the 2020/2030 level in 2050 (depending on region)	
		By 2020, at least 17 % of terrestrial and inland water areas are conserved effectively	

Italics indicate extensions by PBL team based on advisory reports or scientific literature to obtain quantifiable objectives. Goals are formulated for 2050, unless specified otherwise.

Table 2.2
Monitoring goals and targets

Themes	Goals	Targets	Reference
Water scarcity	Ensure sustainable use of water resources Introduce measures to improve the efficiency of water use, to reduce losses and to increase water recycling	Reduce the number of people living in water scarce areas Halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation and ensure full access by 2050	JPoI-Para 26 UN (2001), MDG7, Target 7c
Interference with P and N cycles	Avoid acidification of terrestrial ecosystems and eutrophication of coastal and freshwater systems Avoid a major oceanic anoxic event (including regional), with impacts on marine ecosystems	Reduce N/P use where possible (but without harming the ability of the agricultural system to meet the hunger target)	
Human health	Reduce environmental health threats	Reduce environmental health threats, taking into account the special needs of children	JPoI-Para 7f

and updated Strategic Plan for Biodiversity, for the 2011–2020 period, including the Aichi Biodiversity Targets. These comprise 5 strategic goals and 20 targets – many of which are qualitative and focus on 2020. Long-term goals are completely lacking. We therefore interpreted the CBD vision as an ambition to prevent further long-term biodiversity loss, that is, to halve this rate of loss by 2020 (Target 5) and for 2050 to stabilise biodiversity at the 2020/2030 level. For quantifying biodiversity, this report uses the mean species abundance (MSA), as explained in Box 2.3.

In addition to the goals and targets described above, we identified three themes that are relevant to the integrated analysis of land and energy issues. These are water scarcity, interference with the phosphorous and nitrogen cycles and human health. Water scarcity and access to safe drinking water and basic sanitation are addressed in the JPoI and MDGs. For interference with P and N cycles, there are planetary boundaries as proposed by Rockström et al. (2009). Unfortunately, these are formulated at the global level – which is not so relevant for local environmental and development risks. Therefore, instead of adopting these, we decided only to try and minimise the burden. Human health in relation to the environment is also addressed in the JPoI.

Box 2.3 Measuring aggregated biodiversity trends

The broadness of the biodiversity concept and the different interpretations mean that many different indicators have been used to measure biodiversity. Some indicators focus on species and emphasise the importance of retaining species richness at different geographical levels, whereas other indicators focus on the extent and intactness of the original ecosystems. Yet other indicators focus on the drivers of biodiversity loss, largely because these are easier to monitor. However, most indicators have been developed for small, well-known ecosystems and can generally not be applied at the global level. At this level, indicators need aggregating over large areas, grouping together entirely different systems, but this is hampered by insurmountable data gaps.

One indicator that can be used at the global level is the mean species abundance (MSA) of the original species. This indicator uses the species composition and abundance of the original ecosystem as a reference situation. The level of intactness of ecosystems is measured by the change in species composition and abundance as a consequence of changes in driving forces or pressures, such as land–use and overexploitation. If the indicator is 100 %, biodiversity is assumed to be similar to the undisturbed or low-impacted state, implying that the abundance of all species equals the natural state. If the indicator is 50 %, the average abundance of the original species deviates by 50 % from the undisturbed state. Converting natural systems to agriculture, plantation and urban areas is assumed to have an immediate impact on the MSA, which can be further reduced by environmental pressures. MSA is determined by multiplying the impact of different pressures and summing the MSA values of different use types and ecosystems. For more information on MSA and the relationship with environmental pressures, see Alkemade et al. (2009) and www.globio.info.

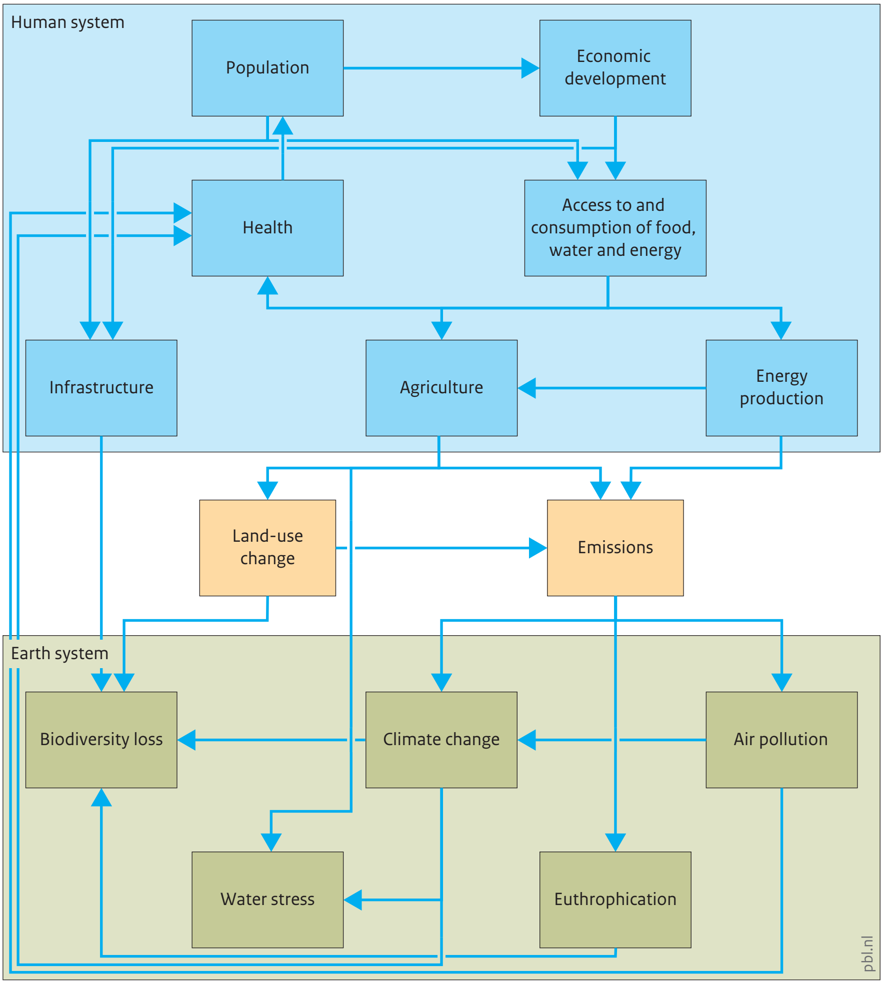
2.3 An integrated approach

The environmental and human systems are intrinsically interconnected

There are many important connections between the various goals and targets mentioned in the previous section.

The demand for and production of energy, food and water play a critical role in the connection between the human and Earth system. For instance, lack of access to food, water and modern energy forms a major part of the global problems of poverty and

Figure 2.2
Relationships between the main themes



Source: PBL

impacts directly on human health. Increasing this access is likely to increase food and energy production, with consequences for environmental degradation.

There are also important linkages between the provisioning of water, food and energy. This is now often referred to as the water, food and energy nexus (Hoff, 2011; Bazilian et al., 2011; World Economic Forum, 2011; European Report on Development, 2012). For instance, food production (agriculture) and energy production are major drivers of water use. Water scarcity, therefore, may lead to important trade-offs between its direct use, use for agriculture and use in the energy system. At the same time, agriculture and water supply both lead to energy demand. The energy system and land use are also connected. For instance, several energy technologies require land. The agricultural system is in turn one of the sectors leading to energy demand (both directly and indirectly for fertiliser production).

The energy and land-use systems are also interrelated parts of the Earth system. Both systems lead to greenhouse gas and air pollutant emissions as well as to land-use/land-cover change. Demand for land for agriculture (cropland and pasture land), the energy system (bio-energy) and urban areas leads to competing claims for scarce, fertile land resources, potentially leading to a reduction in natural areas. Emissions, in turn, lead within the Earth system to air pollution, climate change and the disturbance of various natural cycles. Air pollution and climate change are related to health, agriculture production and biodiversity. Some of these relationships are shown in Figure 2.2.

Addressing the many trade-offs between the individual sustainable development goals requires an integrated approach that takes into account the interconnectedness of the system

The connections between the various elements of the human-environment system imply that for sustainable development an integrated approach is required in order to manage (and potentially even avoid) trade-offs between the various objectives and to capture possible synergies. Chapters 5 and 6 highlight the relationships between the development and environmental aspects of the food and energy challenges. Because of the multiplicity of goals and targets an integrated approach could help optimise the effort required to achieve them. For example, slowing down climate change would improve water availability and crop yields, and reduce the pressure on biodiversity. Furthermore, there are co-benefits between the different measures. Lifestyle changes and efficiency improvements, for instance, may have synergistic effects. Decreased consumption of food, water and fossil fuels decreases the respective mitigation requirements of biodiversity, water stress and climate change, while increased agricultural productivity reduces the pressure on biodiversity.

In some cases, options for a specific theme might induce important trade-offs with other themes. For example, policies that combat biodiversity loss by creating bio-reserves may have negative impacts on land and subsequently food prices may increase. That may also happen as a consequence of increasing biofuel production. Not considering such cross-sector links will decrease the success of the sustainability transition effort and lead to significant delays in reaching the goals and targets.

To capture the linkages, we use a model-based approach to explore different possible scenarios

Many assessments in the past have looked at specific environmental and development problems such as biodiversity loss, climate change or energy use. In order to achieve the sustainable development goals set in the Rio Declaration, it would not be sufficient to achieve goals for only one of these issues; instead, goals for all issues need to be met, simultaneously. Integrated assessment models can be used in a consistent exploration of the various linkages between these issues. For this report, we used the integrated assessment model IMAGE, in combination with related models for biodiversity, human health and climate policy (GLOBIO, GISMO and FAIR, respectively) (see summary in Appendix A).

THREE

Historical progress and future developments without new policies

Progress towards realisation of the intentions and agreements of the Rio declaration has been mixed. Moreover, in some key areas, internationally agreed sustainable development goals will not be achieved. This section provides an overview of the progress regarding key indicators. It also assesses the impacts of future trends in key drivers on progress towards the sustainable development goals, assuming no new intervention policies will be implemented.

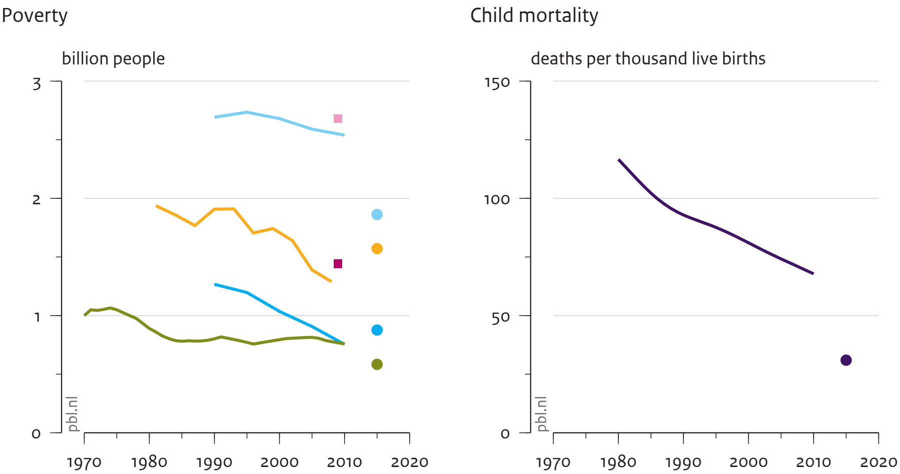
3.1 Progress since the Rio Declaration

Since 1992, progress has been made in some areas, but for other, key areas existing unsustainable trends have not been bent

The success of the Rio Declaration can be evaluated from the progress that has been made in the achievement of the sustainable development goals. The focus of this chapter is on the degree of realisation of the goals and targets as introduced in Chapter 2. These goals and targets have underlying trends in population, economic growth, energy and land use. Since 1992, the world population has continued to grow, although at a declining rate. GDP per capita growth rates have been around 1% to 2 % in OECD countries, as well as in Latin America and Africa. In many Asian regions, growth has been considerably faster. For the world at large, the growth in population and GDP have led to a significant increase in the production of food, the use of water and the mining and use of minerals and fossil fuels.

In the context of sustainable development, a key question is whether the world is on the right track towards achieving the MDGs. Figure 3.1 presents a number of indicators based on the targets introduced in Chapter 2, which provide a partial answer to this

Figure 3.1
Human development indicators



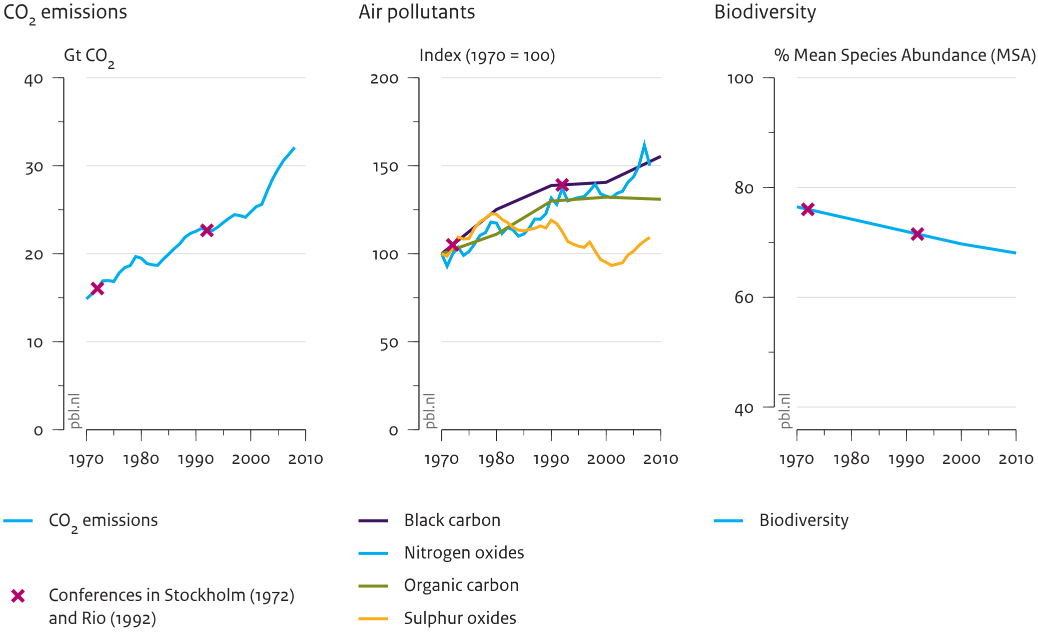
Number of people
- Without basic sanitation
- Living on less than 1.25 dollars a day
- Without access to safe drinking water
- Suffering from hunger
- Under-five mortality rate
- Using traditional enery for cooking and heating
- Without electricity

Millennium Development Goals (targets for 2015)
- Sanitation
- Poverty
- Safe drinking water
- Hunger
- Child mortality

Source: poverty (Chen and Ravallion, 2010); food (FAO, 2010); energy (IEA et al., 2010); water (UNICEF and WHO, 2012); health (UNDESA, 2009)

question. Since 1990, the numbers of people living on less than USD 1.25/day and those without access to safe drinking water have fallen significantly. In fact, these MDG targets were already achieved in 2010. The child mortality rate also dropped, sharply. However, here, progress is still behind schedule. Finally, hunger levels and access to basic sanitation have shown no or only small improvements. Given the current trends, it is very unlikely that the MDG targets on child mortality, food and sanitation will be achieved – at least not in critical regions, such as sub-Saharan Africa and South Asia. Finally, no MDG targets exist for access to modern energy sources; however, one billion people still lack access to electricity and three billion lack access to clean fuels for cooking and heating.

Figure 3.2
Global CO_2 emissions, air pollutants and biodiversity



Source: CO_2 emissions (CDIAC, 2011); air pollutants (Granier et al., 2011); biodiversity (PBL)

Overall, progress on the environmental goals and targets, as described in Chapter 2, has not moved in the right direction (Figure 3.2). Since 1992, carbon emissions (CO_2) have clearly continued to increase – even at an accelerated rate. The average global mean surface temperature has increased by about 0.4 °C. According to UNEP, current policies need to be strengthened significantly if the target of limiting the rise in temperature to 2 °C by 2100, agreed upon in the Cancun meeting in 2010, is to be reached (Rogelj et al., 2011). For air pollutants, global emissions have increased for NO_x and black and organic carbon. Because of stringent policies in the OECD countries from the 1980s onwards, global emissions of SO_2 have decreased but the surge in fossil fuel combustion in the strongly growing economies in Asia has reversed this trend. Although the overall rate of deforestation is decreasing, large forest areas are still declining, particularly in Latin America and Africa. Important drivers of loss of mostly tropical forest are the expansion of crop and pasture land and increasing timber demand. Biodiversity, measured using proxy indicators such as the Living Planet Index (UNEP, 2011a) and the Mean Species Abundance (MSA), has also continued to decline, mostly driven by habitat loss.

All in all, empirical evidence shows that, since 1992, the hoped for increase in human development and decrease in environmental degradation did not occur. Although human development indicators have slowly improved, although insufficiently, ecological indicators have continued to worsen.

Several generic barriers to achieving sustainable development goals exist

Although most countries signed the Rio Declaration, it seems – based on the progress in meeting actual targets – that the political will to deal with these issues is in reality quite low. According to the UN High Level Panel (2012), efforts to meet the MDGs and other social and economic targets are hampered by both an inability to agree on decisive and coordinated action in national and multilateral forums and by unmet commitments for financial support. For example, the delivery of official development assistance (ODA) by many OECD countries has stayed far behind pledges made internationally. UNDP (2011) has pointed at the lack of effective approaches for dealing with environment–poverty linkages.

Several other generic barriers to implementing sustainable development policies can be identified:

- *A lack of an elaborated vision* on where to go in more concrete terms than the overall ambitions formulated in the international agreements.
- *Many different interests*. More specifically, short-term interests tend to take priority over long-term ambitions. Policy-making is continuously confronted with short-term and partial issues and interests and, in the absence of a strongly legitimised and integrated long-term political vision, sustainable development goals and policies are forgotten or only paid lip service.
- Policy-making on energy and land-use issues is often *fragmented*. At all levels of decision-making, the main picture shows a legacy of fragmented institutions established around single-issue ‘silos’, deficits of both leadership and political space, lack of flexibility in adapting to new kinds of challenges and crises and a frequent failure to anticipate and plan for both challenges and opportunities. In this context, it should also be noted that achieving development, climate or biodiversity goals depends less on purely development, climate or biodiversity policies and much more on whether these concerns are integrated into general, economic decision-making (mainstreaming).
- *Incentive structure*. Policy-makers at all levels have so far failed to deliver the proper incentive mechanisms for pricing, investment and financial transactions that help to achieve sustainable development in the longer term (UN High-Level Panel, 2012). The decisions various actors make (governments, businesses) are often evaluated in a strictly economic sense, without sufficiently ensuring that natural assets will continue to provide the resources and environmental services on which human well-being relies (OECD, 2011b; Stiglitz et al., 2009).
- The *inability to address poverty, especially in Africa*, is also visible in the insufficient progress with respect to ensuring access to modern energy and food security.

- Other *problems specifically related to global governance also hamper progress.* Examples are finding the right level at which to solve problems (the subsidiarity principle), the lack of a strong institutional framework at the international level to handle global problems, differences in preferences and interests between countries, the reliance on ethical choices for 'winners' to transfer or share benefits with 'losers', the free-rider problem, the dependency on the weakest link, keeping up the momentum in implementing international agreements and the lack of credible sanction mechanisms (Carbone, 2007; Hajer, 2011; Kok et al., 2011; Weiss, 2008; Schrijver, 2010).

3.2 Future developments without new policies

3.2.1 General characteristics

The baseline scenario is a benchmark, not a forecast

To understand the nature of the challenges posed by the sustainable development, goals and targets, and the efforts needed to realise them, we need to be specific about possible future developments in the world community. Unfortunately, the world system is so complex that we cannot predict it or assign probabilities to possible developments. The common approach is therefore to construct a future that is 'surprise-free' in the sense that the trends in key variables continue more or less unmodified. In particular, it is assumed that the basic socio-economic mechanisms continue to operate in the same fashion and, in the present context, no explicit new policies are introduced to meet sustainability goals. Such a scenario is called the baseline, trend or 'business-as-usual' scenario. Here, we call it the *Trend* scenario and use it as a benchmark against which possible alternative future developments are evaluated. The *Trend* scenario stems from the baseline scenario used for the third OECD Environmental Outlook (OECD, 2012; Box 3.1). It is not a prediction or forecast, but serves as a benchmark and point of reference (see Box 3.2).

Important current trends include new technologies, involvement of civil society in decision-making, and remaining economic inequalities

The baseline scenario in this report assumes that the trend towards modernisation according to the western model continues, albeit with regional specificities. Economically, development is guided by the paradigm of maximising productivity and efficiency through competition, innovation and the abolition of trade barriers. Important drivers are the search for high returns on capital savings and decreasing consumer prices. In such a world, multinational corporations are the prime actors in a further globalising world (Dicken, 2009). Clearly, this development might benefit consumers and investors, but it may also result in significant negative side-effects for the environment and the poor. It is the role of governments (including international organisations) to ensure a level playing field for the corporations and to manage access to resources, environmental side-effects and the like (Schrijver, 2010).

Box 3.1 Differences between the baseline in this study and the OECD Environmental Outlook

The baseline scenario in this study shares its storyline and economic and population projections with the baseline scenario in the OECD Environmental Outlook (OECD, 2012). There are however some differences:

- For land use, a recently calibrated version of the IMAGE model is used that includes calibrations up to 2005. As a result, land use in 2005 is somewhat lower. Yield projections after 2005 have also been revised downward slightly. As a result, the land use in 2050 is somewhat higher.
- The energy use and greenhouse gas emission projections in the OECD Environmental Outlook originate mostly from the ENV-LINKAGES model. Here, model outcomes are presented from the IMAGE model. As shown in the OECD report, results are comparable but not exactly the same. Moreover, some recent changes in the energy modelling are included – such as a more detailed representation of the transport sector, resulting in slightly different projections.

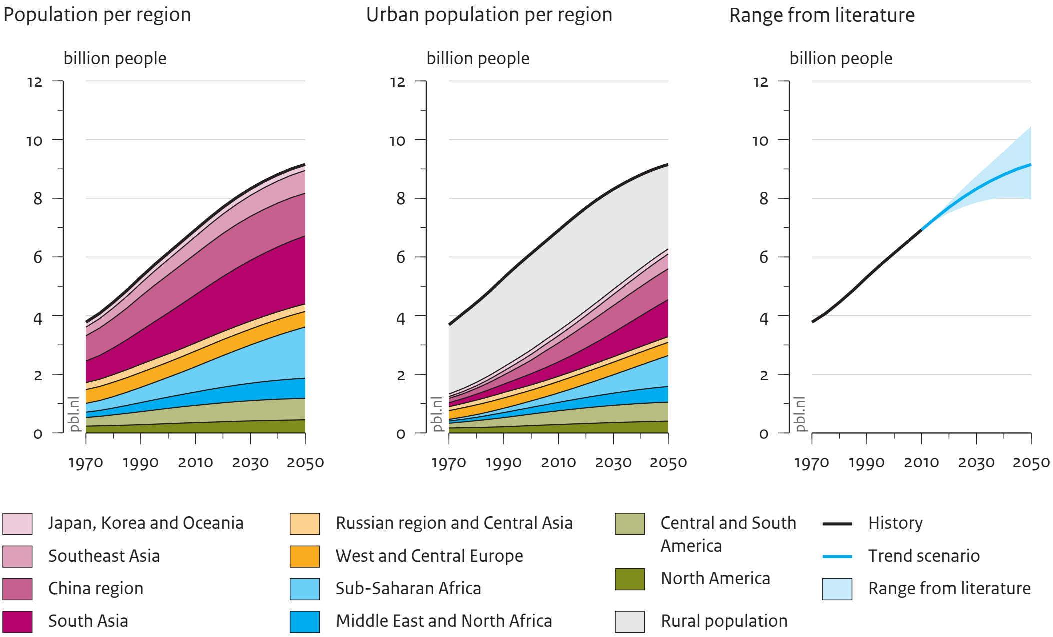
The continuation of current trends is considered in this context. The *Trend* scenario assumes that world development continues to be characterised by a focus on economic development and globalisation. The scenario also assumes a continuing increase in the consumption of food, the production of material goods and services and the use of energy carriers, although with a tendency towards saturation at high income levels. Finally, we introduce some reactive responses to environmental degradation (e.g. reduced sulphur emissions to protect health). However, no pro-active policies to reduce the risks associated with environmental degradation are presumed.

The continuation of current trends was also assumed for a couple of other key determinants of future sustainable development issues:

- New technologies will continue to contribute to the rapid increase in global connectedness and interdependencies. This will provide new opportunities for economic prosperity; for instance, through exploiting comparative and scale advantages, but has also introduced complexities that are difficult to understand and manage.
- New technologies and changes in society will also continue to strenghten the involvement of civil society in decision-making. Information is now readily available via Internet and social media, and societal groups are able to quickly organise themselves around specific issues.
- Finally, it is expected that economic inequality between and within countries will persist.

We briefly discuss the main trends in population, economic activities and land and energy use below.

Figure 3.3
Global demographics in the Trend scenario



Source: UNDESA (2009, 2010)

3.2.2 Demographic trends

The global population is projected to grow with 2.2 billion people, predominantly in urban areas

Under the *Trend* scenario, by 2050, another 2.2 billion people will have been added to the current 7 billion (UNDESA, 2011). This falls well within the uncertainty range given in the literature of between 8 and 10.5 billion people by 2050 (Lutz et al., 2008; UNDESA, 2011) (Figure 3.3). There are significant differences in demographic developments across regions and countries, as can be seen from the differences in growth rates. Population growth is concentrated almost completely in the current low-income countries. Except for Northern America, the high-income regions show a decline in population size. The differences also show up in ageing dynamics. China and the OECD countries are projected to experience significant population ageing. In contrast, the more youthful populations in South Asia, the Middle East, North Africa and especially sub-Saharan Africa, are projected to grow significantly until 2050.

Another key trend is that the world's population is becoming increasingly urbanised. Currently, around 50 % of the world's population lives in urban areas. This is projected to rise to nearly 70 % by 2050 (UNDESA, 2012). The increase in the urban population is projected to be 2.8 billion. Urban areas are thus likely to absorb the total growth of the world's population between 2010 and 2050, while the rural population is projected to decrease slightly by 0.6 billion. In principle, it is easier to ensure access to modern energy and water infrastructure for the higher concentrations of people in urbanised areas. Nevertheless, one-third of the world population is projected to live in urban slums by 2050, with negative consequences for both health and the environment.

3.2.3 Economic trends

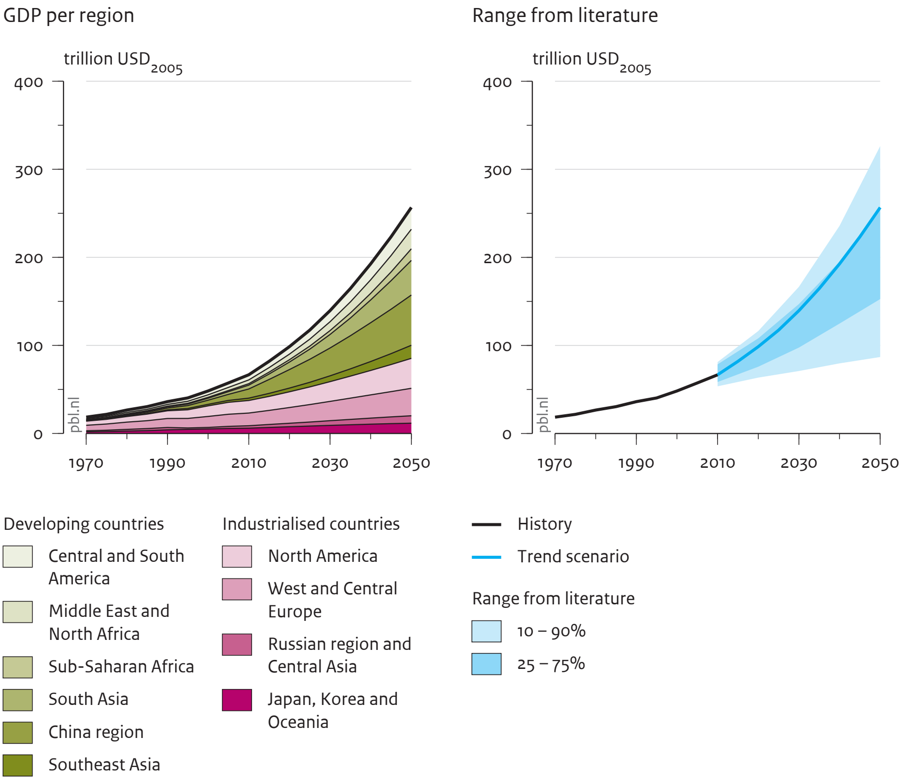
The global economy is projected to grow further along historical rates, with the highest growth rates in developing countries
Historically, the world economy measured as the sum of estimated country GDP has nearly quadrupled over the last 40 years. In the *Trend* scenario, it is assumed that the economic growth continues, mostly driven by economic growth in current low-income countries. This is illustrated in Figure 3.4 in terms of GDP.

Economic growth in OECD countries is projected to be, on average, a historically low 1.5–2 % per year. In low income regions, growth rates are assumed to be in the order of 3–5 % per year due to the large potential for growth in labour and capital productivity and a large unmet demand. For Latin America, the Middle East and Africa, projections are higher than the historical rates as these regions are assumed to profit from globalisation and a favourable demographic situation. For the Asian regions, growth rates will be similar to or slightly lower than the historical rates as a result of the assumed maturing of their economies. For sub-Saharan Africa , GDP growth is forecast to be relatively slowly until 2030, after which there will be the same 'take-off' as earlier in Asia. One implication is that the income gap between sub-Saharan Africa and the rest of the world will widen in the coming decades.

These projections imply a strong shift not only in the nature of economic production and consumption, but also in their global distribution. For instance, by 2050 the OECD's share of the global economy is projected to fall to less than 32 % compared to 54 % in 2010, while the share of Brazil, Russia, India, Indonesia, China and South Africa (BRIICS) is projected to grow to more than 40 %. The relative share of agriculture will continue to decline as part of the structural shift towards manufacturing and services.

Economic growth and income distribution determine the extent of poverty reduction
Average income data hides the large inequities in the world. Long-term differences in living standards (GDP per capita) between countries are driven primarily by differences in productivity levels (Hall and Jones, 1999). These, in turn, depend on a large array of factors and there is as yet no clear empirical evidence of their relative importance (Helpman, 2004). Clearly, trade and technology transfer are important mechanisms for

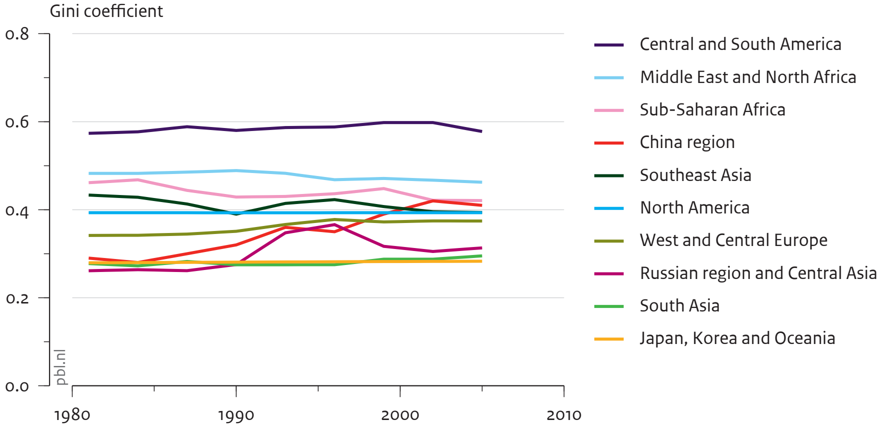
Figure 3.4
Global economic growth in the Trend scenario



Source: World Bank (2009) and OECD (2012) and literature range from Van Vuuren et al. (2012b)

reducing income differences between countries. On the other hand, weak institutions can cause stagnation for long periods. There is a growing body of empirical work that highlights the importance of economic growth for poverty reduction (Melamed and Scott, 2011). Empirical data show that an increase in average income implies on average an increase in the income of the poorest segments of society. Econometric analysis of historical data indicates that growth in average incomes did in the long run account for approximately 80 % of absolute poverty reduction (Kraay, 2006). If this were to also apply to the coming decades, economic growth can still be expected to make the largest contribution to poverty reduction (MDG1). At the same time, however, the diversity and complexity of income distribution in and between countries makes it clear that there are significant opportunities for accelerating poverty reduction and realising other MDGs, notably government taxation policies, institutional reforms and appropriate public spending (e.g. see Melamed and Scott, 2011). A fresh reconsideration of the actual and

Figure 3.5
Income inequality per region

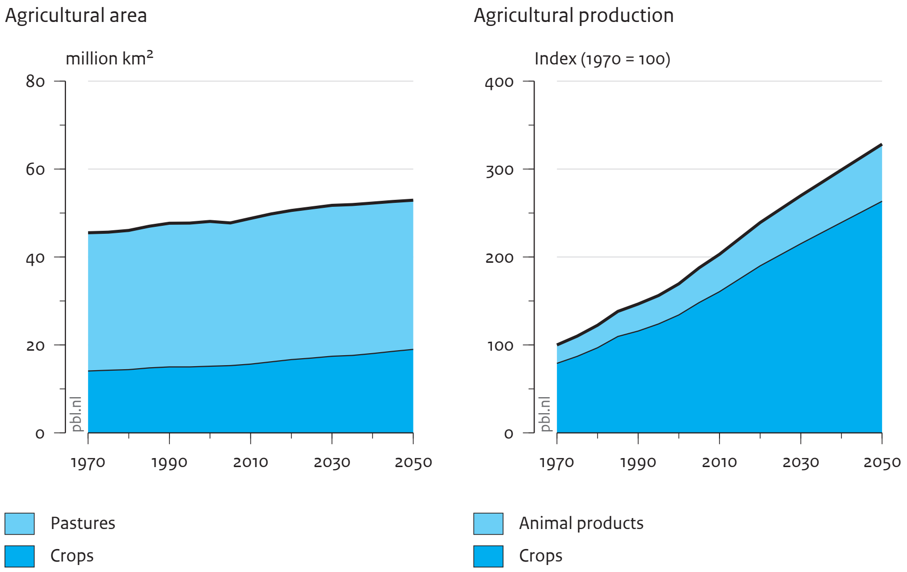


Source: Ackah et al. (2009) for developing countries, and World Bank (2009) for developed countries, mostly for one year in the 1993–2005 period

High values represent larger inequality, low values more equality.

Box 3.2 Uncertainty in economic projections
There is considerable uncertainty in parts of the *Trend* scenario. The main uncertainties in the economic projections can be divided into short-/medium-term and long-term uncertainties, and give an impression of the plausibility of the *Trend* scenario. There are several reasons why, in the short term, economic growth rates could be lower than under the *Trend* scenario. One is the financial crisis that started in 2008, as a result of which the OECD and IMF already downgraded their short-term forecasts. It now seems that the crisis will also affect medium- to long-term prospects. IMF and OECD projections indicate that global imbalances (large current account surpluses and deficits in different parts of the world) remain high. From a sustainable development viewpoint, most serious is the risk that the current financial crisis absorbs all the attention and makes it even more difficult to address sustainability problems. A critical assumption in the OECD baseline scenario is that, in the long term, productivity will play an important role in economic growth in poor countries. As in several low-income countries (including those in Africa), the recent high economic growth was mostly driven by the high demand for their natural resources; it remains to be seen if these trends will continue. It is also possible that feedbacks, such as high prices for natural resources, will limit productivity growth.

Figure 3.6
Global agricultural area and production in the Trend scenario



Source: PBL

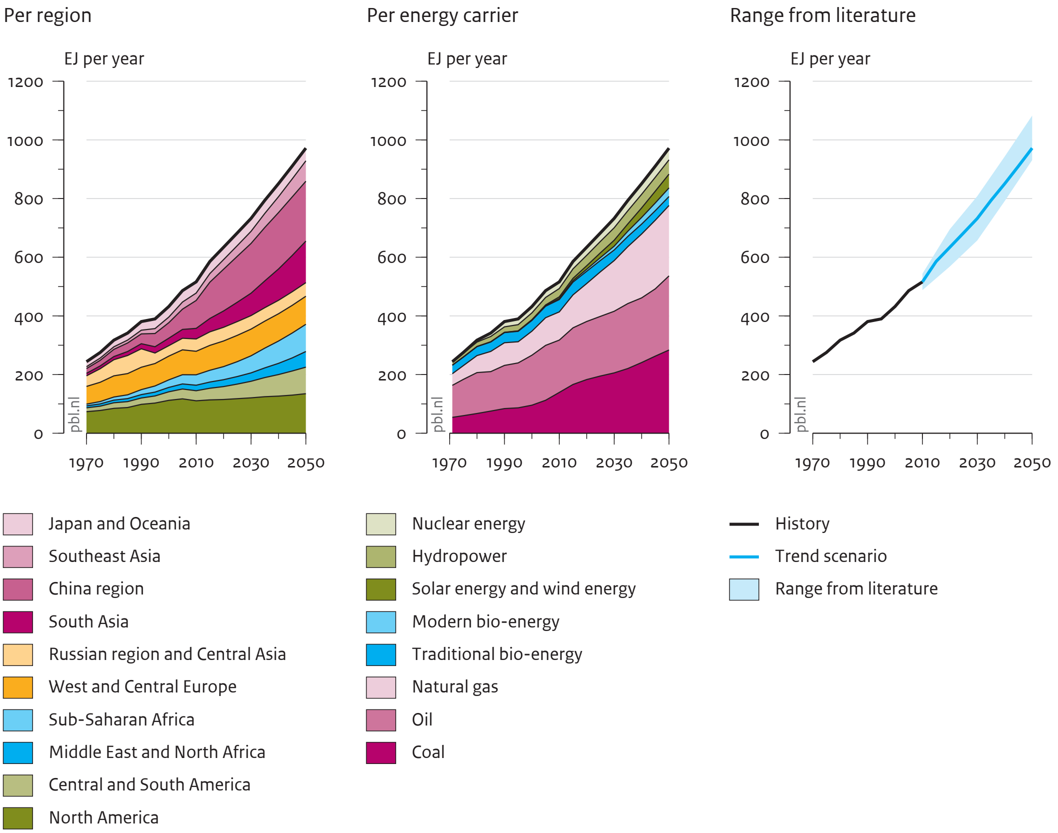
desirable role of income transfer through migrant workers, trade and aid is also part of the discussion. Historical trends in the Gini coefficients in different regions (a measure of inequality) are shown in Figure 3.5. Higher income inequalities make it more difficult to decrease poverty through economic growth only, while uneven growth increases income inequality, as was the case in China in the 1982–2005 period.

3.2.4 Trends in land use and energy production

Increasing demand for food, feed and biofuels results in a further expansion in land use
World food production is projected to increase significantly in the coming decades (Figure 3.6). This will be driven by an increasing demand for food products due to population growth and diet changes, mostly in current low-income countries. The share of animal products in diets is expected to increase along historical trends, inducing further increases in demand for feed crops. Finally, demand for biofuels will also increase significantly, mainly as a result of current biofuel mandates.

Although yield increases will provide the vast majority of the increase in agricultural production, also agricultural area is projected to increase between 2010 and 2050. This

Figure 3.7
Global primary energy supply in the Trend scenario



Source: PBL and Clarke et al. (2010) for literature range

is a continuation of the historical trend. This increase will be particularly strong over the next 20 years, after which the slowdown in population growth will also slow down the expansion in agricultural area. The *Trend* scenario falls within the ranges of other projections, including scenarios that show a rapid expansion in agriculture area as well as scenarios that show a decrease.

Growing demand for energy services, predominantly in developing countries, results in a two-third increase in energy use
The *Trend* scenario projects a 65 % increase in energy consumption in the 2010–2050 period, which is comparable to other projections (Van Vuuren et al., 2012b) (Figure 3.7). The larger part of this increase takes place in presently low-income countries. In the *Trend* scenario, per capita energy consumption in high-income countries does not

change much, but is mostly a shift towards electricity and natural gas. In many low-income countries, per capita energy use increases strongly (sometimes even doubles), with the largest increases in oil and electricity use.

In terms of energy supply, the energy system continues to be dominated by fossil fuels. Assuming no fundamental change in current policies, fossil fuels are expected to retain a large market share as their market price is expected in most situations to stay below that of alternative fuels. In the longer term, with further depletion of low-cost oil and gas reserves and a transition towards the exploitation of non-conventional deposits, there will be an upward pressure on costs and thus on prices. This is not the case for coal. As a result, it seems likely that in the *Trend* scenario the use of coal will strongly increase, particularly for electric power generation. Energy production from non-fossil sources is also expected to increase substantially in the *Trend* scenario.

3.3 Progress towards sustainable development goals

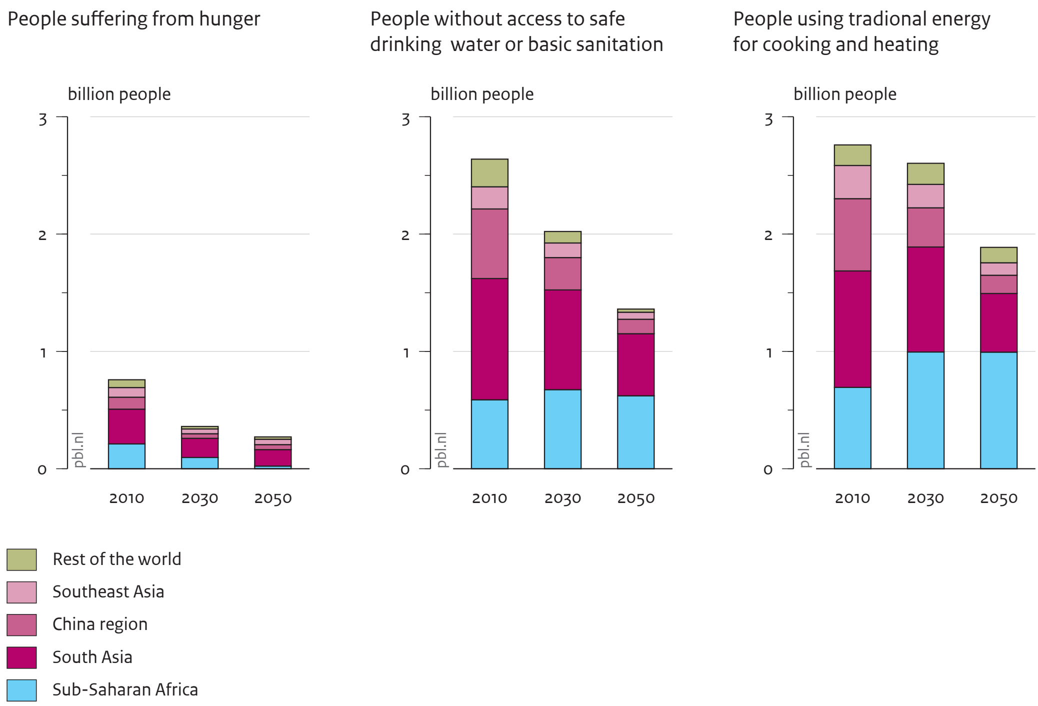
Access to food, modern energy services, and safe drinking water and improved sanitation is projected to increase significantly
Currently, over 90 % of people that suffer from hunger or lack access to modern energy sources, safe drinking water and improved sanitation live in sub-Saharan Africa and Asia. Future developments in access to these resources are given in Figure 3.8.

With respect to hunger, the global situation improves significantly in the *Trend* scenario, mainly due to increasing per capita availability of food (Figure 3.8). Rising incomes also tend to result in decreasing inequality in access to food, as long as prices, especially of staples, remain stable. In Asia in particular, inequality in access to food decreases, significantly, due to strong economic growth. However, despite the enormous global increase in food availability and the decreasing inequalities in access for most regions, 11% of the population in sub-Saharan Africa and Asia is projected to still suffer from hunger in 2030, and this will be around 5% by 2050. These percentages represent 450 and 250 million people, respectively.

The share of the global population living without access to modern fuels for cooking and heating also decreases, significantly, in the *Trend* scenario, from 40 % in 2010 to around 20 % in 2050, although this is still 1.8 billion people. Improvements are largest in East and Southeast Asia (10–15%) and slightly lower in South Asia (around 20%). Per capita income levels in 2050 will be much higher in South Asia than in most countries in sub-Saharan Africa, where access on average will still be low in 2050 (57%). Electrification also follows the same regional trends, with people lacking access to electricity dropping from 22% in 2010 to 6% in 2050.

Finally, the same trends are projected for access to safe drinking water and improved sanitation, although the numbers are much lower. Here, access levels also improve

Figure 3.8
Human development indicators in the Trend scenario



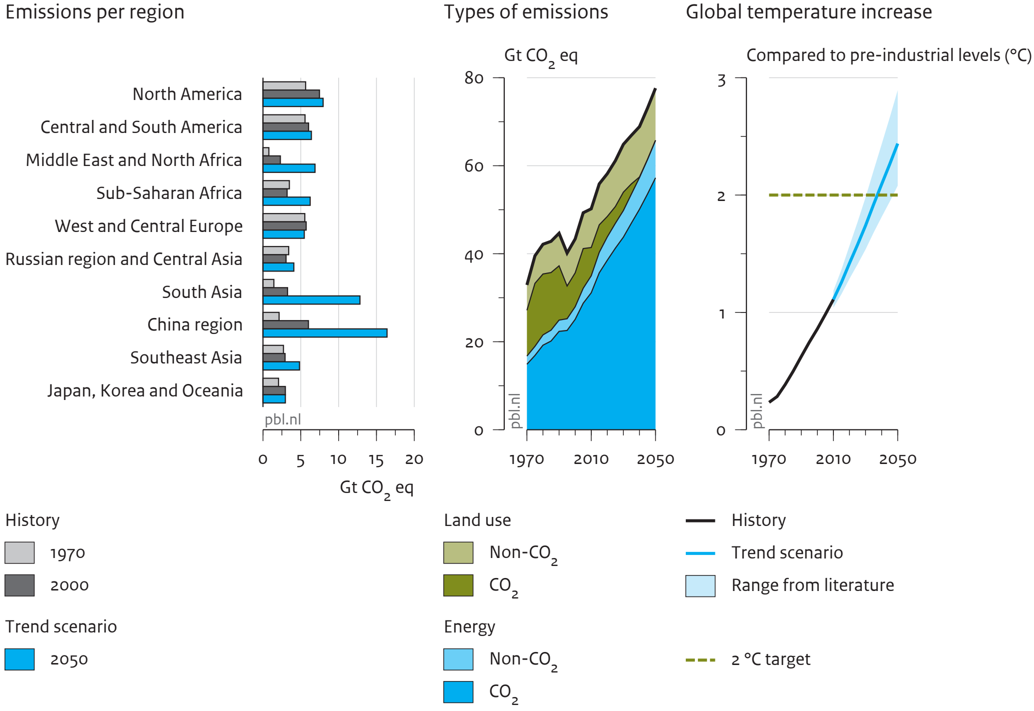
Source: PBL

significantly between 2010 and 2050, mainly as a result of rising income levels and increased urbanisation. For safe drinking water, universal access will be achieved by 2030, in most parts of Asia, while, in sub-Saharan Africa, access levels remain behind, reaching 80% to 90 % by 2050. For the latter, sanitation levels in 2050 are projected also to be much lower than in Asia. As a result, most of the people lacking access to safe drinking water and improved sanitation in 2050 will live in sub-Saharan Africa.

The projected increase in food and energy production increases the pressure on climate, air and biodiversity

Projected trends in energy and food production increase the pressure on the global environment (see Figure 3.11). Increasing fossil-fuel use implies increasing greenhouse gas emissions and air pollution levels (Figures 3.9 and 3.10). For the 2010–2050 period, greenhouse gas emissions are projected to increase by about 60%. Although most of this increase would take place in low-income countries, per-capita emissions remain highest in the OECD countries. As a result of the global emission increase, global

Figure 3.9
Global greenhouse gas emissions and temperature changes in the Trend scenario

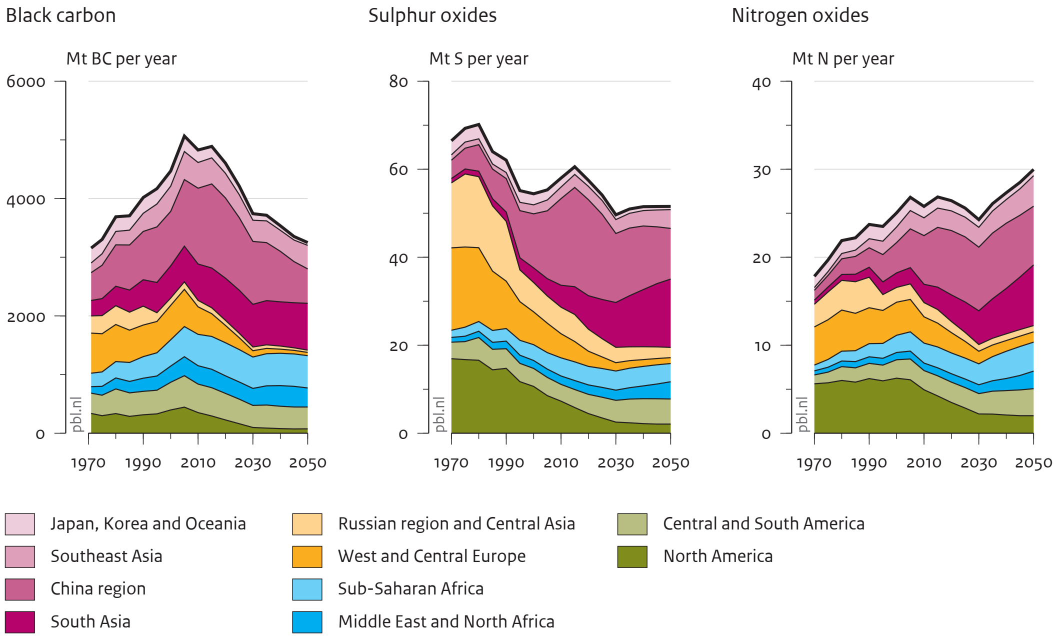


Source: PBL and literature range from Van Vuuren et al. (2008)

temperature is expected to increase to around 4 °C above pre-industrial levels by 2100, most likely passing the 2 °C target before 2050.

Projections for different regions with respect to air polluting emissions diverge. In high-income countries, emissions are mostly expected to decline further as a consequence of increasingly tight emission standards – followed by a leveling off. For low-income countries, emission trends are determined by a rapid increase in energy consumption and the introduction of emission control technology. This implies that in some regions emission levels increase, while in others they decrease. Comparison between the *Trend* scenario and the scenarios developed for the Global Energy Assessment (Riahi et al., 2012) show that concentration targets for air pollution are not met under the *Trend* scenario.

Figure 3.10
Global emissions of air pollutants in the Trend scenario



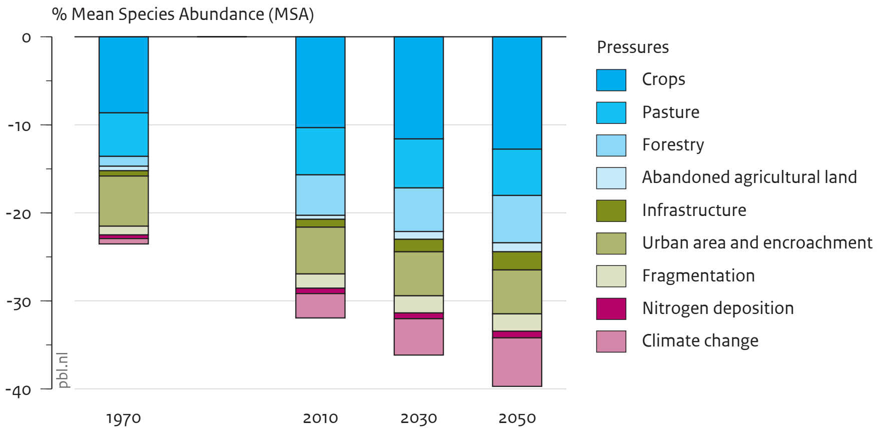
Source: PBL

Given the further expansion in agricultural area, climate change and trends in other environmental pressures such as nitrogen deposition, global biodiversity is projected to decline further at a rate similar to the historical rate. As a result, the global MSA value is expected to decline from 68% in 2010 to 60% by 2050, with a large role for agricultural land use, encroachment and climate change (Figure 3.11).

Without new policies sustainable development goals will not be achieved

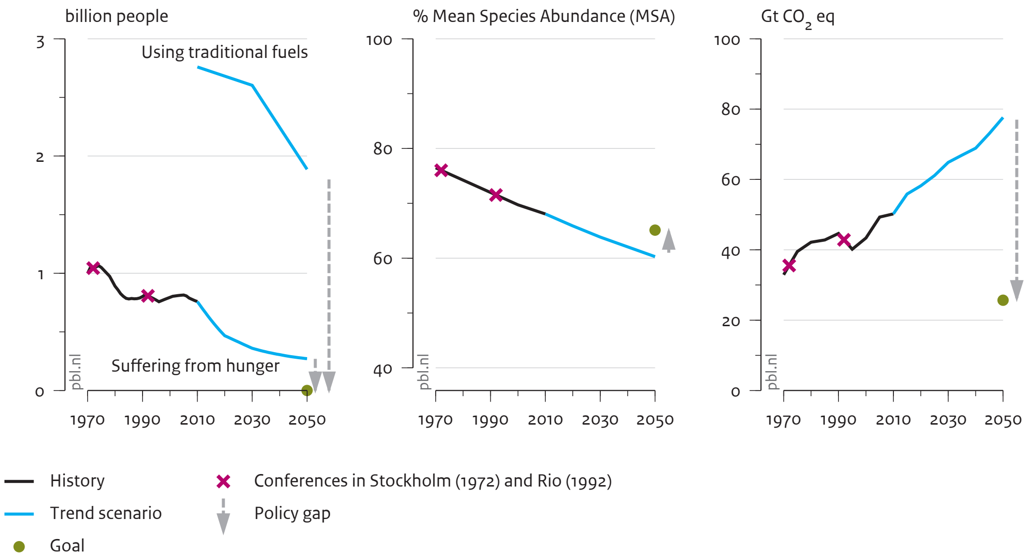
Figure 3.12 compares the *Trend* scenario with the different targets discussed in Chapter 2. The relationship between greenhouse gas emissions, concentrations and global mean temperature is beset with important uncertainties. In order to have a high probability of reaching the 2 °C target, greenhouse gas concentrations should be below 450 ppm CO_2 eq (Meinshausen et al., 2006), which means that global emission reductions of 40% to 60% from to 1990 levels in 2050 would be necessary (Van Vuuren and Riahi, 2011). Here, we translated the 2 °C target to a 50% emission reduction by 2050. In the *Trend* scenario, however, emissions overshoot this target by about a factor of three. Furthermore, for biodiversity, as the decline in MSA continues after 2030, the target to stabilise biodiversity at the 2020/2030 level by 2050 will not be met. For people without access to

Figure 3.11
Pressures driving global biodiversity loss in the Trend scenario



Source: PBL

Figure 3.12
Key indicators of sustainability in the Trend scenario



Source: PBL

The sustainable development goals analysed in this study and the policy gap are also indicated.

modern energy and those who suffer from hunger, progress is projected to be made, under the *Trend* scenario. However, this progress will not be enough to fully eradicate hunger and provide full access to modern energy sources. Finally, a similar trend can be observed for air pollution (not shown in Figure 3.12); although globally the *Trend* scenario would leads to a small decrease in emissions, this progress would be insufficient to achieve the targets. In other words, in the *Trend* scenario, the sustainable targets selected in Chapter 2 will not be reached. This is also confirmed by the scenario assessment in the fifth Global Environment Outlook (UNEP, 2012). Chapter 4 introduces three alternative pathways that explore what would be required in order to reach these targets.

FOUR

Pathways towards sustainable development

The previous chapter clearly shows that under current trends the sustainable development goals will not be achieved. This chapter presents alternative, normative scenarios that would achieve the sustainable development goals and close the sustainability gap identified at the end of the previous chapter. Three alternative scenarios are explored to analyse how these goals can be realised along quite different pathways. These three scenarios (or pathways) are the 'Global Technology pathway', the 'Decentralised Solutions pathway' and the 'Consumption Change pathway'. Together, these pathways help to span a wide and diverse 'solution space' for achieving the sustainability goals. The options included for land use and energy are presented for each of the pathways.

4.1 Alternative pathways

The *Trend* scenario described in the previous chapter clearly would not achieve the sustainable development goals and targets introduced in Chapter 2. Therefore, we developed three alternative, normative scenarios that would achieve these goals and targets. The reason for exploring three alternative scenarios is that they could be realised along quite different routes. The scenarios, referred to as pathways, therefore, differ with respect to the options that are used (e.g. technologies and lifestyle change) but also with respect to the societal changes and underlying governance structure that is assumed. The pathways also share some characteristics, the most important being that, under all three scenarios, the sustainable development goals and targets would be achieved.

An important assumption, made partly for practical reasons, is that the population and economic activities are the same as in the *Trend* scenario. In other words, we hypothesised that neither the policies that are introduced nor the avoided resource scarcity and environmental change in the coming forty years (2010–2050) influence the average growth trajectory of population and economic activity outside the uncertainty ranges presented for the *Trend* scenario. Regarding economic growth trajectories, resource scarcity and environmental degradation can also have significant impacts at the regional level. For instance, waves of food price hikes could be triggered by a combination of droughts, protectionism, biofuel subsidies, land grabbing and speculation. Economic growth will also be influenced by the technical, institutional and policy changes that are assumed to occur in the three alternative scenarios. These impacts are quite uncertain too, although most studies seem to agree that rigorous interventions to redress climate change and its consequences only modestly influence economic growth (Azar and Schneider, 2002). Given the large uncertainties, these macroeconomic feedbacks were not taken into account. The same holds for population dynamics. Although not included in the pathways, an illustration of potential changes in global population growth due to targeted policies is presented in Box 4.1.

The three alternatives presented here are not exhaustive. Several more pessimistic projections have also been presented over the last decade, in which much more intense disaster and catharsis sequences are explored (Raskin et al., 2002). Although the dynamics in these more dismal futures may also be at work in our alternative scenarios, we assumed that they would merely be triggers in the right direction and not lasting trends of collapse.

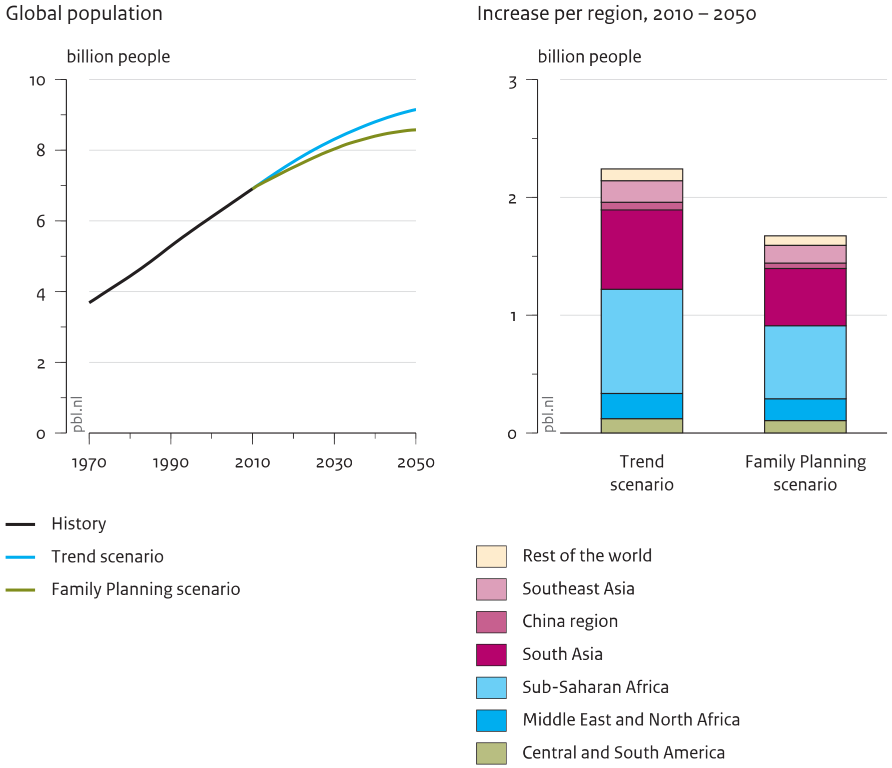
Differences between the alternative pathways and the *Trend* scenarios occur in three dimensions: the nature of economic activities ('lifestyle'), the availability and performance of technologies, and the interventions, regulations and policies that are applied. Naturally, these differences lead to differences in the associated effort levels, synergies and trade-offs to achieve sustainability goals. The three scenarios presented here should be interpreted as illustrations of possible pathways toward a sustainable development as delineated in the goals, and not as well-defined blueprints. The scenarios are elaborated in detail in the next sections and applied in Chapters 5 to 7, and Chapter 8 elaborates on the governance implications.

The three alternative pathways outlined in this report are, in essence, ways to strengthen and direct, or redirect, the technologies, preferences and incentives in society in more sustainable directions. This involves activities at all scales – local, regional and global. The scenarios differ in their emphasis on human behaviour as leverage for change, in the relative weight of regulation versus markets and, related to this, in coordination versus competition and on the characteristics and scale of the technologies to be stimulated. These changes are oriented at reducing global environmental pressures, but also at fostering development in the form of better access to a sufficient quality of food, water and modern energy for billions of people. This has a global dimension (e.g. via trade), but some other concerns are mostly regional or local, as are the responses and solutions. Conversely, the global sustainable development

Box 4.1 The option to reduce population growth

Every person born now will consume energy, food and other natural resources for about 70 years, the current average global life expectancy. Therefore, reducing population growth compared with the *Trend* scenario might be one of the most effective ways of avoiding additional pressure on the environment. However, population policies aiming to reduce the number of future newborns have either been neglected (Bongaarts and Sinding, 2011) or delicately avoided while discussing environmental issues. In contrast, pro-natal policies have been introduced in many European countries without strong public debate.

Figure 4.1
Global population and regional increase



Source: PBL

Education and family planning measures will reduce population growth by 500 million, compared to the Trend scenario.

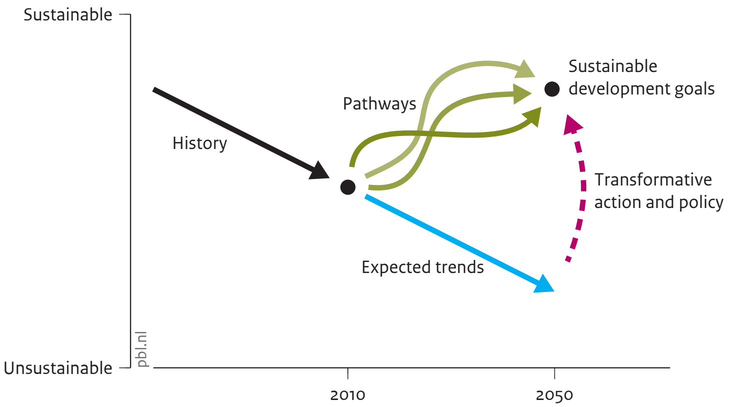
However, instead of primarily focusing on reducing population size, this can also be approached from a development perspective. In many developing countries, the number of children born is higher than that desired (Bongaarts, 1997). This is referred to as the unmet need for contraception (Bongaarts and Bruce, 1995). In less developed countries, around 17% of all married couples (about 100 million) would prefer to avoid pregnancy, but are not using any form of contraception. Facilitating these couples to only have the number of children that they would like to have; for example, through family planning programmes, is an effective way of mitigating population growth. Another, more indirect way is by increasing development levels, such as through education and then especially for girls and women (UNICEF, 2003). This then would lead to the use of contraception by couples to actively control child birth in light of other goals. The combination of these options allows couples to have the family life they want and reduces population growth in the long term. It has been estimated that the total cost of investing in modern family planning and maternal and newborn health services to meet existing needs is around USD 25 billion or USD 4.5 per capita (Singh et al., 2010). According to some studies these investments would be very cost-effective (UN, 2009).

For the variant presented here, we assumed universal primary enrolment in education by 2015 and universal secondary enrolment by 2030, combined with universal family planning by 2015. We assumed this to reduce unmet needs by 74%. This alternative scenario results in a population increase of about 1.7 billion over the period 2010–2050 compared with the 2.2 billion in the *Trend* scenario. The main differences take place in sub-Saharan Africa and South Asia (which experience the most rapid growth rates in the *Trend* scenario). It should be noted that increasing educational attainment will take decades rather than years and its effect on lowering fertility rates will not have been fully accomplished by 2050.

goals and targets described in Chapters 2 can only be effectively addressed if both the local and global dimension of the causes and the responses and consequences are considered. Given the intense across-scale interactions in the world of the twenty-first century, governance and institutional developments in the various scenarios should be explicit on the nature of lifestyles, economic mechanisms and technology features. Figure 4.2 sketches the idea of a *Trend* scenario and the three alternative scenarios. The different trajectories for the alternative scenarios can be explained by the differences in perceived urgency, economic and institutional effectiveness and feasible rate of lifestyle changes.

The three alternative scenarios can be summarised as follows:
- *Global Technology*. International and national elites feel an urgency to deal with global sustainability issues and manage to convince a majority of citizens to introduce

Figure 4.2
Pathways for meeting sustainable development goals



Source: PBL

The horizontal axis is time; the vertical axis represents an aggregate of indicators that cause unsustainable development.

large-scale, global solutions to resolve these issues, notably climate change and biodiversity loss. The large income and wealth inequalities are also addressed as they are considered a major cause of global insecurity, resource conflict and social and political turmoil. The problems and solutions are primarily perceived and solved as large in scale and global in outreach. It is a 'top-down' managed world.

- *Decentralised Solutions*. The belief that a sustainable quality of life can only be realised at the local or regional level gets more priority than the possible impacts of long-term issues. As a result, sustainability problems are primarily seen and resolved in the form of small-scale and decentralised technologies and organisational efforts. Still, ICT facilitates the dissemination of smart and novel forms of technologies and institutions to also ensure a sufficient level of global coordination. This is a 'bottom-up' evolving world.
- *Consumption Change*. Partly because there is a growing awareness of sustainability issues, important changes in lifestyle take place that facilitate a transition towards less material- and energy-intensive activities. Targets that still have not been achieved are bridged with additional existing technologies.

The three pathways follow distinctions made in previous scenario sets. For instance, the *Global Technology* pathway resembles the Millennium Assessment (MA) Technogarden scenario and parts of the B1 storyline. The *Decentralised Solutions* pathway is comparable to the MA Adaptive Mosaic scenario and the original storyline of the B2 scenario (see

Table 4.1
Main characteristics of the three sustainable development pathways

	Global Technology	Decentralised Solutions	Consumption Change
Achieve sustainable development goals	Yes	Yes	Yes
Consumption changes	Not considered (other than implicitly induced)	Not considered (other than implicitly induced)	Included
Key actors leading the transition	International policy-makers, multinational corporations	Citizen groups and civil society, local and national policy-makers	Citizens and firms
Scale	Top-down; global	Bottom-up; local	All scales
Goals	Global, compensation at global level	Possible local differentiation, but based on strictly local policies	See Global Technology

More detailed assumptions are indicated in Chapters 5 and 6.

Van Vuuren et al., 2012b). For each scenario, reasons can be found for its plausibility as well as its implausibility. For instance, the *Decentralised Solutions* and *Consumption Change* pathways may fail because people are too fragmented and disorganised to sustain their efforts, whereas the *Global Technology* pathway may become ineffective because of distrust of the intentions of the 'top-down' people and policies. We did not consider such failure risks here (De Vries and Petersen, 2009).

It should be noted that the translation of a storyline behind a scenario into model parameters always requires additional subjective assumptions on proximate variables. In order to keep our work transparent, in each storyline we only accommodated for a limited set of scenario-specific interventions, regulations and policies – this is also to preserve internal consistency.

4.2 Global Technology pathway

In the *Global Technology* pathway, international organisations, national governments and multinational corporations take the lead in steering demographic and economic trends in more sustainable directions. The 'planetary boundary' notion is taken seriously and the crucial countries and regions in the world engage in concerted action programmes, notably, to address greenhouse gas emissions, biodiversity conservation and trade agreements for key resources. They are willing to accept a few free riders and to compromise in the form of Green Funds and other 'fairness' arrangements. The inherently top-down agenda is translated throughout the UN framework into local and regional action programmes that are funded and monitored in consultation with local stakeholders. The active regions agree that a more bottom-up approach is necessary to obtain popular support but that more centrally steered large-scale solutions are also needed.

Innovations in agriculture continue to take place, through crop and livestock breeding, better soil management and the reduction in losses in the food chain. More importantly, great efforts are made to reduce existing yield gaps between developing and high-income countries. Together this makes a second Green Revolution a reality. Sophisticated yet effective arrangements are made between high-income countries and emerging and low-income economies about the organisation of bioreserves and the slowdown and subsequent end of deforestation in the tropics. Strong international consortia work on accelerating novel technologies large-scale carbon sequestration and storage (CSS) and inherently safe nuclear power.

The most important assumptions in this scenario are:

- there is a significant increase in crop and livestock productivity (yields) between 2010 and 2050 compared with the *Trend* scenario;
- food markets continue to become more global with ongoing trade liberalisation policies;
- the expansion of protected areas takes place according to 'global optimisation', which results in the least diverse forms of protection;
- the larger end-use of energy is supplied within the carbon constraint by the massive expansion of non-carbon sources, notably nuclear and 'clean coal' and, to a lesser extent, renewable sources.

4.3 Decentralised Solutions pathway

The widespread scepticism about the effectiveness of international organisations and global environmental agreements and, more generally, the ability of governments to deal with the problems, gives increasing momentum to local and regional initiatives – the kernel of the *Decentralised Solutions* pathway. Therefore, in this scenario citizen groups, local authorities and firms and NGOs take the initiative in the form of a large variety of locally adapted and supported plans and actions. Local resources and skills are used creatively and effectively, which contributes to social coherence and economic fairness.

To some degree, the development can be seen as a response to the previous era of globalisation and the result of an increased emphasis on local and regional values and identities. As a result, societies may believe that the best prospects lie in a more independent and local economy, re-linking the impacts of behaviour to local environmental systems. Production on the competitive 'global market' gradually declines in importance, although it will obviously remain as a tool to balance differences in local demand and supply.

One key element in this scenario is the search to integrate ecological production (agriculture) and supportive functions (nature). Agricultural methods are adjusted to allow for higher biodiversity values in nearby nature systems. Local organic produce and cooperative distribution channels become important ingredients of the emerging new food system. Another lever for change is in the provision of mobility. Smart grids' for electricity stabilise the construction of power plants and permit the much higher penetration of local renewables. There is an increase in the use of local building materials, in combination with innovations in building design and resource-use efficiency.

The most important assumptions in this scenario are:

- as in the *Global Technology* pathway, the regional inequalities in access to food disappear as regions converge to the European situation;
- a the yield improvement less than in the *Global Technology* pathway because of more nature-friendly and extensive forms of agriculture which also serves nature protection goals;
- biodiversity protection is more diverse than in the other scenarios, emanating from a variety of local/regional initiatives;
- the growing use of energy is supplied within the carbon constraint by the massive expansion of non-carbon sources, but with a larger role for renewable sources as local/regional resources are used to a greater extent. Other technologies are used in case of a shortfall.

4.4 Consumption Change pathway

In this pathway, the world population becomes increasingly aware of environmental degradation and the lack of progress made in reducing global poverty in major parts of the world during the first decade of the twenty-first century. Consumers are prepared to seriously change some of their consumption patterns. People realise that their search for the lowest cost and highest returns gives them private gain as consumers and investors but collective loss as global citizens. Citizens start to develop innovative customer and business models to resolve these tensions and, as they become better informed, as consumers.

In the food sector, a shift towards vegetarian diets occurs. This shift is driven by health concerns about meat consumption (cardiovascular disease, pandemics) and other effects of 'cheap food' (diabetes, obesity), but also by the fact that people become more aware of the indirect systemic consequences of the large-scale industrial food system. Another change is a reduced growth in personal travel and freight transport in response to rising fuel costs and stimulated by more convenient infrastructures for other transport modes in the urban setting (bicycle, electric scooter, bus and high-speed train). Infrastructural investments in combination with ICT make public-private transport modes such as car lease/hire in combination with high-speed train/plane the prevailing travel mode in most regions in the world. However, these changes are still not enough to achieve the goals and other technology changes are added to the response mix.

The most important assumptions in this scenario are:
- the worldwide consumption of meat converges across regions to a level that is at most twice the level recommended for a healthy diet (but lower than current average meat consumption in high-income countries);
- waste food flows throughout the food chain gradually decline to 50% of present-day values, totalling about 15% of production;
- the inequality in access to food converges towards average western distribution values;
- energy end-use increases at a lower rate than in the *Trend* scenario thanks to changes in lifestyle: more public transport, lower cooling loads and higher material reuse/recycling rates;
- improved access to modern energy carriers, partly due to better stoves (possibly biomass) and electric power grid expansion;
- shortfall in regional greenhouse gas emission targets are met with end-of-pipe fossil fuel technologies, notably Carbon Sequestration and Storage (CCS).

The food and biodiversity challenge

In achieving sustainable development pathways, competing claims on land play an important role in meeting food and biodiversity challenges. An estimated 925 million people were undernourished in 2010, and agricultural production will need to grow by 60% to 70% in order to feed a global population of over 9 billion by 2050. At the same time, the world has committed to conserve biodiversity and maintain ecosystem services by 2050. This chapter focuses on the level of effort required to reach food and biodiversity goals for 2050 and identifies strategies for achieving these goals.

5.1 Aligning the food and biodiversity challenges

Achieving food security is a crucial pillar of human development and an important part of the Millennium Development Goals to eradicate extreme poverty and hunger. Although food security is essentially an issue of income, availability and affordability, it needs to be achieved against a backdrop of a sharply increasing demand for food and feed from a growing and wealthier global population. Therefore, increased food production is necessary for achievement of the food security goal. The consequence is increased pressure on natural habitats from agricultural expansion, further amplified by increased bio-energy production for climate change mitigation, energy security, expansion of urban areas and infrastructure. Opportunities may be found in smartly combining ecosystem services with human land use.

Food insecurity hampers development

Food insecurity has multiple negative effects on development. For households, it increases stress and anxiety about the short-term future, often harming longer-term plans and investments (Banerjee and Duflo, 2011). The large proportion of income spent on food, in several countries, means that price hikes lead to a quick crowding out of other spending or additional borrowing or lead to the sale of assets. Food insecurity may also lead to nutrient deficiencies that can damage the physical development of children and young adults and, consequently, their future prospects (FAO, 2011c). Therefore, with an estimated 925 million people undernourished in 2010 (FAO, 2010) food insecurity affects social and economic development at global, national and regional levels.

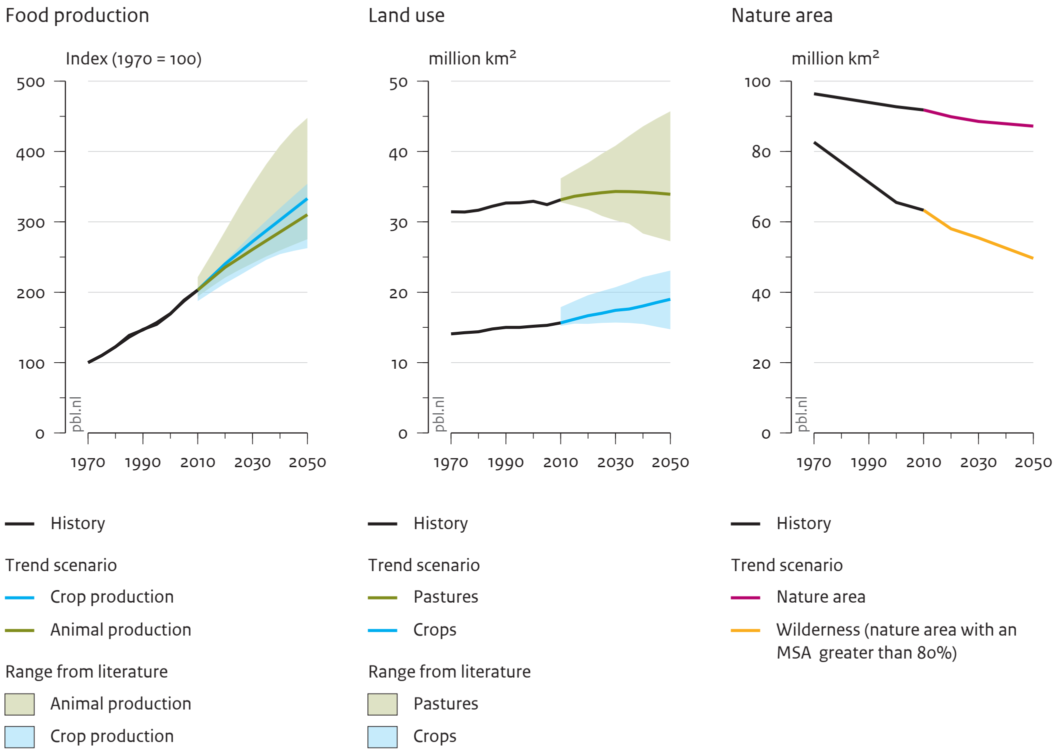
Global food demand is growing rapidly

The global population is expected to grow from almost 7 billion in 2010 to more than 9 billion by 2050. They will also be wealthier, thus increasing the total demand for food – meat and dairy products, in particular. To meet this increased demand, agricultural production needs to grow by 60% to 70% towards 2050 (Figure 5.1). Currently, an estimated 30% of agricultural products are being wasted along the food chain (Gustavsson et al., 2011). Between the early 1960s and 2010, the production of cereals increased by a factor of 2.72 (FAOSTAT, 2012), while the world population between 1961 and 2006 increased by a factor of 2.23. Today, physical resources, such as land and water, are more constrained. For example, the potential for increasing the use of water for irrigation – historically an important factor in production increases – is now much more limited (FAO, 2011c), due to an increased water demand for other uses (OECD, 2012). The cultivation of crops used for bio-energy also increases demand for agricultural land. In addition, climate change will also affect agricultural conditions. In sub-Saharan Africa and South Asia in particular, this is expected on average to negatively affect production potential (Cline, 2007; Easterling et al., 2007). These are also the regions where population growth and additional demand for food will be highest.

Agricultural expansion will remain a large driver of biodiversity loss, while other pressures are expected to increase

Global biodiversity, expressed in MSA (see Box 2.3), declined from 76% in 1970 to 68% by 2010 (Figure 5.2). Between 1961 and 2009, the global area used for agriculture and livestock increased by 10%, or 4.4 million km^2 (FAOSTAT, 2012). Because of an increase in the demand for timber, the forested areas used in timber production have expanded to about one-third of the world's forests (FAO, 2006b). In addition to habitat loss due to agricultural expansion, biodiversity loss is also driven by climate change, the expansion of infrastructure and urban areas, and certain types of pollution, such as excessive nitrogen deposition. The inertia in the system means that mitigating climate change to a maximum of 2 °C by 2050 – a major effort (see Chapter 6) – will not diminish climate impacts on biodiversity by much. In addition, the increasing role of bio-energy in low-carbon strategies represents a trade-off with biodiversity and the carbon sink function of nature areas.

Figure 5.1
Global food production, land use and nature area in the Trend scenario



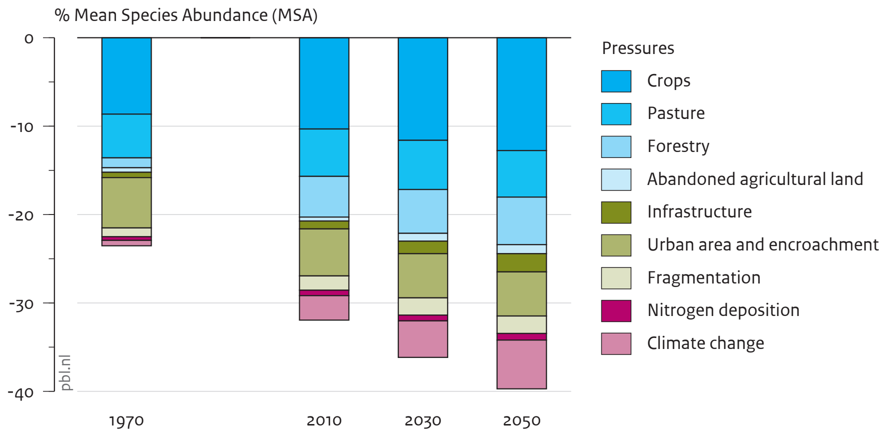
Source: PBL/LEI

Increased demand for food, over the coming decades, will partly translate in area expansions for crops and pasture, and partly in increased production intensity on existing agricultural lands. Reductions in nature area and wilderness, in particular, would be one of the consequences. Uncertainty margins for agricultural production are based on IAASTD (2009); IPCC (2007b); OECD (2008a, 2012).

Ecosystems provide valuable goods and services on which poor people depend to a disproportionally large extent

Land conversion and degradation not only lead to loss of biodiversity, but also to the loss of ecosystem services that provide local, regional or global benefits, such as pollination, water retention and carbon storage. These ecosystem services underpin uses that are often taken for granted and that are key to agricultural production, water cycles and climate regulation. Although highly context dependent, high public costs may be incurred if the benefits of ecosystem services are not taken into account in decisions on land use and land-use change (TEEB, 2010, 2011).

Figure 5.2
Pressures driving global biodiversity loss in the Trend scenario



Source: PBL

Projected biodiversity loss, expressed in MSA, under the Trend scenario would be the result of different human induced pressures, with a large role for agricultural land use, encroachment and climate change.

More directly, ecosystem services also underpin many rural livelihoods, especially in developing countries. The poor tend to depend disproportionally on biodiversity for their subsistence needs (CBD, 2010c). About 70% of the world's poor are estimated to live in rural areas and to depend on agriculture for food and income (World Bank, 2007). Also, 1.6 billion people are estimated to depend on forests in some way, many of them extremely poor (OECD, 2012; World Bank, 2004; WRI, 2005).

Ongoing pressures may lead to land degradation and tipping points

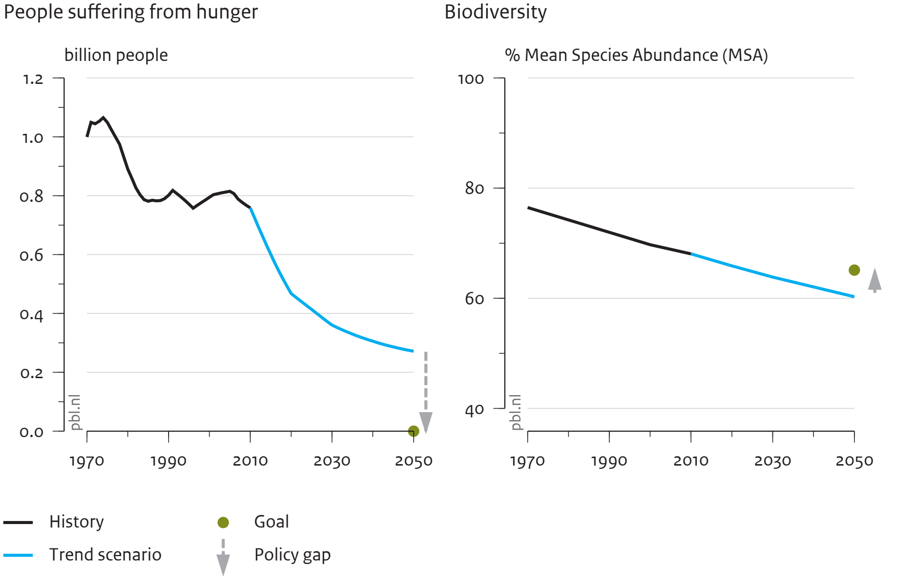
Ecosystems may, under certain circumstances, shift from one stable state to another after reaching a tipping point. A well-known example is a lake shifting from a situation of clear water and submerged plants to turbid water dominated by algae (Scheffer et al., 2001). There is increasing concern that large ecosystems, such as the Amazon and tundra regions, may be reaching tipping points due to global environmental change (Leadly et al., 2010). Although highly uncertain, passing such a critical threshold may lead to dramatic changes, for example, a shift of the Amazonian rainforest towards dry savanna, consequently leading to shifts in regional climate and agricultural productivity.

An example of ecosystem service decline can be seen in the global extent and severity of land degradation and consequent losses in economic and biological productivity. This is difficult to estimate, but the FAO signals that some 32% of land is highly or moderately

Box 5.1 Summary of the food security and biodiversity goals

1. *Eradicate hunger*. In the *Trend* scenario, 272 million people are projected to still be undernourished by 2050 (Section 3.4). The target is to halve the proportion of people suffering from hunger by 2015 and to fully eradicate hunger by 2050. This means reducing the number of undernourished from around 850 million to zero over the next 38 years – an average of 22 million a year (Figure 5.3, left panel).
2. *Conserve, value, restore and wisely use biodiversity by 2050*. According to current developments, biodiversity loss is expected to continue, falling from 68% MSA in 2010 to 60% by 2050 (Section 3.3). The Aichi Target 5 aims to at least halve the rate of natural habitat loss and to bring it as close to zero as possible by 2020. This aim together with the stabilisation of biodiversity by 2050 (our interpretation of the CBD 2050 vision for biodiversity) translates to a target for 2050 of 65% measured in MSA, in other words preventing over half the loss that is projected to take place over the coming 38 years (Figure 5.3, right panel).

Figure 5.3
Sustainable development goals for global hunger and biodiversity in the Trend scenario



Source: PBL/LEI

Trends in the population facing hunger (left-hand panel) and in biodiversity loss (right-hand panel). The dotted lines show the goals as set in this report (see Chapter 2).

degraded (FAO, 2011c). In addition, 42% of the world's very poor and 32% of the moderately poor are estimated to live on degraded lands (Nkonya et al., 2011). This makes land degradation a potential threat to future agricultural productivity and an important factor in addressing rural poverty and development.

The land challenge: ensuring food security and production while conserving biodiversity and ecosystems

The above considerations may be summarised in one overarching challenge:
Eradicate hunger and maintain a stable and sufficient food production by 2050, while conserving biodiversity and ecosystems.
As indicated in Box 5.1, this chapter focuses on two of the globally agreed goals and targets presented in Chapter 2.

1. Eradicate hunger

Food security is defined as a situation where all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life (World Food Summit, 2009). Achieving food security has been a development policy priority for decades. In 2000, the MDG target on food security was formulated as to halve the proportion of people suffering hunger by 2015 compared to 1990. Progress in achieving food security has, however, been very mixed. In some regions, such as East Asia, considerable progress has been made. The challenge will be the greatest in sub-Saharan Africa and South Asia. Undernourishment is currently highest in these regions, while the highest population growth is also expected in Africa and South Asia. This chapter focuses on hunger (see Box 5.2) by looking at the availability of and access to food. The utilisation dimension, representing the need for diverse diets and proper use of food, is part of Section 7.3.

2. Conserve, value, restore and wisely use biodiversity

The Convention on Biological Diversity (CBD) formulated its long-term goal in Nagoya, Japan in 2010, stating that in 2050 biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people. Twenty more specific targets were also agreed upon, with a shorter timescale to serve as intermediate milestones: the Aichi Targets. Using the Aichi Targets 5 (limiting or halting biodiversity loss by 2020) and 11 (expanding protected areas to 17% of the terrestrial area by 2020), we quantified the 2050 vision as slowing the rate of loss until 2030 and bringing it down to zero by 2050. Other Aichi Targets are not explicitly quantified, but a number of them are indirectly addressed in the analysis below (e.g. Target 7 on sustainable management of agricultural and forestry areas and Target 8 on pollution from excess nutrients, see Section 7.2).

Box 5.2 Definitions of food security, hunger and underweight

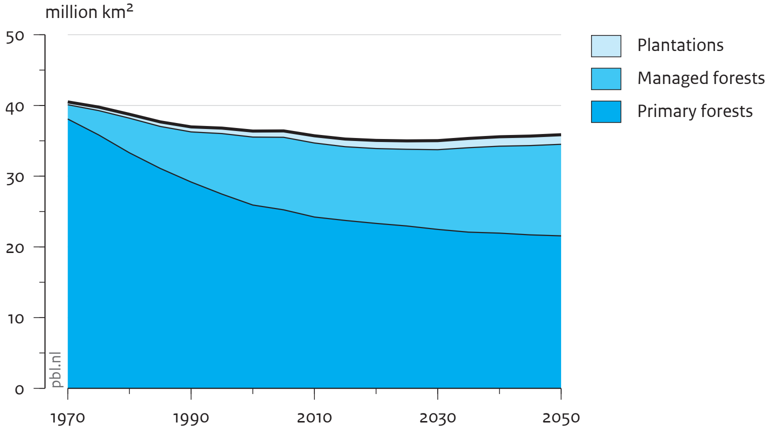
There is a broad and not unambiguous use of terminology on the topic of hunger and food security. In this report, hunger, undernourishment and undernutrition are used interchangeably, referring to an insufficient level of food intake. This only considers the intake of kilocalories, although undernourishment could also refer to dietary aspects, such as vitamin and mineral deficiencies. Malnutrition includes not only undernourishment, but also the excessive consumption of food leading to overweight or obesity. Underweight is therefore the result of chronic undernourishment and defines the status of a person affected by chronic undernourishment. Underweight children can be expressed as low weight-for-age (wasting), and this can also result in low height-for-age (stunting) (WFP, 2012). Stunting can lead to slower brain development and a lower learning capacity (WHO, 2012).

The FAO indicates four dimensions that are relevant to food insecurity: availability, access, utilisation and stability (FAO, 2006a). Availability is related to agricultural production as a combination of land and agricultural productivity. The access dimension includes food prices, income and food distribution. The utilisation dimension concerns the impacts of the inadequate use of food, in particular the prevalence of child underweight, and the interaction with other risks such as limited access to safe drinking water. Stability, the last component, is about having access at all times and is closely interlinked with the other three dimensions.

The Millennium Development Goal 1 aims at 'halving, between 1990 and 2015, the proportion of people who suffer from hunger'. The indicators used to monitor progress are 'the prevalence of underweight children under five years of age' and 'the proportion of population below minimum level of dietary energy consumption' (UN, 2001) . Underweight refers in the MDGs to weight-for-age, and this is also used in this report as the underweight indicator.

Most available indicators show the continuing decline of biodiversity at the global level. However, large regional differences exist. For instance, globally, the forest area has decreased since 1970 (Figure 5.4) and for the near future this is expected to continue in tropical regions, in particular. Still, the rate of deforestation has been reduced, for instance, in the Amazon region, and reforestation is taking place in temperate regions (CBD, 2010b).

Figure 5.4
Global forest area in the Trend scenario



Source: PBL/LEI

Forest area has decreased, globally, since 1970. Managed forests (for timber production) have expanded substantially in recent decades and, although currently still small, the area of the more productive forest plantations is also increasing.

5.2 Barriers to eradicating hunger and conserving biodiversity and ecosystems

As shown in Chapter 2, ambiguous progress has been made on reaching the targets on hunger and biodiversity. Although substantial progress has been made in reducing the proportion of undernourished people, this progress has slowed down in recent decades. However, the trend in biodiversity loss has not been bent at all. Based on the literature, we identified seven obstacles that have prevented the goals and targets on hunger and biodiversity from being achieved:

1. persistently low incomes limit access to food;
2. higher and more volatile food prices are a new reality;
3. many smallholder farmers have limited opportunities for increasing production levels;
4. agricultural research and development systems are weak and ill-equipped in many developing countries;
5. natural capital is undervalued in public policy and planning;
6. mainstreaming biodiversity into other sectors and policy areas is limited;
7. many countries have a limited financial, technical and administrative capacity to manage natural capital.

These points are briefly described below.

Persistently low incomes limit access to food

Poverty limits people's ability to acquire the appropriate foods that make up a nutritious diet. Poor people spend as much as 60% to 70% of their income on food, making them more vulnerable to increases in food prices (FAO, 2011b). This applies not only to urban dwellers, who are mostly net food buyers, but also to many rural people such as small-scale farmers and agricultural labourers. Higher food prices, therefore, puts people into a situation of having to choose between short-term food goals and long-term investments into education or health, which makes it even more difficult for them to escape the poverty trap. The limited extent in many developing regions to which economic growth translates into higher incomes at the bottom of the social scale (either via trickle-down effects or redistributive measures) is a primary cause of continued food insecurity.

Higher and more volatile food prices are a new reality

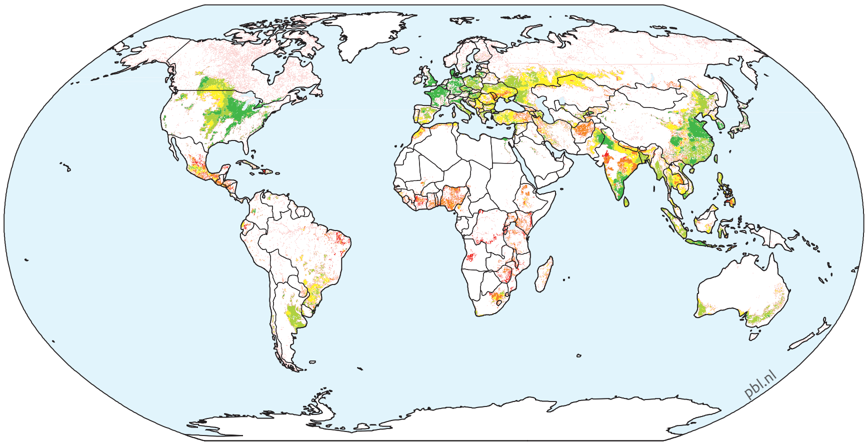
A large proportion of urban dwellers, such as in sub-Saharan Africa, currently depend on imported goods. This makes the population vulnerable to high prices on the world market. Compton et al. (2010) found that the high world market prices of recent years have caused not so much additional persons to fall into poverty, but have increased hardship for people already poor and hungry. This was mainly the case in areas in which there was considerable transmission of international price rises to local markets, in particular in grain-importing countries. The transmission of world prices was, however, uneven. Some countries, including China and India, had sufficient domestic stocks and were not importing from the world market, and so were able to insulate their domestic markets from international shocks. For India, this meant banning the export of ordinary ('non-basmati') rice. Other areas, isolated from world markets by distance and high transport costs and where local harvests normally meet local demand, were little affected by higher world food prices. This applied across much of inland Africa (Keats et al., 2010).

Many smallholder farmers have limited opportunities for increasing production levels

Various socio-economic barriers currently prevent small-scale farmers from responding in the short term to changing or increasing consumer demand. They, therefore, are unable to increase production and thus the availability of food. Such barriers include access to capital and the market, as well as access to land and water. This is especially the case in sub-Saharan Africa. On a field level, this is often reflected by a wide 'yield gap': the gap between the potential physical yield under certain climatic conditions and the current one (Figure 5.5). Wide yield gaps are the direct result of biophysical constraints, such as infestations of weeds, pests and diseases, poor soil fertility and compaction, or poor timing of field operations. Farmers are unable or unwilling to follow recommendations to increase production, because this would be too expensive, too difficult to fit in with other practices, involve too much effort, investments would be too risky, or the nearest market to sell the extra produce is too far away or too difficult

Figure 5.5

Yield gaps for wheat, maize and rice combined, 2000



Ratio between actual and potential yields, under similar climatic conditions and soil fertility (the higher the percentage, the smaller the yield gap)

- Lower than 20 %
- 20 – 40 %
- 40 – 60 %
- 60 – 80 %
- 80 % and higher

Source: Adapted by S. van Asselen (IVM) from Neumann et al. (2010)

This example shows that significant gains in production can be achieved by closing yield gaps. The potential shown in this map is according to Neumann et al. (2010)

to access (e.g. Mahlangu and Lewis, 2008; Röling, 2010). Moreover, the high product prices of recent years have not shown to be an incentive for farmers in developing countries to increase production levels, in the short term (FAO, 2009).

In many countries, agricultural research and development systems are weak and ill-equipped. Publicly funded agricultural research and development (R&D) has stagnated between the mid 1970s and early 2000s. Today, agricultural R&D investments, as a percentage of agricultural GDP, on average total 0.58% in developing countries, compared with 2.4% in the developed countries (GFAR, 2011). A few emerging economies, however, have seen very rapid growth in agricultural R&D. Currently, China, India and Brazil, together, account for nearly half of all public agricultural R&D investments in developing countries. The situation is bleakest for sub-Saharan Africa. Even though, for the subcontinent as a whole, agricultural R&D spending has slightly recovered since 2000 (after a decline in the 1990s), in 2008, only eight countries presented a level above the investment target of 1% of agricultural GDP (Beintema and Stads, 2011). Most other sub-Saharan countries presented a level of below 0.5%. An even greater challenge, perhaps, is to ensure that agricultural R&D has maximum relevance and effectively gears sustainable innovation to tackle tomorrow's problems to cope with climate change, increased price volatility, resource scarcities and erratic weather patterns (Beintema and Elliott, 2009; GFAR, 2011).

Natural capital is undervalued in public policy and planning

An overarching limitation to reaching the 2010 biodiversity goals was the lack of a sense of urgency. Efforts to better assess the need for urgency began with the Millennium Ecosystem Assessment (MA) in 2005, and more recently the TEEB (The Economics of Ecosystems and Biodiversity) project. The MA highlighted ecosystem services to illustrate nature's benefits, the TEEB study did a follow up by emphasising the economic value and benefits of biodiversity and ecosystem services, as well as the costs of biodiversity loss, and highlighted the link with human development.

The TEEB study reinforced and substantiated the notion that most of the services provided by ecosystems are not valued in the markets, and that many of them are severely undervalued in decision-making or not valued at all. The idea, according to the TEEB study, is to move from implicit valuation (often resulting in neglect) to explicit valuation (e.g. by monetisation, but other expressions are possible, as well). Inadequate valuation can lead to decisions with negative social costs, or with large private gains at the expense of a public good. An example is the decision whether to grant a logging concession to a private company versus the carbon sink function of an area or its role in the hydrological cycle that supplies farmers downstream with water for their fields. The numbers are not trivial, given the many multimillion dollar public benefits obtained through smart ecosystem management in a large number of case studies in recent years (TEEB, 2010, 2011).

Mainstreaming biodiversity into other sectors and policy areas is limited

Most of the factors driving biodiversity loss have to do with economic drivers, choices about livelihood and consumption, market organisation and land-use planning (or its absence). Consequently, mainstreaming biodiversity into policy-making areas that influence these decisions is often the only way to mitigate many of the most pressing drivers of biodiversity loss (CBD, 2010b; Kok et al., 2010). These are thus often beyond the scope of the classic instrument for biodiversity conservation; the protected area network. Protected areas have specific roles to play in biodiversity conservation; for instance, by protecting species or important ecosystems. However, they are unable to address many of the ongoing pressures that drive biodiversity loss (Mora and Sale, 2011; PBL, 2010).

Many countries have a limited financial, technical and administrative capacity to manage natural capital

Most of the impacts on biodiversity take place at a local level, and many are decided at either local or national level. International policy often has only an indirect effect, through national strategic plans or reporting obligations and very limited financial transfers. This makes the implementation of biodiversity policies for the most part contingent on national and local capacities, in terms of financial, human and technical capabilities. A clear example is the lack of effective enforcement in many of the nominally protected areas (TEEB, 2011). Choices are inevitable as there are trade-offs between different land uses and the corresponding public or private benefits. Implicit choices are also present in subsidy design and perverse subsidies contribute to the wasteful use of resources and increased consumption. Both developed and developing countries require a greater institutional, financial and technical capacity to assess the potential impacts of these trade-offs and to manage their natural capital.

5.3 Exploring different pathways towards the goals

5.3.1 Design and components of three different pathways

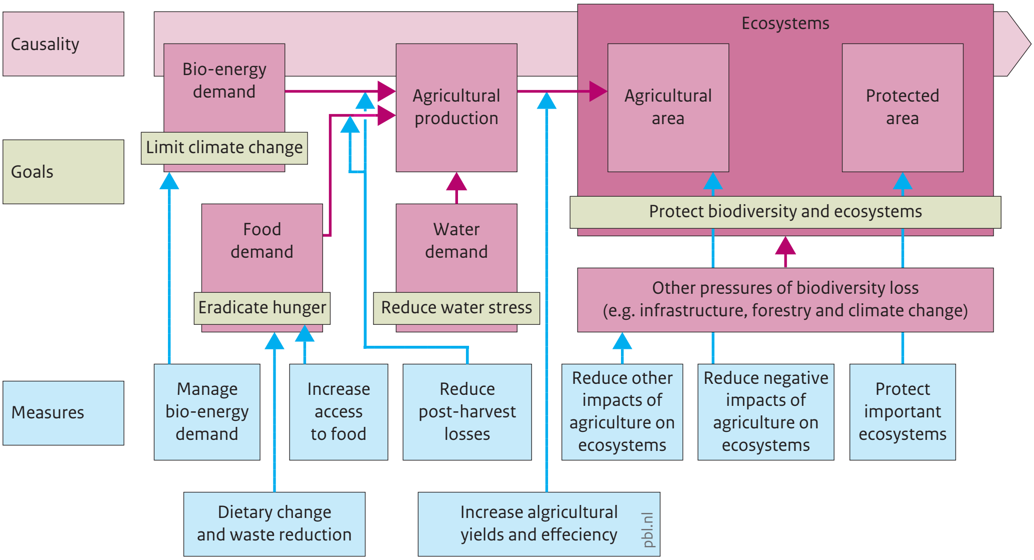
This section discusses three different pathways for reaching the sustainable development targets. The focus is mostly on the changes that are required in the physical system to ensure that these targets are met. Policies and instruments for implementing the changes are discussed in Section 5.4 and Chapter 8. The general assumptions and storylines of these three pathways were introduced in Chapter 4.

Figure 5.6 shows the main linkages between the goals and potential measures to attain them. Five large changes that, potentially, could greatly contribute to the eradication of hunger and maintain a stable and sufficient food production, by 2050, while conserving biodiversity are highlighted:

1. increase access to food for people below the poverty line;
2. alter demand for agricultural products; for example, through dietary changes, waste reduction and a limited use of bio-energy;
3. increase efficiency of agriculture to minimise agricultural area;
4. arrange agricultural land allocation and management to minimise impacts on ecosystems;
5. protect the most important ecosystems and their goods and services.

Combinations of these options were used to design the three pathways that all attain the goals on eradicating hunger and halting biodiversity loss, as well as the targets on climate change, air pollution and access to energy (the latter are discussed in Chapter 6). Table 5.1 shows the combinations of options that are most relevant to food security and biodiversity. The different combinations were chosen to demonstrate that the same goals can be reached along contrasting pathways. Many other intermediate routes are also possible.

Figure 5.6
Linkages between goals and measures to eradicate hunger and protect biodiversity



Source: PBL

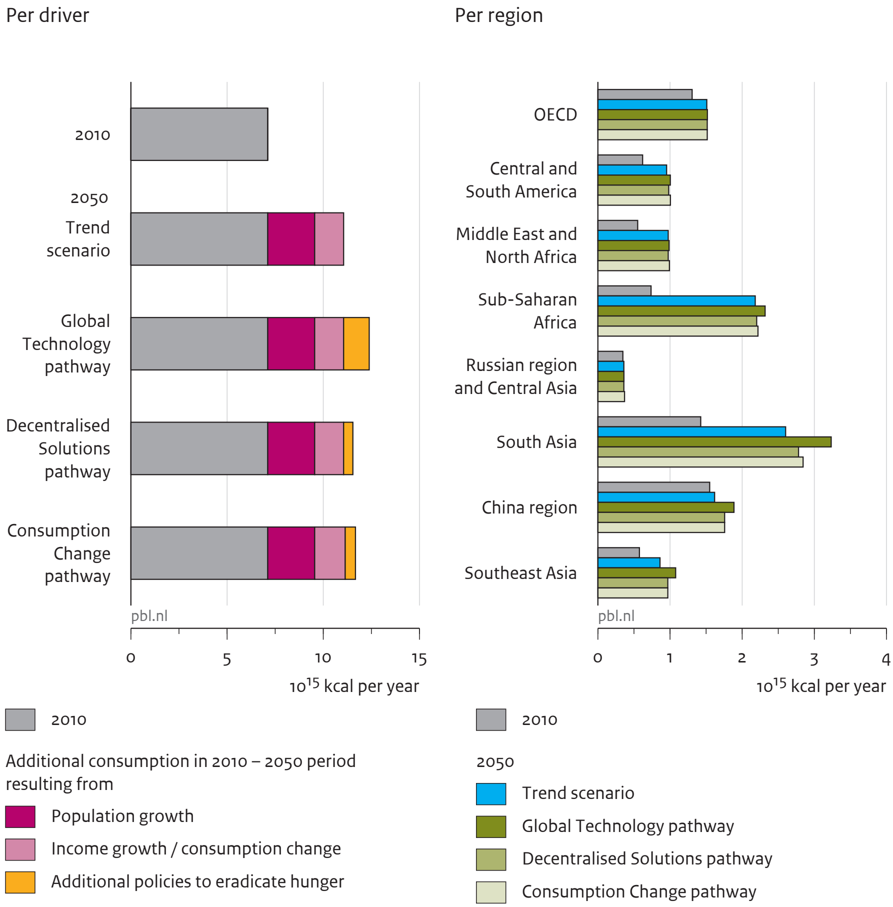
Characteristics of the three pathways for access to food, agriculture and biodiversity
Along the *Global Technology* pathway, the main focus is on high-yielding agricultural technologies. Equity in access to food is not pursued as a target, but is a consequence of the availability of cheap food products and overall income growth. Whenever possible, highly productive agricultural land is utilised to its full potential, with a strong focus on resource efficiency to preserve this potential and to avoid wasting nutrients and chemicals. Agricultural land and nature areas are segregated, which enables the conservation of large tracts of high-quality nature to achieve the biodiversity goal. Trade is liberalised and regions that are less well-suited to agricultural production rely on imports to complete any food deficit. This pathway is the only one that does not assume additional effort to mitigate biodiversity loss due to infrastructure expansion.

In the *Decentralised Solutions* pathway, there is a strong focus on equity in access to food and on innovative, ecologically sound, locally adapted agricultural production technologies. Agricultural and nature areas are far more mixed and interwoven. This pathway leads to smaller semi-pristine nature areas than in the other pathways, but to more biodiversity-rich agricultural areas. The expansion of protected areas is best targeted in this pathway, resulting in the most ecologically representative system compared to the other pathways.

Table 5.1
The design of the three pathways for achieving the goals

	Global Technology	Decentralised Solutions	Consumption Change
Access to food	Trend	Inequality in access to food due to income inequality converges to zero by 2050	Inequality in access to food due to income inequality converges to zero by 2050
Trade	Full liberalisation of trade in agricultural products	Trend	Trend
Consumption	Trend	Trend	Meat consumption per capita levels off at twice the consumption level suggested by a supposed healthy diet (Stehfest et al., 2009; Willett, 2001)
Waste	Trend	Trend	Waste is reduced by 50% (15% of production)
Agricultural productivity	In all regions, 30% increase in crop yields and 15% increase in livestock 'yields' by 2050, compared with the *Trend* scenario	In all regions, 20% increase in crop yields and 15% increase in livestock 'yields' with least possible impacts on biodiversity (Biodiversity: MSA in agricultural area 40% higher than in the *Trend* scenario)	In all regions, 15% increase in crop yields by 2050, compared with the *Trend* scenario
Allocation of agriculture/ nature	Agriculture allocated close to agriculture to retain highly distinct land functions	Production area shared with nature elements to reinforce an ecological network, environmentally friendly production; keep at least 30% of the landscape as nature elements	Trend
Protected areas	17% of each of the 7 realms Expansion allocated far from existing agriculture	17% of each of the 779 eco-regions Expansion allocated far from existing agriculture	17% of each of the 65 realm-biomes Expansion allocated close to existing agriculture
Forestry	Forest plantations supply 50% of timber demand; almost all selective logging based on Reduced Impact Logging	Forest plantations supply 50% of timber demand; almost all selective logging based on Reduced Impact Logging	Forest plantations supply 50% of timber demand; almost all selective logging based on Reduced Impact Logging
Infrastructure	Trend	Slower expansion of infrastructure (by 2050 at the level of the *Trend* scenario for 2030)	Slower expansion of infrastructure (by 2050 at the level of the *Trend* scenario for 2030)

Figure 5.7
Global calorie consumption



Source: PBL / LEI

Growth in population and incomes represent most of the additional calorie intake up to 2050. Differences between the pathways are due to the efforts to eradicate hunger, which is shown to represent a small part of the additional calorie intake.

The *Consumption Change* pathway follows a route of moderate consumption and efficient resource use to minimise ecological impacts and accomplish the biodiversity goal. It also focuses on increased equity in access to food as a major contributor to attaining food security. This pathway still requires a sustainable increase in agricultural productivity, although the effort is smaller than in the other pathways, thanks to moderated consumption patterns.

Table 5.2
Total calorie consumption per year attributed to drivers

		Increase in consumption growth (2010-2050) due to:					
	2010 consumption	Population growth	Income growth	Consumption Change	Hunger eradication in:		
	($x10^3$ kcal/ year)				Global Technology	Decentral Solutions	Consumption Change
OECD	1308	9%	7%	-3%	1%	1%	4%
Latin America	621	36%	17%	7%	8%	5%	2%
Middle East and North Africa	552	50%	27%	3%	2%	0%	0%
Sub-Saharan Africa	738	93%	103%	3%	19%	3%	2%
Former Soviet Union	347	-8%	12%	3%	0%	0%	0%
South Asia	1427	55%	28%	6%	44%	13%	11%
East Asia	1552	11%	-7%	-4%	17%	9%	13%
Southeast Asia	577	37%	12%	2%	38%	19%	17%

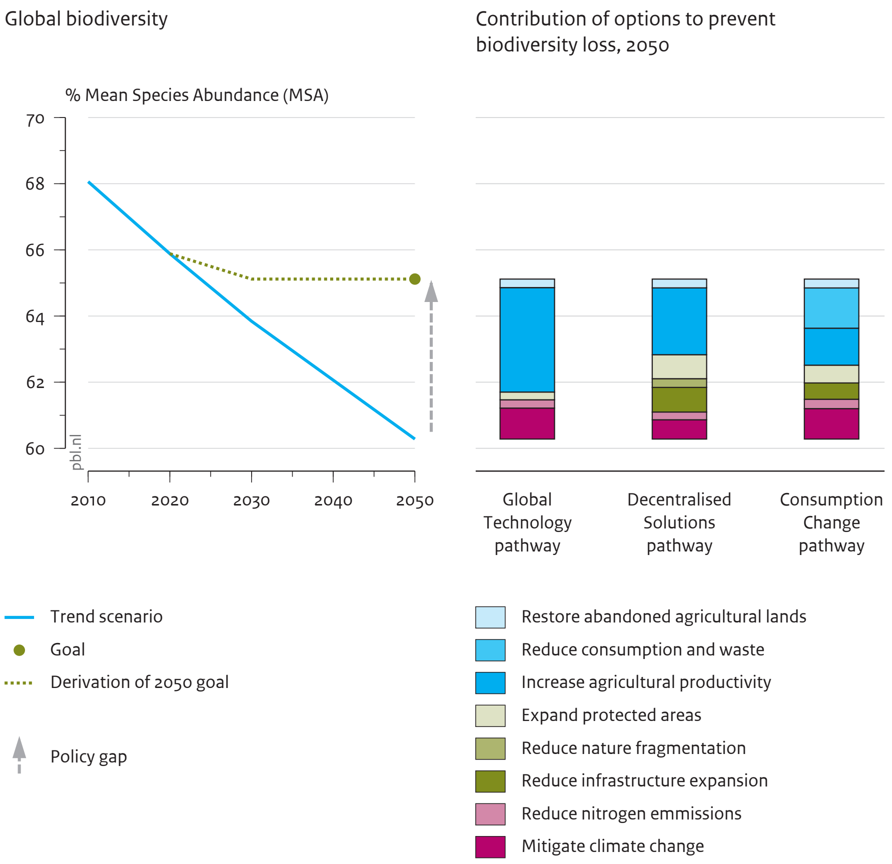
Attaining the hunger eradication goal

The goal has been set in such a way that the number of people with hunger is reduced in all regions to the current, low level of hunger in the OECD region. Sub-Saharan Africa and Asian regions, in particular, require additional effort – on top of the income growth that is expected in the *Trend* scenario – to lift consumption levels above the hunger line. Figure 5.7 shows the total additional calories required to achieve the goal, per region, by 2050, compared to the 2010 level. Table 5.2 shows a breakdown of the drivers of the increase. Population growth and increasing income are developments that cause major increases in calorie consumption. Changes in consumption, such as a reduction in the consumption of animal products, have minor impacts on calorie consumption as the animal products are replaced with crop products. Relatively little additional calorie production is required to eradicate hunger; the effort required to get these calories to the right people is the real bottleneck.

There are several routes to achieving the biodiversity goal

We explored measures to slow down and where possible halt biodiversity loss at the 2020/2030 level (in developed/developing regions). All pathways arrive at the biodiversity target set at 65% MSA by 2050, reducing projected biodiversity loss by more than half, compared to the *Trend* scenario (Figure 5.8), and attain Aichi Targets 5 (halving or even halting further loss of nature areas (Figure 5.9)) and 11 (protected area expansion and management). The three different pathways achieve these targets along different routes, with important roles for consumption changes, agricultural

Figure 5.8
Global biodiversity and options to prevent biodiversity loss

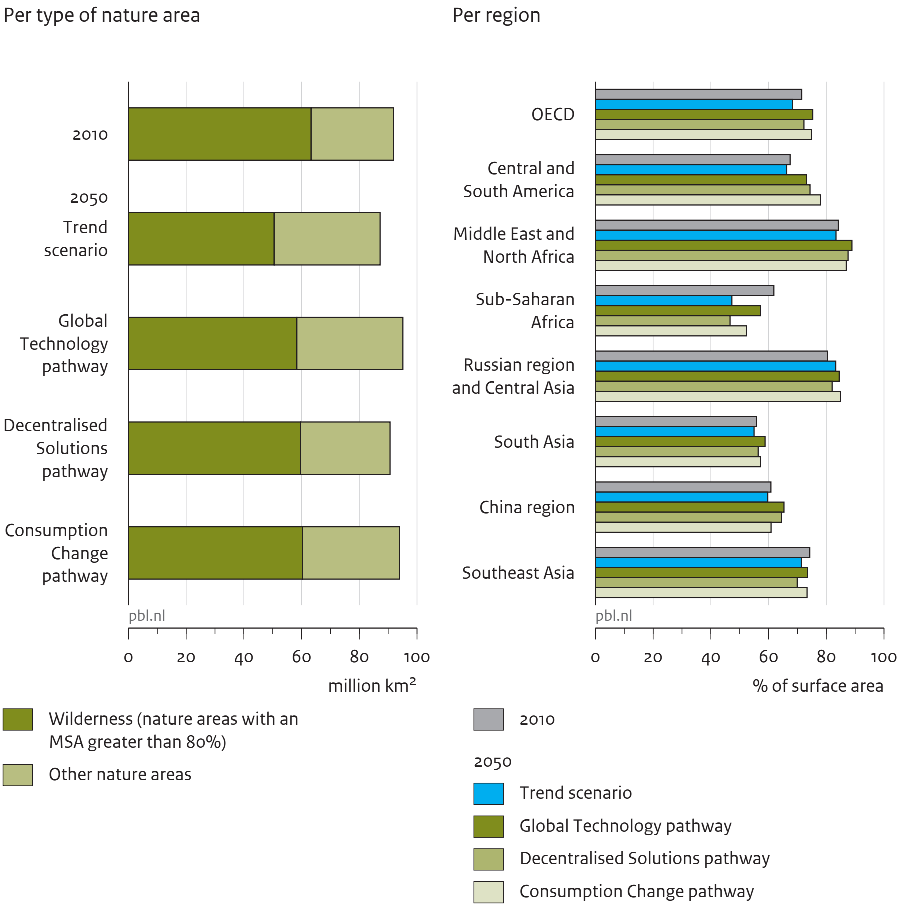


Source: PBL/LEI

The pathways differ greatly in the way they limit pressures and thereby avoid biodiversity loss. The potential of increased agricultural yields, for instance, is best shown in the Global Technology pathway, whereas changes in diet and waste reduction contribute significantly in the Consumption Change pathway. In these graphs, the reduced pressure due to climate change mitigation is net of any additional pressure from the use of bio-energy. Abandoned lands are assumed to fully recover to their natural state by 2050.

productivity improvement, expansion of protected areas, climate change mitigation and other measures. After 2050, there will still be a risk of further biodiversity loss, unless new or more ambitious measures are introduced. In particular, pressures, such as infrastructure expansion and climate change, are expected to increase further. There are some reasons to assume that the level of effort required after 2050 will be less than before 2050. The expected further levelling off of population growth will reduce additional demands for food and other products, thus reducing the pressure to convert

Figure 5.9
Global nature area



Source: PBL/LEI

The pathways would considerably reduce the loss of nature areas – and of wilderness, in particular – compared to the Trend scenario for 2050. The differences between regions, in the pathways, are often larger than the global comparison, signalling alternative distributions of land use. Nature area includes deserts and mountain areas which in some regions represent a large share of the surface area.

nature areas. In the pathways, pressure from climate change reduces beyond 2050 due to mitigation policies that limit climate change to 2 °C (see also Chapter 6). Finally, there are also other policy levers that have not been included in the pathways, such as those to reduce the consumption of timber and paper, or global forest protection through a REDD-type instrument[1]. Measures to limit the impact of invasive species are not represented because this pressure was not included in the model.

Box 5.3 Bio-energy

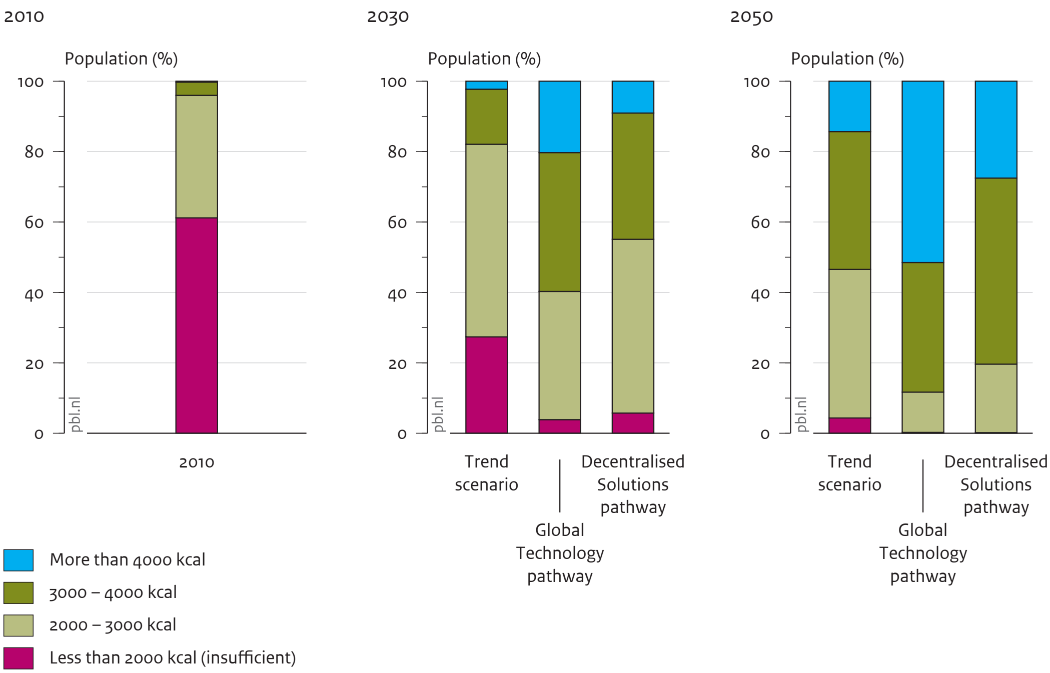
The use of bio-energy is an important option from the perspective of climate change mitigation. For some sectors, such as freight and air transport, it is even one of the few options available to reduce greenhouse gas emissions (see Section 6.3.3). However, the use of bio-energy also includes risks. The production of bio-energy requires land which can directly and indirectly induce habitat loss (Eickhout et al., 2008; Overmars et al., 2011). Although such a mitigating measure would eventually avoid climate change and thus avoid biodiversity loss, the negative impact of agricultural area expansion on biodiversity will be higher in the short term (Oorschot et al., 2010). Demand for bio-energy crops also competes with demand for food crops. Equally important is the link between bio-energy and conventional energy prices, as well as the link between bio-energy crop and food crop prices. Since energy prices are highly volatile, the demand for bio-energy can be expected to fluctuate as well. The energy price is also expected to increase in the coming decades. Together, these are underlying reasons for expecting higher and more volatile food prices in the coming decades (OECD and FAO, 2011). Policy options to stimulate the use of bio-energy to mitigate climate change should therefore address these issues to ensure policy coherence with food and biodiversity goals.

5.3.2 Eradicating hunger through increasing access to food

To decrease the number of people that suffer from hunger, enough food must be available at stable prices and it must be affordable for the poorest households. The eradication of hunger is here defined as all people consuming at least the minimum dietary energy requirement, taking age structure and access to food into account. In this sense, policies to eradicate hunger include increasing total production – specifically targeting staples such as wheat, rice and other cereals – thereby keeping overall food prices low and increasing availability for all. Policies could also specifically target food prices for the poorest households –for example, through a subsidy system – increasing the availability for those households more specifically. Section 7.3 describes the issues concerning the scope for improvement in the utilisation of food, in other words the health aspects of dietary choices and food preparation.

Different combinations of options are applied in the three pathways. In the *Decentralised Solutions* and *Consumption Change* pathways, increasing agricultural production is combined with specifically improving the affordability of food for the poorest households. Trade barriers for agricultural products are assumed to be the same as today. These options result in particular in an increased caloric intake of the people suffering hunger, leading to a more equal level of consumption within countries. Alternatively, the *Global Technology* pathway assumes far-reaching trade liberalisation in agricultural products and highly intensive production in the most agriculturally productive regions. The result is lower food prices on the world market and cheaper

Figure 5.10
Food availability in Central Africa



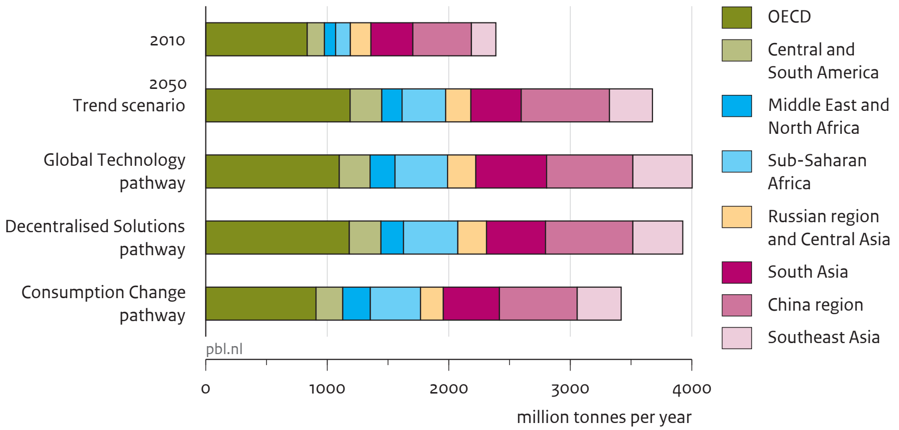
Source: PBL

The distribution of food availability in Central Africa in 2030 and 2050. In both the Global Technology and Decentralised Solutions pathways, virtually everyone will have adequate access to affordable food. However, the distribution in Global Technology pathway will be less equal and less efficient (intake levels that are too high for a large part of the population or large amounts of waste) than in the Decentralised Solutions pathway.

food for everyone. No specific targeting of poor households is assumed. As a consequence, the total population consumes more calories, while the skewed distribution among rich and poor remains. Figure 5.10 shows how this works out for food distribution in Central Africa, a region where many people currently live below the hunger line.

The success of the *Global Technology* pathway in eradicating hunger depends on its ability to provide food at lower prices through more efficient production (Figure 5.11), as well as on countries honouring agreements to maintain free trade in agricultural products. The consequence is an increased dependency of many currently net-food importing countries on trade with countries with highly specialised agricultural industries. The greatest scope for increased agricultural trade lies in regional trade between neighbouring countries, the inland areas of eastern and southern Africa being prime examples (World Bank and IMF, 2012). This region has high harvest variability and

Figure 5.11
Global cereal production



Source: PBL/LEI

By 2050, global cereal production would be increased by 54% under the Trend scenario, compared to the situation of 2010. In both the Trend scenario and the pathways, significant increases are projected for every region, while sub-Saharan Africa would see the relatively largest increase compared to current production. Production in the Decentralised Solution pathway is lower than in the Global Technology pathway, because policies especially target access to food for poor people, whereas the Global Technology pathway focuses on low food prices for all. The lower production especially in OECD countries in the Consumption Change pathway is caused by the particularly large reduction in the consumption of meat and egg products.

frequent policy interference with the trade of grain across borders. Progress is being made towards reducing barriers to trade through regional agreements, but there is still some way to go before the potential of regional grain movements can be realised.

The *Decentralised Solutions* and *Consumption Change* pathways are markedly different. The much more localised production in these pathways makes many current net-importers of food more self-sufficient. Furthermore, rural poverty can be reduced by this local development of agriculture (Christiaensen et al., 2010). In these pathways, the key to hunger eradication is the ability of governments to effectively target the households most in need through well-designed food price support. Subsidising the price of staple foods market-wide is often not efficient since many of those benefitting could pay higher prices, at worst resulting in increased inequality in terms of disposable income. Targeting food subsidies to specific income groups is more complicated administratively and, for low income countries, food subsidies may represent a sizeable claim on public funds.

It is important to strike a balance between the benefits and drawbacks of the different pathways. Price stability remains a challenge as small reductions in supply can lead to large changes in world food prices, which can translate into domestic market price fluctuations. Overall, a mix of policies stimulating local production is required, while gathering the benefits from increased global trade (see Sections 5.4.1 and 5.4.2).

5.3.3 Shifting consumption of food and other agricultural products

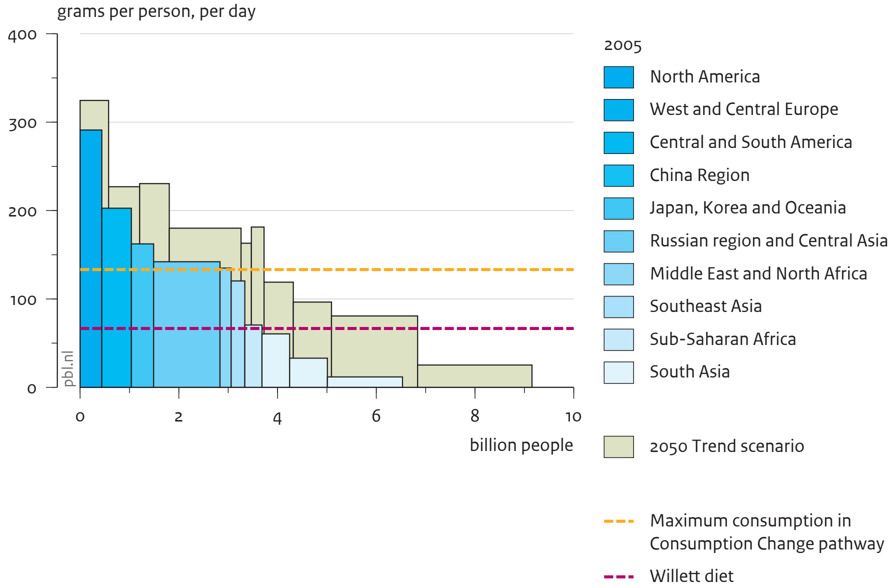
Reducing the demand for agricultural products is the most straightforward way to save land for biodiversity and reduce greenhouse gas emissions from land use and land-use change. Three entry points to reduce demand are reduced meat and dairy consumption, reduced food waste and the restricted use of bio-energy. A reduction in the use of bio-energy has consequences for the possibilities to mitigate climate change.

In general, the consumption of animal food products has a greater environmental impact than that of plant-based protein-rich products (PBL, 2011a). Only 10% to 30% of animal feed is ultimately converted into edible livestock products. The rest is consumed by parent animals, by the animal for sustenance, or is excreted (PBL, 2011a). Therefore, reducing the consumption of meat, dairy and eggs, technically, would be one of the most efficient options for reducing total crop production demand.

The intake of animal proteins is reduced in the *Consumption Change* pathway. The starting point is a diet with less meat consumption, based on dietary recommendations by the Harvard Medical School for Public Health (the Willett diet). The main characteristic of this diet is the low beef and pork intake, resulting in 10 g beef, 10 g pork and 46.6 g chicken meat and eggs per person per day (Stehfest et al., 2009; Willett, 2001). This would imply a reduction in the consumption of beef, pork, mutton and goat meat in North America, South America, Europe, the Russian region, China, Japan and Oceania, ranging from 76% to 88%, compared to 2005 consumption levels. For poultry and eggs, the reduction is much lower for those regions; except for China, where the average 2005 consumption level for poultry and eggs was lower than that of the Willett diet. In the *Consumption Change* pathway, for the 2030–2050 period, the maximum consumption level for meat and egg products is set at twice the recommended level. Regions where the average consumption level is already higher, or regions that are projected to cross this threshold up to 2050 converge linearly to this level from 2010 onwards. Applying this reduces meat and egg consumption compared with the *Trend* scenario in many regions, except for Africa and some Asian regions (Figure 5.12).

Food losses and waste have recently been estimated at roughly one-third of global production, which is about 1.3 billion tonnes a year (Gustavsson et al., 2011). The highest waste per capita at the end of the food chain (at the retail and consumption stage) occurs in North America (estimated at 115 kg/year/capita), which is almost 20 times higher than these types of food losses in sub-Saharan Africa (estimated at 6 kg/year/capita). Food losses during production, or post-harvest and processing stages, range

Figure 5.12
Consumption of meat and eggs, per region



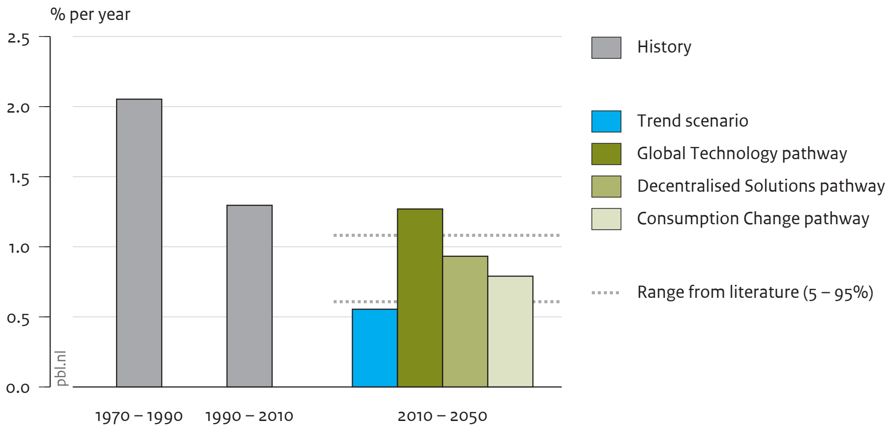
Source: PBL

In most regions, the average per-capita consumption of meat and eggs is far above the Willett diet. For 2030 onwards, the Consumption Change pathway assumes a maximum per-capita intake of twice the Willett diet level in regions that are currently over, or are projected to pass this threshold.

between 110 kg/year/cap in South Asia and Southeast Asia and around 180 kg/year/capita in North America, Oceania and Europe. This implies that although most losses occur at the production stage in developing regions, total losses for these regions are far below those of developed regions (Gustavsson et al., 2011). Food waste and losses are reduced by 50% in the *Consumption Change* pathway. Together with limited meat consumption, this helps to restrict the amount of agricultural land required considerably. However, some extra yield increase is still needed to attain both biodiversity and hunger targets (see Figure 5.13).

The last entry point is the restricted use of bio-energy. The production of bio-energy puts a claim on land, which causes biodiversity loss, or prevents abandoned agricultural land from being restored or returning to its natural state. However, to reach the 2 °C target, the use of bio-energy is inevitable. No other 'climate-friendly' options exist to fuel part of aviation and road freight traffic (see Chapter 6). In all three paths, bio-energy use has been limited as much as possible.

Figure 5.13
Increase in global cereal productivity



Source: PBL / LEI

Focusing on agricultural productivity increase, as is done in the Global Technology pathway, requires annual yield increases for cereals comparable to those of the last two decades. The range from the literature is based on IAASTD (2009); IPCC (2007b); OECD (2008a, 2012), and includes scenarios that assume new and additional policies to improve yields. The improvement under the Trend scenario is on the low side of this range, as recently yield improvement rates towards 2030/2050 have been adjusted downwards. Compare, for example, an annual 1% between 1998 and 2030 (Bruinsma, 2003), and an annual 0.67% for the 2006–2050 period (Bruinsma, 2011).

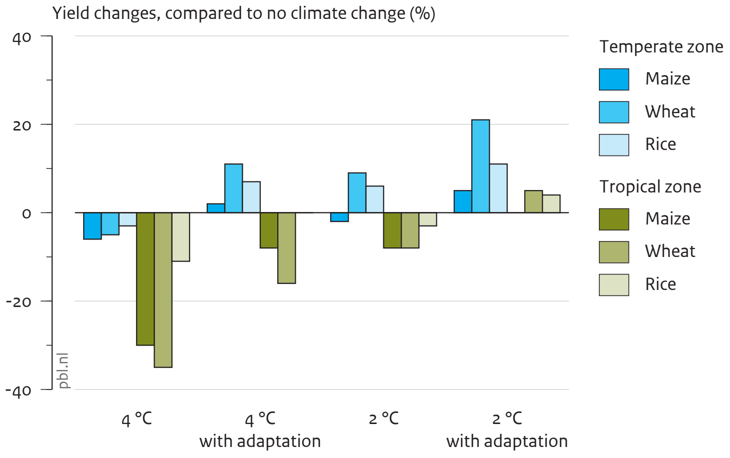
5.3.4 Many ways to increase yields sustainably

Limiting agricultural expansion and emissions from land use and land-use change will enable the joint realisation of the biodiversity and climate goals. To reconcile these goals, cereal yields must increase above the average trend increase of about 0.6% per year in all three pathways. An average increase of 1.3% is required for the *Global Technology* pathway and 0.9% for the *Decentralised Solutions* pathway (Figure 5.12), as policies to achieve sustainable agriculture relieve part of the pressure on biodiversity in this pathway. Even under the *Consumption Change* pathway, in which people consume fewer animal products, an annual yield increase of more than 0.8% would be required to reach the targets. Comparable yield growth rates have been achieved in the past. However, there are doubts as to whether such rates could be achieved in the future, as yields in developed regions are close to their potential and expansion of irrigated areas is expected to be much slower than in the last decades (FAO, 2011c). This section briefly describes some concrete examples of agricultural systems and their potential for yield increase.

Box 5.4 Agriculture and climate change
Agriculture is not only a key contributor to greenhouse gas emissions, but the sector could also 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 5.14). Adaptation measures may for instance include changes in crop variety and agricultural practices. Climate impacts on yields have been reported for low latitude regions (tropics) and mid to high latitude regions (temperate zones) (Easterling et al., 2007).

Although the results are highly uncertain, some preliminary conclusions can be drawn from this graph. First of all, following the *Trend* scenario, if no adaptation is accounted for and assuming high climate change, there would be a 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 for). It should be noted that the figure reports impacts for highly aggregated regions – hiding the fact that impacts in underlying countries and regions are more diverse and can in fact be positive. Secondly, engaging in either

Figure 5.14
Yield sensitivity to global mean temperature change, 2050



Source: Easterling et al. (2007)
The temperature increases of 4 °C and 2 °C correspond to the Trend scenario and the pathways, respectively.

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 (which would still experience a reduction in yields of around 10%). In the pathways, which assume a combination of mitigation and adaptation, negative impacts would be avoided, and this could even result in an improvement compared with the situation without climate change.

Fully bridging the gap between current yields and potential yields might be physically possible, but is generally economically unfeasible. Trends in regions with technologically advanced agriculture suggest that, as a rule of thumb, commercial farm yields tend to converge to a level of about 80% of potential yields (Lobell et al., 2009). There is also a limit to the maximum potential yield, determined by fundamental characteristics of leaf photosynthesis and respiration, crop canopy development, and the partitioning of newly formed biomass between plant roots, leaves, stems and seed.

Potentials of different farming systems in different situations

Farming systems differ on many aspects, for example, in terms of scale, multi-functionality, management style and the use of different types of resources such as land, labour, machinery, chemicals, knowledge, information and technology. The reasons behind these differences are related to different kinds of produce (e.g. meat, dairy, grains or horticulture) but just as much to differences in cultural and economic settings, soils, climatic conditions and farmers' mind-set (Van der Ploeg, 2003; see also Section 5.2). Obviously, such differences will not be wiped out in the future. We rather imagined farms evolving in different ways and towards different constellations along each of the pathways towards the goals envisaged. The *Global Technology* pathway, for example, would show a stronger trend of scale increase and a larger proportion of very knowledge-intensive, highly productive farms than any of the other pathways. Low external environmental impacts would be achieved thanks to a very strong emphasis on resource efficiency through cutting edge technological refinements, agronomic optimisation of the farm environment and new animal breeds and crop varieties that perform best under these optimised conditions.

Such systems would also be common in the *Decentralised Solutions* pathway, though there would be more of an inclination towards innovative ecological solutions (often labelled as ecological intensification) rather than mostly relying on constantly developing technological innovations. Such eco-oriented farming systems strive towards a combination of high productivity and resilience by harnessing ecosystem functioning. Pest control, for example, would rely much more on the conservation or enhancement of natural landscape elements to encourage the proliferation of natural predators rather than the development of new, more targeted chemicals. A number of the organic farming systems fall into this category.

The *Consumption Change* pathway, on the other hand, would see a relatively large proportion of semi-traditional farming systems with a stronger focus on low external inputs and the appreciation of sharing experience and traditional knowledge to sustainably improve farm performance. The other part of the organic farming systems falls within this category, as well as semi-traditional systems in developing countries.

Concrete examples of farming systems that could evolve in any of these directions are given in Box 5.5. It is not possible to make any general judgement on which development would be 'better' or 'worse'. All systems and the practices employed in them have their advantages and disadvantages, the relative weights of which depend on cultural, socio-economic and environmental conditions. An overview of innovative

Box 5.5 Examples of agricultural systems and transitions towards sustainable pathways

Intensive wheat-based production systems
This capital-intensive system is characterised by high inputs, a high degree of mechanisation, high yields (close to ten tonnes per hectare for top producers), relatively large fields and low diversity. Such systems are particularly common in flat to gently undulating areas in temperate regions such as in parts of western Europe, central United States, Argentina, southern Australia and New Zealand. They are mostly rain-fed, although some benefit from supplementary irrigation.

Over the past forty years, technological innovation has resulted in low labour requirements, high-yielding disease-tolerant varieties and a predominance of the use of chemical pest and weed control and mineral fertilisers, alongside soil protection and resource efficiency measures enhancing these systems' environmental performance (Carberry et al., 2010). As a result, these systems tend to operate close to their potential in terms of sustained high yields but serious environmental challenges persist, such as low (typically <0.6) nitrogen-use efficiency and consequential high emissions of reactive nitrogen (Spiertz, 2009), unwanted effects of agrochemicals (Smith et al., 2008) and soil degradation.

Further yield increases are possible, mainly through the adoption of modern practices by the many farmers lagging behind, or by improving the potential of these systems; for example, by introducing new varieties whose phenology (e.g. length of grain filling period) better match their environment. The environmental performance of these systems may be enhanced by the more widespread adoption of integrated pest management, including smart rotations, and less-damaging chemical control methods (Smith et al., 2008), and by applying elements of precision agriculture, such as permanent traffic lanes, improved water management and variable rates, and nutrient scheduling technologies (see Appendix B). Perennial grain crops (Glover et al., 2010) could eventually also improve soil protection and nitrogen use efficiency. Small strips of natural vegetation, for example, along streams or contours can provide a very basic level of biodiversity with little impact on the available land for agricultural production (Olson and Wäckers, 2007). The main ecological advantage of this system, however, would be its high productivity, which could help spare land with natural vegetation elsewhere.

Improved rice production systems

Rice is the most common staple food of the largest number of people (Maclean et al., 2002). Rice productivity greatly benefited from new high-yielding varieties introduced in the 1960s, combined with the increased use of water, fertiliser and agrochemicals (Khush, 1995). Rice is very sensitive to water stress. Most rice (about 75%) is grown as irrigated lowland rice in bunded fields (paddies), usually less than 0.5 ha, on which farmers maintain a permanent water layer and grow two or three crops a year (Bouman et al., 2006). The negative environmental consequences of these systems are (i) high water use (about 40% of irrigation water worldwide) often including the overexploitation of groundwater and surface water (Bouman et al., 2006; Kürschner et al., 2010), (ii) a very low (0.3–0.4) nitrogen-use efficiency and associated high emissions, especially of ammonium (NH_3), (iii) high emissions of methane (CH_4), a powerful greenhouse gas, associated with water-logged conditions, (iv) high energy requirements, particularly for pumping groundwater, and (v) the pollution of water resources and non-target fields with agrochemicals. Most of these constraints can be overcome without affecting yields or even with increased yields (Palis et al., 2004; Rejesus et al., 2011). The best yields in some intensively cropped rice areas (Thailand, Vietnam, Indonesia and the Philippines) suggest that average yields could increase by between 20% and over 60% (Laborte et al., 2012).

At the core of many of these developments towards more sustainable rice production is carefully controlled irrigation involving alternate wetting and drying (AWD). AWD has reportedly resulted in water savings of 20% or more, more efficient nutrient use, reduced labour requirements and a decrease in nutrient and CH_4 emissions. However, weeds can be more difficult to control and an increase has been reported in the emissions of nitrous oxide (N_2O) during the transition from wet to dry. Adoption of AWD has been mixed as it depends less on convincing farmers of its benefits than on conditions beyond their direct control, such as the availability of flexible irrigation infrastructure so that farmers can irrigate according to their own needs (difficult when several farmers are linked to a single pump), the availability of adequate advisory structures and charging water and electricity per unit rather than at a flat rate (Ding et al., 2010; Kürschner et al., 2010; Palis et al., 2004; Sibayan et al., 2010). Further potential improvements include crop rotation, integrated pest and disease management and more nutritious rice varieties. Integrated rice–aquaculture production can also offer opportunities for more efficient resource use and nutrient recycling (FAO, 2000).

Small-scale, integrated crop-livestock production systems

Small-scale crop-livestock production systems provide livelihoods for millions of people in the developing world. In spite of the common denominator, they vary greatly in crops, animals and farm management. Most of these systems are mainly geared towards resilience and providing subsistence, but part of the produce is often traded for cash. High yields are often possible, but would require investments beyond the reach of most farmers. However, considerable productivity improvements, often well over 100%, can also be achieved using affordable technologies (Pretty et al., 2011).Even though the resulting yields tend to still be low compared to developed nations' standards, such improvements can make these systems more sustainable – economically, socially and environmentally. Examples are:

- drought resistant varieties – offering more stable yields and better soil cover;
- more efficient use of manure – offering better crop nutrition and reduced losses of nutrients to the environment;
- improved control of livestock grazing – offering better-fed livestock while avoiding overgrazing, soil degradation and damage to cropped fields;
- integrated pest management – resulting in healthier and more productive crops and livestock;
- small doses of fertilisers – to improve yields and stop nutrient mining;
- improved storage and marketing – to improve cash income and avoid waste and losses.

The adoption of such practices mainly depends on how they fit into each particular system. The huge variation amongst these systems, even within regions, ensures resilience and adaptability but also presents a stumbling block in terms of technology transfer (IAC, 2004; Pretty et al., 2011). Furthermore, such improvements will not always be sufficient to ensure the economic viability of very small units. The policy challenge then is to avoid land abandonment and social decline, and to create the structures and conditions for the emergence of new generations of vibrant farm communities, as discussed in Section 5.4.1.

practices that can be used in these systems is given in Appendix B. Section 5.4.1 elaborates on policy measures that should enhance the socio-economic conditions.

5.3.5 Mono- or multi-functional landscapes?

The increase in total crop production in previous decades has been achieved by intensifying existing crop production systems and by expanding the cropland area at the cost of forest and grassland areas. Both processes have resulted in an increase in large-scale mono-functional agricultural landscapes and a reduction in natural elements. Highly mechanised agricultural practices and chemical inputs to improve plant nutrition and protection reduce the role of natural processes and the use of ecosystem services in these landscapes. Losses in plant and animal genetic resources make agricultural systems more vulnerable to pests and diseases, and limit the potential for adaptation to changing environments (FAO-CGRFA, 2007, 2010; Thrupp, 2000).

The *Global Technology* pathway puts emphasis on increasing yields in large-scale agri-technological landscapes and the strict separation of land-use functions. The result is a reduced total claim on land compared to the *Trend* scenario due to higher productivity on less land (see Section 5.3.4), effectively conserving remaining nature areas (Figure 5.15). However, a decrease in biodiversity and ecosystem services in the monotonic agricultural landscapes is expected due to increased land-use intensity and lack of refuge for species. In addition, the remaining nature areas, although large, will be separated by large agricultural landscapes, leading to fragmentation.

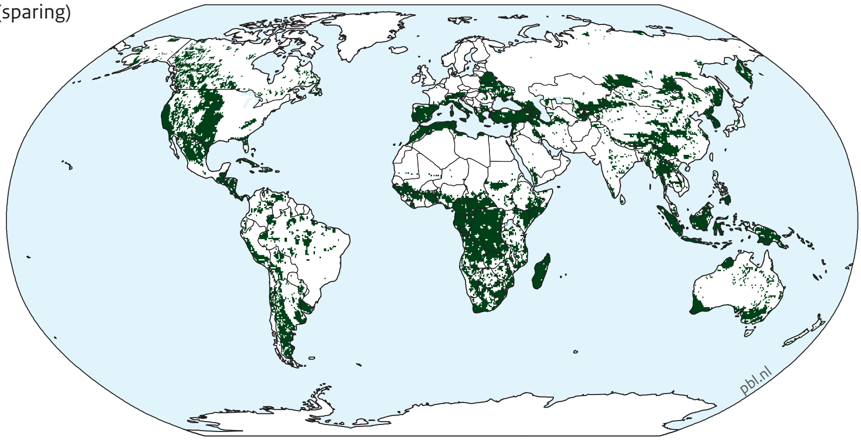
Alternatively, *Decentralised Solutions* describes a pathway towards more ecologically oriented agriculture where technology is adapted to smaller-scale agriculture. It assumes agricultural practices that combine technological advances and the services provided by natural processes. Examples are advanced agroforestry practices and the use of set-aside land for pollination and pest control (see also Section 5.4.3 and Appendix B). These forms of agriculture can result in mosaic landscapes, consisting of a mixture of agricultural land and a great proportion of natural elements. The increased focus on harnessing ecosystem services prevents overexploitation and, therefore, land degradation (Reyers et al., 2009; Pereira et al., 2005). The consequences are a lower production intensity and related larger claim on land compared to the *Global Technology* pathway, an increase in biodiversity and ecosystem services in agricultural fields and surrounding areas, or for example, river streams influenced by them, reduced negative effects of fragmentation on remaining nature areas since natural elements within agricultural fields form corridors and stepping stones for species, and reduced emissions of nutrients.

Discussions of the net effects of land-sparing on biodiversity (the strategy applied in the *Global Technology* pathway) or land sharing (as in *Decentralised Solutions* pathway) have sometimes been heated (Fischer et al., 2011; Godfray, 2011). Defenders of the land-sparing concept would argue that, over the past 50 years, agriculture has mainly developed in this direction and, without the massive yield increases that have been achieved, suitable agricultural land would not be sufficient to feed today's world (CGIAR, 2011; Rabbinge and Bindraban, 2012; Spielman and Pandya-Lorch, 2010). On the other hand, critics of the land-sparing concept argue that high productivity will lead to higher

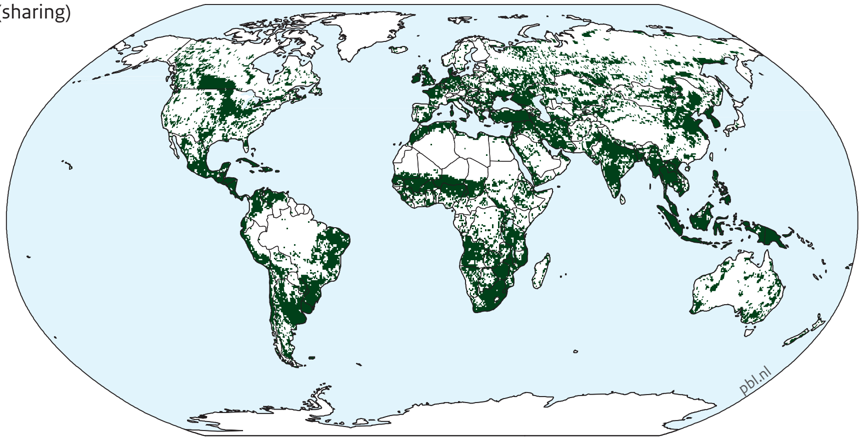
Figure 5.15

Effects of mono-functional and multifunctional landscapes on biodiversity

Global Technology pathway
(sparing)



Decentralised Solutions pathway
(sharing)



Biodiversity expressed in MSA, by 2050, will be more than five percentage points better than under the Trend scenario

Source: PBL / LEI

The Global Technology pathway is projected to result in higher MSA values compared to those under the Trend scenario in regions with large nature areas (e.g. in the Congo basin), as highly intensive and concentrated production limits agricultural expansion. Conversely, the Decentralised Solutions pathway projects higher MSA values in areas that are currently used for large-scale agriculture (e.g. in large parts Europe), as here nature areas will be more interwoven with existing agriculture and production is assumed to have less impact on ecology. The maps depict not only the effect of sparing or sharing land but also the biodiversity effects relative to the Trend scenario for all the measures in the pathways combined.

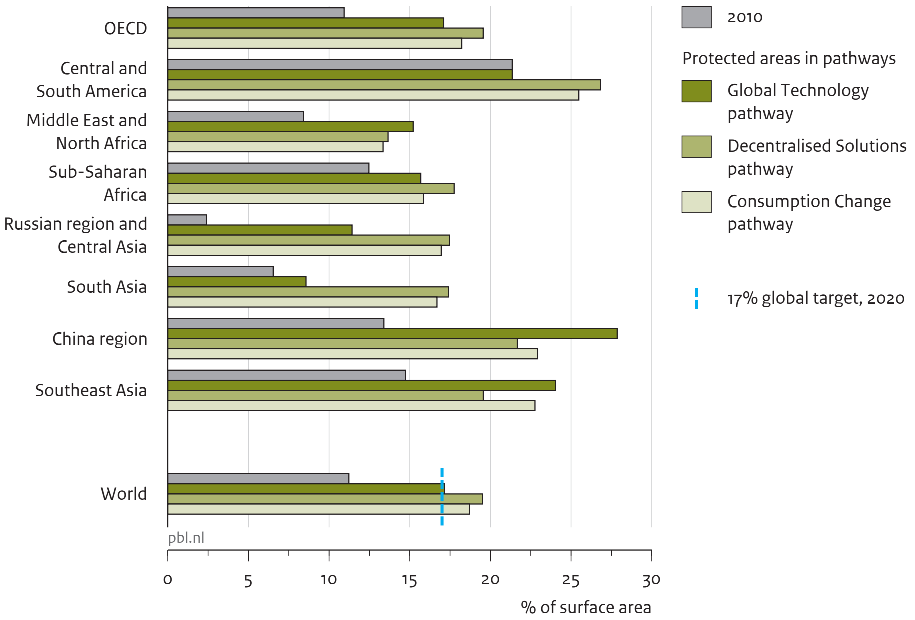
consumption and to increased production and consumption of food and non-food products, such as biofuels, rather than sparing land (Lambin and Meyfroidt, 2011; Tscharntke et al., 2012). In more recent years, a more nuanced picture seems to have emerged (Brussaard et al., 2010), in which high-yielding, land-sparing technologies are advocated in areas that are physically and socio-economically particularly suited to agricultural production, and ecologically oriented land-sharing technologies and approaches in regions with environmental restrictions or highly valued ecosystems that may be incompatible with intensive agriculture (Bennett and Balvanera, 2007). In this sense, land-sparing versus land-sharing becomes an optimisation and land planning exercise with respect to different types of ecosystem services. Furthermore, high-tech high-yielding systems are being developed that are much less environmentally damaging than simply scaling up today's conventional systems (see Box 5.5), at least in terms of nutrient-use efficiency and water-use efficiency. On the other hand, ecologically oriented systems are being developed that are much more productive than, for example, today's organic systems. As a consequence, the difference between these systems will become less dramatic than often suggested, although some trade-offs between yield level and local environmental impact will probably remain. The challenge is to align policies so that these systems may coexist in competitive markets.

5.3.6 Protect the most important ecosystems

The Aichi Target on protected areas aims for the effective protection of at least 17% of terrestrial areas and inland water areas in ecologically representative systems (the target on marine protected areas was not included here). In 2010, 11% of the terrestrial area (excluding Antarctica and Greenland) was already protected. The pathways include three alternative distributions of protected area expansion that lead to a total global protected area of at least 17% of terrestrial areas. The expansion is achieved by making sure that, where possible, at least 17% of each distinguished ecosystem has a protected area status, thus ensuring an ecologically representative network. The expansion in the pathways varies in its level of aggregation of ecosystems and allocation rules. These rules use priority areas from different sources (Kapos et al., 2008; OECD, 2012). This leads to different levels of competition with other land uses (see Table 5.1). Effective protection is assumed in all pathways. A high level of ecosystem aggregation leads to more flexibility for a representative allocation, but at the potential cost of losing smaller and equally diverse ecosystems. A lower level of aggregation (i.e. a higher number of ecosystem types that all require 17% protection to ensure a representative coverage) would require more precise allocation. As some existing protected areas already cover more than 17% of an ecosystem, a lower level of aggregation can lead to a total protected area coverage of over 17% (we assumed existing protected areas remain, even if more than 17% of an ecosystem is already protected; see Figure 5.16).

In the *Global Technology* pathway, protected areas reach 17% at the highly aggregated level of realms. The new protected areas are established where they are least in conflict with agricultural expansion. In the *Decentralised Solutions* pathway, however, the protected area system is assigned at the highly detailed level of 779 different eco-

Figure 5.16
Globally protected areas per region



Source: PBL

The different level of allocation in the pathways causes differences in the efforts that would have to be undertaken in regions to achieve the Aichi Target on the expansion of protected areas to 17% of terrestrial and inland biomes in ecologically representative systems.

regions (Olson et al., 2001). Furthermore, new protected areas are placed close to existing agriculture, creating more intense competition with agricultural expansion. The *Consumption Change* pathway has an intermediate level of ecosystem detail but new areas are also allocated close to existing agriculture. Figure 5.16 illustrates the different ways in which this will play out in terms of protected area per region and the resulting additional efforts required per region. In both the *Decentralised Solutions* pathway and the *Consumption Change* pathway, the total protected area is higher than 17%.

Given the distribution of diverse ecosystems over the globe, there are differences in total area protected between regions in each of our pathways. In Central and South America, China and Southeast Asia, more than 17% would have to be designated as protected area in every pathway, owing to their diversity in ecosystems. In the *Decentralised Solutions* and *Consumption Change* pathways it is more likely that distribution between countries is more equal due to the more detailed aggregation level of ecosystems. However, differences remain, which suggests that international cooperation on the allocation and financing of protected area expansion could result in a more ecologically representative set of protected ecosystems at the global level.

5.4 Managing competing claims: key issues for the coming ten years

The three pathways described above use combinations of potential interventions in access to food, agricultural production, lifestyle and the allocation of different land uses. They represent the lower boundary of efforts required to bring the goals within reach.

The scenario analysis in Section 5.3 points to a number of key issues that are most promising for contributing to both future food security and limiting biodiversity loss:

- **Accelerate the sustainable intensification of agriculture**
  An increase in agricultural production is necessary to satisfy increasing demand. To avoid agricultural expansion into nature areas, higher yields on existing land are required. Yield improvements seem to level off however, prompting the need for larger investments in agricultural productivity. On the other hand, more intensive production can increase local pressures on ecosystems, demanding sustainable practices to accompany productivity improvements. Developing countries suffer the largest yield gaps and here sustainable intensification can contribute to food security and reduce land degradation.

- **Create a more robust food system**
  Aside from increasing production, long-term food security requires improvements in access to affordable food and the limitation of the volatility of food prices. Higher world food production is of little use if food is unaffordable for food-insecure people or if the price swings dramatically, leading people to sell long-term assets for short-term food purchases. There is also the competition between food and bio-energy to consider.

- **Integrate land-use planning with biodiversity and ecosystem services**
  The pathways describe an increased competition for land for different uses, most notably between agriculture and biodiversity and the provision of ecosystem services. The shift in the *Decentralised Solutions* pathway to a high degree of interweaving of nature and agriculture creates a trade-off between ecologically oriented farming and encroachment on remaining nature areas. As competition for land increases, ensuring that it is put to the best use possible and incorporating ecosystem services in decision-making will lead to more optimal solutions.

- **Initiate a shift towards alternative consumption patterns**
  The projected increase in consumption per capita of especially red meat that goes with increased incomes, and the inefficiency in converting feed to meat (requiring more land) make the adjustment of meat-intensive diets a potentially powerful measure for lifting the pressure on cereal production and agricultural expansion.

The interdependencies in the systems mean that there is no single line of solutions that will bring the goals of food security and biodiversity conservation within reach. There is a need to create incentives for the more efficient use of land, to design policies for more equitable access to affordable food, to find a more optimal allocation of different land uses to make maximum use of ecosystem services and protect a representative selection of ecosystems, and to organise a drive to reduce resource use per capita by changing consumer habits and meat-intensive diets.

5.4.1 Accelerate sustainable intensification of agriculture

Sustainable agricultural intensification means (i) increasing long-term farm productivity (see Section 5.3.4) while (ii) minimising environmental and social costs (negative externalities) and maximising environmental and social benefits. How can these goals be brought about, and what does this mean from an actors' perspective?

Increasing long-term farm productivity requires investments – either financial or in terms of labour (see Section 5.2). These will only be realised if the means to do so are available and if the investments are perceived as attractive (high return, low risk). Meeting these prerequisites is far from obvious, especially in developing countries. This could be redressed by creating enabling conditions. The following are key (based on FAO (2011c), FAO and WorldBank (2009), Gurib-Fakim and Smith (2009), IAC (2004), Izac et al. (2009), OECD (2011a), Pretty et al. (2003), Pretty et al. (2010), Prokopy et al. (2008), Röling (2010) and Spielman and Pandya-Lorch (2010)):

- Proper infrastructure (transport, power, Internet, mobile phone) to lower transaction costs by ensuring optimum connection between producers, suppliers, buyers and consumers, and up-to-date market information.
- Access to credit against affordable conditions, for example, through cooperative banks and micro-credit schemes.
- Transparent and fair price formation for produce and inputs, and minimal price volatility.
- Secure land tenure, for example, through formalised property rights (either individual or communal) and respect for the rule of law, so that farmers do not risk losing the fruits of their investments (Barrows and Roth, 1990; Deininger and Chamorro, 2004; Goldstein and Udry, 2008; Smith, 2004; Soule et al., 2000).
- A fair balance of power between governments, producers and their buyers and suppliers. For example, unorganised farmers have no political clout to put pressure on their governments to provide adequate and reliable services (e.g. electricity, road maintenance) and no bargaining power with their suppliers and buyers (Vermeulen et al., 2008).

- Removal of other forms of urban bias regarding, for example, the provision of government services (e.g. schools, medical services), minimum wages and public servant salaries. Less tangible impediments such as the lack of status of farmers and farm workers can also distract potential investment capital away from rural areas and frustrate the emergence of rural entrepreneurs.

Furthermore, investments in long-term productivity will only be realised if stakeholders are aware of the need (which may not be perceived as imminent) to do so and if the required knowledge is available locally. Crucial elements are:
- an awareness among farmers and other stakeholders (including consumers) that agricultural land is a fragile scarce resource, and that sustainable practices are crucial to maintain or improve long-term land productivity (Prokopy et al., 2008);
- well-functioning farm advisory systems, in co-operation with research organisations and farmers groups, to ensure that advice is up-to-date and relevant.

Improving long-term farm productivity in itself involves a number of important environmental and social safeguards such as improving soil health, avoiding erosion, minimising waste and losses and ensuring proper labour conditions. Additional action will be needed, however, to address externalities; in other words to minimise environmental and social costs and to maximise environmental and social benefits beyond the direct interest of farmers. Examples are:
- the removal of distortions such as subsidised energy and water that direct investments towards inefficient energy-intensive farming or groundwater depletion (FAO, 2011c);
- regulation to discourage land conversion, foster soil conservation, avoid emissions and ensure equitable access to water, while avoiding excessive water abstraction;
- the creation of added value or access to new markets by adhering to sustainable production standards, for example, through labelling and certification;
- income opportunities from conserving nature and biodiversity (e.g. ecotourism, payment schemes for environmental services, or payments for the conservation of agrobiodiversity through natural gene banks).

The need for an integrated approach to policies on sustainable agriculture

Policy action to create the conditions described above is multi-actor, multi-level and multi-faceted. Actions must be firm to achieve the ambitious goals set but co-ordination should mostly be decentralised with sufficient room for social learning and adjustments. After all, the issues are far too complex and too specific to be addressed using a single line of solutions.

Multi-actor policy action means that, as well as governments, other stakeholders also play an important role in governance. Multi-level policy action means that policies are required at international, regional, national and local levels. However, for many of the above-mentioned conditions, the pith of the matter seems to be at the national level.

For example, the formalisation of land tenure, the removal of market distortions, the establishment and control of farm advisory systems and enforcement of the rule of law are all typically areas within the sphere of national governments which can (at least in theory) be addressed through proper legislation and by ensuring that institutions are properly equipped. Success in these policy areas, however, is unlikely if there is obstruction at the local level – something which can be expected to occur quite often, as there will always be people trying to manipulate the process and those who tend to lose out through reform (Gong, 2006; Holden and Yohannes, 2002). For the same reason, local-level governance and policy actions, such as the formation of co-operatives or water management boards, also need strong support and pressure from national government to overcome obstructive forces. Regional policies are especially important with respect to trade, sanitation issues and transboundary waters (including aquifers), whereas international policies are required to determine international trade regimes, sustainability objectives and monitoring schemes, product standards and international financing mechanisms.

Multi-faceted policies means that we are dealing with complex issues relating to many subject areas, which require diverse policy responses. Common resource scarcity issues, such as the management of shared freshwater resources, require a totally different policy response from poverty-driven land degradation. Because of the complexity and inter-linkages of sustainability issues, the outcome of policies is often uncertain, increasing the need for an integrated approach to policymaking and continuous monitoring on policy effects.

5.4.2 Create a more robust food system

Recent years have seen larger price spikes and higher average food prices in general. Food prices are projected to stay both higher and more volatile in the near future (FAO, 2011b). Addressing the consequences for food security requires at least three courses of action. First of all, increased agricultural production is required to structurally address the escalation of average food prices. Secondly, the food system can be made more robust by mitigating extreme or unexpected price volatility. Thirdly, policy options are available for reducing the effects of higher and more volatile food prices on consumers and increasing stable access to affordable food.

Persistent higher prices worsen food security, at least in the short term. Higher food prices help make production expansion more attractive, yet without additional public investment many smallholders will be unable to respond with increased supply in the short term. Many of the measures outlined in Section 5.4.1 can help increase food production capacity, which is most important to put downward pressure on food prices. Another potential measure is the curbing of biofuel mandates for first generation fuels, or only allowing them if their use is economical. Dietary changes in lifestyles (see Section 5.4.4 below) can also have a price depressing effect. Reducing agricultural subsidies in developed countries may lead to higher prices in the short term.

Table 5.3
Policy measures to limit food price volatility

	Advantages	Drawbacks	Remarks
Develop climate-resilient agricultural systems	Reduced risk of crop failure contributing to price spikes.	Public and private costs in long-term development (e.g. new varieties). Farm system adaptations require investments and may be less profitable in short term.	Agricultural research lacks international co-ordination and is still underfinanced. Publicly funded risk management schemes (e.g. 2011 CAP reform proposal) remove incentive to invest in resilience.
Improve stock management	Ability to regulate prices. High certainty to buffer price spikes. Can be combined with a floor price (e.g. Indonesia).	Expensive to store. Transaction costs to maintain quality. Can amplify price spikes if built up at the wrong time.	Applied by a few countries, but limited potential in the face of extreme shocks.
Greater transparency on stocks	Better estimates of existing stocks, especially private stocks, and quality.	Private holders are no incentive to reveal their stocks.	The Agricultural Market Information System (AMIS) was established by the G20 for this purpose in 2011.
Trade agreements to limit export bans	Avoid exacerbating prices by further limiting supply on world markets.	Not sure countries will abide. Some grain exporters outside WTO.	In the face of a shock, countries might still renege on their commitments. AMIS is also intended to facilitate early discussion among key exporters.
Divert from feed and fuel	Feed and fuel are ample to compensate shocks to food grains. Cheaper than holding stocks.	Difficult to organise. Interference with other grain users.	

Food price volatility is inherent in the system due to the slow supply response to price spikes, the dependence on the weather and the amplifying effect of the relatively small amount of food traded internationally. Also, the agricultural system is likely to become more vulnerable to plagues and diseases due to their dispersion by international transport and the reduced genetic diversity of crops. Policy measures can mitigate the risk or extent of unexpected price volatility. Predictability is in general more important than higher prices for small and medium-sized farmers and can help insulate consumers from price shocks. Such policies include developing more weather-tolerant varieties, managing reserve stocks, maintaining open trade channels and increasing market transparency (Table 5.3). It is technically possible for governments to mandate the diversion of staples from fuel and feed to food, though legal implementation would be difficult in market-oriented economies. Better facilitated and less restricted trade in food products, especially in regional markets, may also greatly reduce price volatility (World Bank and IMF, 2012).

The measures available for shielding domestic consumers from unexpected or extreme price spikes will differ depending on countries' circumstances. Short-term instruments include cash or food transfer programmes, or the release of emergency stocks by the government to push prices down. More permanent policies are safety nets that are designed in advance or more elaborate programmes that limit domestic price volatility; for instance, through the combination of floor prices and public stocks. The design of safety nets requires the identification of vulnerable parts of the population to properly target the response. Improved research is required on the pass-through of international prices to local prices in different regions (World Bank and IMF, 2012).

Although increasing production and creating a more robust food system are important components of future global food security, they are not sufficient. Governments' abilities to implement redistributive policies and permanent safety nets depend on public resources — and hence a tax base and a growing economy — and the administrative capacity to target specific groups. This also applies to additional investments in education and the distribution of information about nutritional values and required intakes.

5.4.3 Integrate biodiversity and ecosystem services into land-use planning and management

In 1992, Agenda 21 acknowledged the need for integrated land planning and management (UN, 1993). The urgency remains, given that competing claims on land will become starker in the coming decade. Optimising land use will be most important in urbanising deltas and coastal areas, but the efficient management of land and natural resources will also be crucial in many rural areas facing soil degradation and the overuse of available water (FAO, 2011c). Land-use planning that allows a balance to be made between all the potential land uses encourages optimal allocation and better coordination between stakeholders. The two most prominent issues to address are the integration of a more complete set of biodiversity and ecosystem services in land-use planning and management and the improvement of the institutional capacity in developing countries.

Building technical, financial and administrative capacities in developing countries

The countries and regions that are projected to experience the largest land-use changes in the coming decades often have less capacity to regulate land rights and plan land use, either in terms of legal establishment or enforcement, lacking, for instance, land registers or detailed mapping procedures. The allocation of formal property rights – or, in many cases, the recognition of long-standing locally recognised rights – is often said to promote investment, reduce poverty and improve natural resource management.

However, loss of access, for example, through privatisation of commons, can be detrimental to the poor who rely on an area's natural resources. In strengthening land tenure in many developing countries, a dilemma arises due to the sheer size and cost of the task of formalising land rights and the various local systems and claims that determine property (Toulmin, 2009). Titling of land, therefore, may not yield the expected benefits and other options may be preferable, such as locally organised tenure systems that provide a sense of security for farmers without excessive bureaucracy. Also, individual titling may be incompatible with nomadic livelihoods that depend on commons and alternatives may produce better results (e.g. Ostrom et al., 1994). Securing land tenures is an expensive and elaborate process requiring considerable technical, financial and human capacities in many developing countries.

Integrate biodiversity and ecosystems in land-use planning

An effective planning framework can help align competing claims on land and make the process more transparent and inclusive. It can also optimise land use through an integrated analysis of trade-offs and external land-use change effects. This is where biodiversity and ecosystem services need to come in. Spatial planning can be applied at local to national scales. For some aspects of biodiversity (most notably the carbon sink function of ecosystems and the assignment of protected areas) a case could even be made for international planning for optimal efficiency (e.g. see below on REDD). Green or ecological planning opens the door to synergies; for instance, between recreation space and habitat conservation, or for natural erosion control, flood protection and carbon storage, and allows planners to prioritise which areas are worth more under what type of land use. Examples of spatial planning instruments include cost-benefit analyses and urban and agricultural zoning laws (see Table 5.4).

The consideration of ecosystem services in land-use planning can also inform decisions on the large-scale restoration and sustainable use of ecosystems. Examples are the Chinese Loess plateau, where restoration and a return to sustainable farming practices increased incomes and well-being significantly, or the intention of the Kenyan government to restore five large forest areas to serve as water catchments, biodiversity reservoirs and carbon sinks, and a National Spatial Plan based on mapping land-use patterns and the zoning of urban and agricultural areas (Republic of Kenya, 2008).

When political decision-making focuses on a particular geographical area a place-based approach to incorporate ecosystem services in spatial planning is potentially the most effective (TEEB, 2010). This approach aims to demonstrate the relevance of ecosystem services in the area by answering questions, such as: which systems are there, where do they emanate from, what is their importance to human well-being, who relies on them, are substitutes available and how can actions influence their provision (Haines Young and Potschin, 2008; TEEB, 2010). Looking at the distribution of ecosystem services in developing countries can highlight the extent of dependency on natural resources for livelihoods. As much of the income that the poor derive from their immediate environment never enters official accounting figures, this has 'led to the systematic

Table 5.4
Examples of instruments to integrate biodiversity into land-use decision-making

Information measures	Economic incentives	Regulation
Decision-support instruments (cost-benefit analysis, participatory appraisal, multi-criteria analysis)	Taxes (e.g. on groundwater, pesticide and fertiliser use) Fees/charges (e.g. for natural resource use, access, hunting or fishing licenses)	Access restrictions or assignment of Protected Areas
Integrate a place-based approach into spatial planning (including ecosystem service mapping)	Payments for ecosystem services (e.g. locally organised or publicly funded payments for watershed maintenance, or linked to subsidies as in the EU Common Agricultural Policy)	Obligations to compensate environmental impacts (e.g. through spatial or financial compensation)
	International payments for ecosystem services (e.g. REDD)	Mandatory execution and public disclosure of Environmental Impact Assessment or Strategic Environmental Assessment
	Premiums for sustainable land-use certification (e.g. Green Development Initiative)	(Agro-ecological) zoning laws

Source: OECD, 2012; TEEB, 2010

undervaluation of assets of the poor and an underestimation of the benefits of sound ecosystem management' (Vedeld et al., 2004; WRI, 2005). Better ecosystem management, securing rights of access and the use of natural resources, improving the marketability of nature-based goods and pro-poor Payments for Environmental Services (PES) are four key steps to ensure the poor profit more and longer from their natural resource base (WRI, 2005).

The UNFCCC attempt to design a REDD scheme is an example of PES on an international scale. Because of the global public good characteristics, this system is being organised in an international setting. However, reducing deforestation can also yield local benefits, such as maintaining hydrological functions and reducing forest fires, air pollution and soil erosion (Nepstad et al., 2009). This illustrates the potential for bundling different ecosystem services into a payments system, though transaction costs obviously increase the more the benefits diffuse across scales and the more diverse the services and actors involved are. Policy coherence also requires calibrating REDD in such a way that it provides the greatest benefits to both biodiversity and the maintenance of ecosystem services, emphasising the importance of land-use planning capacity. Mapping areas, prioritising based on the international and national perspective, is a crucial ingredient (Karousakis, 2009).

Effective management and expansion of protected areas require international financing

The estimated global funding for protected area management ranges between USD 6.5 and USD 10 billion, per year (Gutman, 2007). These funds do not cover effective protection in many countries, resulting in 'paper parks', areas with a legal protected areas status but without effective management. Funding gaps are highest in developing countries (Balmford et al., 2003; James et al., 2001; TEEB, 2011); for example, the 45% annual gap to meet estimated protection needs in Latin America and the Caribbean (Bovarnick et al., 2010) and, in monetary terms, a total annual gap of USD 261 million for Brazil, Colombia, Bolivia, Chile, Ecuador and Peru, and USD 100 million for Indonesia (TEEB, 2011).

Costs for expanding protected areas are more elusive and depend on the size of the expansion and on allocation, as well as on opportunity and management costs. Balmford et al. estimated annual costs of USD 20 to 28 billion, spread over 10 to 30 years, for 15% of the land area in each region (Balmford et al., 2002). Bruner et al. estimated additional annual management costs at USD 1.8 billion and purchasing costs at USD 9 billion, over a ten-year period, for a 30% increase in total protected area in developing countries (Bruner et al., 2004). Obstacles other than gaps in funding exist, as well, such as shortages of conservation professionals (Balmford and Whitten, 2003).

The benefits of protected areas are often more difficult to quantify than costs, but can be substantial and various, including clean water provisioning, natural hazard reduction, and the support of tourism (TEEB, 2010). To maintain these benefits and cover the financing gap, mechanisms to facilitate and scale up the international financing of protected areas will be required, involving significant financial transfers from developed countries to developing countries (Balmford and Whitten, 2003; James et al., 2001; PBL, 2009b). A collaborative process for identifying and appointing areas eligible for this kind of support can increase the support for international financing.

Agriculture is perhaps the most important policy area in which mainstreaming biodiversity could make a difference; in particular, through incentives for sustainable intensification, for example, by making systems more productive and resilient with fewer environmental impacts. This would simultaneously contribute to biodiversity and food security.

Although land-use planning policies are one of the most valuable tools in allocating land uses to optimal combinations, the bigger picture requires that they are matched by efficiency and sustainable improvements in agricultural production (see Section 5.4.1) and by consumption changes to avoid shifting biodiversity pressures, for instance, those related to imported goods from other countries or regions.

Box 5.6 Addressing the impacts of large-scale land acquisitions

The realisation that fertile lands have become scarce, combined with concerns about the future security of the food supply, have, in recent years, led to large-scale land acquisitions by other countries or private investors. Other drivers are demand for biofuels and speculation both on high and more volatile food prices as well as on the price of land itself. Recent land acquisitions have taken place largely in sub-Saharan Africa but also in Russia, Asia and Latin America (Daniel and Mittal, 2009; World Bank, 2011b). The World Bank reported deals on some 0.56 million km^2 during 2008/2009. There is particular concern over the human impacts of these projects (such as loss of access to land), over the speculative nature as large parts of concessions have not been brought into cultivation, and over the effects on livelihoods and development potential (De Schutter, 2011a; World Bank, 2011b). Recommendations that aim to mitigate the potential negative consequences of the large-scale acquisition of agricultural land include:

- Ensure there are strong and clear land rights in place (World Bank, 2011b).
- The transparent management of public lands and a tightly controlled and open process of the potential sale and acquisition of public lands (World Bank, 2011b).
- Legitimate and legally valid mechanisms to resolve disputes, accessible to the population and able to resolve cases fair and expeditiously (World Bank, 2011b).
- Improve up-front assessment of land deals' potential contribution to development and assess required type of investment (e.g. cultivation, support of smallholders) (World Bank, 2011b).
- Develop guidelines for land governance or a code to regulate international investments backed up by capacity-building at all levels (FAO, 2011c). The seven principles for responsible agricultural investment outlined by the WB, FAO and others (World Bank, 2010), the 'Minimum Human Rights Principles' (De Schutter, 2009) and the 'Voluntary Guidelines on the Responsible Governance of Tenure of Land and Other Natural Resources by the Committee on World Food Security (CFS) provide a starting point.

5.4.4 Initiate a shift towards alternative consumption patterns

The pathways in Section 5.3 illustrate the significant potential contribution of less resource-intensive consumption to a more sustainable future. Our pathways incorporate only a reduction in the consumption of meat and eggs, although potential lifestyle changes could also include the purchase of more sustainably produced products. Less resource-intensive consumption makes the effort required in other areas less stringent and the probability that sustainability targets will be achieved much more robust.

Changing consumption patterns in the short term requires government action

Lifestyle and consumption habits are often culturally or habitually entrenched and may take decades to adjust when left to voluntary action. Examples of relatively fast adjustments, such as reductions in smoking (Massachusetts) or healthier eating (Finland), generally depend on government action. An important aspect is whether the potential effect of the change involves citizens' health. Government action has been more prevalent in cases where unhealthy habits threaten life-spans or well-being. For instance, a large majority of the Danish parliament agreed to a tax on saturated fats in 2011 to combat obesity and Denmark has banned trans fats and put higher levies on sugar. Levers to directly influence consumption habits are regulation and economic instruments (taxing certain types of food or limiting contents), choice-editing (restricting people's choices of products), campaigns (increasing awareness about healthy consumption) (The Government Office for Science, 2011) and the mandatory labelling of food with nutritional content information. However, coherence with other policies is also warranted, most notably in the area of advertising and the marketing of foodstuffs and in the agricultural subsidy systems (e.g. subsidised maize is used in increasingly larger quantities to produce sweeteners) (De Schutter, 2011b). The WHO has set guidelines for healthy levels of meat consumption that could serve as a guideline for governments (Dellas and Pattberg, 2011; PBL, 2011a).

Business and consumers are primary drivers of sustainable supply chains

The links between consumption and its impact have diffused as a result of trade and urbanisation. In attempting to provide transparency on production conditions and the related impacts on social and environmental circumstances, various certification initiatives provide information for more informed consumer choice. The creation of more sustainable supply chains has largely been left to private initiatives by businesses and NGOs. Voluntary certification instruments have become important in making chains more sustainable; for instance, regarding timber, coffee and cotton. Impacts can be reduced at the point of extraction or by using resources more efficiently in the production chain. Green Government Procurement policies, where governments use their market power to demand more sustainably produced products, are gaining more traction. Here, the actual setting of criteria by governments (thereby taking a stance on what is at that moment considered sustainable) creates a new dynamic. Potentially, it could lead to harmonisation and in the future even standardisation amongst governments on sustainable production criteria.

Note

1 REDD; Reduced Emissions from Deforestation and Forest Degradation. See PBL (2010) for estimates of potential biodiversity effects of such a scheme.

The energy and climate challenge

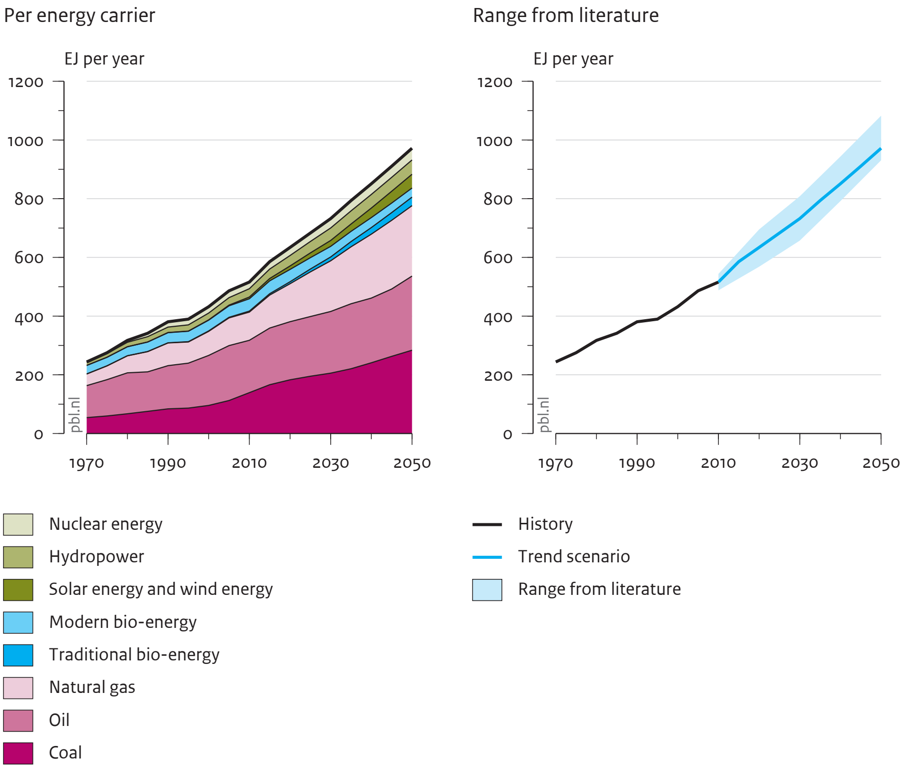
Energy and climate play a major role in achieving sustainable development goals. Historically, energy use and the associated greenhouse gas emissions have increased rapidly. Still, nearly three billion people have no access to modern energy. This chapter focuses on the level of effort required to reach energy, climate and air pollution goals for 2050 and on strategies to achieve these goals.

6.1 Energy system trends and targets

The energy system plays a crucial role in achieving sustainable development. The use of energy is a prerequisite for human welfare. The future of the energy system is also of critical importance in terms of achieving the global development and environmental goals discussed in Chapter 2. The present energy situation is characterised by the following key problems (Van Vuuren et al., 2012a):

1. *There will be a rapid global increase in energy demand*. Scenario studies indicate that energy demand could grow significantly over the next decades. Without new policies, fossil fuels are expected to supply most of this demand as their average prices will remain lower than those of alternative fuels (see Figure 6.1 and Chapter 3).
2. *A large share of the global population has only limited access to modern energy sources*. Approximately 40 % of the global population still cooks using traditional biomass or coal on an open fire or self-made stove and over 20 % does not have access to electricity, with negative impacts on health and development prospects. Improved access is an essential component of accelerating human development (Modi et al., 2006; IEA, 2010b; Van Ruijven et al., 2012).
3. *Energy use is a major factor in many environmental problems*. The energy system, and in particular fossil fuel combustion, plays a key role in anthropogenic climate change,

Figure 6.1
Global primary energy supply in the Trend scenario



Source: PBL and literature range from Clarke et al. (2010)

Global primary energy supply in the Trend scenario. The blue areas indicate the 10–90th percentile of scenarios in the literature

air pollution, biodiversity loss, landscape disturbance, waste generation and the risks of nuclear accidents.

4. *Energy security is an important consideration for many countries and increasingly under pressure*. Although a reliable energy supply has to be ensured, high-quality energy resources are limited and unevenly distributed across the globe. As part of the energy transition, energy security is expected to become a major concern in several world regions, with not only market, but also military, means determining allocation – as has often been the case in the past.

The energy challenge: energy access for all with minimum impact on the environment

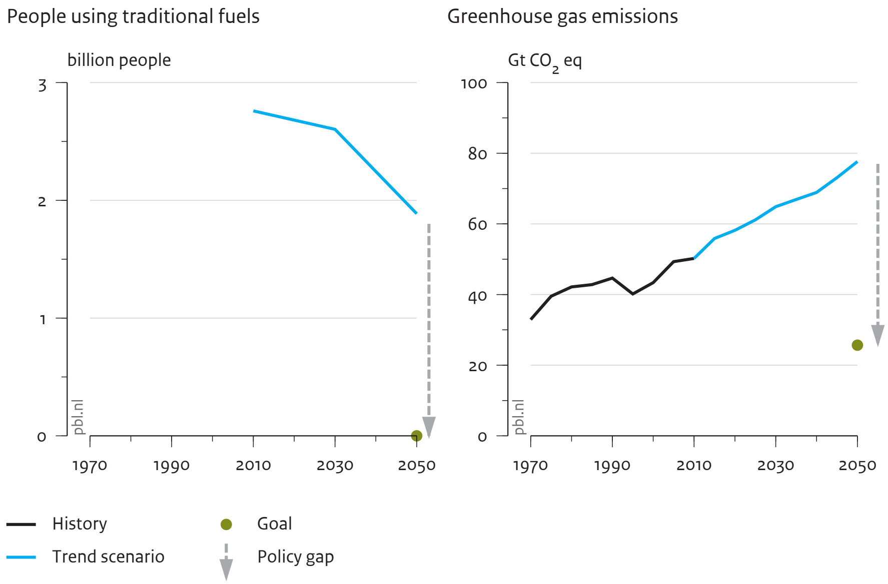
The energy challenge can be summarised as providing access to sufficient modern energy for all in a way that supports human development and minimises the impacts on

Box 6.1. The energy challenge

The three Challenge pathways all aim to achieve the following three goals:

1. *Ensure universal access to modern energy*. In the *Trend* scenario, 2.6 billion people still depend on solid fuels for cooking and heating and 1 billion people do not have access to electricity in 2030. The target is to ensure everyone has access to electricity and modern fuels for cooking and heating.
2. *Prevent dangerous anthropogenic interference with the climate system*. Under the *Trend* scenario, global greenhouse gas emissions will be about 60 to 70 GtCO_2 equivalents per year, by 2050, leading to a global mean surface temperature increase of 2.5 to 5 °C by 2100. The target is that the temperature increase will not exceed 2 °C by 2100, with a high probability. Therefore, by 2050, global greenhouse gas emissions must be reduced to around 20 to 25 GtCO_2 equivalents per year.
3. *Reduce air pollution*. Under the *Trend* scenario, in many places around the world, targets for air pollution would still be exceeded. The target is to keep annual mean $PM_{2.5}$ concentration below 35 µg/m³ by 2030.

Figure 6.2
Sustainable development goals on global greenhouse gas emissions and use of traditional fuels in the Trend scenario



Source: PBL

Trends in people using solid fuels for cooking and heating (left-hand panel) and in greenhouse gas emissions (right-hand panel). The dotted lines show the goals as set in this report (see Chapter 2) the local and global environment. As indicated in Box 6.1, this chapter focuses on three of the globally agreed goals and targets presented in Chapter 2.

1. Ensure universal access to modern energy

The goal is to provide full access to electricity and to modern 'clean' fuels for cooking and heating (natural gas, LPG, kerosene, modern biofuels and solar stoves). This expansion is clearly not achieved in the *Trend* scenario, especially in sub-Saharan Africa and Asia (see Chapter 3). Providing full access to electricity requires accelerating the pace of electrification, specifically targeting poor communities that, from an economic perspective, would otherwise not be connected. To provide full access to modern fuels for cooking and heating, the affordability, availability and safety of cooking fuels and practices should first be improved (Modi et al., 2006).

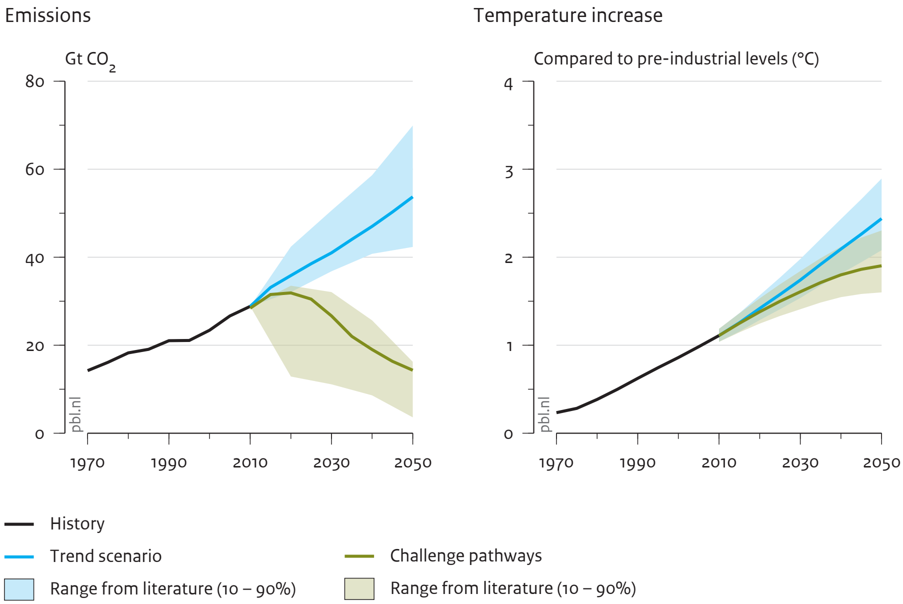
2. Prevent dangerous anthropogenic interference with the climate system

The goal is to avoid a temperature increase above 2 °C. The relationship between greenhouse gas emissions, concentration and global mean temperature is beset with important uncertainties, above all that of climate sensitivity. Meinshausen et al. (2006) indicate that in order to have a high probability of reaching the 2 °C target, greenhouse gas concentration should be below 450 ppm CO_2 eq by 2100, which would require global emission reductions by 2050 in the order of 40% to 60%, compared to 1990 levels (Van Vuuren and Riahi, 2011). Here, we have translated the 2 °C target into a 50% emission reduction by 2050. There are different emission pathways that can achieve this, in which many factors play a role, including short-term options to reduce emissions and risk acceptance. The inertia in the climate system means that some overshoot in greenhouse gas concentration levels can be allowed. A critical issue, however, is that of expected long-term technology availability, and in particular the question of whether technologies that result in negative emissions (e.g. biofuels combined with carbon capture and storage) may come about during the 21st century. The pathways correspond to annual emissions in the order of 20 to 25 $GtCO_2$ equivalents by 2050 (10-15 $GtCO_2$/yr CO_2-only) – a drastic reduction with respect to the *Trend* scenario (Figure 6.3).

3. Reduce air pollution

The energy system also adds significantly to both indoor air pollution from inefficient stoves using traditional fuels and outdoor air pollution largely related to fossil-fuel combustion. In OECD countries the enactment of planned legislation is expected to further decrease emission levels, whereas emission trends in non-OECD countries are more mixed due to rapidly increasing energy consumption and related air pollution and, in some cases, new abatement policies. At the global level, this implies that only modest declines in pollutants can be expected (see Chapter 3). The target is to keep annual mean $PM_{2.5}$ concentrations below 35 µg/m^3 by 2030. This requires significant reduction in pollutants especially in cities in developing countries. Some of these reductions are a co-benefit of climate policy, as less fossil-fuel use also leads to lower air pollution. A further tightening of emission standards are therefore required. These are implemented

Figure 6.3
Global greenhouse gas emissions and temperature changes



Source: PBL and literature range from Clarke et al. (2010) and Van Vuuren et al. (2008)
Global greenhouse gas emissions and temperature change in the Trend scenario compared to those required to reach the 2 °C target. The coloured areas indicate the 10–90th percentile of scenarios in the literature.

through end-of-pipe abatement measures using the emission levels of the IIASA GEA scenarios as a basis (Riahi et al., 2012).

6.2 Barriers to providing modern energy for all and limiting climate change and air pollution

As shown in Chapter 3, there has been limited success in achieving the sustainable development goals so far. As most of these goals have officially been agreed upon in various international negotiations, therefore, a key question is which barriers have prevented the goals from being reached. Based on the literature, we have identified six main barriers:

1. conflicting interests regarding energy system decisions;
2. short-term focus of decision making, both in business and policy;
3. pervasive doubt about the extent and seriousness of climate change;

4. uncertainty regarding energy prices;
5. bias towards supply-side investments over demand-side investments;
6. lack of commitment to address the energy needs of the poorest segments of the population.

These barriers are obviously a result of interplay between the technical and economic realities of present-day systems, incentives, views, values and power relations. We briefly discuss them below.

Conflicting interests regarding energy system decisions

Many countries formulate their energy policies around three goals: 1) affordable energy, 2) clean energy and 3) reliable energy. The European Energy Strategy, for instance, uses the motto 'competitive, sustainable and secure' (EC, 2010). However, other goals also exist, such as maximising the rents of national fossil fuel reserves, protecting the position of national industries through low energy prices, subsidising energy for households and stimulating national energy-innovating industry and business. Clearly, these goals present difficult trade-offs, with the conflicting interests of actors playing an important role. Maximising the rents of national fossil fuel reserves, for instance, can only be combined with stimulating a transition towards low-carbon fuels if carbon capture and storage (CCS) is applied on a massive scale. Also, increasing supply security could imply an emphasis on coal, given its abundance. In other words, the sustainable development targets formulated in Chapter 2 are weighed against multiple interests, and often implicitly. A further obstacle is that the costs and benefits of these goals vary for different actors. Industries, for instance, may be opposed to climate policy if they expect the higher energy costs to harm their international competitiveness. Subsidies to increase energy access and affordability for the poor can cause irresponsible debt levels for companies or governments. Similarly, conflicts occur between groups of countries, such as between oil and gas exporting and importing countries and between existing suppliers and alternative fossil fuel suppliers such as Australia (coal) and Canada (tar sands). The conflicts are also relevant to international cooperation regarding sustainable development issues.

Short-term focus of decision making, both in business and policy. Current deregulation and globalisation trends have even strengthened this

Clearly, energy system transitions take considerable time, partly due to the long lifetime of energy infrastructure. Every coal-fired power plant being built will require a large and continuous coal input – and generate high CO_2 emissions unless CCS is applied – for several decades to come (see also the recent World Energy Outlook (IEA, 2011b)). This implies that in order to meet long-term objectives, present day decisions will also need to be viewed in this context. This, in turn, means that in the trade-off of different interests discussed above, long-term goals need to be constantly weighed against short-term interests. Currently, however, incentive structures are not able to give long-term interests enough priority. This is illustrated, for instance, by the fact that RD&D investments clearly lag behind the growth in energy consumption and are overall low compared with other industries, despite some reversal in recent years (IEA, 2011a; Grubler et al., 2012). The net result is that the resulting physical, economic and political inertia tends to keep fossil fuels in their dominant position; the inertia is not only due to physical equipment.

Pervasive doubt about the extent and seriousness of climate change
Although in science there has been convergence on the theory that the Earth is warming and that most of this is driven by the anthropogenic greenhouse effect (IPCC, 2007a), a similar level of agreement does not exist in the public debate, including politics. People disagree on the historical changes and the underlying causes. Several researchers argue that differences in views on climate change are related to more general differences in world views (Hulme, 2009). Sceptical views also seem to correlate with interests. Recent discussions on the quality of the IPCC reports and the credibility of climate science seem to have further fuelled climate scepticism. Doubts on the need for climate policy clearly do not help build consensus on stringent measures and reducing global greenhouse gas emissions.

Uncertainty regarding future energy prices
In the last few years, oil prices – and energy prices in general – have been relatively high, but also volatile (prices were low in the early 2000s, rapidly increased during the mid-2000s and have shown rapid ups and downs since then). Economic theory shows that uncertainty tends to shy investors away as the risk is too high that there will be no return on investment. Investments in alternatives for oil that would be induced by constant high oil prices will, for instance, not be made if there is a risk that prices will drop to a much lower level. Similarly, volatile energy markets also imply that governments focus more on energy security issues (and arguably less on climate change and energy access).

A bias towards supply-side investments over demand-side investments
Technology-oriented bottom-up engineering consistently finds a high potential for increasing energy efficiency. However, there has been limited progress in implementing this potential. Several reasons for this 'market failure' have been identified, such as a lack of front-end investment funds, the absence or inadequacy of information and the previously mentioned uncertainty about energy prices and policies. Another important factor is the asymmetry between the few energy suppliers and the many energy users in terms of resources. The role of material-intensive lifestyles has also received little attention from policy-makers, partly because there has been little empirical success in attempts to influence lifestyles and possibly because the involvement of government in individual consumer choices runs counter to existing ideologies. The discussion about the link between economic well-being and resource use has recently again come to the attention of policy-makers (e.g. Stiglitz et al., 2009).

A lack of commitment to address the energy needs of the poorest segments of the population

Studies have shown that improving access to modern energy has important benefits for development and the environment (Hutton et al., 2006). Still, also here little progress has been made. One factor is that the benefits often concerns poor rural populations and urban slum dwellers. As a result, the issue faces the same difficulties and controversies that surround development policies. For instance, poor people spend almost all of their income on survival needs, leaving little money for energy services. Major concerns are also the lack of electricity infrastructure, often due to government failure or corruption. With respect to general development policies, although they have been in place for many decades, very often they have not led to a reduction in income gap between the poor and the rich – neither within developing countries nor between low- and high-income countries. Perhaps the ongoing re-evaluation of development policies in OECD countries and the initiatives in China and India may lead to a reframing of the problem and bring new and effective approaches.

6.3 Exploring different pathways towards the goals

6.3.1 Design and components of three different pathways

In this section we discuss three different pathways that ensure the sustainable development targets are met. The focus is mostly on the changes required in the physical system rather than the policies and instruments required to implement them; these are addressed in Section 6.4 and Chapter 8. The general assumptions made in these three pathways have been introduced in Chapter 4. Table 6.1 shows various options that could be introduced to achieve the long-term sustainability goals.

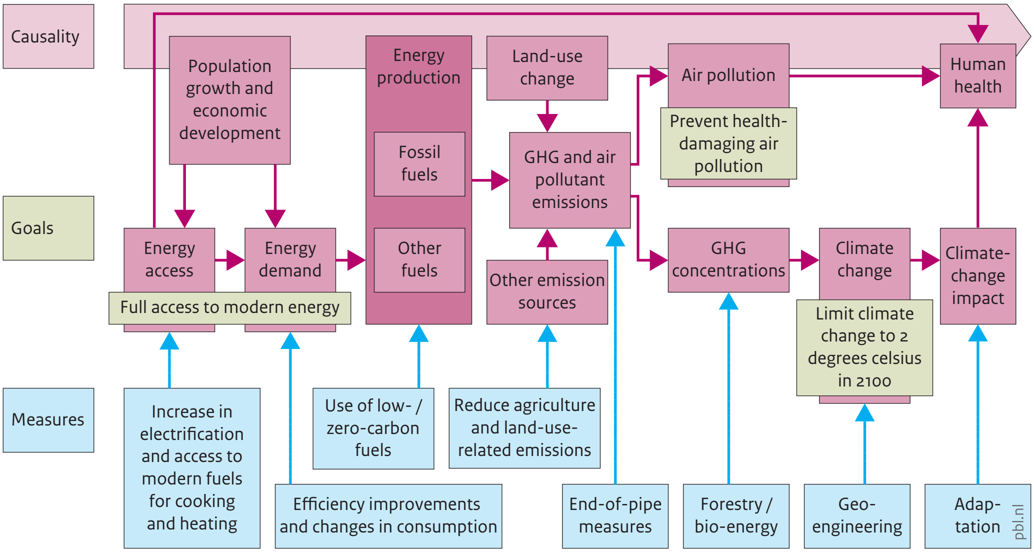
Figure 6.4 shows the main linkages between the goals and potential measures to attain them. As indicated earlier, the three pathways are designed as normative, backcasting scenarios. This means that all three achieve the sustainable goals set. However, the routes along which the goals are met differ substantially. From the available options, we have selected a set of specific options that form the basis of each of the three pathways focusing on energy access, climate mitigation and air pollution control (see Table 6.2).

Table 6.1
Options to achieve energy-related sustainability goals

	Options to achieve sustainable development goals	Possible policy instruments to promote these changes
Improve access to energy	• Expand electricity infrastructures • Promote transition towards modern fuels for cooking and heating • Provide improved stoves	• Investment in expanding infrastructure • Provide financial incentives for use of modern fuels for the poor (e.g. targeted subsidies) • Programmes to promote use of improved biomass stoves
Reduce energy demand growth	• Influence behaviour/lifestyle changes • Improve efficiency in end-use • Improve production efficiency	• Efficiency standards for new equipment and buildings • Efficiency standards for existing equipment and buildings (e.g. when sold) • Retrofit programmes • Financial instruments • Information campaigns
Shift energy production from fossils to low-/ zero-carbon fuels	• Increase use of renewable energy (including bio-energy, hydropower, solar and wind energy) and nuclear energy • Increase use of CCS • Increase use of electricity and H_2 in end-use (increasing the ability to provide energy from low-/ zero-carbon electricity and H_2 production)	• Financial instruments such as carbon taxes or emission trading systems • Renewable energy standards • Instruments to promote R&D to reduce costs of alternative energy • Demonstration programmes
Adaptation to climate change	• Various options to decrease vulnerability to changes in climate and the likelihood of extreme events (such as coastal protection, city planning, agriculture)	• Long-term adaptation planning
Reduce air pollution using end-of-pipe measures	• Stimulate air pollution control	• Emission standards • Financial instruments

Source: Based on IPCC (2007a)

Figure 6.4
Linkages between goals and measures for energy access, climate change and air pollution



Source: PBL

Table 6.2
Pathways to achieve the energy goals

	Global Technology	Decentralised Solutions	Consumption Change
Access to modern energy	Grid investments Subsidies for modern fuels and micro-credit for stoves Improved biomass stoves for poorest households		
Lifestyle measures	None	None	Preference for public transport Lower material consumption / recycling Lower heating/cooling demand
Energy supply technology	Emphasis on CCS, H_2 and nuclear	Additional emphasis on renewables	Intermediate
Efficiency	Strong efficiency improvement in energy supply	Implementation of best available technology in residential sector, services and industry	Default
Trade	Further liberalisation	Constraints on energy trade	Further liberalisation
Air pollution	End-of-pipe measures		
Bio-energy	Constrained by sustainability criteria restricting potential		

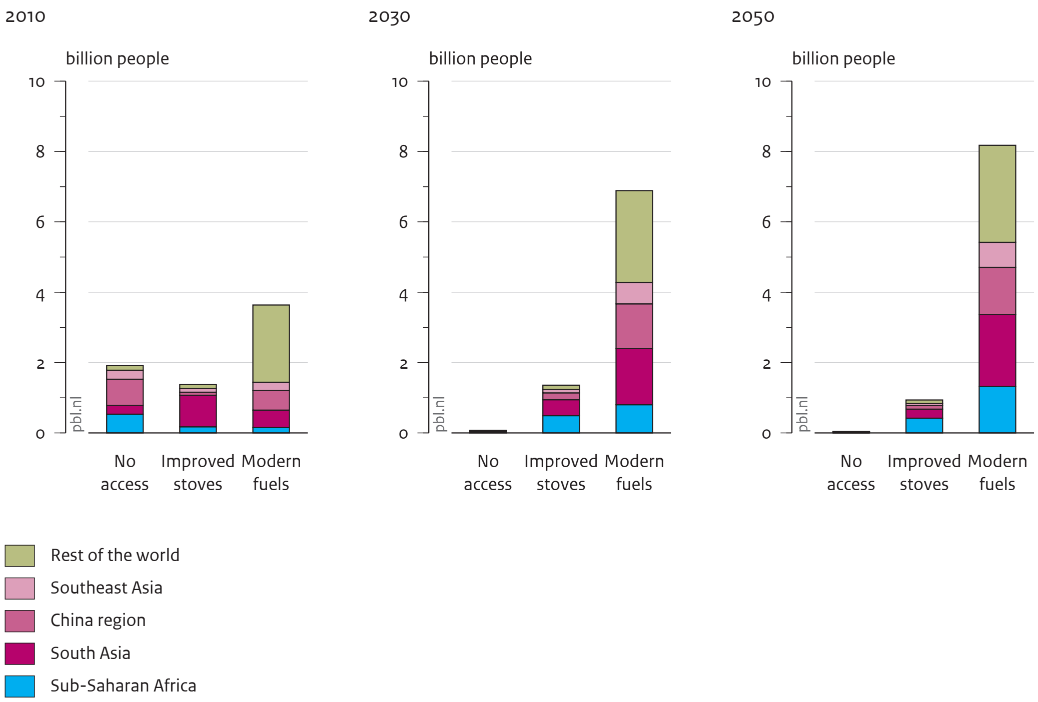
6.3.2 Access to modern energy

In the *Trend* scenario, billions of people will still have no access to modern energy sources in 2030 and 2050. Lack of access to modern energy has many negative development and environmental impacts. The development impacts include health-damaging indoor air pollution from the solid fuels used for cooking and heating (see Section 7.3), reduced education and income opportunities due to the time spent collecting firewood, and limited access to healthcare and education due to the lack of electricity (Venkataraman et al., 2010). The environmental impacts include increased local deforestation – reinforced by inefficient cooking practices – and the emission of greenhouse gases and particulate matter, such as black carbon, both related to burning biomass in unimproved stoves.

In our pathways, we define an improvement in access to energy sources for cooking and heating as when households either make a full transition towards modern fuels (here only target LPG is targeted) or use improved biomass stoves. Other modern cooking fuels may be better suited to certain regions or nations. Furthermore, in the *Decentralised Solutions* pathway, a focus on zero-carbon alternatives, including locally produced biogas, may be a more logical choice. However, the modelling framework does not include these options and LPG is used as a proxy for all clean cooking fuels to quantify the costs and impacts of alternative policies. The main policies considered to encourage a more rapid transition away from solid fuels for cooking and heating are fuel subsidies and grants or micro-lending facilities to make access to credit easier and lower households' cost of borrowing (Van Ruijven, 2008). We assume 80 % fuel price support on LPG coupled with more easy credit access. Furthermore, for those households for which a shift away from biomass may still be out of reach under the induced financial policies, improved biomass stoves are distributed, being a cost-effective interim solution. In fact, the use of improved biomass stoves may result in actual gains instead of costs, as the investment in improved stoves would be coutered by the reduction in spending on firewood, especially in urban areas where people are already used to paying for biomass (Hutton et al., 2006). The financial instruments are assumed to be targeted at the poor population only. Finally, the induced policies are the same in the three pathways and their impacts are similar.

The introduced policies would significantly improve global energy access, especially in Asia. It should be noted that, in the pathways, full access to modern fuels would not be achieved by 2030, and that, by 2050, around one billion people would still be using traditional biomass, but now in improved biomass stoves, mainly in sub-Saharan Africa and South Asia (see Figure 6.5). As far as access to electricity is concerned, clearly much progress would already be made under the *Trend* scenario. However, the pace of electrification in the least developed countries and regions would need to be accelerated to provide full access, either through grid expansion, decentralised mini-grids or off-grid systems (AGECC, 2010). In the pathways, we reach 95 % grid connectivity in 2030, mainly through massive grid expansion in rural areas in South Asia and sub-Saharan Africa. Although we assume all additional electricity generation is supplied

Figure 6.5
Global household access to modern fuels for cooking and heating in pathways

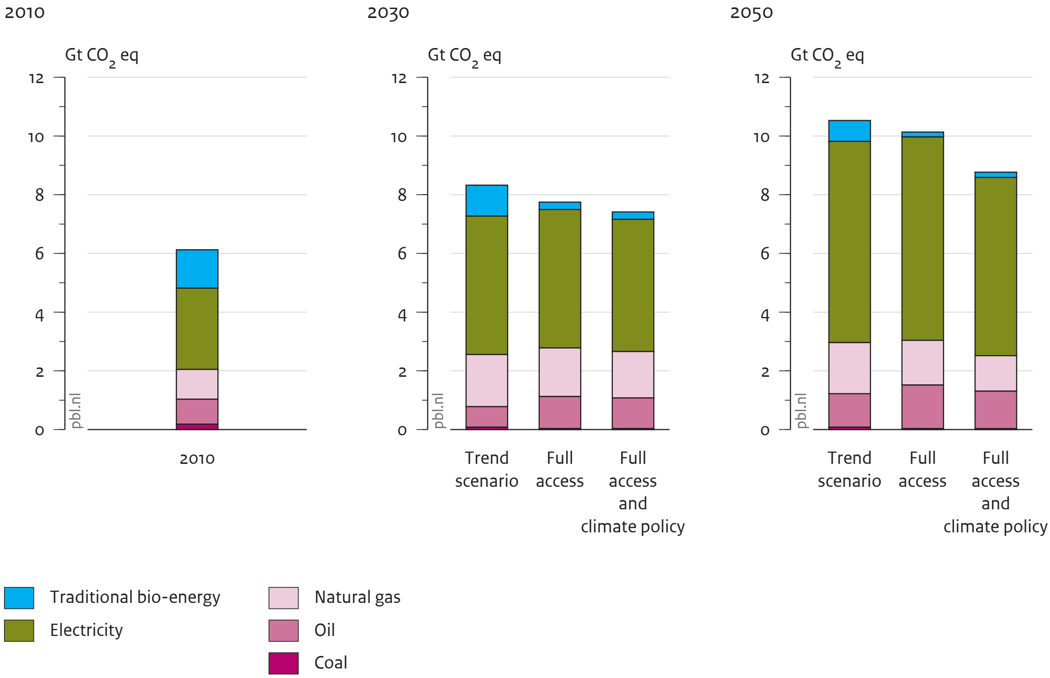


Source: PBL

through centralised grids, decentralised and off-grid or mini-grid options may be more preferable and economical in some rural regions.

A key question refers to the environmental consequences of providing full access to modern energy. Often, the targets of providing access to modern energy and reducing greenhouse gas emissions are portrayed as a trade-off. However, our calculations show that the additional greenhouse gas emissions resulting from full access to modern energy will be around 200 $MtCO_2$ or 3%, by 2030 (Figure 6.6). There are two main reasons for this. First of all, the per-capita energy consumption of the people who gain access through these policies, initially, will be relatively low. Second, modern fuels are much more efficient than traditional biomass for cooking and heating. In addition, emissions from deforestation and, for instance, black carbon emissions also would be reduced. These last impacts are much more uncertain, although the reduction in emissions from deforestation could easily be much larger than 200 $MtCO_2$. The projected resulting small decrease in greenhouse gas emissions is in line with other estimates (GEA, 2012; IEA et al., 2010). Climate policy would further reduce household

Figure 6.6
Global household CO_2 emissions



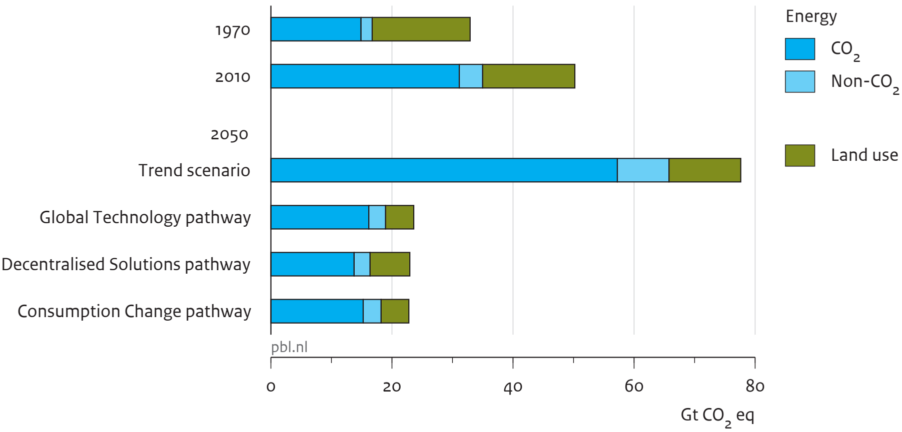
Source: PBL

emissions, mainly due to mitigation actions in the electricity sector (Figure 6.6). However, it is important to note that climate policies that increase fossil-fuel prices to reduce greenhouse gas emissions will make the transition towards modern energy sources and services more difficult for poor households. Therefore, climate policy should be designed to save poor households from carbon policies that interfere with their energy transition.

6.3.3 Climate change mitigation

Greenhouse gas emission reductions
We explored the possible challenges associated with the 2 °C target by introducing a carbon price in our model calculations. Such a carbon price could be implemented in reality, in the form of a carbon tax, or result from an emissions trading scheme. In this report, however, the carbon price is meant as a generic pressure to explore attractive responses to climate policy. Each of the pathways responds to this pressure according to the preferences and technology assumptions described earlier. The same price is also

Figure 6.7
Global greenhouse gas emissions



Source: PBL

applied to emissions from the land-use system. Figure 6.7 presents the energy-related and land-use-related greenhouse gas emissions in the *Trend* scenario and the three pathways for 2050. Although the 2050 level in each of the three pathways is more or less similar, the pathways differ in reductions in the energy and land-use sectors.

Land-use and non-CO_2 emission reductions

Although most greenhouse gas emissions originate from the energy system, land use and land-use change also play an important role. In Chapter 5, we looked at the same pathways in the context of land-use developments. The different land-use patterns described in that chapter have clear implications for greenhouse gas emissions. In particular, the reduction in global agricultural land use in the three pathways would lead to a net carbon storage by 2050. In addition to these structural changes, land-use related emissions are also reduced through specific abatement measures (Lucas et al., 2007). For example, CH_4 emissions from animal husbandry can be partly mitigated through improved stables, different waste handling and the use of different feed.

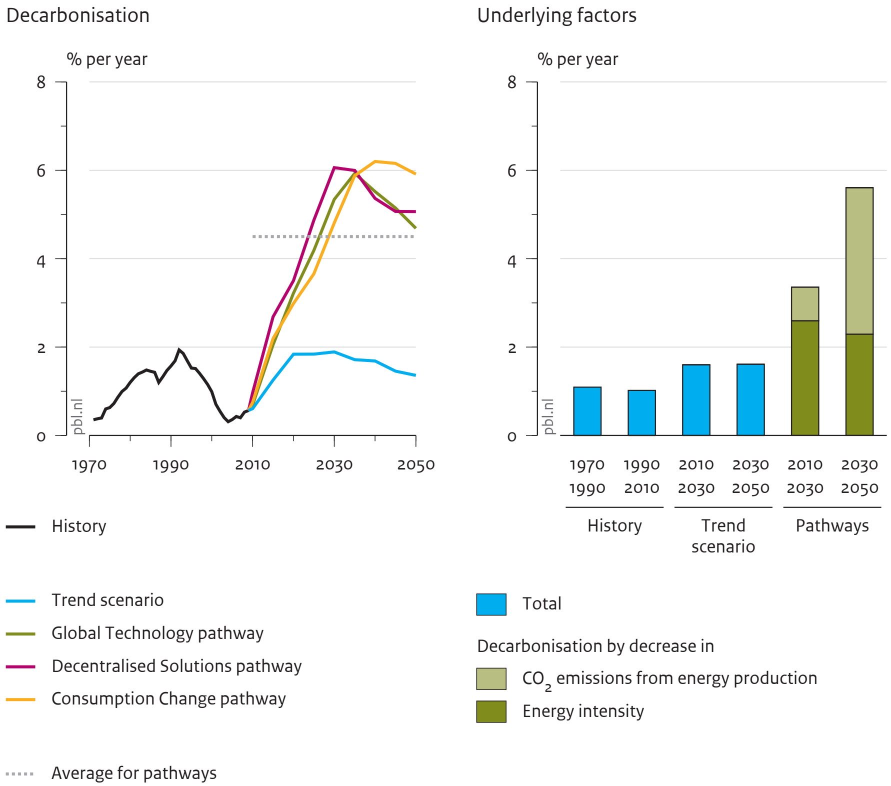
Non-CO_2 emission sources other than agriculture also exist, such as CH_4 emissions from coal mining and natural gas exploitation. Some of these non-CO_2 emissions could be easily mitigated, at relatively low cost. This implies that in cost-optimal climate strategies, initially, a relatively large share of emission reductions would originate from these sources. Over time, however, the abatement potential for non-CO_2 emissions would tend to run out. For instance, it is hard to imagine how CH_4 emissions from freeroaming cattle could be reduced to zero. The same holds for CH_4 emissions from surface mining of coal.

In the pathways, land-use-related emissions would be reduced by more than two thirds from the 2010 level, corresponding to a substantial amount of the total emission reductions. Reductions would be slightly less in the *Decentralised Solutions* pathway, due to a higher deforestation rate (see Chapter 5). Also, the non-CO_2 emission reductions from the energy and industry sectors are reduced substantially (about two thirds of the *Trend* scenarios). However, still the lion´s share of greenhouse gas emission reductions need to come from the CO_2 emission reductions in the energy system.

Energy sector emission reductions
Energy-related CO_2 emissions, as a result, would need to be reduced by about 40% to 50% by 2050, compared to 1990 emission levels. The decarbonisation rate associated with these reductions provides an insight into the challenge that such reductions would pose. This rate is the decrease in the ratio between emissions and GDP. Historically, this rate has been between 1% and 2% per year, driven by energy efficiency improvements and sectoral changes. The high values – 2% per year – occurred during the oil crisis in response to prices and government policies in OECD countries that aimed to conserve energy. For reaching the 2 °C target, the decarbonisation rate would need to be around 4% to 6%, annually (4.5% on average) (Figure 6.8). This level is around three times higher than the values historically achieved over the last forty years.

Key questions, therefore, relate to whether and how such a decarbonisation rate could be achieved. A first indication is provided by further disaggregating the data. Emissions can be mitigated by reducing energy demand (by means of energy efficiency and/or different and lower activity levels) and by changing energy supply (renewables, CCS, nuclear, fuel substitution). These two factors are represented in Figure 6.8 by an annual change in energy intensity (energy per unit GDP) and annual change in the carbon factor (emissions per unit of energy). The energy intensity shows the impact of demand-side measures, while the carbon factor indicates the contribution of energy supply changes. Historically, the energy intensity has improved by around 1% to 1.5% per year. Although relatively high values were observed in the 1980–2000 period, the energy intensity improvement has actually slowed down in recent years, mostly due to trends in China. In the pathways, the improvement (decrease) in energy intensity would reach an annual level of 2.5% to 3.0% in the 2010–2050 period. This is about twice the historical rate. The difference is even greater for the carbon factor. Historically, there has been very little improvement (decrease) in this factor, whereas in the pathways, the annual rate would increase to around 1% to 3.5 %. The changes underlying these pathways are discussed in more detail, below.

Figure 6.8
Global decarbonisation rate



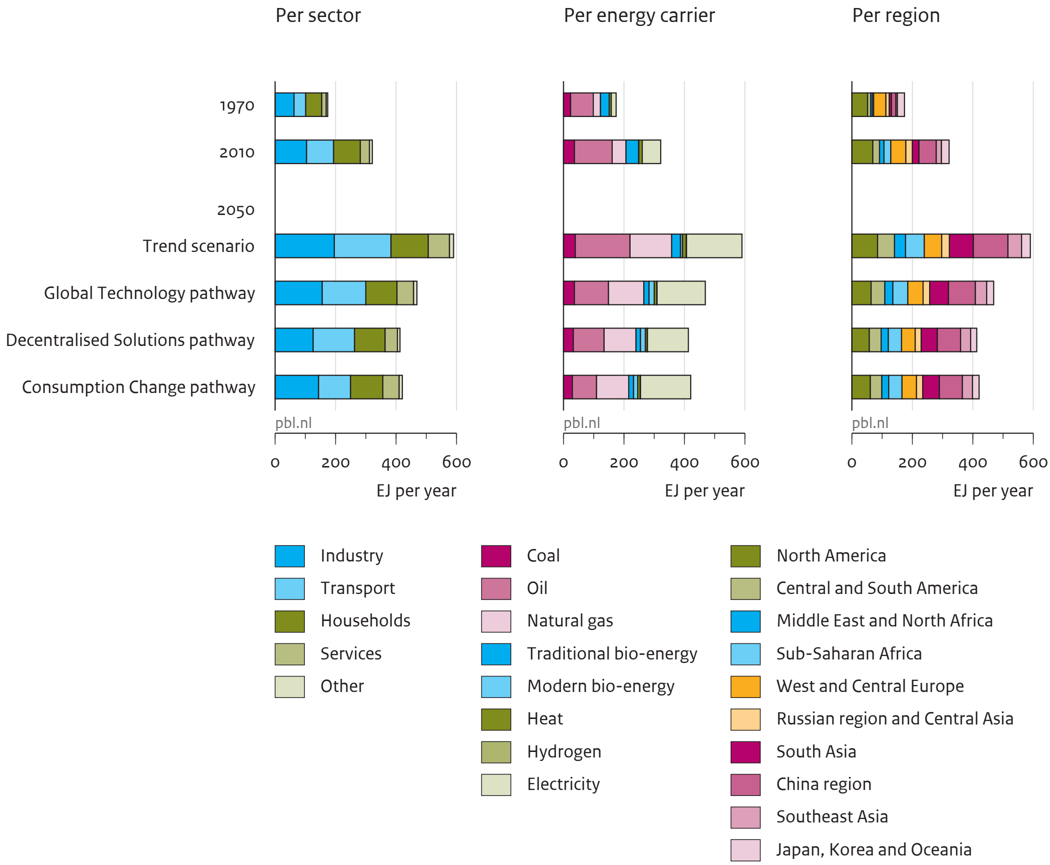
Source: PBL

The graph shows the decrease in the ratio between CO_2 emissions and GDP, referred to as the decarbonisation rate. A positive value thus implies a decrease in emissions. The right panel disaggregates this factor into the change in energy intensity (reduction in energy demand) and change in the carbon factor (change in energy supply emissions).

Demand focus

Figure 6.9 presents the aggregated energy demand for five major end-use sectors, eight energy carriers and ten world regions, in the *Trend* scenario and the different pathways. Final energy demand is dominated by the industry, transport and residential sectors. These three sectors also contribute significantly to the additional energy efficiency improvement required in the pathways. The total reduction in energy demand in the pathways would be about 25%, compared with the situation under the *Trend* scenario. Studies focusing on the potential for energy efficiency tend to find even higher numbers (Graus et al., 2010; Cullen et al., 2011). The *Trend* scenario already shows a transition towards electricity. This trend is important from a mitigation perspective, as, compared

Figure 6.9
Global secondary energy use



Source: PBL

with other sectors, there is greater scope for emission reductions in electricity production. The use of oil and coal is significantly reduced in the pathways and replaced partly by modern biofuels and electricity use. Finally, developing regions are responsible for the largest proportion of the increase in final energy use in the *Trend* scenario as well as the pathways. Furthermore, these regions also make a greater relative contribution to energy reduction, as in general still more potential exists for energy savings. These observations emphasise the importance of developing regions to the mitigation strategy.

Box 6.3 Relationship between diet and climate change

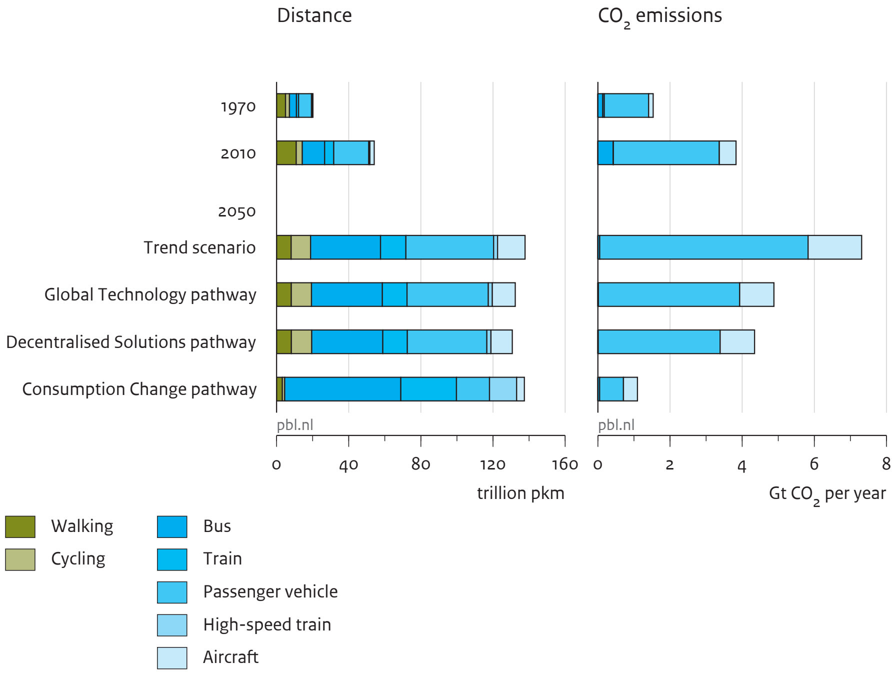
One of the measures included in the *Consumption Change* pathway in Chapter 5 is a shift in diet. Meat production currently uses 80% of the agricultural land, but accounts only for 15% of caloric intake. Reduced meat (or specifically beef) consumption can therefore contribute substantially to decreasing land-use pressure. The same dietary changes would also substantially decrease the greenhouse gas emissions associated with agriculture, partly by reducing the direct methane and nitrous oxide emissions associated with animal husbandry but, more importantly, indirectly through the re-growth of natural vegetation on abandoned agricultural land. Model calculations show that reducing meat consumption in high-income countries to the levels recommended for health reasons could achieve as much as 20% to 30% of the emission reduction required to realise the 2 °C target in the period up to 2050 (Stehfest et al., 2009). A modest reduction in meat consumption would still have a substantial, impact. The decrease in emissions associated with dietary changes would clearly decrease the costs of more traditional measures to reduce greenhouse gas emissions.

Transport sector

The transport sector represents the most rapidly increasing end-use emission source. Important activities within the transport sector driving future emissions are car travel, road freight transport and air travel. There are different responses in the pathways:

- Different technology pathways can be followed to reduce transport emissions: In the *Global Technology* and *Decentralised Solutions* pathways, we mostly look at the impact of a generic increase in the carbon tax (Figure 6.10). The calculations show that it is rather difficult to decrease emissions in the transport sector compared to other sectors. Girod et al. (2012) identified increased bio-energy use as an effective response strategy, assuming low biofuel emissions. However, because in the pathways the use of biofuel has been limited, the impact of bio-energy use is much less. Therefore, it would be important to further develop mitigation options for the transport options. Moreover, governments could consider the use of fuel standards and infrastructure measures, in addition to financial measures.
- In the *Consumption Change* pathway, we assume that people move away from using cars to local electric public transport and fast trains. This would obviously reduce greenhouse gas emissions, although it also partly would lead to an increase in indirect emissions in the power sector. However, such emissions are relatively easy to abate (Figure 6.10).

Figure 6.10
Global transportation



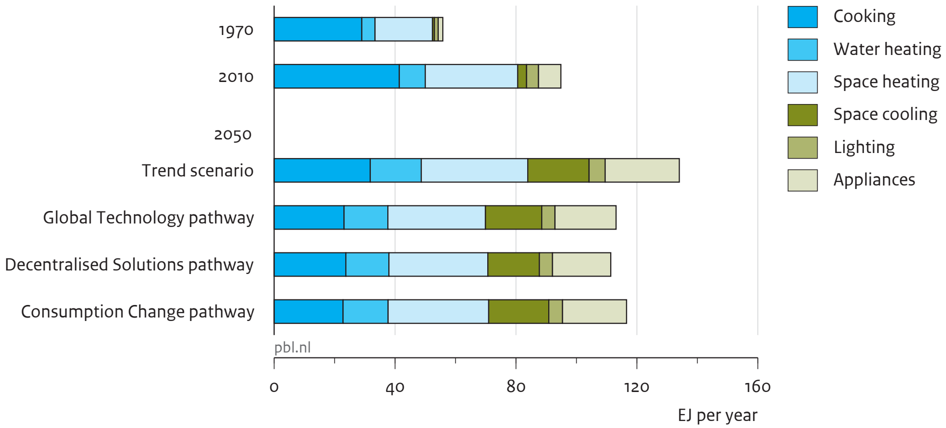
Source: PBL

Transport: breakdown in mode (left) and emissions (right). For the Consumption Change pathway, we explored the impact of rapid modal shift from aeroplanes and cars towards high-speed trains and electric local transport.

Residential sector

Although substantial efficiency improvements exist in the residential sector, historical evidence shows that they are not easy to implement. A challenge to improving the energy efficiency of end-use functions is that energy conservation is often rather expensive if evaluated against the short pay-back time periods usually used by end users. The most important forms of energy use in the residential sector include heating and cooling, appliances and cooking (Figure 6.11). For the first two functions, the use of more efficient equipment (including improved biomass stoves and those on LPG or biogas), but also improving the thermal integrity of houses, can substantially save energy. There is evidence that building standards and equipment standards can effectively implement this potential, possibly combined with financial instruments.

Figure 6.11
Global household energy consumption

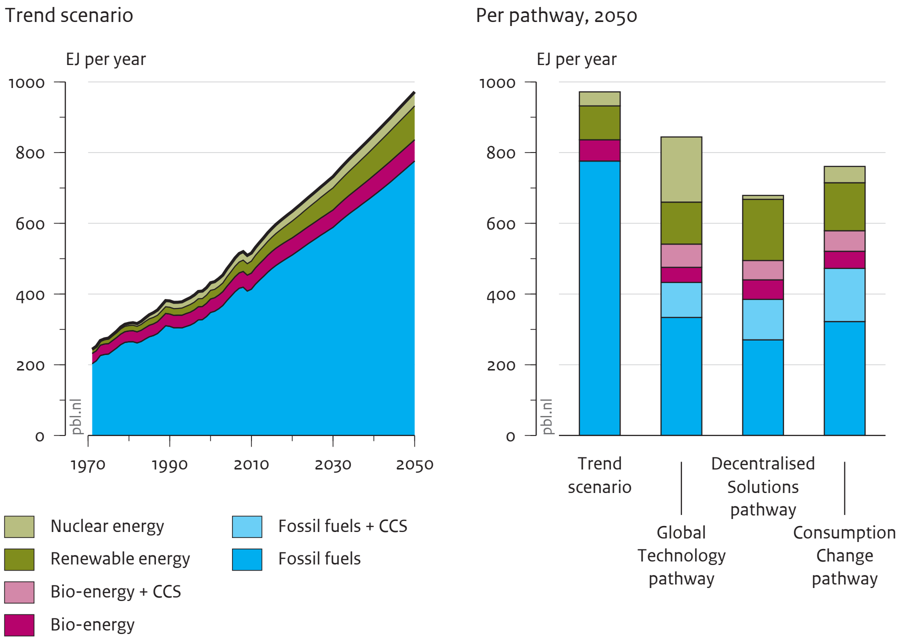


Source: PBL

Supply side focus

A high proportion of the emission reductions would come from supply side changes. Figure 6.12 shows the total primary energy supply for each of the pathways. Table 6.3 compares the results against some of the characteristics of 2 °C scenarios in the literature. Above all, the results show that a fundamental transformation of the energy sector is needed. Although the share of unabated fossil-fuel use is still 80% of total primary energy under the *Trend* scenario, this would need to be around 40% by 2050 in the pathways (Figure 6.12). The rest of the supply would come from bio-energy, other renewables, nuclear energy, and fossil-fuel energy combined with CCS. The results show that there is some degree of freedom in choice of technology. The main difference between the *Decentralised Solutions* and *Global Technology* pathways is the role of renewable energy and nuclear power. These more or less replace each other in these pathways – although they play similar roles in the power system, these roles are played by other technologies.

Figure 6.12
Global primary energy supply



Source: PBL

Primary energy in the Trend scenario and the pathways

Table 6.3
Share of different technology categories, trend versus alternative pathways (%)

	2000	2050							
		Trend			Alternative pathways				
		This report	EMF22		This report			EMF22	
			Avg	Range	GT	CC	DS	Avg.	Range
Fossil fuel	81	80	79	[68–95]	40	42	40	35	[13–48]
Fossil fuel +CCS	0	0	0	[0–0]	12	20	17	20	[0–31]
Bio-energy	9	6	9	[0–13]	13	14	16	15	[0–28]
Nuclear energy	6	4	3	[1–6]	22	6	2	14	[3–37]
Other Renewables	5	10	9	[2–14]	14	18	25	16	[8–24]

Note: GT, CC and DS represent the three pathways considered in this report (Global Technology, Consumption Change and Decentralised Solutions). For comparison, the results of a model comparison study (EMF22) (Clarke et al., 2010) are added for both the Trend scenario and a 2 °C scenario.

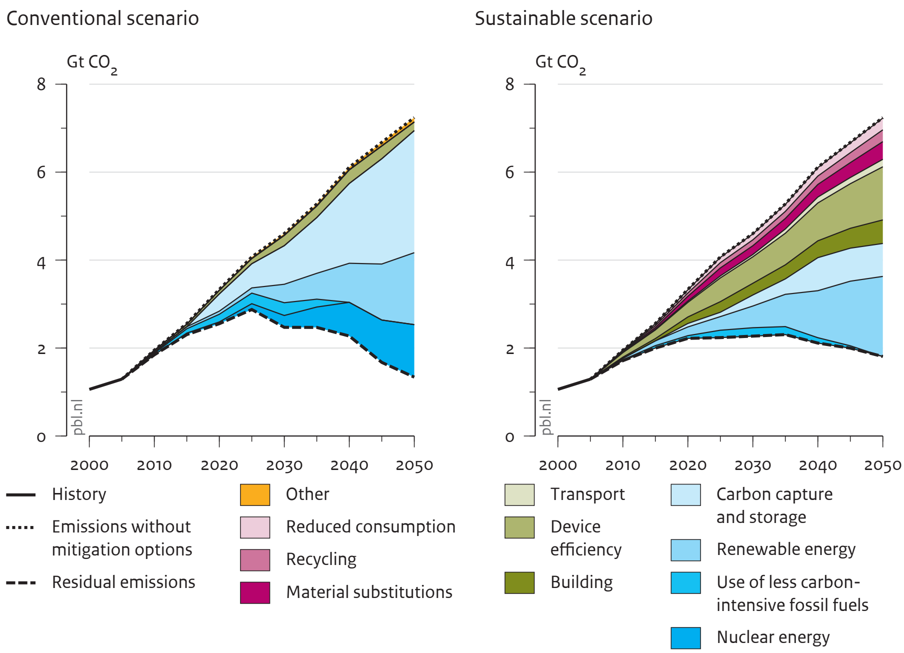
Box 6.4 Aligning national development goals and climate actions: climate agreements in India

The analysis presented here is based on a global analysis. Obviously, strategies will be implemented mostly at lower aggregation levels. For India, Shukla et al. (2011) examined the possibility of achieving multiple sustainable development goals in the energy sector – including reduced greenhouse gas emissions. They contrasted a ´sustainable´ scenario with a more conventional greenhouse gas mitigation scenario (see Figure 6.13).

In a conventional mitigation scenario, a global carbon tax induces a large transformation in the energy system, leading to a large penetration of renewable, nuclear energy and fossil-fuel use with CCS. In the sustainable mitigation scenario, five additional measures are introduced: (1) reduction in population growth, (2) reduction in the use of materials

Figure 6.13

CO_2 emissions and mitigation options for stabilising emissions at 450 ppm CO_2 eq, in India



Source: Shukla et al. (2011)

Conventional and sustainable emission scenarios for India, for stabilising global greenhouse gas emissions at 450 ppm CO_2 eq.

through recycling, material substitution and dematerialisation, (3) sustainable urban planning and efficient infrastructure choices (e.g. investment in public transport), (4) greater regional cooperation, which would help to remove barriers to renewable energy, and (5) greater innovations in technology. These measures already lead to a reduction of about two-thirds of the total emission reduction required for the 2 °C target. The required carbon tax to achieve the remaining reductions would therefore be much lower than in the conventional case.

The analysis led to the conclusion that, for India, it would be possible to match domestic development goals and climate mitigation. Win-win options exist and co-benefits – in terms of energy security and local pollution – are important. Specific climate policy would still be needed, but with a considerably lower carbon price. Therefore, shifting negotiations away from the current climate-centric focus towards development may lead to more co-benefits and therefore greater support.

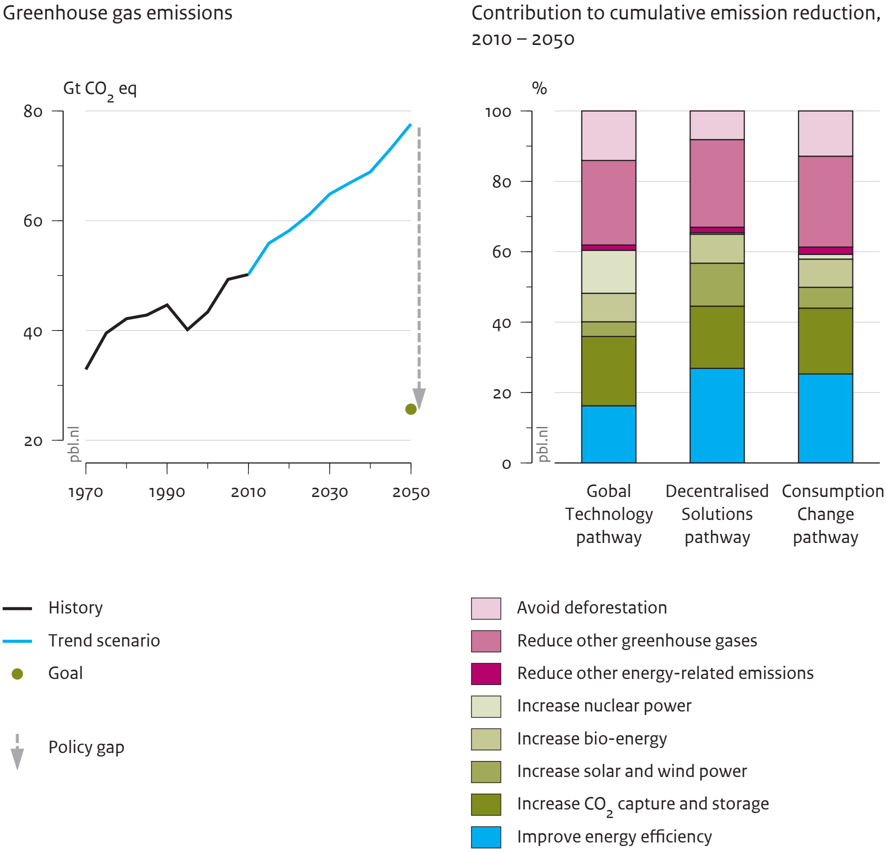
All measures together

Figure 6.14 provides an overview of the measures taken in each of the pathways for reducing greenhouse gas emissions. The scenarios rely on different combinations of measures as discussed in the sections above. The results imply that a broad portfolio of measures is implemented in each pathway. There are both advantages and disadvantages to this situation. Although a broad portfolio implies that a strategy does not depend on the success of a single technology, it also implies that the transition – as well as, for instance, the associated R&D effort – cannot be highly targeted.

6.3.4 Inertia in energy capacity expansion

Inertia plays a critical role in the energy system. This is shown in Figure 6.15 by depicting how the global power sector evolves under the three pathways. The figure shows that existing infrastructure and new infrastructure play an important role in the 2010–2050 period. Only by 2050 will most of the current infrastructure be replaced. Taking this one step futher: if the emissions related to the existing capacity would be added to those associated with the capacity still to be built in the coming five to ten years, the emission budget for the 2010–2050 period would already be largely 'filled'. Decisions taken over the next 10 years, thus, are important for the situation in 2050. In all the pathways, coal plants without CCS are reduced in the 2012–2020 period and after 2020 no new coal plants without CCS are built. For natural gas, construction is halved compared to the *Trend* scenario until 2035, after which no unabated natural gas plants are built. In terms of new capacity, renewable energy and CCS plants play a major role in the pathways, as shown in the right-hand graph. Nuclear power can also be part of the pathway, as illustrated for the *Global Technology* pathway, but is nearly absent in the *Decentralised Solutions* pathway. It should also be noted that in the pathways, CCS plants would already be built from 2020 onwards – implying that it is important to focus on learning

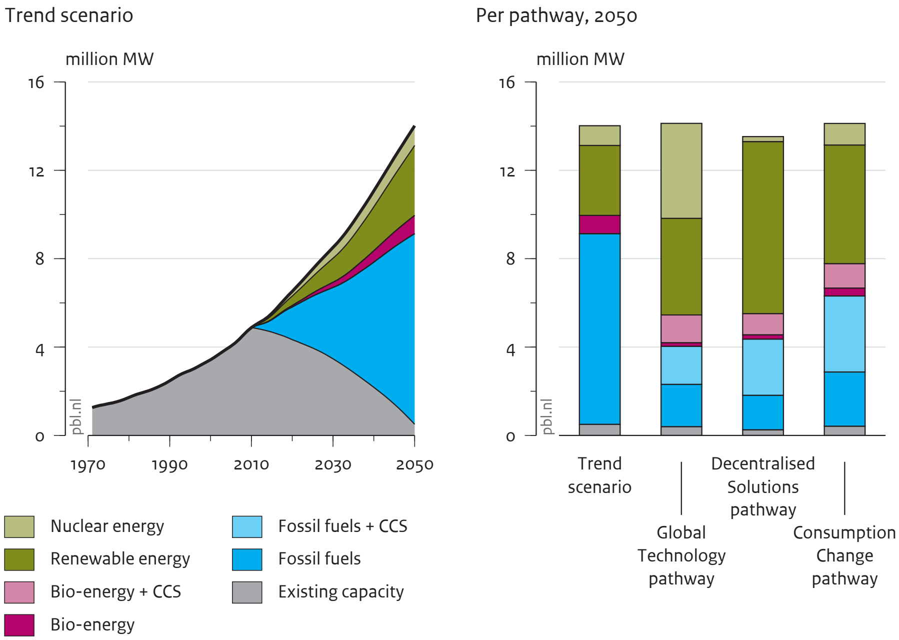
Figure 6.14
Global greenhouse gas emissions and options to reduce emissions



Source: PBL

today. Although all our scenarios show a high contribution by CCS, in principle, here it would also be possible to substitute CCS technology with available alternatives. In all pathways, the electric power sector would be fully decarbonised by 2050. This also makes a further push for the electrification of end-use sectors an attrative option.

Figure 6.15
Global capacity of the power sector



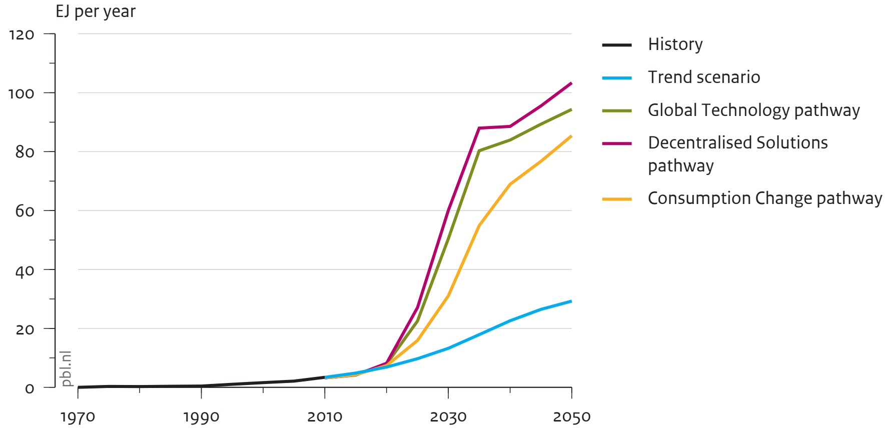
Source: PBL

6.3.5 Constraints in technology deployment

The pathways depict a major shift in the technology portfolio. Clearly, there are advantages and disadvantages to each of the alternative options. Although CCS plays a key role in most pathways due to the relative ease with which this technology can be implemented in the power system, it should be noted that this technology is still very uncertain. Many studies identify the combination of CCS and bio-energy (BECCS) as a key technology for the long term, given the fact that this may result in negative emissions – bio-energy to sequestrate CO_2 from the air and CCS to store it underground. These negative emissions allow the postponement of some of the rapid emission reductions over the 2020–2030 period that would otherwise be required. However, the use of BECCS depends on constraints with respect to CCS and bio-energy.

In this study, we constrained bio-energy by not allowing its production in areas that already suffer from water scarcity or major land degradation. Furthermore, we also did not allow bio-energy production to take place in current nature areas. This implies that almost half the supply would come from residues, while bio-energy from crops would all be second-generation production in former agriculture areas (see also Chapter 5). Still, total bio-energy use would increase to around 100 EJ by 2050 in the pathways, in

Figure 6.16
Global bio-energy use

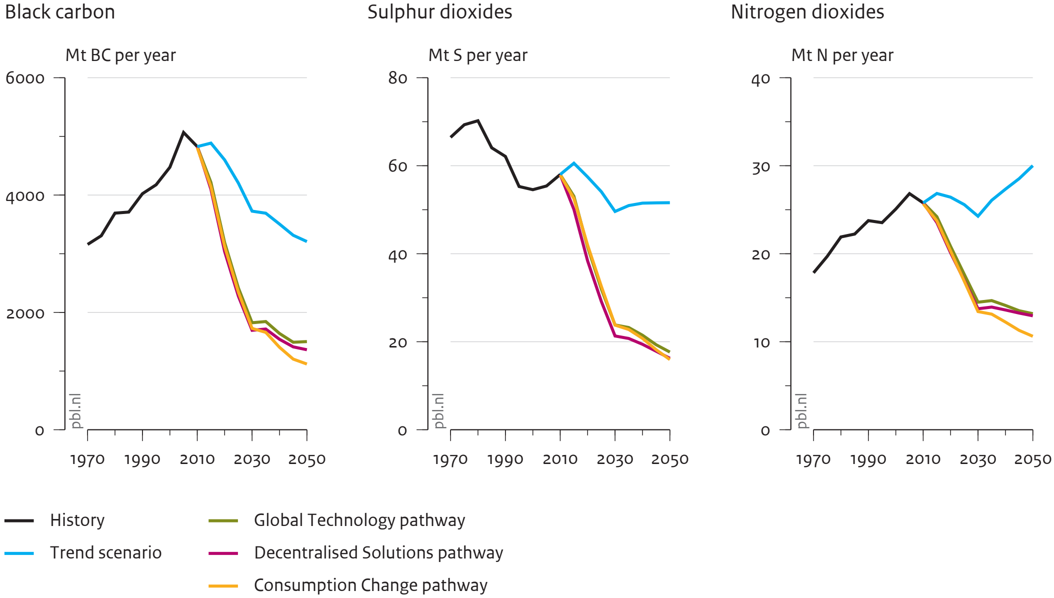


Source: PBL

contrast to 30 EJ used in the *Trend* scenario (Figure 6.16). As a result of subsidising modern fuels for cooking and heating and providing improved biomass stoves, the use of traditional bio-energy would be significantly reduced. As currently around 40% of all the traditional bio-energy is harvested from deforestation (the remainder comes from other sources, such as crop residues, cow dung and wood gathering), a reduction in such traditional bio-energy would also significantly reduce land-use emissions.

In two of the three pathways, a substantial part of the supply also comes from nuclear power. Here too, current problems with respect to safety, proliferation risks and the used fuel disposal and storage need to be overcome. Renewables also have limitations, for example, in the case of bio-energy with respect to land use. However, they can reduce greenhouse gas emissions, improve energy security and offer both centralised and off-site energy conversion. Most renewables, however, are also intermittent and require storage or back-up capacities (usually natural gas or hydropower). Renewable technologies also tend to have high up-front capital costs. And while all energy can theoretically be produced from renewable sources, there are large economic and infrastructural constraints to achieving this. Debate is still ongoing regarding how constraining these are. It seems that, if substantial investment is made in grid improvements, this barrier can be overcome – as shown in various technical studies (De Jonghe et al., 2011; Denholm and Hand, 2011; Teske et al., 2010).

Figure 6.17
Global emissions of air pollutants



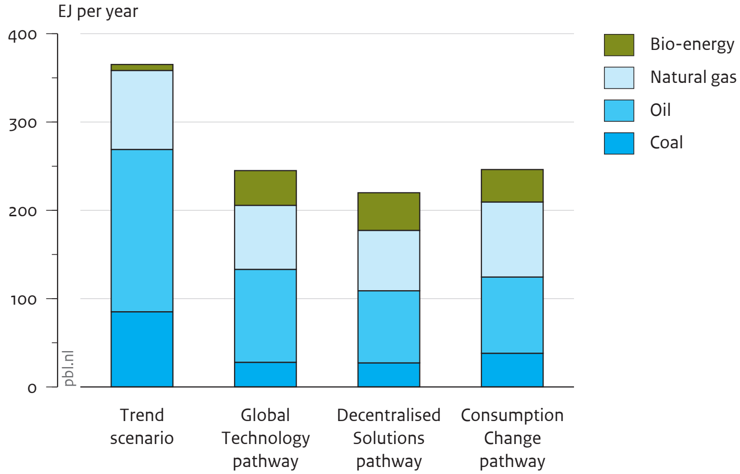
Source: PBL

6.3.6 Emissions of air pollutants

Fuel combustion is currently responsible for a large proportion of the five million premature deaths each year from air pollution and for more than 8 % of all ill health (lost healthy life years from both morbidity and premature mortality (Smith et al., 2012)). In the *Trend* scenario emissions of air pollutants stay globally at high levels. In the pathways, in contrast, emissions are reduced worldwide to meet the WHO guidelines. A substantial part of the emission reductions in fact occur as co-benefits of the changes in the energy system induced by climate policy: many of the technologies that reduce greenhouse gas emissions also have low emissions of air pollutants. Although these reductions are substantial, they are not enough to meet the WHO guidelines everywhere. In other words, further reductions are required. These emission reductions come from prescribing further reduction by using end-of-pipe abatement technology. As a result, emissions are reduced as shown in Figure 6.17. Earlier experiences in OECD countries have shown that such measures can be implemented on the basis of integrated consideration of benefits (health improvements; increased crop yields) versus costs.

Figure 6.18

Global energy trade, 2050



Source: PBL

6.3.7 Energy security consequences

Energy security relates to the uninterrupted provision of vital energy services, which has a high priority in many countries. The notion is strongly context-dependent. For many countries, energy security is related to import dependency and thus directly depends on the availability of domestic resources. For other countries, energy security might also be related to insufficient capacity and rapid growth in demand. Most energy security concerns are related to oil, given its importance in the current transport system and the geographical concentration of resources. In addition, production capacities are limited, resulting in price volatilities affecting especially low-income countries. Supply concerns related to natural gas are mostly regional. As the *Trend* scenario leads to a strong increase in fossil-fuel consumption, the increased dependency also increases energy security concerns, particularly in energy resource-poor regions in Asia.

The calculations show that climate policy significantly improves energy security for most fossil-fuel importing regions due to decreased import dependency on fossil fuels (Figure 6.18). This is, for instance, the case for Europe, China, South Asia and Central and South America. However, in some regions the effect of reduced fossil-fuel imports is partly offset by increased imports of biofuels. Obviously, energy exporting regions see the other side of the coin here as their revenues from fossil fuel export decrease. However, South America, Russia and West Africa may offset their losses through increased revenues from biofuel production.

6.4 Managing the energy transition: key issues for the coming ten years

The previous section outlined three different pathways that would all achieve the energy-related goals described in Chapter 2. An important conclusion from these pathways is that, while it seems technically possible to achieve the goals, the required effort would be substantial – also from a historical perspective. In that light, some of the consequences of these pathways are discussed below in terms of governance challenges. First of all, it should be noted that each of the three pathways would require a different governance approach:

- A focus on global technology, with a preference for large-scale technological options, requires large investments in RD&D as well as large investments in the implementation phase of technologies. Such investments only seem possible as a result of governmental intervention or through public-private cooperation. In either case, a tendency towards top-down approaches seems implied.
- A focus on decentralised solutions would imply first-mover action by local communities and firms. Initial investments in the implementation phase would be smaller than in the *Global Technology* pathway, although investments in RD&D might still be substantial before implementation would become possible. Hence, the tendency of governance approaches in this case would focus on bottom-up initiatives.
- A bottom-up governance focus is also implied in the *Consumption Change* pathway, where action would focus on voluntary lifestyle changes. However, if these actions would prove to be insufficient to achieve the goals, top-down governmental intervention would still be necessary – starting with information and persuasion, and turning to financial incentives or direct regulation where required.

However, the pathways also show that it might be attractive to combine them, as this would further increase the portfolio of options and could help achieve the substantial changes. In this light, it is important to note that in all three pathways there are also a number of key issues that stand out in the next ten years for meeting the long-term energy challenge. These issues should address the barriers that were identified in Section 6.2. To take into account the multi-level policy strategy that will be required for the next ten years, the main target audience is also mentioned for each of the following recommendations.

6.4.1 Remove policy inconsistencies and aim to reap the benefits of integrated policy-making

In Section 6.2 we identified competing interests and a lack of policy coherence as an important barrier to achieving more progress in the past. In that context it is important to note that the approach of taking a long-term, integrative vision as starting point can help in the formulation of more coherent policies. Clearly, policy coherence is relatively easy to achieve where synergies are possible. Table 6.4 provides an indication of important linkages that exist in achieving different long-term goals. As short-term goals

Table 6.4
Interactions between measures to promote sustainable energy

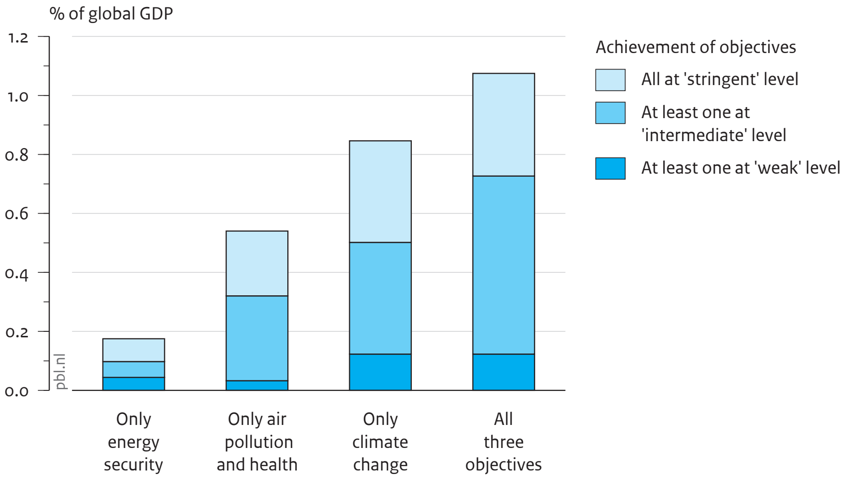
	Climate change	Air pollution	Energy security	Energy access
Climate change		Often positive - for example, less use of fossil fuels due to energy savings and renewable energy use. Exception, some local biomass applications (NO_x and emissions of Particulate matter)	Often positive - (especially with stringent 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 and cooking and heating 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
Energy security	Negative - use of coal and exploitation of unconventional oil and gas sources; positive for reneable energy	Possibly negative - use of coal, less use of clean fossil fuels; positive - renewable energy		No significant effect
Energy access	Limited negative if electrification is based on fossil fuels; neutral/ positive if based on renewable energy. Positive for cooking and heating due to efficiency gain	Positive for indoor air pollution; For electrification 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 sources	

Box 6.6 Examples of the benefits of integrated policy-making

Recent analysis using the IIASA MESSAGE model provides an excellent illustration of how an integrated approach to energy policy and planning would reduce the combined costs of energy access, climate change mitigation, energy security and air pollution control (Riahi et al., 2012). Figure 6.19 shows the sum of required investments for resolving three energy-related global challenges independently of each other – mitigating climate change, reducing pollution and increasing energy security (first three bars). The total sum of the investments for reaching the individual targets is much larger than that of an integrated policy approach to achieve the same three targets simultaneously (last bar). This is because many of the measures required to reach the climate target (by itself the most expensive goal) also help reduce the energy intensity and air pollution problems.

Policy costs for single-issue policy approaches to deal with climate, pollution and energy security (first three bars) compared with the policy costs required for an integrated policy approach achieving the same targets (last bar). Integrated policy approaches that target all objectives, simultaneously, benefit from synergistic effects and achieve the targets more cost-effectively. Stringency of the policies varies from 'low' (dark blue) to 'stringent' (light blue). Policy costs represent the net financial requirements (energy-system and pollution-control investments, over and above a *Trend* scenario energy-system development.

Figure 6.19
Global costs for energy-related policies, 2010 – 2030



Source: Riahi et al. (2012)

also play a role (see Section 6.2), there is a need to discuss publicly at the national scale how the competitiveness of national energy-intensive industries in the short term can be combined in an optimal way with sustainability, innovation and transition in the long term. Energy policy coherence would also require finding a balance between the 'private' and 'global public' aspects of the global energy system (Slingerland and Kok, 2011). Energy-efficiency measures could, for instance, contribute to multiple targets including climate, air pollution and energy security. The removal of harmful subsidies is another example where possible multiple benefits can be obtained. In other cases, trade-offs between policy targets exist that have to be dealt with in a transparent way vis-à-vis the long-term vision. Box 6.6 shows how an integrated approach can lead to cost reductions.

6.4.2 For the 2 °C target to be achieved, global emissions need to peak soon

In the previous section, we discussed the strategies towards the 2050 targets. Obviously, a key question refers to what these pathways imply for the actions to be taken towards 2020. On the basis of the analysis, the following suggestions were made:

- Start decarbonising the economy early. As discussed in Box 6.7, if no action on climate policy is taken in the next eight years, the 2 °C target might become unachievable. Although it may not be necessary to reduce emissions at the same rate as later in the century (given current policy inertia), emission reduction would still need to be in the order of the Copenhagen Pledges.

Box 6.7 2020 Copenhagen pledges in a long-term perspective

The Cancún Agreements (UNFCCC, 2010) mentioned both the need for urgent action to limit global warming to 2 °C and the short-term emission reductions based on voluntary pledges made by developed and developing countries for 2020. This raises the question of whether these pledges are consistent with the long-term objective. This question is not easy to answer. The level of global emissions for 2020 that will be needed to limit global warming to 2 °C strongly depends on assessments of the short-term emission reduction rate (limited by policy inertia), the performance of technology later in the century (and in particular BECCS), the degree of probability of exceeding the climate target and the costs of reducing emissions (see Van Vuuren and Riahi, 2011). To date, analyses usually concentrated on scenarios in which all countries participate in climate policy. In such a situation, in order to have a likely chance of staying below 2 °C, most models agree that emissions need to be reduced to between 39 and 46 $GtCO_2$ eq, by 2020. This is considerably lower than the projected business-as-usual emission level of about 56 $GtCO_2$ eq, but also significantly below the estimated emission levels from the Copenhagen Pledges (51–52 $GtCO_2$ eq). However, new analysis has shown that it is probably still possible to reach 2 °C scenarios from emissions around that level, but at higher costs compared with the optimal (lower) trajectories (OECD, 2012).

- Reduce unsustainable action. In each of the challenge pathways, the introduction of coal-based fossil fuel plants without CCS is already heavily reduced in the 2012–2020 period, and after 2020 no new plants without CCS are built. For natural gas, construction is halved compared to the *Trend* scenario until 2035, after which no unabated natural gas plants are built. Real world implementation would need to be consistent with these actions. Targets for efficiency and renewable energy may also be derived from the scenarios in this and other studies.
- Build confidence. Above all, it is important in the next few years to build up sufficient confidence that achieving the long-term targets is possible, even if the reductions themselves are only small. If actors and countries see that emission reduction strategies are indeed implemented successfully, possibly as co-benefits of other policies, and if there is sufficient confidence that different interests are taken seriously, internationally binding targets can be negotiated more easily.

6.4.3 For international climate policy, seek progress based on pragmatic approaches

The level of effort required to realise the climate challenge is very large, and the need for transformative change clear. This calls for fundamental policy change, but this has been hard to achieve so far. It might therefore be useful to realise that small steps in the right direction are also helpful. At the international level, this approach implies that action should not only focus on building a top-down multilateral framework, but it should also work on stimulating and connecting bottom-up initiatives for energy transition at national, business and civil society levels. Such alternative routes have flourished in the climate field in recent years, and there seem various ways to use these routes to build greater societal support for climate policies, varying from linking coalitions of the willing to stimulating other policies that have greenhouse gas emission reductions as a co-benefit (Slingerland et al., 2011).

Further, it also means to stress the importance of policy learning (e.g. Henry, 2009; Voss et al., 2009). Often mentioned in this respect are dynamic standards, such as the Euro standard for emissions from cars, or the Japanese Top Runner programme for the energy efficiency of electric appliances. The German feed-in tariff for renewable energies into the electrical grid can also be regarded as such a dynamic standard (Del Río, 2012). The key element is to put in place a system whereby the long-term vision is trusted sufficiently as a guiding star to trigger innovation, while sufficient freedom is given in terms of short-term measures.

6.4.4 Consider policies that address energy-intensive consumption patterns

Energy efficiency has much potential and can lead to the simultaneous achievement of multiple targets. However, the potential for energy efficiency measures is still not fully exploited. Some of the reasons for this were given in Section 6.2. Specific policy instruments, both financial and regulatory, might make it more likely that efficiency measures are implemented. As well as efficiency measures, however, low-energy lifestyles also offer an interesting potential for change. The analysis has shown that stimulating diet changes, increasing the use of public transport and reducing the use of heating and cooling can all be effective in reducing emissions. In the past, however, voluntary approaches to promote lifestyle changes have shown at best mixed success (e.g. Abrahamse et al., 2005). Furthermore, people in emerging economies and developing countries seem to follow a similar pathway, resulting in a global consumer class. Given the reluctance of governments to promote lifestyle changes, such initiatives will first come from civil society and business. Communication about such 'best practices', possibly together with financial incentives or even direct regulation, would therefore at this moment seem an appropriate way for authorities to deal with behavioural changes. Fortunately, such best practices can be found in many places and in many forms (e.g. Transition Network, 2011; Ulvila and Pasanen, 2009). The challenge will be to connect these initiatives to sensible regional and global networks that also receive societal support for an energy transition on a larger scale.

6.4.5 Arrange public and private financing for energy transition infrastructures

Sustaining the energy system requires huge sums of money, even without meeting any of the sustainable development targets. Even under the *Trend* scenario, the world would need to spend around USD 50 to 100 trillion in the 2010–2050 period to meet global energy demand, or about 3% of the cumulative GDP over this period (Table 6.5) (Van van Vuuren et al., 2009b (IEA, 2008; Rao, 2009; Riahi et al., 2012); Rao, 2009; IEA, 2008; Riahi et al., 2012). On energy supply, several studies indicate that investment would be around USD 50 trillion in the 2010–2050 period (amounts of some studies have been extrapolated). Expenditures on the demand side (equipment for energy transformation and efficiency) are more difficult to determine because of system boundaries, but are estimated to be at least of the same order of magnitude. The Global Energy Assessment estimates current annual demand-side investments to be around USD 100 to 700 billion (GEA, 2012). Scaling this number with changes in energy demand, the expected total energy expenditure would be around USD 60 to 100 trillion, over the 2010–2050 period.

The transition towards achieving objectives for climate change and air pollution control would require a shift in existing investments, but also considerable additional investments. Based on information on abatement costs, the IPCC has published estimates of additional annual expenditures on climate policy measures for reaching low greenhouse gas concentration levels of USD 20 to 70 trillion, for the period up to 2030, which would amount to around 0.5% to 2% of cumulative GDP (IPCC, 2007a). The Global Energy Assessment more recently estimated the total costs of meeting the climate, air pollution and energy security targets at between USD 68 and 84 trillion (GEA, 2012). Other studies show similar orders of magnitude with equally large ranges (Table 6.4). Together, global costs are likely to be around USD 25 to 85 trillion, or, on average, around 1.5% of cumulative world GDP. Thus, climate policy would lead to an increase in the aggregate investment in the energy sector of around 50%, compared with the situation under the *Trend* scenario.

Table 6.5
Present value of energy and climate costs to 2050

	Cumulative investments 2010-2050 (trillion USd)	Cumulative investments 2010-2050 (trillion USD)	Annual investments (billion USD)
***Trend* scenario**	IEA (2011): 38[a,b] GEA (2012): 50 - 90[c] Other literature: 120	60-100	1600-2500
Combined climate policy, energy security and air pollution (additional)	IEA (2011): 15.2 - 4.6[a,d] IMAGE-studies: 25 - 80[d] GEA (2012): 68 - 84 Stern (2007): -10 - +50[d] IPCC (2007): 20-70[d,e]	25-80	600-1940
Access to modern energy	IEA (2011): 1[e] IMAGE: 1.4[e] Bazilian (2010): 0.2 – 2.8 Literature: 0.2 – 0.8[e]	0.6-1.4[e]	30-70[e]
Adaptation to climate change	UNFCCC: 2.0-6.8	2.0-6.8	50-170

[a] 2010-2035; [b] supply side only; [c] Based on current investments and increase in energy consumption; [d] climate policy only; [e] 2010-2030.

The costs of achieving other targets are lower. Annual investments required for reaching the 2030 targets for electrification and modern fuel use for cooking and heating in South and Pacific Asia and sub-Saharan Africa are estimated at an annual USD 7 to 38 billion (GEA, 2012), with around 50% for electrification and 50% for modern fuels for cooking and heating. Bazilian et al. (2010) published a larger, global, annual range of USD 10 to 140 billion, including fuel costs for electricity production, operation and maintenance. The higher end of the range is mainly the result of higher cost estimates for providing full access to electricity. For adaptation, the UNFCCC (2007) estimated that annual funding would need to be in the range of USD 50 to 170 billion. The more recent study of Parry et al. (2009) confirms these numbers. Because of the large investments required, private and institutional investors are increasingly often sought to complement the funds for infrastructures provided by public authorities .

Clearly, the above figures mostly require a significant re-direction of investments. Most of the additional aggregate investments would be in energy efficiency. Although in energy supply there would be a shift towards more capital-intensive options, this effect is – at least partly – offset by reduced energy demand. The macroeconomic impacts of the changes in investments are even more uncertain. Many studies show a limited reduction in economic growth (see IPCC, 2007a; Stern, 2006). Limited by insufficient 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, 2007a). Lower losses (2–3 %) would be conceivable if greater technological progress is taken into account (Knopf et al., 2009). However, economic costs are not equally distributed. Costs are higher in countries with

Box 6.8 R&D and infrastructure investments are a bridge to the future
For new energy technologies to emerge, research and development is first required. Research budgets for such new technologies have long been in decline, not only in the public sector but also in the private sector, certainly relative to the total volume of the energy sector. Recently, however, there is some evidence that this trend has been reversed. Nevertheless, investments in R&D in the energy sector seem to remain low compared to other sectors. To ensure the sustainable development targets are met in the future, it is important that R&D investments are increased. Just as important as investment into R&D are investments in infrastructure. It should be noted that, in particular for renewable energy use, investment in the physical infrastructures is required. Carbon capture and storage, hydrogen, electrical cars, offshore wind parks, concentrated solar power: they all require either completely new physical infrastructures or the significant expansion and adaption of existing electrical power grids. This includes making the infrastructures 'smart', that is, adaptable to the intermittent nature of many new renewable energy sources.

a high carbon intensity and in energy-exporting countries. The recent attention paid to the Green Economy emphasises that, under the *Trend* scenario, large costs are also made to adapt to environmental degradation that are not accounted for in most studies. Moreover, the Green Economy literature also emphasises the economic benefits of increased R&D levels and the opportunities for specific sectors.

It is important to note that a substantial share will have to be spent in developing countries – both for climate adaptation and climate mitigation. This presents a challenge in itself. Clearly, the existing pledge of rich countries (Copenhagen Accords)to provide developing countries with USD 100 billion a year is much lower than what would be needed by developing countries for adaptation and mitigation. Cantore et al. (2009) estimates that an equivalent of 50 % of the current Official Development Assistance (ODA) spending for some SIDS (Small Islands Developing States) will be needed to cover just adaptation costs to protect coastal zones. Brown et al. (2010) also show that the current flows of ODA would not be sufficient to cover the funding needs for MDGs and climate change adaptation, therefore additional finance for climate change is required.

Most of the finance actually needs to come from within individual countries. However, for the least developed countries the situation is clearly different. People have been discussing different ways of raising finance for developing countries. Brown et al. (2010), for instance, summarise some alternative tools to raise climate finance including the use of finance raised by the auctioning of assigned amounts, the revenues of a global tax, the levies on air travel and maritime transport emissions and carbon market levies. Other studies, such as Cantore et al. (2009) and the Report of the Secretary-General's High Level Advisory Group on Climate Change Financing (AGF, 2010) also suggest similar measures. In fact, if sufficient finance is raised, this can also be used to stimulate development.

SEVEN

Relationships with water, nutrients and human health

The challenges for food and biodiversity as well as for energy and climate are not only related to each other, but also to other sustainable development issues, such as water scarcity, imbalances in the Earth's nutrient cycles, and human health loss. Here, the implications of our pathways for these issues are discussed, followed by a brief consideration of the effectiveness of additional measures.

7.1 Reducing water scarcity

7.1.1 Physical and economic water scarcity

Freshwater plays an indispensable role in sustaining various aspects of human life. This includes drinking water as well as water for food preparation, personal hygiene, cleaning and other purposes in households. Furthermore, vast amounts are used to irrigate agricultural lands with a precipitation deficit, and in many industrial processes for washing, blending, dissolving and other purposes. Relatively small amounts are needed for livestock operations. Finally, large water flows are used as coolant in thermal electric power plants and in many industrial processes.

On a global scale, the renewable volume of available fresh water (the average annual amount of surface water and shallow groundwater), far exceeds the current extraction for human use. However, its uneven geographical distribution and patterns of human activity mean that many regions are seriously affected by an imbalance in the availability and withdrawal of water. This imbalance may lead to water shortages. The severity of such shortages can be expressed in different ways – in absolute terms, such as litres per capita, per year, or in relative terms, such as physical and economic water scarcity, and the water stress index.

According to the Comprehensive Assessment of Water Management in Agriculture (2007), more than 1.2 billion people – a fifth of the world's population – currently live in areas of physical water scarcity, while a further 1.6 billion people live in areas of economic water scarcity, where the lack of investment in water makes it impossible to meet the demand, including that for drinking water, sanitation and irrigation facilities. Water stress can be further aggravated by water pollution from different sources that may reduce the application of available water for various purposes, most critically for drinking water. The lack of access to safe drinking water and basic sanitation is associated with considerable health impacts, primarily through diarrhoea (see also Section 7.3). The number of people living under water stress is increasing. In the model-based analysis made for this report, the number of people living under severe water stress in 2000 amounted to 1.9 billion, or 30% of the global population. This is not to say that all inhabitants of these river basins are confronted with acute or sustained shortages. Proper management, including hardware such as reservoirs and long-distance pipelines, and software such as water demand-regulating policies, can alleviate many of the potential scarcity problems. On top of this, in 2010 more than 800 million people still lacked access to safe drinking water and 2.6 billion people lacked access to basic sanitation (UNICEF and WHO, 2012).

The JPoI Paragraph 26(c) calls for an 'efficient and well-balanced use of freshwater resources' as well as for 'safeguarding drinking water quality'. We translated these goals to 'reduce the number of people living in water-scarce areas compared with the *Trend* scenario' (see Chapter 2). The pathways are extended with stringent efficiency measures in the different water-use sectors. Water scarcity is expressed as the ratio between demand and availability, referred to as the water scarcity index or the degree of water stress (the degree of water stress is broken down into four categories: no (less than 10%), low (10–20%), medium (20–40%) and severe (over 40%) water stress). Ensuring access to safe drinking water and basic sanitation is one of the Millennium Development Goals (to halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation). We extended this target to 'further halve this number of people by 2030 and to ensure full access by 2050' (see Chapter 2). We therefore also addressed the required effort of providing full access to safe drinking water and basic sanitation by 2050.

7.1.2 Future trends in water scarcity

Important drivers of physical water scarcity include increasing demand and decreasing supply due to land-use change and climate change

Important drivers of water scarcity are increasing water demand for households, the energy sector, industry and agriculture, and changes in water supply due to land-cover and land-use change and climate change. Historically, water consumption has increased rapidly – driven by the population increase and activity increases in each of the water-demanding sectors. It is worth noting that not all water withdrawn from rivers, natural lakes, reservoirs and groundwater bodies is for consumptive use. For example, cooling water used in electric power plants returns almost entirely to the river from which it was taken. However, it re-enters the river at an elevated temperature, affecting the water quality and the usability further downstream. It is also worth noting that in many parts of the world, water cannot be supplied from renewable resources but is withdrawn from deep groundwater reservoirs, sometimes formed many millennia earlier and not, or only very slowly, refilled by infiltration. Such supplies are not considered to contribute to renewable water availability.

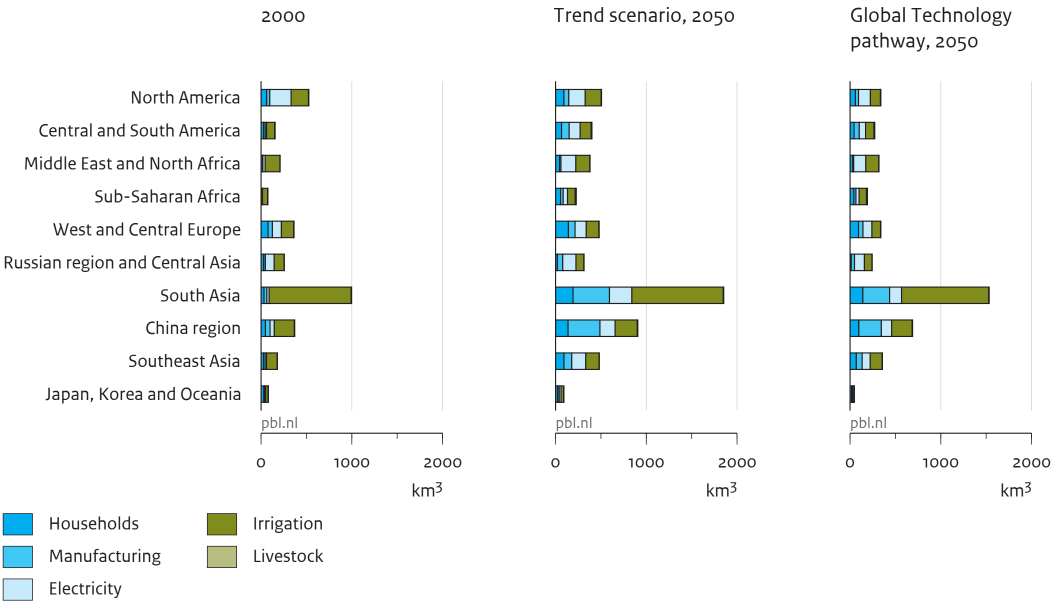
Global water demand had reached a level of 3 200 km^3 by 2000 – with about two thirds used for irrigation in agriculture, followed by electricity production, domestic use and industrial manufacturing. A large-scale study by Schneider et al. (2011) showed that climate change will alter the volume, duration and timing of floodplain inundation events and therefore constitutes an additional threat to river ecosystems. Climate change may also have negative impacts on water quality, including the reduced dilution capacity of rivers or increased bacterial loads (Bates et al., 2008). Salinisation, partly driven by sea-level rise, is also an important degradation factor. In addition to climate change, increasing water use, river and reservoir regulation or non-treated return flows lead to alterations in flow regimes, causing an intensifying and complex conflict between ecosystem requirements and the management of rivers for water supply and energy purposes.

In summary, worldwide, hundreds of millions of people live in areas with at least looming temporary shortages in the water supply. There are various factors that contribute to water stress:
- water is often available at relatively low prices, or is even extracted at no charge at all;
- water scarcity crosses regional and national boundaries;
- different sectors contribute to water demand, mostly independently of each other;
- a lack of investment in water management, reservoirs and water-saving equipment in irrigation, households, industry and the power sector.

Water demand is projected to increase significantly, mainly outside the agricultural sector, thereby almost doubling the population living in severely water-stressed areas by 2050

Several scenario assessments show large variations in projected water demand, taking into account changes in climate, population, the economy, electricity production, irrigated area and technology (Comprehensive Assessment of Water Management in Agriculture, 2007; Alcamo et al., 2007; Shen et al., 2008; Shiklomanov and Rodda, 2003). It is worth noting that current water demand and withdrawal estimates are subject to substantial uncertainty, and projections for the largest contributor today, irrigation, vary greatly, from no increase (or even a 10–15% decrease) to a 30% increase or more (Comprehensive Assessment of Water Management in Agriculture, 2007; Bruinsma, 2011; Alcamo et al., 2007; Shen et al., 2008; Fischer et al., 2007; Shiklomanov and Rodda, 2003). There is greater consensus over the fact that demand in the other sectors is

Figure 7.1
Global water demand per region



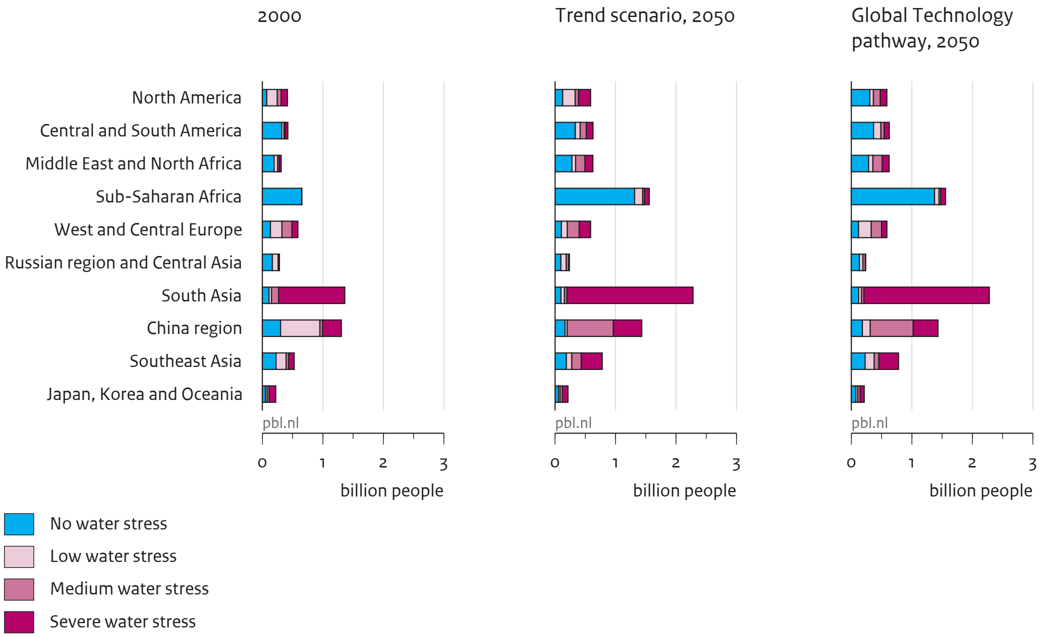
Source: PBL

bound to increase considerably up to 2050 and jointly overtake irrigation as the dominant user. Most of the estimates of water demand indicate a large net global increase, but with significant regional differences. Variations in global scenario outcomes range from 4 000 to 7 000 km³/yr in 2050 and are the result of different population and income projections and differences in technology assumptions driving water-use efficiency.

Future developments in water demand in the *Trend* scenario are presented in Figure 7.1. Total global demand increases by some 75% between 2000 and 2050, mostly because of strongly growing demand for domestic uses, manufacturing and electricity production in currently emerging economies (including India and China). Despite some further expansion of irrigated agricultural land, the irrigation water demand increases by just 9%.

Given the limited changes in projected water availability, the increasing demand will lead to an increase in water stress. The number of people living in highly water-stressed areas is already considerable and estimated here at 1.9 billion, almost 60% of who live in South Asia (see Figure 7.2). Around 80% of all people in the region live in river basins characterised by severe water stress, where more than 40% of the available water

Figure 7.2
People in water stressed areas, per region



Source: PBL

resource is used. In the *Trend* scenario, water stress is expected to grow in many world regions due to population growth, increased water use and, to a limited extent, climate change. The number of people living in severe water-stressed basins almost doubles towards 2050 in the *Trend* scenario, reaching 3.7 billion people by 2050, of which 2.1 billion live in South Asia. The projected population growth in water basins already under severe water stress is the main factor explaining these outcomes, in addition to growing water demand.

In the pathways, climate mitigation and water-use efficiency will significantly reduce the demand for water, but the total number of people living in severely water-stressed river basins will only marginally decrease

The three pathways with respect to food, biodiversity, energy and climate of Chapters 5 and 6 show positive synergies for reducing water stress. Climate mitigation policies lead to a reduced demand for thermal cooling in power generation as fossil-fuel powered plants are partly replaced by renewables. However, given the interest in keeping the agricultural land area as compact as possible to reduce pressure on nature areas and biodiversity, the irrigated area is not changed from the *Trend* scenario and hence the water deficit at the field level remains the same. To further reduce the imbalance between demand and supply, water-use efficiency has to increase. Stringent efficiency measures are taken in industry and domestic water use, implying behavioural changes besides the widespread deployment of water-saving equipment. Irrigation demand is reduced as the efficiency of the irrigation systems is increased and this improves the ratio between water effectively applied to sustain plant growth and water withdrawn from rivers, lakes, reservoirs and groundwater. These measures are in line with results from sectoral studies (Alcamo et al., 2005; WBCSD, 2006; OECD, 2012; Van den Berg et al., 2011).

Figure 7.1 presents the impacts on global water demand resulting from the changes in the *Global Technology* pathway, including water-use efficiency measures. Total global water demand is reduced by around 25% in 2050 compared with the *Trend* scenario. However, although the degree of water stress will decrease in most, if not all, river basins, the number of people living in areas under severe water stress changes by less than 10%, from 3.7 to 3.4 billion in 2050 (see Figure 7.2). The main reason for this is that the population in many basins already under severe water stress today is projected to grow strongly until 2050. Even if demand, in terms of total and per capita, is reduced below the *Trend* scenario this, with a few exceptions, is not enough to cross the 40% level that defines the severe water stress category.

7.1.3 Future trends in access to safe drinking water and improved sanitation

Full access to safe drinking water and improved sanitation requires an acceleration of progress, especially with respect to sanitation

Since 1990, more than 2 billion people have gained access to improved drinking water sources and 1.8 billion people have gained access to basic sanitation. However, progress towards the MDG target is mixed. Although the MDG target for safe drinking water was already met in 2010, it is unlikely that the world will meet the target for sanitation by 2015 (UNICEF and WHO, 2012). This apparent success concerning drinking water can also be misleading. Firstly, although progress has been rapid in rural areas, the absolute number of people in rural areas without access is still a concern. Secondly, the number of city dwellers worldwide without access to an improved water supply actually increased between 1990 and 2008 as service extension failed to keep pace with rapid city growth. Thirdly, an improved water source obviously does not guarantee access to safe water. Finally, untreated urban wastewater is an important source of nutrients that potentially leads to eutrophication, causing aquatic biodiversity loss in rivers, lakes and wetlands (see also Section 7.2) and that can also affect human health.

In the *Trend* scenario, access to both safe drinking water and basic sanitation improve (see Chapter 3), mainly due to increasing income levels and continuing urbanisation, which makes water supply and sanitation coverage easier to achieve. However, 450 million people will still be without access to safe drinking water by 2030, and 2 billion people without access to basic sanitation. By 2050, these numbers are 250 million and 1.4 billion, respectively.

There is no distinction between the three pathways. Access to both safe drinking water and improved sanitation is first halved by 2015, from 1990 levels (the MDG target), and halved again by 2030, compared to the 2015 target, while universal access is achieved by 2050. This means that, to reach the target by 2030, an additional 230 million people must have access to an improved water source, and around 1 billion more people must have access to basic sanitation facilities. Furthermore, by 2050, an additional 250 million people would need to have access to an improved water source and an additional 1.4 billion would have to have access to basic sanitation facilities.

Improving access to safe drinking water and improved sanitation requires significant investments in existing and new infrastructure

Increasing access to water supply and sanitation requires additional investments to retrofit poorly adapted infrastructure and to build new facilities. In addition, significant and stable financial flows will be needed to maintain and operate this infrastructure. On average, additional annual investments of USD 6.8 billion will be needed between 2010 and 2030, to achieve the 2030 target, and USD 9.9 billion between 2030 and 2050, to achieve the 2050 target, with almost 50% of these investments in sub-Saharan Africa. The associated costs for the projected connection rates are based on Hutton and Haller (2004), whose estimates include initial investments and annual recurrent costs for the various connection levels. These additional investments are substantial, especially in sub-Saharan Africa and South Asia. In sub-Saharan Africa, where the relative costs of water supply and sanitation as a share of GDP are higher than in OECD countries, this share by 2030 would be 0.9% under the *Trend* scenario and 1.3% in the pathways. By 2050, this share would be 0.4% under the *Trend* scenario and 0.6% in the pathways. This will require well-developed and realistic strategies that tap three main sources of finance: revenues from tariffs for water services, taxes channelled through public budgets and transfers from the international community (WHO, 2010). Furthermore, the private sector (the water industry and financial institutions) can also play a key role in developing and channelling innovations and enhancing efficiency (OECD, 2009, 2010).

According to existing literature, the benefits of increased access to safe drinking water and sanitation clearly outweigh the costs, especially in the least developed countries. Economic benefits could range from USD 3 to 34 for every dollar invested (Hutton et al., 2007), potentially increasing a country's gross domestic product by an estimated 2% to 7% (WHO, 2010). Three quarters of these benefits stem from decreased collection time, especially when water is piped to premises, while other benefits are mostly linked to a reduction in waterborne disease and death, for example, from diarrhoea (see Section 7.3).

A person needs on average 20–50 litres of water a day to ensure their basic needs for drinking water, hygiene, sanitation and food preparation, with around 5 litres for drinking water and 20 litres for basic sanitation (Gleick, 1996). A quick calculation concludes that providing full access to safe drinking water and improved sanitation in

2050 requires an additional freshwater supply of around 10 km^3. This might be an underestimate as access to an improved water source potentially increases water use. However, compared with total freshwater use, this is a very small concern at the global level – around 0.2% of total water use in 2050 in the *Trend* scenario. Nevertheless, local access to sufficient volumes can be more challenging and alternative sources, such as using fossil water reserves or the desalinisation of seawater, might be required.

7.1.4 Managing demand for water

Reducing the number of people who live under severe water stress is very difficult
The water stress projections illustrate that it is very difficult to alleviate the situation for large parts of the global population living under conditions of severe water stress. Using less water, using it more efficiently and reducing water pollution to improve the opportunities for the re-use of water remain important for enhancing the adaptive capacity. Furthermore, improving access to safe drinking water and basic sanitation requires significant investments in infrastructure expansion. On average, however, the related additional demand for freshwater is small compared with demand for the food supply and the cooling of industrial and power facilities, and therefore does not significantly exacerbate the water scarcity situation. Furthermore, the benefits of improving access can be high, mainly related to reduced water collection time and decreased loss of health due to waterborne disease.

Potentially, significant increases could be made in water use efficiency, but there are also clear economic and governance obstacles
Many technological measures and improvements are well-known and are relatively simple to apply, such as water-saving household appliances and more efficient irrigation systems. However, their widespread deployment is hampered by a lack of financial incentives. Water charges, if in place at all, tend to be too low to warrant investing in such improvements. Water is typically used in a river basin by thousands to millions of small users (households, smallholders and small businesses), plus a small number of very large users (big, water-intensive industries and power plants). Moreover, water quality requirements can differ substantially between the various applications. This makes efficient, effective, affordable and fair management of the available water far from straightforward, and this is further complicated as ecological requirements add to the puzzle. Local conditions and opportunities will need to be taken into account in the development of more sustainable pathways, but various generic options to improve access to safe drinking water and reduce water scarcity include integrated resource management, efficiency improvements for all users, putting the right price on water, investing in reservoirs, infrastructure and pumps and ensuring water quality.

7.2 Reducing imbalances in the Earth's nutrient cycles

7.2.1 The Earth's nutrient cycles

Nutrients are required to sustain current and future crop production but also cause several environmental problems

Disturbances to the nitrogen and phosphorus cycles are identified as critical sustainability problems. The most important causes are the large-scale production of animal manure in livestock production and the use of artificial fertilisers in crop production systems. Clearly, without fertiliser application it will be difficult to sustain the current and future crop production levels that are required to feed nine billion people by 2050. There are, however, many sustainability problems associated with disturbances to the global nitrogen and phosphorus cycles. Nitrogen fertiliser use is currently almost 100 million tonnes of nitrogen per year and, also taking into account the nitrogen fixation by leguminous crops, man has accelerated the global nitrogen cycle by a factor of three. Phosphorus fertiliser use currently totals 16–17 million tonnes a year. Main consequences of the excessive use of fertilisers are the re-deposition of atmospheric emissions of nitrogen species onto land and aquatic ecosystems as well as large flows of nutrients into groundwater through leaching and surface water through surface run-off. This causes the eutrophication of freshwater and marine ecosystems and, consequently, will have certain impacts, such as algal blooms (including harmful toxic ones), algal scum, enhanced benthic algal growth and the massive growth of submersed and floating macrophytes. It also causes secondary problems such as oxygen depletion in water and fish death. Nitrogen deposition on terrestrial ecosystems can also lead to serious degradation. Finally, phosphorus fertiliser is primarily produced from phosphate rock, a non-renewable resource. There are claims that resources of phosphate rock are limited. Depletion risks do not exist for nitrogen, although its synthesis leads to a considerable energy demand.

Land and biodiversity (Chapter 5) and energy and climate (Chapter 6) have important linkages with the nutrient challenge. First of all, development of future agricultural systems may have direct consequences for fertiliser demand and the management and use of animal manure. Also, as indicated above, emissions of both nitrogen and phosphorus will lead to biodiversity loss (as accounted for in the MSA calculations in Chapter 5). Recently, there has been an increasing interest in the interaction between nitrogen and climate change. Nitrogen is linked to climate change through direct N_2O emissions, the interaction of nitrogen with the carbon cycle and through air pollution. Finally, limitations in phosphorus availability could obviously seriously limit future agricultural production.

7.2.2 Future trends in nutrient use

Historical trends and options to reduce nutrient use
The use of fertilisers has increased rapidly. In industrialised countries, the use of nitrogen and phosphorus fertilisers rapidly increased in the 1950s, peaking in the 1980s. In developing countries, fertiliser use in agriculture started later; for example, in China and India in the 1970s, and is still rapidly increasing. Research has shown that options exist to reduce fertiliser use significantly. There are, however, various reasons why this potential has not been made use of in the past. These include: 1) the focus on productivity increase in agricultural strategies, 2) the subsidies for fertiliser application and 3) the limited attention paid to the ecological services impacted by disturbances to the nutrient cycles. Options that could reduce disturbances to the nutrient cycles include:
- more efficient fertiliser utilisation practices;
- improved knowledge of crop production practices;
- general changes in agricultural production (food waste reduction, dietary changes; see Chapter 5);
- improve the phosphorus conversion efficiency in livestock production systems;
- close the agricultural phosphorus cycle by better integrating animal manure in crop production systems to reduce fertiliser use;
- recycle human excreta in agriculture to replace fertilisers from primary sources;
- in households, replace phosphorus-based laundry and dishwasher detergents to reduce phosphorus use and the emission of phosphorus to surface water.

The following measures are specifically considered in our analysis:

The *Trend* scenario assumptions for fertiliser-use efficiency are based on the baseline scenario of the OECD Environmental Outlook (OECD, 2012). The pathways assume a different growth in crop yields from the *Trend* scenario. This has an effect on the fertiliser use. With no further changes in technology, crop yield increases can be achieved through improved management and higher fertiliser inputs. However, improved varieties will also be introduced with higher nitrogen and phosphorus recoveries. The assumptions made here represent the combined impact of these trends. Animal nutrient excretion per unit of product (meat or milk) decreases with increasing productivity in the *Trend* scenario. In the pathways, further efficiency improvements are assumed to take place. Based on improved feeding strategies, nutrient excretion per animal will decrease by 15% in 2030 in the *Global Technology* pathway compared with the *Trend* scenario, while a 5% decrease is assumed in the *Decentralised Solutions* pathway. The amount of phosphorus in feed additives in pork and poultry production and therefore phosphorus excretion can be reduced by improving the capability of monogastric animals to degrade phytate, or by reducing the phytate content of grain (Abelson, 1999). For manure, we furthermore assumed that all the manure that ends up outside the agricultural system in the *Trend* scenario is recycled in crop production systems in the *Decentralised Solutions* pathway. Finally, it is assumed that human excreta are recycled in

Table 7.1
Pathway assumptions

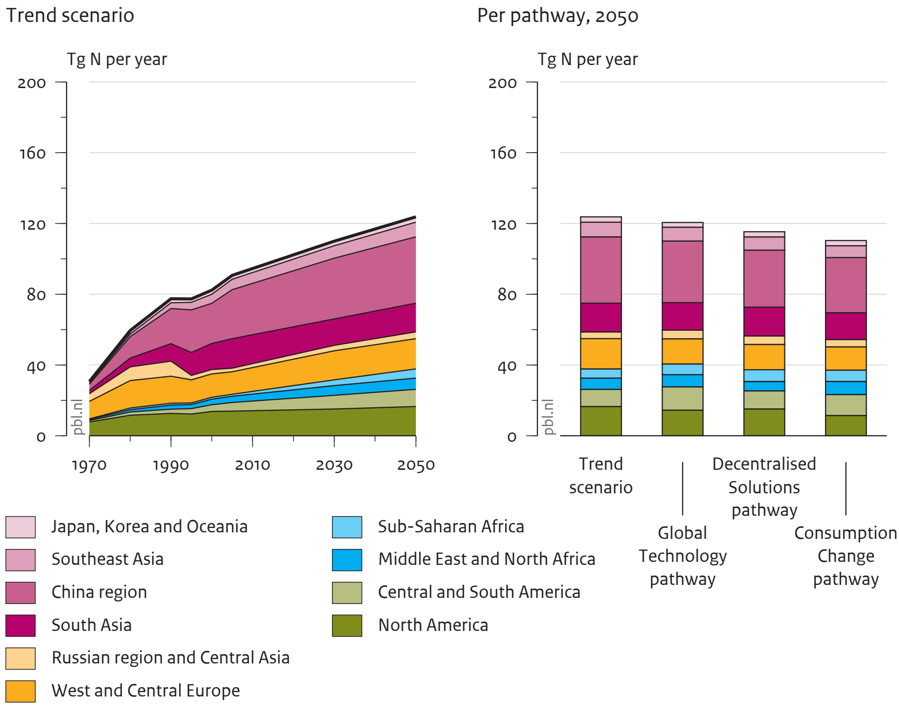
	Trend scenario	*Global Technology*	*Decentralised Solutions*	*Consumption Change*
Fertiliser-use efficiency	Increase in fertiliser utilisation, mostly in developing countries, despite assumed improvements in utilisation efficiency	Fertiliser-use efficiency improved by 50% for extra yield increase compared to *Trend* scenario	Similar to *Global Technology*	Similar to *Global Technology*
Animal excretions	Decreases with increasing productivity	15% lower excretion rates due to higher feed-use efficiency	5% lower excretion rates than in *Trend* scenario	Decreases with increasing productivity
Manure integration	No	No	Manure is recycled and better integrated in the agricultural system	No
Recycling of human excreta	No recycling	No recycling	Recycling of human N and P from households with access to improved sanitation	No recycling

agricultural systems in the *Decentralised Solutions* pathway, following the work by Van Drecht et al. (2009).

The *Trend* scenario leads to a rapid increase in nitrogen and phosphorus fertiliser use in 'deficit' countries

The *Trend* scenario portrays the results for a rapidly growing population and rapid increase in food production in developing countries. These vast increases will lead to rapidly increasing nitrogen and phosphorus fertiliser use in nutrient-deficit countries, with phosphorus fertiliser use projected to increase by a factor of four or more in eastern, western and southern Africa, between 2005 and 2050. For industrialised countries, too, the *Trend* scenario shows an increase in nitrogen fertiliser use (Figure 7.3); for example, by 19% in North America and 34% in western and central Europe. Increases in phosphorus fertiliser use are projected to be even larger. Globally, the increase in nitrogen fertiliser use between 2005 and 2050 will be 36%, from an annual 91 to 124 million tonnes, and for phosphorus this will be 44%, from an annual 17 to 25 million tonnes (Figure 7.4).

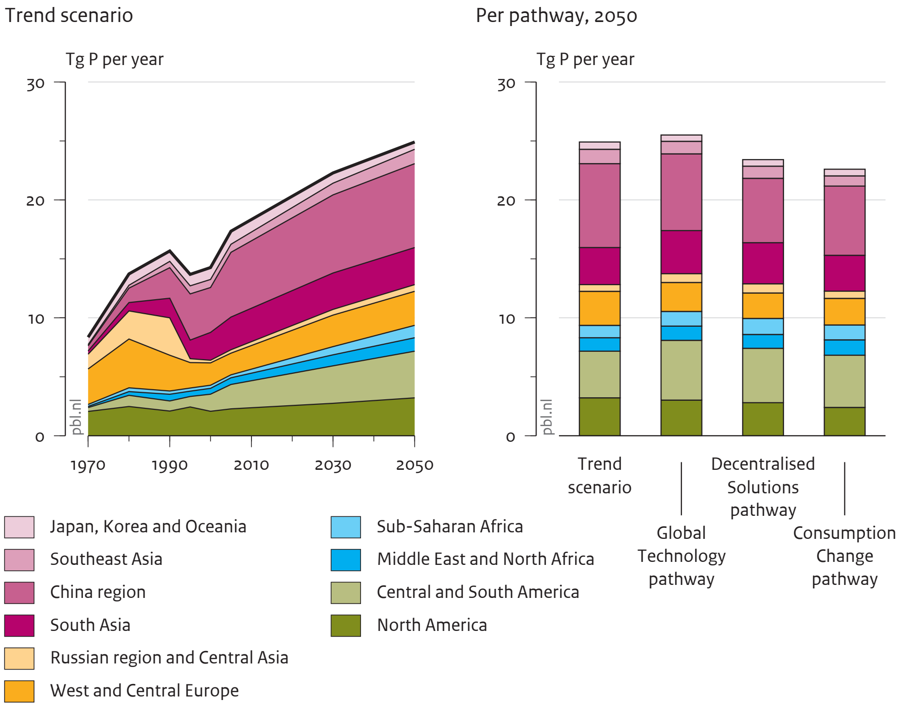
Figure 7.3
Global nitrogen fertiliser use



Source: PBL

The pathways show that nitrogen and phosphorus fertiliser use may be reduced, compared to the levels under the *Trend* scenario, but would still increase compared with today's levels, primarily in transition and developing countries
In the *Global Technology* pathway, higher crop yields will require less fertiliser in most industrialised countries and more fertiliser in countries where its use is currently low. In the Russian Region and Central Asia, much less fertiliser is currently used to produce the same amount of dry matter than in industrialised countries, hence, the fertiliser use would need to increase with higher crop yields. However, since crop production will be lower in most industrialised countries and higher in most developing countries compared with the *Trend* scenario, the total nitrogen and phosphorus fertiliser use will shift even more towards developing countries. Crop production in most industrialised countries and China is lower in the *Decentralised Solutions* pathway than in the *Trend* scenario, while production in most developing countries exceeds that in the *Trend* scenario. With higher fertiliser-use efficiencies in industrialised countries, China and South Asia and increased fertiliser use in other developing countries, this leads to a reduction in the use of nitrogen fertiliser in industrialised countries and to an increase in

Figure 7.4
Global phosphorus fertiliser use



Source: PBL

most developing regions. In the *Consumption Change* pathway, with all the strategies to improve resource-use efficiency, global fertiliser use in 2050 is 13% less than in the *Trend* scenario for nitrogen and 15% less for phosphorus. In this scenario, the increase in crop yields lead to significant increases in fertiliser use in nutrient-deficit developing countries. On the other hand, the increased feed conversion together with the reduction in phosphorus supplements in the feed of monogastric animals leads to less phosphorus excretion.

The calculations show that the better integration of animal manure is a very effective strategy for reducing fertiliser use in industrialised countries. Global nitrogen use is reduced by 10% and phosphorus use by 11%, but in many regions the reductions are larger (e.g. for phosphorus 16% in North America and 22% in western and central Europe). In developing countries with a nutrient deficit, the better integration of animal manure is considered difficult because fertiliser use is minimal and animal manure already plays an important role in sustaining crop production. Finally, the recycling of human excreta is an effective strategy for reducing phosphorus fertiliser use. Global human excretion currently accounts for around 30% of nitrogen and phosphorus fertiliser use. Therefore, recycling this would reduce fertiliser use considerably. However, due to limited sanitation and financial barriers, we estimated that this can account for a maximum reduction of 6% of phosphorus fertiliser use by 2030 and 16% by 2050. For nitrogen, we assumed that 30% of the nitrogen is lost during transport and processing, mainly through ammonia volatilisation and denitrification. Taking this into account, 5% of global nitrogen fertiliser use can be substituted in 2030, and 6% in 2050.

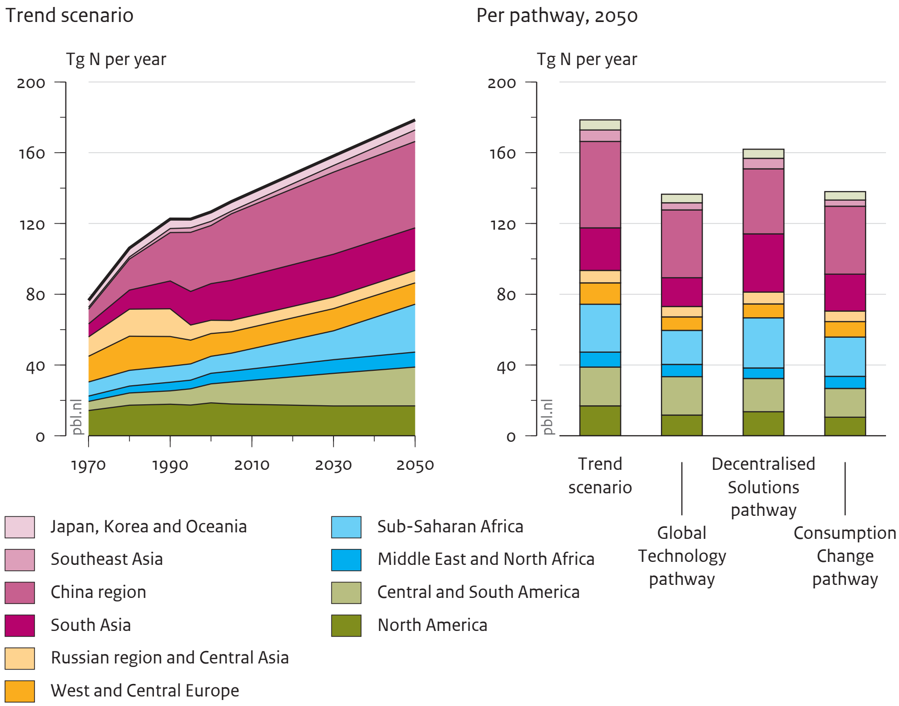
The overall conclusion is that nitrogen and phosphorus fertiliser use will inevitably have to increase to sustain the increasing food production. The increase is particularly strong in developing countries. The amount of phosphorus required in agriculture will increase from current levels of around 17 million tonnes a year to 24 million tonnes in 2050 in the *Trend* scenario, and by similar amounts in the pathways. Only in the *Decentralised Solutions* pathway do the additional measures reduce the use of phosphorus fertiliser by about 20% to 30%.

Environmental impacts
Surface water and groundwater quality is projected to deteriorate in the coming decades without further policies, especially outside the OECD. Globally, nutrient flows to freshwater are expected to increase as the population and economic activities grow much faster than efficiency gains. This will have severe impacts on water quality, ecosystems and biodiversity.

Soil nutrient budgets are generally regarded as useful indicators of the losses to the environment. Soil nutrient budgets represent the difference between nutrient inputs from fertiliser and animal manure and withdrawal through harvesting crops and grazing or mowing grass. A positive budget is a surplus, which represents a potential loss to the environment or accumulation in the soil; a negative budget indicates a deficit, in other words soil nutrient depletion. A varying but substantial part of surplus phosphorus accumulates in the soil. This residual soil phosphorus can contribute to phosphorus in soil solution and be taken up by crops for many years (Syers et al., 2008). In the *Trend* scenario, nitrogen surpluses will increase by 35% globally (Figure 7.5). This is the result of decreasing trends in North America, western Europe and Japan, stabilisation in South Asia and an increase in all other regions. This increase is particularly large in sub-Saharan Africa and Southeast Asia. For phosphorus, a similar picture can be seen, with large increases in developing countries. There is also an increase in the phosphorus surplus in the *Decentralised Solutions* in South Asia, which is the result of the vast increase in animal manure recycled in the agricultural system (manure that in the *Trend* scenario is used as fuel) (Figure 7.6). This is not balanced by a reduction in phosphorus fertiliser use.

Planetary boundaries have been proposed for the amount of nitrogen fixed by humans and the amount of phosphorus flowing into the world's oceans (Rockström et al., 2009). These boundaries were set to 35 million tonnes of nitrogen per year and 11 million tonnes of phosphorus. The planetary boundary for phosphorus was refined by

Figure 7.5
Global nitrogen surplus

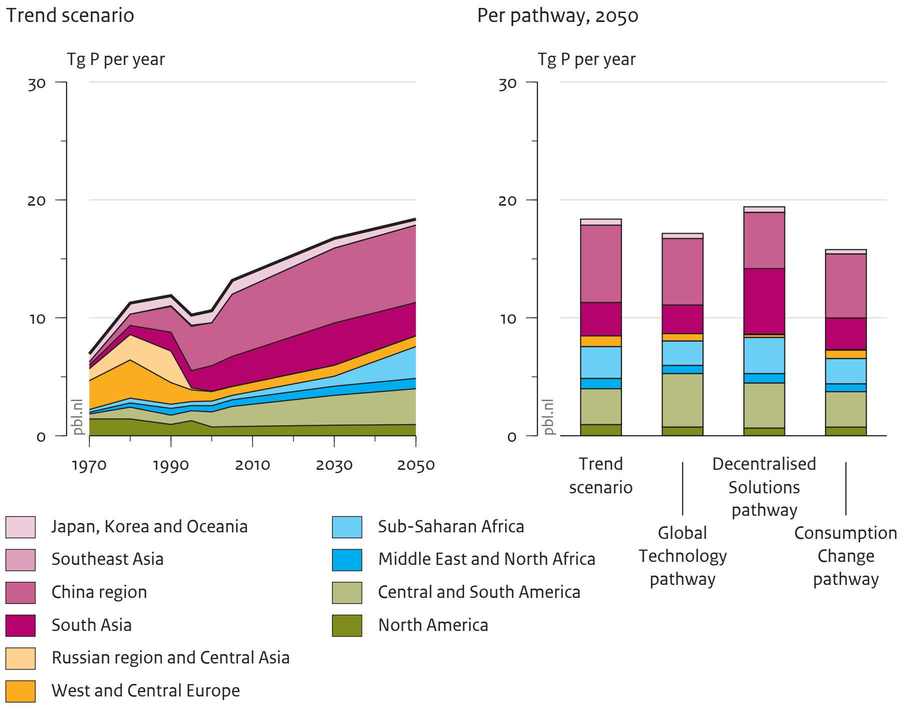


Source: PBL

Carpenter and Bennett (2011) to 22 million tonnes (with a range of 9 to 32). It should be noted that the budgets currently show nitrogen and phosphorus deficits in many countries. Even under the *Trend* scenario, this form of soil degradation, one of the primary causes of forest clearing for agricultural expansion, is assumed to be partially avoided by increasing the use of fertilisers. This is particularly important for tropical countries with strongly weathered phosphorus-fixing soils.

The planetary boundaries for nitrogen (Rockström et al., 2009) and phosphorus (Carpenter and Bennett, 2011) are currently already being exceeded. Globally, the use of nitrogen fertiliser will increase by 36% under the *Trend* scenario, between 2005 and 2050, and the phosphorus surplus by 42%. This is related to rapidly increasing fertiliser use in developing countries. For example, nitrogen fertiliser use in sub-Saharan Africa increases by more than a factor of four in the *Trend* scenario between 2005 and 2050, while the phosphorus budget increases even more rapidly. Hence, at the global scale the boundaries will be exceeded even more than they are at present. Meanwhile, the problems associated with an overload of nutrients will stabilise or slightly decrease in

Figure 7.6
Global phosphorus surplus



Source: PBL

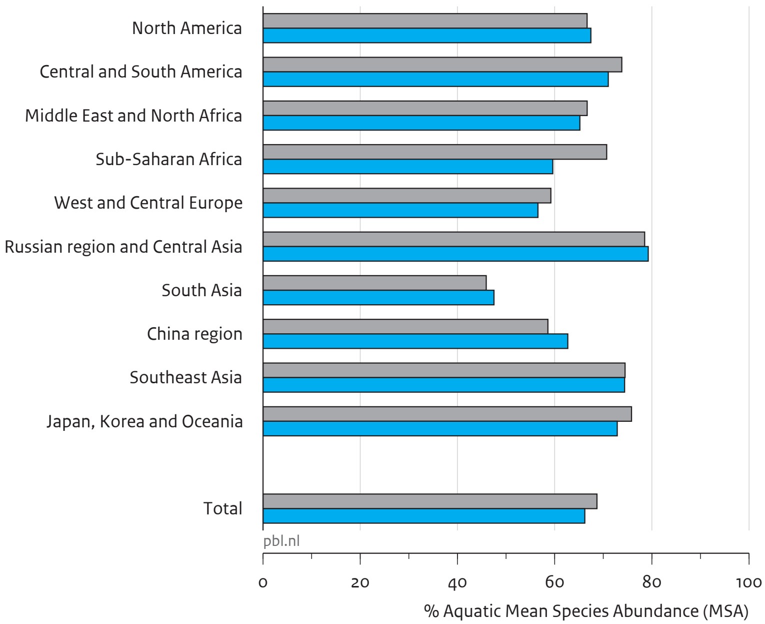
industrialised countries, China and India and strongly increase in many developing countries. The pathways show a decline in nitrogen use in industrialised countries.

7.2.3 Managing the nutrient surplus

Further increases in nutrient surpluses is inevitable, but may be mitigated by consumption changes and recycling
The analysis shows that nitrogen and phosphorus fertiliser use will inevitably have to increase to sustain the increasing food production. Although the pathways show that agricultural nutrient use can be reduced compared to the *Trend* scenario, its use will still increase compared to today's levels, primarily in transition and developing countries. The pathways account both for the measures taken to achieve the sustainable development goals in Chapters 5 and 6 and the additional assumptions made here. Under these conditions, it is also clear that a further increase in nutrient surpluses is inevitable, but significant improvements in crop and livestock production, the recycling

Box 7.1 Freshwater biodiversity
Similar to terrestrial biodiversity, the biodiversity in marine and freshwater systems (rivers, lakes and wetlands) is impacted by human behaviour, via reduced water quality and quantity. Eutrophication, habitat loss through land drainage, river flow regulation, soil erosion and climate change all contribute to declines in aquatic biodiversity and changes in ecosystem structure and functioning. Several assessments indicate that freshwater species, in general, are at much greater risk of extinction than terrestrial species (Stein et al., 2000; Smith and Darwall, 2006). Simulations with the GLOBIO-aquatic model of the average biodiversity intactness (MSA) in freshwater biomes already show a considerable decline in most regions, something that will continue up to 2050, particularly in Africa (Figure 7.7) (Alkemade et al., 2011; OECD, 2012). The simulated decline is likely to be an underestimation, because the effects of wetland reclamation and of future river dams and climate change are not included in the projections. Algal bloom problems in lakes and coastal seas due to eutrophication with phosphorus and nitrogen will aggravate, as well. The nutrient efficiency option could help to

Figure 7.7
Global freshwater biodiversity per region



Source: PBL; OECD, 2012

reduce further biodiversity loss in fresh waters, in the long term, and may even allow for some local recovery. However, this will probably be countered by the effects of global warming (Jeppesen et al., 2009). In the coastal seas the problems would only slightly be alleviated, due to imbalance between the different nutrients.

of human excreta and the better integration of animal manure in crop production systems can lead to a reduction in fertiliser use and losses to the environment.

7.3 Reducing human health loss

7.3.1 Environmental risk factors for human health

The vast majority of child deaths in developing countries is related to hunger and inadequate access to modern fuels, safe drinking water and basic sanitation
The environment is important for human development and quality of life. Unequal access and reduced resource quality may lead to reduced welfare and health loss (Millennium Ecosystem Assessment, 2005; UNEP, 2007; World Bank, 2008). On average, 23% of all global deaths can be attributed to environmental factors, with a disproportionate share for children in developing countries (Prüss-Üstün and Corvalán, 2006). The JPoI Paragraph 7(f) calls to 'reduce environmental health threats, taking into account the special needs of children'.

The world is currently not on track to reach the MDG target on child mortality (MDG4 – reduce by two-thirds, between 1990 and 2015, the under-five mortality rate (see Chapter 3)). Of the estimated 8.8 million annual child deaths in 2008, the vast majority were related to preventable and treatable infectious diseases and conditions, including pneumonia (18%) and diarrhoea (15%) (Black et al., 2010) with undernutrition being an important underlying factor responsible for about 35% of child deaths (Black et al., 2008). These diseases are strongly related to the issues all discussed in the preceding chapters: undernutrition (Chapter 5), pneumonia due to indoor air pollution resulting from traditional fuel use for cooking and heating (Chapter 6) and diarrhoea due to lack of access to safe drinking water and basic sanitation (Section 7.1). As well as indoor air pollution, urban air pollution is also an important health risk factor (see Chapter 6). Urban air pollution is responsible for 3.3% of all global deaths in 2004, being more of a health risk for elderly people than for children (WHO, 2009a).

Inadequate access to food, energy and water results in significant health impacts for children under the age of five. Outdoor air pollution mainly impacts the elderly
Maternal and child undernutrition is an important underlying cause of mortality and overall disease burden and is attributable to more than 3.5 million deaths, annually

(Black et al., 2008). Undernutrition is the result of protein-energy malnutrition (a lack of sufficient proteins and calories) and deficiencies in micronutrients (essential vitamins and minerals). It reinforces the mortality of diseases, such as pneumonia, diarrhoea and malaria (Caulfield et al., 2004), and also has a direct effect on mortality through deficiencies of micronutrients. Undernutrition can result in limited physical and neurological development and low productivity among current and future generations. It is therefore also a major constraint to a country's ability to develop economically, socially and politically (UN Millennium Project, 2005).

Lack of access to modern energy sources causes indoor air pollution, resulting in almost two million premature deaths, per year, with approximately a million of these deaths caused by lower respiratory infections or pneumonia in children, and the other million due to chronic lung disease and lung cancer, which occurs primarily in the elderly (WHO and UNDP, 2009). Indoor air pollution is caused by the burning of traditional fuels such as coal and traditional biomass (e.g. cow dung, wood) on an open fire or on an inefficient traditional stove – exposing people to a dangerous cocktail of pollutants, primarily carbon monoxide and fine particles.

The lack of a safe water supply and adequate sanitation exposes people to pathogenic micro-organisms and is responsible for around 1.6 million deaths annually, mainly due to diarrhoea. Approximately 88% of all diarrhoeal deaths globally are caused by unsafe water, sanitation or hygiene, and 99% of these are in developing countries (WHO, 2009a). Children are most affected, with almost 30% of all diarrhoea-related deaths in children under five (Prüss-Üstün and Corvalán, 2006).

Globally, over one million premature deaths in 2004 were associated with exposure to particulate matter (PM_{10} and $PM_{2.5}$) in urban areas (WHO, 2009a). This urban air pollution – mainly the result of fossil fuel combustion – negatively impacts human health through lung cancer, cardiopulmonary diseases and respiratory infections. Older people are most susceptible to this environmental health risk.

7.3.2 Future trends in human health

Premature deaths associated with urban air pollution projected to increase, also because of rapid urbanisation and ageing of the population

The number of premature deaths associated with exposure to PM_{10} and $PM_{2.5}$ is projected to increase in the *Trend* scenario to almost 3.5 million in 2050, with most of this increase in fast-growing Asian countries due to increasing air pollution emissions and urbanisation levels. Another key factor is the ageing of the population, since the impacts of air pollution will especially be felt among the elderly. Ageing is now a concern in most developed countries, but will also become much more important in the emerging economies, especially in China. China currently has the highest rate of premature deaths linked to air pollution, and this rate is expected to more than double by 2050 in the *Trend* scenario, with ageing of the population an important factor. Although the estimated

Box 7.2 Climate-related health impacts

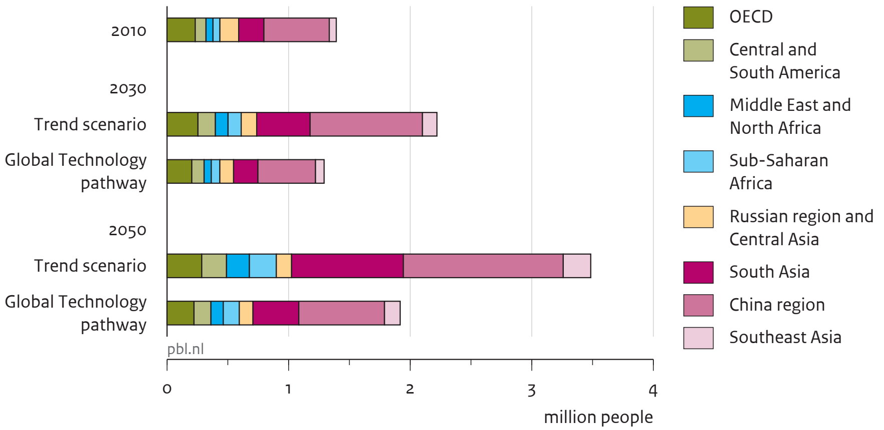
Climate change can be seen as another potential risk to human health through extremes in temperature, weather disasters, photochemical air pollutants, vector-borne and rodent-borne diseases, and food-related and waterborne infections. In many cases, the poorest and least able to respond to such impacts will be most affected. The IPCC's Fourth Assessment report concluded, with very high confidence that climate change is currently contributing to the global burden of disease and premature deaths, and that while these effects are currently small, they are 'projected to progressively increase in all countries and regions' (Confalonieri et al., 2007). Health risks related to climate change can be direct, such as temperature-related mortality (i.e. cold and heat stress) or more indirect through, for example, malnutrition, diarrhoea, flooding and malaria (Campbell-Lendrum et al., 2003). The WHO estimates that, in 2004, climate change was responsible for an estimated 3% of diarrhoea, 3% of malaria and 3.8% of dengue fever deaths globally (McMichael et al., 2004; WHO, 2009b). Projections of malaria risk as a result of changing temperature and precipitation conditions favourable for the malaria mosquito show only some slight changes in areas suitable for the malaria mosquito. Other factors such as urbanisation and vector control policies might be more important for achieving a decrease in malaria. Furthermore, the increased risks of diarrhoea due to higher temperatures are much lower than the progress being made in connection rates. Climate change is therefore projected to have a small impact on health aspects. Future impacts on other climate-related health risks such as flooding and heat and cold stress are more uncertain and could have adverse effects on human health.

premature death rates are lower, for example, in South Asia and Southeast Asia, they are projected to nearly triple during the same period.

Improved urban air quality decreases related mortality, while urbanisation and ageing dampen the effect of reduced exposure on overall mortality

In the pathways, $PM_{2.5}$ concentration in cities is reduced to levels below 35 µg/m^3 by 2030 (WHO Interim Target 1). As a result, overall mortality attributable to particulate matter is reduced to 1.3 million deaths by 2030, from 2.3 million deaths in the *Trend* scenario, and by 2050 to 1.9 million from 3.5 million, respectively. Most of the reductions would take place in Asia, where current levels are the highest, and to a lesser extent also in Africa (Figure 7.8). Although the particulate matter concentration is projected to remain almost constant at 35 µg/m^3, between 2030 and 2050, total deaths increase, mainly due to the larger number of people exposed as a result of rapid urbanisation and the increasing number of elderly.

Figure 7.8
Global deaths due to urban air pollution



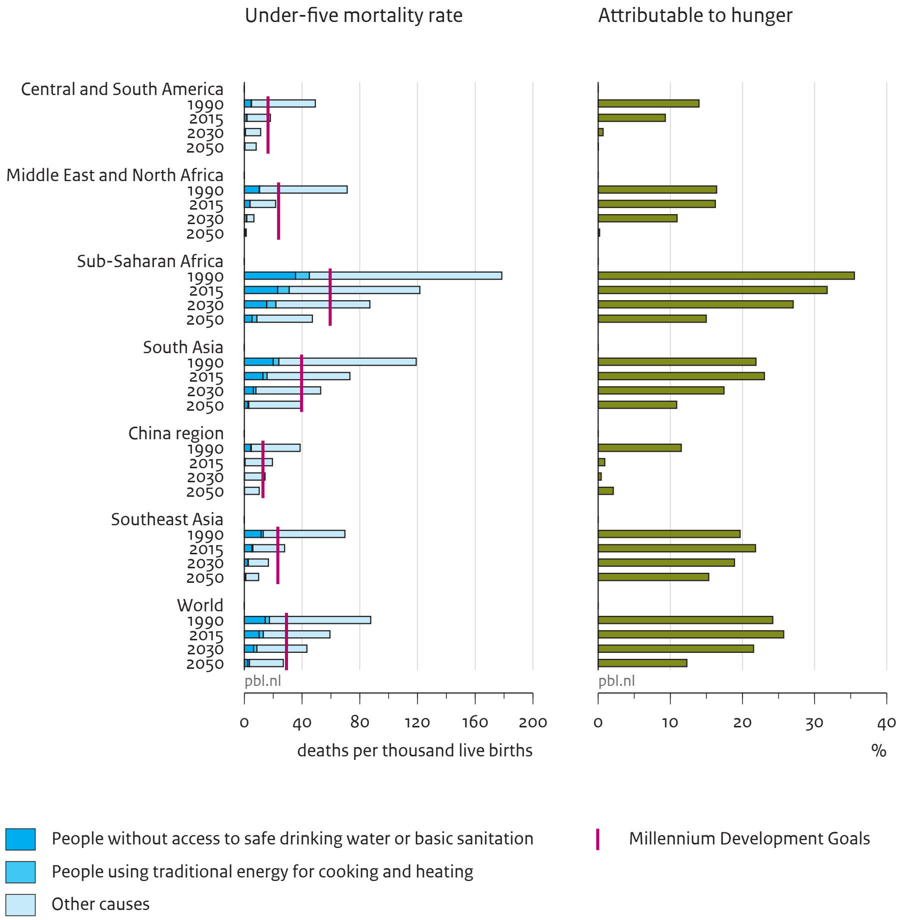
Source: PBL
As the pathways are the same with respect to air pollution, their impact on overall mortality is also similar.

Child mortality decreases, significantly, under the *Trend* scenario, but not by enough to reach the 2015 MDG target before 2030

Access to food, improved drinking water, basic sanitation and modern energy sources increases significantly in the *Trend* scenario (see Chapter 3). Yet even with this large increase, a significant proportion of the population will still be without adequate services, mainly in sub-Saharan Africa and South Asia. By 2050, around 300 million people will be without adequate access to food, 250 million people without sustainable access to safe drinking water, 1.4 billion people without basic sanitation and 1.9 billion people without access to modern energy sources for cooking and heating. At the same time, urban air pollution will surpass critical limits in many cities in Asia and Africa and global temperature increases will also having adverse effects on human health (See Box 7.2).

Global child mortality is projected to reduce significantly, from 67 child deaths per 1000 children born in 2010 to less than 45 in 2030 and 28 in 2050, with large improvements in all world regions (Figure 7.9). To comply with MDG4, child mortality should be reduced to around 30 child deaths per 1000 children born in 2015. Without new policies, this target will not be reached before 2030, mainly due to persistent high levels of child mortality in sub-Saharan Africa and South Asia (see also (PBL, 2009a).

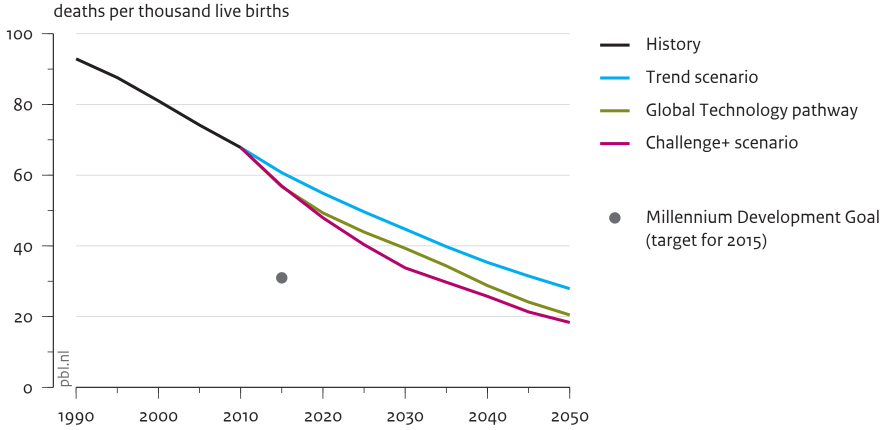
Figure 7.9
Child mortality in the Trend scenario, per cause, per region



Source: PBL

Providing full access to food, water and energy, while also targeting quality of access, further improves child mortality rates and brings the MDG target closer
Proving full access to food, water and energy, as induced in the three pathways, improves child mortality significantly. As the three pathways are the same for access to food, water and energy, their impact on child mortality is also similar. Therefore, only the *Global Technology* pathway is presented here. In this pathway, the child mortality rate is reduced by 12% by 2030 and by more than 26% by 2050 (see Figure 7.10). It should be noted that, at the same time, mortality rates for the elderly will increase. This increase is the direct result of increased food availability in developing countries. Although by 2050

Figure 7.10
Global under-five mortality rate



Source: PBL

global hunger is eradicated, overnutrition surges, especially in the *Global Technology* pathway where food consumption also increases for the better nourished. This double burden of disease is already observed in various developing countries where underweight and obesity are occurring simultaneously (Beaglehole et al., 2011).

Nevertheless, although the prevalence of undernourishment is brought close to zero and full access to improved drinking water, basic sanitation and modern energy sources is provided, by 2030 the child mortality rate is still slightly above the 2015 MDG target. This is because, as well as access level, the quality of access is also important. Furthermore, other health risks and health systems determine health outcomes. The quality of access is further discussed below.

Eradicating hunger by 2050 decreases the prevalence of child underweight by approximately 50%. The remaining underweight – mainly in sub-Saharan Africa and South Asia – can be explained by the low level of education of mothers and the status of women in society. In fact, between 1970 and 1995, improved women's education contributed to decreases in child undernutrition to a larger degree than improvements in food availability (Smith and Haddad, 2000). Furthermore, health risks are reduced by only 30% when people obtain access to an improved water source such as a public standpipe or borehole rather than an unprotected dug well. Hygiene measures such as hand washing, as well as households' connection to a drinking water supply, could further reduce water-related mortality (Prüss-Üstün et al., 2009). The health impacts of

Box 7.3 Other relevant health risks

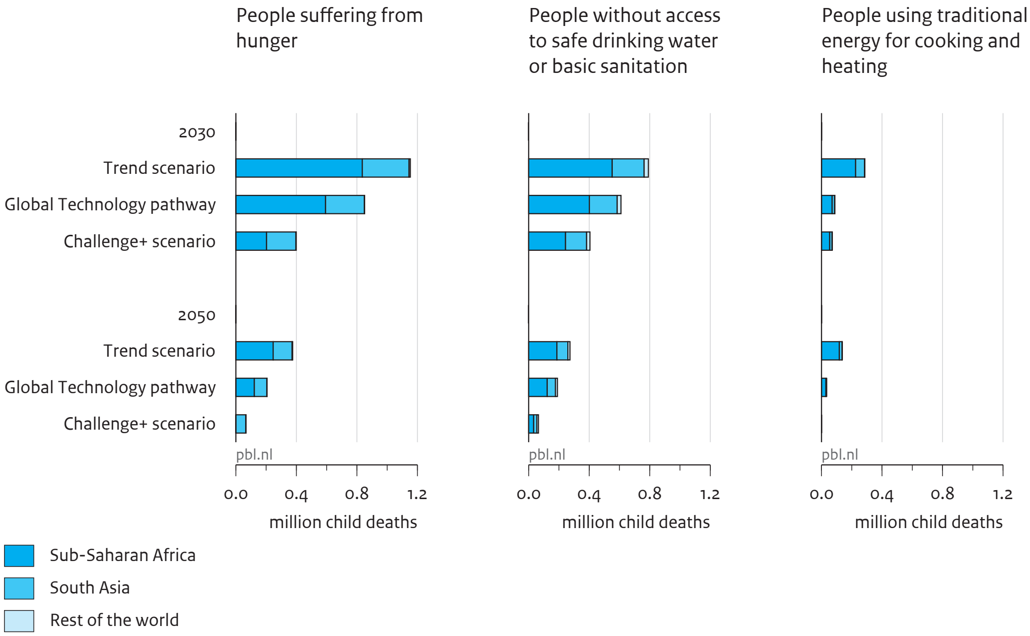
To further reduce mortality it is also necessary to target the other main causes of death. In 2030, the main remaining causes of death among children are perinatal conditions, such as low birth weight, attributable to 1.5 million annual deaths, and childhood diseases such as measles, attributable to 0.5 million annual deaths (WHO, 2008). Furthermore, by then chronic diseases will have become very relevant, especially among the elderly. In 2030, the two most important chronic diseases (i.e. cardiovascular and cancers) will be responsible for 50% of all deaths worldwide. Not only the current developed regions will face this chronic disease burden; developing countries will also experience this (Fuster and Voûte, 2005; Horton, 2005). In the light of urban air pollution and heat stress, cardiovascular diseases, lung cancer and respiratory infections are very relevant.

indoor air pollution can be further reduced by behavioural methods, such as good ventilation or the complete transition away from traditional biomass to modern energy sources, such as electricity and LPG. Finally, substantial increases in education level, especially of girls and women, have important implications for health (Marmot, 2010). Education reduces poverty through increased employment and provides skills for attaining better health. Women benefit through increased knowledge of how to protect health and seek proper healthcare for themselves and their children.

These issues are addressed in a fourth scenario: the Challenge+ scenario (see Figures 7.10 and 7.11). This scenario is based on the *Global Technology* pathway with some additional, more-stylised policies, such as further improvements in access levels (household connections to drinking water for all and a full transition towards modern fuels for cooking and heating, both by 2050) and investment in female education (full enrolment in secondary education for girls by 2030) (MDG2 is universal primary education by 2015). These extra policies were stylised in the sense that they were not calculated using the full modelling framework and, therefore, do not take into account socio-economic and environmental constraints. This Challenge+ scenario almost completely removes the environmental health risks and improves child mortality further by almost 25% by 2030 and 34% by 2050, compared with the *Trend* scenario. Removing health risks due to further improved energy and water services eliminates most of the attributable mortality. Furthermore, targeting female education significantly improves the utilisation of food – reducing child underweight due to better nutrition – especially in sub-Saharan Africa where secondary school enrolment for women in the *Trend* scenario is still only around 80% in 2050.

It should be noted that with respect to undernutrition, the *Global Technology* pathways and the Challenge+ scenario only capture the impacts of increased energy intake on the child mortality rate; they do not address the related effect of proteins and micronutrients (for those, historical developments were taken). However,

Figure 7.11
Global child deaths per cause



Source: PBL

micronutrients are still responsible for almost one-third of all undernutrition-related child deaths, while interventions to improve micronutrient consumption of especially vitamin A, Zinc, Iron and Iodine could be very cost-effective, with cost–benefit ratios of 1:30 for salt iodination and 1:4 to 1:43 for vitamin A supplementation (World Bank and IMF, 2012).

Health expenditures should be increased and should not be regarded as costs but as investments

Concerted international effort for scaling-up essential interventions for health promotion, disease prevention, treatment and risk-factor reduction through a coordinated sector-wide approach has been advocated by several reports (World Development Report, 2003; World Health Report, 1999 and 2002). The Commission on Macroeconomics and Health estimates that around eight million deaths could be avoided through increases in investments in global health and that this will in return generate at least a USD 360 billion annual gain during the 2015–2020 period (Commission on Macroeconomics and Health, 2001). Although these figures, both in economic and in health terms, are much higher than those discussed in this report, for which we looked specifically at food, water and energy, it raises two important notions, namely that health expenditures should be further increased, and also that this money should not be regarded as a cost but as an investment with a gain in return. Investing in health can be profitable from a national, macroeconomic perspective. And even at a lower level, investments in health have been shown to be highly cost-effective. For example, investments in water supply and sanitation have a cost–benefit ratio of 1:7 (Section 7.1). Investments in modern energy sources for cooking and heating also have average cost–benefit ratios of 1:7 (Chapter 6) and investments in micronutrient consumption can be even as high as 1:43 (previous section).

7.3.3 Managing human health risks

Human health and, especially, child mortality may be significantly improved through well-targeted policies on food, energy and water

Improving environmental health factors, such as eradicating hunger, providing full access to safe drinking water, improved sanitation and modern fuels for cooking and heating, significantly improves human health and brings the child mortality target (reduce by two-thirds, between 1990 and 2015, the under-five mortality rate) more within reach. In general, these health risks are relatively easy to avoid. Developed countries have already shown that with the right policies and investments these risks can be almost completely eradicated and even in developing countries there are many examples of countries fighting these risks with success. As well as these environmental health factors, the broader global environmental context should also be taken into account, not only through the adequate access to food, water and energy, but also more broadly through climate change, though these effects remain rather uncertain.

Furthermore, education, and then especially female education, has many positive effects; for example, through reduced risks of child underweight. In addition to this direct effect, increased education levels have indirect effects – such as a potentially lower population (see Chapter 4) – which can help make various goals more achievable.

A significant proportion of health outcomes is determined not by health policies but by policies in adjacent policy domains such as agriculture and energy. The inclusion of the concept of health in all policies recognises this broader interwovenness, and a plea is made for a coherent approach by integrating, wherever possible, public health impacts in all policies (Ståhl et al., 2006). All policies, for example, on energy, water and agriculture, should also be assessed in terms of possible health impacts.

Finally, the benefits of a healthy population should be taken into account when designing policies. The perspective of health costs needs to be changed into health investments by also indicating socio-economic returns. These returns can be regarded in the broadest sense, from the gain in time due to no longer having to collect water or firewood for several hours a day, to being more productive and earning a higher income, to valuing avoided morbidity and mortality.

EIGHT

An integrative response to sustainable development challenges

Previous chapters analysed how combinations of technological measures and changes in consumption patterns could contribute to achieving a set of sustainability objectives, taking into account the interlinkages between them. The potential exists for achieving all of the objectives. The fundamental question here relates to the type of governance structures that could bring about the transformative changes required to achieve the sustainable development objectives. This study suggest a pragmatic governance approach that consists of a shared vision for 2050, strengthened short-term targets, and strong policy actions by governments, building on the strength of civil society and business. This chapter relates these further to the international sustainable development agenda. This includes Sustainable Development Goals (SDGs), the transition towards a green and inclusive economy, the institutional framework for sustainable development and new strategies for international cooperation.

8.1 Common findings, dilemmas, trade-offs and synergies

The previous chapters discussed what it would take for a broad selection of sustainable development goals and targets to be achieved, in particular in relation to land and energy. Several important connections between the different goals and targets are identified. These connections are due to physical linkages between relevant elements as discussed in Chapter 2, and connections also exist between the related policy domains.

The total effort required to achieve the sustainable development goals is substantial
Achieving the goals and targets requires substantial changes in current consumption and production patterns. For instance, in order to meet the targets the energy system needs to be very different from the current situation and expected trends. The

improvement in carbon intensity needs to be around 4–6% per year, which is about three times higher than the historical rate. Major changes are also needed in agriculture. Where yields have declined in recent years, in the challenge pathways they would need to reach high levels compared to historical rates. Substantial investments are also required, in the order of a few percent of GDP. Macroeconomic studies show that such levels of investment are not likely to lead to disruptive economic impacts, whereas the cost of inaction would be considerable.

Meeting the development targets does not need to stand in the way of meeting environmental targets
Providing full access to modern energy sources will not exacerbate climate change problems. Additional CO_2 emissions are assessed to be less than 1% as the use of electricity and LPG is much more efficient than burning solid fuels on traditional cooking stoves. Furthermore, if access to food is well targeted and if the growth in meat consumption can be tempered, additional land use will be limited and could be further mitigated through efficient agriculture.

The pathways to achieve the goals have been explored as alternatives; however, as they all indicate that substantial effort is required it seems necessary to combine elements from the different pathways
The scenarios were defined as alternatives. However, they all to some extent require the same portfolio of options in order to meet the targets. For instance, while the storyline of the *Decentralised Solutions* pathway does not favour carbon capture and storage, the scenario is not able to reach the target without this technology. Consumption change measures will help to reduce demand and lower the total effort required to achieve goals, and therefore increase the chance of achieving them. The fact that many rates of change in the challenge pathways s seem high compared to historical rates means that it will be necessary to combine options.

Integrated responses can reap important benefits, but some areas require careful consideration
There are important synergies and trade-offs in achieving these goals. Several factors contribute to achieving multiple goals, such as efficiency improvements, consumption changes and reduced fossil-fuel use. Other factors achieve one goal but may have negative consequences for others, such as bio-energy and desalinisation. These connections are partly due to physical linkages between the different relevant variables, but connections also exist between the related policy domains. To ensure that sustainable development goals are met, both important dilemmas and potential synergies are identified in our analysis. Table 8.1 summarises the interactions between interventions to accomplish the goals analysed.

Dilemmas and trade-offs between the different issues
Some important dilemmas and trade-offs that need to be taken into account are:

- Population and economic growth imply that the demand for food and, especially, energy will strongly increase in the next 50 years. Because of this 'pressure' on the system, it is difficult to see how demand can be met without an increase in both renewable and fossil fuels (for energy) or high-yield agriculture (for food). However, this must be done properly to prevent a further increase in environmental pressures.
- In agriculture, key dilemmas exist with respect to further intensification to increase yields and avoid the further expansion of agricultural land versus aiming to reduce the environmental impacts in the immediate surroundings. In other words, how can we ensure the compatibility of high-yield sustainable systems with minimising current impacts in terms of water, pesticide and fertiliser use?
- From an energy and climate perspective, bio-energy could be a very attractive alternative to oil in transport, as well as being important to create net negative emissions in combination with CCS. At the same time, bio-energy will probably require additional land and thus lead to even more claims on land.
- For some technologies and measures, rebound effects exist that reduce the effectiveness of these measures. For instance, improving energy efficiency is likely to reduce energy prices, which, in turn, may result in a higher demand. As a result, part of the original gains might be lost. A similar situation exists with reducing meat consumption, certainly if implemented in only parts of the world. Significant rebound effects might be overcome through additional taxation or other measures to ensure high enough price levels.
- Response strategies face important questions regarding timing. For instance, with respect to climate change the optimal 2020 targets depend on different assumptions with respect to short-term inertia in emission reductions, long-term technology development (in particular the possibility of net negative emission technologies from biofuels combined with CCS), the acceptance of risk and the valuation of future costs versus short-term costs. In fact, assumptions on research and development also play a role; while some emphasise the importance of 'learning-by-doing', others emphasise the role of R&D in research laboratories. Based on the above considerations, people may take different positions on the question of whether short-term (2020/2025) goals should be set at an ambitious level or to allow for a learning period. Similar choices also exist with respect to other policies; for instance, with respect to bio-energy deployment or the importance of the short-term establishment of nature reserves.

Important opportunities for synergies also exist

There are some important examples of synergies illustrated with this study:

- As shown in Chapter 6, the combined cost of climate policy, air pollution control and energy security concerns can be significantly reduced by applying an integrated response. In fact, most of the synergy is due to climate policies. However, the fact that both air pollution control and energy security may result in immediate benefits may lead to a very different appreciation of the costs and benefits.
- There is likely synergy between climate policies, biodiversity and high agricultural yields. This synergy is clear for high temperature changes. At low levels of

temperature change additional carbon fertilisation may actually have a net positive impact on agricultural yields.

- Ecosystems provide important regulating and supporting ecosystem functions. The loss of ecosystems reduces these functions. At some level, this will become costly; for instance, the ability of ecosystems to prevent land degradation and to contribute to soil formation at some point may harm agricultural productivity. In other words, synergy exists between conserving ecosystems and sustaining the functions they provide.
- Reducing consumption results, in general, in synergies. In the case of reduced meat consumption, there are clear benefits for biodiversity protection and ensuring food security by reducing the competition for land. However, there is also a clear benefit for limiting climate change (by allowing for the re-growth of ecosystems due to more efficient land use). Moreover, studies suggest that the over-consumption of meat leads to negative health impacts. There are similar findings for reduced energy consumption, which helps mitigate climate change, improve energy security and reduce air pollution.
- Important synergies also exist with respect to reducing air pollution. First of all, positive impacts are likely for human health and ecosystems. Secondly, by reducing specific air pollution sources such as methane and black carbon it is possible to induce strong short-term positive effects on climate change mitigation.

Preparing for the undesired

This report analyses possible pathways and strategies for achieving sustainable development goals, but the track record in achieving agreed goals and targets unfortunately does not bode well. The challenges are huge and surprises are likely to happen. It is therefore wise to also prepare for the negative consequences of developments if current trends continue and, even if goals are met, the world is still committed to a certain level of global environmental change that we need to be prepared for. First and foremost the poor and most vulnerable groups in society will bear the brunt of unmitigated global environmental change, but it may also impact on human well-being and economic development worldwide. This is already illustrated by the fear of resource scarcity and the risks of supply chains being damaged.

Vulnerability, adaptation and resilience therefore need be on the agenda for the international community. This could be in the form of financial and technical support for adaptation in developing countries. It could also take the form of strengthening environmental rights, as rights-based approaches can play a valuable role in ensuring that governments stay on track in terms of achieving environmental goals and providing effective safeguards against the adoption of policies that reduce human and ecological well-being.

Table 8.1

Interactions between interventions to accomplish goals

Action to / Effects on	Eradication of hunger	Universal access to safe drinking water	Universal access to modern energy	Ensuring clean air	Climate change mitigation	Halting biodiversity loss
Eradicate hunger		ns	ns	ns	More GHG emissions from increased production (fertilisers; land expansion, tractors)1)	More impact of agriculture on ecosystems
Universal access to safe drinking water	Access to safe drinking water helps to prepare safe food Competition as well as synergy between water for residential use and in agriculture		ns	ns	ns	ns
Universal access to modern energy	Allows making use of income opportunities when less time is spent on collecting fuels, and health improved through less indoor air pollution	Water required for power generation Modern energy helps to improve access to safe water (e.g. pumps)		Less pollution from traditional energy sources (charcoal, firewood)	Less deforestation vs more fossil-fuel use, but modern energy more efficient than traditional energy systems	Less disturbance of natural ecosystems from wood collection for fuel or charcoal
Ensuring clean air	Less impact of air pollution on crop yields and quality	Less contamination from the deposition of airborne pollutants	ns		Depends on the choice of air pollutants to be targeted (BC/CH_4)	Lower deposition of atmospheric pollutants on ecosystems

Effects on / Action to	Eradication of hunger	Universal access to safe drinking water	Universal access to modern energy	Ensuring clean air	Climate change mitigation	Halting biodiversity loss
Mitigate climate change	Less risk of disruption of vital ecosystem services	Effects of climate change on precipitation patterns and potential evapo-transpiration	Higher energy price	Less pollution thanks to a reduced use of fossil fuels, particularly oil and coal		Less impact of climate change on biodiversity
	Bio-energy competes with food and feed and may spur scrambles for land; but also opportunities for poor in rural areas					Effects of GHGs and climate change on crop yields
						Additional land required for bio-energy crops
Halt biodiversity loss	Less land used for food production	A more gradual / uniform flow and cleaner water to rivers and aquifers	ns	More intact ecosystems contribute to air quality	Fewer CO_2 emissions from land conversion and agriculture Restoration of degraded land creates new CO_2 sinks	
	Preservation of ecosystem services helps safeguard long-term sustainable food supply	Increased water use by permanent vegetation				

Type of interaction: positive; negative; mix of positive and negative; ns: no significant interactions expected (until 2050).

8.2 International goal-setting for sustainable development

Currently, an overall vision on sustainable development is lacking. Although visions are sometimes regarded as soft tools, they may have a serious effect if they mark the clear choice for a sustainable future. Converging towards consensus at international and national levels on an overall vision may help to provide direction in policy-making. Such a vision would link sustainable development issues and involve formulating and agreeing on priorities for different types of countries. An important element here could be to agree on a set of sustainable development goals and targets.

The core of the sustainable development ambition is the twin challenge of satisfying human needs and aspirations as well as the carrying capacity of our planet. The analysis in this report is based on a translation of existing internationally agreed objectives for land and energy into long- and medium-term quantitative goals and targets.

Current goal-setting for sustainable development can be characterised as relatively unbalanced: goals are often unrelated, use different timeframes, have different degrees of concreteness and, in important areas of concern, are even sometimes missing. The previous chapters have operationalised these challenges further for food and energy. This provides elements for a more consistent formulation of visions, goals and targets, as well as pathways to achieve the goals. However, it will also be necessary to consider principles and processes, as well as means of implementation, to come to an agreement on a new set of goals.

A coherent set of priorities for sustainable development.
An import element of governance is developing a coherent set of priorities for society to make the sustainable development ambition operational. For global issues, this needs to happen at the international level. A common set of priorities, as a functional component of governance, may be articulated as a vision, in qualitative terms, and operationalised further in the form of quantified, time-bound goals and targets (see also Nilsson et al., 2012). A key advantage of a connected set of long- and short-term targets is that it provides a better way of monitoring progress.

The preparatory process for Rio+20 resulted in the idea to shape the international goal-setting process for sustainable development. The Rio+20 Conference comes three years before another important global date for sustainable development – the expiry, in 2015, of the Millennium Development Goals. The closeness of the two events has led some to start thinking about how a new goal-setting framework – more closely integrating environmental and development concerns – could be developed.

The governments of Colombia and Guatemala proposed a set of 'sustainable development goals' (SDGs), to be agreed in Rio. They suggested prioritising those themes and issues that are considered critical factors in moving forward the sustainable development agenda, inspired by Agenda 21. This could broadly include issues such as combating poverty, changing consumption patterns, promoting sustainable human settlement development, advancing food security, biodiversity and forests, oceans, water resources and energy.

Agreeing on sustainable development goals has been widely adopted as a possible concrete outcome for Rio. The remainder of this section identifies some of the pertinent questions that will need to be addressed to further elaborate the idea of 'sustainable development goals' (Lalonde, 2011; Raworth, 2011; Sanwal, 2012; UN High-Level Panel, 2012; United Nations General Assembly, 2011).

Sustainable development goals can build on strong features of the MDGs

Sustainable development goals can build on the strongest features of the MDGs – in particular their time-bound and quantitative nature as part of results-based policy-making. They can be applied to a broader set of sustainability goals for all countries to drive changes in policy and behaviour. Particular strengths of the MDG framework that could apply to other goal-setting exercises, such as sustainable development goals, are (Melamed, 2012):

- Brevity: many commentators agree that one key reason for the impact the MDGs have had lie in the limited number of goals and targets (Melamed, 2010). Rather than trying to encapsulate everything that was or could be known about development and poverty, the MDGs are a succinct list of a few goals on which there is global consensus and through which popular support and political action was mobilised.
- Quantitative targets: too many global agreements are expressed as vague commitments that are almost impossible to monitor. Most MDGs can be monitored through a set of specific quantitative targets that allow governments, civil society organisations and international organisations to monitor progress. The existence of quantitative targets may also have provided incentives for better data collection.
- Time-bound: having targets with a deadline has focused political attention and increased the sense of urgency around the MDGs. Repeated UN summits and civil society campaigns, for example, have emphasised the importance of accelerated action to meet the 2015 deadline.

Nevertheless, there are key differences between a poverty agenda, such as the MDGs, and a sustainable development agenda. This would make both agreement and implementation more politically difficult for SDGs, regardless of the structure of an agreement, as discussed below (Melamed, 2012).

Risks and opportunities of sustainable development goals

The MDG project has been largely about putting forward a set of positive targets that need to happen for poor people to escape poverty: more equity, more money, better health and more and better education. Some sustainability goals do fit directly into this sort of framework, including cleaner energy, better provision of water and more food grown in ways that does not irrevocably deplete natural resources. These are goals that could be included in a new set of goals to go alongside the more traditional MDG concerns of health, education and poverty. Some of them, such as access to drinking water and sanitation, are already included in the MDGs. Furthermore, ensuring environmental sustainability is one of the eight goals, although it lacks clear quantitative targets but includes indicators such as percentage of forest cover, CO_2 emissions and total freshwater used.

However, a longer-term sustainable development agenda is quite different from poverty reduction. In addition to the immediate and individual-focused goals of poverty reduction to which everyone can easily agree, sustainable development implies a set of outcomes that are more contested. A possible agreement on sustainable development goals would need to be an inclusive framework that is relevant to goal-setting in different country groupings, as illustrated in the previous chapters. It would need to focus on poverty reduction for the poorest in the world but also guide sustainable development pathways and sustainable production and consumption for middle-income and industrialised countries. In other words, for example, following the analysis in Chapter 6, a long-term ambition might be to prevent an increase in global mean temperature of more than 2 °C. In terms of more short-term targets, emission reduction targets may be formulated for the world as a whole, as well as for certain country groupings. This also raises the question of how to link sustainable development goals and existing and new environmental agreements. For example, in the UNFCCC, in which countries agreed that a new treaty or agreement will be drawn up in 2015, to come into effect in 2020.

Including sustainability in an economic development agenda for all countries worldwide will therefore be much harder than adding in, for example, a new goal for sustainable energy access for all, and requires a different and more difficult set of political trade-offs. The recent difficulties in achieving agreement on the Sustainable Production and Consumption agenda within the CSD may be illustrative for the negotiations to be expected when combining development and environmental goals in a single universal framework.

The potential difficulty of such negotiations indicates that there are significant risks in going down the sustainable development goals route as negotiations may end up with the same problems as currently experienced in multilateral environmental agreements on common and differentiated responsibilities (see Box 8.1). The MDGs, although having a limited agenda, have had great success in focusing attention on the problem of extreme poverty. A diversion of that agenda into more politically difficult territory could lead to a loss of the focus and moral power of the MDGs and a weakening of international action on extreme poverty. However, a successful agreement on sustainable development goals could be the first step towards a more integrated and successful approach to tackling global problems by providing direction for a green and inclusive economy.

Box 8.1 Sharing the safe and just operating space: new common and differentiated responsibilities to achieve sustainable development goals

Chapters 4 to 7 showed that staying within a 'safe and just operating space' is possible, but will have very different consequences for different groups of countries. The differentiation of responsibilities and obligations between countries worldwide, however, is highly controversial and will also influence the political deliberations on sustainable development goals. Different principles can be used to justify the one or the other allocation mechanism. The equal reduction in emissions by a certain globally agreed percentage, for example, advantages countries with high per capita emissions. For many developing countries, equal per capita emissions, for example, would be preferable, although even here some rapidly industrialising countries in the South would soon catch up with the traditional industrialised countries.

How are conflicts relating to equity and fairness to be resolved? It would seem that political struggles would eventually need to be resolved in mutually agreed principles and formulas for the allocation of obligations to individual countries. However, the principles that will guide these formulas are still far from being generally accepted. It is likely that there will not be a single operationalisation of equity principles that would be identical across issues. Equity will need to be defined and redefined for each issue, according to the particular complexities of the case and its particular constellation of interests, causalities and power. One important element in the search for novel, widely agreed principles of justice is the procedural context for these norm-setting processes. Here, the wide participation of stakeholders from both government and civil society is crucial and requires further attention.

Questions for designing a sustainable development goals framework

If this approach were to be successful as a successor to the MDGs, it is crucial to find a set of goals that are meaningful in sustainability terms for all countries but that also would be politically feasible. A number of issues would arise in trying to design such a set of sustainable development goals that bring development and environment together:

- What would they be for? Would the main aim be to mobilise global action and resources towards specific ends (a global public goods approach) or to set aspiring norms to inspire civil society action and mobilisation leading to national level policy change (the human rights approach), or would it be to set boundaries for national regulators and policy-makers (the approach of environment and trade negotiators)?
- What type of agreement would it be? The MDGs are not legally binding but rely more on the moral suasion of the cause to ensure action. Many environmental and other agreements, such as trade agreements in the WTO, are legally binding. How could

SDGs incorporate the moral force of the MDGs without watering down the legal power of current and future environmental agreements? Could a sustainable development goals framework guide further norm development in other multilateral fora if clear lacunae were to exist?

- What would they cover? The SDGs would need to cover all three domains of sustainable development: the social, the economic and the environmental domain. Thematic priorities could be identified in which goals, targets and indicators could be further determined, covering these three domains. As sustainable development is often perceived as an environmental issue, care needs to be taken to do this comprehensively and to equally include social and economic dimensions. Ample attention also needs to be paid to inter-linkages between issues. The SDGs would provide an important opportunity to put gaps in the sustainable development agenda on the agenda; for example, energy and oceans (WRI, 2012).
- Would sustainable development goals include means as well as ends? The MDGs are framed, quite deliberately, as goals relating to ends rather than means. How countries achieve, for example, universal primary education is not specified. This would encroach on countries' policy choices and sovereignty and make negotiations more difficult. It may be wise to follow the example of the MDGs on this and concentrate on ends. Means of implementation will be covered in the broader policy debates towards 2015. One of the other big debates at Rio+20, on the green economy, points to a possible direction for a discussion about means – but also to some of the difficulties in elaborating and agreeing on this approach.
- How would the sustainable development goals be defined? The MDGs are framed around individual entitlements to the basics for a decent life. Sustainable development goals would, from an environmental perspective, start with the whole planet as the key unit of analysis, considering global problems such as climate; for other problems that occur worldwide (e.g. water stress and biodiversity loss) local and regional goals would make more sense. It is also important to ensure that goals and targets focus on the aspects of the environment that exert the most powerful impacts on the lives of the poor (WRI, 2005). These types of goals need to be combined with development goals, targets and indicators to bring together both the social and the environmental agenda. A human and environmental rights approach could perhaps be applied here.
- At which level would they apply? The MDGs were established as a set of goals to be monitored globally, but since policy-making happens at national level they were inevitably applied at the national level too. SDGs would require action at both the global and national level, but creating the framework for this might require quite a different structure to that of the MDGs.
- Over which time period would they apply? The MDGs had a 15 year timeframe, but this may be too short to implement and monitor action on the environment. However, a longer timeframe might lead to a loss of political momentum as the goals would not be politically salient to current governments. Long-term vision and objectives for 2050 may be more explicitly combined with operational goals and targets for 2020/2030.

- To which countries would they apply? The MDGs imply different expectations from different country groupings – resources from donor countries (the global partnership in MDG 8) and policy change from recipient countries (MDG 1-7). For SDGs, it would be important that they are universally applicable, but differentiated to country circumstances. The question of who should do what has been one of the most highly charged in environmental negotiations, and introducing this element into the discussion of post-2015 goals could be one of the factors that most puts the global poverty project enshrined in the MDGs at risk.
- How could their impact on policy and actions be expanded? As important decisions on sustainable development are taken on a supranational level, it would be important to initiate a process in which sustainable development goals are adopted by international financial institutions, such as the World Bank, the IMF and regional development banks, as well as by the WTO and the private sector. Civil society and businesses could also be expected to pick up on the SDGs, if these would receive high-level political support.
- Which indicators to use? To ensure that sustainable development goals play a strong role in learning and accountability, goals and targets need to be measurable and verifiable and reflect the substantive choices that are indicated above. Indicators have to cover all three domains of sustainable development, be relevant for different country groupings, and so on. The indicators for sustainable development goals could benefit from the groundwork that has been done on 'beyond GDP' indicators in different sustainability domains (Stiglitz et al., 2009).

Careful process design necessary
Answering these questions will be a highly political process. Although it is impossible to predict the outcome, it needs to be clear that the most likely way to obtain an outcome that reflects all interests and represents a genuine consensus would be to have a balanced, inclusive and fair process, further guided, for example, by the UN SD Council (if agreed upon). One idea might be to organise this process around thematic areas in the form of issue networks around food, energy and water that include relevant actors from governments, international organisations, civil society and the business community to combine goal-setting and actions to achieve the goals. To be able to realise this, the Rio+20 conference could result in a clear mandate for a strong expert-based and bottom-up process between Rio and the expiry of the MDGs in 2015 to come up with a post-2015 set of sustainable development goals.

8.3 Key issues for making the transition towards a green and inclusive economy

Agreeing on new sustainable development goals is of little value if it is not followed by changes in the rules of the game. This report demonstrates technically feasible pathways towards achieving sustainability goals that green the economy and contribute to poverty reduction. Greening the economy in the context of sustainable development and poverty reduction is one of the key issues on the Rio+20 agenda. Although many definitions exist, the green economy can be defined as an economy 'that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities. In its simplest expression, a green economy can be thought of as one which is low carbon, resource efficient and socially inclusive' (OECD, 2011b; UNEP, 2011b; World Bank, 2011a)

There is however no obvious route to a green economy, but the focus on the 'greening of the economy' does signal an increasing interest in international policy-making for a new sustainable development paradigm that is more concrete and concerned with integrating environmental and social issues in economic decision-making. In international processes the green economy, however, may also become a new battleground for old debates between north and south about the relationship between the environment and development, economic growth, trade and green protectionism and aid conditionality. It is in this context interesting to note that both developed and developing countries are embarking on green development pathways that work within their specific country context (PEP, forthcoming; UNEP, 2011b).

As soon as there is a broad political commitment on the need to head for a green economy, this in itself also becomes a battleground as a variety of actors, businesses, industries and NGOs will then argue that their definition is the 'true' operationalisation of the green economy. Therefore, to get the process going, it is important to urgently think about the criteria by which the various suggested solutions should be evaluated to achieve the goals of a green and inclusive economy.

Realising the pathways presented in the previous chapters requires navigating a wide range of highly complex and interrelated issues simultaneously. This will involve a constant process of experimentation, incremental change, revision and re-ordering, in which long periods of stability may be interrupted by short periods of radical change. It is almost impossible to create optimal policies in such an unpredictable setting. What will be required instead is an inclusive, learning-by-doing process with careful monitoring of policy effects, and an ability to make critical choices and improvements consistent with the trajectories leading to long-term goals (Folke, 2010; Grin, 2010; Hajer, 2011; Loorbach, 2007; Swanson and . 2010; UNEP, 2012).

Realising the pathways also implies transformative changes to reach the sustainability goals, both in terms of human activities and the underlying systems that influence these activities. It is often difficult to see exactly how such changes can be implemented – and therefore exploring different pathways and experimenting with policy instruments is required. This process can be characterised as 'radical incrementalism'. On the one hand, policies need to be radical by shifting the direction of change to true alternatives rather than small efficiency gains along current routes. On the other hand, there is no blueprint of how to meet the targets and big changes are usually hard to implement.

Decision-making therefore needs to be a step-wise process of acting and learning. Under a radical version of incrementalism, governments try to run processes much more pointedly so that many relatively small steps may lead to a sizeable result (Hajer, 2011).

Society has an enormous capacity for innovation and learning. It is important that this capacity is channelled towards sustainable development, by ensuring that sustainable development considerations become part of the decision-making process. Our analysis also showed that there is no single and simple solution for the transformation; consequently, changing the incentive structures and allowing for flexibility in societal responses seems a more promising strategy than focusing on specific response options that would steer society along a single, preset path.

It is in this context that a long-term and sustained vision is required, so that the direction of development is clear for different societal actors. Experience with environmental and development goal-setting processes has shown that such an approach can enhance the effectiveness of policy-making by acting as a 'guiding star' in the day-to-day public and private decision-making required to move towards a green economy. It is necessary to establish a relationship between sustainable development goals and the greening of the economy. This section highlights some of the important elements for making this transition, based on the analysis in this report.

Transitions need to build on initiatives taken by the energetic society
It is important to recognise that very many initiatives are already being taken to realise a more sustainable development worldwide. It is exactly in these initiatives that we see the seeds of possible transitions. The underlying assumption is that there is 'social energy' available within society, and governments can build on this 'energetic society' (Hajer, 2011). Public policies need to better capitalise on the numerous consumer, civil society and business initiatives for sustainable development, which arise thanks to or in spite of government policies. A key step is to create convergence on a shared vision and policy objectives ('the future we want' which is a future that holds perspectives for all) to provide direction for multiple initiatives at all levels. By approaching sustainability issues from the perspective of the energetic society, governments can gain effectiveness and legitimacy if they view society as producers of sustainable development and allow scope for further cooperation between public organisations, businesses and citizens.

Ensure that the rules and regulations which govern day-to-day decision-making are adapted to create the right incentive structure for transformative changes
This means changing the rules that govern the day-to-day decisions of various societal actors in both public and private decision-making to release the energy of businesses and civil society. Changing the rules of the game would be the outcome of policy decisions, but may also mobilise new energies that could help to change patterns of institutionalised behaviour. This could also be done by providing a physical and institutional infrastructure that fosters more sustainable consumption patterns, by

influencing citizens' choices by changing the default (e.g. making vegetarian diets the standard), by paying more attention to rules in accounting or in insurance and risk, by strengthening monitoring and feedback mechanisms (e.g. information on energy use and smart metering) and by paying better attention to people's routines. Other examples include voluntary certification schemes, extended producer responsibility and green procurement by governments.

New ways of measuring growth and new orientations in the assessment of risk and viability are inevitable and potentially powerful components of the transition strategy for sustainable development

An important element of making the transition towards achieving the goals is rethinking the way we currently measure and monitor economic development and human well-being (Stiglitz et al., 2009). This requires a broader set of indicators for measuring economic, social and environmental dimensions of sustainable development that go beyond GDP, as the traditional and most-used indicator of development. This can also help establish a new normalcy. Here an international agreement on the adjustment of key indicators of progress is crucial. Indicators for both production and consumption will be needed, and they need to include both relative and absolute indicators to show both efficiency improvements and whether or not we are staying within environmental limits. These indicators have furthermore to reflect various dimensions of sustainable development: quality of life here and now, opportunities for future generations to achieve their well-being goals and the impacts that the pursuit of well-being and material welfare have on other regions in the world. These indicators are now starting to be applied in national accounts in different countries worldwide and in different thematic areas of the green economy (including energy and ecosystem goods and services). An example of what such a dashboard of indicators could look like is presented for the Netherlands in Figure 8.1 (CBS et al., 2011). Measuring what matters, systematic monitoring and periodic – comparative – reviews of progress on the agreed goals would promote continuous improvement and social learning as well as accountability (UNEP, 2012).

Policy instruments that help change the 'normalcy' towards sustainable development

The energetic society on its own may not be able to realise the transformative changes required to achieve sustainability goals. It is important to recognise that market signals are often incomplete and insufficient to introduce transformative change and public policies ought to correct for this. In a political context in which much is left to the market, a key role for the government, in addition to providing a stable, long-term vision and related short-term targets, is to provide a level playing field in which laggards in the system are also pushed in the direction of achieving sustainability goals. Here the enabling and regulatory role of governments comes into play.

Figure 8.1
Sustainability Monitor for the Netherlands 2011, scores on main dimensions

Source: CBS/CPB, PBL and SCP, 2011

The Sustainability Monitor for the Netherlands centres around three goals: guaranteeing a sufficient quality of life (1), which is not at the expense of the ability of future generations to meet their needs (2), and has no detrimental effect on the quality of life in other countries (3). This figure illustrates these three aspects of sustainability for a number of themes. The circles show scores on a number of indicators. The column 'Trend in NL' indicates whether the development in the Netherlands since 2000 has been positive (green), negative (red) or neutral (yellow). The column 'Position of NL in EU' compares the Dutch scores with those of the other 26 countries in the European Union. If an indicator is green, the Netherlands is one of the nine highest scoring countries. Red indicates that the Netherlands is one of the nine lowest scoring countries. Yellow means that the Netherlands is in the middle category. An exclamation mark denotes that the theme is an area of concern – that the score is low compared to the past, or compared with other countries (CBS et al., 2011).

The general approach would be to stimulate innovation through a combination of push and pull policies. A policy mix to make the green economy happen would need to:

- include the environment in the prices (including green taxation);
- abolish perverse incentives (e.g. environmentally harmful subsidies);
- include dynamic regulation that stimulates continuous improvements and innovation policies directed at RD&D, and in particular the scale up of best practices.

From a poverty-reduction perspective, building blocks for a green and inclusive economy would also include: natural resource access and tenure rights, green policies and investments that also focus on poverty reduction, markets and supply chains that promote innovations that are pro-poor, and harmonised international policies and country support for a sustainable economy for all.

Policies for less resource-intensive consumption patterns need to be part of the green economy

The analysis in the previous chapters shows the important contribution less resource-intensive consumption patterns can make towards the realisation of sustainable development goals. Rethinking consumption patterns also needs to be part of the green economy; in this report this is illustrated by the *Consumption Change* pathway. The multiple benefits make consumption change seem attractive, but in reality major voluntary behavioural changes are not very likely in western societies as incentives are usually lacking. This begs the question of how much to rely on or emphasise changes in lifestyle or consumption. Government intervention is often needed to avoid the 'social dilemma' and to establish and maintain rules for a large group of people in order to compel desired behaviour at an individual level for the interest of the collective. This can be done by setting standards or pricing collective goods and services. However, this is often considered politically unacceptable for changing consumption patterns and therefore other, less binding, approaches are often applied. Examples are providing a physical and institutional infrastructure that fosters more sustainable consumption patterns, influencing citizens' choices by changing the default (e.g. making vegetarian menus the standard), by strengthening monitoring and feedback mechanisms (e.g. information on energy use and smart metering) and by paying better attention to people's routines (Backhaus, 2012; Hajer, 2011; Vringer, 2007). As consumption issues are even more contentious at the international level than nationally, it is most important to develop careful international processes in which policy-makers, civil society, businesses and scientific communities work together to uncover what works and what does not in terms of changing consumption patterns, and to gradually work towards increasing political focus on this issue on national and international agendas. Parts of the answers at the international level lie therefore in information exchange, information systems (see Box 8.2), joint programmes and public-private partnerships as well as private initiatives (e.g. certified products) (Backhaus, 2012; UNEP, 2012).

Box 8.2 A global framework for product information tools aimed at sustainability

Information on more sustainable and less resource intensive production and consumption practices is potentially of immense value to society. That value depends, however, on the degree to which the information is available to those who make decisions about consumption and production at all levels. Currently, part of this value is created through the development and use of product information tools (e.g. voluntary labelling and certification) which may have a public and/or private origin. However, substantially more of this value could be generated if an attempt were made to coordinate and harmonise effective, inclusive and fair practices relating to the large diversity of product information tools. A possible step in this direction is to develop a global framework for product information tools aimed at strengthening their effectiveness, inclusiveness and fairness and as part of the policy mix for advancing sustainable consumption and production worldwide. Such a framework could be developed by consumer organisations with business, environmental and development NGOs and governments, for example, under the auspices of UNEP. The elements of this framework should be derived from an improved understanding of the functioning of product information tools under various conditions, leading to the establishment of procedural criteria for the development, implementation, monitoring and evaluation of product information tools. Hence, the framework should allow for the design and assessment of product information tools aimed at well-balanced forms of sustainability. It will thus create a basis for the harmonisation of approaches and the promotion of information tools with the highest potential to advance sustainable consumption and production globally.

Policy coherence is important: integrated responses can reap important benefits but some areas require careful consideration

There are important synergies and trade-offs in the pathways towards achieving the sustainability goals, as illustrated so far. Several factors contribute to achieving multiple goals, such as efficiency improvements, consumption changes and reduced fossil-fuel use. Other factors can achieve one goal but can have negative consequences for others, such as bio-energy and desalinisation. These connections are due to physical linkages between the different relevant variables, but they are not usually dealt with in an integrated manner in related policy domains. Focusing on synergies may make it easier to come to agreements. It will be especially important to align long-term goals and short-term targets and ensure consistency between different levels of decision-making. The green economy implies taking a 'whole of government' approach, combining sectoral and consumption policies.

8.4 Opening new strategies for global governance for sustainable development

Multilateral solutions are a key element of policies to achieve sustainable development goals. In theory, there are important advantages to this strategy, in terms of effectiveness, efficiency and legitimacy. So far, however, the diversity of interests between countries has meant that the multilateral level has been far less successful than hoped. There is thus a clear need to reform the current international sustainable development framework and to find new strategies for global governance, to be able to resolve the issues addressed in this report.

Three complementary strategies

Instead of aiming for a global consensus we envisaged a positive dynamic, stemming from the combination of (1) a global convergence on strategic visions and goals and (2) progress in a multiplicity of policy-making spheres. Smaller coalitions working together on particular key issues such as improving agricultural productivity in specific regions, or energy strategies for the billion people most in need, may be able to produce positive change if these separate trajectories start from a recognition of the overall strategic goals.

More pragmatic, polycentric, multi-actor and multi-level approaches to complex global challenges are emerging that may be better able to overcome some of the problems of the current system, may also mobilise more energy and yield better results, in the long term. Action at international level, ineffective as it may be, does however provide important legitimation and institutionalisation for more effective action on other levels or within civil society and the private sector. (Ostrom, 2010; Underdal, 2010; Verweij and Thompson, 2011).

Three complementary strategies for international collaboration are suggested that together may be better able to kick-start and push the transition:

- Build on societal initiatives to form new coalitions of the willing: this involves loosening the multilateral approach and focusing on new groups of non-state actors such as multinational companies or cities that are willing to adopt changes.
- Reframe sustainable development: this may help find new concepts and narratives that can mobilise citizens, businesses and governments in many different circumstances worldwide.
- Reform the current multilateral system: existing sustainability institutions at the international level need to be reformed to be better able to support the changes mentioned.

None of these strategies are new, but they are not usually considered togetherIn practice, a balance needs to be found between bottom-up initiatives within societies on the one hand and top-down steering by providing vision, regulation and enabling frameworks on the other.

Strategy 1: Build on societal initiatives to form new coalitions of the willing
Coalitions working together on particular key issues may be able to produce positive change. This could be smaller coalitions of countries making progress on specific issues. In the introduction we noted that the increased participation of non-state actors has given rise to new forms of global governance beyond that by the state. These are activities that are already ongoing at different levels in societies worldwide and include numerous small and large civil society initiatives (e.g. Transition Towns, MDG and Fairtrade Towns, renewable energy cooperatives and biological gardening initiatives), or initiatives by non-national governments, such as cities or provinces (e.g. C40 climate coalition, Covenant of Mayors and various US State climate corporations) or business initiatives (e.g. energy services companies focusing on efficiency, the World Business Council on Sustainable Development and Fairtrade networks). This increased participation offers potential for positive results, but following this strategy will also give rise to new questions for governments on how to relate to these developments – for example, regarding the disclosure of public and private information (see Box 8.3).

These actors are taking on new roles and responsibilities beyond lobbying and influencing governments, both nationally and internationally. This includes agenda-setting, norm- and standard-setting, verification, monitoring and implementation. New forms of global governance are emerging in this way, but these activities are dependent on anchoring within more formal negotiation processes (Galaz et al., 2012). Nevertheless, many such initiatives flourish without government intervention, based on the ideas of entrepreneurs who see the opportunities of green business, or motivated municipalities or provinces that wish to contribute to sustainability through direct action. Governmental interventions in these cases are often unnecessary and sometimes even counterproductive.

It is important, however, to examine these developments critically. In the run up to the 2002 Johannesburg World Summit on Sustainable Development much hope was placed on the success of multi-sectoral partnerships, 'type-2 outcomes', one of the main results of Johannesburg. These partnerships were expected to increase the engagement of industry and civil society in a major global effort of implementing the intergovernmental goals and targets set in Agenda 21 and in the conventions from the Rio Conference from 1992. More than 300 partnerships have been set up under this umbrella since 2002, and their effects have been mixed. Yet overall, recent research findings suggest a sobering picture regarding the type-2 partnerships. Even though some agreements seem to make a difference, many partnerships lack the means to show much effectiveness. Numerous partnerships even seem to be non-existent. Overall, without a stronger role for key UN agencies, an upgraded CSD and governments, these type-2 public-private partnerships appear today much less promising as effective instruments of global governance than in 2002 (Pattberg, 2012).

This, however, does not imply that the potential for an energising of civil society and the business sector in transnational settings is fully exhausted. On the contrary, many new initiatives suggest that policy experimentation by non-state actors can indeed lead to new ideas and the quick diffusion of new technologies, ideas and practices. Still, to be able to form part of a global transition towards sustainability, safeguards that ensure the legitimacy and accountability of non-state-actors also need to be in place. What is true for the type-2 public-private partnerships can be generalised to the broader set of new multi-stakeholder governance initiatives that have proliferated in the past 20 years within the field of sustainability governance. Although countres, by and large, have taken a back-seat position in the formation phase of novel governance arrangements, their crucial role in implementation, monitoring and possibly regulation or re-regulation is now widely acknowledged by scholars and practitioners.

What is more, we can see how fairly traditional government powers can play a key role in 'unleashing' these societal energies. Regulation based on the insights and preferences of partnerships, the fiscal translation of 'the polluter pays' principle or changes in the accountancy rules regarding the analysis of risks can be crucial in mainstreaming practices that have been working in a niche but would falter in the face of competition with firms that continue to produce in a traditional style. In that sense, the transition towards a green economy is based on a functioning 'triple helix' between business, knowledge institutes and government.

Furthermore, governments will need to play a role in monitoring the large variety of initiatives towards sustainability. Only if it is known what initiatives take place where and to what extent they contribute to global sustainability goals can it be judged whether additional government actions are required. If necessary, such monitoring can also form the basis of further support and the scaling up of existing activities; for instance, by linking actors that are operating at local and national scales to others working on similar activities in other countries, or by collecting and disseminating information about successes and failures in individual cases (e.g. see Vermeulen and Kok, in press). A recent assessment of the knowledge-base for the much needed institutional reform of sustainable development concludes that: 'New governance mechanisms cannot take away from the urgent need for effective and decisive governmental action, both at the national and intergovernmental level. Governance at supranational level can sometimes be a useful supplement especially when they avoid being captured by powerful interests and instead focus on problem amelioration. Yet even for this, it requires support and oversight from national governments.' (Biermann, 2012b).

The current situation is thus less a strict juxtaposition of either intergovernmental negotiations or non-governmental initiatives; rather it needs a careful integration of both perspectives in novel types of global governance arrangements.

Box 8.3 A Global Aarhus Convention

An important means to maintain human rights related to the environment is to grant citizens access to environmental information, participation in environmental decision-making and redress in environmental matters. With such procedural environmental rights citizens can contribute information to decision-making and hold governments accountable. The 1998 UNECE Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters is the most prominent example of a policy instrument to foster environmental rights. Suggestions have been made to create a global agreement based on the Aarhus Convention (e.g. see UNEP, 2012). Such an agreement would provide for global standards for the disclosure of information by governments, and possibly also by industry and private actors. Given widely different systems of governance and government across the world, a global agreement could provide for several core standards (e.g. governmental disclosure on core environmental indicators) combined with a range of additional standards for more controversial types of information, including private disclosure. Such a variation in standards around a fixed core could help find global acceptance for such a new agreement.

Strategy 2: Reframe sustainable development to find new mobilising concepts and narratives for action

Politically, it would be logical to let the framing follow an analysis of the geopolitical situation, an analysis of the actors that are able to make a difference and, of course, a careful reading of the political rifts, lock-ins and rivalries. Assessing the possible scenarios for breaking away from the trend requires considerable 'think space' (see also Box 8.4).

Possible questions could be: What is going to be the most effective way of using the power of framing for the political purposes at hand? And: Which frames would have the capacity to mobilise action and could have a lasting impact after Rio? This is hard to foresee, but it will be important to look for those sustainable development strategies that have a clear benefit for countries and other actors themselves; in other words, they have to relate to primary concerns. It is also important to keep the mechanisms that drive particular developments well in focus.

Applying market mechanisms to the logic of the transition towards a green and inclusive economy at least helps to see this transition as something that may be co-produced by the players in the current system in the first place. The ideas of a 'shared development agenda' (Nilsson et al., 2011) for a safe and fair operating space and a 'new social contract for sustainability' (WGBU, 2011) would provide frames that may bring development and the environment together. It is, for instance, also conceivable that green growth and the green economy really take off and are furthered through an 'Earth

Box 8.4 What is framing?
Framing plays a crucial role in complex issues such as sustainable development. For climate change, this is discussed in Hulme (2009). This is also highly relevant for the broader field of sustainable development. Climate change can be approached in various ways. It can be seen as a technological challenge, the result of market failures, a global distribution issue, or as the ecological limit to over-consumption. The frame determines not only the proposed solution strategy, but also singles out guilty parties and distributes power. Different frames appeal to different groups of people. For a more productive debate, we need to better define and recognise the different frames, and not conceal the political aspect. Solutions come from recognising the pluriformity in society and that people involved in a discussion are led by different frames (Hajer, 2011, p 23–25).

Race', as Thomas Friedman called it – a competition between national societies and companies that, motivated by self-interest, choose to head for a greening of their futures. In this frame, the role of government will be to create a level playing field. Applying the frame of green growth and relying on competition for sustainable development would not be unproblematic. Competition inherently comes with winners and losers and in this context could imply attempts to outperform rivals with a large technological innovative capacity, something which not all countries have access to. For developing countries, this may cause major concerns of losing out. Nevertheless, the green economy is a subject of powerful discourse that may help to understand what is happening in many developing and developed countries worldwide.

Strategy 3: Reform of the current multilateral system for sustainability
The multilateral system for sustainability also needs to be reinforced. The UN's ability to guide the global sustainability transition may be strengthened through a number of reforms. Transformative change (as opposed to incremental change that has so far been the case) at the UN level is needed that would result in better integrated sustainable development policies, strengthened decision-making and effective implementation. In a transformative-change context, five current shortcomings of the institutional architecture of sustainable development would be remedied.

First, such change could address the lack of integration of economic, social and environmental policies in the UN system towards stronger policy coherence for sustainability, hence integrating environmental, social and economic agendas. One option currently being discussed is the creation of a high-level UN Sustainable Development Council to replace the UN Commission on Sustainable Development and possibly even the Economic and Social Council of the United Nations (Biermann, 2012a). Internationally agreed sustainable development goals, as discussed in Section 8.2, would be the normative basis for the work of this council. The council could focus on voluntary peer review and sharing best practices for integrated approaches to sustainable development and a link to financing global public goods could perhaps be established.

Secondly, institutional fragmentation and the weakness of the environmental pillar of sustainable development could be addressed by upgrading the UN Environment Programme to a fully fledged international organisation, as proposed by amongst others the European Union, so that it is more on a par with other international organisations. Such an organisation could also play a stronger role in the discussion and promotion of more sustainable consumption patterns, possibly similar to the work of the World Health Organization in promoting healthy lifestyles. It could also play an important role in strengthening the synergy in the implementation of international environmental conventions and increase their effectiveness. The risks of fragmentation in global governance are addressed in Box 8.5

Thirdly, a stronger global governance architecture could also review the current governance of the areas beyond national jurisdiction and narrowly defined national interests. A more fundamental transformation of the international governance system could also give a stronger role to non-governmental organisations and move away from the traditional, purely intergovernmental policy system. One concrete proposal that dates back to the recommendations of the Commission on Global Governance (1995) is to create a special chamber for representatives of civil society, which could have clearly defined consultative rights in the various UN governing bodies.

Fourthly, there is little integration of information within the UN system. Existing scientific assessment bodies such as the Intergovernmental Panel on Climate Change are issue-specific and largely reactive to governmental mandates. Assessments that link the economic, social and environmental domains are rare. In addition, large areas of concern are not covered by such assessment institutions, such as the inter-linkages between issue areas. One concrete proposal in the environmental domain is to create a Global Environmental Assessment Commission. Such a commission would operate independently of governments as an autonomous early warning system (for details see Biermann, 2012a). Others plea for a global sustainability assessment (UN High-Level Panel, 2012) covering the various sustainability domains. In light of the interests and interrelations involved it seems important to consider creating a global assessment facility that could provide policy-makers at the various relevant sites with accurate and uncontroversial information and analysis. This does not need to be a big new institute, but could be a network of existing organisations currently working in this area. In any case different mechanisms need to complement each other and overlaps are to be avoided.

Fifthly, in the implementation of policies for specific issues such as land, water and energy, policy coherence between the different social, economic and environmental domains becomes ever more important, within the UN and between organisations within and outside the UN. Suggestions so far address the institutional sustainable

Box 8.5 Risks of fragmentation of global governance for sustainable development

The route of legally binding multilateral agreements is and remains the preferred strategy for addressing interconnected global issues, such as poverty, biodiversity loss and climate change. However, we do have to face the fact that this 'high route' is now difficult to attain. Internationally, policy domains are marked by a patchwork of international and transnational institu¬tions that are different in their character (organisations, regimes and im¬plicit norms), their constituencies (public, non-profit, for-profit), their spatial scope (from bilat¬eral to global), their subject matter (from specific policy fields to univer¬sal con¬cerns) and their underlying political formations. These situations can be understood as fragmented global governance architectures and it is becoming a major source of concern.

There is an apparent lack of con¬sensus in the academic lit¬erature on the consequences of fragmentation. Different predictions can be found in different strands of academic research that range from a positive, affirmative assessment of fragmentation to a rather negative one (e.g. Benvenisti and Downs, 2007; Hafner, 2004). Recent empirical analysis suggests (Biermann et al., 2009, 31) that, in the climate change domain, increased fragmentation has a negative impact on the problem-solving capacity of existing mitigation efforts: 'Different types of fragmentation are likely to have different degrees of performance. Although cooperative forms of fragmentation may entail both significant costs and benefits, we did not find convincing arguments in favour of a high, or conflictive, degree of fragmentation. On balance, fragmentation of global governance architectures appears to bring more harm than positive effects, and can generally be seen as a burden on the overall performance of the system'.

In this context, it becomes paramount to remain aware of how the need for further integration and coordination within and across governance architectures can be balanced against the benefits of a polycentric governance approach.

development framework in a general sense, providing for a more effective international architecture. Policy coherence can be defined as avoiding negative impacts of one policy domain on another or the shifting of a problem from one level to another level of decision-making. Timing is also important – short- and long-term goals need to coincide. Additionally, potential synergies can be identified and prioritised as part of a policy coherence agenda. Common goals and integrated policy frameworks will be needed at the international level that also take the important connections between these issues into account. An example is provided in Box 8.6 of how financing by development banks can have a more positive impact. Within the United Nations, a relatively soft form of coordination takes place through, for example, UN Water and UN

Box 8.6 Making public finance institutions more sustainable

Public finance can play an important role in stimulating investments in infrastructure and new technologies that support the transition towards more sustainable development paths. In addition, such investment may attract many times the initial investment from other financing sources through the 'leverage' effect. The EU, the G20 and the OECD have all recognised the importance of redirecting public investments to foster a sustainable future. However, many of the agencies charged with these investments have no strong strategic and operational frameworks in place to guide their decision-making in that direction.

A major player worldwide is the European Investment Bank (EIB), which is owned by the 27 EU Member States (Robinson, 2009). The mission of the bank is to further EU strategic objectives, including those related to climate change, biodiversity and development. In order to achieve this, the EIB provides funding and technical assistance to projects in EU Member States as well as in developing countries. In 2010 alone, the EIB invested 72 billion euros in projects (63 billion in the EU and 9 billion in third world countries).
In comparison with the total EU budget of 141.5 billion euros in 2010 (CEC, 2010), EIB's investments cannot be ignored to have an influence on the achievement of EU´s strategic objectives. Its total project portfolio is considerably larger than that of the World Bank. In 2010, the World Bank had USD118 billion in outstanding loans (IBRD, 2010) compared to 360 billion euros (USD 482 billion) of the EIB (EIB, 2011).

Although the EIB acknowledges the importance of the EU sustainability policy goals in various statements (e.g. EIB, 2009), these policies are not yet adequately translated and implemented in sustainable investment and reporting practices (EIB, 2010; Both Ends, 2010; Husova, 2009). Most significantly, there is a need for a drastic improvement of impact assessment and carbon footprint methodologies that need to be used consistently and for all projects. Furthermore, information about project appraisal procedures and project performance based on indicators needs to be more accessible and transparent in order to facilitate public control.

Energy. This includes the relevant parts of the UN, World Bank, IMF and WTO. More streamlined approaches will be necessary including stronger common principles and an institutional framework to operate in (Biermann, 2012b). Comprehensive target-setting as foreseen with the SDGs, the green economy as a common policy framework and more consistent monitoring could help focus these organisations, which have in most cases already subscribed to the principles of sustainable development.

For land-related issues, it is very relevant to emphasise the need for policy coherence as the issues are highly complex with many stakeholders involved. At the global level, it will be necessary to bring together the global trade regime, the biodiversity regime, agricultural policies worldwide and development assistance. These are very unequal institutional regimes with different degrees of authority. They therefore need to be put on a more equal footing and be given an institutional framework in which to operate. The trade regime and trade-related policies need to play an important role in creating a more robust food system that mitigates uncertainty and extreme food price volatility and favours, rather than hinders, trade in sustainably produced agricultural products (sustainable supply chains). More coherent international policy-making may help prevent unintended consequences of increasing claims on land, for example, including land-use change due to increases in biofuel production, large-scale land acquisitions ('land-grabbing') and new protected areas. This, for example, could include implementing codes of conduct, temporary moratoria, reporting mechanisms and registries as well as the better use of sustainability impact assessments for new policies that are likely to result in land-use changes here and elsewhere. Stimulating rights-based approaches that contribute to improving land tenure also has to be part of the policy mix.

For energy, for instance, comprehensive multilateral cooperation and an institutional home to address social, economic and environmental concerns relating to energy are lacking, or at best very weak (Karlsson-Vinkhuyzen, 2011). A start therefore has to be made on constructing a multilateral energy governance regime that is able to manage a long-term energy transition. Such a system should take into account not only the interests of potential winners of an energy transition, but also bear in mind that the countervailing power of existing fossil energy interests will have to be dealt with in order to make any progress at all. Closer cooperation between the organisations representing the interests of main fossil-fuel importers and exporters, IEA and OPEC, and the inclusion of main new fossil-fuel importers such as China in this cooperation, would provide a basis for managing key differing international interests around a global energy transition.

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Appendices

Appendix A: The integrated assessment model suite used in this report

This report is based on analysis using a set of coupled integrated assessment models developed at PBL. The core is formed by the IMAGE integrated assessment model. The main objectives of IMAGE today are to contribute to scientific understanding and support decision-making for global environmental and sustainable development problems by quantifying the relative importance of major processes and interactions in the society-biosphere-climate system (see also http://www.pbl.nl/image). The model is coupled to several other models, including the GLOBIO model, which describes changes in biodiversity worldwide, the GISMO model, which examines human development, including human health, and the FAIR model, which examines international climate policy.

The modelling framework operates at a resolution of 24 to 27 world regions for most socio-economic parameters and a geographical 0.5 x 0.5 degree grid for land use and environmental parameters. This medium level of complexity allows analyses to take into account key characteristics of the physical world (e.g. local soil and climate characteristics and technological detail) without excessive calculation times.
For IMAGE, the model version IMAGE 2.5 is used, a further development of IMAGE version 2.4, documented in MNP (2006). For GISMO, version 1.0 is used (Hilderink et al., 2008), for GLOBIO the model version GLOBIO 3 is used (Alkemade et al., 2009) and for FAIR, FAIR2.3 is used (Den Elzen et al., 2008; Den Elzen et al., 2011). Below we briefly discuss some of the main assumptions relating to model analysis in this report. A more in-depth description of the models used can be found in Kram and Stehfest (2012).

A1. Land

An important aspect of the IMAGE model is the geographically explicit description of land-use and land-cover change. The model distinguishes 14 natural and forest land-cover types and 6 man-made land-cover types. The IMAGE land and climate module computes land-use changes based on the regional production of food, animal feed, grass and timber and changes in natural vegetation due to climate change. This allows emissions and carbon exchange from land-use changes, natural ecosystems and agricultural production systems to be calculated. The land-use model describes both crop and livestock systems on the basis of the demand for food and feed crops, animal products, energy crops and forestry products. A crop module based on the FAO agro-ecological zones approach (FAO, 1978-81) computes the spatially explicit yields of the different crop groups and pasture and the areas used for their production, as determined by climate and soil quality. Where expansion of agricultural land is required, a rule-based 'suitability map' determines the order by which grid cells get selected on the basis of the grid cell's potential crop yield and its proximity to other agricultural areas, water bodies and human settlements. An initial land-use map for 1970 is incorporated on the basis of satellite observations combined with statistical information. For the period 1970–2000, the model is calibrated to be fully consistent with FAO statistics. For the period 2001–2050, the simulations are driven by the input from the TIMER (See Appendix A3) model (bio-energy) and LEITAP (demand for agricultural production), and by additional scenario assumptions, for example, on technology development, yield improvements and the efficiency of animal production systems.

Changes in natural vegetation cover are simulated in IMAGE 2.5 on the basis of a modified version of the BIOME natural vegetation model (Prentice et al., 1992). This model computes changes in potential vegetation for 14 biome types on the basis of climate characteristics. The potential vegetation is the equilibrium vegetation that should eventually develop under a given climate.

A2. Agricultural land supply and land use

Land-use factors in IMAGE are processed through the agro-economic LEITAP model to give sectoral production growth rates, land-use change and the degree of intensification resulting from endogenous technological improvement as estimated by FAO (Bruinsma, 2003) and other endogenous factors. The LEITAP model is a multi-regional, multi-sectoral, static, applied general equilibrium model based on neo-classical microeconomic theory (Nowicki et al., 2006; Van Meijl et al., 2006). It allows for the substitution of different primary production factors (land, labour, capital and natural resources) and intermediate production factors (e.g. energy and animal feed components). Regional land-supply curves in LEITAP represent the total area available for agriculture, in the order of the degree of suitability according to the IMAGE allocation rules. IMAGE also makes scenario-specific assumptions about the breakdown of livestock production over different systems, with consequences for feed composition, land conversion and overall productivity.

Regional endowments of labour, capital and natural resources are fixed and fully employed and land supply is modelled by land-supply curves (Eickhout et al., 2008) that specify the relationship between land supply and a land rental rate. The regional land-supply curves determine how additional outputs are met by a combination of land expansion and intensity of land use. Labour is divided into two categories – skilled and unskilled. These categories are considered imperfect substitutes in the production process. Land and natural resources are heterogeneous production factors, and this heterogeneity is introduced by a constant elasticity of transformation (CET) function that allocates these production factors among the agricultural sectors. Capital and labour markets are segmented between agriculture and non-agriculture. Labour and capital are assumed to be fully mobile within each of these two groups of sectors, but imperfectly mobile across them.

Hunger, defined as the proportion of the population with food consumption below the minimum dietary energy requirement, is determined using a lognormal distribution of food intake – estimated on the basis of the mean food availability per capita and a coefficient of variation – and the minimum energy requirement (FAO, 2003). For mean food availability per capita, 2008 regional food availability statistics from FAO (2011a) are multiplied with the change in private consumption volume from the LEITAP model for the different food types included. The coefficient of variation is taken from FAO (2011a) and changes in time are based on changes in per capita income. Finally, the minimum energy requirement is based on age and country-specific data (FAO, 2004).

A3. Energy production and consumption

The global energy system model TIMER (Targets IMage Energy Regional) has been developed to simulate long-term energy baseline and climate mitigation scenarios (De Vries et al., 2001). The model describes the investments in, and the use of, different types of energy options influenced by technology development and resource depletion. Inputs to the model are macroeconomic scenarios and assumptions about technology development, preference levels and restrictions on fuel trade. The output of the model demonstrates how energy intensity, fuel costs and competing non-fossil supply technologies develop over time. It generates primary and final energy consumption by energy type, sector and region; capacity build-up and use; cost indicators; and greenhouse gas and other emissions.
In TIMER, implementation of mitigation is generally modelled on the basis of price signals (a tax on carbon dioxide). A carbon tax (used as a generic measure of climate policy) induces additional investments in energy efficiency, fossil-fuel substitution, bioenergy, nuclear power, solar power, wind power and carbon capture and storage. Selection of options throughout the model is based on a multinomial logit model that assigns market shares on the basis of production costs and preferences (cheaper, more attractive options get a larger market share but there is no full optimisation) (De Vries et al., 2001). The TIMER model describes the chain from demand for energy services (useful energy) to the supply of energy by different primary energy sources and related emissions. The steps are connected by demand for energy and by feedbacks, mainly in the form of energy prices. The TIMER model has three types of sub-models: (i) the energy demand model, (ii) models for energy conversion (electricity and hydrogen production) and (iii) models for primary energy supply.

To determine access to modern energy sources for cooking and heating, access to electricity and related household energy demand the IMAGE-REMG (Residential Energy Model–Global) model has been developed. IMAGE-REMG is a bottom-up system-dynamic energy system simulation model integrated with the TIMER model. The model describes household energy demand in terms of fuels and electricity on the basis of several household end-use functions (cooking, lighting, appliances, space heating and cooling, warm water). These are based on the electrification rate and perceived costs (fuel costs, stove costs and fuel-specific penalties) (Van Ruijven, 2008; Van Ruijven et al., 2011). The available energy carriers in the model are coal, traditional biomass, kerosene, LPG, natural gas, secondary heat and electricity. Electrification rates are driven by per capita income, rural population density and urbanisation levels (Van Ruijven et al., 2012b).

A4. Climate

Data on emissions of greenhouse gases and air pollutants are used in IMAGE to calculate changes in concentrations of greenhouse gases, ozone precursors and species involved in aerosol formation at a global scale. These calculations, with the exception of CO_2, are based on the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007a). Changes in climate are calculated as global mean changes using a slightly adapted version of the MAGICC 6.0 climate model, which is also extensively used by the IPCC (Schaeffer and Stehfest, 2010). As climatic changes do not manifest themselves uniformly over the globe and patterns of temperature and precipitation change differ between climate models, changes in temperature and precipitation in each 0.5 x 0.5 degree grid cell are differentiated using the IPCC approach to produce global patterns. This includes the approach proposed by Schlesinger et al. (2000) to account for the regional temperature effect of short-lived sulphate aerosols. IMAGE 2.5 uses temperature and precipitation projections from the HadCM2 climate model run by the UK's Meteorological Office (data obtained from the IPCC Data Distribution Centre). The inputs into the climate model are emissions. These originate from the energy model and from the land-use/land-cover model. The consequences of land-use and land-cover changes for the carbon cycle are simulated by a geographically explicit terrestrial carbon cycle model. This simulates global and regional carbon pools and fluxes (pools include the living vegetation and several stocks of carbon stored in soils). The model accounts for important feedback mechanisms related to changing climate (e.g. different growth characteristics), carbon dioxide concentrations (carbon fertilisation) and land use (e.g. conversion of natural vegetation into agricultural land or vice versa). In addition, it allows for an evaluation of the potential for carbon sequestration by natural vegetation and carbon plantations.

International climate policy

The integrated modelling framework FAIR (Den Elzen and Lucas, 2005), version 2.3 (Den Elzen et al., 2012; Den Elzen et al., 2011) generally is used for the quantitative analysis of emission reductions and abatement costs at the level of 26 world regions for different climate mitigation regimes or effort sharing approaches. The FAIR–SiMCaP model (Den Elzen et al., 2007) combined with the MAGICC 6 climate model (Meinshausen et al., 2011) is used to determine the long-term emission pathways, consistent with the 2 °C target. These pathways are determined by minimising cumulative discounted mitigation costs under specific, user-determined criteria, such as long-term climate targets and 2020 emission levels. For the cost calculations, FAIR–SiMCaP uses the FAIR model. Emission reduction rates are limited to the maximum reduction rates found in the expert model. Also limited is the rate at which emissions can change from an increase to actual reductions (Den Elzen et al., 2010). The MAGICC 6 model is calibrated to reproduce the medium response in terms of time scale and amplitude of 19 IPCC AR4 General Circulation Models (Meinshausen et al., 2011).

The cost calculations are based on aggregated demand and supply curves for emission credits, as derived from marginal abatement cost (MAC) curves for different regions, gases and sources. More specifically, the MAC curves for energy- and industry-related CO_2 emissions were determined with the TIMER energy model by imposing a carbon tax and recording the induced reduction in CO_2 emissions[1]. For non-CO_2 greenhouse gases, MAC curves were derived from the EMF21 study, but made consistent with the baseline used here and time-dependent to account for technological change and removal of implementation barriers (Lucas et al., 2007). Using demand and supply curves, the model determines the carbon price on the international trade market, its buyers and sellers, and the resulting domestic and external abatement costs for each region. The abatement costs represent the direct additional costs due to climate policy, but do not capture their macroeconomic implications.

A5. Biodiversity

The GLOBIO model is a joint venture between the PBL Netherlands Environmental Assessment Agency, the UNEP World Conservation Monitoring Centre in Cambridge (United Kingdom), and the UNEP GRID-Arendal Centre. The model, including GLOBIO aquatic, was used to calculate changes in MSA (mean species abundance). The MSA indicator maps the compound effect of drivers of biodiversity loss and uses a suite of direct and indirect drivers provided by IMAGE in conjunction with the economic model LEITAP. The compound effect on biodiversity is computed using the GLOBIO3 model for terrestrial ecosystems. In addition, the future pathway of direct and indirect drivers depends on a variety of socio-economic assumptions, technological developments and policy assumptions, which are represented in the IMAGE and LEITAP models. As the IMAGE and the GLOBIO3 models are spatially explicit, the impacts on MSA can be analysed by region, main biome and pressure factor. GLOBIO 3 takes into account the impacts of climate and land-use change, ecosystem fragmentation, expansion of infrastructure such as roads and built-up areas and acid and reactive nitrogen deposition. For future projections, the underlying assumption is that higher pressures on biodiversity lead to lower MSA. The GLOBIO3 model contains global cause-effect relationships between each of the pressure factors considered and mean species abundance, based on more than 700 publications. These are applied in a spatially explicit fashion, namely using grid cells of 0.5 x 0.5 degrees with a frequency distribution representing the occurrence of various biomes within each cell. The effects of the considered pressure values are calculated and combined per grid cell to obtain an overall MSA score. The MSA per region or for the world is the uniformly weighted sum over the underlying grid cells. In other words, each square kilometre of every biome is weighted as equal (Ten Brink, 2000).

A6. Nutrients

The Global Nutrient Model describes the fate of nitrogen (N) and phosphorus (P) emerging from concentrated or point sources such as human settlements and from dispersed or non-point sources such as agricultural and natural land. Through rivers and lakes, the remaining nutrient load eventually enters coastal water bodies.

For point sources, a conceptual relationship between per capita N emissions and per capita income was used to calculate urban wastewater N discharge (modified from Van Drecht et al., 2005; Van Drecht et al., 2003). The N emission is calculated as an annual mean per capita and country as a function of food intake. Low-income countries have per capita N emissions of about 10g per day, and industrialised countries between 15g and 18g per day. The amount of N that is actually discharged to surface water is calculated as a function of the N emission, the rate of removal in wastewater treatment plants (expressed as a fraction of the N emission in raw wastewater) and the total population connected to public sewerage systems. In this approach, wastewater N emissions from rural populations are excluded and coastal areas with direct discharge to the sea are not accounted for. Different types of wastewater treatment with varying removal rates are distinguished for the removal of nitrogen: no treatment, mechanical, biological and advanced treatment.

For non-point sources, each IMAGE agricultural grid cell is divided into four aggregate agricultural land uses: grassland, wetland rice, leguminous crops (pulses, soybeans) and other upland crops. The annual surface nitrogen balance includes the nitrogen inputs and outputs for each land-use type. Nitrogen inputs include biological nitrogen fixation, atmospheric nitrogen deposition and the application of synthetic nitrogen fertiliser and animal manure. Outputs in the surface nitrogen balance include nitrogen removal from the field by crop harvesting, hay and grass-cutting and grass consumption by grazing animals. The surplus of the surface nitrogen balance is calculated from these components. The different input and output terms of the surface balance are discussed in detail in various publications (Bouwman et al., 2005; MNP, 2006; Bouwman et al., 2011).

The groundwater flowing into draining surface water is a mixture of water flows with varying residence times in the groundwater system.

The total nitrogen from point sources, direct atmospheric deposition and nitrate flows from shallow and deep groundwater act as the input to the surface water within each grid cell. In-stream metabolic processes remove nitrogen from the stream water by transferring it to the biota, the atmosphere or stream sediments. A global river-export coefficient of 0.7 (implying retention and loss of 30 % of the nitrogen discharged to streams and rivers) is used, which represents the mean of a wide variety of river basins in Europe and the United States (Van Drecht et al., 2003).

A7. Water

Recently, the IMAGE land and climate model has been extended by coupling with the LPJmL (Lund-Potsdam-Jena managed Land) model to better simulate the global terrestrial carbon cycle and natural vegetation distribution. The LPJmL model also includes a global hydrological model and improved crop modelling (MNP, 2006). Having started life as a dynamic global vegetation model (Sitch et al., 2003), the LPJmL model has since been extended to include managed land (Bondeau et al., 2007) and the

hydrological cycle (Gerten et al., 2004). For this report, IMAGE 2.5 was used without the coupled LPJmL model. However, for the water stress analysis, LPJmL was used as a stand-alone model.
LPJmL's hydrological model has been validated against discharge observations for 300 river basins worldwide (Biemans et al., 2009) and against irrigation water use and consumption (Rost et al., 2008). By linking with the LPJmL hydrological model, IMAGE scenarios now also model future changes in water availability, agricultural water use and an indicator for water stress. Water availability in the form of renewable water supply is computed by the LPJmL model hydrology module, although water in deep aquifers is not considered. LPJmL also estimates the water demand for irrigation, starting from the gap between precipitation surplus and potential evapotranspiration for the crop types grown on irrigated land. Current demand for other sectors (households, manufacturing, electricity and livestock) is adopted from the WaterGAP model calculations for the OECD Environmental Outlook 2008 (OECD, 2008b). The 2008 WaterGAP projection was only adjusted for differences in the development of key drivers since the 2008 Outlook, such as industrial value added and thermal electricity production by fuel as projected with IMAGE-TIMER.
Water supply levels and sanitation were modelled separately for urban and rural populations by applying regressions based on available data for 1990 and 2000 (WHO/UNICEF, 2008). The explanatory variables include GDP per capita, urbanisation rate and population density. Region-specific parameters are included for calibration purposes.

A8. Human health
The health model describes the burden of disease per gender and age. The methodology used for communicable (infectious) diseases – such as malaria, diarrhoea, lower respiratory infections, protein deficiency and AIDS – is a multi-state modelling approach that largely follows the approach described in the World Health Report 2002 (WHO, 2002) and the Disease Control Priorities Project (DCPP) (Cairncross and Valdmanis, 2006). The distinguished states are those of exposure, disease and death. This implies that, for various health risk factors, incidence and case fatality rates (i.e. the ratio between the number of deaths caused by a specific disease and the number of diagnosed cases of that disease) are taken into account. Some risk factors (such as underweight children) can also enhance other risk factors (e.g. lack of improved water supply). The level of health services can also modify these rates. The method for projecting the other causes of death – such as from non-communicable (chronic) diseases, other communicable diseases and injuries – is based on Mathers and Loncar (2006), who developed a method to link changes in mortality rates for the most important causes of death to factors such as GDP, smoking behaviour and human capital.

Child underweight is modelled as a linear function of improvements in average food intake, the ratio of female to male life expectancy at birth, female enrolment in secondary education and access to clean drinking water (Smith and Haddad, 2000). Based on a normal distribution, the total number of underweight children is divided into a mild, a moderate and a severe underweight group (De Onis and Blossner, 2003). The main risk factor for pneumonia, chronic obstructive pulmonary disease (COPD) and lung cancer is indoor air pollution, caused by cooking and/or heating with solid fuels, based on the IMAGE-REMG model (see energy production and consumption). The effect is increased in children who are underweight. The methodology to describe the burden of disease attributable to this risk factor is adopted from the WHO (Desai et al., 2004). Given the different levels of connection to water supply and sanitation facilities in the regions, relative risks are used to calculate incidence levels of diarrhoea (Cairncross and Valdmanis, 2006). The incidence is modified by the level to which a child is underweight (Edejer et al., 2005) and temperature levels (McMichael et al., 2004). The case fatality rates are modified by underweight levels and the use of oral rehydration therapy.

Urban air pollution is determined using the Global Urban Air quality Model (GUAM). GUAM originates from the GMAPS model (Pandey et al., 2006) and links observed PM10 concentrations to a set of variables of economic activity, population, urbanisation and meteorological information for 3 200 'major' cities in the world (i.e. cities with populations over 100 000 or national capitals). Based on these concentration levels, the health effects (acute respiratory diseases, lung cancer and cardiopulmonary diseases) on the population exposed are determined.

Note

1 In order to capture the impact of inertia and technology development, these MAC curves have been recorded as a function of time and for different tax profiles (representing early action and delayed response situations).

Appendix B: Selected farm-level practices in strategies of sustainable intensification

Practice	Explanation	Benefits	Threats / risks	Actions required to overcome threats	Applicable to	References
Patches or strips of natural vegetation on cropland	Provide habitat for pollinating insects and insect predators; along contours they provide a barrier against runoff water	• improved pollination and pest control • soil and water conservation (if along contours) • increase in biodiversity (beyond agriculture)	• less land available for crops • no warrantee against pest outbreaks (occasional outbreaks may undermine confidence) • transition towards a beneficial system may take many years	• awareness-raising • payments for environmental services • restrictive regulation for pesticide use	Any production system. Crucial in organic systems and systems with IPM	Olson and Wäckers (2007); Klein et al. (2007); Bianchi et al. (2006)
Rehabilitation of degraded land	Agronomic or ecological restoration of degraded land	• provision of more ecosystem services (e.g. water regulation, carbon sequestration, biodiversity, agricultural production) • stop provision of disservices from degraded land (e.g. dust storms, sediment loads in streams)	• requires high investments • tends to take many years • high labour requirements (can be an advantage if cheap labour is available that would otherwise be idle or migrate to cities)	• demonstrate benefits • social marketing • payments for environmental services (e.g. carbon sequestration, decreased sediment in streams) • government investments	Situations of • severe land degradation • land scarcity • high social or economic costs associated with degraded land • availability of cheap labour	Benayas et al. (2009); Papanastasis (2009); Westley et al. (2010); Mekuria et al. (2011)

Practice	Explanation	Benefits	Threats / risks	Actions required to overcome threats	Applicable to	References
Crop rotation / intercropping	Different crops are grown on the same land, in succession (rotation) or together, e.g. mixed or in alternating rows (intercropping)	• helps to avoid build-up of pests and diseases • rotation with legumes provides nitrogen for following crop • more permanent soil cover under short rotation helps to suppress weed proliferation and protects the soil against erosion and sealing • use of facilitative interactions in intercrops • mix of varieties increases the general resilience of the crop compared to monocultures	• labour, knowledge • in short term, combination of crops often less profitable than single focus on most profitable crop • difficult to select appropriate combinations to take advantage of synergies in intercrops while avoiding competition or other tradeoffs • difficult or impossible to apply specific management to intercrops	• training, investigate alternatives to increase choice of crops for farmers • research to improve and quantify understanding of interactions between crops and to identify optimum combinations for specific situations • tools / techniques for specific management of intercrops	• organic systems • regions with long growing season where one intercrop can be sown towards the end of growing cycle of the other, as quasi-rotation • any other system if difficulties can be overcome	Kirkegaard et al. (2008); Liebman and Dyck (1993); Letourneau et al. (2010); Liebman and Dyck (1993); Malézieux et al. (2009); Hauggaard-Nielsen and Jensen (2005)
Soil and water conservation structures	Bunds or terraces of soil or stones built along contours (or at a small angle)	• prevent soil erosion • prevent runoff of water and nutrients	• construction and maintenance are costly and/or labour-intensive • soil disturbance (less fertile subsoil comes to the surface next to embankments)	• minimise the need for such structures by investigation of alternatives, for example, permanent covering with crops or natural vegetation	Sloping land in highly productive areas, or where opportunity costs are low	Sahrawat et al. (2010); Liniger and Critchley (2007)

Practice	Explanation	Benefits	Threats / risks	Actions required to overcome threats	Applicable to	References
Precision farming techniques	Includes practices such as: • automatic dosing of inputs in accordance with field variability (variable rate technology) • permanent traffic lanes (machinery always use the same tracks for field operations) • computer-assisted decision support, e.g. to optimise scheduling of field operations	• more profit through higher yields and/or lower costs thanks to more appropriate practices, more efficient use of resources, less waste • less environmental impacts • improved trafficability on permanent traffic lanes, supports soil structure improvement between traffic lanes thus decreasing runoff and erosion	• knowledge-intensive • sensing and information systems to determine site-specific optimum rates not yet fully developed • generic computer-assisted decision support systems rarely respond to needs of individual farmers. Tailor-made systems are expensive and/or difficult to use • some operations require expensive high-precision field guidance systems	• R&D to improve technology and make it more affordable • participatory user-oriented system development • research, training and awareness-raising about costs / benefits vs. conventional practices	Capital-intensive systems. Some concepts can be adapted for low-capital systems	Boyer et al. (2011); Robertson et al. (2009); Hochman and Carberry, (2011); Woodward et al. (2008); Matthews and Stephens (2002); Lamers et al. (1986); Tullberg (2010)
Push-pull technologies	Combination of insect-repellent vegetation (push) with attractive plants or pheromone traps (pull) to keep insect pests out of crop fields	• lower pest incidence, less need for insecticide	• often difficult to fit into farm system. Life cycle of repellent and trap plants must be tuned with target crop • labour- and knowledge-intensive, push and pull plants require management and occupy land area but usually have little commercial value	• integrate the concept with strips of natural or semi-natural vegetation • R&D to identify combinations that combine effectiveness with ease of management and high economic returns	Any system, as part of integrated pest management strategy. Genetically modified pull crops (e.g. Bt) not fit for organic systems	Hassanali et al. (2008); Khan et al. (2011), Cook et al. (2007); El-Sayed et al. (2006); Witzgall et al. (2010)
Sterile insect techniques	Release of large numbers of sterile insects (usually males) that outnumber wild insects with whom they compete for mating, resulting in reduction in next generation's population	• disrupts proliferation of pests	• knowledge-intensive • large area needs to participate (risk of free-rider behaviour of non-participants)	• research to optimise the technique for specific conditions • community level extension	IPM	Dyck et al. (2005); Alphey et al. (2008)

Practice	Explanation	Benefits	Threats / risks	Actions required to overcome threats	Applicable to	References
Smarter use of chemicals (pesticides, herbicides, chemical fertilisers)	Optimised use of chemicals in time and dose to kill pests and weeds and to provide nutrients to the crop	• easily applied, rapid response	• costly, especially when patented • health and environmental risks • crops treated with cheaper patent-free chemicals are sometimes banned from exports to rich countries because of alleged health risks • difficult to access in remote areas • build-up of herbicide/ pesticide resistance by target weeds and pests • subject to theft	• dynamic regulation against excessive use • smarter chemicals (e.g. more specific pesticides, controlled release through encapsulation) • publicly funded R&D for better chemicals, avoiding issues with patents • novel application techniques, training and legislation to avoid environmental and health risks • minimise use by adopting preventive measures and biological control and organic fertilisers and green manures whenever possible • introduce small packs of fertiliser	Any system, except organic	Smith et al. (2008); Hack et al. (2012); Morris et al. (2007); Spiertz (2009)
Improved integration of animal manure in crop production	Efficient use of animal manure as fertiliser for crop production on the same or nearby farm	• improved nutrient recycling: – less need to purchase chemical fertilisers – reduced emissions of nutrients and greenhouse gases	• the structural changes required for full integration are difficult to accomplish in regions with highly intensive strongly specialised production • high transport cost of manure from regions with high livestock density to regions with predominantly arable agriculture	• policy incentives to shift towards mixed farming rather than specialised crop or livestock production (at farm or regional level) • concentrate or retrieve nutrients from manure • legally restrict or charge inefficient manure use	• any situation with suitable conditions for crop and livestock production	Wilkins (2008); Russelle et al. (2007); Oenema et al. (2007); Steinfeld et al. (2010); Herrero et al. (2010)

Practice	Explanation	Benefits	Threats / risks	Actions required to overcome threats	Applicable to	References
Improved plant varieties or animal breeds	For example, more robust or more productive animals, or drought-resistant, insect-resistant, herbicide-resistant, higher-yielding, perennial versions of grain crops such as maize, wheat, rice and oilseed, developed through conventional breeding or genetic engineering (GM)	• higher yields, better adapted to specific conditions • resistance to herbicides and pests allows more environmentally friendly management • more efficient water and nutrient use and less soil disturbance with perennial grains (no-till) and soil protection by permanent cover	• breeding programmes are costly and take a long time, commercially unattractive for resource-poor farmers • varieties adapted to extreme conditions often perform less well under good conditions • dependence on patented genetic material • risk of genetic drift of GM crops • development of resistance in weeds • little advancement of operational GM technologies beyond insect and herbicide resistance in field crops • ethical concerns and societal resistance with respect to GM crops, can be difficult to market for export	• public funding to develop wider range of varieties (e.g. drought-resistant, more nutritious) • address risks and concerns of GM • novel trait-based methods to speed up selection of promising varieties • participatory plant breeding to ensure good match with farmers' needs	Any system (GM not in organic)	De Melo-Martin and Meghani (2008); Batista and Oliveira (2009); Gressel (2010); Rains et al. (2011); Glover et al. (2010); Bell et al. (2010)

Practice	Explanation	Benefits	Threats / risks	Actions required to overcome threats	Applicable to	References
Improved animal husbandry	Includes practices such as controlled grazing, improved feeding and water management,	• avoids overgrazing and soil trampling which cause soil compaction and erosion • improved labour efficiency • facilitates animal management (reduced costs) • improved feed conversion efficiency • reduced emissions per unit produce	• knowledge to manage and take advantage of improved system • labour requirements for feed and forage management (but animal management requires less labour) • misfit with cultural habits • high-quality feed requires dedicated production or must be purchased	• education and training • research into improved feed and forage based on locally available crops or residues	Any livestock or crop-livestock production system	Drewry and Paton (2000); Haskell et al. (2006); (Amede et al., 2009)
Improved sanitary measures and housing for livestock production	Includes, for example, vaccination, deworming, dipping baths, and housing that provides adequate shelter, ventilation and cleanliness	• lower incidence of disease and mortality • improved feed conversion efficiency • reduced emissions at systems level • public health benefits of improved sanitation	• knowledge of adequate measures and availability of veterinary services • (trained) labour requirements • contamination of soil and water at dip sites • capital investment for improved housing • risks and inconvenience associated with mega-units • trade-off between efficiency gains and animal wellbeing in intensive confined systems	• training; establish adequate veterinary services; • regulation to ensure responsible handling of chemicals and medicines • development of safer control and prevention methods • provide affordable credit • regulation to avoid excessive concentration of livestock and/or negative impacts thereof	Any livestock or crop-livestock production system	Haskell et al. (2006); Walker (2011); Waage and Mumford (2008); Gilchrist et al. (2006)

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PBL Netherlands Environmental Assessment Agency is the national institute for strategic policy analysis in the field of the 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.

In 1992, in Rio de Janeiro, governments worldwide agreed to work towards a more sustainable development that would eradicate poverty, halt climate change and conserve ecosystems. Although progress has been made in some areas, actions have not been able to bend the trend in other, critical areas of sustainable development, such as providing access to sufficient food and modern forms of energy, preventing dangerous climate change, conserving biodiversity and controlling air pollution. Without additional effort, these sustainability objectives also will not be achieved by 2050.

This report analyses how combinations of technological measures and changes in consumption patterns could contribute to achieving a set of sustainability objectives, taking into account the interlinkages between them. The focus is on identifying the necessary level of effort, possible pathways, synergies and trade-offs. In a technical sense, the potential exists for achieving all of the objectives. However, the question to be answered is: What sort of governance structures could bring about the transformative changes required to meet the sustainable development objectives? We suggest that a pragmatic governance approach that consists of a shared vision for 2050, strengthened short-term targets, and strong policy actions by governments, building on the strength of civil society and business, could bring us further along the roads that lead from the 2012 Rio Conference into the future.

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