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Background report to the OECD Environmental Outlook to 2030 Overviews, details, and methodology of model-based analysis

Netherlands Environmental Assessment Agency

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About this report

This background report provides overviews of the forward-looking analyses carried out for the *OECD Environmental Outlook to 2030* (OECD, 2008). The first of these overviews gives the results of three comprehensive policy packages that were simulated: enhanced environment-related policies in *OECD countries*, in *OECD countries+BRIC* and in *OECD countries+BRIC+Rest of the World*. The second overview summarises the impact of the Baseline and policy packages on the various regions, showing important differences and similarities. These overviews are important in order to appreciate the case for international collaboration.

The focus of this report is on the comprehensive analyses conducted with the suite of models of OECD, MNP and others. It does not discuss theme-specific simulations that were run directly with the ENV-Linkages model of OECD. Moreover, the focus of the report is on the analyses in which model-based quantification is important.

Furthermore, this report documents the results of model-based quantification in more detail than available in the *OECD Environmental Outlook* report. Frequently these details have featured in discussions with delegates and other reviewers and, from a good practice point of view, are therefore documented in this report.

Other examples of the importance of documenting details are the time series that were developed as part of the modelling for the Outlook. For many environmental variables, the full set includes the period from 1970 to 1980, which helps to put the projections into perspective. Additionally, the analysis for the slow-changing processes features a policy horizon of 2030 and an impact horizon of 2050. This background report gives this sort of wider information, allowing the Outlook reader a better understanding of the results in the main report.

Finally, this report describes the modelling framework and the assumptions behind the outcomes in the *OECD Environmental Outlook to 2030*. It explains the relation between the variables used in the Outlook. Also, it discusses the main uncertainty issues at a deeper level than in the main report.

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Keywords:
Assessment, outlook, environment, model, scenario, world, future, policy, economy, globalisation, integrated assessment, uncertainty

Rapport in het kort

Wanneer Brazilië, Rusland, India en China meedoen én wanneer er snel actie wordt ondernomen, heeft internationaal milieubeleid een kans van slagen. Serieus klimaatbeleid is in dat geval uitvoerbaar en betaalbaar. Het Milieu- en Natuurplanbureau heeft hiervoor samen met de OESO een pakket maatregelen doorgerekend op het gebied van vrijhandel, klimaat, water en lucht. Deze analyses vormen de basis van de *OECD Environmental Outlook to 2030*.

Résumé

La politique environnementale internationale a une chance de réussir si le Brésil, la Russie, l'Inde et la Chine participent, et si une action rapide est prise. Alors, une politique climatique sérieuse sera abordable et faisable. L'Agence Néerlandaise d'Évaluation Environnementale (MNP) et l'OCDE ont évalué un ensemble de mesures de politique dans le domaine du libre échange, du climat, de l'eau et de l'air. Ces analyses forment la base des *Perspectives de l'Environnement de l'OCDE à l'horizon 2030*.

Ce rapport de base offre la présentation et les détails des analyses pour les Perspectives, basées sur des modèles d'évaluation intégrées. Les analyses globales ont été menées dans 24 régions. Elles couvrent le changement climatique, la pollution de l'air en milieu urbain et les impacts sanitaires liés; la charge nutritive à l'environnement aquatique par l'agriculture et par les tendances en assainissement et systèmes d'égout; la biodiversité terrestre.

Un scénario de ligne de base a été développé, ainsi que trois ensembles de politique. La majorité des analyses basées sur les modèles pour les *Perspectives de l'Environnement* incluent un examen rétrospectif jusqu'en 1970 et prospectif jusqu'en 2050. Ceci permet l'évaluation du coût de l'inaction politique et de la remise à plus tard d'une telle action.

Ce rapport de base compare les impacts de la ligne de base pour les différentes régions du globe. Il évalue également l'impact des incertitudes dans la modélisation des messages clés des *Perspectives de l'Environnement*.

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Summary

What will be the consequences, over the next decades, if no policy action is taken to address the key environmental issues? What can be done about the problems? What is the significance to governments of OECD countries of the increasing global interconnectedness and the emerging significant players such as Brazil, China, India and Russia? What does this mean in terms of the potential for and type of solutions to environmental problems of the next decades?

The new *OECD Environmental Outlook to 2030* reports on these questions (OECD, 2008). Its backbone is model-based quantification. This background report of the Outlook provides overviews, details and a methodological account of the model-based analyses developed for the Outlook. It focuses on the environmental projections. A closer look at uncertainties is included.

The key dimensions of the analyses for the Outlook are as follows. Most of them cover the past from 1970 and the future up to at least 2030 (2050, for many issues). As a reference for policy options, the consequences of a no new policies Baseline are quantified. Among other things, this provides the basis to assess the consequences and some of the consequences of inaction.

Three policy packages are analysed, comprising measures on issues ranging from agricultural trade to worldwide air pollution. They illuminate the link between policies of OECD countries and those of the new significant players in the world economy. The packages are distinguished as follows: enhanced policies in OECD countries only; in OECD countries plus Brazil, Russia, India and China (BRIC); and in OECD countries plus BRIC plus the Rest of the World.

In order to properly assess efforts and the distribution of impacts, a fairly detailed regional breakdown has been applied, namely 34 regions in the economic modelling and 24 regions plus a spatial grid for the environmental projections.

The overviews in part 1 of this background report show, for example, that the impact of air pollution on human health can be actively pushed back. In many parts of the world outside OECD, air pollution policies have to row against the tide of urbanisation and ageing, when attempting to effectively reduce health impacts. Global circulation of air pollution in the northern hemisphere is becoming a handicap for local air quality managers.

The details in part 2 make up the lion's share of this report. They show, for example, expansion of sanitation and sewerage in the spirit of the Millennium Development Goals, competing with the need to protect water ecosystems and human health – necessitating that sewage treatment is part of sanitation programmes. Also, they show that limiting global warming at two degrees Celcius is achievable but requires, among other things, a more compact agriculture. In another example is shown that biodiversity is declining in the Baseline as well as in the policy packages, for lack of specific policies.

The methodological account in part 3 decribes the models of OECD and MNP, as well as of others, that have been used in support of the analysis in the Outlook. Special attention is given to the way they have been combined for this exercise. The discussion of uncertainty issues identifies sources of uncertainty, as is also briefly touched upon in the Outlook itself. The Baseline, problem framing and indicator selection are important factors. It is important to realise that the Baseline is not the sure autopilot path to 2030 and 2050 in terms of environmental conditions.

For example, the coming decades could conceivably bring lasting dependence on large-scale low-tech coal use in some regions. This would mean much more air pollution, much more greenhouse gas emissions and consequently the cost of inaction would be much larger.

The Baseline

The Baseline projects a stylised picture of the environmental developments in the next decades. Its hypothesis is no new policies in response to environmental pressures - as well as no new policies on subsidies in agricultural production and on tariffs in agricultural trade. The picture from an environmental perspective is disconcerting. In the absence of additional policy interventions and under conservative economic assumptions, the environmental outcomes deteriorate as the expanding and more affluent population exerts increasing pressure on the natural resource stocks.

Under the conservative assumptions of the baseline, by 2030, annual emissions will have increased by more than fifty percent, compared to 2000. By 2050, they will have increased by almost seventy per cent. (Counting from 2005, as reported in the Outlook main report, this is +37% and +52%, respectively.) Together with previous emissions, the ongoing build-up of atmospheric concentrations keeps global warming going at a rate of almost 0.3°C every ten years. Biodiversity keeps deteriorating. Once plentiful land resources (for agriculture, energy crops and carbon sequestration, urban uses and transport, leisure and nature) will be squeezed.

On the positive side, production technology keeps improving, as reflected in improvement of labour productivity and sectoral composition of the world's economies. Specifically, energy efficiency continues to improve, as does land-efficiency in agriculture. But this is more than offset by the increased demands of a world population of over 9 billion by 2050 (+ 50% since 2000) with on average three times greater affluence.

Much of the increase in pressures has to do with the growth of significant new players outside the current OECD, such as Brazil, Russia, India and China. But at the same time, in OECD countries key driving forces of environmental pressure – for example, energy use per capita - continue as before.

In OECD countries, conventional pollution will by and large cease to grow under Baseline conditions, or the growth will level off. Transport-related problems such as air pollution are a notable exception.

The methodology applied in this study allows a regional specification of this picture, as shown by the maps and regional charts. These illustrate the broad distinction between OECD, BRIC and the Rest of the World for most issues at stake. Broadly speaking, the Baseline development sends red flags going up for atmosphere and water issues in particular in India, China and the Middle East; for land use in particular in Brazil, India and Africa; and for climate and biodiversity in all regions.

Energy and land emerge from the analysis as the key resources which use in the next decades governs interdependence as well as environmental problems. However, also for the old-fashioned problems of urban air pollution and sewage the Outlook reveals noteworthy insights.

On urban air pollution, the news is twofold. Firstly, even if the concentration of air pollution in urban agglomerations would not increase, the health damage such as premature mortality would. This is caused by urbanisation and ageing during the next decades, in particular outside OECD countries. Secondly, on the Northern hemisphere, global circulation of air pollution will increasingly frustrate the work by local air quality managers in relatively clean areas.

For sanitation and sewerage, the – perhaps unsurprising – news is that the increasing number of urban dwellers with access to improved sanitation and public sewerage, although a great asset for health and development, will at the same time severely increase the pollution burden on coastal marine ecosystems. This, too, is related to urbanisation and will happen at a large scale outside OECD countries.

An analysis of variants to the economic Baseline mostly indicate a potential for an even stronger increase in economic activities. This applies especially to the BRIC group, if developments over the next decades would continue like they have since 2000, rather than between 1980 and 2000. In addition, it is conceivable, even without new policies, that production stages will continue to be spread internationally and this in turn would mean a stronger growth of environmental pressures from transport than there is in the Baseline. In all, from an environmental viewpoint, the uncertainties around the Baseline seem asymmetric, more towards the side of larger environmental pressures than is projected in the Baseline.

In the Outlook, these projections are used to assess the cost of inaction. They also set the stage for the model-based policy simulations that are central to the outlook and presented in detail in the following sections.

The policy simulations

Comparing the results of the policy simulations to the Baseline reveals, above all, that serious environmental issues can be addressed at moderate cost. In addition, comparison between three comprehensive policy packages with broadening participation -- OECD only; OECD+BRIC and OECD+BRIC+Rest of the World -- underscores the point that the current round of globalisation also may pave the way for effective environmental policies at the global scale.

Climate change options have been explored in detail, separate from the three comprehensive packages. This quantifies examples of the environmental cost of delaying action and of the benefits of burden sharing between countries.

Two sets of findings are particularly illustrative regarding ambition levels of environmental policies. Firstly, the modelling results indicate that stabilising greenhouse gas concentrations at approximately 450 ppm carbon dioxide equivalent is feasible and affordable to the world as a whole. But it requires nearly the full range of the considered technologies to be deployed and worldwide participation is necessary. Secondly, there is biodiversity. None of the analysed policy packages includes policies specifically targetted at halting biodiversity loss. Consequently, the results show biodiversity will continue to decline. Only certain side-effects from, for instance, climate policies have some impact.

The policy packages reveal synergies as well as complications.

- Liberalising agricultural production and trade creates opportunities for a more efficient use of resources and for fair trade. At the same time, it will induce a shift in the location of agricultural production towards regions where land is cheap. Thus, other things being equal, this may result in a net increase of pressures on biodiversity. The outlook concludes that 'depending on where agricultural production is reduced and where it is increased in these shifts, this could lead to a reduction in global biodiversity value'.
- Air polluting emissions typically decrease as an ancillary effect of climate policies. On the other hand, serious air quality policies worldwide will considerably decrease aerosol concentrations and thus affect global warming – temporarily hampering the effect of climate change mitigation efforts. This requires more detailed analysis.
- Providing improved sanitation and sewerage to urban dwellers more rapidly than in the Baseline would be in the spirit of the Millennium Development Goals. However, even the projected extra increase in sewage treatment is not enough to keep up with this. The net result is a very large increase of the environmental pressure on coastal marine systems.

The Outlook's main report has combined the model-based findings with insights on policy instrument mixes and institutional capacities. Interestingly, for some global problems the technical potential to address them is currently clearer than the policies that would mobilize this potential. An important example of this is the potential to keep worldwide agriculture more compact in terms of land use, than under the conditions of the Baseline or the comprehensive policy packages. Modelling shows this to be a key factor from a point of view of climate stabilisation and biodiversity conservation. But policy options that to promote this are currently lacking

Part 1: Overviews

1.1 Policy packages with participation by OECD, BRIC and the Rest of the World

1.1.1 Introduction

The *OECD Environmental Outlook to 2030* presents comparative policy analysis: what difference can policies make over the next decades, relative to a no new policies Baseline? Most importantly, it revisits the case for collaboration between OECD countries and non OECD-countries. The analysis has been set up in such a way that it highlights the role that newly emerging players – on particular Brazil, Russia, India, China (BRIC) - play among the other world regions.

This is reflected in the three comprehensive policy packages which were analysed, namely more ambitious policies in *OECD countries* only; in *OECD countries+BRIC* or in *OECD countries+BRIC+Rest of the World*. These simulations focus on the impact that *OECD countries* and other countries joining forces, have on environmental policies and related issues. Logically, the benefits of co-ordinated global policies would show in a comparison of these three packages against the Baseline. Equally, trade-offs would show, too.

The detailed design of the Baseline and the three policy packages are addressed in part 2 of this report; the current overview highlights the results. In a nutshell, these policy packages address a specific set of issues, namely:

- agricultural liberalisation
- climate change policies
- air pollution
- sewage treatment

with the ambitions summarized in *Table 1.1*. A number of other, individual policy simulations was undertaken for the outlook report and are reflected in the relevant chapters of the report accordingly. This background report focuses on the Baseline and the three policy packages analysed; of the individual simulations only those on climate policy are presented.

Obviously, the issues above are only a selection of the issues reported in the main report. For example, biodiversity protection or water use are not addressed in the policy packages examined, although the Outlook finds that in these areas urgent action would be required.

1.1.2 Global results

What difference will it make if OECD countries and other significant players join forces? To which kind of issues is this essential? What can be achieved, for example, by simultaneous liberalisation of trade in agricultural products, as well as worldwide climate policy? Much depends on timeliness and ambition level, exact agreements and concrete implementation. Undoubtedly, different perspectives exist on which principles are primarily applicable to such a package and on its format and effectiveness. The example of combining trade liberalisation and climate change policy is already characteristic of one specific perspective, namely the logic of globalisation -- in terms of economic and environmental policies. With these limitations in mind – a

Table 1.1 Overview of environmental policy packages for integrated analyses

	pp OECD	pp OECD+BRIC	pp global
Agriculture	Baseline	Baseline plus agricultural liberalisation between OECD and BRIC. Subsidies and tariffs are reduced by 50% by 2030: starting in year 2010, decreasing by 3% per year. This is applied to import tariffs and export subsidies between countries of OECD and BRIC (bilateral) as well as input, output and factor subsidies within OECD and BRIC countries (unilateral).	Baseline plus global agricultural liberalisation. Same as *pp OECD+BRIC* but applied to import tariffs and export subsidies between all countries and input, output and factor subsidies in all countries
Climate change	Carbon tax in OECD countries, starting at US $ 25 per ton of carbon dioxide and increasing 2.4% per year. Starting in 2012.	Carbon tax in OECD and BRIC, starting at US $ 25 per ton of carbon dioxide and increasing 2.4% per year. OECD countries start in 2012. BRIC starting in 2020.	Carbon tax in OECD, BRIC and ROW starting at US $ 25 per ton of carbon dioxide and increasing 2.4% per year. OECD countries start in 2012. BRIC starting in 2020. ROW starting in 2030.
Air pollution	Development towards but not quite reaching Maximum Feasible Reduction(as defined in Cofala et al., 2005) in OECD countries. Onset and speed differentiated by region (26 regions) and sector (Transport; Power, Refineries and Industry; Domestic and other.) Phased decrease of sulphur dioxide emissions from marine shipping.	Same as *pp OECD* but applied in BRIC as well. Some countries reach target level after 2030.	Same as *pp OECD* and *pp OECD+BRIC*, but applied worldwide. Some low income countries reach target level long after 2030.
Water quality[1])	Installing sewage treatment on new and existing sewerage systems. For existing sewage treatment, upgrading the treatment to the next best level in terms of removal of nitrogen compounds.	Same as *pp OECD* but applied in BRIC as well.	Same as *pp OECD* and *pp OECD+BRIC*, but applied worldwide.

1): The simulations assume that (i) access to improved sanitation will develop according to the Baseline and that (2) in the country groupings included in the policy package, the gap between the 2000 situation and a target of access to improved sanitation and/or access to public sewerage for all urban dwellers would be halved by 2030.

limited set of issues; contingency upon details; and the existence of very different perspectives – the results of the analyses can be read as follows.

The global participation policy package sees a strong decrease in the emission of greenhouse gases. By 2030, as shown in *Figure 1.1*, the effect would be almost twice as large as it would be if only OECD countries implement the measures. The largest step comes with the participation of BRIC. By 2050, participation of the rest of the world will have helped to decrease emissions significantly, but even then the largest difference is created by BRIC participation. The effect of action in OECD countries is a basic ingredient in all three cases and remains by far the largest. Obviously, as explained in part 2, the level of carbon tax and when it starts (e.g. 2012 or 2030) determine how large the emission reduction will be. However, at a tax that gradually increases from US $25 per ton of carbon dioxide, the decrease in emissions is not enough to limit greenhouse gas concentrations at 450 ppm carbon dioxide equivalents, one of the most ambitious limits being discussed internationally.

Emissions of classical air pollutants can be considerably decreased. The health damage avoided by these measures makes them cost-effective, in the sense of cost-benefit analysis. This applies even in regions that are already advanced in control of air pollution. Among other things, the

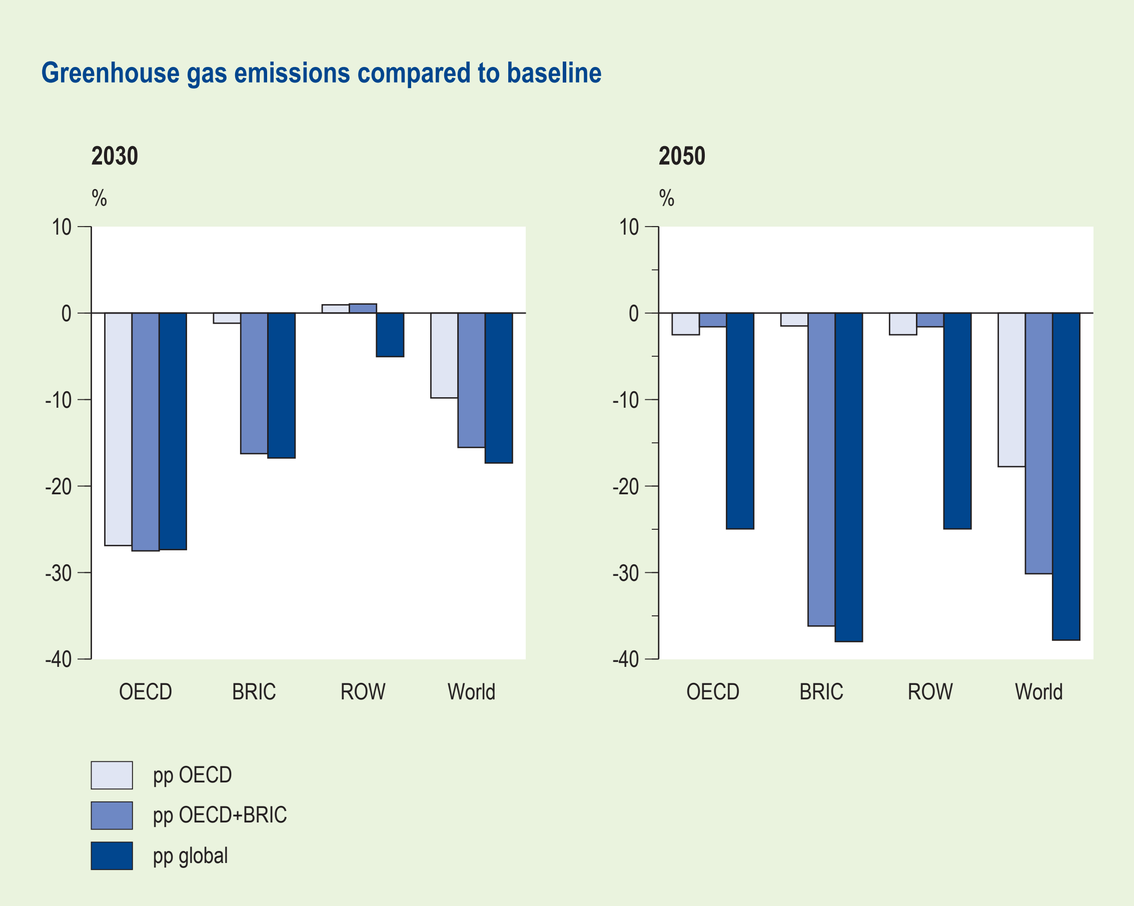


Figure 1.1 Emissions of greenhouse gases, difference with the baseline
OECD Environmental Outlook modelling suite, final output from IMAGE cluster (001x_oec08)

outlook policy simulations assumed the introduction of measures in those sectors in which action will become cost-effective during the scenario period, such as in marine shipping. It is also assumed that present low-income countries will not enhance their air pollution policy until their GDP per capita has grown above a certain minimum, later this century. *Figure 1.2* shows the decrease of sulphur dioxide emissions. Following the design of the simulations, the decrease in sulphur dioxide emissions by 2030 is by far the largest in OECD countries. Comparing global totals (the right hand group of bars in each chart) between the three policy packages shows that participation by BRIC and the Rest of the World each add a further step of roughly same order of magnitude to the decrease of global sulphur dioxide emissions. The 2050 chart shows the pattern by the time the policy package would have its full effect in most regions. Then, sulphur dioxide emissions are approximately 85% less than they would have been under 'no new policies' conditions. While these air pollution policies are cost-effective in themselves, combining them with climate change policies in the global policy package results in an additional benefit.

Liberalisation of agricultural production and trade without specific biodiversity policy does not reduce the rate of biodiversity loss for the world as a whole. Most importantly, the deterioration of terrestrial biodiversity in the Baseline remains at least as steep as it has been over the past decades. In particular, the enhanced growth of agricultural areas outside the current OECD countries is an important factor. Relative to the decline in the Baseline, the policy simulations reveal only small differences. For example, *Figure 1.3* shows a slightly less steep deterioration of worldwide biodiversity by 2030, compared to the Baseline. This slight improvement reflects

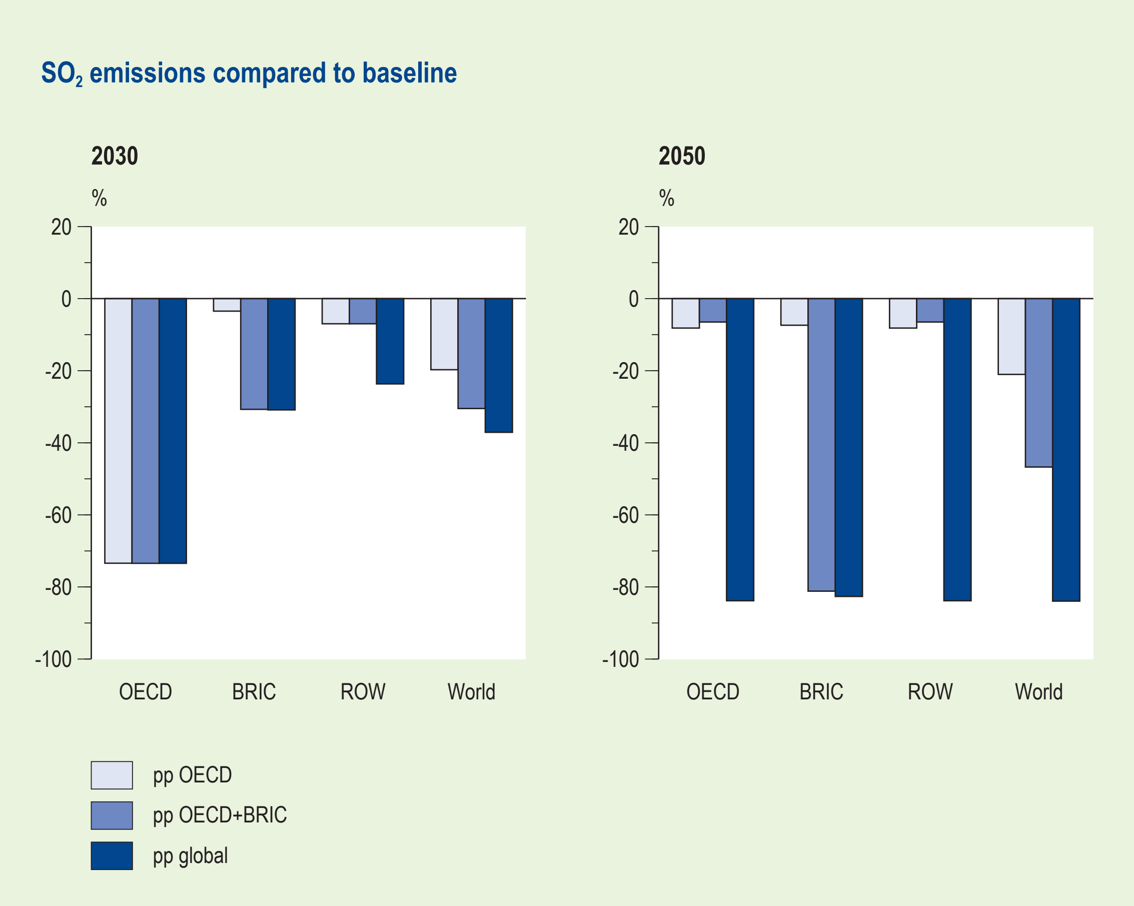


Figure 1.2 Emissions of sulphur dioxide, difference with the baseline
OECD Environmental Outlook modelling suite, final output from IMAGE cluster (003x_oec08)

a small shrinkage of OECD agricultural area, resulting from the global policy package. However, even this is probably an overestimation. An increase in natural areas in OECD countries typically leads to an improvement in biodiversity but only after a couple of decades, while the decrease elsewhere has immediate effect. By 2050, the difference between the policy packages and the Baseline has become negligible.

In the Outlook, the nutrient load exemplifies the pressure on aquatic ecosystems. *Figure 1.4* shows the effect of the policy package, expressed as changes to the load of nitrogen compounds at the river mouth. This load is mostly caused by agricultural activities and sewage. In the policy package analysed here both factors increase outside the present OECD countries. In the Rest of the World group, even additional sewage treatment cannot keep up with the Millennium Development Goals-related drive to provide more people with improved sanitation and access to sewerage.

The aggregate economic cost of implementing the global participation policy package would be relatively low. On average, it is expected to reduce global GDP growth by about 0.02% per year up to 2030. This would mean a cumulative 1.2% loss in gross GDP up to 2030. In other words, instead of realising the projected 98.5% in growth under the Baseline, the growth in GDP would be 97.3% between 2005 and 2030. These calculations have taken into account the effect of measures on trade and agriculture; mitigation of greenhouse gas emissions; and air pollution.

Figure 1.3 Remaining terrestrial biodiversity, difference with the baseline
OECD Environmental Outlook modelling suite, final output from IMAGE cluster (005x_oec08)

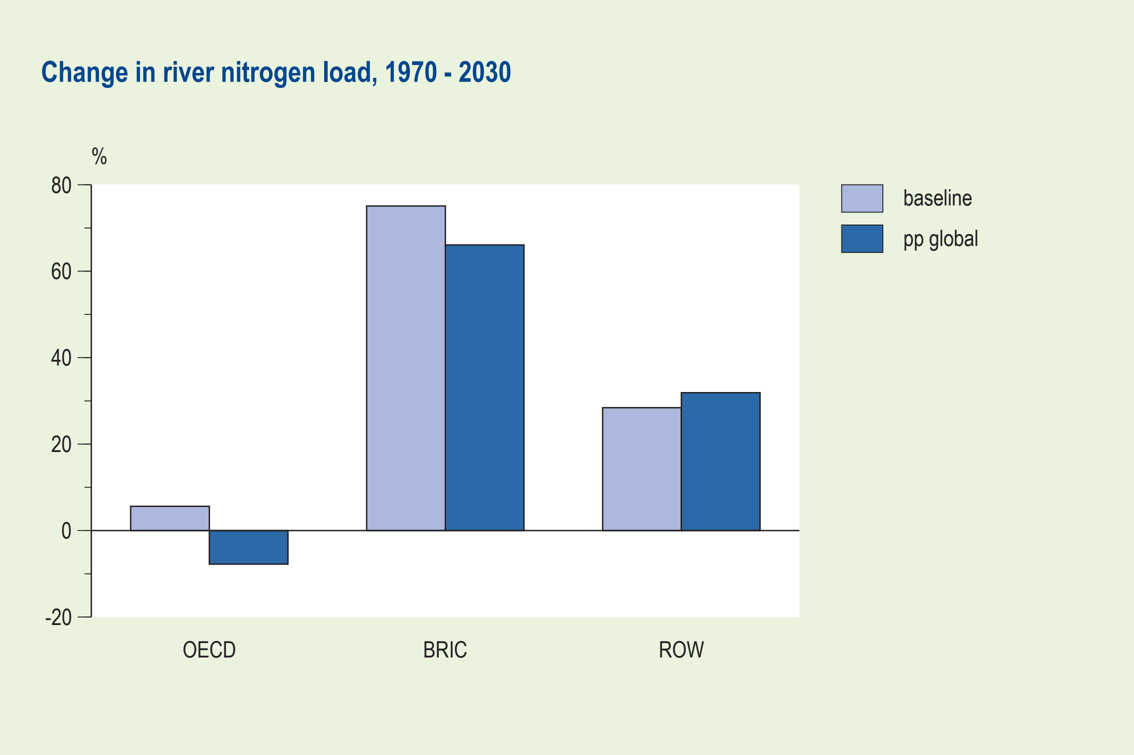


Figure 1.4 Load of nitrogen compounds on fresh water ecosystems, difference with the baseline
OECD Environmental Outlook modelling suite, final output from IMAGE cluster (007g_oec08)

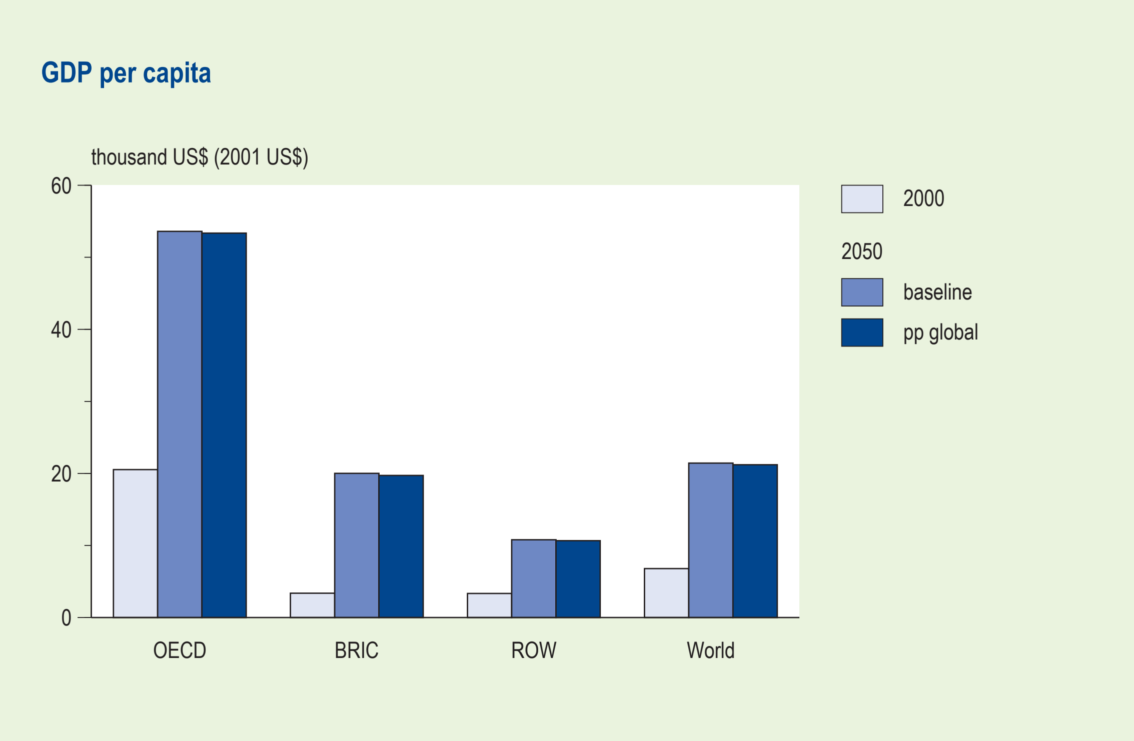


Figure 1.5 GDP per capita
OECD Environmental Outlook modelling suite, final output from ENV-Linkages (008g_oec08)

In reality, these losses might be counter-balanced to some extent by the social welfare improvements arising from the global participation policy package, such as improved environmental and health conditions. However, these effects were not monetized in the analyses.

These examples illustrate that the combination of economic and environmental globalisation, although logical in itself, will require additional policies. Liberalisation of agricultural production and trade, such as a decrease of subsidies and removal of tariffs, is an attractive component of this combination. But agricultural liberalisation in particular, requires additional – 'flanking' - policy in order to realise expansion of production in BRIC and the Rest of the World. This policy should be aimed at mitigating the cost to biodiversity – by a fast expansion of agricultural areas or by increased use of nutrients and pesticides. Water use in agriculture is another example of this.

1.2 Environmental impacts of Baseline and policy packages, by region

The Baseline and policy packages impact the various regional groups in different ways. This section shows important differences and similarities, which are important in appreciating the case for international collaboration.

Table 1.2 provides a synthetic overview of the environmental impacts on the thirteen regional clusters, under of the conditions of the Baseline and the three comprehensive policy packages. In the Outlook itself, this information is rather fragmented because of the theme/instrument oriented chapter structure. *Box 1.1* describes the method used to arrive at this overview.

Climate

The climate policy component in the policy packages on which Table 1.2 is based, is the US $ 25 per ton carbon tax. As discussed in Section 2.3.4, this is not enough to mitigate the increase in radiative forcing. Mitigating the increase will require measures on the scale of the 450 ppm multigas stabilisation case, as is described in the same section in the Outlook. Note that the rating in the table considers the change and rate of change in mean temperature only.

Atmosphere

The impact of air pollution on human health is reduced under the policy packages –from orange to green in OECD regions and from red to orange, elsewhere. In many parts of the world outside OECD, air pollution policies have to row against the tide of urbanisation and ageing when attempting to effectively reduce health impacts. In Eastern Europe, Central Asia, Other Latin America and Africa, little difference is visible between the Baseline and policy packages. However, this is only a matter of time: the policy simulations project decreasing emissions in those regions, later this century.

From the global perspective of the Outlook, the development of air pollution policies and their impact over this century begins to resemble that of climate policies – which makes it more attractive to study co-benefits.

Nutrient load

Typical of non-OECD regions, the improvements in treatment of sewage are not enough to keep up with the increased access to sanitation and connection to sewerage. This problem is foreseeable for the Baseline but also in the case of acceleration of environmental policies. At the same time, an even larger load of nutrients originates from agriculture. As a result, for the regions Other Asia and Africa, a marked deterioration of the nutrient load on aquatic systems is projected precisely under the conditions of a global environmental policy package.

Terrestrial biodiversity

The policy packages do not foresee specific policies aimed at protecting biodiversity, like measures to keep agriculture compact; expansion and interconnection of protected areas; or revenue-sharing arrangements of protected areas in low-income countries. Therefore, no change is anticipated in the rate of decrease of terrestrial biodiversity.

Land use

Under the *no new policies* Baseline, human land use increases in most regions. This is, in part, due to the urban sprawl and conversion of landscapes everywhere, but mainly because of agricultural land use. The two policy packages involving BRIC anticipate an even faster expansion of land use in regions such as Brazil and Other Latin America. This is due to liberalisation of agricultural production and trade, causing the production to increase with a preference for low-income countries where land is cheap. The development in North America shows by and large the mirror image.

Fresh water

Under the *no new policy* conditions, water stress is projected to increase strongly in precisely those regional clusters that are vulnerable to this additional strain. As these projections looked ‘only’ to 2030, the modelling does not yet show effects of climate change on water availability a scale that would influence the results. The policy packages influence this projection only marginally, indirectly through changes in size and agricultural location and, eventually, through some mitigation of climate change. Therefore, without incentives to use water much more efficiently, especially in agriculture, the regional pattern of deteriorating water stress will develop unchecked.

Original forests
The overall pattern of loss of original forest is driven by agricultural developments. Because of this, the policy packages involving BRIC feature a red traffic light for Brazil, instead of amber as in the Baseline. This reflects side-effects of the reform of agricultural tariffs, as explained under 'land use'.

The pattern across issues and regions
(1) Trade-offs are real and need further exploration. One example featuring in this table is the connection between trade liberalisation, agricultural technology and protection of biodiversity. A possible implication is that policies on agricultural technology and biodiversity protection form a necessary ingredient for liberalisation of agricultural production and trade.
Also, there is the connection between improving access to better sanitation worldwide and waste water treatment that has to keep up with expanding connections to public sewerage. Failure to do so will result in steep increases in the loading of pollutants on ecosystems and in public health risks. In relation to this, a certain proportion of investments in better sanitation should be earmarked – or added – in order to boost waste water treatment, as well.

(2) Environmental goal-setting needs to be ambitious. In fact, relative to a benchmark of climate stabilisation at global mean temperatures not much more than two degrees Celsius, all of the broad policy packages fall short. But the more ambitious 450 ppm multigas stabilisation case does go in this direction.

(3) Inertia is a factor to be reckoned with. It is the common factor that makes the rows in *Table 1.2* look so similar, even between the Baseline and the global policy package. When focusing on impact (such as climate change) rather than pressure (such as emissions) the slowest element in the chain is highlighted. At the end of the chain all delays accumulate: from the time needed for education, replacement of capital stock and year after year improvements in resource efficiencies, to the longevity of some human-induced changes to the environment.

The delay between action and result surely is a political handicap. It is also a key reason to prioritise those actions that deal with durable infrastructure and capital goods, such as city layout, power plants or the fishing fleet, and seize opportunities arising through the current dynamic development of the BRIC economies.

(4) The difference between the issues also highlights a need for policies that address some issues head-on. For example, without explicit protection, biodiversity will keep on deteriorating at the current rate or even faster. Also, without policies targeted at agricultural water use, problems of water stress will only become more serious.

Table 1.2 Synopsis of environmental impacts, by regional cluster

		NAM	EUR	JPK	ANZ	BRA	RUS	SOA	CHN	MEA	OAS	ECA	OLC	AFR	World
Climate change Temperature change and rate of temperature change	*Baseline*	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
	pp OECD	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
	pp OECD + BRIC	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
	pp Global	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
	450 ppm	🟧	🟧	🟧	🟧	🟧	🟥	🟥	🟧	🟧	🟧	🟧	🟧	🟧	🟧
Atmosphere Excess mortality attributable to urban air pollution by PM10	*Baseline*	🟧	🟧	🟧	🟩	🟧	🟩	🟥	🟥	🟥	🟥	🟧	🟧	🟧	🟥
	pp OECD	🟩	🟩	🟧	🟩	🟧	🟩	🟥	🟥	🟥	🟥	🟧	🟧	🟧	🟥
	pp OECD + BRIC	🟩	🟩	🟧	🟩	🟩	🟩	🟧	🟧	🟥	🟥	🟧	🟧	🟧	🟧
	pp Global	🟩	🟩	🟧	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
Nutrient loading Agricultural nitrogen losses and nitrogen load at river mouths	*Baseline*	🟧	🟧	🟧	🟧	🟧	🟧	🟥	🟥	🟥	🟧	⬜	🟥	🟧	🟧
	pp Global	🟩	🟩	🟩	🟧	🟥	🟧	🟥	🟥	🟥	🟥	⬜	🟥	🟥	🟧
Biodiversity Mean Species Abundance	*Baseline*	🟥	🟥	🟥	🟧	🟥	🟧	🟥	🟥	🟧	🟥	🟥	🟥	🟥	🟥
	pp OECD	🟥	🟥	🟥	🟧	🟥	🟧	🟥	🟥	🟧	🟥	🟥	🟥	🟥	🟥
	pp OECD + BRIC	🟥	🟥	🟥	🟧	🟥	🟧	🟥	🟥	🟧	🟥	🟥	🟥	🟥	🟥
	pp Global	🟥	🟥	🟥	🟧	🟥	🟧	🟥	🟥	🟧	🟥	🟥	🟥	🟥	🟥
Land use Change in agricultural land area	*Baseline*	🟧	🟧	🟩	🟧	🟧	🟧	🟥	🟧	🟩	🟥	🟧	🟧	🟥	🟧
	pp OECD	🟧	🟧	🟩	🟧	🟧	🟧	🟥	🟧	🟩	🟥	🟧	🟧	🟥	🟧
	pp OECD + BRIC	🟩	🟧	🟩	🟧	🟥	🟧	🟥	🟧	🟩	🟥	🟧	🟧	🟥	🟧
	pp Global	🟩	🟧	🟩	🟧	🟥	🟧	🟥	🟧	🟩	🟥	🟧	🟥	🟥	🟧
Fresh water Population living in areas under severe water stress	*Baseline*	🟧	🟧	🟧	🟧	🟧	🟧	🟥	🟥	🟥	🟥	🟧	🟧	🟥	🟧
	pp Global	🟧	🟧	🟧	🟧	🟧	🟧	🟥	🟥	🟥	🟥	🟧	🟧	🟥	🟧
Forests Change in natural forest area	*Baseline*	🟧	🟧	🟧	🟥	🟧	🟧	🟥	🟥	⬜	🟧	🟥	🟧	🟥	🟧
	pp OECD	🟧	🟧	🟧	🟥	🟧	🟧	🟥	🟥	⬜	🟧	🟥	🟧	🟥	🟧
	pp OECD + BRIC	🟧	🟧	🟧	🟥	🟥	🟧	🟥	🟥	⬜	🟧	🟥	🟧	🟥	🟧
	pp Global	🟧	🟧	🟧	🟥	🟥	🟧	🟥	🟥	⬜	🟧	🟥	🟧	🟥	🟧

Legend
🟥 increase of a large problem in the context of internationally articulated objectives
🟧 intermediate situations, including hotspots or situations getting worse before getting better
🟩 significant decrease in problem
⬜ inconclusive

OECD Environmental Outlook modelling suite, final output from IMAGE cluster
For definitions of Baseline and policy cases see part 2 (Baseline), Table 1.1 (policy packages) and Table 2.20 (450 ppm multigas)
(164t_oec08)

Box 1.1 Process of deriving the ‘traffic lights’ in Table 1.2

The ‘traffic light’ table presents a simplified synopsis of the regional impacts of the Baseline and of the policy packages that have been analysed for the Outlook, The table compares the Baseline and the three policy packages in terms of the pattern of their regional impacts. It is not meant to provide a concrete predicament of a specific policy package.

The ‘traffic light’ table is the product of a judgmental process, i.e.

- Themes were operationalised by narrowing them down to specific issues. For example, air pollution is assessed using information on premature mortality which is attributable to urban air pollution, with suspended particulate matter smaller than 10 micrometers by 2030, and trends in sulphur dioxide emissions after 2030.
- Estimates for the chosen issues were derived from a visualisation system filled with modelling results for the Outlook. These were primarily considered at the level of 13 regional clusters, then checked at the 24 regional levels for the underlying distribution within regions.
- The projections for the next quarter century were compared to the current trend of a specific issue, to see the degree of change across Baseline and policy packages. Three dimensions were taken into account..
    - First off, most weight was given to the change in environmental pressures between now and 2030 (direction and rate of change).
    - Secondly, the 2030 and 2050 levels of environmental pressure were considered: would they come anywhere near to targets discussed in the Outlook?
    - Thirdly, a more detailed check was carried out. Spatially, by checking for important hotspots within a regional cluster (by looking at the underlying results of the environmental modelling in terms of 24 regions), and temporally: would the situation become significantly worse before getting better? If such hotspots or bumps in time were indicated, then the traffic light score could never be higher than amber.
- For themes that feature particularly large delays between changes in driving forces and environmental impacts such as climate, developments have been considered for the next half century rather than for the next quarter century.
- The table depicts environmental impacts as changes towards the end of the causality chain: health impacts, biodiversity impacts and the like.
- The table highlights differences and similarities between regional impacts. In addition, a ‘world’ column has been included to provide an overview of the impacts on a global scale. • For some issues, such as climate change, the outcome of the model based analysis directly shows a relevant impact on the world as a whole.
- For other issues, such as for population living in areas with water stress, the signal in the ‘world’ column is a weighted average of the regional signals.
- For biodiversity, the remaining mean species abundance was considered rather than the decrease. Considering the decreases would not have differentiated between the cases that were investigated, partly because of the inertia of the natural system.
- For urban air pollution, the modelled health impacts up to 2030, as reported in part 2, were considered. In order to differentiate in BRIC and the Rest of the World, the trends in 2030-2050 in emissions of sulphur and nitrogen oxides were weighted in.
- Generally, a red signal shows an increase of a large problem in the context of internationally articulated objectives. An amber signal shows either improvement or deterioration of the problem, and a green signal reveals a significant decrease in the problem.
- The amber lights in the table span a range of intermediate situations, hiding the differences. For example, projections of water stress tend to come with wide intra-regional variations but were often allocated an amber traffic light for the region as a whole. Or, decreases in original forest cover of 200 and 250 thousand square kilometers in North America were both allocated an amber traffic light.

Part 2: Detailed findings

Part 2 of this report describes some detailed outcomes of the *OECD Environmental Outlook* process that were not included in the main report. Outcomes of the analysis of the Baseline are in *chapter 2.1*, while *chapter 2.2* deals with the policy simulations. As the focus is on environmental analysis, the description of the population and economic Baseline has been kept shorter than in the outlook main report. The regional classification can be found in *Annex 1*.

2.1 The Baseline

By design, the Baseline is a no-new policies scenario. It imagines the world developing over the next decades largely as it does today, without new or intensified policies in response to the projected developments.

The Baseline assumes that many aspects of today's world remain the same – not frozen in time, but evolving along the same lines as today. Population and income are projected to increase, and diet preferences, mobility demand and other consumption preferences keep shifting and increasing with income in the same way as in the past decades.

By implication, the Baseline is not the most plausible future development. It is likely that decision makers in governments and elsewhere will react to all sorts of developments, including the environmental trends described in the Environmental Outlook, and that the Baseline trends will never show in reality. The Baseline is thus only a benchmark for comparison. The purpose of a well-described Baseline is to identify the need for new policies in certain areas, and to provide a background for assessing the effect of new policies.

Although the Baseline shows an continuously increasing burden on the environment, the models used behave as if the projected quality of the environment would not disturb demographic and economic development. In modelling terms: there is no feedback from environmental pressures onto economic and social development.

Because the purpose of the Baseline to support a discussion that centers on policy options and possible alliances, rather than on the merits of the Baseline, it has been aligned as much as possible with authoritative thematic projections (as for population, energy, agriculture) and long-term historic series (in particular long-term growth rates of labour productivity). References are included in the discussion.

As the focus is on environmental analysis, the description of the Baseline for population and aggregate economic development has been kept shorter than in the outlook main report.

2.1.1 Population and economic developments

Population

The Baseline uses the medium population projection of the United Nations, which shows a stabilisation of the world population at around 9.1 billion inhabitants by the middle of this century (UN, 2005). Almost all of this increase will be in the developing countries. (See *Figure 2.1* and *Table 2.1*). Ageing of the population will be a dominant feature of demographic

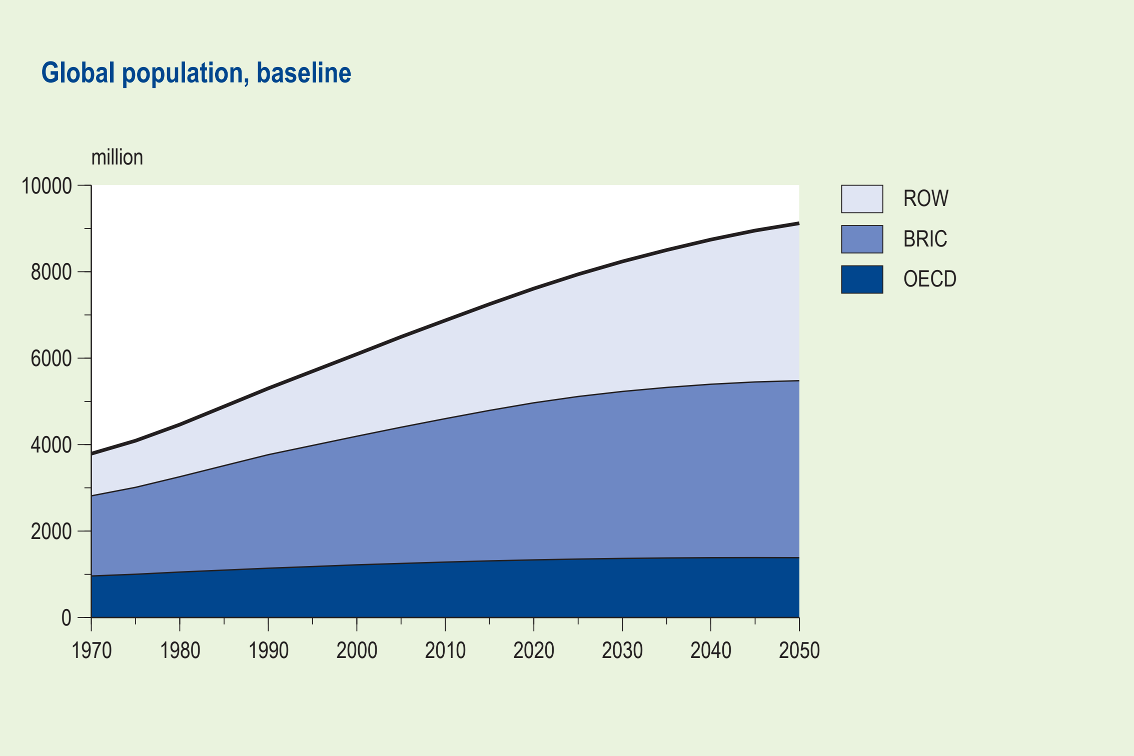


Figure 2.1 **World population, baseline**
Source: UN (2005) (009g_oec08)

development. It is already apparent in OECD countries, but will show its effects in the developing countries in the coming decennia – quite soon in China. Without policies, ageing of the population leads to a decrease in labour participation and an increased economic burden on the working segment of the population.

The medium population projection of the United Nations is a middle-ground scenario with 8.2 billion people in 2030, compared to the extremes of the IIASA probabilistic population projections, that range between 7.7 and 8.8 billion in 2030 (Lutz et al., 2004).

2.1.2 Economic developments

Points of departure
At the level of generality and the time horizon of the outlook, the following three factors are considered as the long-term determinants of growth in economic activity for each region. For each of these, a time-path was developed that reflected convergence (as per Sala-i-Martin, 1996) and the notion of 'no new policies'.
- labour force
- labour productivity – influenced by skills and production technology
- trade.

The Baseline does not incorporate feedbacks of the projected environmental changes on regional economies

However, the projections of the two main forms of resource use linking economy and environment, energy use and land use, are realistic in the sense that they do take into account scarcities by region and fuel type and land type.

Table 2.1 Population increase, baseline

	1970-2000	2000-2030	2020-2050
%			
North America	43	27	15
OECD Europe	17	5	-2
OECD Asia	27	0	-11
OECD Pacific	44	26	18
Brazil	72	34	15
Russia & Caucasus	15	-13	-16
South Asia	79	33	15
China region	47	14	-2
Middle East	156	74	42
Other Asia	84	49	26
Eastern Europe & Central Asia	29	3	-7
Other Latin America & Caribbean	74	43	21
Africa	120	85	57
World	**61**	**35**	**20**

Note: overlapping 30-year periods: 2000-2030 and 2020-2050

Source: UN (2005, 2006)

In particular for the economic Baseline, 'no new policies' is very different from 'policy-free'. It means no policy initiatives that bring important changes to the dynamics of economic development.

In fact, the Baseline projects for the next half-century a world that is very similar to today's in factors such as the role and size of government, policy priorities, taxes, technology diffusion, intellectual property rights, liability rules and resource ownership. Hence ongoing technological change will impact on the economy in much the same way it has in the past.

It is also similar to today's world in terms of dietal preferences, mobility demand and other consumption habits for given income levels. Since incomes in developing countries will change, there will be some change in consumption patterns, but in a manner that will make them look more like today's developed countries.

Labour force

Labour force participation in OECD countries is assumed to follow past trends while in non-OECD countries it was assumed to converge slowly to the OECD average of 60 per cent. (Labour force participation is the percentage of the adult population that considers itself part of the labour force – i.e. works or is looking for work.) The assumed convergence is slow, at a rate of one per cent gap closure per year in the direction of the OECD average.

Taken together, the population and participation rate projections lead to increases in the labour force of 10, 27 and 50 per cent in OECD, BRIC and ROW, respectively, between 2005 and 2030.

Here, the assumptions for the labour force are a challenge to reconcile with the 'no new policies' character of the Baseline. UN population projections estimate the most probable development. For some regions, this implies new polices on health care, education and migration. Similarly, participation in the labour market is a policy rich field. Government policies are thought to have added to downward trends in labour force participation in OECD countries. Thus, the assumed slow trend towards the current OECD average may in some regions involve new government policies for example on pensions, child care facilities, lifelong learning and migration. Nonetheless, since these policies are largely uncorrelated to environmental policies and issues of the type being discussed in this report, the 'no new policies' rule remain valid.

Labour productivity

The central assumption is how of labour productivity in each region will change over time. Labour productivity quantifies how much more goods and services a worker generates per unit of time. The assumption is that gradually, over the first three to five decades of this century, the annual changes in this variable in all regions will start to move in the direction of – not necessarily attaining - the long-term average in industrialized countries.

Countries slowly converge to that rate by closing the growth rate gap by 2% per year (implying that half the gap is closed in about 35 years). The process of moving toward growth convergence occurs in two stages: (i) moving from current productivity growth rates to the average for 1980-2001 (this is largely completed by 2015) (ii) then moving to the 1.75% growth target, by closing the growth rate gap by 2% per year. In other words, a country whose productivity is growing at 5% at the beginning of the convergence process will grow at 4.94% in the following year, 4.87% the next year, and so on.

This long-term benchmark is taken at 1.75 per cent per year. It has been gleaned from time series over the two past centuries (Maddison, REF; Crafts, REF) and is thus meant to capture the productivity effect of technological transitions even if they are as large and important as the introduction of electric power, the motor car, antibiotics and ICT. At the most general level, two evident assumptions are institutional stability in most countries and unspecified but continuing technological progress.

Sectoral productivity is differentiated in the same way, for each region. This leads to shifts in sectoral composition over time, with the familiar pattern of stronger growth in the service sectors than in for example agriculture. Thus, by 2030 or 2050 the weight of agriculture vis a vis the other sectors in most economies will be less than today. But importantly to the environment, this only means that the value added of – in this example – the service sector has increased more than that of agriculture. It does not necessarily mean that the activity in agriculture in that region will shrink in physical terms. In most regions, it will not.

Although the assumption of ongoing improvement in production technology is fundamental to the projected rates of labour productivity improvement, this assumption is purposely general. Specification in terms of technology developments that influence environmental implications has been entered in subsequent stages of the analysis. For example, the mix and efficiency of energy production technologies, or the extent of irrigated crop area. These specific technology developments in the Baseline are described in the sections of this report that focus on environmental implications.

Trade

In most regions, imports and exports have grown faster than the regional economy in general, as measured by GDP. To the extent that this is the result of explicit policies on tariffs and quota, the Baseline assumes no new policies and therefore a gradual leveling off of the rate of trade growth. Thus, eventually, the Baseline features trade growing at just the same rate as the

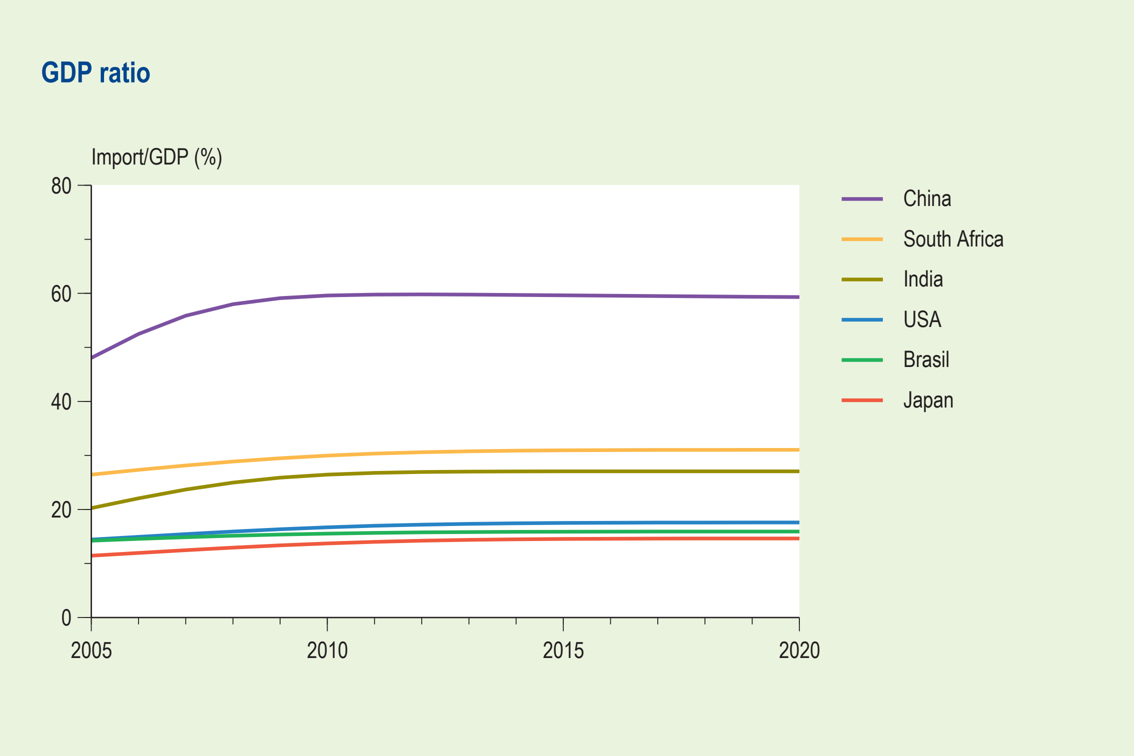


Figure 2.2 Imports in proportion to GDP, baseline
OECD Environmental Outlook modelling suite, final output from ENV-Linkages (141g_oec08)

economy in general. This is visualized in *Figure 2.2*, depicting imports relative to GDP for the three regional groupings of the outlook.

In contrast to the Baseline, new policies on agricultural trade (a 'new Doha round') are included in the outlook as part of its broad policy packages.

Not all impediments to trade are directly and explicitly driven by policies. In particular, changes in transport and communication costs are important while not directly determined by trade policies. In order to investigate the effect of changes along this line, a variant to the Baseline has been analysed (see below).

Aggregate economic activity

The economic undercurrents of these three trends combine to produce a seemingly modest, but uniformly positive growth in real GDP for the world as a whole under Baseline conditions. The global average is would be 2.8 per cent per year between 2005 and 2030. China and India would see growth rates of 5 per cent per year averaged per over the whole period (from approximately seven per cent per year in the first years to approximately four per cent during 2020-2030). *Figure 2.3* and *2.4* show the resulting levels of GDP and GDP per capita.

The graphs show that the BRIC group, notwithstanding its strong and sustained growth, remains at a large distance from the OECD average in terms GDP per capita. By and large, this implies a similar distance for the average standard of living in this regional group.

Figure 2.4 shows that the increase in GDP per capita is especially fast in Russia, China and India. Details are given in *chapter 3* Economic Development of the Outlook main report.

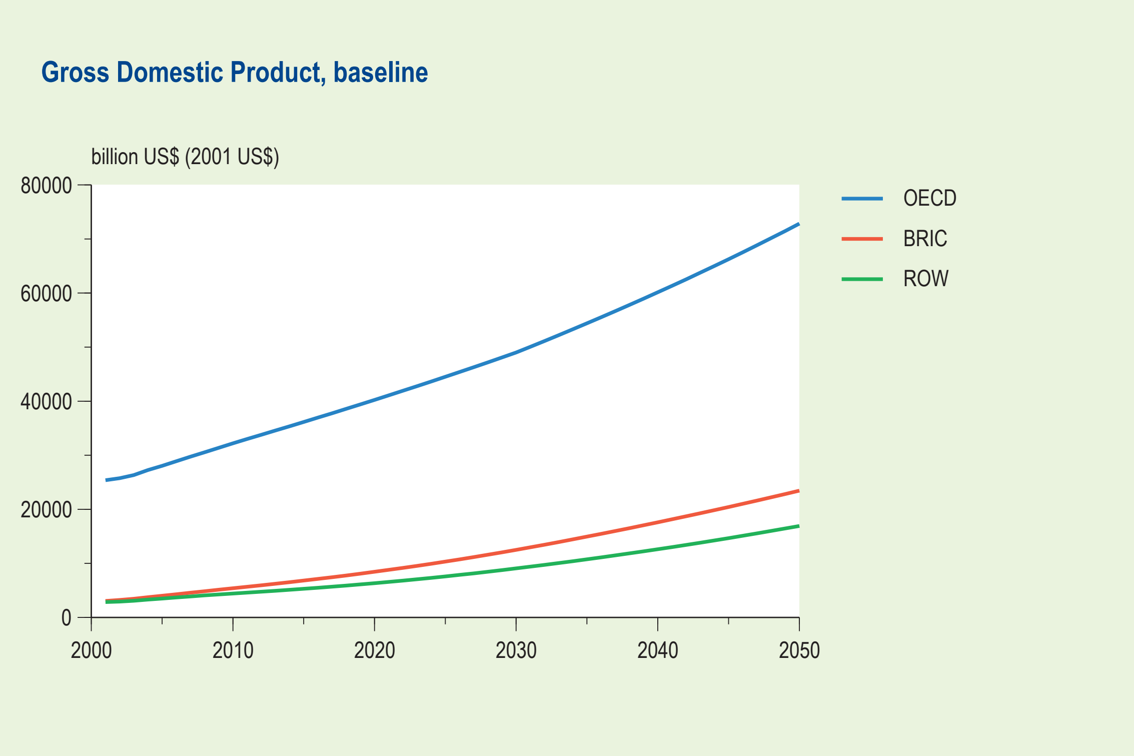


Figure 2.3 Gross Domestic Product, baseline
OECD Environmental Outlook modelling suite, final output from ENV-Linkages (010g_oec08)

Sectoral shifts

The resulting changes to the sectoral composition of the economies, in very broad terms, are shown in *Figure* 2.5. Overall, there is an especially large growth in value added of services as well as industry.

The chart is in value terms, not in terms of a percentage of GDP. This is to underline that whereas the significance of sectors like agriculture will decrease in relative terms, their value-added in constant dollars might well increase. For example, in *Figure* 2.5, see agriculture in the OECD Pacific cluster (ANZ), Russia and Caucasus (RUS) as well as in the world total.

Variants

Against the background of a wider notion of uncertainties for the outlook, the following key uncertainties have been identified in the three driving forces of the economic Baseline.

- *Active labour force:* a relatively large uncertainty was identified here, given that the UN population projections come with substantially wide confidence limits (+/- 7 per cent by 2030, as well as uncertainty about subnational differences) and statistics on current participation rates are problematic for important parts of the world.
- *Rate of labour productivity increase:* two variants have been explored, namely with convergence benchmarks of 1.25 and 2.25 per cent per year instead of 1.75.
- *Trade development:* a variant was explored assuming a continued decline in impediments to trade such as transportation and communication costs and border delays. (The Baseline assumes that in the next decades the decline in these factors will level off.) This variant is designated as the globalisation variant.

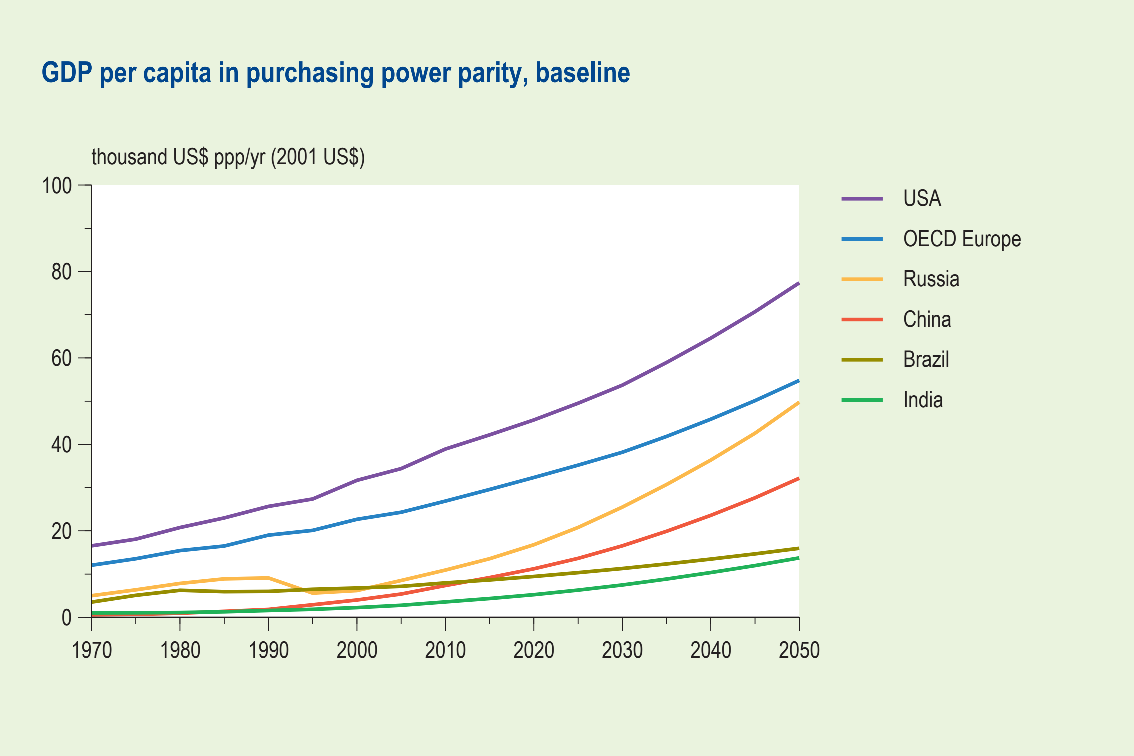


Figure 2.4 Gross Domestic Product per capita in purchasing power parity, baseline
OECD Environmental Outlook modelling suite, final output from ENV-Linkages (011g_oec08)

Lat but not least, a variant was explored for the recent history to which the Baseline is grafted. The Baseline evolves from growth rates in the 1980-2000 period. In contrast, the variant is derived from five-year growth rates around the year 2000 – for important countries a period of fast growth. It is designated here as the 'millennium' variant.

Table 2.2 presents summary results of the variants in productivity growth rate. It clearly shows that the millennium variant has a large effect (a much larger GDP growth, especially in the BRIC group).

The effect of the two alternative benchmarks for labour productivity improvement is much smaller, even though they constitute considerable deviations from the Baseline assumption. Interestingly, between the latter two variants the resulting differences relative to the Baseline are asymmetric. This reflects that in the initial years of the Baseline, connecting to recent trends, rates of labour productivity increase are assumed high in many countries.

The globalisation variant, continued decrease in transportation costs and the like, only increases cumulative GDP growth to 2030 by one or two per cent. However, it does increase the value of international trade in proportion to GDP in almost all regions, typically adding one-third to a half to the Baseline numbers. Assumedly, China and India would see a lesser or almost no effect, as it is doubted whether the proportion of trade to GDP is can increase much beyond the already high numbers of the Baseline.

Key lessons are the following.

- In a no new policies future, the volume of economic activity can be less, but especially much more than projected as the Baseline. The latter could happen if productivity trends in the next

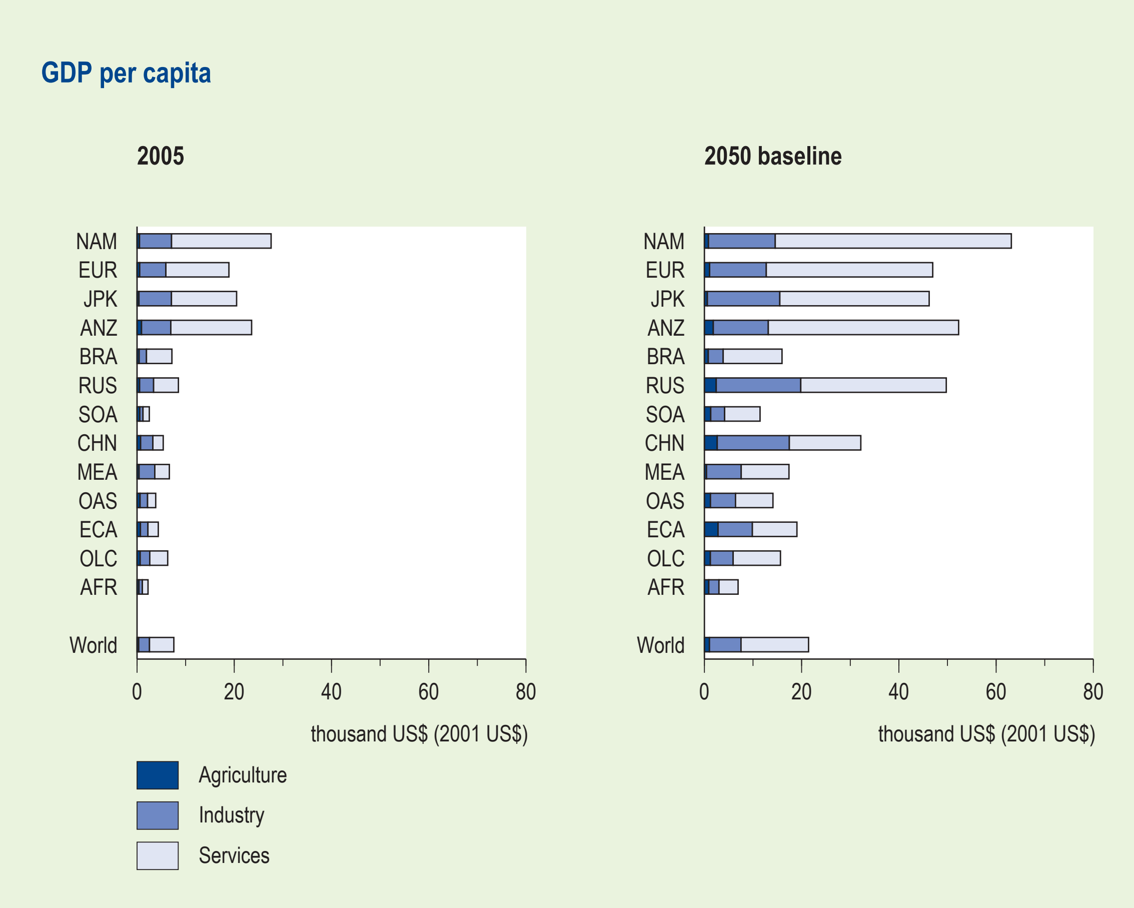


Figure 2.5 Sectoral value added, baseline
OECD Environmental Outlook modelling suite, final output from ENV-Linkages (012x_oec08)

decades resemble the past few years, rather than the past two decades. Especially in countries such as the BRIC activity volumes can be larger.

- Autonomous developments such as a further decrease in transportation cost (moneywise or timewise), could increase international trade more than projected in the Baseline. This can influence the location of production as well as the spatial spread of production.

2.1.3 Energy use

The energy consumption for the OECD Baseline follows more-or-less the 2004 World Energy Outlook scenario of the International Energy Agency, adjusted for the small differences in economic growth assumptions of this Baseline and for the higher energy price trajectory adopted from WEO 2006. This implies that final energy consumption increases from 280 EJ in 2000 to 470 EJ in 2030, somewhat faster than the historic trend. This is due to (1) specific events that have slowed down energy consumption in the last decades, e.g. the energy crisis in the OECD, the economic transition of the countries of Central and Eastern Europe, the Caucasus and Central Asia, and the Asia crisis and (2) the increasing weight of developing countries with typically higher growth rates in the global total. While OECD countries made up more than half of energy consumption in 2000 (53%), their share drops by 10 percentage points in 2030. In absolute terms, the energy consumption in BRIC and ROW groups roughly doubles until 2030 (*Figures* 2.6 and 2.7).

Table 2.2 Productivity growth variants: GDP difference from baseline by 2030

	Variant 1 *adopting 1.25%/yr benchmark for labour productivity increase*	**Variant 2** *adopting 2.25%/yr benchmark for labour productivity increase*	**Millennium variant** *derived from recent five-year productivity trends*
	%		
OECD countries	-7.3	6.4	4.3
Brazil	-5.0	1.4	-0.6
Russia	-4.8	1.4	31
India	-5.2	1.5	38
China	-4.9	1.4	84
Rest of the world	-4.9	1.4	23
World	**-6.6**	**4.8**	**15.9**

OECD Environmental Outlook modelling suite, final output from ENV-Linkages

The oil price in the Baseline (as modelled in the TIMER energy model and calibrated to the *IEA World Energy Outlook 2006*) reaches a level of 60 US $ per barrel in 2005. After a slow relaxation to 45 $ per barrel around 2020 it climbs, as a result of depletion, to a value of just over 60 $ per barrel in 2050. The high price of oil leads to a lower share for oil products in final energy, partly replaced by modern bio-fuels in the transport sector. Coal use increases slightly, as the price differential with oil and gas makes it attractive for large industrial users to burn coal. This offsets the ongoing trend in the residential and services sector – where coal use is gradually phased out. Natural gas keeps its market share and, as observed in the past, the share of electricity in final energy use keeps increasing to reach 23% in 2030 (from 17% in 2000).

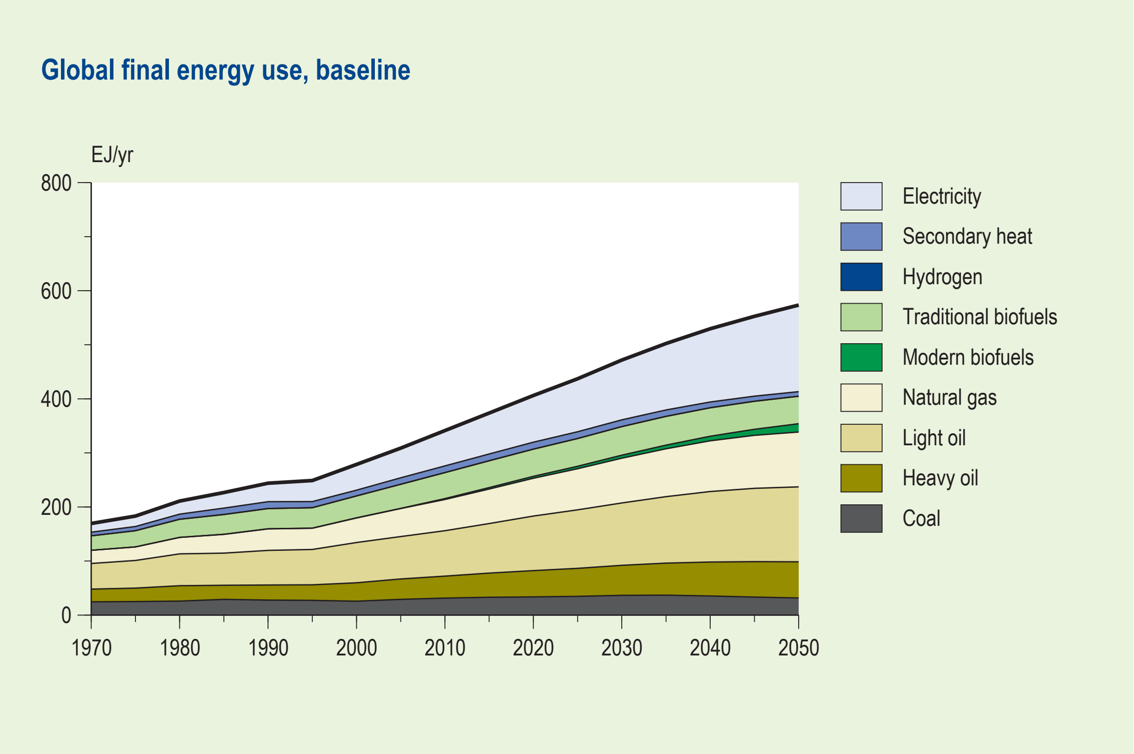


Figure 2.6 Final energy use by energy carrier, baseline

OEC D Environmental Outlook modelling suite, final output from IMAGE cluster (015g_oec08)

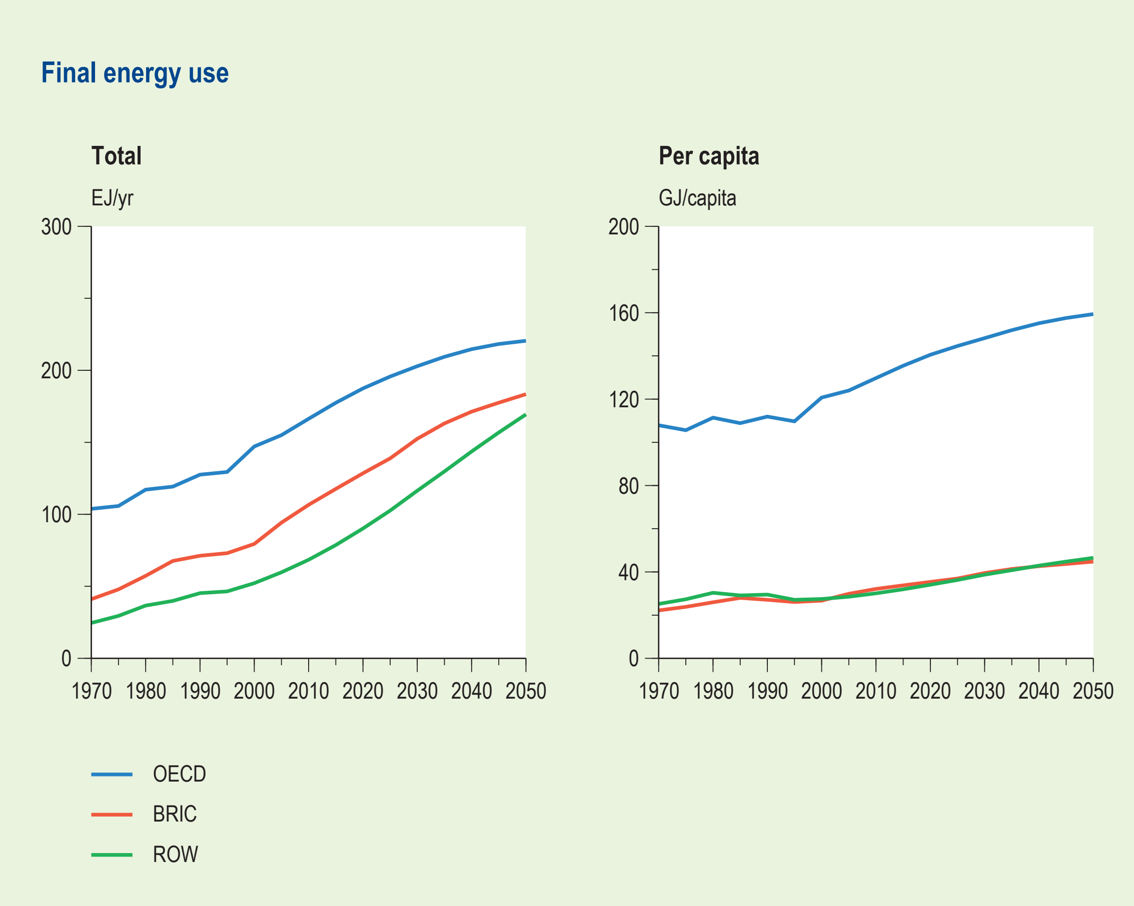


Figure 2.7 Final energy use OECD, BRIC and ROW, baseline
OECD Environmental Outlook modelling suite, final output from IMAGE cluster (016x_oec08)

Per capita energy consumption will slowly increase in most OECD regions, after a historic period of almost stable per capita consumption. (*Figure 2.7*, right-hand panel.) In many developing countries including BRIC, per capita energy use grows much more rapidly – and nearly doubles for most regional clusters. Nevertheless, per capita consumption remains below 60 GJ/capita for the medium income clusters such as South East Asia, Middle East and Latin America) and below 20 GJ/capita for Africa and South Asia up to 2020. On aggregate, a wide gap remains between the OECD on the one hand, and BRIC and Rest of the World on the other. In 2000, average energy consumption in OECD countries is more than two times larger than in the other groups, and by 2030 the ratio still is around 1.9.

In the power sector, the main trend observed over the last decade is replacement of coal as the dominant fuel for power production by natural gas, driven by the low investment costs, high efficiency and favorable environmental performance of combined cycle plants. Exceptions are regions with ample access to relatively low-cost, often domestically produced, coal and limited access to natural gas supplies, such as China and South Asia. As a result of the assumed continuation of high oil and gas prices, however, coal becomes the fuel of choice in practically all regions and its share in the fuel mix expands. This is illustrated in *Figure 2.9* for OECD Europe and the China region. In both regions, oil loses market share in the power sector. Natural gas use grew strongly in the nineties in OECD Europe, but the slower growth observed in recent years continues until 2030. In China, coal remains the dominant fuel for power production and supplies 83% of all electric power in both 2005 and 2030.

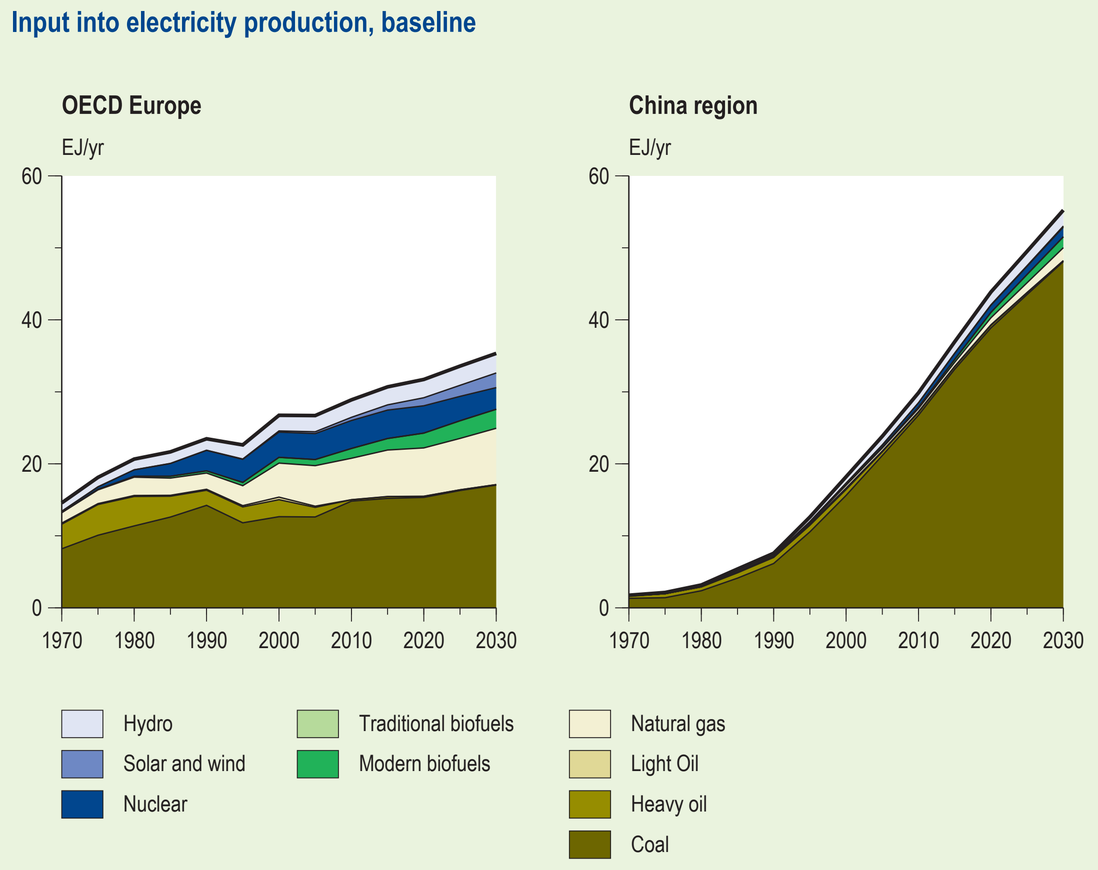


Figure 2.8 Primary inputs into electric power production, baseline
OECD Environmental Outlook modelling suite, final output from IMAGE cluster
Note: Renewables and nuclear measured by electric output (017x_oec08)

Globally, the position of coal as an input to the power sector increases from 51% in 2000 to 55% in 2030, and in absolute terms the volume more than doubles. The share of oil becomes very small and natural gas gains 5 percentage points in market share. The gas volume grows by 135% over the same period. Non-fossil power generation increases slightly, but on aggregate fossil fuels retain their high share (84% both in 2000 and 2030). Among the non-fossil resources, use of modern biofuels and renewables expands the most, together supplying 11% of global electricity in 2030.

The growing share in electricity generation plus the modest increase in final consumption imply that total coal use increases by 2.1% per year on average. Oil consumption, strongly driven by the transport market, grows by just over 1% per year. The continued high price of oil induces introduction of alternative transport fuels, mainly produced from bio-energy. Natural gas use grows by 2.3% per year between 2000 and 2030. Over the entire period, fossil fuels remain the primary source of energy, despite increases in the use of non-fossil resources such as modern biomass and renewables.

The Baseline sees the energy intensity (that is: primary energy use in proportion to GDP) continuing to improve worldwide. This improvement is strongest in the BRIC grouping. However,

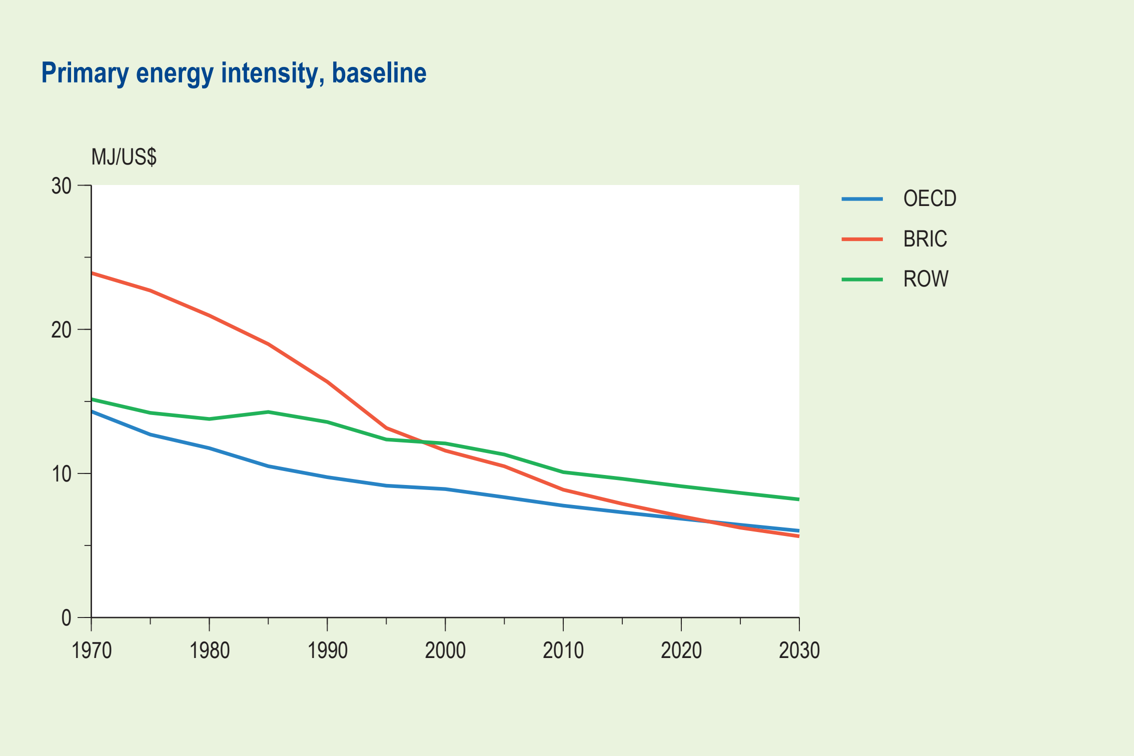


Figure 2.9 Primary energy intensity of OECD, BRIC and ROW economies, baseline
OECD Environmental Outlook modelling suite, final output from IMAGE cluste (167g_oec08)

perhaps surprisingly, the energy intensity of the economies of BRIC and the Rest of the World regional groupings has over the past decades in aggregate terms already improved to a level that is comparable with OECD countries. Compared to the 1970s and 1980s, the continued improvement proceeds in a fairly narrow band on the chart.

Historically, the dominant consumer of oil has been the OECD regional group (see *Figure 2.10*). This is even more clear for oil trade, as a major share of oil consumed in OECD countries is produced in the Rest of the World. In 2000, the BRIC group, in particular because of Russia, is still a next oil export exporter. Between 2000 and 2030, the Baseline shows a strong increase in global oil trade. The flow from BRIC (Russia) to OECD countries doubles while the flow from the Rest of the World group to BRIC (India and China) quadruples. As a result, the 2000 situation where OECD countries dominate oil demand has evolved by 2030 to a more complex situation.

In terms of the total of energy traded (fossil fuels and biomass) a similar trend can be observed *(Figure 2.11)*. Also here, energy flows from ROW to OECD are the largest in 2000 as well as 2030. But other flows increase faster. In particular the flow from ROW to BRIC, comprising coal as well as oil, gas and biomass, increases to a five-fold by 2030.

2.1.4 Agriculture and land use

Up to 2030, it is projected that global agricultural production will need to increase by more than 50% in order to feed a population more than 27% larger and roughly 83% wealthier than today's. Although it is assumed that productivity of land will increase substantially, the global agricultural area will have to increase by roughly 10% to sustain this production *(Figure 2.12)*.

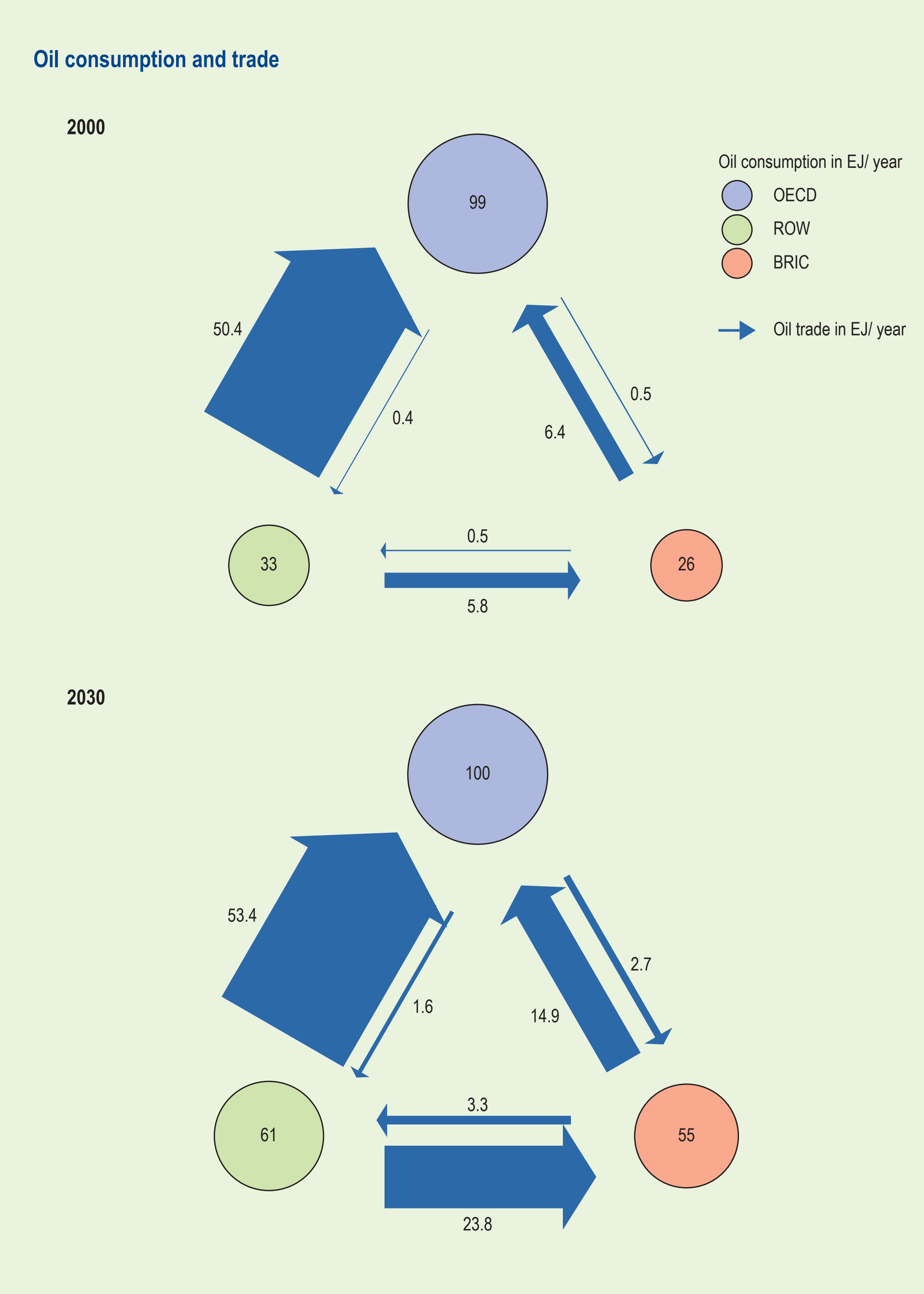


Figure 2.10 Oil consumption and trade, baseline

OECD Environmental Outlook modelling suite, final output from IMAGE cluster (161s_oec08)

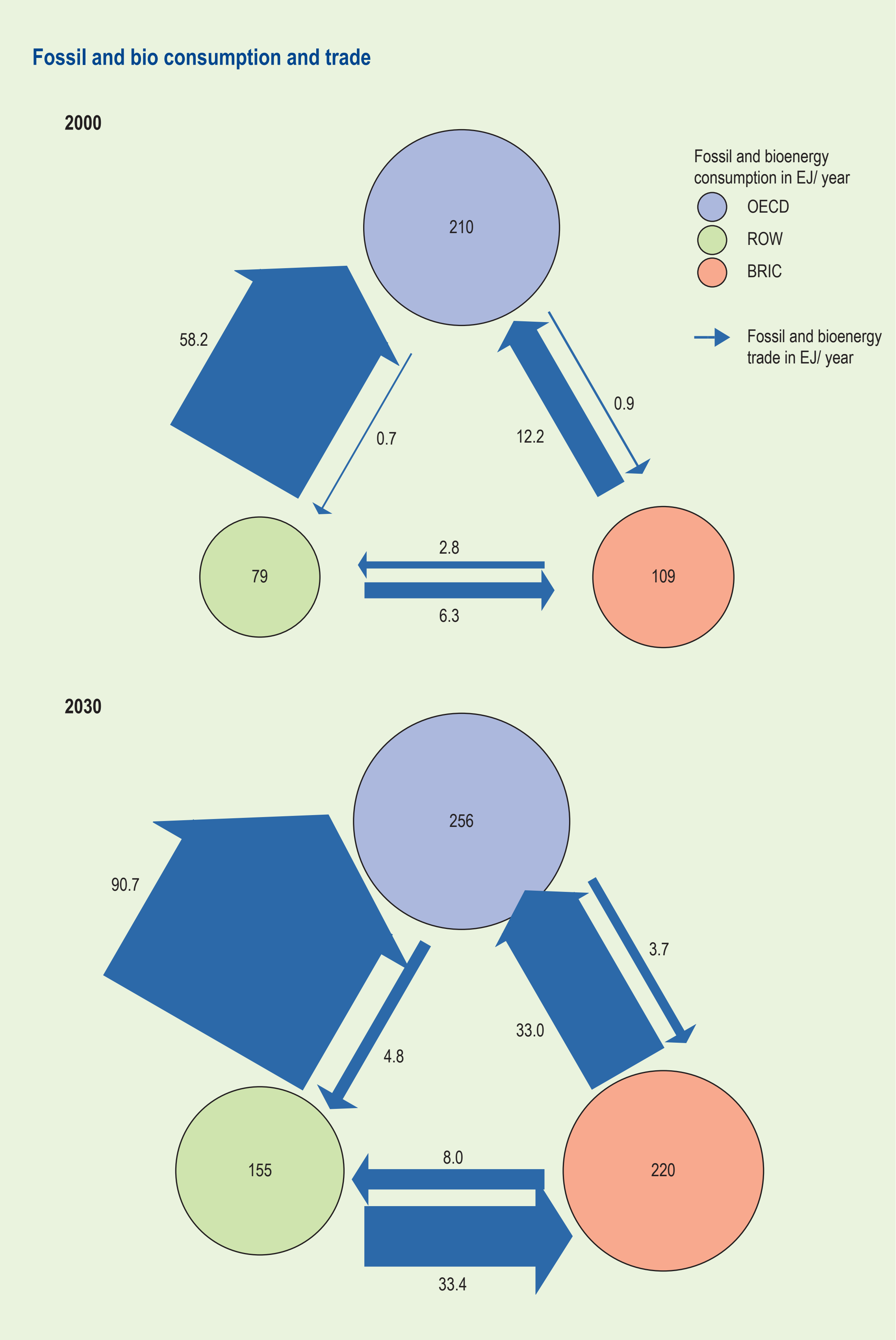


Figure 2.11 Consumption and trade of fossil fuels and biomass, baseline

OECD Environmental Outlook modelling suite, final output from IMAGE cluster (162s_oec08)

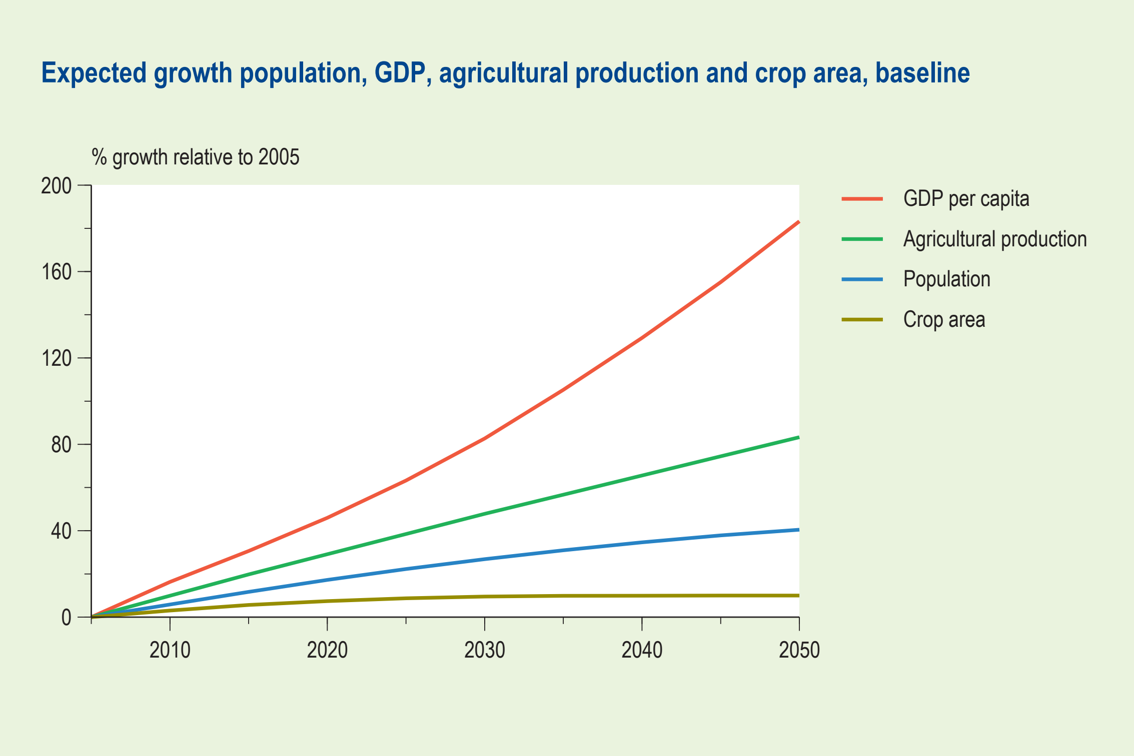


Figure 2.12 Growth of world population, GDP per capita, agricultural production and crop area; baseline
OECD Environmental Outlook modelling suite, final output from IMAGE cluster (019g_oec08)

After 2030, the growth in crop area is slowing down, mainly due to a reduced population growth.

Trends in agricultural consumption, trade and production

The largest part of the increase in agricultural production, as shown in detail in *Figures 2.13*. and 2.14, can be explained by an increasing domestic demand. In developing countries, agricultural production is growing four times faster than in OECD countries, due to faster economic and demographic change, and availability of new agricultural areas. In OECD countries, however, per capita consumption of agricultural products is almost stable, while it is projected to grow by 70% in developing countries to 2030. Trade, however, plays an important role for some countries and commodities. In general, countries with a high population growth have increasing imports and decreasing exports. Consequently, OECD countries have the highest rates of export growth, exceeding their production and consumption growth rates (clearly these totals mask important differences among countries).

Oilseed production is projected to grow about 50% faster than overall average agricultural production to 2030. This growth is boosted not only by growing demand for vegetable oils for human consumption, but also for oilseed meal for feeding animals and for biodiesel production. Oilseed trade is also projected to outstrip the trade in grain. The most important importer of oilseed is expected to continue to be China, which will double its imports from 2001 to 2030. The leading exporters are the United States and Brazil, with the United States almost tripling its oil seed exports by 2030.

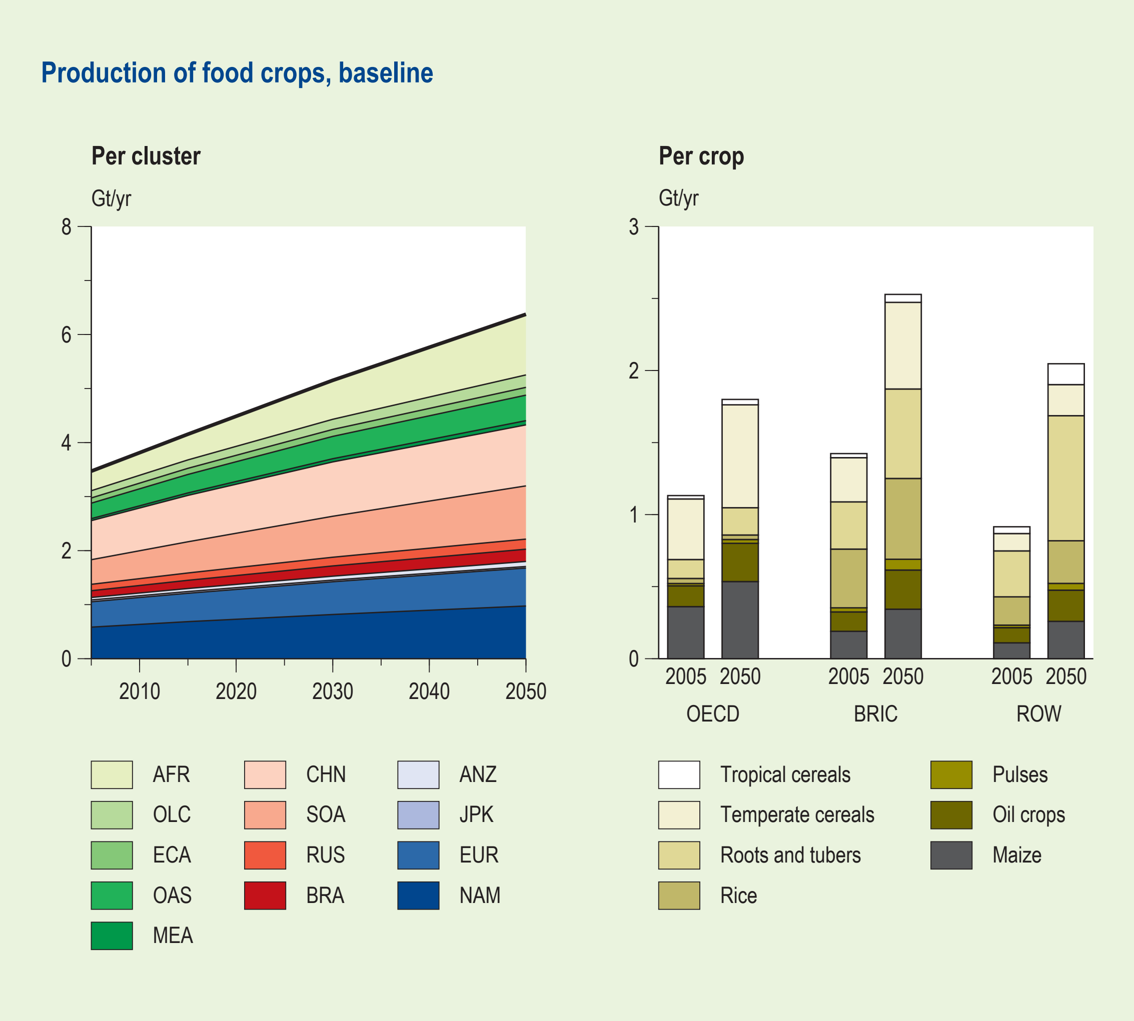


Figure 2.13 Production of food crops, baseline
OECD Environmental Outlook modelling suite, final output from IMAGE cluster (020x_oec08)

Land use

The increasing demand for agricultural products results both in an intensification of agriculture (more output per unit of land), and in an expansion of agriculture. *Table 2.3* presents the change in land used for agriculture between 2005 and 2030 as projected in the Baseline; *Figure 2.15* pictures the changes between 2000 and 2050. Total land used for agriculture, including crops, grass and energy crops, is projected to increase in all regions except Japan and Korea, mostly at the expense of remaining forest areas (both tropical and temperate), savannah and scrubland. In Europe, the increase is caused by an expansion of agricultural area in Turkey, while in West and Central Europe land continues to be taken out of production. After 2030, agricultural areas are roughly stable or decreasing in all regions except for Africa and Oceania.

Agriculture and land degradation

The expansion of agriculture, together with the development of other pressures, leads in the Baseline to an increase of the global agricultural area with high soil erosion risk by 30% between 2000 and 2030, from 20 to 27 million km². In the OECD the increase is only 19%, from 6 to 7 million km². In the BRIC countries the increase is close to 40%, from 6 to 8 million km². In the ROW the increase is also 40%, from 8 to 11 million km². Turning to the absolute areal

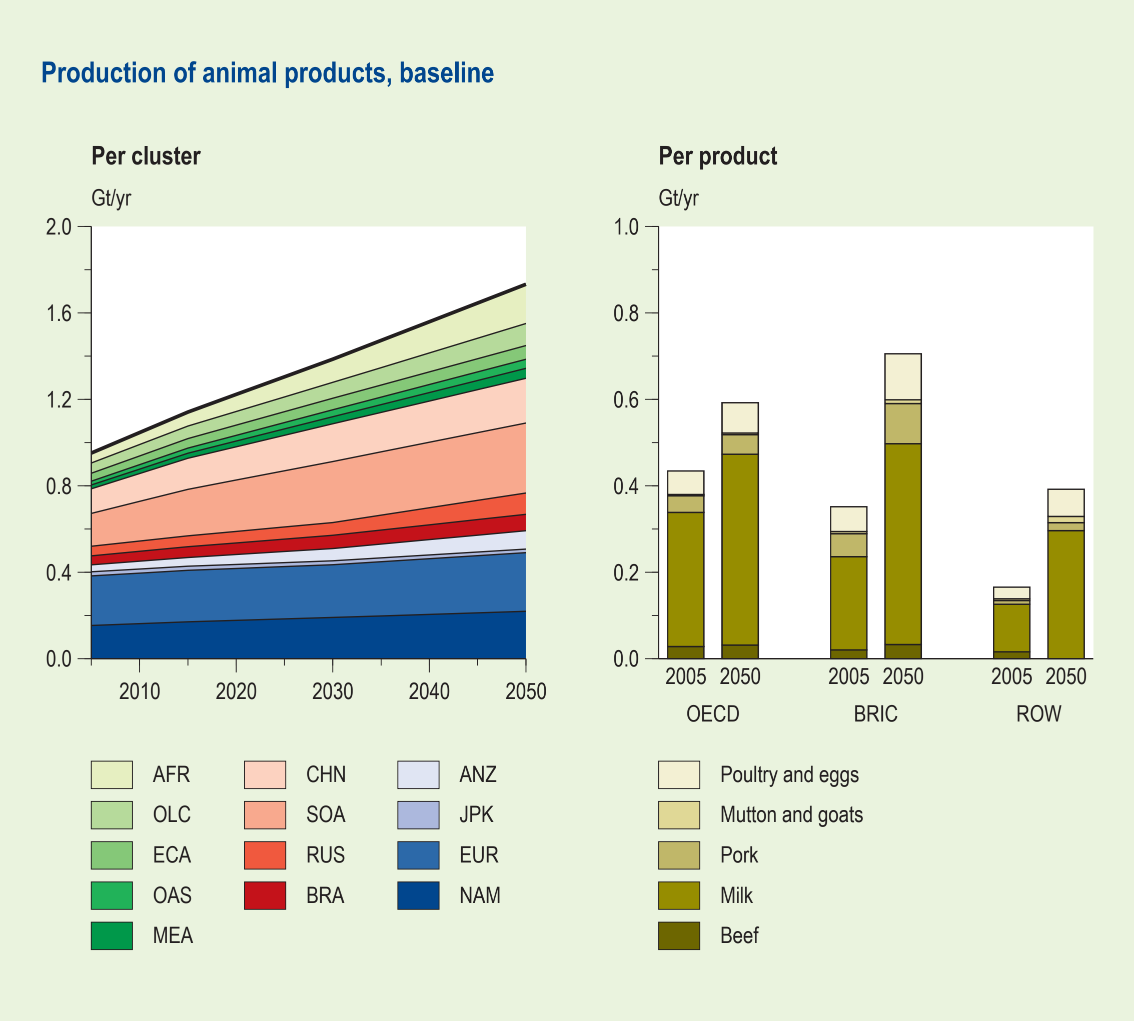


Figure 2.14 Production of animal products, 2005-2050, baseline
OECD Environmental Outlook modelling suite, final output from IMAGE cluster (022x_oec08)

increase, we see that almost 50% of the increase in the global agricultural area with high erosion risk is in ROW, and 34% and 16% in the BRIC and OECD countries, respectively.

These estimates do not consider agronomic soil conservation practices such as contour ploughing, mulching, et cetera, and mechanical conservation practices such as deviation ditches, grassed waterways, terracing, et cetera. The actual land degradation strongly depends on such conservation measures taken to prevent soil erosion or reduce soil erosion risks. The results therefore indicate where problems of water erosion may be present and where they may be most

Table 2.3 Change in land used for agriculture in 2030, baseline

	North America	Europe	Japan Korea	Australia New Zealand	Brazil	Russia	South Asia	China	Middle East	South East Asia	Caucasus and Other Central Asia	Other Latin America	Africa	World
Index 2005=100														
	104	105	83	104	108	115	124	101	100	127	104	109	118	110

Note: if indexed at 2000=100, the global increase would show as fourteen per cent
OECD Environmental Outlook modelling suite, final output from IMAGE cluster

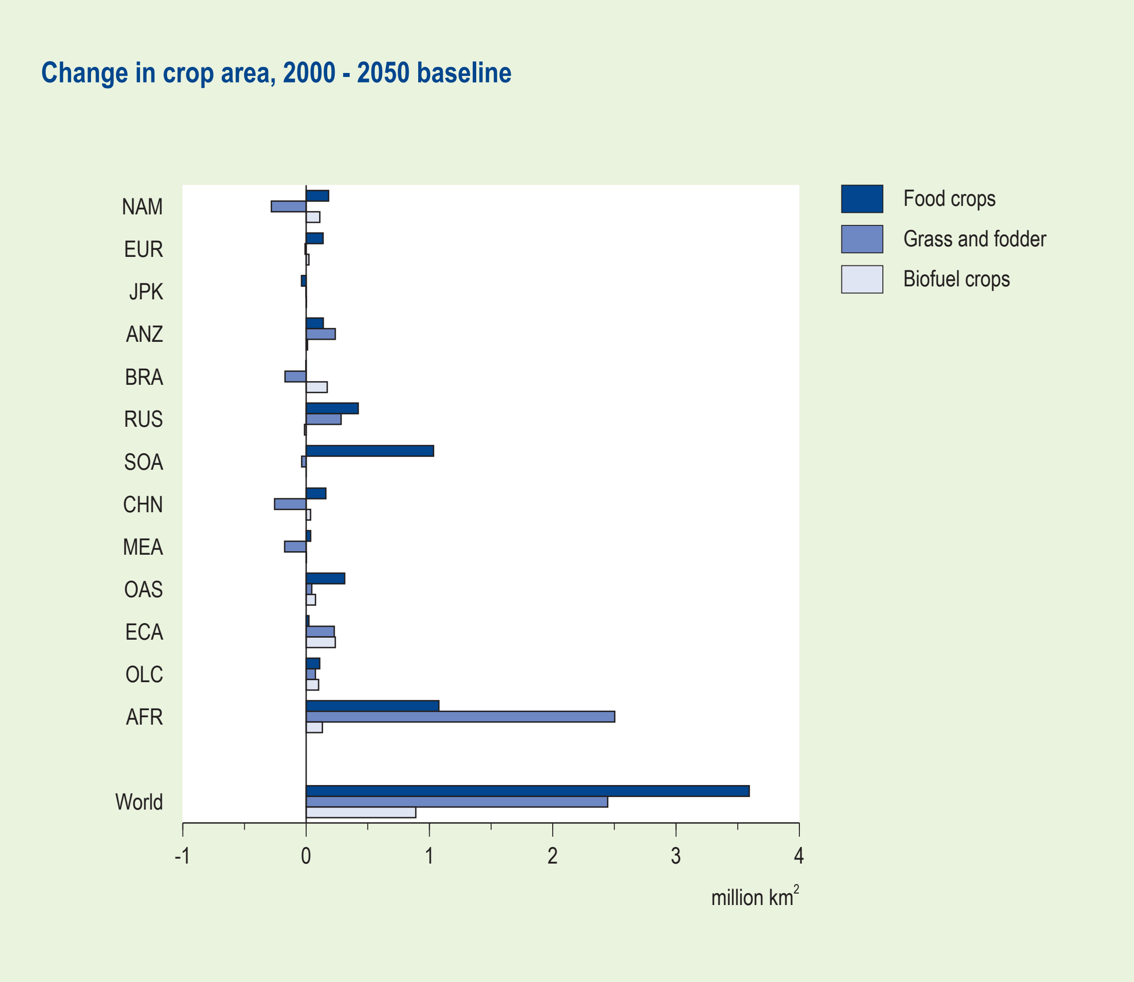


Figure 2.15 Change in crop area, 2005-2050, baseline
OECD Environmental Outlook modelling suite, final output from IMAGE cluster (024g_oec08)

severe, and how the land's sensitivity to water erosion may be in the future under scenarios of population growth, economic growth, technological development and climate change (see *Figure 2.16*).

Agriculture and the risk of desertification

The Baseline projects a considerable expansion of agricultural land in Africa, driven by population growth and relatively fast increases in food demand. As shown in *Figure 2.17*, a considerable part of that expansion is likely to occur in arid areas, contributing to the risk of desertification – a trend that has happened already over the last decades too. The change shown for Europe is mostly in Turkey, where a significant expansion is projected in the Baseline. In Brazil, the small amount of agriculture that is in arid zones is gradually being phased out in favour of other, more profitable, areas. The results for Russia and South Asia are explained by a general expansion of agriculture, but because South Asia can only expand into arid zones, the impact is greater there.

Climate change and agriculture

Agriculture is both contributing to climate change and being affected by it. The IPCC's Fourth Assessment Report documents an observed global warming trend and projects a wide range of climate changes that will affect agricultural production and food security worldwide (IPCC,

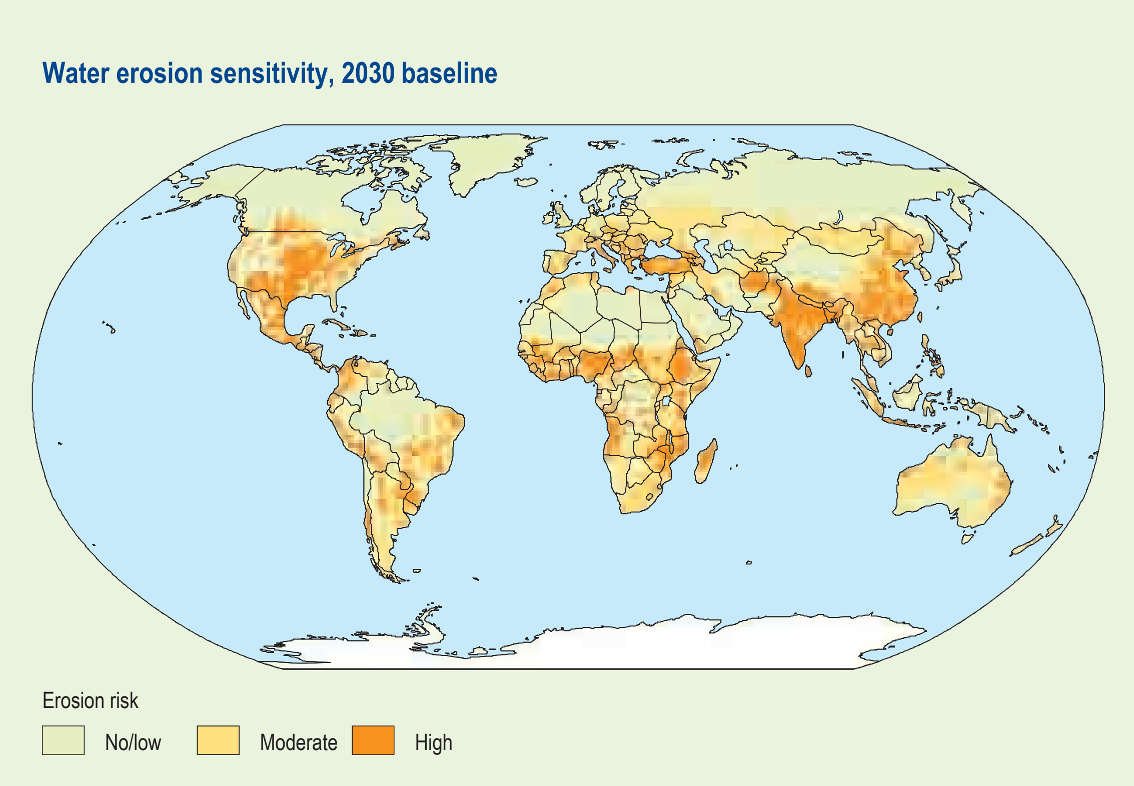


Figure 2.16 Water erosion sensitivity, 2030 baseline
OECD Environmental Outlook modelling suite, final output from IMAGE cluster (148k_oec08)

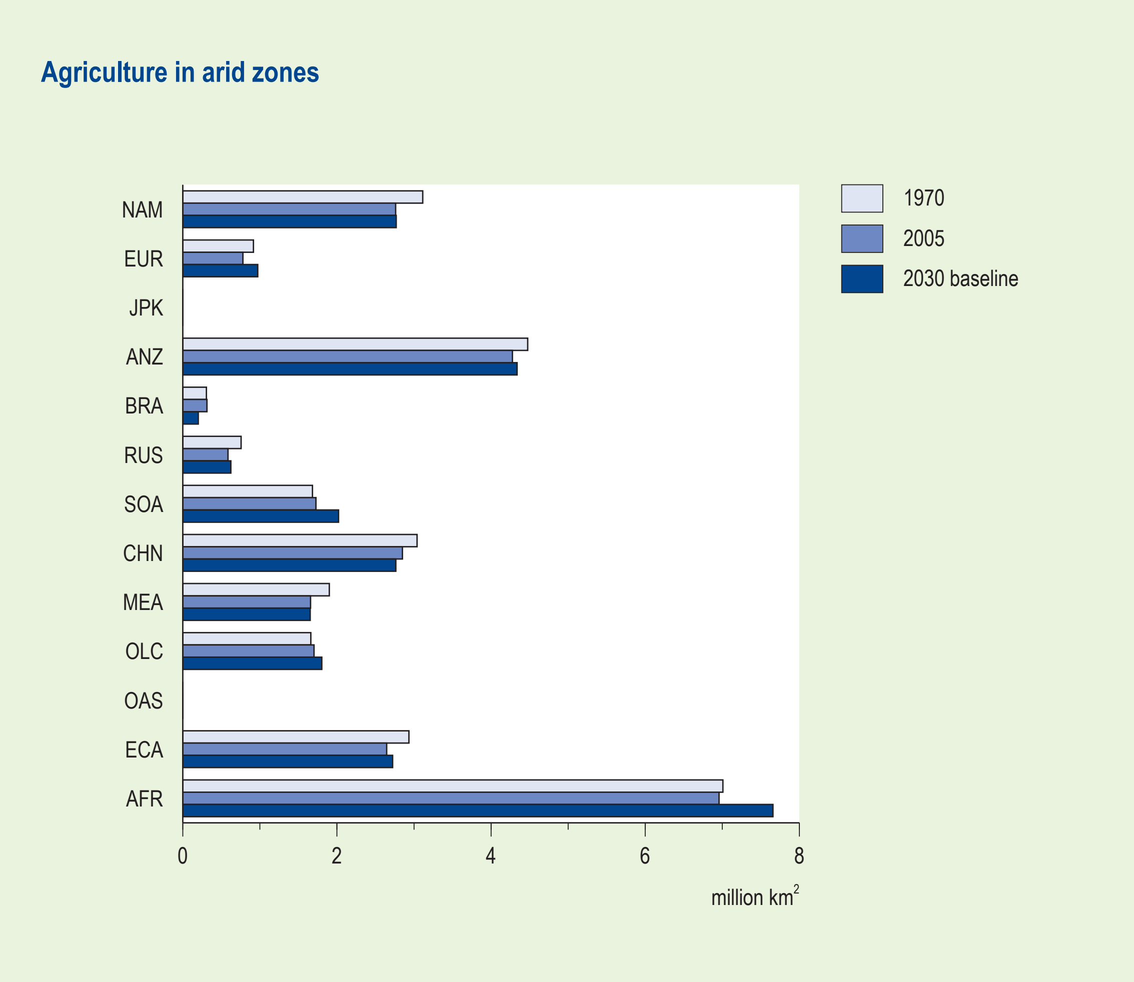


Figure 2.17 Agricultural areas in arid zones
OECD Environmental Outlook modelling suite, final output from IMAGE cluster (165g_oec08)

2007b). With higher temperatures, the hydrological cycle will be intensified as more water evaporates and on the whole more precipitation results. On the other hand, increasing temperatures can reduce crop productivity via heat stress and increase drought risks due to higher evaporation. The effect of both temperature and precipitation will be very unevenly distributed and in many areas climate may even become dryer. The impact of climate change on wheat yield under the Baseline is shown in *Figure 2.18*. While yields are rather stable in most regions and increase in some temperate areas, the combined effect of temperature increase and reduced precipitation is likely to reduce yields significantly in some areas of Oceania, South Asia, and Africa.

Currently, agriculture contributes roughly 50% of global methane emissions (from rice paddies, manure and enteric fermentation), 90% of global nitrous oxide (N_2O) emissions from manure and fertilizer application) and about 14% of global carbon dioxide emissions from deforestation. Global GHG emissions from land use between 2005 and 2030 show only small changes for the world, as increasing nitrous oxide and methane emissions from crop and livestock production are compensated by decreasing emissions from deforestation. However, the changes are large in specific regions *(Table 2.4)*. In Brazil and China, deforestation is slowly declining, and therefore, the deforestation emissions are decreasing as well. In Russia and Central Europe, the decrease in agricultural land in the 1990s led to re-growth in vegetation, which in turn led to carbon uptake that is counted as anthropogenic. From 2005 onwards, this re-growth is expected to stabilise or reverse – partly due to renewed economic growth. The region thus passes from sequestering carbon, to emitting carbon from land use. In North America, a small increase in agricultural land is projected to lead to increases in carbon dioxide emissions by deforestation.

2.1.5 Climate change

Globally, carbon dioxide emissions from fossil fuel combustion (which constitute the main source of greenhouse gas emissions) increase under Baseline conditions from 6.9 Gt C equivalent in 2000 to 11.7 Gt C equivalent in 2030 and 13.8 Gt C equivalent in 2050. Among the energy-related emissions, those from electric power generation and transport are the largest and also increase the most over the Outlook period. Per capita emissions in OECD countries remain much higher than for most non-OECD countries.

Total global greenhouse gas emissions *(Table 2.5)* amount to 11.5 Gt C-equivalent in 2000 and are projected to be 17.5 Gt C-equivalent in 2030 and 19.5 Gt C equivalent in 2050. This is consistent with a 37 % increase between 2005 and 2030, as reported in the outlook main report, and a 52 % increase between 2005 and 2050. Whereas emissions from OECD increase by nearly one-third (1.4 GtC) from 2000 to 2030, emissions from BRIC and Rest of the World nearly double over the same period and their share in the global emissions increases from 57% to 64%.

These Baseline emissions would lead to a temperature increase in the range of 1.7 to 2.4 °C above pre-industrial level by 2050. By the end of the century temperatures would have increased to 3 to 4°C above pre-industrial level. The discussion of *Figure 2.45* explains how the simuations of the Outlook relate to climate change beyond 2050.With higher temperatures, the hydrological cycle is also intensified as more water evaporates and on the whole more precipitation results. As with the temperature pattern, the effect is very unevenly distributed and in many areas it may even become dryer, while adjacent areas receive more precipitation. Specifically in already water-stressed areas, such as southern Europe and India, the negative impact on agriculture and human settlements can be substantial. Obviously, the risk of drought-related problems will be biggest in areas where the future drop in net precipitation is large

Table 2.4 Change in greenhouse gas emissions from land use changes 2005-2030, baseline

	North America	Europe	Japan Korea	Australia New Zealand	Brazil	Russia	South Asia	China	ROW	World
%										
	21	41	19	12	-23	158	8	-18	-1	2

OECD Environmental Outlook modelling suite, final output from IMAGE cluster
Note: Land use change includes agriculture emission sources (e.g. emissions of methane and nitrous oxide)

relative to the current level. Moreover, areas with substantial increases over already high levels in 2000 will be more susceptible to run into water drainage or flooding problems. In general, all areas facing considerable changes in net precipitation (see *Figure 2.44*) will have to adapt to

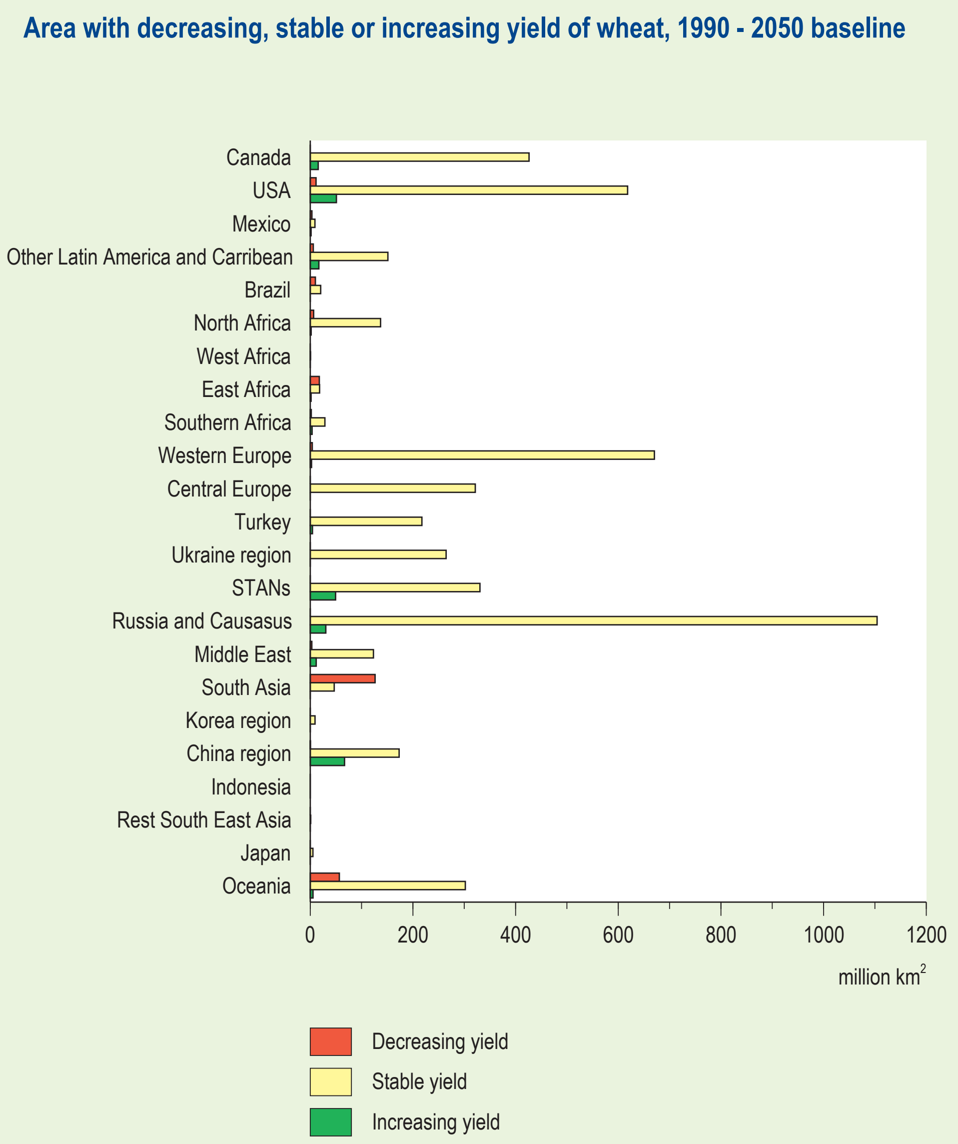


Figure 2.18 Area with decreasing, stable or increasing yield of wheat since 1990, baseline 2050
OECD Environmental Outlook modelling suite, final output from IMAGE (149g_oec08)

Table 2.5 Emissions of greenhouse gases from energy use, industry and land use; baseline

	1970					2000					2030					2050				
	CO_2	CH_4	N_20	HFC, PFCs & SF_6	total	CO_2	CH_4	N_20	HFC, PFCs & SF_6	total	CO_2	CH_4	N_20	HFC, PFCs & SF_6	total	CO_2	CH_4	N_20	HFC, PFCs & SF_6	total
	Gton C-equivalent per year																			
North America	1.36	0.27	0.09		1.71	1.99	0.36	0.10		2.44	2.67	0.43	0.12		3.22	2.65	0.45	0.12		3.22
OECD Europe	1.25	0.23	0.11		1.59	1.37	0.21	0.08		1.66	1.75	0.23	0.09		2.07	1.86	0.23	0.09		2.19
OECD Asia	0.29	0.03	0.01		0.32	0.55	0.04	0.01		0.60	0.65	0.05	0.01		0.70	0.68	0.04	0.01		0.73
OECD Pacific	0.06	0.04	0.01		0.11	0.05	0.13	0.01		0.20	0.20	0.06	0.02		0.28	0.20	0.06	0.01		0.28
Brazil	0.07	0.05	0.02		0.13	0.26	0.09	0.04		0.40	0.27	0.14	0.05		0.46	0.29	0.17	0.05		0.51
Russia & Caucasus	0.58	0.12	0.02		0.72	0.58	0.16	0.01		0.68	0.67	0.24	0.03		0.94	0.58	0.22	0.03		0.84
South Asia	0.11	0.17	0.05		0.32	0.47	0.28	0.10		0.85	1.08	0.45	0.14		1.67	1.55	0.50	0.15		2.20
China region	0.24	0.16	0.04		0.44	1.38	0.30	0.12		1.80	2.74	0.21	0.01		3.35	2.99	0.49	0.12		3.59
Middle East	0.11	0.02	0.00		0.13	0.34	0.06	0.01		0.41	0.73	0.10	0.02		0.85	1.04	0.16	0.02		1.22
Other Asia	0.07	0.08	0.01		0.16	0.48	0.15	0.04		0.66	0.83	0.20	0.06		1.09	1.04	0.21	0.06		1.31
Eastern Europe and Central Asia	0.29	0.06	0.02		0.38	0.21	0.06	0.01		0.28	0.30	0.12	0.02		0.44	0.31	0.12	0.02		0.45
Other Latin America and Caribbean	0.13	0.07	0.02		0.23	0.42	0.12	0.05		0.58	0.45	0.17	0.05		0.66	0.55	0.19	0.05		0.80
Africa	0.14	0.11	0.04		0.29	0.70	0.19	0.07		0.96	1.23	0.39	0.14		1.76	1.43	0.53	0.18		2.14
World	4.69	1.40	0.44	0.03	6.53	8.81	2.06	0.65	0.10	11.52	13.58	3.04	0.65	0.25	17.48	15.18	3.39	0.90	0.41	19.47

OECD Environmental Outlook modelling suite, final output from IMAGE cluster

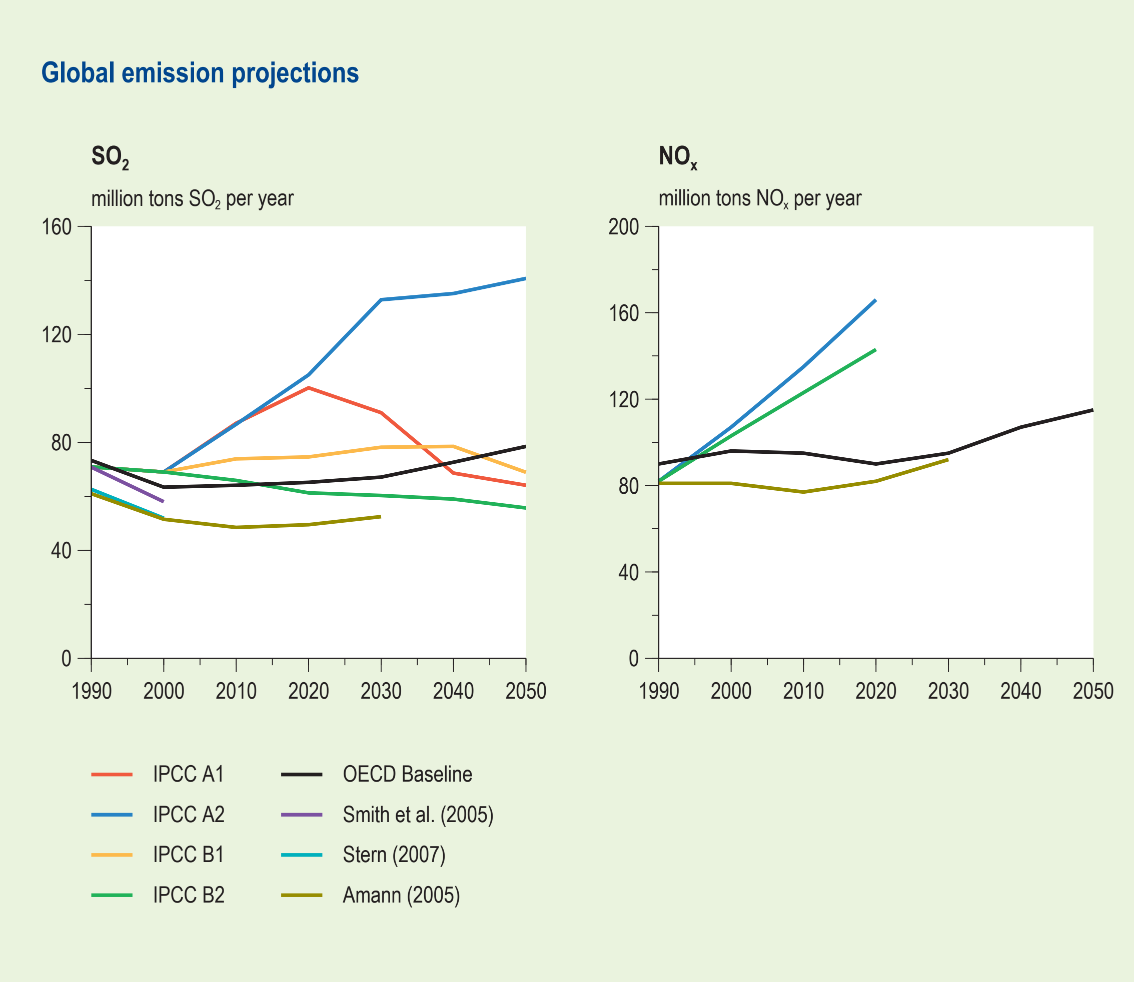


Figure 2.19 Global baseline emissions of sulphur dioxide and nitrogen oxides
OECD Environmental Outlook modelling suite, final output from IMAGE cluster (115x_oec08)

cope with these changes, including through adjustments in water management practices and/or infrastructure.

2.1.6 Air pollution

In the Baseline the global totals of emission of sulphur dioxide and nitrogen oxides remain almost unchanged between now and 2030. However, the regional contributions to the global total change drastically over this period, decreasing in OECD countries reflecting the progress in abating air pollution, stabilizing in the BRIC countries and increasing in the rest of the world where the institutional capacity or the financial resources to control air pollution are frequently insufficient. Emissions per unit in the transport sector are projected to decrease, for example in the China Region, as a result of policies in place (see OECD, 2006).

Compared with the global projection by IIASA (Cofala et al., 2005) the OECD Baseline features larger emissions in the base year as well as in the future, reflecting a less optimistic view on industrial emissions outside OECD countries. The development over time is very similar *(Figure 2.19)*. Both projections are lower than those of the IPCC (2000) and reflect newer insights in the most plausible development of emissions sulphur and nitrogen oxides under Baseline conditions.

Key uncertainties include the future use of coal worldwide, quantity as well as technology; use or non-use of existing abatement equipment in power plants in China; and industrial emissions for example from metallurgy in Russia.

The industrialization initiated a world-wide urbanization. It is estimated that nowadays more than 50% of the global population lives in urban areas. The number of cities with more than 100 000 inhabitants is well over the three thousand. Due to the high density of economical activities (and resulting emissions) the urban population is exposed to concentrations frequently exceeding the target values set by the WHO for the protection of human health.

Many epidemiological and toxicological investigations have shown that exposure to air pollution causes adverse health effects leading to, for example, hospital admissions or premature death. Recent work indicates that the most severe effects originate from the exposure to particulate matter (PM_{10} or $PM_{2.5}$, small particles with a diameter less than 10 µm or 2.5 µm, respectively) and ozone. For particulate matter there are no reliable world emission estimates available. Sulphur dioxide is one of the precursors of secondary fine particles. Nitrogen oxides are precursors to both ground-level ozone as well as particulate matter.

It is suggested that for both particulate matter and ozone there is no safe level: even at concentrations below current air quality guidelines they may pose a health risk (WHO, 2006).

For the Environmental Outlook concentrations of particulate matter (PM_{10}) and ozone and their health impacts have been estimated for over 3000 large urban agglomerations (see Section 3.1.9 for details). Between 2000 and 2030 the population living in these 3000 world cities will increase from 2.06 billion (34% of the world population) to 3.56 billion (44% of the world population).

The population weighted results of the modelled annual average concentration of PM_{10} in these 3000 cities are presented in *Figure 2.20*. The World Health Organisation (WHO, 2006) has recommended three interim targets (decreasing from 70 to 50 to 30 µg/m³) and a guideline of 20 µg/m³ for PM_{10} with decreasing risks of premature mortality from exposure to airborne particulate matter. In the most polluted areas (Middle East, Africa, Asia except Japan) concentrations are substantially larger than the WHO interim target of 70 µg/m³; these levels are associated with approximately 15% larger long-term mortality than at the guideline level. OECD-Pacific is the only region with an averaged concentration meeting the WHO-Air Quality Guideline (AQG).

Within a region, large differences occur. In OECD-Pacific 80% of the people live in an agglomeration with PM_{10} concentrations meeting the AQG. In the Middle East, and most of Asia 70 to 90% of the population is exposed to concentrations larger than the least demanding WHO interim target. The large concentrations in the South Asia are modelled mainly for urban agglomerations in Bangladesh and Pakistan. The model might overestimate the levels here although there is observational evidence that urban concentrations in Pakistan frequently exceed 200 µg/m³ (Ghauri et al., 2007).

Under the Baseline assumption urban air quality is projected to deteriorate in seven of the thirteen regions with a range from less than 5% to more than 25% between 2000 and 2030. In the four least polluted regions, more than 50% of the urban population would live in healthy cities with an averaged particulate matter concentration meeting the AQG. In the five most polluted

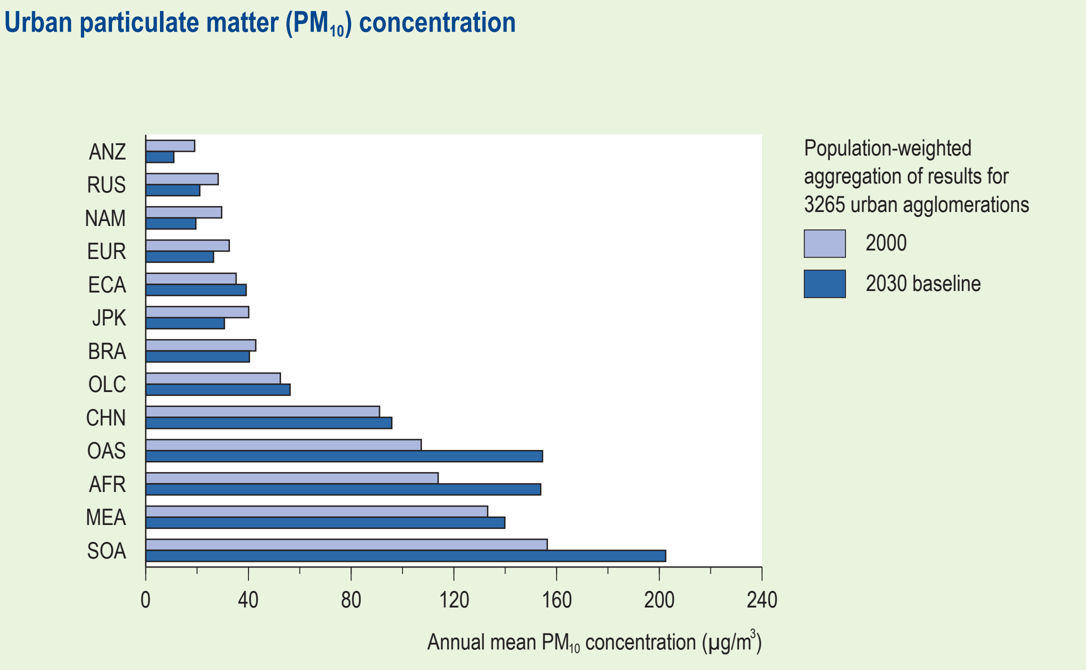


Figure 2.20 Annual mean particulate matter (PM10) concentrations, baseline
OECD Environmental Outlook modelling suite, final output from IMAGE cluster (029g_oec08)

regions, 50 to 90% of the urban population would be exposed to concentrations exceeding the WHO interim target of 70 µg/m³ in 2030 (see *Figure 2.21*).

For the OECD Baseline, the area with annual mean ozone concentrations exceeding 45 parts per billion is projected to increase by 2030 to become one large continuous area from Spain to Japan, along with two additional areas over coastal USA *(Figure 2.22)*.The maximum concentrations found in the Himalaya region are mainly from a natural origin; these are due to the high altitude of this region and to the resulting mixing with ozone-rich stratospheric air. Large man-made concentrations are found over the Arabian Peninsula, over the Mediterranean and the Eastern coast of the USA. Observational data in Europe indicate that, despite the decrease in the European emissions of ozone precursors, ozone concentrations are not projected to decline. They are expected instead to increase, especially in urban areas, because of the interaction with local emissions of nitrogen oxides (EEA, 2006; ETC/ACC, 2007).

Following well established methods (see part 3 for details) the health impact of the urban population attributable to PM_{10} and ozone has been estimated. For 2000 it is estimated that exposure of the urban population to particulate matter caused approximately 960 000 premature deaths and 9.6 million DALYs (disability adjusted life years) worldwide. The largest contribution to premature deaths is from cardiopulmonary disease in adults (80% to more than 90%, depending on the region).

Figure 2.23 shows that an increase in premature deaths respectively loss of DALYs attributable to PM_{10} is estimated for most of the regions in 2030, even those where concentrations of particulate matter are estimated to decrease (for example, the cluster OECD Asia and Brazil). Factors other than the changes in PM levels influence this outcome. These include increasing

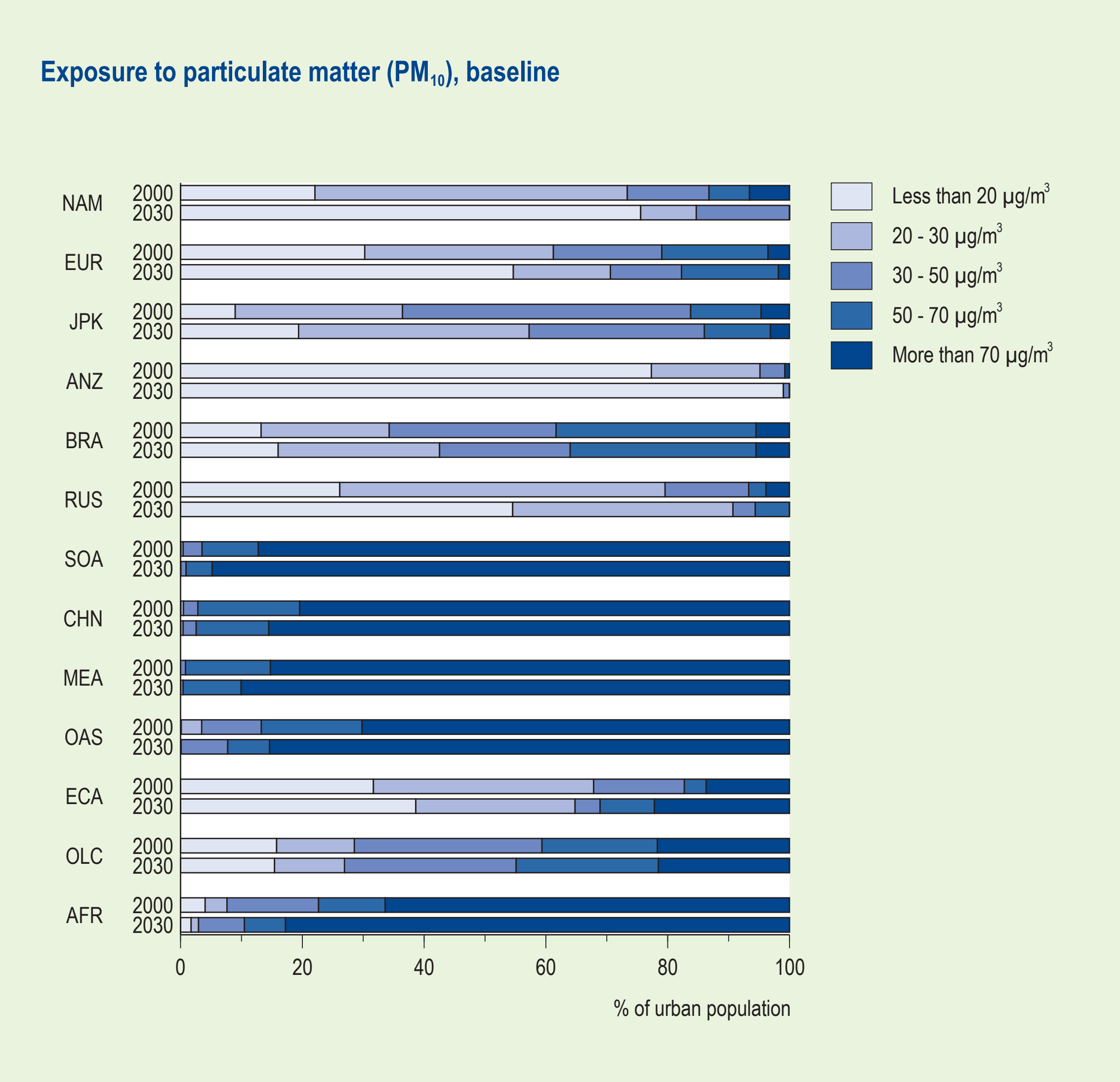


Figure 2.21 Exposure of the urban population to particulate matter (PM_{10})
OECD Environmental Outlook modelling suite, final output from IMAGE cluster (150g_oec08)

urbanisation, especially in China and South Asia, as well as the ageing of the population, as the elderly are generally more susceptible to air pollution. In 2030 a more than fourfold increase in premature deaths from lung cancer is expected, though premature deaths from acute respiratory infection in children decrease both in absolute numbers as well as relatively. In the OECD Pacific region the average concentrations are projected to be below the minimum threshold of 15 µg/m³.

The estimates of premature deaths respectively loss of DALYs attributable to the exposure to ozone are presented in *Figure 2.24*. The Baseline projects a strong increase in ozone-attributable deaths to 2030 in all regions. By comparing with the corresponding data for particulate matter it is evident that the projected concentrations of ozone have less impact on human health. However, as discussed above, the impact might be underestimated, as below the cut-off of 35 ppb health effects can still occur.

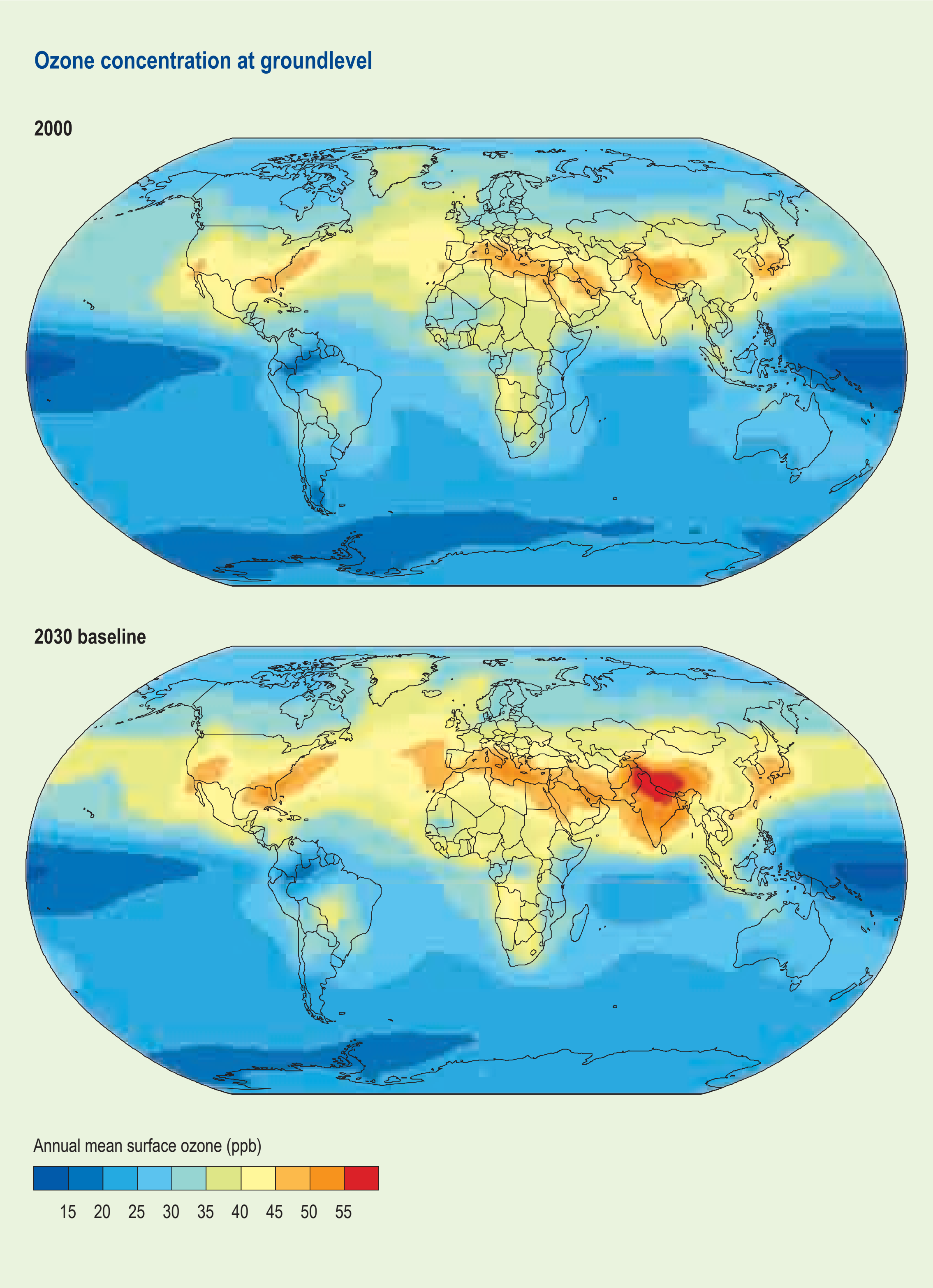


Figure 2.22 Ozone concentrations at ground level, 2000 and 2030 baseline

OECD Environmental Outlook modelling suite, final output from IMAGE cluster. Based on data from Dentener et al., 2005 (030x_oec08)

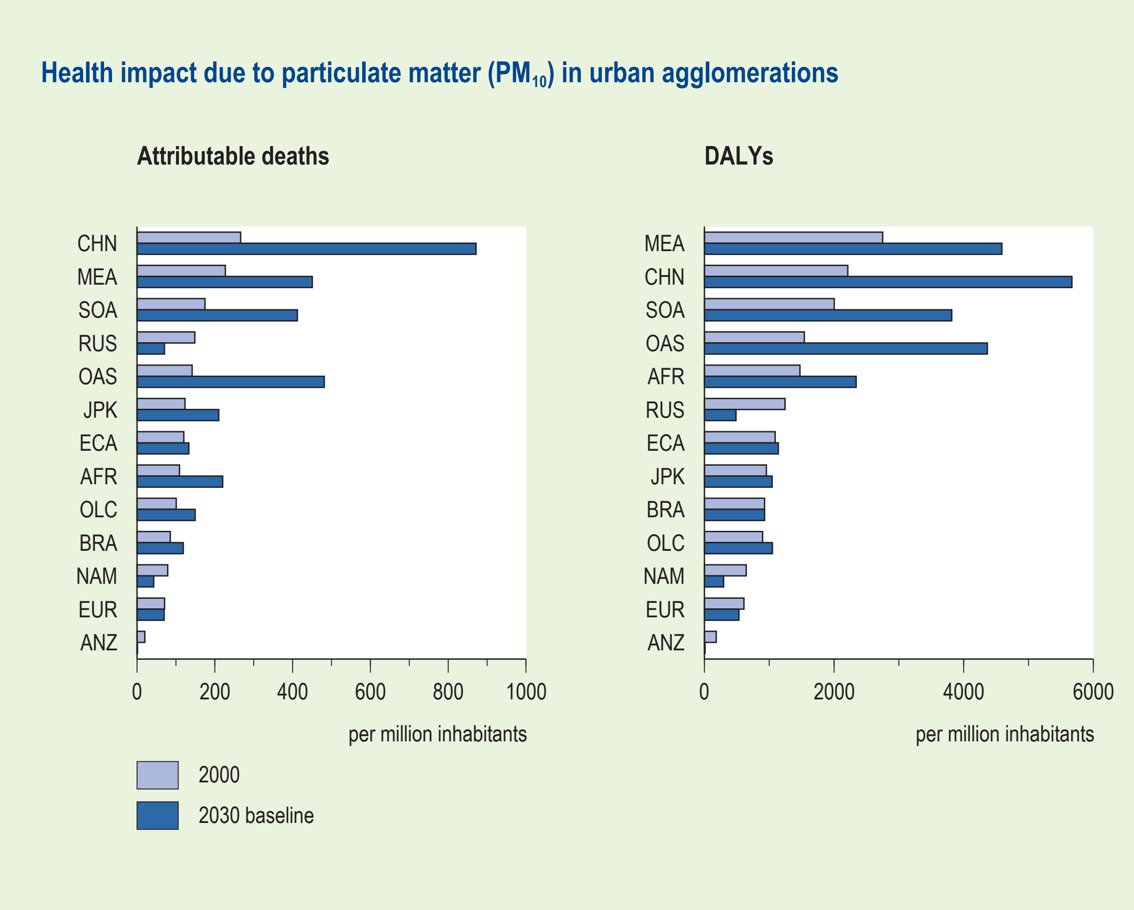


Figure 2.23 Baseline estimates of premature deaths and of the loss of DALYs from airborne particulate matter in urban agglomerations
The health impacts are quantified relative to the total number of inhabitants of the regions
OECD Environmental Outlook modelling suite, final output from IMAGE cluster (GUAM) (105x_oec08)

2.1.7 Water quantity issues

The Baseline simulation for water demand reveal a considerable increase of about 26% for overall water withdrawals between 2005 and 2030 (see *Tables 2.6 - 2.7*). In almost all regions overall water demand increases, except in Canada and Japan (decrease of water withdrawals of -6% and -11%, respectively). Especially in Central and South America, in Western Africa, Ukraine and in many parts in the South East Asia water demand increases by more than 40%. In Indonesia and Western Africa water use doubles, however with medium or low contribution to the global demand. In contrast, in the two countries with the largest overall water use, namely India and China, water use increases less (18% and 49%, respectively). This is in both cases due to a larger water demand in the electricity and manufacturing sector, with smaller increases in the domestic sector and a decrease in water use for irrigation.

In fact, the decrease in worldwide water demand for irrigation is dominated by the developments in India and China, as the volumes involved in these regions are so large. The orders of magnitude, year 2000, are: India 1200 cubic kilometres; China 500; most other regions 200 or less. The decrease reflects autonomous efficiency improvement. There is much room for improvement in terms of efficiency and some of that takes place under Baseline conditions.

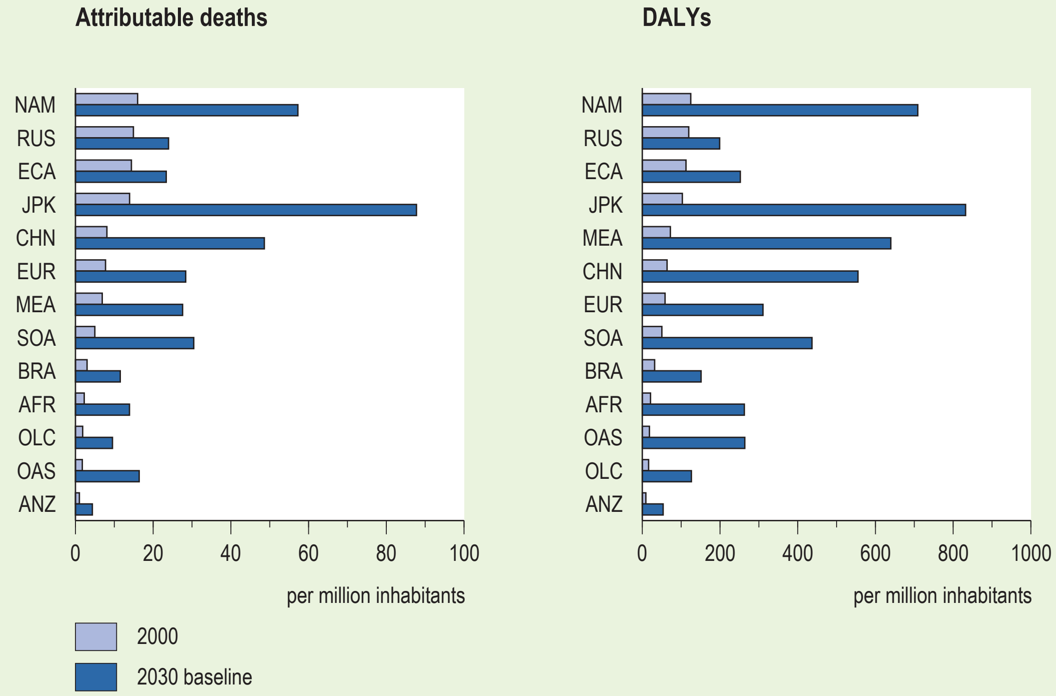

Health impact due to ozone in urban agglomerations

Figure 2.24 Baseline estimates of premature deaths and of loss of DALYs due ozone exposure in urban agglomerations

The health impacts are quantified relative to the total number of inhabitants of the regions

OECD Environmental Outlook modelling suite, final output from IMAGE cluster (GUAM) (032x_oec08)

Table 2.6 Water use, baseline

	2005	2030	change 2000-2005
	km^3		%
North America	639	679	1.1
OECD Europe	484	588	8
OECD Asia	61	75	8
OECD Pacific	34	37	3
Brazil	39	99	10
Russia & Caucasus	153	187	17
South Asia	1283	1713	-0.3
China region	689	1460	5
Middle East	236	342	5
Other Asia	163	382	14
Eastern Europe & Central Asia	134	155	4
Other Latin America & Carribean	121	214	4
Africa	192	343	1.4
World	**4230**	**6275**	**3.5**

OECD Environmental Outlook modelling suite, final output from IMAGE cluster (WaterGAP)

Table 2.7 Global water use, by sector, baseline

	domestic	electricity	irrigation	livestock	manufacturing	total
km^3						
2005	377	710	2806	30	308	4230
2030	633	1167	2631	38	878	5347
	%					
2005	9	17	66	1	7	100
2030	12	22	49	1	16	100

OECD Environmental Outlook modelling suite, final output from IMAGE cluster (WaterGAP)

Consistent with the expectation in the Comprehensive Assessment on Water Management (Molden, 2007), it is assumed that irrigated area does not expand much. The room for change in irrigation globally is in efficiency of water use in existing systems rather than in expanding irrigated areas. Hence under the no-new policies Baseline, the total amount of water withdrawn for irrigation does not change up to 2030. At the same time, water use in the electricity and manufacturing sectors increases considerably(see *Table 2.7* and *Figure 2.50*). As a result, the irrigation sector, which dominates global water use today with 66% of total water use, will fall back to less than half of total water use in 2030.

The increase in total water demand together with the envisaged growth of the population in affected areas will increase the number of people living under water stress (see *Figure 2.26*).

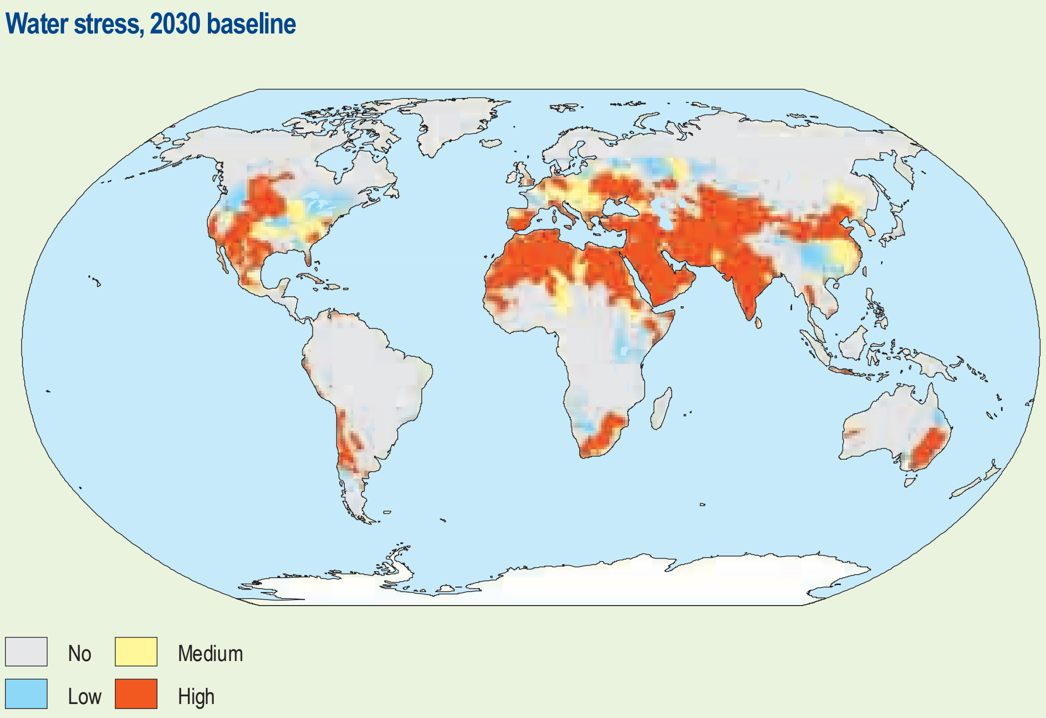


Figure 2.25 Water stress areas in 2030, baseline
OECD Environmental Outlook modelling suite, final output from IMAGE cluster (WaterGAP) (040k_oec08)

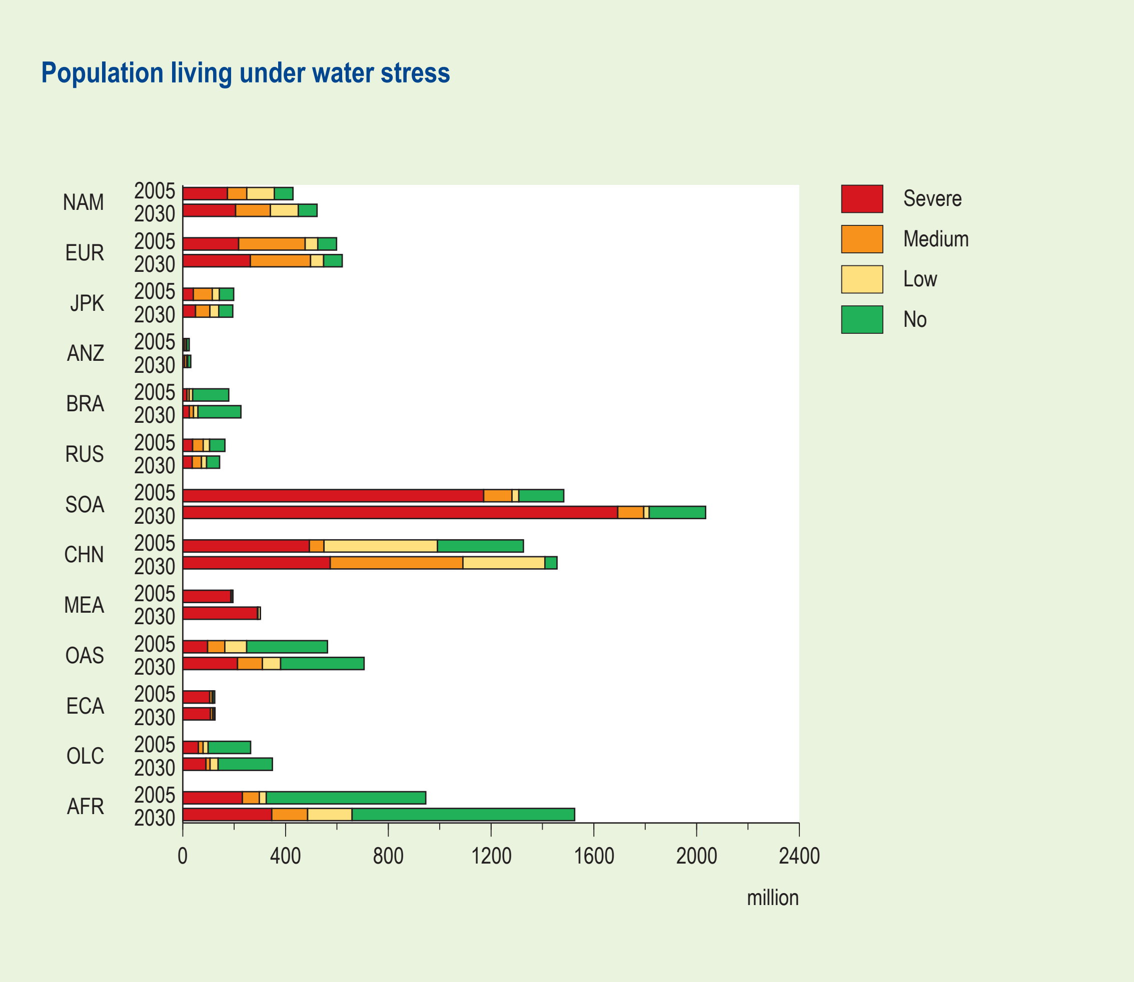


Figure 2.26 Population by degree of water stress in the drainage basin, baseline
OECD Environmental Outlook modelling suite, final output from IMAGE cluster (WaterGAP) (106g_oec08)

Large population growth rates can be found in Central and South America, Africa, Middle East and India (with population growth exceeding 30%; see *Table 2.1*), but only in Eastern Africa an equivalent high percentage of people will suffer from increased water stress. An increase in population affected can also be noticed in Mexico, China and Indonesia. Besides people living already in regions with severe water stress (like in Mexico, Northern Africa, Turkey, Ukraine, Asia-Stan, Middle East and India where more than 50% of the population is exposed to high water stress) where the situation will not change, there will be an absolute change in the exposure to high water stress in Korea and Indonesia, where by 2030 respectively 36 and 41% of the population will be living in areas with high water stress. There are only a few regions where the proportion of people in areas without water stress will increase, like Canada and Japan.

In terms of annual totals and applied at the level of the world's 6000 major drainage basins, a withdrawal-to-availability ratio of 0.1 to 0.2 is classified as 'low water stress'. A ratio between 0.2 and 0.4 is classified as 'moderate water stress'. A ratio of 0.4 or larger is classified as 'severe water stress'. A short explanation of the limitations of this indicator can be found in the discussion of uncertainty issues (section 3.2.2, under 'Indicator choice and presentation'). Climate change as projected by the outlook is factored in but by 2030 that is not yet large enough to influence these modelling results.

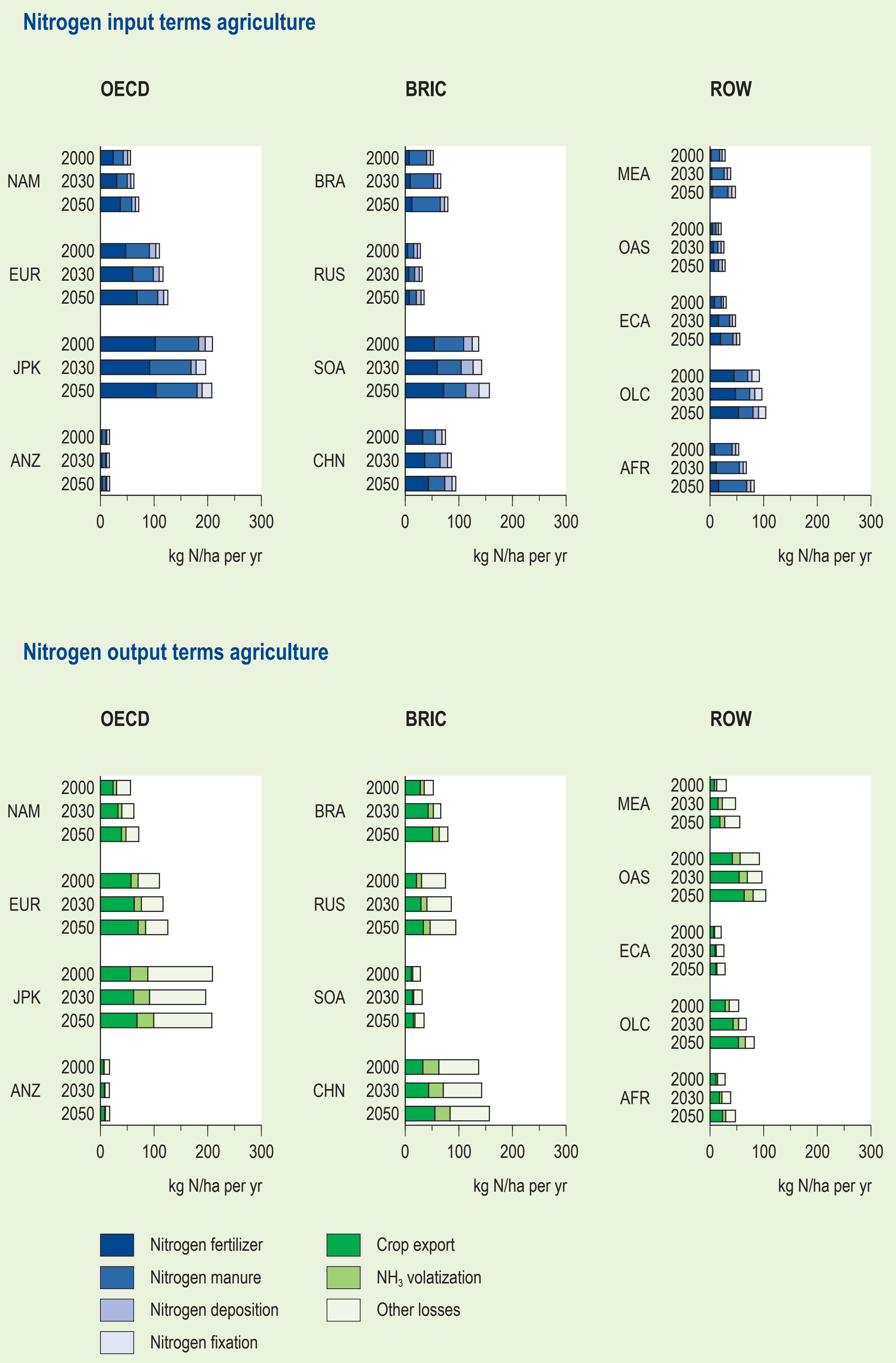


Figure 2.27 In- and output terms constituting the agricultural nitrogen balance, baseline
OECD Environmental Outlook modelling suite, final output from IMAGE cluster (107x_oec08)

2.1.8 The nitrogen cycle

Introduction
Anthropogenic disturbance of river nutrient loads and export to coastal marine systems is a major global problem affecting water quality and biodiversity. Eutrophication of aquatic ecosystems has advanced in all densely populated countries, particularly after World War II, and is affecting lakes, reservoirs, estuaries and coastal seas (Vollenweider, 1992). During the last two decades harmful effects of eutrophication in coastal marine systems have been spreading rapidly with large-scale implications for biodiversity, water quality, fisheries, and recreation in industrialized and developing regions (Li and Zang, 1999; Andersen et al., 2002) and is considered to be a major and growing environmental problem (UNEP/GPA, 2006). In aquatic systems inputs of nitrogen (N) and phosphorus (P) stem from point and nonpoint sources. Point sources are primarily associated with sewage effluents, including wastewater from households and industrial activities. Nonpoint sources comprise all nutrients entering the surface-water system in a diffuse manner and are associated with agricultural land use and the disturbance of natural ecosystems.

The agricultural system
For a given agricultural area the inputs in the nitrogen balance *(Figure 2.27)* include biological fixation, atmospheric deposition, and application of synthetic nitrogen fertilizer and animal manure. Outputs include nitrogen removal by crop harvesting, cutting of hay and grass, grass consumption by grazing animals and ammonia volatilization. If there is a nitrogen surplus, it enters into groundwater and surface water bodies. During its journey through the environment, some of the active nitrogen is removed from the system by natural processes (denitrification and retention - see *Part 3* for details.)

With the assumed increase in fertilizer use efficiency, most industrialized countries and developing countries with a current surplus (India, China) show a decrease of total N inputs per hectare of agricultural land relative to Baseline, while many developing countries with a current deficit show an increase. However, due to expanding agricultural areas this increase is often small. In reality grassland receives small inputs compared to arable land. Hence, considering only the intensively managed agricultural areas would show a marked increase in nitrogen inputs in these countries.

The major N surface balance output terms are crop N uptake and N uptake in the form of grazing or grass or hay cutting, and ammonia volatilization. There are different developments that simultaneously influence the N recovery. Many areas within developing countries had a net N deficit in the period 1970-1995, implying that soil organic matter N depletion occurred leading to high apparent N efficiency (Bouwman et al., 2005). However, gradually the N inputs in the form of fertilizers, animal manure and biological N fixation have increased in most developing countries and will continue to do so in the coming three decades. Hence, agricultural systems with N deficits gradually change into systems with N surpluses, leading to growing losses of reactive N to the environment. At the same time, there is an increasing efficiency of the agricultural system as a whole. It depends on the importance of each of these developments (intensification, increasing efficiency) whether the loss of reactive N will increase or decrease.

The N recovery depends on climatic conditions (precipitation, temperature) which influence crop growth and nutrient uptake, ammonia volatilization, denitrification and leaching rates. Furthermore, efficiencies also depend on the mix of crops, since some crops have low N contents and thus inherently low N recovery. For other crops such as wetland rice it is difficult to achieve high N recoveries due to the specific conditions in inundated rice fields. The potential efficiency is, therefore, not the same for all countries.

Although the livestock production in OECD decreases somewhat between 2000 and 2030 (and associated manure production even more by higher efficiency), fertilizer use increases as a consequence of the strongly increasing crop production for all crops, and the assumption that the fertilizer use efficiency is the same as that assumed in the FAO-Agriculture Towards 2030 study. The overall result is a slightly decreasing (3% less than in 2000) total ammonia emission in the Baseline. However, the ammonia emission per hectare is constant (or a minimal increase), due to the fact that the agricultural area shrinks somewhat (also a minimal change) by assumed productivity growth.

For ammonia volatilization the assumption is that manure is incorporated in arable land, and broadcast in grassland. For stables there are no additional emission reduction techniques included in the calculation. The resulting loading of the environment adds to the natural load and to effect of discharges by point sources, which includes sewage water and effluents of sewage treatment.

Nitrogen compounds from sewage

Three factors have been modelled to estimate changes in the amount of reactive nitrogen from urban domestic wastewater that gets into surface water worldwide:

- changes in the number of urban dwellers that have access to 'improved sanitation'
- changes in the number of urban dwellers with improved sanitation that have connection to public sewerage
- changes in sewage treatment.

Details of the estimation method can be found in *Part 3*.

Of these three factors, the Baseline development is as follows. Firstly, it is assumed that access to improved sanitation in urban agglomerations keeps up with urbanisation. In other words, the fraction of the population with access in 2030 will be the same as in 2000. Secondly, it is assumed that the reach of sewerage systems will keep up with the increase number of people with access to improved sanitation. In other words, the fraction of the urban population with access to improved sanitation that will be served with a sewer connection will be the same in 2030 as in 2000. These developments in themselves constitute a considerable effort in increasing sewerage in some countries. They are the concrete translation of 'no new policies' in this field. *Figures 2.52* and *2.53* illustrate how these assumptions play out differently in different regions.

For example, North-America. The USA and Canada feature almost complete coverage in terms of sanitation right from the earliest year of the chart in 1970. Both show an almost constant (slightly decreasing) number of people with access to improved sanitation but without connection to public sewerage - slightly more in Canada than in the USA because there are more remote areas in Canada. By comparison, Mexico features a noticeable number of people without improved sanitation. But between 1970 and 2000, the number of people served with improved sanitation and sewer connection in Mexico has as increased sharply – mostly in conjunction with fast urbanisation. The Baseline sees this continuing to 2030, but at a rate more like the USA and Canada.

A similar steep increase, reflecting urbanisation, is projected to 2030 for China and India. But here the majority of the population remains not served with improved sanitation and/or public sewerage.

Thirdly, in the spirit of 'no new policies', under Baseline conditions removal of nitrogen compounds in sewage treatment would typically improve halfway to the next best step in effectiveness between 2000 and 2030. This is consistent with a twenty-year investment cycle in treatment installations. Typical removal rates are: primary/mechanical treatment: 10-20%; secondary/biological: 35-55%; tertiary/advanced: up to 80%. No treatment means : 0% removal.

Figure 2.49 shows the combined effect of these three changes on the quantities of nitrogen discharged onto surface water or removed by treatment. For OECD countries as a group, it is projected that treatment can almost, but not completely, keep up with the increase in reactive nitrogen feature in sewage. On balance, the annual amount discharged to surface water keeps slowly increasing. The increases in BRIC and the Rest of the World are much larger. While between 2000 and 2030 these regional groups as a whole see a multiplication of the annual amount of nitrogen compounds removed by treatment, this accomplishment remains overshadowed by the amount that gets into surface water. On balance, the annual amount of reactive nitrogen discharged via sewage and treatment effluent will almost double in these regional groups.

Combined nitrogen loading at the river mouth

On the basis of the Baseline projections for agricultural production, deposition from the air and urban sewage, the global quantity of reactive nitrogen exported by rivers to coastal marine systems will increase by 4% in the coming three decades.

While the nitrogen export by rivers will decrease by about 5% in OECD countries, an 11% increase is projected for the BRIC countries and 2% in the Rest of the World. This is a continuation of the trend observed in the past decades *(Table 2.18)*. There are, however, large differences between regions *(Figure 2.55)*. For example, fast increases in nitrogen loads will occur according to the Baseline in India and Middle East, with a somewhat slower increase in China.

2.1.9 Terrestrial biodiversity

Biodiversity definition and indicator

Biodiversity is formally defined by The Convention on Biological Diversity (CBD): 'biological diversity means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems'. There is no single indicator that can express biodiversity in all its facets. Here, biodiversity is expressed with the indicator mean species abundance (MSA), which combines two of the agreed CBD indicators, namely the extent of ecosystems and the abundance of selected species. It gives an idea of the impacted state of ecosystems, relative to the pristine unimpacted situation. As such, it can be regarded as an indicator of ecosystem naturalness (see Alkemade et al., 2006).

The MSA value is affected by a range of human induced stress factors. For terrestrial biodiversity these include loss of habitat and land use change, climate change, excess nitrogen deposition, infrastructure and fragmentation. These stress factors are the direct drivers of biodiversity loss and are related to indirect drivers like growth in population, income and energy use. Future

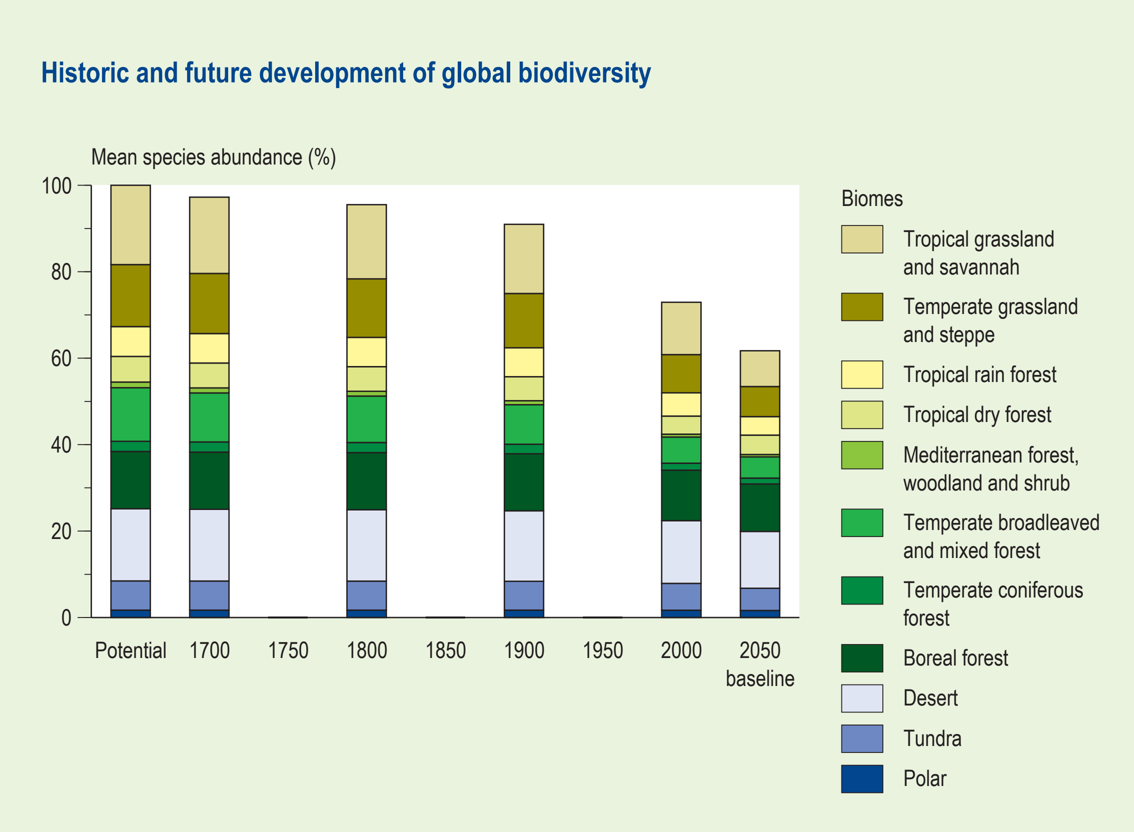


Figure 2.28 Global biodiversity from 1700 to 2050, baseline
OECD Environmental Outlook modelling suite, final output from IMAGE cluster (034g_oec08)

developments in indirect and direct drivers are projected with IMAGE and LEITAP. The GLOBIO3 model contains dose-response relationships between direct drivers and the biodiversity-MSA response (Bouwman et al., 2006; Alkemade et al., 2006).

Baseline development

Biodiversity loss in natural biomes already started many centuries ago, as can be seen in the historical graph from 1700 to 2000 *(Figure 2.28)*. The strongest declines occurred in the temperate en tropical grasslands and forests. Remaining biodiversity is found more and more in biomes that are less suitable for human development, such as desert, tundra and polar biomes. For the OECD Baseline, there is a projected further biodiversity loss: the remaining MSA at the world level drops from 73% in 2000 to 66% in 2030 and 62% in 2050. The rate of decrease for this period is higher than in the period 1970 to 2000. This means that the CBD goal for 2010 of reducing the rate of loss will very likely not be reached. The role of agricultural land-use (crops and pastures) remains the largest of all pressure factors *(Table 2.8)*, which is obvious as the total crop area continues to grow.

The major contributors to the additional biodiversity loss between 2000 and 2030 are: expanding infrastructure, agriculture (mainly crop areas), and climate change (see *Figure 2.28*). The influence of nitrogen deposition and fragmentation do not increase, even though these factors share similar indirect divers as the other factors. Through expanding agriculture, less natural biomes are left where these stresses can exert their influence.

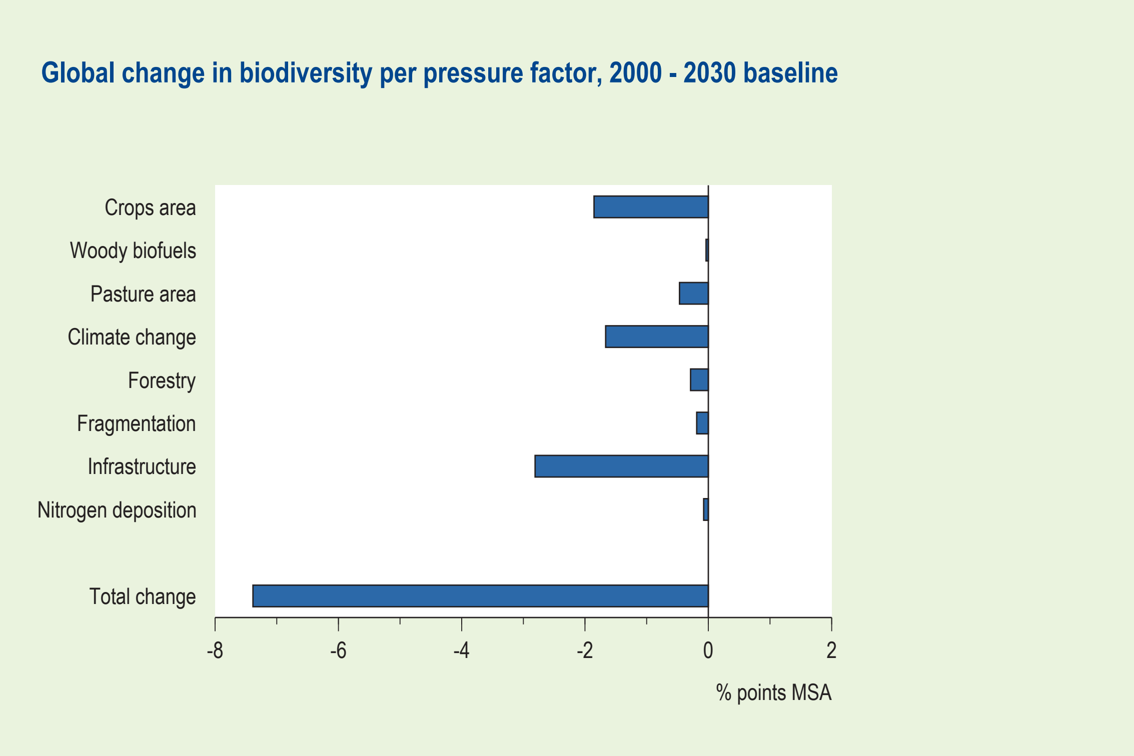


Figure 2.29 Global biodiversity loss in the baseline
OECD Environmental Outlook modelling suite, final output from IMAGE cluster (035g_oec08)

The results for the groups OECD, BRIC and Rest-of-World groups are similar to the global average (see *Table 2.8*). However, there are strong differences in biodiversity levels between regions within the groups, both in the rate of decline and in the breakdown over the various stress factors (see *Figure 2.30*). The strongest increase in crop area can be seen in the BRIC group, whereas in the OECD group agricultural influence even declines from 2030 to 2050. Pastures are not expanding, so their impact stays more or less the same. Impacts of infrastructure development are considerable in all regions, which is the consequence of increasing economic activities. Through the global increase in temperature, all groups show a similar and increasing climate change effect.

The lowest further loss is seen in the OECD group (- 6%). The overall biodiversity level in the OECD group is strongly influenced by the vast natural areas in USA, Canada and Oceania with relatively high biodiversity levels (see *Figure 2.30*). By contrast, remaining biodiversity in the densely populated regions Japan and especially Europe is much lower. The further decline to 2030 for the OECD group is mostly due to infrastructure expansion (additional 2% loss) in the densely populated countries of this group and to global effects of climate change (additional 2% loss).

The main causes for the further decline to 2030 in the BRIC group are agricultural expansion (additional 3%), expanding infrastructure (additional 3%) and climate change (additional 2%). The differences within the BRIC group are also large (see *Figure 2.30*). The vast natural and sparsely populated areas in Russia and Brazil have a large influence on the overall biodiversity level. At the other extreme are the densely populated and strong developing countries in South Asia. These have the lowest biodiversity of the BRIC group, and the mean species abundance declines through further growth in already important agricultural activities.

The highest further loss is found in the Rest-of-the-World group (- 8%). Again, large differences in both levels and trends are found between regions *(Figure 2.30)*. The main cause for the further decline in the ROW-group to 2030 is the strongly expanding infrastructure (additional 3%) through economic development. In all regional clusters in Rest-of-World the influence of climate change on biodiversity increases (additional 1%). The last important cause is agricultural expansion (additional 1%).

The Other Asia and East and Central Asia regions show the lowest biodiversity values, with large additional losses due to strong expansion of especially infrastructure. Infrastructure development is also a significant factor on the vast African continent, which exerts a large influence on the total Rest-of-World group. This development is caused by growth in population and GDP, and natural resource exploitation. In the Middle East, biodiversity levels remain relatively high, due to the widespread arid and desert biomes that are not easily converted to human activities. Agricultural expansion plays an important role in Other Asia and Africa.Figure 2.12 Growth of world population, GDP per capita, agricultural production and crop area; baseline

OECD Environmental Outlook modelling suite, final output from IMAGE cluster (019g_oec08)

Figure 2.30 Biodiversity levels in the OECD and BRIC regions and Rest-of-the-World: remaining levels and contributions to the decline, baseline

OECD Environmental Outlook modelling suite, final output from IMAGE cluster (036x_oec08)

Table 2.8 Remaining biodiversity levels and contribution of various pressures, baseline

		OECD	BRIC	Rest of the World	World a)
	% of reference situation				
1970	Decline of mean species abundance by…				
	Crops	-13	-13	-8	-11
	Woody biofuels	0	0	0	0
	Pasture	-4	-3	-6	-4
	Climate change	-1	0	-1	0
	Forestry	-2	-1	0	-1
	Fragmentation	-1	-1	-1	-1
	Infrastructure	-5	-3	-5	-4
	Nitrogen deposition	-1	0	0	-1
	Remaining mean species abundance	**74**	**78**	**79**	**78**
2000	Decline of mean species abundance by…				
	Crops	-13	-14	-10	-12
	Woody biofuels	0	0	0	0
	Pasture	-4	-4	-6	-5
	Climate change	-2	-1	-2	-2
	Forestry	-2	-1	-1	-1
	Fragmentation	-2	-1	-1	-1
	Infrastructure	-7	-4	-7	-6
	Nitrogen deposition	-1	-1	0	-1
	Remaining mean species abundance	**71**	**72**	**74**	**73**
2030	Decline of mean species abundance by…				
	Crops	-15	-17	-11	-14
	Woody biofuels	0	0	0	0
	Pasture	-4	-4	-7	-5
	Climate change	-4	-3	-3	-3
	Forestry	-3	-1	-1	-1
	Fragmentation	-2	-1	-1	-1
	Infrastructure	-9	-7	-10	-9
	Nitrogen deposition	0	-2	-1	-1
	Remaining mean species abundance	**64**	**65**	**66**	**66**
2050	Decline of mean species abundance by…				
	Crops	-14	-17	-12	-14
	Woody biofuels	0	0	0	0
	Pasture	-4	-4	-7	-5
	Climate change	-5	-4	-4	-4
	Forestry	-3	-2	-1	-2
	Fragmentation	-2	-1	-1	-1
	Infrastructure	-11	-9	-12	-11
	Nitrogen deposition	0	-2	-1	-1
	Remaining mean species abundance	**61**	**61**	**61**	**62**

a) Totals may not match due to rounding. Greenland is included in the world total, but not in the three regional groups. Antarctica is not included.

OECD Environmental Outlook modelling suite, final output from IMAGE cluster

2.2 Policy simulations

The principle of the policy simulations in the OECD Environmental Outlook is that of alternatives in the worldwide coverage of enhanced policies in relation to the environment.
In order to analyse this, simulations were conducted for a package of four issues: liberalisation of agricultural production and trade; mitigation of climate change; control of urban air pollution; sanitation and sewage treatment. Worldwide coverage varied from OECD countries; to OECD countries + BRIC; to global coverage.

The effect of modalities for action on global issues, on the environment and on required effort, was analysed for climate change mitigation. Policy cases were analysed for delayed action, or staggered entry into participation; for burden sharing; and for two strategies, reflecting different ambition levels.

Table 2.11 introduces three broad policy packages that have been explored with the suite of environmental models. In addition, nine variants of climate policy have been analysed. These are listed in Table 2.12. Furthermore, the OECD Environmental Outlook reports on simulations carried out directly with the ENV-linkages general equilibrium model. Those simulations are not addressed in this background report.

2.2.1 Policy simulations agriculture and land use

The policy packages explore different levels of international cooperation and environmental policies. For agriculture and land-use, the largest changes are induced by agricultural trade liberalisation and the use of biofuels, while differences in climate change and GDP due to differences in climate policy and agricultural liberalisation are of minor importance.

Figure 2.31 shows the change in global agricultural area between 2000 and 2050 for the different policy cases. While bioenergy crops are expected to occupy about 1 million km² in the baseline in 2050, this area is substantially larger under the increasingly ambitious policy cases, with almost 3 million km² used in *pp Global*. As we do not account for competition between ‘conventional’ agriculture and biofuel crops, this increase in bioenergy does not affect managed grassland and crop areas, and therefore the changes in projected land use for the policy packages are solely caused by very small changes in GDP, climate, and trade liberalisation. As *Figure 2.31* shows, the change in global crop and grass area due to trade liberalisation is rather small.

However, important regional shifts in agricultural production do occur. Under increasing agricultural liberalization in the global policies policy package agricultural production is moving from OECD countries to BRIC, and also to other non-OECD regions (see *Figures 2.32* and 2.33). Especially in Brazil and the rest of South America, both cropland and grassland area will increase in this policy case. In North America, Europe and Japan, both cropland and grassland will decrease. While the changes observed for total cropland can generally be indentified across all crop types, the trend is most prominent for decreasing maize and cereal production in North America and Europe, and for increasing oil seed production in South America, much of which is used as animal feed. The shift of agricultural areas has important implications for biodiversity, as agricultural area mostly expands into natural forests and grasslands with large and immediate loss of species, while the restoration of natural vegetation on abandoned land in temperate regions only results in a very slow restoration of biodiversity (section 2.2.6).

Table 2.8 Broad policy packages analysed with environmental models

	pp OECD	pp OECD+BRIC	pp global
Agriculture	Baseline	Baseline plus agricultural liberalisation between OECD and BRIC. Subsidies and tariffs are reduced by 50% by 2030: starting in year 2010, decreasing by 3% per year. This is applied to import tariffs and export subsidies between countries of OECD and BRIC (bilateral) as well as input, output and factor subsidies within OECD and BRIC countries (unilateral).	Baseline plus global agricultural liberalisation. Same as *pp OECD+BRIC* but applied to import tariffs and export subsidies between all countries and input, output and factor subsidies in all countries
Climate change	Carbon tax in OECD countries, starting at US$ 25 per ton of carbon dioxide and increasing 2.4% per year. Starting in 2012.	Carbon tax in OECD and BRIC, starting at US$ 25 per ton of carbon dioxide and increasing 2.4% per year. OECD countries start in 2012. BRIC starting in 2020.	Carbon tax in OECD, BRIC and ROW starting at US$ 25 per ton of carbon dioxide and increasing 2.4% per year. OECD countries start in 2012. BRIC starting in 2020. ROW starting in 2030.
Air pollution	Development towards but not quite reaching Maximum Feasible Reduction(as defined in Cofala et al., 2005) in OECD countries. Onset and speed differentiated by region (26 regions) and sector (Transport; Power, Refineries and Industry; Domestic and other.) Phased decrease of sulphur dioxide emissions from marine shipping.	Same as pp OECD but applied in BRIC as well. Some countries reach target level after 2030.	Same as *pp OECD* and *pp OECD+BRIC*, but applied worldwide. Some low income countries reach target level long after 2030.
Water quality¹)	Installing sewage treatment on new and existing sewerage systems. For existing sewage treatment, upgrading the treatment to the next best level in terms of removal of nitrogen compounds.	Same as pp OECD but applied in BRIC as well.	Same as *pp OECD* and *pp OECD+BRIC*, but applied worldwide.

1) The simulations assume that (1) access to improved sanitation will develop according to the baseline and that (2) in the country groupings included in the policy package, the gap between the 2000 situation and a target of access to improved sanitation and/or access to public sewerage for all urban dwellers would be halved by 2030.
This table is identical to Table 1.1

In order to reach the ambitious mitigation target in the worldwide climate stabilisation case (450 ppm multigas, explained in section 2.2.2) starting from a baseline which is characterized by rather large growth in emissions of greenhouse gases, it is necessary to assume additional measures to prevent deforestation and therefore to keep agriculture compact. This was simulated by assuming an additional increase of agricultural productivity of 12.5% in the period 2010–2030. This additional increase corresponds to half of the range in productivity growths assumed in the upcoming World Agriculture Assessment scenarios, and can be regarded as feasible when appropriate policy measures are taken. Due to this additional intensification, crop and grassland area in 2050 increase is about 2 million km² and 3.5 million km², respectively, less than in the baseline. These areas largely correspond with land use for additional production of energy crops *(Figure 2.31)*.

It has to be noted that it is unclear which political measures could increase agricultural produc¬tivity and keep agriculture compact on global scale. Investment in agricultural research and development clearly increased the productivity of crops in the past, but it is not clear how furher productivity increases beyond what is assumed in the baseline can be stimulated at the international level. Only as a secondary effect, less agricultural land might be needed, but also other, partly counteracting, secondary effects of decreasing prices and increase consumption

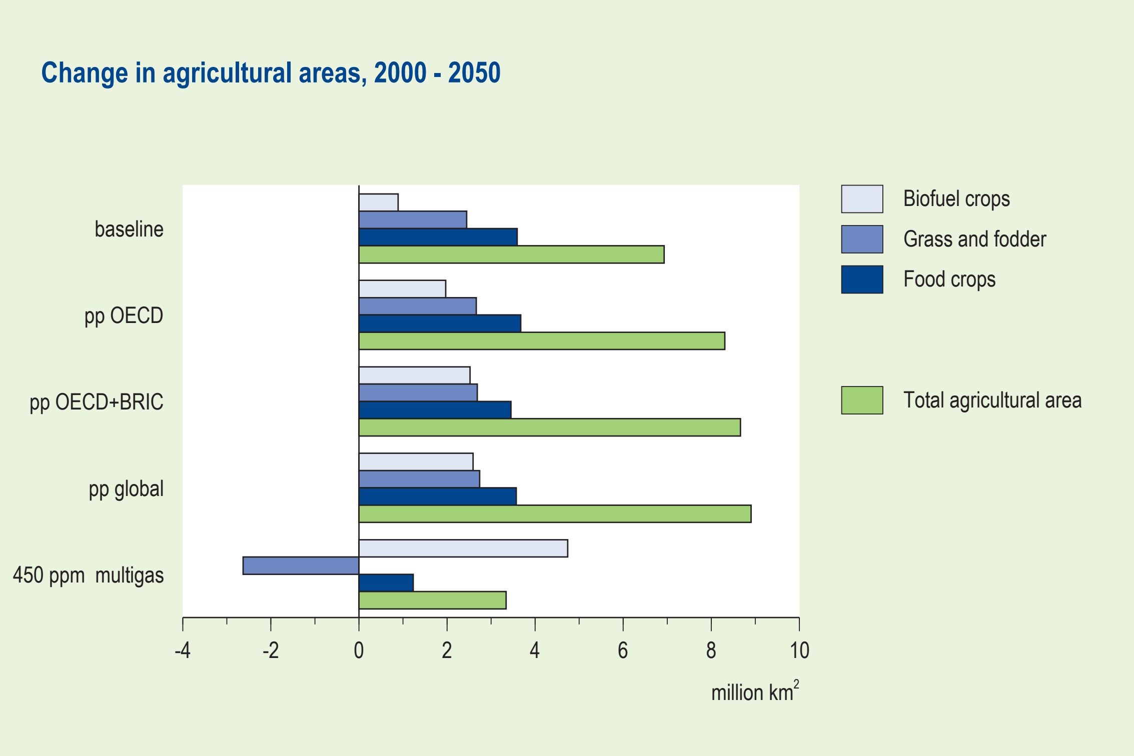


Figure 2.31 Change in agricultural area in 2050 relative to 2000 for Baseline and policy cases
OECD Environmental Outlook modelling suite, final output from IMAGE cluster (045g_oec08)

have to be taken into account. Land prices, on the other hand, also affect productivity. Therefore additional demand for biofuels might, via increased land demand and land prices, keep agricultural land used for food production more compact. Finally, recent discussions in the context of climate change mitigation policies are might spur the development of international measures to avoid deforestation at the global scale.

2.2.2 Policy simulations Energy and Climate change

The Baseline developments are likely to cause major changes in the world climate, possibly resulting in significant climate impacts. In order to avoid the probability of some of these impacts to occur, emission would have to be reduced drastically. At the moment, both the ambition of international climate policy and the instruments that will be used to fulfil this ambition are far from certain. The policy packages and variants analysed in this report (see *Table 2.9* for an overview) serve to explore the uncertainties in this respect. These pertain to:

1. Targets: One of the parties in international negotiations has proposed to limit global mean temperature change to a maximum of 2°C compared to pre-industrial – but other parties have indicated that they would prefer alternative targets (*inter alia* to protect economic growth).
2. Participation: A key characteristic of international climate policy is the number of countries participating in a regime. The advantage of high levels of participations is that they allow for relatively low costs as reduction measures can be taken in all countries using emission trading. However, it is far from easy to get global agreement on comprehensive regimes. The alternative fragmented regimes involve only a selection of countries, while also at the same time different groups may aim for different type of targets. These fragmented regimes allow for more flexibility – and are arguably easier to achieve – but will automatically lead to higher costs as not all countries participate in reductions.

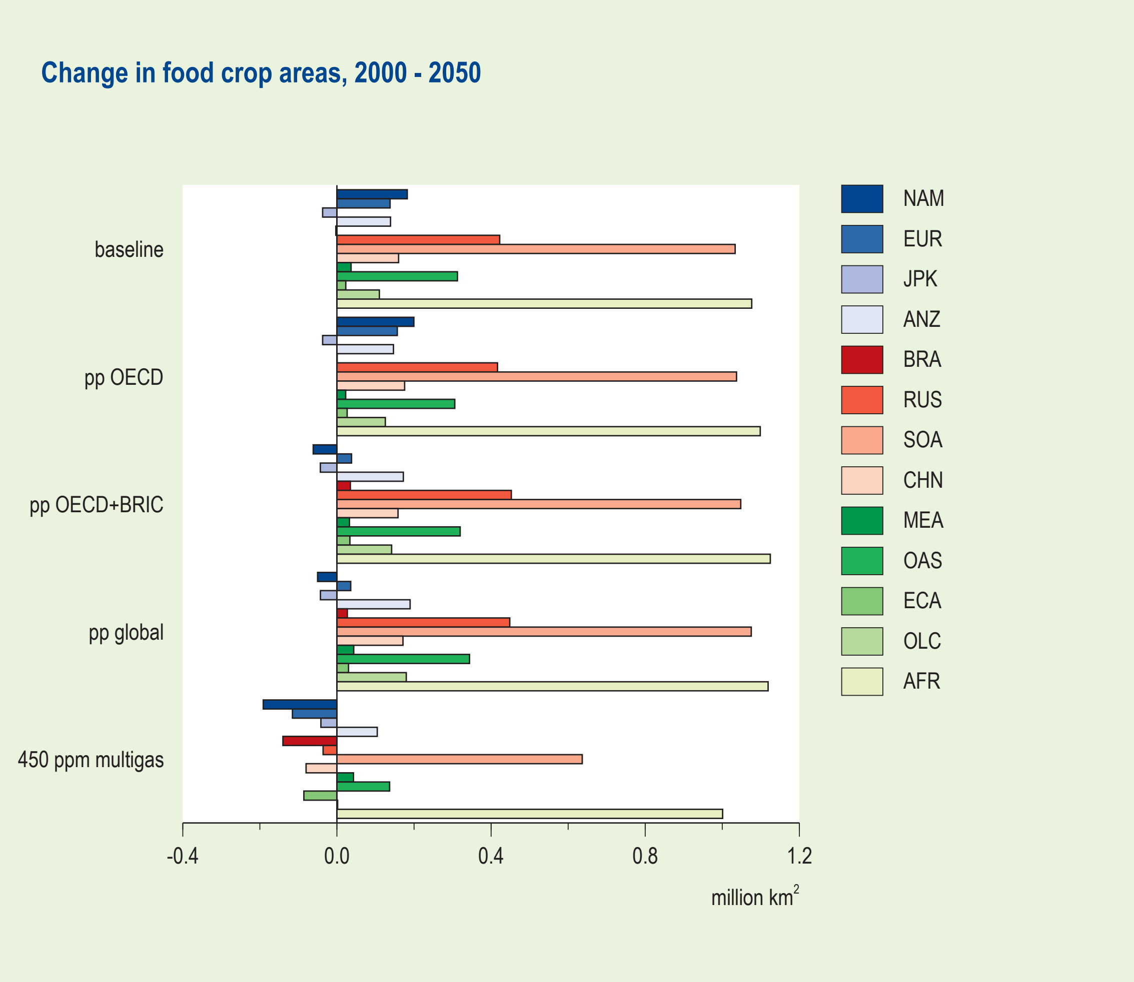


Figure 2.32 Change in food crop area in 2050 relative to 2000 for the baseline and the policy cases
OECD Environmental Outlook modelling suite, final output from IMAGE cluster (046g_oec08)

3. Instruments: Another important distinction is between cap-and-trade systems and regimes that include domestic measures only. The most important example of the latter is an agreement on a carbon tax (either universal or in selected countries). Recently, the attention for carbon taxes as alternative for trading regimes has been increasing. An important advantage of taxes would be lower transaction costs. But this comes at a cost of forfeiting the option of sharing costs more evenly (equitably), unless some additional measure to redistribute the costs of action - such as direct financial transfers or technology transfer - is applied..

In all policy cases simulated except the 450 ppm multigas case, the carbon price over time is determined first and this drives the emissions development. The cases differ in the number of countries participating in climate policy and the time that a carbon price is set. The moment a tax is introduced, how ever, it is always set at 92 dollar per tonne of carbon (25 dollar per ton of carbon dioxide) for all six Kyoto gases expressed as dioxide carbon equivalents increasing over time at 2.4% annually. This corresponds to a median estimate of the Social Cost of Carbon (SCC) in IPCC's 4th Assessment Report. In these, the year of introduction has a substantial impact on price paths. It should be noted that the difference is small between the carbon price profile that is part of the three broad policy packages shown in the left hand panel of *Figure 2.34* and the phased carbon tax of which two cases are shown in the right hand panel of *Figure 2.34*. The only difference is the year of introduction of climate policy in OECD, namely 2013 versus 2008

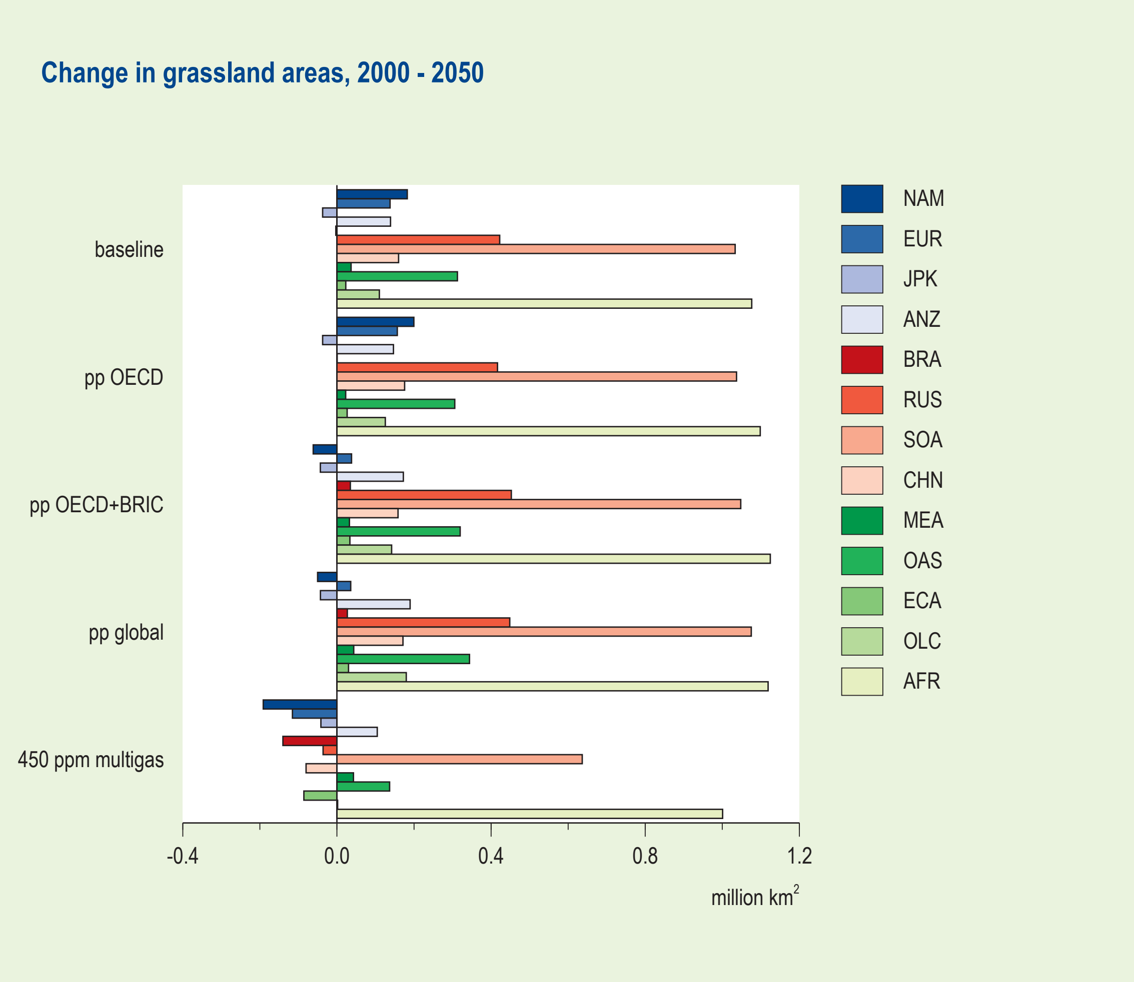


Figure 2.33 Change in grassland area in 2050 relative to 2000 for the baseline and the policy cases

OECD Environmental Outlook modelling suite, final output from IMAGE cluster (047g_oec08)

(see *Table 2.9*, pp 74 versus *cc OECD+BRIC phased* and *cc global phased*). Of course, the broad policy packages comprise additional policies that influence the climate outcome, notably on agricultural production and trade and on air pollution.

In the 450 ppm multigas stabilization case, the carbon price trajectory is actually an outcome and dependent on the emission reduction pathway to meet the 450 ppm multigas target. The emission reduction pathway and hence the carbon price is the result of an optimization strategy used in the modeling. Obviously, the larger emission decreases in the 450 ppm case require a substantially larger carbon price. This was analysed using two models, namely IMAGE/TIMER with a focus on the energy system and other emission sources, not related to production and use of energy; and the ENV-Linkages general equilibrium model with a focus on the macro-economic relations including energy-related emissions of carbon dioxide. Both see carbon prices for the 450 ppm multigas case of roughly two hundred dollar per ton of carbon dioxide, by 2050. They differ in the profile over time. On the one hand, the IMAGE/TIMER modelling of the energy system tends to favour an early, steep increase in carbon price as that stimulates innovation and technology renewal. Moreover, the more build-up of greenhouse gases is avoided during the earlier decades, the less steep the emission reductions will have be later on. On the

Table 2.9 Climate and energy policy variants

	Implication for climate and energy policy simulations	Start years of new climate policies			Other new policies directly influencing climate outcome	Short label (in graphs etc.)
		OECD	*BRIC*	*ROW*		
Baseline	Indication of developments without new climate policy					Baseline
Broad policy packages						
Enhanced environmental policies in OECD countries	Exploring the environmental impacts of a broad set of policy measures in only the OECD. Includes a phased carbon tax in OECD countries.	2013			Land use Air pollution	pp OECD
Enhanced environmental policies in OECD countries and BRIC	Exploring the environmental impacts of a broad set of policy measures in OECD and, with some delay, BRIC countries. Includes a carbon tax.	2013	2020		Land use Air pollution	pp OECD+BRIC
Enhanced environmental policies worldwide	Exploring the environmental impacts of a broad set of policy measures in all countries (although with delays in timing). Includes a carbon tax.	2013	2020	2030		pp global
Climate policy cases						
Climate policy aimed at stabilizing the concentration of the six Kyoto gases at 450 ppm carbon dioxide equivalents	Exploring the type of measures required to drastically reduce greenhouse gas emissions in order to stay within 2°C with a 50% probability	*2013**	*2013**	*2013**	Land use	450 ppm multigas
Immediate carbon tax, OECD	Explores the environmental impacts of a tax case, OECD only, hypothetically starting straight away. (Reference for phased and delayed cases.)	2008				cc OECD 2008
Immediate carbon tax, OECD + BRIC	Explores the environmental impacts of an uniform carbon tax, OECD + BRIC, hypothetically starting straight away. (Reference for phased and delayed cases.)	2008	2008			cc OECD+BRIC 2008
Immediate carbon tax, global	Explores the environmental impacts of an uniform carbon tax, all countries, hypothetically starting straight away. (Reference for phased and delayed cases.)	2008	2008	2008		cc global 2008
Phased carbon tax, OECD+BRIC	Explores the environmental impacts of a tax case, OECD + BRIC, uniform tax scheme, BRIC starting later	2008	2020			cc OECD+BRIC phased
Phased carbon tax, global	Explores the environmental impacts of a tax case, all countries, uniform tax scheme, BRIC and ROW starting later	2008	2020	2030		cc global phased
Delayed carbon tax, global	Similar to the case of an immediate global carbon tax, but with 10 year delay	2020	2020	2020		cc global delayed
Climate stabilization, convergence of per capita emissions by 2050	Explores impact of cap and trade regime, assuming convergence of per capita greenhouse gas emission permits by 2050					PCC2050

*Carbon price profile not an assumption but modelled outcome.

other hand, the macro-economic modelling favours a much more gradual increase in carbon price between 2010 and 2030 and this is what is reported in the *OECD Environmental Outlook*.

In line with Figure 2.35, the ENV-Linkages macro-economic modeling reported in the Outlook is based on the development of GHG emissions over time by the various sources required to eventually limit the GHG concentration in the atmosphere at approximately 450 ppm carbon dioxide equivalents. Of these emissions, energy-related emissions of carbon dioxide were considered in the ENV-Linkages pathway; a carbon price was set to achieve the necessary reductions relative to the baseline (in terms of models: ENV-Linkages followed the relative reductions of TIMER in energy-related emissions of carbon dioxide).

Emissions
Figure 2.34 shows the emission pathways of the various cases that were analyzed. First, to reach the selected emission pathway that leads to stabilization of greenhouse gas radiative forcing at 450 ppm carbon dioxide equivalent, greenhouse gas emissions need to be decreased in 2050 by about two-thirds compared to the baseline and by 40-50% compared to 2000. In fact, emissions already need to peak shortly before 2020 at a level of 20% above 2000 levels. All other cases analyzed bring less reductions and thus will be insufficient to reach stabilization at 450 ppm carbon dioxide equivalent. The left-hand and middle panels of *Figure 2.34* together illustrate the importance of enlarging the number of countries participating in international climate policy. As the middle panel shows, even with phased introduction of a carbon tax (2020 for BRIC and 2030 for the rest of the world) wider participation improves the emission reduction in 2050 from 3.6 Gt C-equivalent per year (OECD only) to 6.2 (OECD+BRIC; a 70% improvement) or 7.7 (all countries, 115% improvement). The latter case corresponds to stabilization in the range of 550-650 ppm carbon dioxide equivalent (see *Figure 2.35*).

The middle and right-hand panels of *Figure 2.34* illustrate the importance of timing. The full participation case *from 2008 onwards* ('cc global 2008') would improve 2050 emission reduction to 10.7 Gt C per year, compared to the *phased* full participation case which is incorporated in the variant *cc Global*. The latter would only see an emission reduction of 7.9 Gt C per year in 2050. In terms of greenhouse gas concentrations, after stabilisation, the former case corresponds to a stabilization pathway of 550 ppm carbon dioxide equivalent. This means a considerable improvement in preventing climate change compared to the latter case, in which only stabilization at a concentration of 650 ppm carbon dioxide equivalent is achievable *(Figure 2.35).*

Mitigation measures and changes in the energy system
The cost-optimal combination of measures that contribute to the reductions of emissions indicated above for the 450 ppm multigas stabilisation scenario is shown in *Figure 2.36*. The initially large contribution of non-carbon dioxide abatement is rational mainly because of relatively low-cost abatement options that have been identified for other gases than carbon dioxide (e.g. decreasing methane emissions from energy production and nitrous oxide (N_2O) emissions from adipic acid industries). In time, more and more emission reductions will need to come from carbon dioxide in the energy system. This shift simply reflects that other gases than carbon dioxide represent about 20% of total greenhouse gas emissions and the abatement potential for some of these other gases is limited.

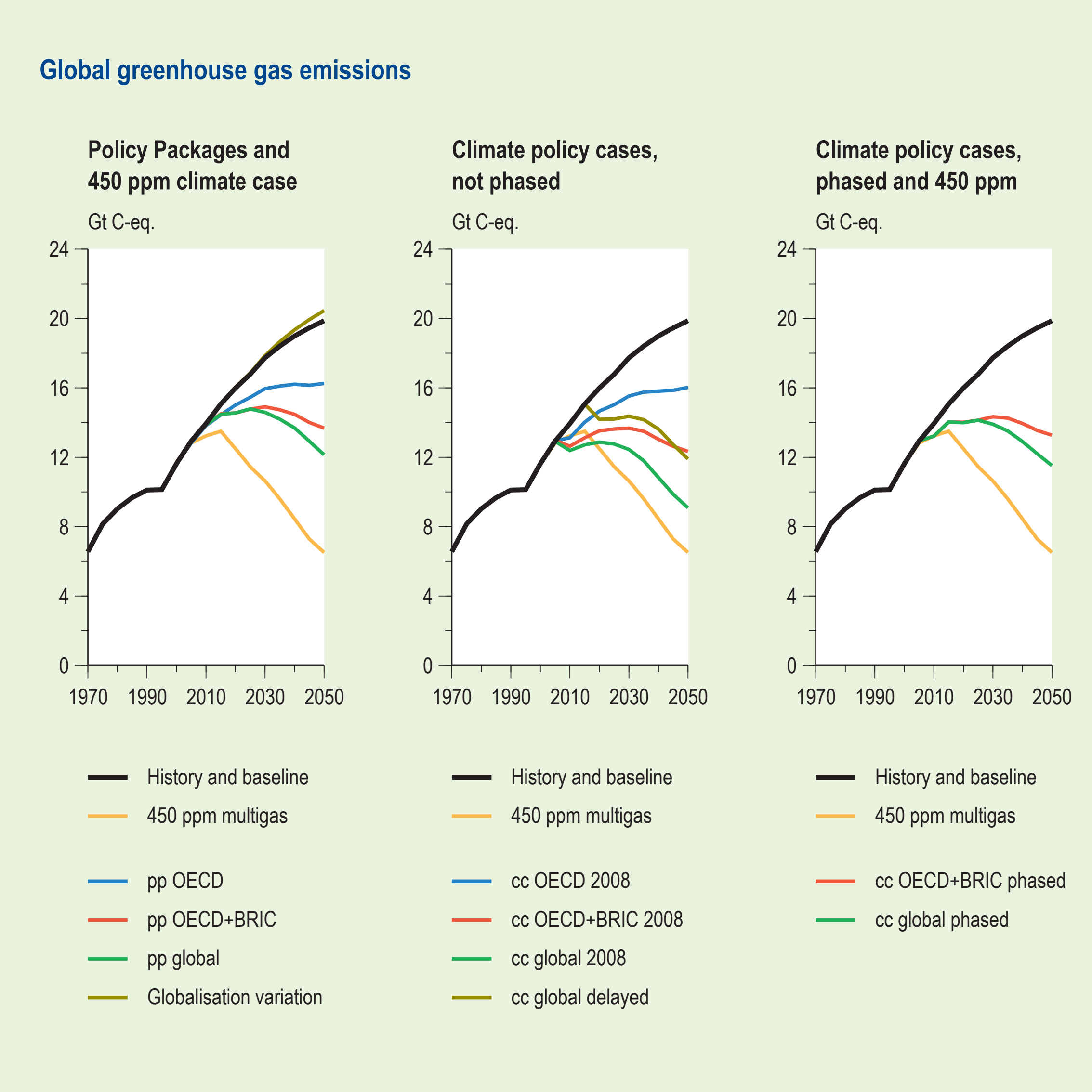


Figure 2.34 Greenhouse gas emissions in the climate policy cases analysed
OECD Environmental Outlook modelling suite, final output from IMAGE cluster (051x_oec08)

In the 450 ppm multigas case, avoiding deforestation and the use of reforestation measures would contribute approximately 1.5 Gt C annually to the overall mitigation objective in 2050. In the other policy cases analysed, the contribution from such measures is assumedly smaller. The largest decrease of greenhouse gas emissions in the energy sector would result from changes in energy supply. First of all, under our default assumptions, carbon capture and storage (CCS) accounts for a major proportion of the emission decrease (up to a third of the decrease in energy-related carbon dioxide emissions, mainly in the power sector). Bio-energy use also accounts for a sizeable part of the emission decrease. Where in the Baseline of this study about 15 EJ of modern biomass are used by 2050, in the most stringent stabilization case use of modern biomass has increased to 70 EJ. Solar, wind and nuclear power also account for a considerable proportion of the required decreases in greenhouse gas emissions.

In the Baseline the application of renewables (i.e. hydro, wind and solar power) is considerably larger than that of nuclear power. This is based on current policies and costs. In the 450 ppm multigas case both categories increase their market share. The finding that under

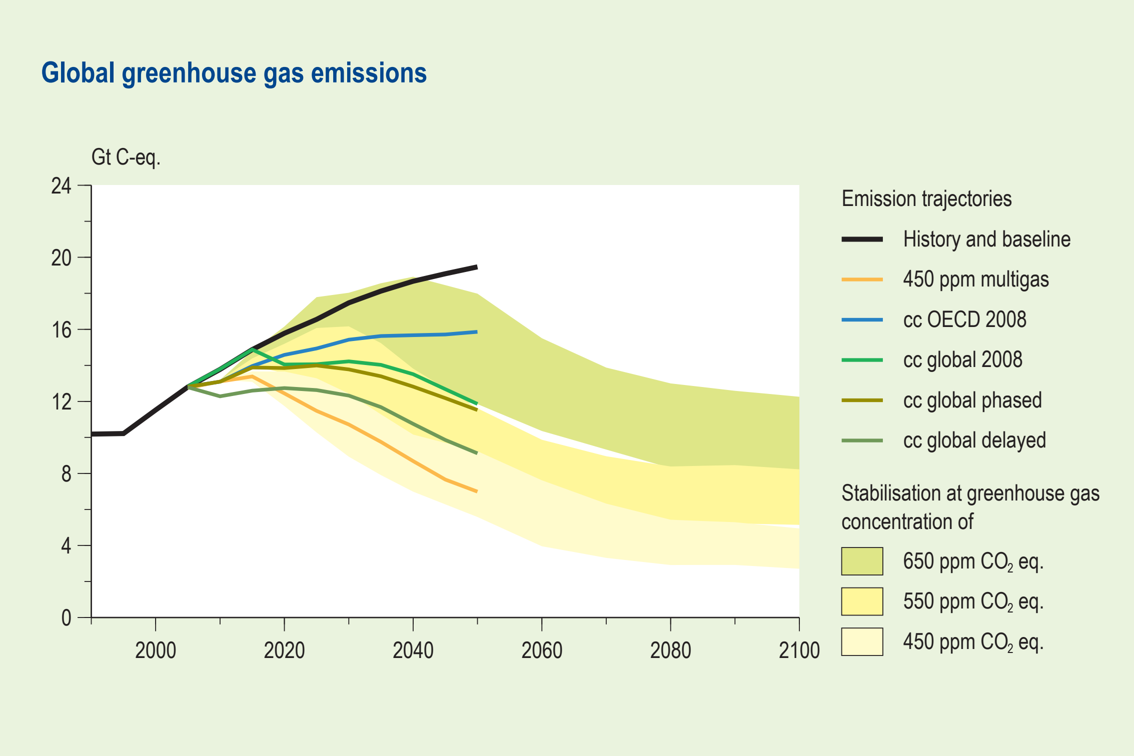


Figure 2.35 Global greenhouse gas emissions; comparison to stabilization profiles
OECD Environmental Outlook modelling suite, final output from IMAGE cluster (054g_oec08)

climate policy, nuclear power could become a competitive option to produce electric power is consistent with several other studies . However, more flexible power systems, different assumptions on the consequences of intermittency for renewables, the development of storage systems, technological breakthroughs or taking account of public acceptance of nuclear power could easily lead to a different mix of nuclear power, solar and wind power and CCS technologies and still lead to similar decreases in greenhouse gas emissions. Energy efficiency represents an important part of the portfolio early on in the century – but a much smaller share later on. The main reason for the decreasing impact is that costs reductions of zero carbon energy supply options would reduce the relative attractiveness of energy efficiency measures.

All in all, climate policies required to reach the stabilization pathways lead to substantial changes in the energy system compared to the Baseline *(Figure 2.37)*. In the 450 ppm case, global primary energy use is reduced by approximately 20% by 2040 compared to the Baseline. Clearly, the reductions are not similar for the different energy carriers. The largest reductions occur for coal use, with the remaining coal consumption being primarily in electric power stations with carbon capture and storage. There is also a substantial reduction for oil use. Reductions for natural gas are less substantial, while other energy carriers – in particular solar, wind and nuclear-based electricity and modern biomass – gain market share. Modern biomass includes gaseous or liquid fuels produced from plants or trees. It differs from traditional biomass (gathered wood, straw, dung, charcoal, et cetera). Among the regions, changes are somewhat comparable. Energy efficiency improvement is somewhat more important in BRIC and the rest of the world than in OECD. BRIC energy consumption is much more dominated by coal – and as result of CCS technology, coal use remains large even in the climate policy cases.

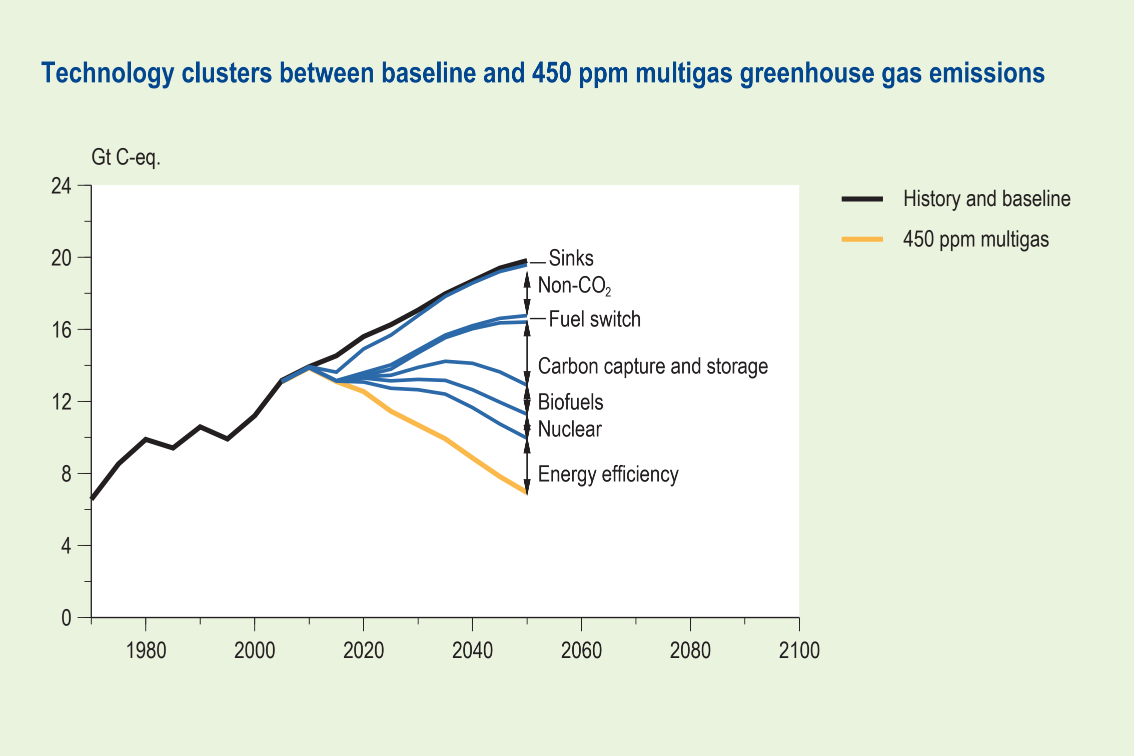


Figure 2.36 Contribution of different measures to decreases of greenhouse gas emissions, 450 ppm multigas case

OECD Environmental Outlook modelling suite, final output from IMAGE cluster (055g_oec08)

Costs of climate policies

Global costs

One way to express the costs of climate policy is in terms of abatement costs, i.e. the annual additional costs of implementing abatement measures. These costs can be expressed in dollars, but can also be expressed as percentage of GDP (simply as a means to provide a reference). Abatement costs do not capture indirect effects in the economy such as impacts of climate policy on competitiveness, fossil fuel trade and the indirect impacts of changes in investment flows – and as such are less comprehensive as a costs measure than for instance GDP losses. However, it has been shown that direct costs do often make up the largest part of the total costs of climate policy – and estimates of GDP losses are by definition more uncertain.

As expected on the basis of the carbon prices the abatement costs are highest in the 450 ppm stabilization case (around 1.5% of GDP)– while for the other cases, abatement costs directly correspond to the number of regions participating in international climate policy (see *Figure 2.38*). For comparison: 2% of GDP is currently spent in the European Union on environmental protection; 6-10% of GDP is spent within the energy system.

Figure 2.39 compares the costs of five policy cases with the level of abatement they would achieve. The figure shows the emission decrease in the 2010-2050 period plotted against the net present value of abatement costs over that period. The left hand part of the curve shows the more or less linear relationship between level of abatement, determined by increasing participation in the different cases, and abatement costs. The relation is linear as the marginal costs level is already defined by the exogenously set carbon price. The small variations from linearity result

Primary energy use by carrier

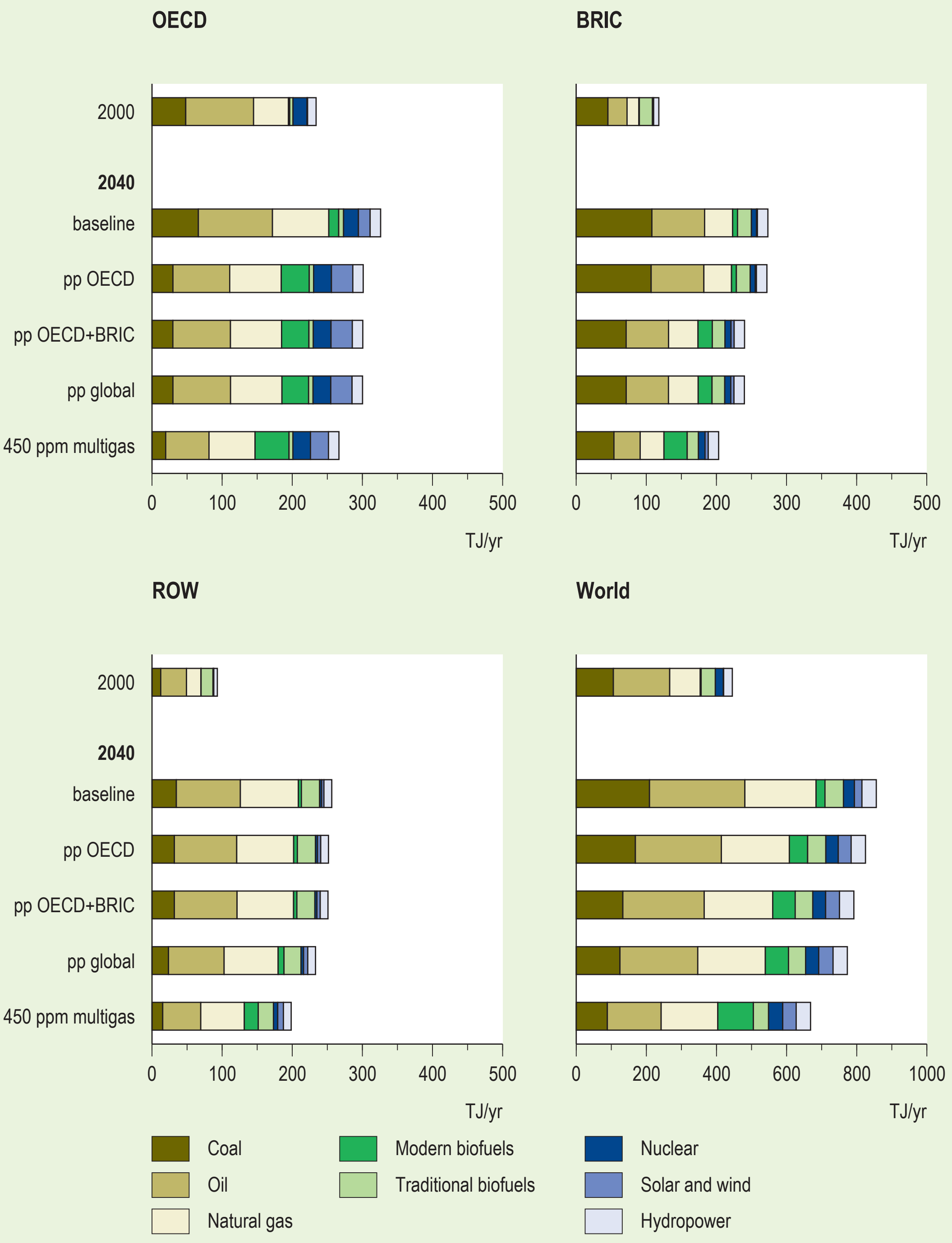


Figure 2.37 Primary energy use, by energy carrier, baseline and climate policy cases
OECD Environmental Outlook modelling suite, final output from IMAGE cluster (056x_oec08)

from the differences in introduction year and the small differences in carbon price across the regions. If all regions are participating in climate policy (the right hand part of the curve), further reduction can only be obtained by increases in the marginal carbon price. In nearly

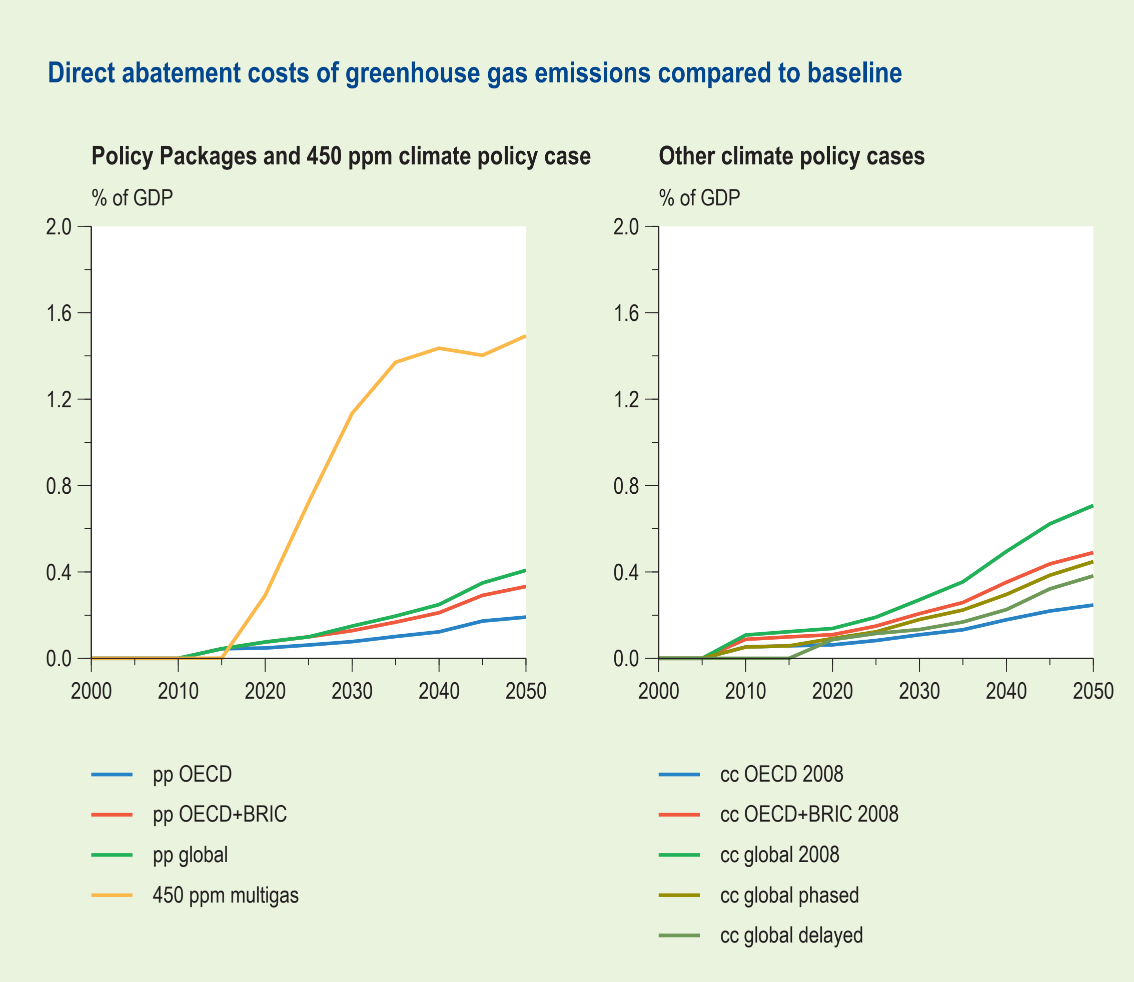


Figure 2.38 Direct abatement costs of greenhouse gas emissions relative to GDP

Note: costs presented in this figure are the direct costs of mitigation; that is, they do not represent change in GDP growth as a result of shifts induced in the wider economy.

OECD Environmental Outlook modelling suite, final output from IMAGE cluster (060x_oec08)

all studies, marginal abatement costs curves are convex: i.e. increasing marginal prices give diminishing returns in the level of abatement. The 450 ppm multigas case does indeed lead to a significantly higher level of abatement, while the increase in the net present value of abatement costs is more than linear.

Regional costs

Regional costs of climate policy strongly depend on how international climate policy is implemented. As an alternative to an international carbon tax (explored so-far) reductions may also be implemented by agreements on the allocation of obligations to decrease emissions in combination with international trading in emission rights (so-called cap and trade systems). Both systems (carbon tax and cap and trade) in principle allow for worldwide cost-efficiency, whereby low-costs measures are implemented first. There are, however, very important differences. First, the cap and trade system allows participating countries to benefit from low-cost reduction world-wide, while these costs are not necessarily covered by the region where measures are taken – but by those regions that have the highest interest in trading of emission rights (in general high income regions). Second, under a tax system the uncertainty in the policy response is mostly in terms of the emissions decrease that will be achieved, while costs are more

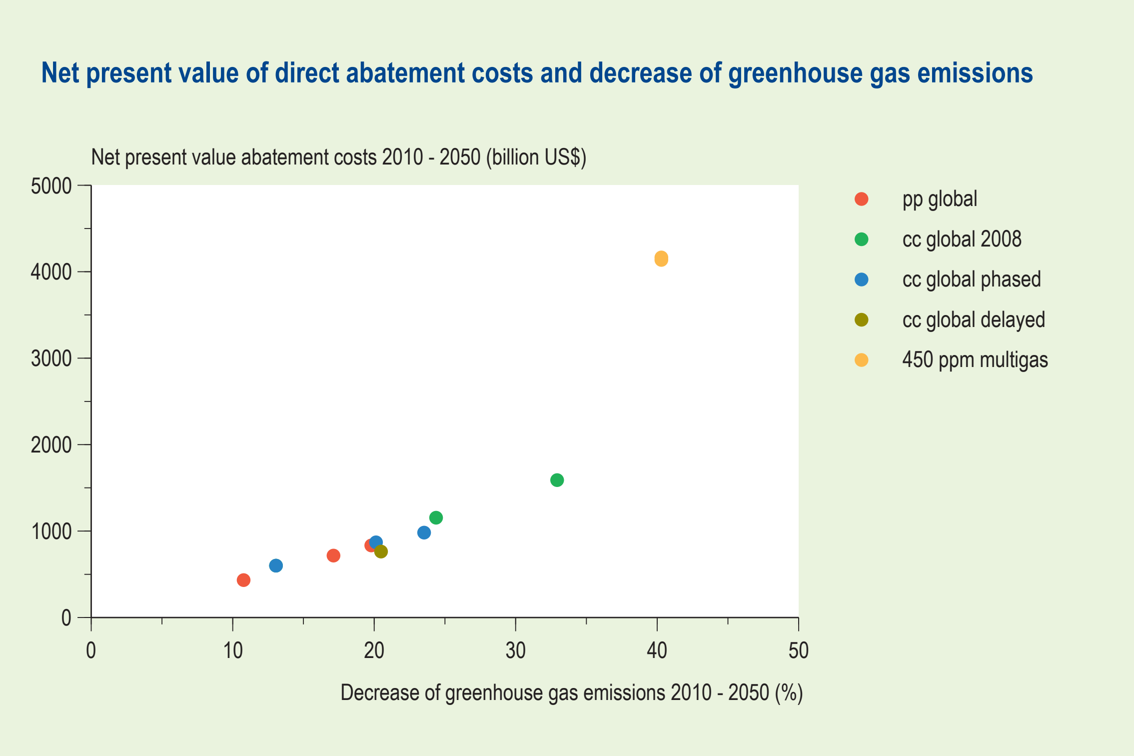


Figure 2.39 Net present value of direct abatement costs and decrease of greenhouse gas emissions in comparison with the baseline, 2010-2050

Note: discount rate 2.5% per year

Note: costs presented in this Figure are the direct costs of mitigation; that is, they do not represent change in GDP growth as a result of shifts induced in the wider economy.

OECD Environmental Outlook modelling suite, final output from IMAGE cluster (062g_oec08)

certain. In contrast, under a cap-and-trade system the amount of emission reduction is relatively certain and costs are more uncertain. Third, revenues of trading of emission rights go to the country or party that sells permits; revenues of a tax system go the corresponding government.

While the regional costs of the tax cases are all similar, we compare here the regional cost of the carbon tax variant for stabilisation at 450 ppm carbon dioxide equivalent and an example of a cap and trade regime. For the latter example, we use the per-capita-convergence approach. The worldwide allocation of emission rights in this example is based on gradual per capita convergence worldwide by 2050. Alternative convergence criteria are conceivable (e.g. emissions per GDP, or emission thresholds) as well as alternative convergence years. For the regional results the effect of an alternative convergence year will be shown. The model simulation assumes that countries trade emission rights in order to minimize their overall cost of abatement. Thus, assuming full trade, full market access and information, the simulation determines what proportion of emission rights would be traded and how that would affect regional costs of abatement.

Because in all simulations exactly the same measures are taken (all cost-effective measures to reduce emissions enough to meet the 450 ppm carbon dioxide equivalent profile), there is no difference in global costs. In all simulations, too, an important share of emission reduction measures is taken in developing countries – as often relatively cheap measures can be taken in these countries. The difference, however, is that in the tax case the costs to implement these measures are borne by the developing countries themselves while in the cap-and-trade scheme they are borne by those countries (or regions) that are assigned the most binding targets.

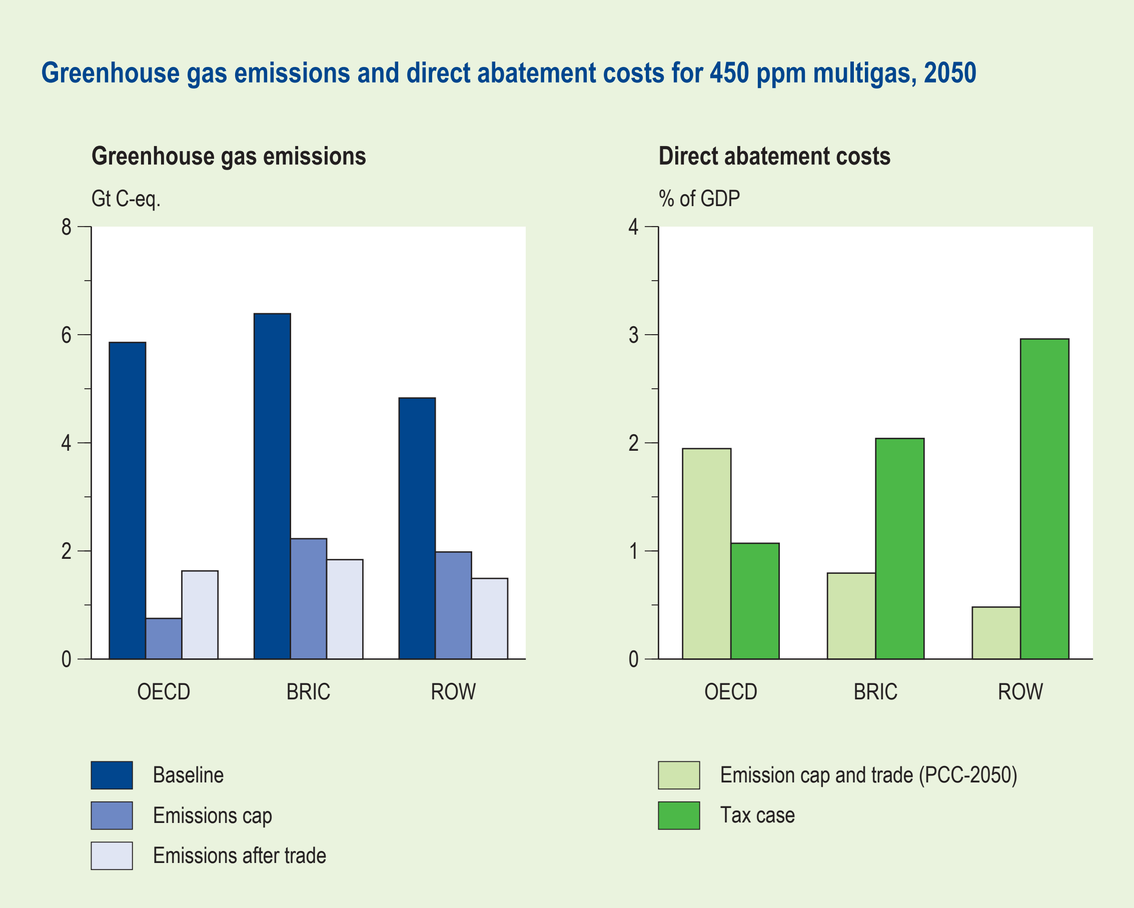


Figure 2.40 Greenhouse gas emissions and abatement costs for stabilisation at 450 ppm carbon dioxide equivalent, comparing a cap-and-trade system and global carbon tax, by three regional groups

Notes:The cap-and-trade example case is based on per capita convergence of emission rights by 2050. See text. Costs presented in this Figure are the direct costs of mitigation; that is, they do not represent change in growth as a result of shifts induced in the wider economy.

OECD Environmental Outlook modelling suite, final output from IMAGE cluster (FAIR) (063x_oec08)

The effect of these differences can be seen in *Figure 2.40* and *2.41*, aggregated to three regional groups and to thirteen regional clusters, respectively. In the left-hand side of *Figure 2.40*, the difference between the bars representing baseline (left) and emissions cap (middle) is the amount of emissions to be cut to stabilise greenhouse gas concentrations at 450 ppm (without trading). In this example, OECD countries would be required to cut emissions with 5100 million ton carbon dioxide equivalent by 2050 compared to the baseline. The difference between these emission caps without trade (middle bars) and emissions after trade (right-hand bars) reflects the emission rights that would be bought or sold between regions with trading. In this example of trading, 0.9 Gt C equivalents of annual emission rights would be bought by OECD countries for 2050.

This system does clearly change the global distribution of direct abatement costs in relation to GDP compared with the uniform global tax case without burden sharing. *Figure 2.40* shows them side by side (right-hand panel). The costs to OECD countries to achieve the 450 ppm stabilisation target would be more than in the global tax case discussed earlier, because of the more ambitious emission target. The global distribution of costs in the cap-and-trade example would avoid the imposition of relatively high costs in non-OECD regions, as shown in *Figure 2.40* (and

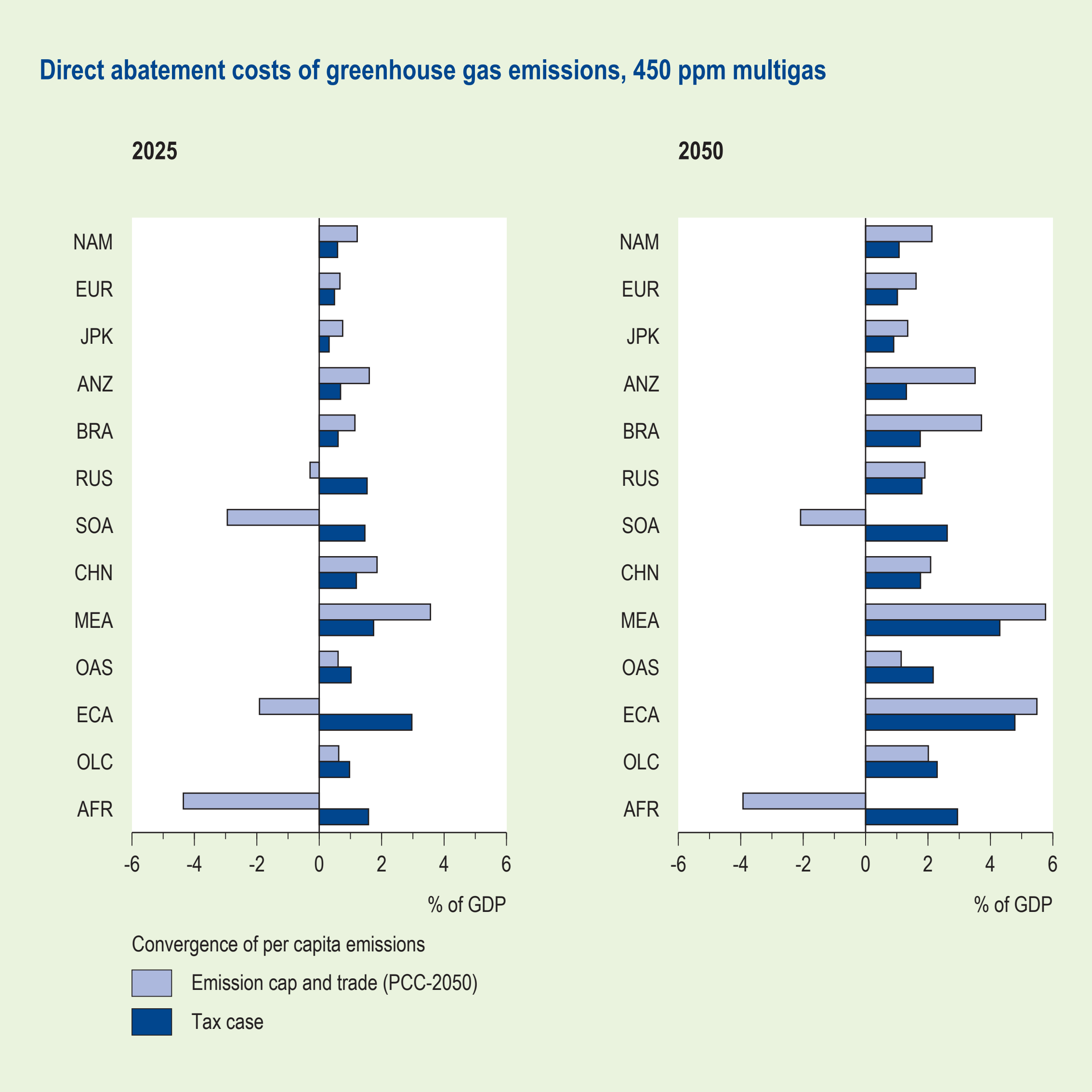


Figure 2.41 Abatement costs for stabilisation at 450 ppm carbon dioxide equivalent, comparing cap-and-trade system and global carbon tax, by thirteen regional clusters

Note: The cap-and-trade examples are based on per capita convergence of emission rights by 2050 or 2100, respectively. See text. Costs presented in this Figure are the direct costs of mitigation; that is, they do not represent change in growth as a result of shifts induced in the wider economy.

OECD Environmental Outlook modelling suite, final output from IMAGE cluster (FAIR) (065x_oec08)

in detail in *Figure 2.41*). In moving towards 2050, the ROW group of countries would even see net annual gains in some periods under the trading case (i.e. in 2025). In the BRIC group, Russia would initially see considerable gains before coming down, by 2050, to a cost level similar to that in North America. Conversely, China would see costs during the whole of the simulated period, going towards the North American level by 2050. The regional grouping of countries mask some of the intra-regional trading activity that would take place, for example within the OECD. This trading, too, serves to keep global mitigation costs to a minimum in achieving a given global emission objective.

Climate impacts

The climate policy cases analyzed here lead to clearly different increases of global mean temperature, in the long-run. In the period up to 2050, however, differences are much smaller

Table 2.10 Atmospheric GHG concentrations, global mean temperature, rate of temperature change

	Baseline		OECD 2008		Delayed		Phased		All 2008		450 ppm	
	2030	2050	2030	2050	2030	2050	2030	2050	2030	2050	2030	2050
GHG Concentration (ppm of CO_2 equivalents)	465	543	458	518	458	507	455	501	448	481	443	463
GMT range (°C)	1.2 - 1.6	1.7 - 2.4	1.2 - 1.5	1.6 - 2.2	1.2 - 1.5	1.5 - 2.1	1.1 - 1.4	1.5 - 2.0	1.1 - 1.4	1.4 - 1.9	1.1 - 1.4	1.3 - 1.8
Rate of GMT change (°C/ ten years)	0.28	0.28	0.25	0.23	0.22	0.19	0.22	0.18	0.21	0.15	0.16	0.10

Note: The range in global mean temperature change is based on MAGICC model calculations as performed by Van Vuuren et al. (forthcoming). The MAGICC range originates from emulation of different climate models, here showing the impact of climate sensitivity with a range corresponding to a climate sensitivity of 2.0 - 4.9°C. The overall range in transient 21st century climate change was used relative to the IMAGE model outcomes to account for differences in the scenarios.
OECD Environmental Outlook modelling suite, final output from IMAGE cluster

yet. This is illustrated in *Table 2.10* and *Figure 2.42*. The maximum warming occurs under the baseline (1.7 to 2.4°C above pre-industrial by 2050) and the minimum warming under the 450 ppm scenario (1.3 to 1.8°C above pre-industrial by 2050).Whereas the *OECD Environmental Outlook* for slow-changing systems applies an impact horizon of 2050, this still underexposes somewhat the differences between the climate policy cases. In part, this is inertia in the climate system. Therefore, this section briefly guides the reader to an interpretation of the 2050 results in a longer-term perspective.

There are two main causes for the relatively small band in outcomes for temperature change between the different cases. First of all, the climate system is governed by important inertia. Much of the temperature increase that is going to happen in the next few decades is determined by the current greenhouse concentration level. A second cause is that part of the decrease in greenhouse gas emissions is offset, in some policy packages, by a decrease in emissions of sulphur dioxide and particulates (elaborated in section 2.2.3). This partly comes from the systemic coupling of carbon dioxide and sulphur dioxide emissions in the energy system (they mostly come from the same sources) – but in the broad policy packages, air polluting emissions decrease even more, as a result of the assumed strengthening of air pollution policies in their own right.

The latter point can be illustrated by comparing the results of the broad policy packages of the environmental outlook (summarized in *Table 2.10*) against the cases that introduce climate policy only. This can be seen by comparing the left-hand panels of *Figures 2.42* and *2.43* with the other panels in these Figures. This comparison shows that, while in all series climate policy gains from increased participation, in the broad policy packages a much larger share of the climate gain is offset by other developments. Whereas the individual climate policy cases reduce warming by up to 0.3°C by 2050, the climate gain in the broad packages is less than 0.2°C by 2050. It should, however, be noted that the impacts from a decrease of sulphur emissions will, in time, be experienced anyway.

A clear picture of the difference between the policy cases can be obtained from the rate of temperature change. In the Baseline, the rate of temperature change is in the range of 0.25 to 0.30°C per ten years. In the climate policy cases, the rate of temperature increase becomes less. By 2050, the slowest temperature increase is found, again, for the 450 ppm stabilization case: less than 0.1°C per ten years. All other cases show results between these extremes.

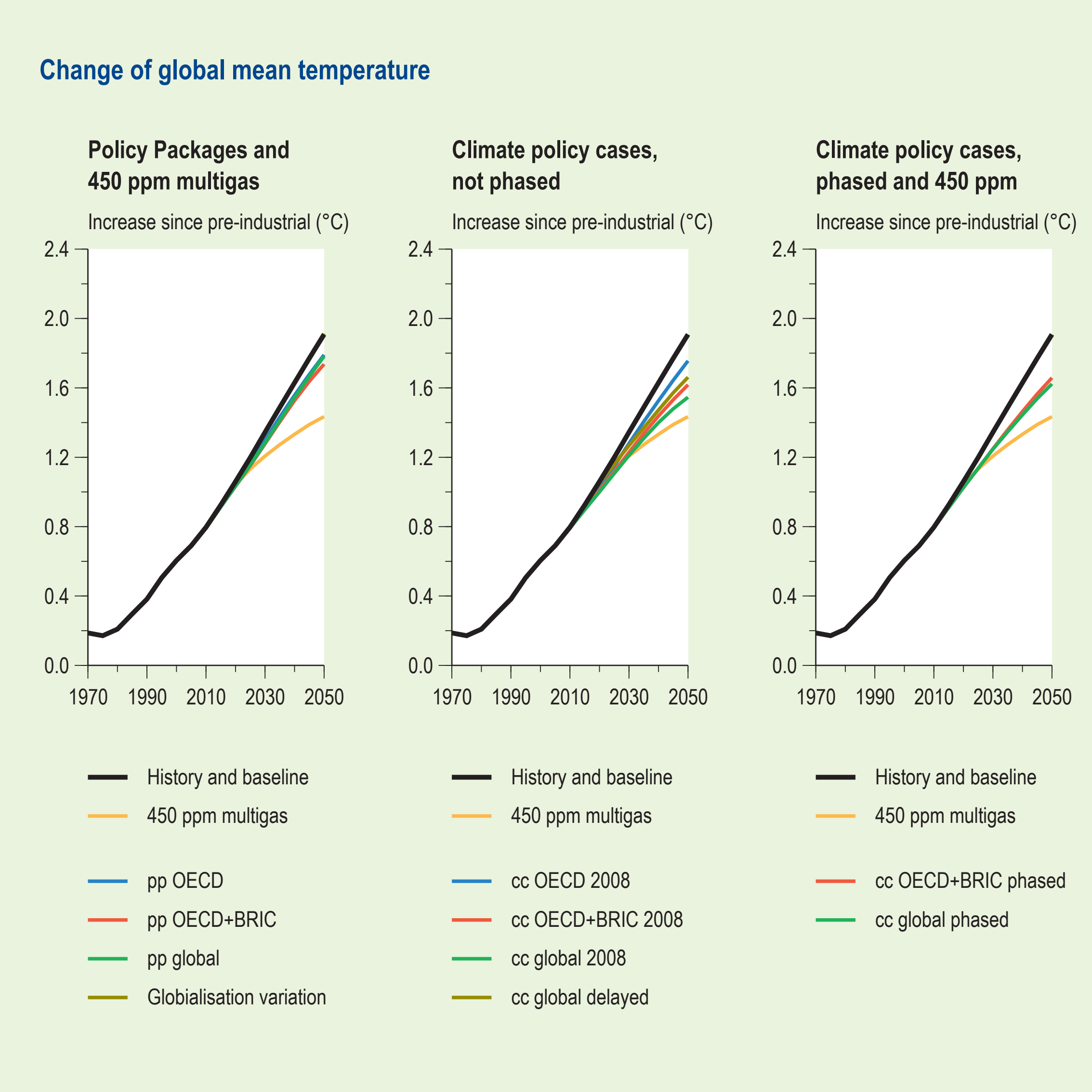


Figure 2.42 Global mean temperature increase to 2050 under various policy cases
Note: see *Table 2.10* for ranges of temperature increase.
OECD Environmental Outlook modelling suite, final output from IMAGE cluster (067x_oec08)

It should be noted that in the early decades until 2030, except for the 450 case, the mitigation cases hardly perform any better than the baseline. The background is, as explained, the correlation between emissions of carbon dioxide and of sulphur dioxide. This was already pointed out in Wigley (1991). The impact of sulphur emissions on temperature increase is calculated in IMAGE based on the pattern scaling methodology that was developed by Schlesinger et al. (2000). In theory, a decrease in 'sulphur cooling' could even mean a temporarily higher rate of temperature increase for some of the mitigation cases, compared to baseline (Van Vuuren et al., 2006b). The somewhat smaller impact of this phenomenon in the cases analysed here is mostly due to our estimates for the potential to decrease emissions of other greenhouse gases than carbon dioxide, in combination with the relatively large abatement efforts. That is, by using global warming potential as the basis of comparing between greenhouse gases, our method evaluates decreasing emissions of methane as cheap compared to decreasing emissions of carbon dioxide.(Furthermore, addressing methane is relatively independent of emissions of sulphur dioxide. Moreover, the impact of decreasing emissions of methane on radiative forcing is rather direct. Thus, the climate policy variants exhibit a

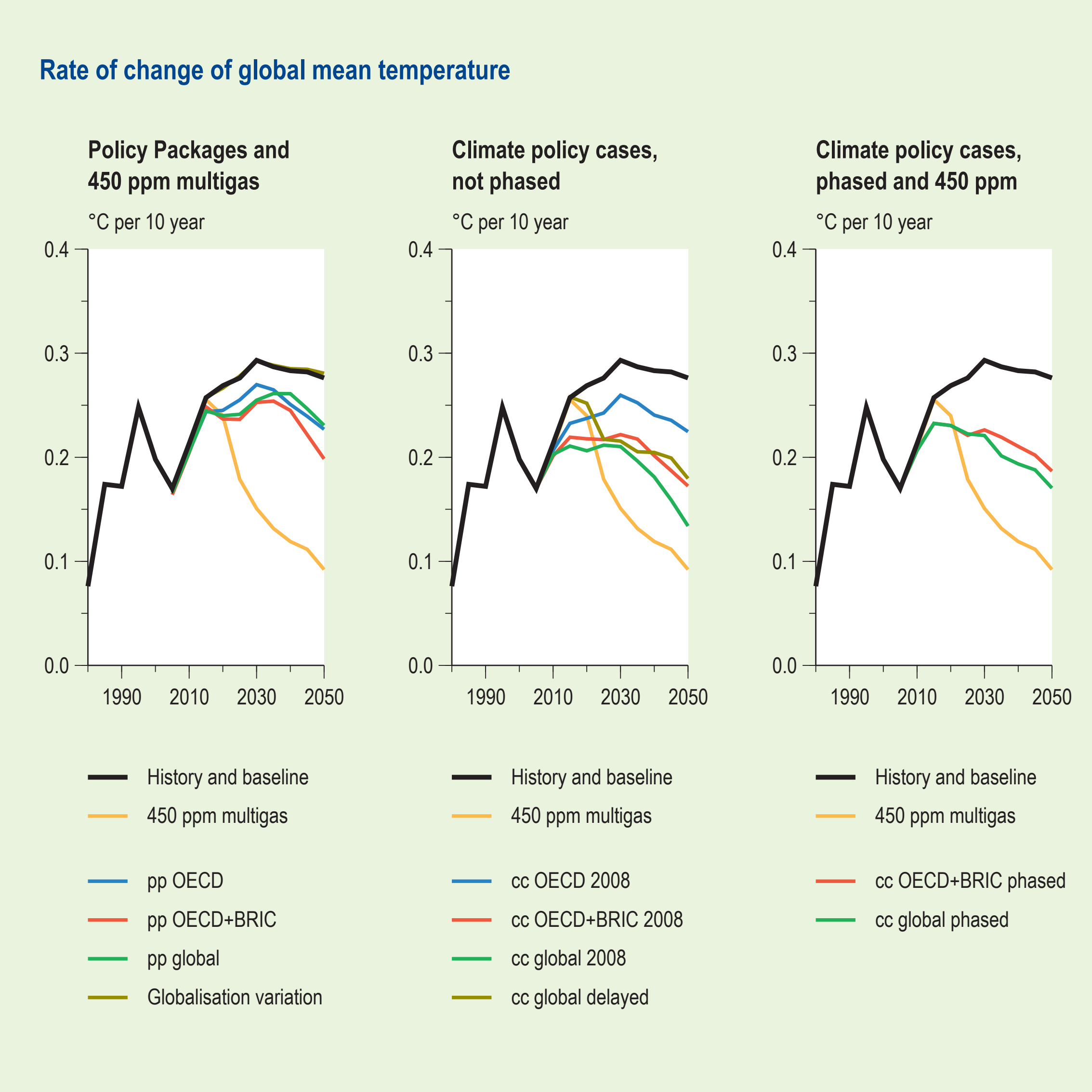


Figure 2.43 Rate of change of global mean temperature
OECD Environmental Outlook modelling suite, final output from IMAGE cluster (069x_oec08)

stronger effect on global warming than the policy packages, which include enhanced air pollution policies. As a result of these factors, our climate policy cases feature a relatively large contribution by decreases in emissions of methane and a comparatively small effect of changes in ‘sulphur cooling’.

The four maps in *Figure 2.44* show a sensitivity in the mean annual precipitation patterns across the world for various policy variants compared to the Baseline. As changes in precipitation tend to be more sensitive in this mid-century timeframe to global temperature change, even with stringent mitigation policies the drier and wetter patches stand out strongly. Hence it is not possible to draw a strong policy conclusion in favour of mitigation from this comparison, in particular as disagreement between different climate models on regional distribution of precipitation changes tends to be much larger than for temperature. Many other factors, some climate related (such as shifts in extreme events) and others, will affect the water stress, agricultural patterns and eventually socio-economic impacts related to changing climates. However combined with the regional temperature patterns, it is clear that aggressive mitigation

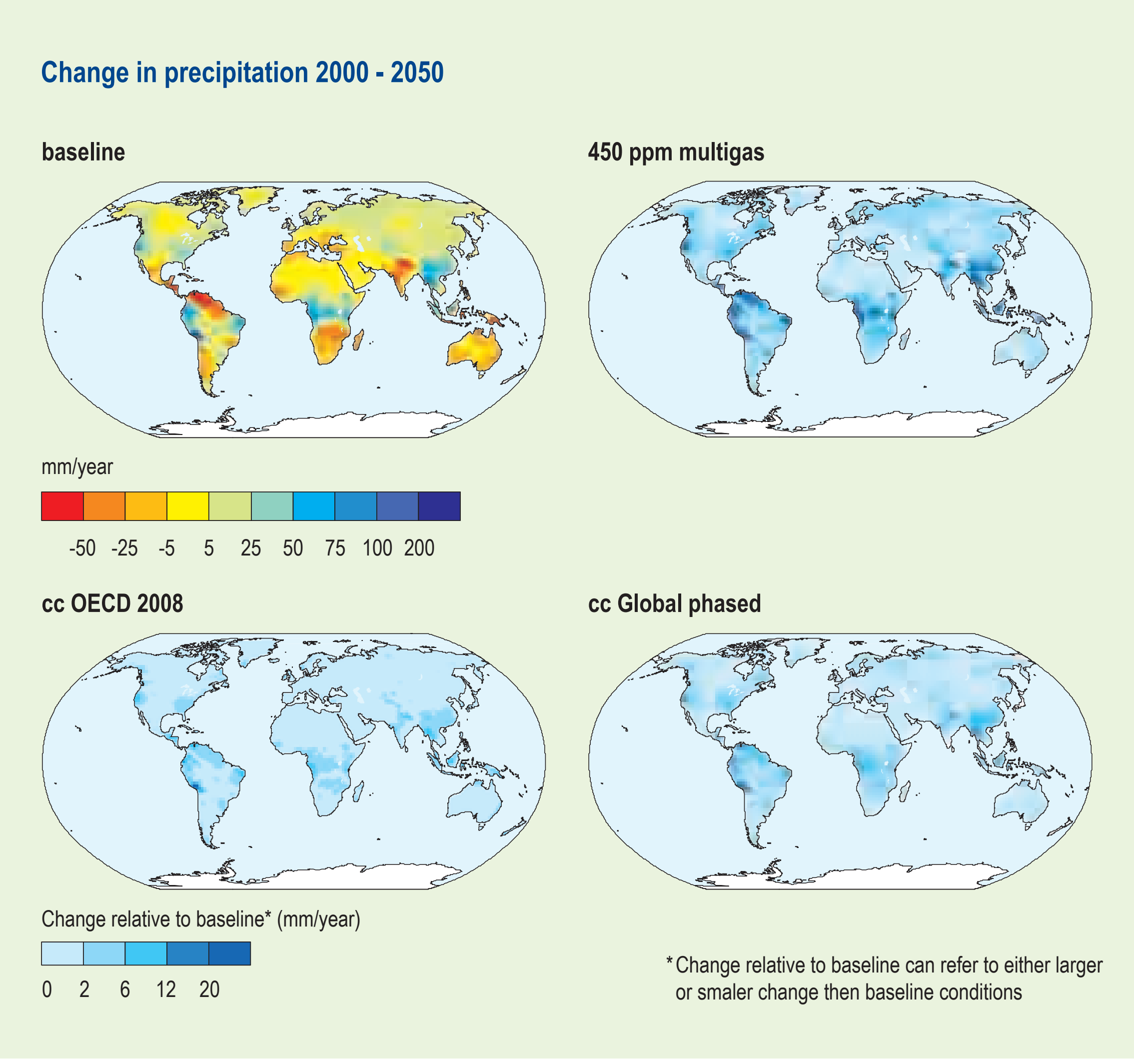


Figure 2.44 Change in annual precipitation: Baseline difference 1990-2050 and policy cases difference with the Baseline by 2050

OECD Environmental Outlook modelling suite, final output from IMAGE cluster (144x_oec08)

will lead to lower temperatures in many world regions which in turn is likely to help reduce water stress even in the face of shifting hydrological patterns.

Figure 2.45 relates the policy cases discussed here to long-term climate change. First, the left hand graph compares the emissions of the baseline and 450 ppm multigas case discussed here to the B2 and B2-450 scenarios published by Van Vuuren et al. (2007) and simulated with the same modelling suite. The figure shows that the OECD 450 ppm multigas case can be compared well to the B2-450 scenario. The same goes for the respective baselines. The right-hand graph of *Figure 2.42* shows the temperature increase, under mean assumptions of the MAGICC model for the B2 scenarios, the OECD baseline and 450 ppm case. Without climate policy the temperature increase is likely to be 3 to 4°C by the end of the century. The 450 ppm multigas policy case could limit temperature increase to a range of 1.2 to 2.3°C. A scenario involving greenhouse gas concentrations of 650 ppm carbon dioxide equivalents (comparable to the phased tax cases; see *Figures 2.42* and *2.43*) would lead to a temperature increase in the order of 2 to 3.5°C.

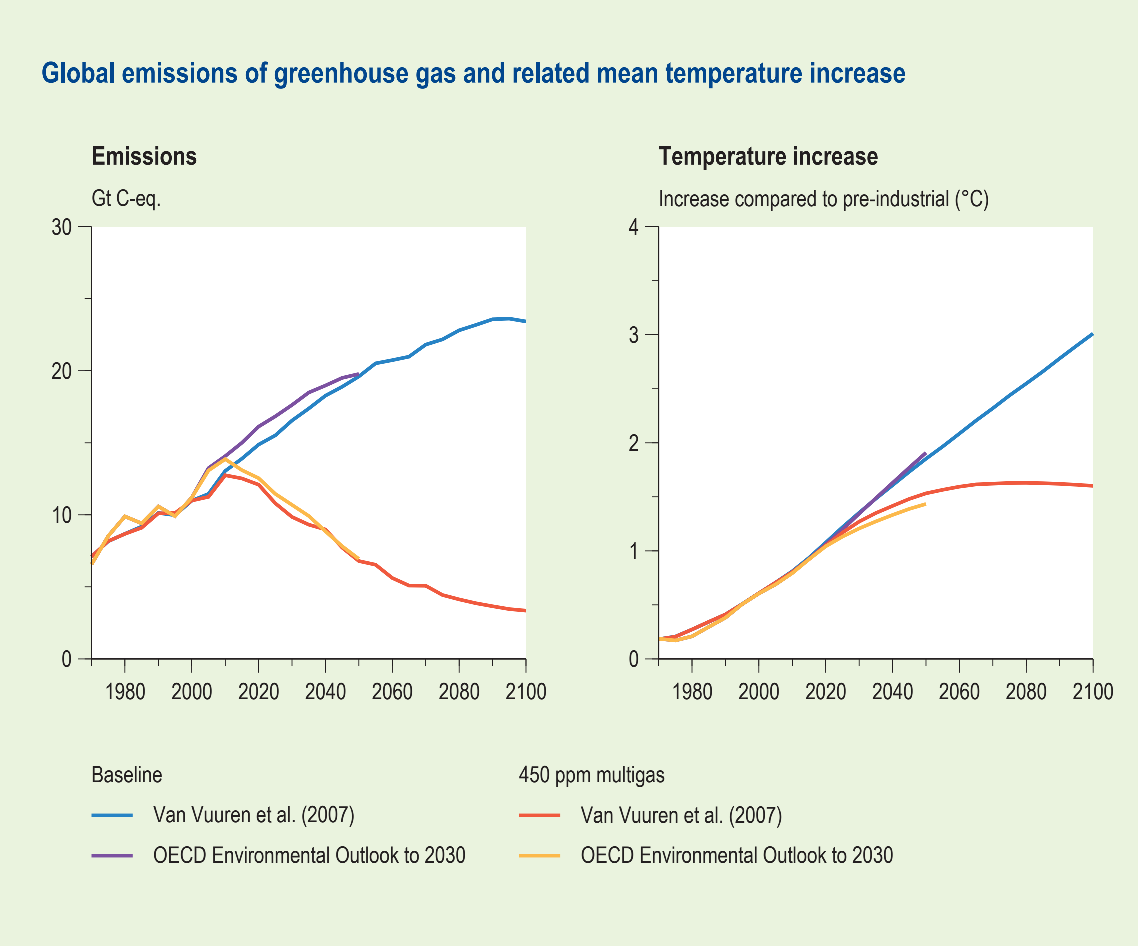


Figure 2.45 Global mean temperature increases to 2100, baseline and stabilization cases
Note: these line graphs reflect a climate sensitivity of 2.5 and do not show uncertainties as discussed in the text.
OECD Environmental Outlook modelling suite, final output from IMAGE cluster (071x_oec08)

Finally, it should be noted that as the temperature results of the different stabilization scenarios depend to a considerable extent on the uncertain relationship between the greenhouse gas concentration and temperature increase, they can better be expressed in probabilistic terms (Climate sensitivity is not the only source of uncertainty – see section 3.2.1.). Work of Meinshausen (2006) shows that, depending on the probability distribution function used, the 650 ppm scenario gives a probability of between 0 and 18% of meeting a 2°C target. By contrast, relative to the same target, the 450 ppm scenarios result in a probability of 22 to 73%. Similarly, for meeting a 2.5°C target, 650 ppm provides a probability between 0 and 37%; for 450 ppm the probability range is 40 to 90%.

Conclusions from climate policy simulations

- Stabilization at 450-550 ppm multigas requires early and full participation of all large emitting countries. For example, delaying mitigation effort of large emitters (developed and developing countries) increases the emissions such that stabilization of concentrations shifts from 550 to 650 ppm for a given global carbon price. Efforts by OECD countries alone will be largely insufficient to stabilize concentrations of ghg and to limit global warming.
- Assuming full participation and immediate implementation, implementing a carbon tax of 92 US $ per ton of carbon (25 US $ per ton of carbon dioxide) that increases with by 2.4% per

year is expected to lead to stabilization of the greenhouse gas concentration around 550 ppm carbon dioxide equivalent.
- The analysis also shows that delaying the implementation of climate policy will lead to consequently less emission decreases. The difference between implementation in 2008 and 2020 (assuming the exact same rate of introduction of the carbon price from the introduction year onwards) corresponds more or less to a difference in stabilization of greenhouse gas concentrations at 550 or at 650 ppm carbon dioxide equivalent. These concentrations, in turn, correspond with temperature increases at equilibrium of 2.8 to 3.2°C, or 3.2 to 4.0°C, respectively, above pre-industrial levels, and with more global warming already by 2050.
- Cost of climate policy are uncertain. The most stringent case that has been analysed, namely stabilization of greenhouse gas concentration at 450 ppm carbon dioxide equivalent, would take off 2.5 per cent of the projected GDP by 2050 relative to the baseline.
- Regional costs strongly depend on the way international climate policy is designed. Climate policy on the basis of a globally uniform carbon tax leads to a relatively large burden in developing countries. Cap-and-trade systems are able to distribute costs across regions.
- The climate policy cases can considerably reduce global mean temperature increase, mainly after 2050. Until then, part of the potential gains from decreases in greenhouse gas emissions (and associated forcing) would be offset by decreases in emissions of sulphur dioxide. The exact temperature impacts are uncertain in part as a result of the uncertainty in aerosol forcing.

2.2.3 Policy simulations air pollution

Many air pollutants come from the same sources as key greenhouse gases. As a result, changes induced in the energy system by climate policy could lead to substantial changes (mostly decreases) in the emissions of conventional air pollutants as well. In most simulations of climate policy cases, we accounted for the consequences of climate policies for emissions of sulphur and nitrogen oxides, volatile organic compounds and carbon monoxide by simply using the same emission coefficients as those assumed under the baseline (reflecting similar air pollution policies), thus quantifying the impact of changes in the energy system on air polluting emissions on a pro rata basis. In the three broad policy cases, however, air pollution policy itself is assumed to be strengthened. Thus, these cases result in lesser air pollutant emissions, both as a direct result of the assumed air pollution policy and as an indirect result of the changes induced in the energy system by climate policy.

Together, the set of policy cases including the baseline represent a very wide range of possible trajectories over time for sulphur dioxides emissions. The actual trajectory is not only important in terms of co-benefits but also for climate impacts.

The baseline sees a small increase in emissions of sulphur dioxide, mostly after 2020. It is assumed that some of the air pollution standards in developed and developing countries will be strengthened (on the basis of currently expressed policies and assuming developments in the minimum abatement level). But this is offset by increases in energy consumption. In particular, increasing coal use in BRIC plays an important role.

Three policy packages have been simulated and their effect on emissions compared with the Baseline. The analysis was carried out assuming that the air pollution policies would be part of a broader movement in boosting environmental policies, with either OECD countries; or OECD and BRIC; or all countries stepping up their ambition in environmental policies. In this manner, some indication of trade-offs and synergies can be gleaned from the modelling results. From an air pollution perspective, this boils down to:

i. enhanced air pollution measures in current OECD member countries (part of *ppOECD*);
ii. BRIC countries move to a similar ambition level in air pollution policy (part of *ppBRIC+OECD*);
iii. the remaining countries eventually move to the same ambition level as well (part of *ppGlobal*).

The measures relate to emissions of sulphur dioxide, nitrogen oxides, volatile organic compounds and carbon monoxide. Their effect on emissions is simulated on the basis of what can be achieved with current technology — even if some countries' actual implementation would in reality be far into the future. In order to reflect ambitious, but not unrealistic policies it was assumed that the last, steep section of cost-effectiveness curves would be avoided. Typically, this corresponds to eventual emission levels, for a country as a whole, that remain 3 to 14 per cent larger than what can be achieved with Maximum Feasible Reduction (MFR). For example, compared with the costs for fully implementing the MFR options in the European Union, this reduces the additional costs with more than 60% (Amman et al., 2005).

A further refinement of the three policy packages assumes that countries will only start implementing the air pollution policies beyond the Baseline after their GDP at purchasing power parity per capita reaches a certain level. For example, in the BRIC policy package, India would start implementing these policies somewhat later than China.

Moreover, also the speed of implementation of emission control options is assumed to be related to GDP per capita, ranging between 15 and 30 years. Full implementation is assumed to take at least 15 years, and large point sources and transport will see enhanced emission control introduced first, with other diffuse sources being addressed typically a decade later.

Abatement of emissions from shipping is included in the policy packages, as this becomes a cost-effective option in regions that have brought a good part of the land-based emissions under control. Emissions of sulphur dioxide from sea shipping affect air quality large distances downwind, typically thousand of kilometres or more away from the source and possibly in the middle of a continent. For example, if emissions from sea ships are not further restricted, the increase in shipping will negate land-based emission control efforts in Western Europe by 2020 (Cofala et al., 2007).

Nitrogen oxides and sulphur dioxide emissions

By 2030, worldwide emissions of nitrogen oxides in the case of enhanced environmental policies worldwide *(pp Global)* are projected to be 30% lower than the Baseline emissions; and 37% lower for sulphur dioxide. By 2050, worldwide emissions of sulphur dioxide would be 84% lower than the Baseline; and 63% for nitrogen oxides (see *Figure 2.46*).

For sulphur dioxide, the largest contribution in 2030 to the decrease in emissions comes from OECD countries (10 million tonnes sulphur per year less), closely followed by the BRIC countries (-8). By 2050, in the case of enhanced environmental policies worldwide, the rest of the world delivers the largest reduction (-32) compared to the Baseline, while the OECD cluster stabilises at -11 and the BRIC countries decrease further to -23 million tonnes sulphur per year.

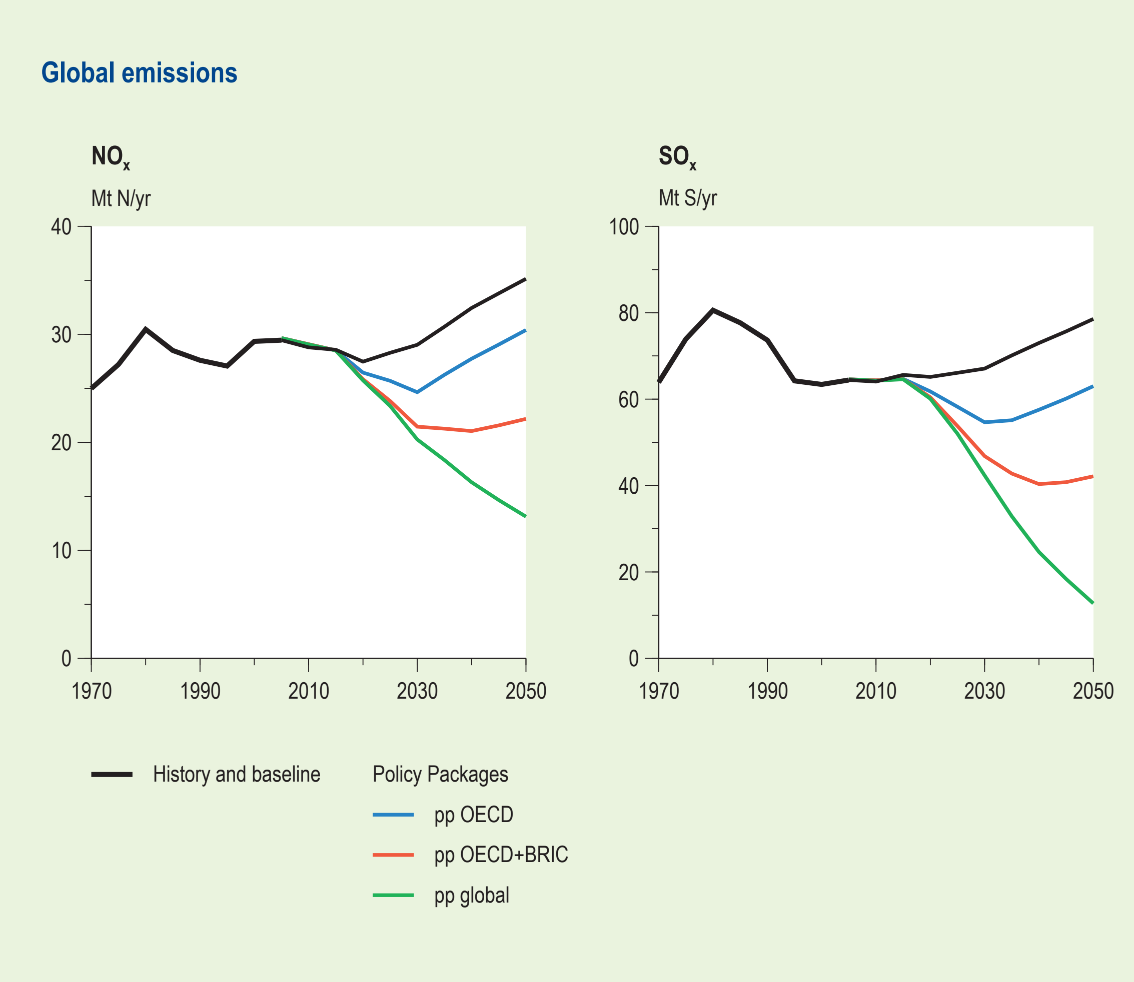


Figure 2.46 Emissions of sulphur and nitrogen oxides: baseline and policy cases
OECD Environmental Outlook modelling suite, final output from IMAGE cluster (073x_oec08)

Policy-induced decreases in emissions of nitrogen oxides are less steep, as it is technically more difficult and thus more costly to achieve deep emission cuts. By 2030 and 2050, the decrease in OECD countries is -4 and -5 million tonnes nitrogen per year respectively. The BRIC cluster achieves a lesser decrease by 2030 (-3 million ton/year) but more than double that (-8) by 2050. The rest of the world sees a small decrease in nitrogen oxides emissions by 2030 (-1 million ton nitrogen per year), but steady decreases after that, passing -9 million tonnes per year by 2050.

As illustrated by the right-hand side of *Figure 2.47*, sulphur dioxide emissions are decreased almost proportionally to the amount of greenhouse gas abatement in the climate policy cases. This can be explained by the fact that phasing out conventional fossil-fired power plants and reducing oil inputs into transport and replacing them by either fossil plants with CCS or renewables does significantly decrease sulphur dioxide emissions. The 450 ppm multigas stabilization case requires the largest reductions in greenhouse gas emissions and consequently leads to the smallest sulphur dioxide emissions.

Figure 2.47 shows that there are clear co-benefits for regional air pollution resulting from climate policy. In low-income countries, a focus on the potential synergies of climate change policies and air pollution policies could be even more important than in high-income countries.

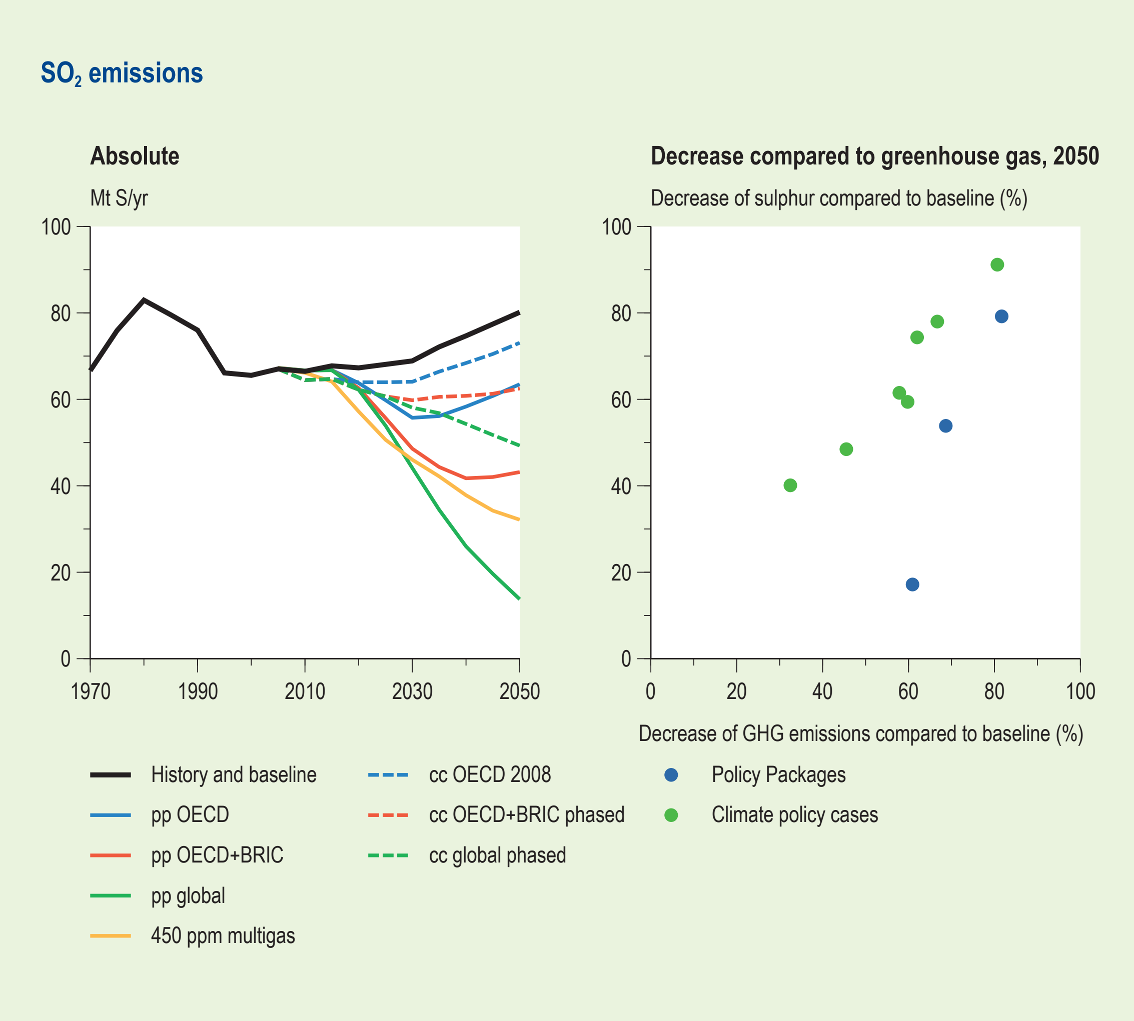


Figure 2.47 Sulphur dioxide emissions in climate policy cases
OECD Environmental Outlook modelling suite, final output from IMAGE cluster (075x_oec08)

Synergy effects of climate policies on regional and urban air pollution may in fact be a reason for non-OECD countries to contribute to early emission reductions.

Urban PM_{10} concentrations have been estimated for the three policy cases. The case of *ppOECD* leads to a 35-45% decrease, compared to the Baseline, of PM_{10} concentrations in urban agglomerations in OECD countries. It would even decrease concentrations in BRIC and the rest of the world by up to 5%. For the *ppBRIC+OECD* case, it is estimated that concentrations of PM_{10} decrease by approximately 25%, although South Asia lags behind with a decrease of 8%. The case of *pp Global* results in a small decrease (between 5 and 8%) in the rest of the world. For the period 2030-2050, projections suggest that emissions of sulphur and nitrogen oxides (precursors of particulate matter) will not substantially decrease in the OECD; concentrations of airborne particulate matter will remain more or less constant here. In the BRIC countries and the rest of the world, the measures result in strong decreases of emissions starting around 2020 and 2030, respectively. This would lead to a correspondingly strong decrease in urban concentrations.

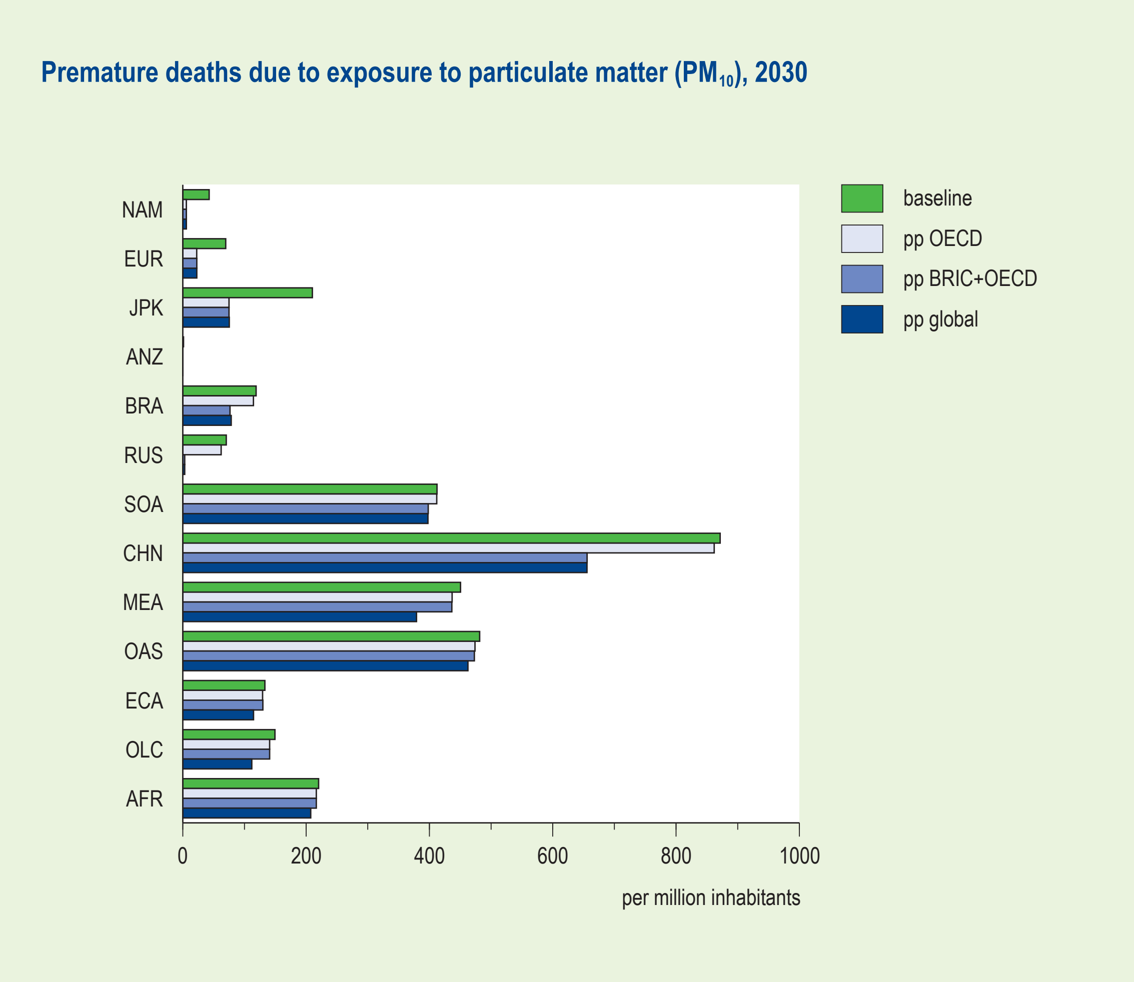


Figure 2.48 Premature deaths from exposure of populations of urban agglomerations to particulate matter, Baseline and policy cases, 2030
OECD Environmental Outlook modelling suite, final output from IMAGE cluster (GUAM) (077g_oec08)

For population exposures for 2030, the situation is projected to improve in the *pp Global* case, but large proportions of the urban population would still be living in agglomerations with annual mean PM_{10} concentrations exceeding the WHO interim target 1 of 70 µg/m³.

Despite the decreases in concentrations in some regional clusters (for example, the clusters South Asia and Other Asia), hardly any decrease in attributable deaths is estimated. There are two main reasons for this result. Firstly, by 2030 the decrease in concentrations in these regions is still limited (further decreases are anticipated by 2050). Secondly, in the health impact assessments the PM_{10} concentrations are truncated at 150 µg/m³ annual mean. Thus, even if concentrations are decreased from the more than 200 µg/m³ observed in for example urban agglomerations in Pakistan (Ghauri et al., 2007) to 150 µg/m³, this will not be reflected in the health benefits. In other words, the difference between dirty and very dirty air is neglected. This assumption will underestimate the number of premature deaths, but despite this, *Figures 2.48* and *2.49* indicate that problems associated with exposure of urban populations to airborne particulate matter will not be solved by 2030.

Direct costs of air pollution abatement
The costs of the additional air pollution policies described here - that is, extra effort in the policy package over and above the level of effort in the baseline – are presented in *Table 2.11*. They are

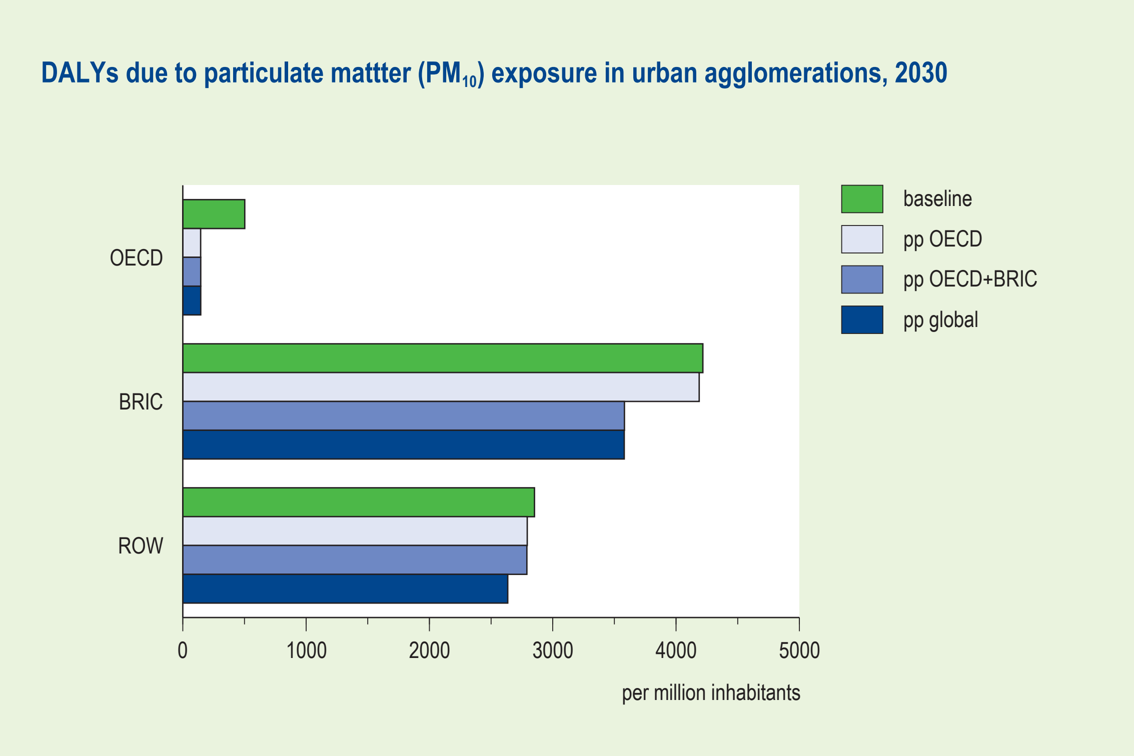


Figure 2.49 Loss of DALYs from exposure of populations of urban agglomerations to particulate matter, Baseline and policy cases, 2030

OECD Environmental Outlook modelling suite, final output from IMAGE cluster (GUAM) (153g_oec08)

based on Bollen et al. (2007) and are by and large limited to end-of-pipe technologies. In other words, they do not cover structural changes in energy production and use and thus have little overlap, or co-benefits, with climate change policies.

2.2.4 Policy simulations water use and availability

The various policy cases reveal an almost similar water demand by 2030.This is largely due to the fact that the policy cases are defined with little differentiation in water use policies. Total water demand varies from 5400 km³ for the globalisation variant to the baseline to 4500 km³ in the worldwide climate policies variant. The most relevant changes can be observed in the electricity sector, due to structural changes in electricity supply (see section 2.1.3). In the worldwide collaboration case *pp Global*, water demand in the electricity sector is only about 1000 km³ whereas in the baseline the use goes up to 1167 km³ (see *Figure 2.50*).

Table 2.11 Air pollution control costs in addition to the baseline, global policy package

	2020	2030	2040	2050
% relative to GDP				
OECD	0.04	0.22	0.22	0.19
BRIC	0.02	0.09	0.13	0.26
ROW	0.00	0.03	0.15	0.14

The cost presented here are direct cost of mitigation, that is, they do not represent change in GDP or GDP growth as a result of shifts induced in the wider economy.

OECD Environmental Outlook modelling suite, final output from IMAGE cluster

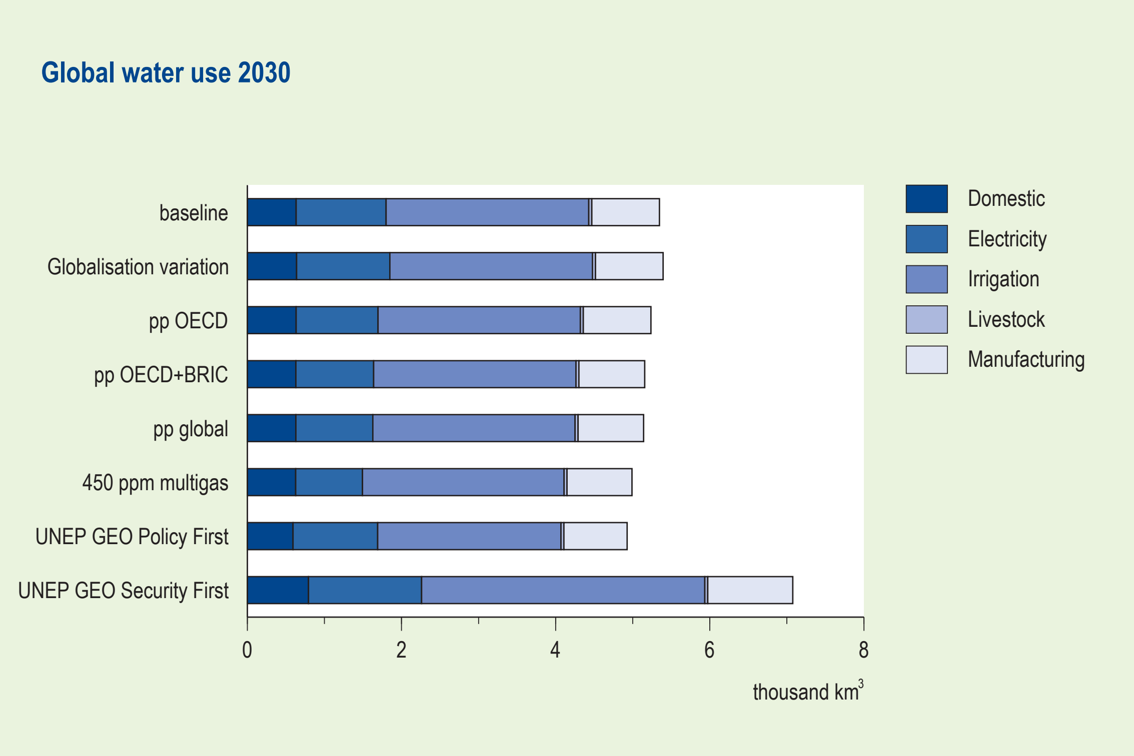


Figure 2.50 Water use in the Baseline, policy packages and two GEO4 scenarios
Note: In addition to the policy packages for the OECD environmental Outlook, sectoral water use is presented for two GEO4 scenarios as an additional sensitivity analysis. Scenario assumptions concerning the technological change were taken from UNEP (2007) for the Policy First and Security First-scenario.
OECD Environmental Outlook modelling suite, final output from IMAGE cluster (WaterGAP) (154g_oec08)

As a result of the lower overall water demand in 2030 a slight general decrease of water stress is projected. However, there is no great difference in regional results compared to the Baseline. There are only meaningful changes from medium to low water stress for the USA and Mexico and from severe to medium water stress for OECD Europe and Canada. Only for the Western Africa region there is a small increase in severe water stress, due to decreased water availability.

As the policy packages for the Environmental Outlook have little differentiation in water policy and technology development in water management, two additional analyses have been done. The rates of technological change derived from two contrasting scenarios from the UNEP GEO-4 assessment (UNEP, 2007) have been applied to the baseline scenario assumptions for water demand from the Environmental Outlook. UNEP's Policy First scenario is comparable to the worldwide collaboration case *(pp Global)*, in that it reflects concerted efforts by government worldwide to solve pressing problems keeping up with sustainable development principles. The scenario assumes increased public investments in R&D and environmental protection, leading to changes in water-use behaviour in households and industry, and efficiency improvements in all sectors. The Security First scenario is characterised by its emphasis on security, at the expense of environmental governance. The scenario assumes little progress in water use efficiency.

In these two sensitivity scenario runs the share of the different water demand sectors does not change. The amount of total water demand in 2030 for Policy First is smaller than in the baseline mainly because of a smaller demand for irrigation. Especially in China there will be a much smaller demand, leading to a shift from a large part of the population living under medium water

Table 2.12 Nitrogen uptake ratio for upland crops, energy crops and wetland rice

	OECD countries		BRIC and ROW, currently nutrient deficit		BRIC and ROW, currently nutrient surplus	
	2030	2050	2030	2050	2030	2050
% relative to the FAO Agriculture Towards 2030 values						
Baseline	100	100	100	150	100	100
pp global	80	75	110 to 200	115-450	80	72

OECD Environmental Outlook modelling suite, final output from IMAGE cluster

stress in the baseline case to low or no water stress in the Policy First case. In the Security First-scenario in 2030 there is a significant increase in water use in all sectors, except for livestock farming, for which no change was assumed.

In this scenario more people will suffer from severe water stress (53% of the population, compared to 47% in the Baseline for 2030). Particularly in the regions of Europe (OECD- and Eastern Europe), Russia and Caucasus, Korea region and Oceania, and also but to a lesser extent in South and East Africa and USA, the water stress situation would become worse.

2.2.5 Policy simulations nutrient cycles

Diffuse sources of reactive nitrogen, including the agricultural system
For estimating the nitrogen fertilizer input for crops and grass we use the concept of fertilizer Nitrogen Uptake Ratio (NUR) (Bouwman et al., 2006), which is the amount in kg of nitrogen or phosphorus used to produce one kg of dry matter. The NUR varies between regions. For example, in many African and Latin American countries fertilizer use is not sufficient to replenish the crop uptake and losses through ammonia volatilization, denitrification, leaching and change in soil organic matter. In contrast, in industrialized countries the crop uptake is generally about 50% of the nitrogen input from fertilizer.

Important improvement in agricultural management and technological progress resulting in increasing nitrogen fertilizer recovery were assumed in the FAO Agriculture Towards 2030 (FAO-AT2030) study (bruinsma, 2003). In the baseline of the current outlook we assumed that the efficiency of fertilizer use in all countries equals that assumed by FAO-AT2030.

For nutrients, only the case of enhanced policies worldwide *(pp Global)* has been explored. To translate the storyline of this policy case into a scenario for fertilizer input, we grouped the world into industrialized countries with inputs exceeding the crop uptake (surplus); developing countries or countries of the former Soviet Union with current deficit; and developing (like China and India) or transition countries with a surplus. This grouping of countries was made for this specific purpose and differs from the OECD, BRIC, ROW. In the policy case farmers are motivated to be increasingly efficient *(Table 2.12)*. In countries where crop export currently exceeds the inputs in terms of nutrients (deficit), we assume for the policy case that the application rates will converge to the NUR values of industrialized countries to a varying degree. This is due to developing aid and improvement of extension services to restore soil fertility and develop sustainable agricultural systems.

Table 2.13 Fertilizer use for all crops, grassland and energy crops

			Baseline		pp Global	
	1970	2000	2030	2050	2030	2050
N in Tg yr^{-1}						
North America	6.5	14.0	19.1	22.0	16.5	19.3
OECD Europe	9.8	12.2	17.0	19.0	13.8	15.0
OECD Asia	0.8	1.1	0.8	0.8	0.6	0.6
OECD Pacific	0.1	1.2	1.4	1.8	1.4	1.8
Brazil	0.3	2.0	2.8	3.3	3.7	5.0
Russia & Caucasus	1.9	1.0	2.0	2.3	2.7	3.3
South Asia	1.9	14.4	21.6	26.2	18.4	20.8
China Region	3.4	21.9	25.4	28.7	20.5	21.0
Middle East	0.1	1.5	2.7	3.3	2.2	2.7
Other Asia	0.6	5.2	7.6	8.4	8.7	9.7
Eastern Europe & Central Asia	2.5	1.4	2.0	2.8	2.4	3.2
Other Latin America & Caribbean	0.5	2.1	4.1	5.9	6.0	7.5
Africa	0.8	2.4	4.4	6.2	7.5	13.3
World	**29**	**81**	**111**	**131**	**105**	**123**

OECD Environmental Outlook modelling suite, final output from IMAGE cluster

This translates into fertilizer use as presented in *Table 2.13* showing a significant increase in fertilizer use in the policy case relative to the baseline in, for example, Africa. Apart from the assumed fertilizer application rates as expressed by NUR, the production of first generation energy crops cause an additional fertilizer use compared to the baseline (e.g., Brazil).

Table 2.14 Total inputs of reactive nitrogen for agricultural land

			Baseline		pp Global	
	1970	2000	2030	2050	2030	2050
N in kg ha^{-1} yr^{-1}						
North America	42	56	62	71	59	64
OECD Europe	98	110	117	126	105	109
OECD Asia	139	209	196	208	188	157
OECD Pacific	15	17	17	17	16	17
Brazil	35	52	66	79	64	76
Russia & Caucasus	41	28	32	35	33	37
South Asia	66	137	142	157	133	137
China Region	30	75	86	94	77	79
Middle East	15	30	47	55	44	48
Other Asia	43	92	97	104	100	104
Eastern Europe & Central Asia	30	21	26	28	27	27
Other Latin America & Caribbean	30	36	43	51	46	51
Africa	19	28	38	47	40	50
World	**34**	**51**	**59**	**66**	**56**	**61**

Note: Inputs include animal manure, biological fixation of nitrogen gas and atmospheric deposition of nitrogen compounds; agricultural land includes arable land, permanent crops, energy crops and grassland.

OECD Environmental Outlook modelling suite, final output from IMAGE cluster

Table 2.15 Crop nitrogen uptake and nitrogen uptake in the form of grazing or grass or hay cutting

			Baseline		pp Global	
	1970	2000	2030	2050	2030	2050
share in total inputs						
North America	0.3	0.4	0.5	0.5	0.6	0.6
OECD Europe	0.4	0.5	0.5	0.5	0.6	0.6
OECD Asia	0.5	0.3	0.3	0.3	0.3	0.3
OECD Pacific	0.3	0.3	0.4	0.4	0.4	0.5
Brazil	0.5	0.5	0.6	0.5	0.6	0.7
Russia & Caucasus	0.4	0.4	0.4	0.4	0.4	0.4
South Asia	0.3	0.2	0.3	0.3	0.3	0.4
China Region	0.4	0.3	0.3	0.3	0.4	0.4
Middle East	0.3	0.3	0.3	0.3	0.3	0.4
Other Asia	0.6	0.5	0.6	0.5	0.6	0.6
Eastern Europe & Central Asia	0.3	0.3	0.4	0.3	0.4	0.4
Other Latin America & Caribbean	0.4	0.5	0.5	0.5	0.5	0.6
Africa	0.3	0.4	0.5	0.4	0.5	0.5
World	**0.4**	**0.4**	**0.4**	**0.4**	**0.5**	**0.5**

OECD Environmental Outlook modelling suite, final output from IMAGE cluster

Since inputs from animal manure, biological fixation of nitrogen gas and atmospheric deposition of nitrogen compounds (see model description for the calculation) do not differ much between baseline and the global policy case, fertilizer use determines the difference in total nitrogen inputs *(Table 2.14)*. Most industrialized countries and developing countries with a current surplus (India, China) show a decrease of nitrogen inputs per hectare of agricultural land relative to baseline, while many developing countries with a current deficit show an increase in inputs. Due to the simultaneous expansion of agricultural areas, this increase of nitrogen inputs per unit land is often apparently small. However, in intensively managed agricultural areas the nitrogen inputs per hectare are much larger, while the expansion of grassland (with much smaller inputs) dilutes the averages.

The major nitrogen surface balance output terms for the agricultural system are crop uptake and uptake in the form of grazing or grass or hay cutting, and ammonia volatilization. There are different developments that simultaneously influence the nitrogen recovery. Many areas in developing countries had a net nitrogen deficit in the period 1970-1995, implying that soil organic matter nitrogen depletion occurred leading to high apparent nitrogen efficiency (Bouwman et al, 2005). However, gradually the inputs of nitrogen compounds in the form of fertilizers, animal manure and biological nitrogen fixation have increased in most developing countries and will continue to do so in the coming three decades. Hence, agricultural systems with nitrogen deficits gradually change into systems with nitrogen surpluses, leading to growing losses of reactive nitrogen to the environment. This is particularly so in the case of enhanced environmental policies worldwide *(pp Global)*. At the same time, there is an increasing efficiency of the agricultural system as a whole. It depends on the importance of each of these developments (intensification, increasing efficiency) whether the loss of reactive nitrogen will increase or decrease *(Table 2.15)*.

Table 2.16 Nitrogen surplus in agricultural systems

			Baseline		pp Global	
	1970	2000	2030	2050	2030	2050
N in Tg yr^{-1}						
North America	17	15	14	14	10	10
OECD Europe	14	10	11	12	8	8
OECD Asia	1	1	1	1	1	1
OECD Pacific	5	5	4	4	4	4
Brazil	3	5	4	4	4	3
Russia & Caucasus	5	3	5	5	5	6
South Asia	10	20	26	27	23	21
China Region	8	30	32	32	27	24
Middle East	2	3	4	5	4	4
Other Asia	1	4	4	4	5	4
Eastern Europe & Central Asia	7	4	5	6	5	6
Other Latin America & Caribbean	5	6	6	6	7	7
Africa	12	16	23	27	23	30
World	**90**	**121**	**139**	**146**	**126**	**128**

OECD Environmental Outlook modelling suite, final output from IMAGE cluster

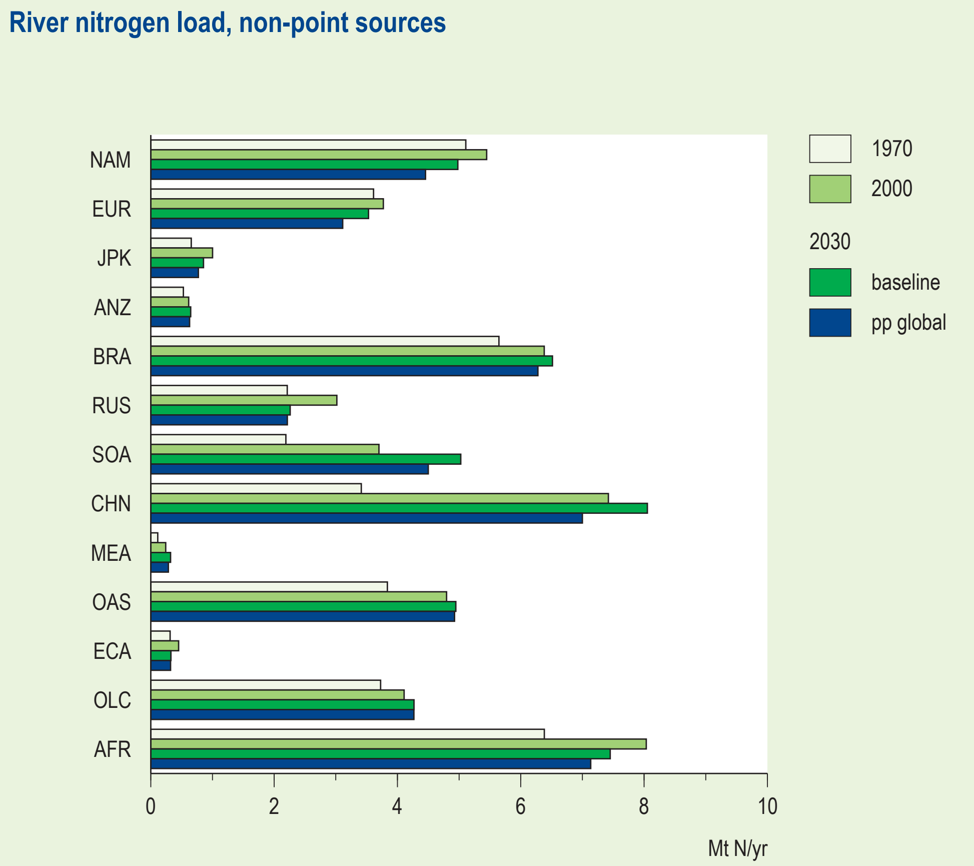


Figure 2.51 River nitrogen load originating from nonpoint sources

Note: load at the mouth of the rivers

OECD Environmental Outlook modelling suite, final output from IMAGE cluster (086g_oec08)

Table 2.17 Population with access to improved sanitation, connection to public sewerage; removal of nitrogen from sewage; 2030

		World		OECD		BRIC		ROW	
		Baseline	pp global	Baseline	pp global	Baseline	pp global	Baseline	pp global
Million inhabitants									
Improved sanitation	Urban	1443	2038	216	234	613	943	614	860
	Rural	-86	970	-65	-45	-33	654	12	360
	Total	1356	3008	151	189	579	1597	626	1221
Public sewerage	Total	836	1829	164	200	396	880	277	748
N in Mton yr^{-1}									
Nitrogen removal in sewage treatment	Total	2.73	5.53	1.54	2.38	0.79	2.11	0.40	1.05

Note: negative numbers reflect rural-to-urban migration
OECD Environmental Outlook modelling suite, final output from IMAGE cluster

The nitrogen recovery depends on climatic conditions (precipitation, temperature) which influence crop growth and nutrient uptake, ammonia volatilization, denitrification and leaching rates. Furthermore, efficiencies also depend on the mix of crops, since some crops have low nitrogen contents and thus inherently low nitrogen recovery. For other crops such as wetland rice it is difficult to achieve large nitrogen recoveries, due to the specific conditions in inundated rice fields. The potential efficiency is, therefore, not the same for all countries.

Many technical and other options are available for reducing emissions of gaseous reactive nitrogen and nitrate leaching (Van Egmond et al., 2002). However, it is difficult to draw general conclusions with regard to the effectiveness of such options. This is particularly so where decreasing one nitrogen flow in the nitrogen cascade of the agricultural system may cause an unwanted increase on another pathway. In baseline we therefore assumed no technical options to reduce ammonia emission from housing and storage systems, while all manure applied to cropland is assumed to be incorporated in all countries in 2030 and 2050. Since this is already an ambitious task for farmers, in *pp Global* we have therefore not considered extra technical measures for reducing ammonia emissions other than the increased efficiency of fertilizer use.

The surpluses of reactive nitrogen are a good indicator of the inputs from agricultural systems through the soil and groundwater system into the surface water. Considerable decreases of the nitrogen surplus in agricultural systems are projected for OECD countries and elsewhere where there is currently a surplus *(Table 2.16)*. In the 2000-2030-2050 period, the *pp Global* policy package would result in smaller nitrogen surplusses in these countries - relative to the baseline as well as relative to the year 2000 (see *Figure 2.51*). Elsewhere, as part of *pp Global* there is an increase in nitrogen inputs from fertilizers in nitrogen deficit countries in order to reduce problems of land degradation due to nutrient depletion in soils (e.g. Other Latin America and Caribbean, and Africa).

Point sources of nitrogen compounds

As baseline it was assumed that the number of inhabitants with access to improved sanitation grows at the same rate as urbanisation. In poor countries this assumption may be optimistic while in industrialized countries it is a pessimistic view. In contrast, for the policy case *pp Global* we assume that between 2000 and 2030 half of the gap to a 100% access to improved sanitation will be closed.

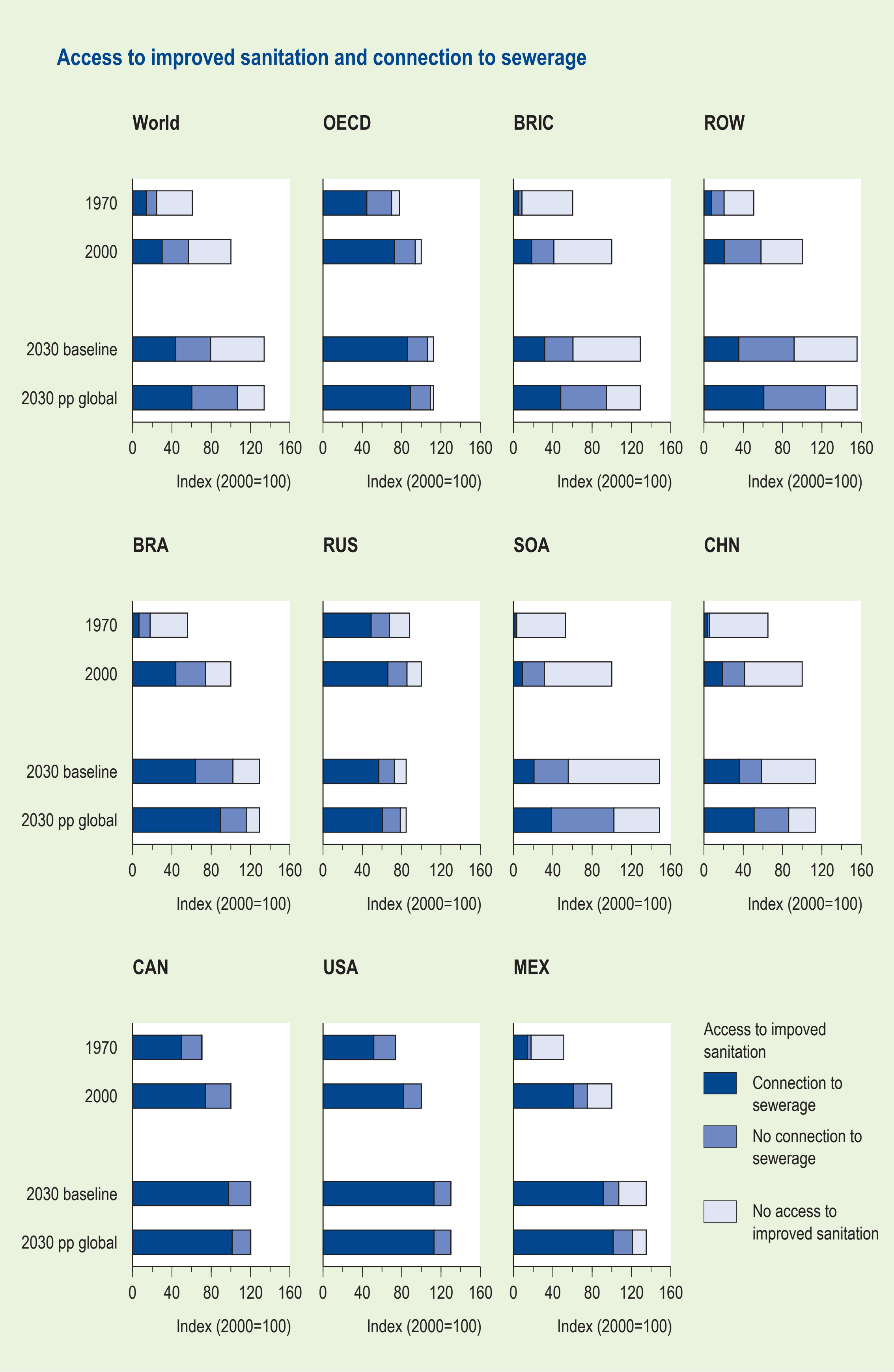


Figure 2.52 Access to improved sanitation and connection to sewerage
OECD Environmental Outlook modelling suite, final output from IMAGE cluster (117x_oec08)

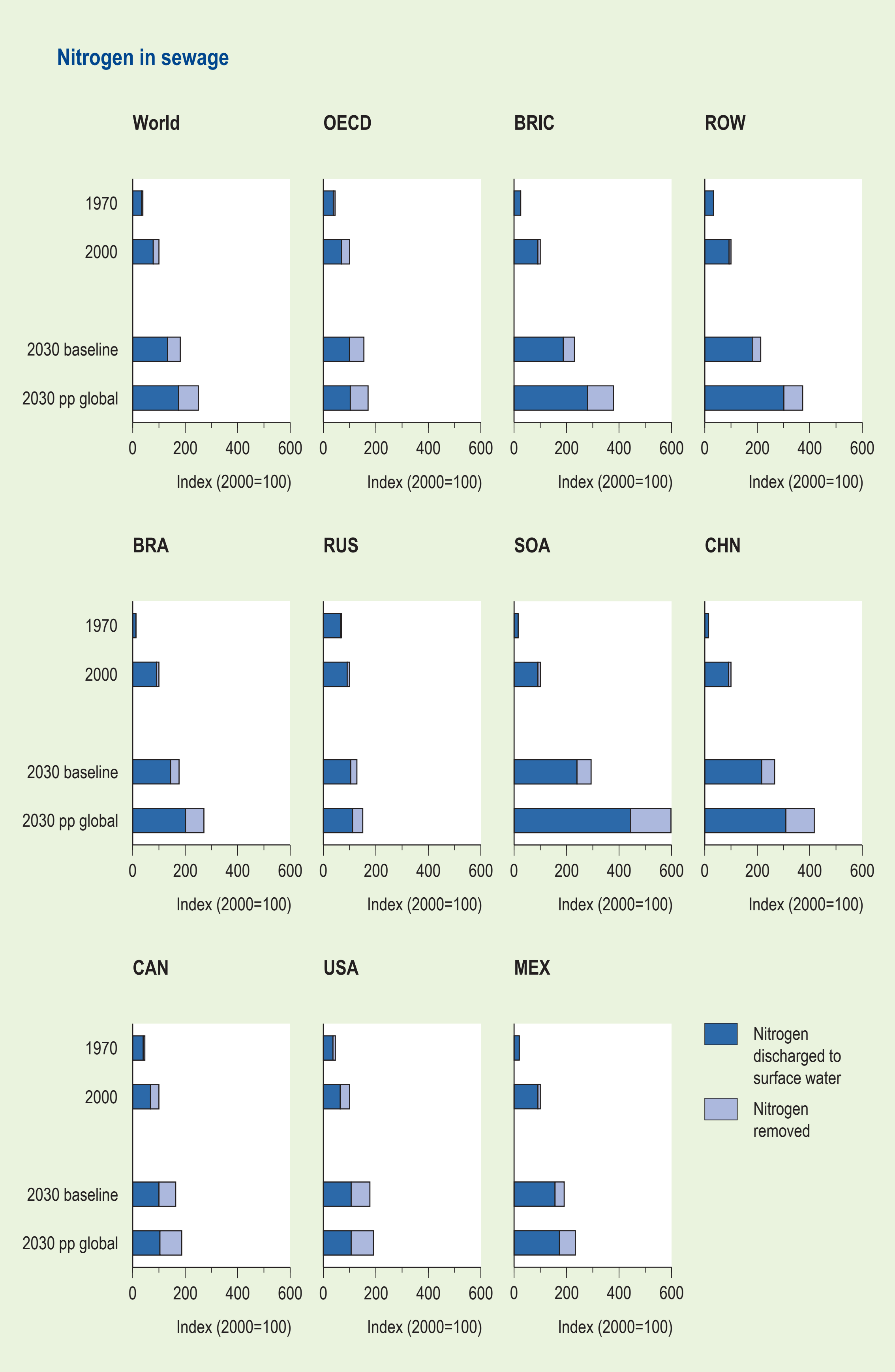


Figure 2.53 Removal of nitrogen from sewage
OECD Environmental Outlook modelling suite, final output from IMAGE cluster (128x_oec08)

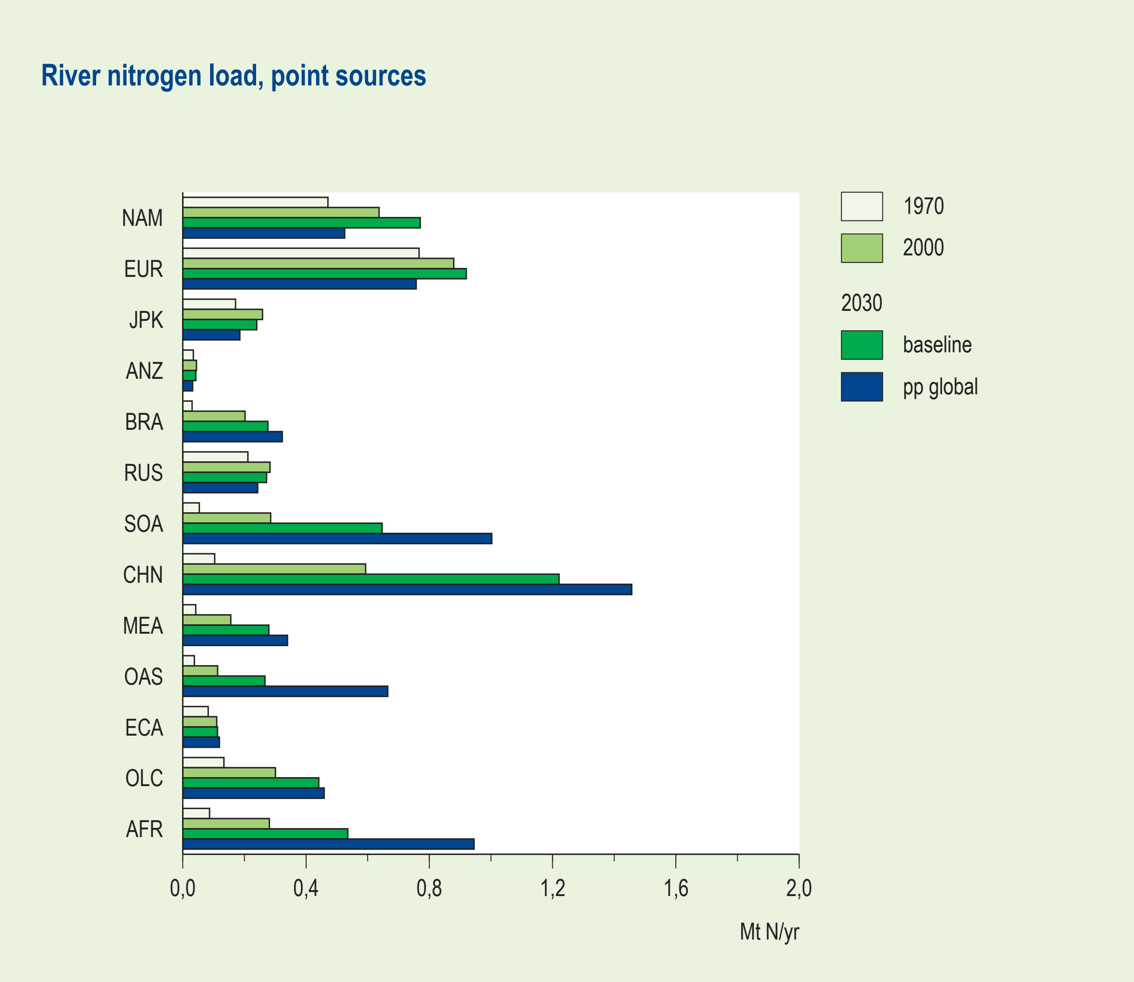


Figure 2.54 River nitrogen load originating from nonpoint sources
Note: load at the mouth of the rivers
OECD Environmental Outlook modelling suite, final output from IMAGE cluster (085g_oec08)

Similarly, for the baseline we assumed that between 2000 and 2030 the urban population served with a public sewer connection remains a constant fraction of the urban population with improved sanitation. This constant fraction is derived from the data for improved sanitation and sewerage connection for 2000. In contrast, in the policy case *pp Global* it is assumed that half of the gap to 100% connection will be closed between 2000 and 2030.

More access to improved sanitation and more connection to sewerage are assumed as ‘autonomous’ developments, reflecting the general political mood of enhanced environmental policies worldwide. The extra effort to improve sanitation and sewerage is not part of the policy package as simulated. Rather, by creating large-scale efficient point sources of nutrients it constitutes a sizeable increase in environmental pressure relative to the baseline. In BRIC countries, the amount reactive nitrogen in sewage is projected to increase from 2.2 to 6.7 million ton nitrogen per year from 2000 to 2030 (see *Table 2.17* and *Figure 2.53*). Under baseline conditions, the increase would be from 2.2 to 4.4 million ton per year. Similarly, in the Rest of the World group the increase in *pp Global* would be from 1.5 to 4.9 million ton per year. By comparison, under baseline conditions, the increase in ROW between 2000 and 2030 would be from 1.5 to 2.9 million ton reactive nitrogen per year.

Table 2.18 River nitrogen export, contribution from various sources

		1970	2000	2030-baseline	2030-pp Global
	Tg N yr^{-1}				
World	Total	40	53	55	53
	of which				
	Point sources	2.2	4.1	6.0	7.0
	Nonpoint sources	37	49	49	46
	of which				
	Nonpoint-Agriculture	9.2	18	24	21
	Nonpoint-Natural	28	31	25	25
OECD	Total	11	13	12	10
	of which				
	Point sources	1.4	1.8	2.0	1.5
	Nonpoint sources	10	11	10	9
	of which				
	Nonpoint-Agriculture	4.0	4.4	4.4	3.6
	Nonpoint-Natural	6.0	6.4	5.7	5.4
BRIC	Total	14	22	24	23
	of which				
	Point sources	0.4	1.4	2.4	3.0
	Nonpoint sources	13	20	22	20
	of which				
	Nonpoint-Agriculture	2.9	8.7	13	11
	Nonpoint-Natural	11	12	9.0	9.2
ROW	Total	15	19	19	19
	of which				
	Point sources	0.4	1.0	1.6	2.5
	Nonpoint sources	14	18	17	17
	of which				
	Nonpoint-Agriculture	2.4	5.0	6.5	7.0
	Nonpoint-Natural	12	13	11	10

Load with nitrogen compounds at the mouth of the rivers
OECD Environmental Outlook modelling suite, final output from IMAGE cluster

In reaction to this, *pp Global* assumedly sees sewage treatment expanded and upgraded. Typically, situations where there was no treatment in 2000, would have mechanical treatment in 2030; where there was only mechanical treatment in 2000 there would be biological treatment; and so forth. This is twice as ambitious as the baseline.

As a result, in OECD countries as a whole the amount of nitrogen compounds discharged with sewage and treatment effluent would slightly decrease between 2000 and 2030, rather than slightly increase (see *Figure 2.54*). In the BRIC countries, developments are much more dynamic. Against the increase in *pp Global* from 2.3 to 6.7 million ton nitrogen per year of nitrogen compounds in sewage stands an increase of nitrogen removal by sewage treatment from 0.2 to 2.3 million ton *(Figure 2.53)*. But even this eleven-fold increase in nitrogen removal does not prevent that in *pp Global* the net emission to surface water increases from 1.9 to 4.3 million tons per year, rather than to 3.4 as under Baseline conditions. In other words, *pp Global* sees a

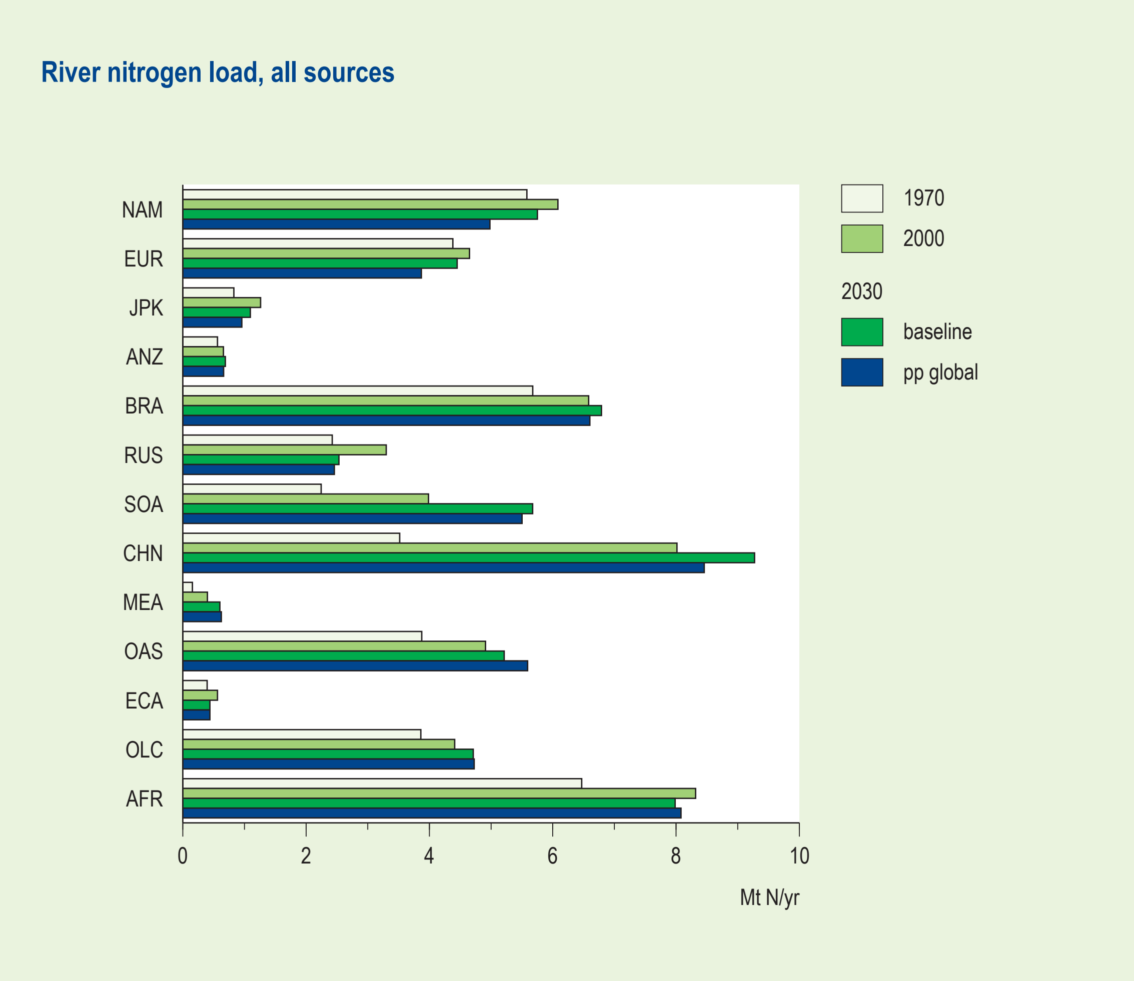


Figure 2.55 River nitrogen load, all sources
OECD Environmental Outlook modelling suite, final output from IMAGE cluster (084g_oec08)

stronger increase of the net emissions of nitrogen compounds from sewage and sewage treatment in BRIC countries, because treatment cannot keep up with sewerage. Within the BRIC group, this development is dominated by China and in particular India.

In the Rest of the World grouping, this development is even more outspoken. Against the increase from 1.5 to 4.9 million tons of nitrogen in sewage stands an increase from 0.11 to 1.2 million tons in removal. The net result is an increase, between 2000 and 2030, in net emissions from these sources to surface water from 1.4 to 3.7 million tons per year, rather than to 2.4 as under Baseline conditions. Here, too, the increase in treatment under *pp Global* can not keep up with the increase in connection to sewerage. Of course, these totals hide important differences between countries, reflecting the inhomogeneity of the Rest of the World group.

Combined load of nitrogen compounds on aquatic systems

On balance, the *pp Global* policy package would result in little change (- 0.3 per cent) to the global total of nitrogen compounds exported by rivers between 2000 and 2030. In contrast, the baseline sees a 3.9 percent increase. However, more important than the global total are the developments per region and these vary *(Figure 2.55)*. The regional developments are so different because of the following. Typically, as a result of the policy package, the contribution of agriculture to the export of nitrogen compounds by rivers to coastal marine systems will increase more slowly than in the baseline. In contrast, in particular in developing countries, the emissions of reactive nitrogen by point sources will increase faster than in the baseline. This is a consequence of the number of people connected to sewerage systems increasing faster than in the baseline, while the expansion and upgrading of sewage treatment is not quite fast enough to compensate for this *(Figure 2.53; Table 2.18).*

Thus, in BRIC and ROW countries the contribution of point sources increases by more than a factor of two in *pp Global* by 2030. In line with increasing production efficiency, due to technology improvement and better management, the contribution of the agricultural nonpoint sources will decrease somewhat in most world regions. The exceptions are mostly located in the Rest of the World group. This is in line with to the nitrogen uptake rates in currently nitrogen deficit countries slowly converging to typical values of OECD. This would be due to efforts in these countries, assumed as part of *pp Global*, to restore soil fertility and develop sustainable agricultural systems.

2.2.6 Policy simulations Biodiversity

Most of the policy packages analysed exert hardly any additional influence on biodiversity, compared to the baseline. This is because the packages do not contain specific policies targeted at reducing biodiversity loss and of the limited changes in indirect drivers. The 450-ppm multigas stabilisation case shows the strongest biodiversity effects, as it contains far reaching measures that affect both land-use change and climate change.

Relevance of policy packages for biodiversity loss

There are no policies included in the policy packages that are specifically targeted at reducing the terrestrial biodiversity loss. They do however contain measures for mitigating environmental change in general, with possible co-benefits for biodiversity as the direct and indirect drivers for biodiversity loss are affected (see MEA conceptual framework - Alcamo et al., 2003 and 2nd Global Biodiversity Outlook – CBD, 2006).

This is especially interesting for climate change mitigation measures, as the ultimate objective of the UNFCCC is to avoid dangerous anthropogenic interference with the climate system. This objective also refers to biodiversity and its functions for mankind. Most of the climate change-measures analysed for this outlook relate to energy savings and replacing fossil energy by more sustainable energy sources. The resulting decrease in greenhouse gas emissions will reduce the global temperature change, which in turn will dampen the predicted global biodiversity loss. Replacing fossil fuels with biomass sources does help to reduce GHG emissions, but will also increase land-use. To avoid carbon losses from forest conversion and still make room for biomass-energy as well as the increased food production, a compact agriculture is envisioned. The most interesting aspect for biodiversity is therefore the balance between avoided climate change and changed land-use for bio-energy crop production. This balance will be analysed in the next paragraph.

Biodiversity policies and instruments

Policies and measures that directly affect terrestrial biodiversity losses have been proposed in several other global assessments, such as the Global Biodiversity Outlook (GBO2; CBD, 2006), the 4th Global Environmental Outlook (GEO4; UNEP, 2007), and MNP's 2nd Sustainability Outlook (MNP, 2007). Further, the biodiversity chapter in the OECD Outlook does include a list of possible instruments, with a focus on market based instruments. Such policies, instruments and measures

Links between biodiversity loss and the direct and indirect drivers of change

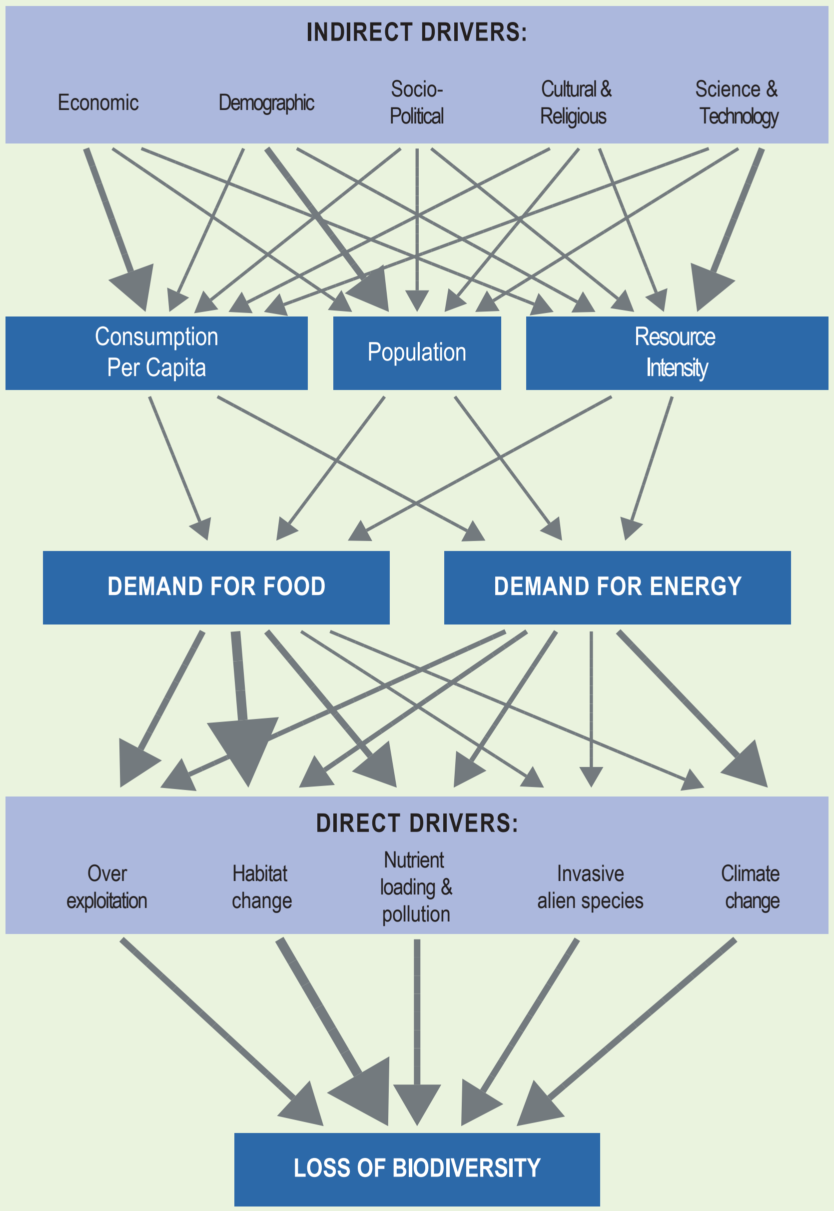


Figure 2.56 Schematic representation of the relation between direct and indirect drivers of change and biodiversity loss

CBD (2006) (078s_oec08)

can be categorized as operating directly (protection, conservation and restoration), indirectly (targeted at consumption and production, technical and demographic developments), or as operating on governance structures (changing international institutions on cooperation, trade and development). None of these strategies to purposely stop or reduce further biodiversity loss have been quantitatively analysed as part of the policy packages for the *OECD Environmental Outlook*. (Some policies which would have an effect on pressures affecting biodiversity --

such as removal of agricultural subsidies -- were analysed in separate simulations using only the ENV-Linkages general equilibrium model. These simulations are reported in the Outlook, towards the end of chapter 14 Agriculture). Examples within each of these categories are mentioned here, without being exhaustive.

The following interventions have a direct effect: increasing the extent of protected areas (including priority setting of which areas to protect; Brooks et al., 2006); establishing connections between isolated nature conservation areas; ending conversion and intensification of natural and semi-natural (low input) grassland habitats; stopping deforestation, ending over-exploitation of natural populations of species; decreasing pollution (nutrients and other agents) and mitigating climate change.

Several policy measures have an indirect influence: changing consumer behaviour (less consumption, dietary shifts, more consumption of eco-labelled products), changing producer behaviour (sustainable production methods), reduced energy and resource use and improved recycling, more efficient production methods (increases in agricultural and forestry productivity under "sustainable" restrictions), include (public) environmental costs in product prices (green pricing), stimulate market mechanisms for biodiversity values (payment for biodiversity and ecosystem services - compensation for biodiversity use).

On the institutional side, several areas can be mentioned: integrate environmental concerns and standards in WTO trade negotiations (non-trade issues), remove 'perverse' subsidies (that stimulate over-production and over-exploitation), integrating biodiversity concerns into sectoral policies (including energy, leading to more coherence between sectoral policies), integral land-use planning at landscape level (balancing and allocating different needs to avoid further conversion), effective law enforcement of national laws already in place.

Not all of the listed instruments can be easily analysed quantitatively with integrated modelling as applied for the outlook. Market instruments will require additional economic modelling of supply shifts, whereas the environmental effects of different ('sustainable') production methods are not yet sufficiently known. Some instruments can already be analysed, including extension of protected areas, dietary shifts and increases in productivity, as has been shown in the scenario study for the GBO2 (CBD & MNP, 2007). In the policy packages of the OECD Outlook, the use of sustainable energy sources has been analysed in the climate change mitigation packages. The effects of a more compact future agriculture have been partially analysed as part of the 450 ppm multigas climate stabilisation case.

Increasing climate change mitigation efforts in the various policy packages

Expanding climate change policy from OECD only to global coverage (from *pp OECD* to *pp Global*) will of course increase its effect, but this applies both on the positive and negative sides of the biodiversity balance (as measured with the biodiversity indicator MSA). In the packages, mainly second generation woody bio-energy is implemented because of their cost-effectiveness for carbon reduction (driven by carbon taxation). The production of woody biomass is stimulated by 2030 from an area of 0.1 million km² in the baseline up to levels of 0.3 million km² for the OECD policy package and 0.4 million km² for both the OECD+BRIC and World policy packages. The temperature change by 2030 due to all mitigation measures is marginally reduced from 1.34°C above pre-industrial levels to 1.30°C for the OECD package and 1.28°C for the other packages.

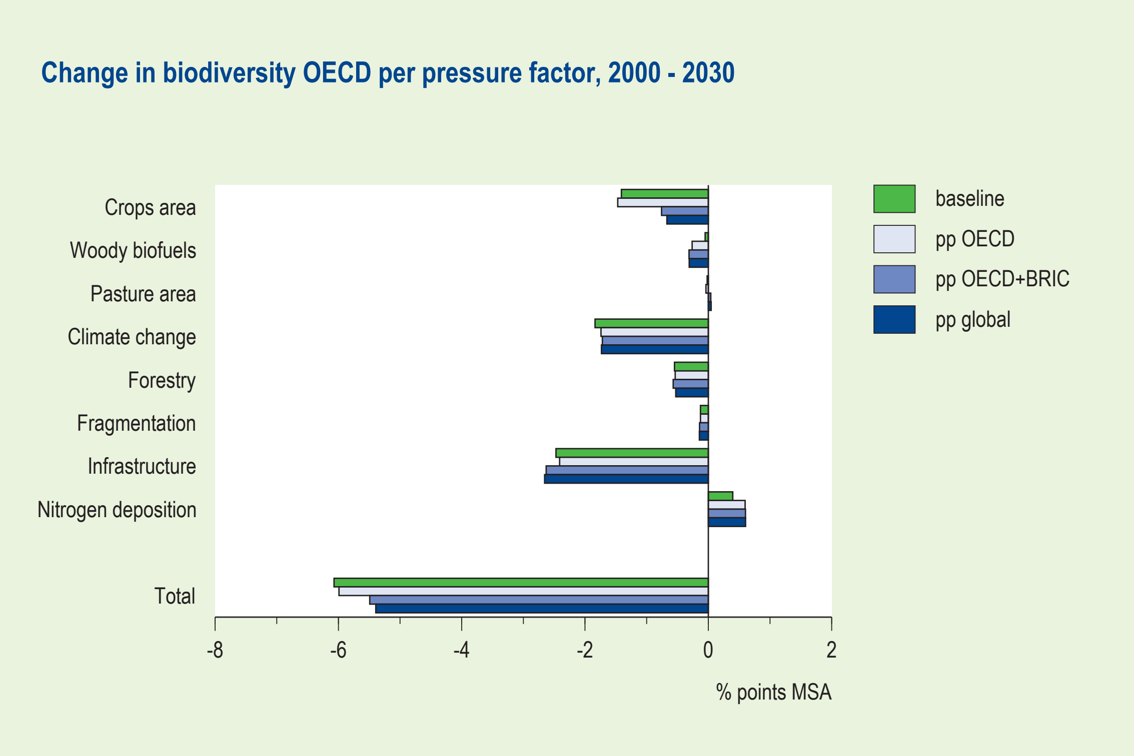


Figure 2.57 Biodiversity loss between 2000 and 2030 in OECD countries
OECD Environmental Outlook modelling suite, final output from IMAGE cluster (GLOBIO) (079g_oec08)

At the global level, the total effect of these packages by 2030 is very small. There is a slightly reduced biodiversity loss because of mitigated climate change effects, but an increased loss from increased land use. Taken together with changes in the other impacts, *pp Global* brings a net global biodiversity gain by 2030 of +0.1 percentage points, which is very small compared to the baseline loss of 7 percentage points. Larger effects can be seen within the OECD regional group (see *Figure 2.57*). The climate change mitigation effects on biodiversity are relatively large here, as the temperate and boreal biomes are more sensitive to climate change. Moreover, the net gain for the OECD group is only partly due to mitigation of climate change, as there is a simultaneous decrease in agricultural land-use and nitrogen deposition. This is the consequence of a shift in the location of agricultural production, mainly to BRIC (*Figure 2.32*; crops area in OECD+BRIC policy package). On balance, all three policy packages result in a net biodiversity loss for the OECD group *(Figure 2.57)*. This shows that especially interaction with agricultural developments determines global land-use, which is widely seen as the most important pressure for biodiversity (Sala et al., 2000; CBD, 2006; CBD & MNP, 2007). This interaction is crucial for the net effect of combined policy packages.

The effects of climate change mitigation will get stronger with time, due to several slow system changes (slow measure implementation and inertia in temperature responses). By 2050 larger effects can be seen. The temperature change by 2050 is somewhat reduced from 1.9°C above pre-industrial levels (baseline) to 1.7 - 1.8°C for the policy packages. The production of woody biofuels of 0.5 million km² (baseline) is stimulated up to a level of 1.5 million km² in *pp OECD* and 2.0 – 2.1 million km² to in *pp OECD+BRIC* and in *pp global*.

The smaller biodiversity loss in 2050 due to increasing efforts in climate change mitigation can be clearly seen (largest areas in *Figure 2.58*). However, the balance between climate change

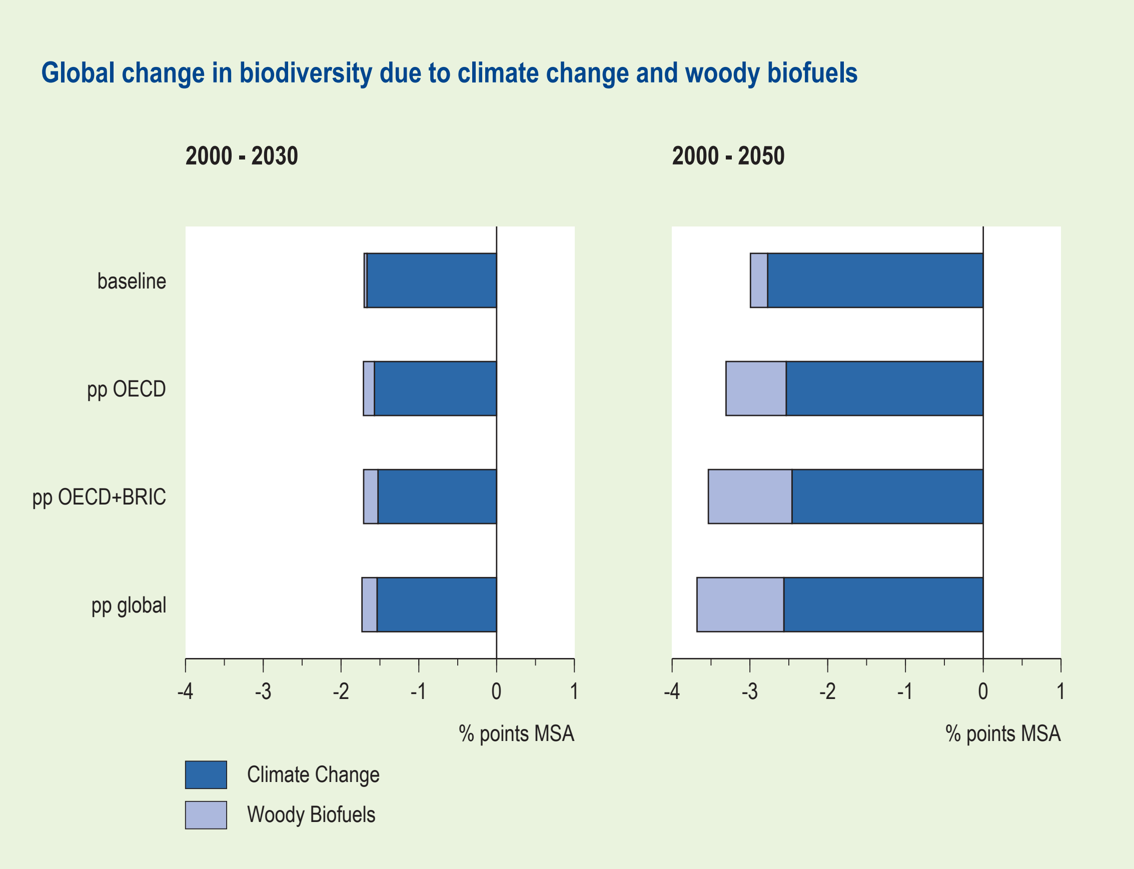


Figure 2.58 Biodiversity change since 2000 due to area use for the production of woody biofuels and to climate change
OECD Environmental Outlook modelling suite, final output from IMAGE cluster (GLOBIO) (142x_oec08)

mitigation and increased land-use for biofuel production is negative for all packages, and gets worse with increasing global implementation. Moreover, the presented effects are the result of *all mitigation* measures and not of biofuel production alone.

This analysis shows that stimulating biofuel production does not deliver significant co-benefits for long-term biodiversity goals, and is a questionable strategy from a policy coherence point of view. Moreover so when one realizes that converted natural habitats (used for production purposes) will only recover slowly to their original natural state after abandonment (see methodology on Biodiversity). Of course, uncertainties play a large role in long-term policy simulations, specifically the expected climate change and its modelled future effects. The projected land-use dynamics (use of pristine versus abandoned or degraded agricultural areas) are highly relevant, and can be analysed using policy cases that comprise alternative land use developments. From the set policy cases developed for the *OECD Environmental Outlook* in particular the 450 ppm multigas climate stabilisation case can be used for comparison.

Biodiversity impacts of the 450 multigas climate stabilisation case

An ambitious climate change mitigation package is included in the Outlook that is specifically designed to stabilize the atmospheric concentration at 450 ppm carbon dioxide equivalents by 2100 (after Van Vuuren et al., 2007). This target can only be attained if deforestation is slowed down, as deforestation results in large (soil) carbon emissions. Therefore, land-use changes for bio-energy production and other increases of agricultural production have to be accommodated

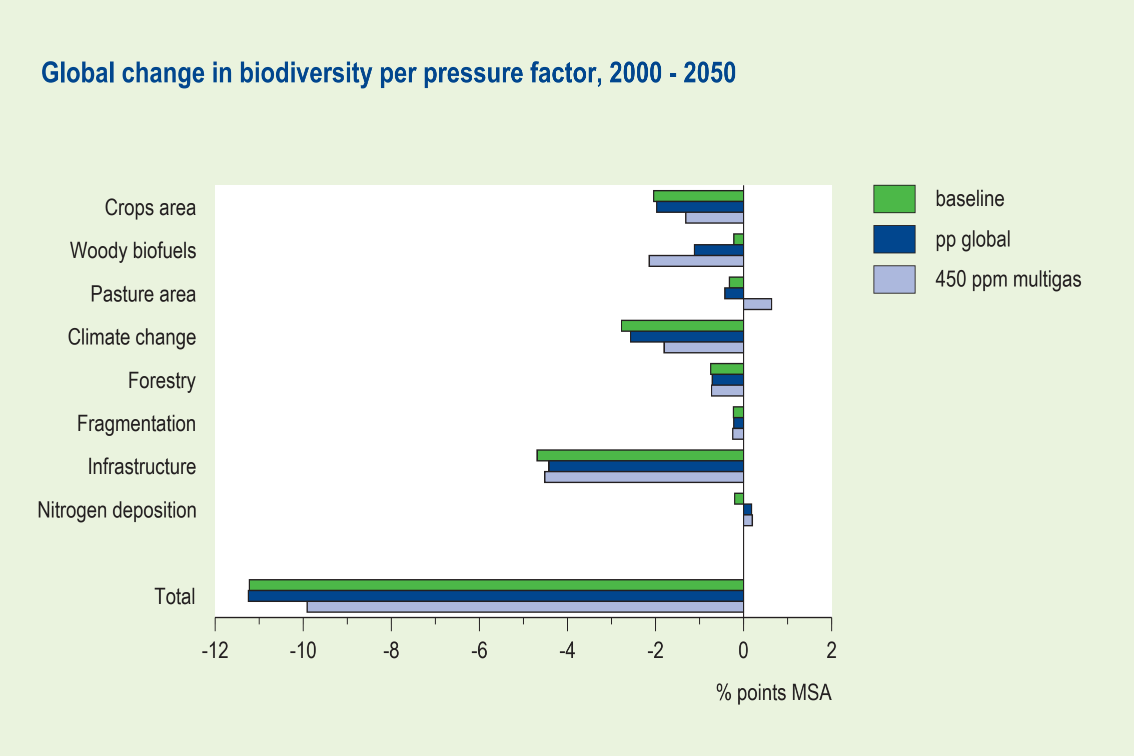


Figure 2.59 Biodiversity loss between 2000 and 2050: baseline, global policy package and 450 ppm multigas stabilisation

OECD Environmental Outlook modelling suite, final output from IMAGE cluster (GLOBIO) (083g_oec08)

within the present total agricultural area ('compact agriculture'). This requires a strong increase in agricultural productivity. The 450-ppm policy package does not describe particular policy instruments to effectuate this global land-use development.

Comparing the 450-ppm case with pp Global shows that the 450-ppm case has a far larger influence on biodiversity (see *Figure 2.59*). By 2050, we find a large-scale production of woody bio-energy crops on 4 million km², and the temperature change is 1.4°C. The required area for crop production and especially for pasture is significantly reduced, and the total net global effect is positive for biodiversity. The baseline biodiversity loss of 11 percentage points is reduced with almost 1.5 percentage points. This is a substantial amount, and can be interpreted as the conservation of the total biodiversity in an area the size of for instance Indonesia.

Conclusions regarding biodiversity

- The biodiversity loss in the projected OECD baseline, according to the Mean Species Abundance (MSA) indicator, is 7 percentage points between 2000 and 2030. Given an expanding global population and a considerable growth in income and consequent growth and change in food demand, further biodiversity loss seems inevitable in a globalizing and developing world.
- Expansion and shifts of agricultural land use; infrastructural developments; and climate change are the most important causes for further decline.
- The various policy packages analysed for the outlook do not include measures that are specifically targeted at reducing the rate of biodiversity loss. Thus, they have a small effect (at the most +0.1 MSA percentage points by 2030 in the case of *pp global*).

- Effectively mitigating climate change does reduce the climate change effects on biodiversity, but this positive effect is offset by increased land-use for bio-energy production. The balance is not beneficial for biodiversity. If follows that only by combining climate change mitigation with increased land-use efficiency (compact agriculture) the negative effects on biodiversity can be counterbalanced.
- Regional improvements are possible, for instance for OECD countries. However, this improvement is accompanied by a shift of agricultural production to other parts of the world. For the world as a whole, biodiversity loss continues at the same rate. The biodiversity increase in OECD countries in abandoned agricultural lands is limited by 2030, as recovery will only take place after a relatively long period of restoration.
- Coherence in policy goals and policy measures deserves more attention, as negative biodiversity effects are mostly side-effects or trade-offs of other policy goals.

2.2.7 Macro-economic impacts of environmental policy efforts

The impact of expenditures for the policy packages on projected GDP per capita is shown in *Figure 1.5*. The overall pattern is that instead of an accumulated increase, between 2005 and 2050, under baseline conditions from 6800 to 21400 US $ per capita the increase would be to 21200 $ per capita under the conditions of *pp Global*. This 1 percent loss of global GDP per capita is lower than Jorgenson and Wilcoxen’s (1990) estimated loss from environmental policy in the US of 1.6 percent, but the policies in *pp Global* are arguably less ambitious and better implemented (by assumption) than environmental regulation in the US during the 1970’s and 80’s.

These calculations for the various policy packages were performed with the ENV-Linkages general equilibrium model. They considered the cost of abatement of energy-related emissions of carbon dioxide and all man-made emissions of sulphur dioxide and nitrogen oxides. They also reflect the impact of changes in agricultural production subsidies and tariffs. The impact of carbon pricing was modelled as a consumer price change, in step with the annual increase in carbon price.

Not included in these calculations, but included in the analysis of environmental impacts are abatement of emissions of carbon dioxide from other sources, as well as greenhouse gases. In addition, measures to decrease nutrient loading of aquatic ecosystems, such as enhancing sewage treatment, are included in the environmental results of the policy packages but not reflected in the estimation of effect on GDP. But arguably, the factors considered make up the lion’s share of cost of the policy packages.

Part 3: Methodology

3.1 Model descriptions

Part 3 of this report contains the technical background for the assessments for the *OECD Environmental Outlook to 2030*. It describes the models used and their interconnections, and gives an overview of assumptions used. An overall assessment of the uncertainty in the outcomes is provided in section 3.2.

The scenarios and projections for the *OECD Environmental Outlook* are the result of an integrated analysis of the economy-environment interface, in which, apart from economic factors influencing the environment, ample attention is given to physical factors related with the energy and agriculture sectors *(Figure 3.1)*. For the analysis a combination of models was used, connected through harmonized dataflows (see *Figure 3.2*). Data on economic activities steer the IMAGE and related models. In addition to the simple one-dimensional relation between economic driving forces and changes in the environment, the physical flows of energy and the availability of land are important drivers and sometimes limiting factors to developments in the environment. In this modelling exercise the last have been taken explicitly into account and these two groups of variables have a central position in the modelling framework: next to the link from the economic modelling in ENV-Linkages to IMAGE, energy use is modelled in detail in TIMER, while land use factors are processed through LEITAP. This section provides a summary of the model

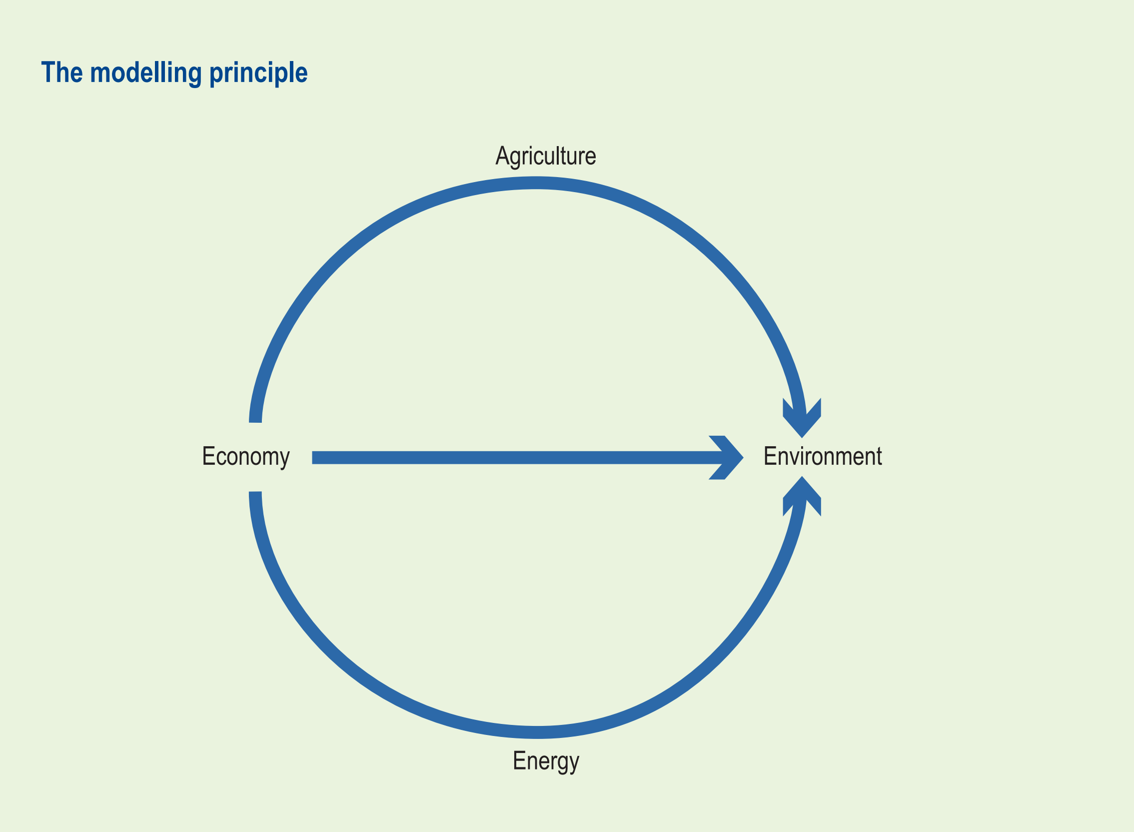


Figure 3.1 The modelling principle applied in the OECD Environmental Outlook
(163s_oec08)

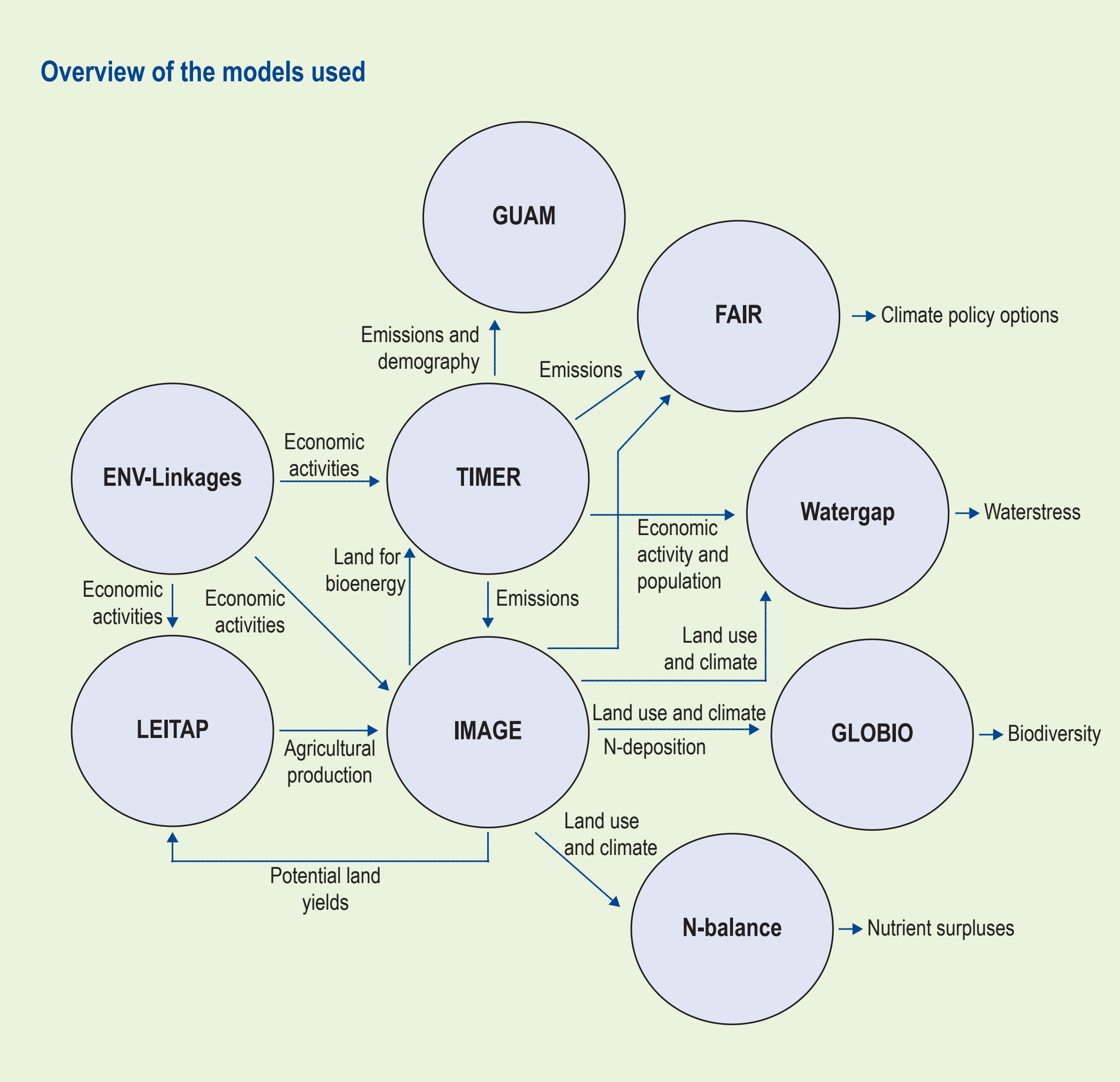


Figure 3.2 Overview of the models used
(087s_oec08)

descriptions to enhance the understanding of the scope and limitations of the modelling exercise. Detailed model descriptions can be found in the referred literature.

3.1.1 ENV-Linkages

The ENV-Linkages model continues an OECD tradition of quantitative simulation analysis. For environmental policy the work with the GREEN model (e.g. Burniaux, et al., 1992) established a line of analyses that has continued to the present. GREEN was originally used for studying climate change policy, and culminated in Burniaux (2002). It was developed into the Linkages model, and subsequently became the JOBS modelling platform. This was used to help underpin the *OECD Environmental Outlook* to 2020 (OECD, 2001). Subsequent versions of the Linkages model are also in use at the World Bank for research into global economic development issues. Further developments have been incorporated, and the ENV-Linkages model is now in use in the OECD's Environment Directorate.

The ENV-Linkages model is a global economic model built primarily on a database of national economies. The model represents the world economy in 34 countries/regions, each with 26 economic sectors. Each of the 34 regions is underpinned by an economic input-output table (usually published by a national statistical agency). These tables identify all the inputs into an industry and identify all the industries that buy specific products. Some industries explicitly use land, while others, such as fisheries and forestry, also have a 'natural resource' input — e.g. fish and trees.

Since it is an economic model, ENV-Linkages does not represent physical processes. Instead, physical processes are summarised from empirically derived relationships between inputs and outputs. That is, industries (rather than individual firms) are observed over time to be able to vary the use of inputs such as labour, capital, energy and materials. When prices for the inputs or outputs change, individual firms adjust, but the industry as a whole adjusts more strongly by favouring the firms that gain advantage as a result of the price changes. In the real world, even firms that produce the same product are very heterogeneous. Such responsiveness can be represented mathematically and tested for robustness (see e.g. Hertel et al., 2003; Valenzuela et al., 2007). Inputs and outputs are measured in the constant currency of a base year — inflation is thus removed from the value of output. Moreover, output can be calculated in either the real price of a given year, or the initial price of the base year. Calculating output in base year price gives a 'volume' measure that would closely parallel physical quantities in that year. If the composition of output in any given sector does not change much over time, then the change in the volume of output is equal to the change in the physical quantities.

Income generated by economic activity ultimately reflects demand for goods and services by final consumers. ENV-Linkages represents consumers as being largely similar at a very aggregated level of consumption. As such, the model postulates a representative consumer who allocates disposable income according to preferences: among consumer goods and savings. More formally, household consumption demand is the result of static maximisation behaviour which is formally implemented as an 'Extended Linear Expenditure System'. A representative consumer in each region — who takes prices as given — optimally allocates disposable income among the full set of consumption commodities and savings. Saving is considered as a standard good and therefore does not rely on a forward-looking behaviour by the consumer.

In the model, the technological representation of production is accomplished using a nested sequence of constant elasticity of substitution (CES) functions. Four factors are specified: land, labour, capital and a sector-specific natural resource. Energy is an input that is combined with capital. There is a parameterisation of the substitutability between inputs, so the intensity of using capital, energy, labour and land changes when their relative price changes: as labour becomes more expensive, less of it is used relative to capital, energy and land.

All production is assumed to operate under cost minimisation, in well-functioning markets and with constant returns to scale technology. Changes to these assumptions are possible, but were not used for the *OECD Environmental Outlook*. The production technology is specified as nested CES production functions in a branching hierarchy. The top node thus represents an output, using intermediate goods combined with value-added. This structure is replicated for each output, where the parameterisation of the CES functions may differ across sectors. *Figure 3.3* illustrates this hierarchy.

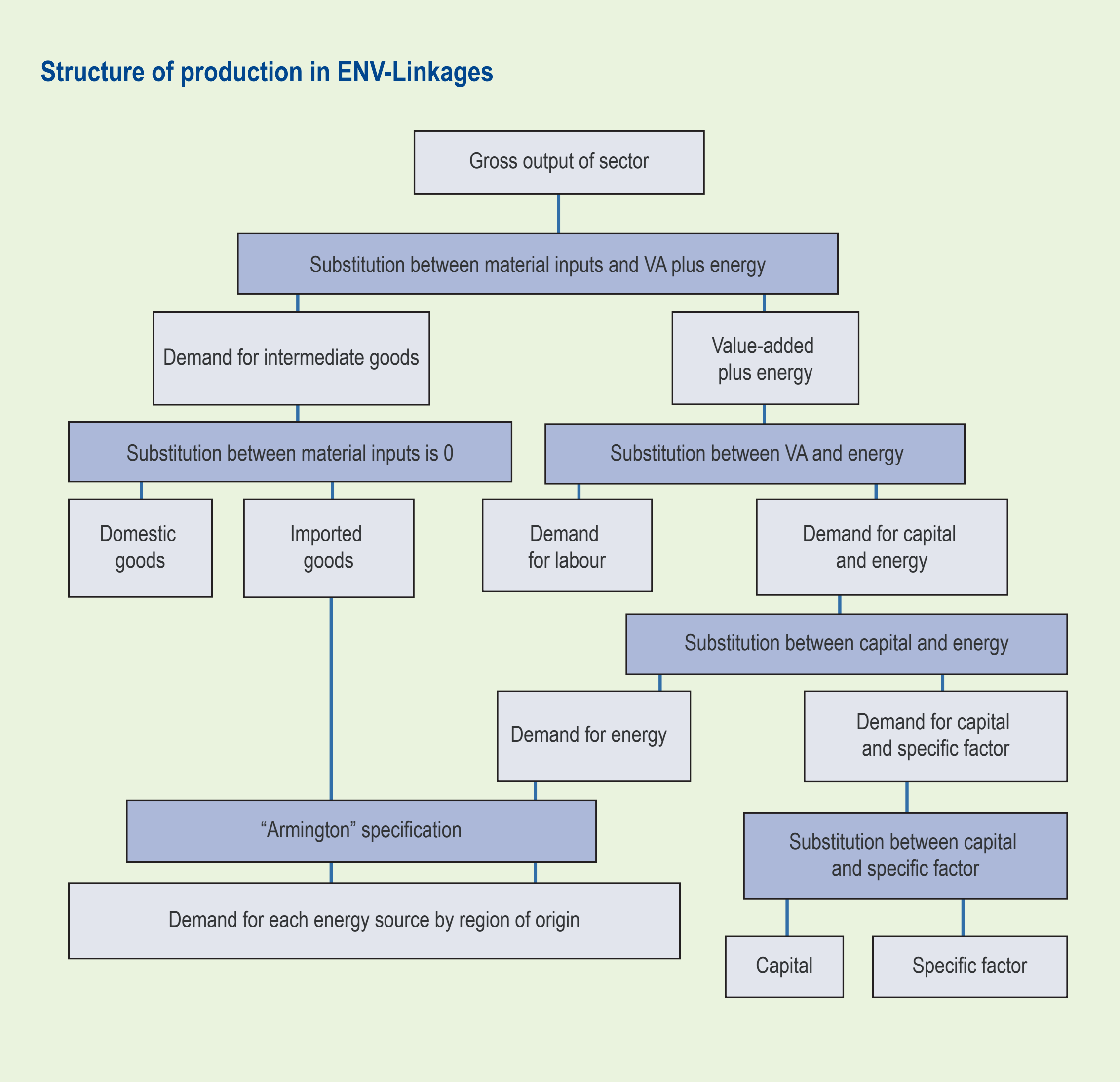


Figure 3.3 Structure of production in ENV-Linkages
(160s_oec08)

As is illustrated, the valued-added bundle is itself specified as a CES combination of labour and a capital/energy input. In turn, the capital/energy bundle is a CES combination of energy and a broad concept of capital. The definition of capital is broad because in some sectors capital will have been combined with a resource input (e.g. land, fish or trees) before it is combined with energy. In the 'crop' and 'livestock' sectors, there are different structures that also incorporate fertiliser and feed. In the 'crop' production sector, the broad capital is itself a CES combination of fertiliser and another bundle of capital-land-energy. The intention of this specification is to reflect the possibility of substitution between extensive and intensive agriculture. In the 'livestock' sectors, substitution possibilities are between bundles of land and feed on the one hand, and of a capital-energy-labour bundle on the other hand. This reflects a similar choice between intensive and extensive livestock production. Production in other sectors is characterised by substitution between labour and a bundle of capital-energy (and possibly a sector-specific factor for primary resources).

Total output for a sector is actually the sum of two different production streams: resulting from the distinction between production with an 'old' capital vintage, and production with a 'new' capital vintage. The substitution possibilities among factors are assumed to be higher with new capital than with old capital. In other words, technologies have putty/semi-putty specifications. This will imply longer adjustment of quantities to prices changes. Capital accumulation is modelled as in traditional Solow/Swan growth models.

This version of the model does not include an investment schedule that relates investment to interest rates. Investment is equal to domestic saving in each period; i.e. investment is equal to the sum of government savings, consumer savings and net capital flows from abroad induced by trade imbalances. The differences in sectoral rates of return determine the allocation of investment. The model features two vintages of capital, but investment adds only to new, more flexible capital. Sectors with higher investment, therefore, are more able to adapt to changes than are sectors with low levels of investment. Indeed, declining sectors whose old capital is less productive begin to sell capital to other firms (which they can use after incurring some cost for modifications).

A full range of market policy instruments (tax, etc.) is also specified. The government in each region collects various kinds of taxes in order to finance a given sequence of government expenditures. For simplicity it is assumed in the Baseline that these expenditures grow at the same rate as the real GDP of the previous period. Since predicting corrective government policy is not an easy task, the real government deficit is exogenous. Closure of the model to ensure reasonable long-term properties therefore implies that some fiscal instrument is endogenous — in order to anchor the given government deficit. The fiscal closure rule in ENV-Linkages is that the marginal income tax rate adjusts to offset changes that may arise in government expenditures, or as a result of other taxes. For example, a reduction or elimination of tariff rates is compensated for by an increase in household direct taxation, other things being equal. If change in the long-term deficit is desired as a result of the tariff change, the deficit can be changed exogenously by the amount of the decreased revenues — so there is no offsetting change in income taxes.

World trade in ENV-Linkages is based on a set of regional bilateral flows for the model's 24 sectors. The basic assumption is that imports originating in different regions are imperfect substitutes; i.e. different countries may produce similar goods, but they are never identical (though some goods, such as crude oil, are very similar). At a 24-sector level, this assumption is tenable since each sector will be composed of different goods and services in each country. Therefore in each region, total import demand for each good is allocated across trading partners according to the relationship between their export prices. This specification of imports — commonly referred to as the Armington specification — formally implies that each region faces a reduction in demand for its exports if domestic prices increase. The Armington specification is implemented using two CES nests. At the top nest, domestic agents choose the optimal combination of the domestic good and an aggregate import good consistent with the agent's preference function. At the second nest, agents optimally allocate demand for the aggregate import good across the range of trading partners. The bilateral supply of exports is specified in parallel using a nesting of constant-elasticity-of-transformation (CET) functions. At the top nest, domestic suppliers optimally allocate aggregate supply across the domestic market and the aggregate export market. At the second nest, aggregate export supply is optimally allocated across each trading region as a function of relative prices.

Each region runs a current-account surplus (or deficit), which is fixed (in terms of the model numéraire basket of goods). Closure on the international side of each economy is achieved by having a counterpart of these imbalances result in a net outflow (or inflow) of capital, which is subtracted from (added to) the domestic flow of saving. In each period, the model equates gross investment to net saving (which is equal to the sum of saving by households, the net budget position of the government and foreign capital inflows). Given the rules for government and international closure, this final particular closure rule implies that investment is driven by saving.

Trade measures are fully bilateral and can include both export and import taxes/subsidies. Trade and transport margins can also be included; in which case world prices would reflect the difference between free on board (FOB) and cartage, insurance and freight (CIF) pricing.

Of the GDP projections produced with ENV-Linkages, IMAGE and related models used 'real GDP' as input in estimations of – for example - energy production and use. For these estimations, IMAGE and related models are calibrated to GDP on the basis of purchasing power parity (ppp). In view of the explanation given in Bagnoli, Chateau and Sahin (2006), changes in 'real GDP' as projected by ENV-Linkages were treated as changes in ppp-based GDP.

A technical description is available for the original World Bank Linkages model in van der Mensbrugghe (2003).

3.1.2 LEITAP

Standard GTAP model

The agro-economic analysis was done with an extended version of the general equilibrium model of GTAP (Hertel, 1997), which is called LEI-TAP here, named after the LEI Agriculture Economics Institute that developed and applies it. The GTAP model is a multi-regional, static, applied general equilibrium model based on neo-classical micro-economic theory. The standard model is characterized by an input-output structure (based on regional input-output tables) that explicitly links industries in a value added chain from primary goods, over continuously higher stages of intermediate processing, to the final assembling of goods and services for consumption. In the model, a representative producer for each sector of a country or region makes production decisions to maximize a profit function by choosing inputs of labour, capital, and intermediates to produce a single sectoral output. Perfect competition is assumed in all sectors. In the case of crop and livestock production, farmers also make decisions on land allocation. Intermediate inputs are produced domestically or imported, while primary factors cannot move across regions. Markets are typically assumed to be competitive. When making production decisions, farmers and firms treat prices for output and input as given. Primary production factors land, labour and capital are fully employed within each economy, and hence returns to land and capital are endogenously determined at the equilibrium, i.e., the aggregate supply of each factor equals its demand. Each region is equipped with one regional household which distributes income across savings and consumption expenditures according to a fixed budget share. Consumption expenditures are allocated across commodities according to a non-homothetic CDE expenditure function.

In contrast to most Partial Equilibrium models, GTAP assumes that land is heterogeneous. The heterogeneity is introduced by specifying a transformation function, which takes total land as an input and distributes it among various sectors in response to relative rental rates. A Constant Elasticity of Transformation (CET) function is used, where the elasticity of transformation is a synthetic measure of land heterogeneity. Prices on goods and factors adjust until all markets are simultaneously in (general) equilibrium. This means that model is solved for equilibria in which all markets clear. While changes in gross trade flows are modelled, changes in net international capital flows are not. Rather the capital market closure involves fixed net capital inflows and outflows. To summarize, factor markets are competitive, and labour, capital and land are mobile between sectors but not between regions.

GTAP assumes that products are differentiated by country. This is modelled using the Armington approach, which assumes that imports and domestic commodities are imperfect substitutes in demand and uses the Constant Elasticity of Substitution (CES) function to describe the substitution possibilities between these goods. In this way the bilateral commodity trade is modelled. Taxes and other policy measures are included in the theory of the model at several levels. All policy instruments are represented as ad valorem tax equivalents. These create wedges between the undistorted prices and the policy-inclusive prices.

LEITAP extensions to the standard GTAP model

The base version of GTAP represents land allocation in a CET structure (see upper left part of *Figure 3.4*). It was assumed that the various types of land use are imperfectly substitutable, but the substitutability is equal among all land use types. In LEITAP the land use allocation structure has been extended by taking into account that the degree of substitutability of types of land differs between types (Huang et al., 2004), using the more detailed OECD's Policy Evaluation Model (OECD, 2003) structure. The last distinguishes different types of land in a nested 3-level CET structure. The model covers several types of land use more or less suited to various crops (i.e. cereal grains, oilseeds, sugar cane/sugar beet and other agricultural uses). The lower nest assumes a constant elasticity of transformation between 'vegetables, fruit and nuts', 'other crops' (e.g. rice, plant based fibres), the group of 'Field Crops and Pastures' and non-agricultural land. The transformation is governed by the elasticity of transformation $\sigma 1$. The 'Field Crops and Pastures' group is itself a CET aggregate of Cattle and Raw Milk (both Pasture), 'Sugarcane and Beet', and the group of 'Cereal, Oilseed and Protein crops'. Here the elasticity of transformation is $\sigma 2$. Finally, the transformation of land within the upper nest, the Wheat, Coarse Grains and Oilseeds group, is modeled with an elasticity $\sigma 3$. In this way the degree of substitutability of types of land can be varied between the nests. It captures to some extent agronomic features. In general it is assumed that $\sigma 3 > \sigma 2 > \sigma 1$. This means that it is easier to change the allocation of land within the Wheat, Coarse Grains and Oilseeds group, while it is more difficult to move land out of Wheat, Coarse Grains and Oilseeds production into, say, vegetables. The values of the elasticities are taken from OECD, 2003.

Moreover, in the standard GTAP model the total land supply is exogenous. In LEITAP the total agricultural land supply is modelled using a land supply curve which specifies the relation between land supply and a land rental rate in each region. Land supply to agriculture can be adjusted as a result of idling of agricultural land, conversion of non-agricultural land to agriculture, conversion of agricultural land to urban use and agricultural land abandonment. The concept of a land supply curve has been based on Abler (2003).

The general idea underlying the land supply curve specification is that the most productive land is first taken into production. However, the potential for bringing additional land into agriculture is limited. If the gap between potentially available agricultural land and land used in the agricultural sector is large, the increase in demand for agricultural land will lead to land conversion to agricultural land and a modest increase in rental rates to compensate for the cost to take this land into production. Such a situation can be depicted by points situated on the left flat part of the land supply curve (see *Figure 3.5*).

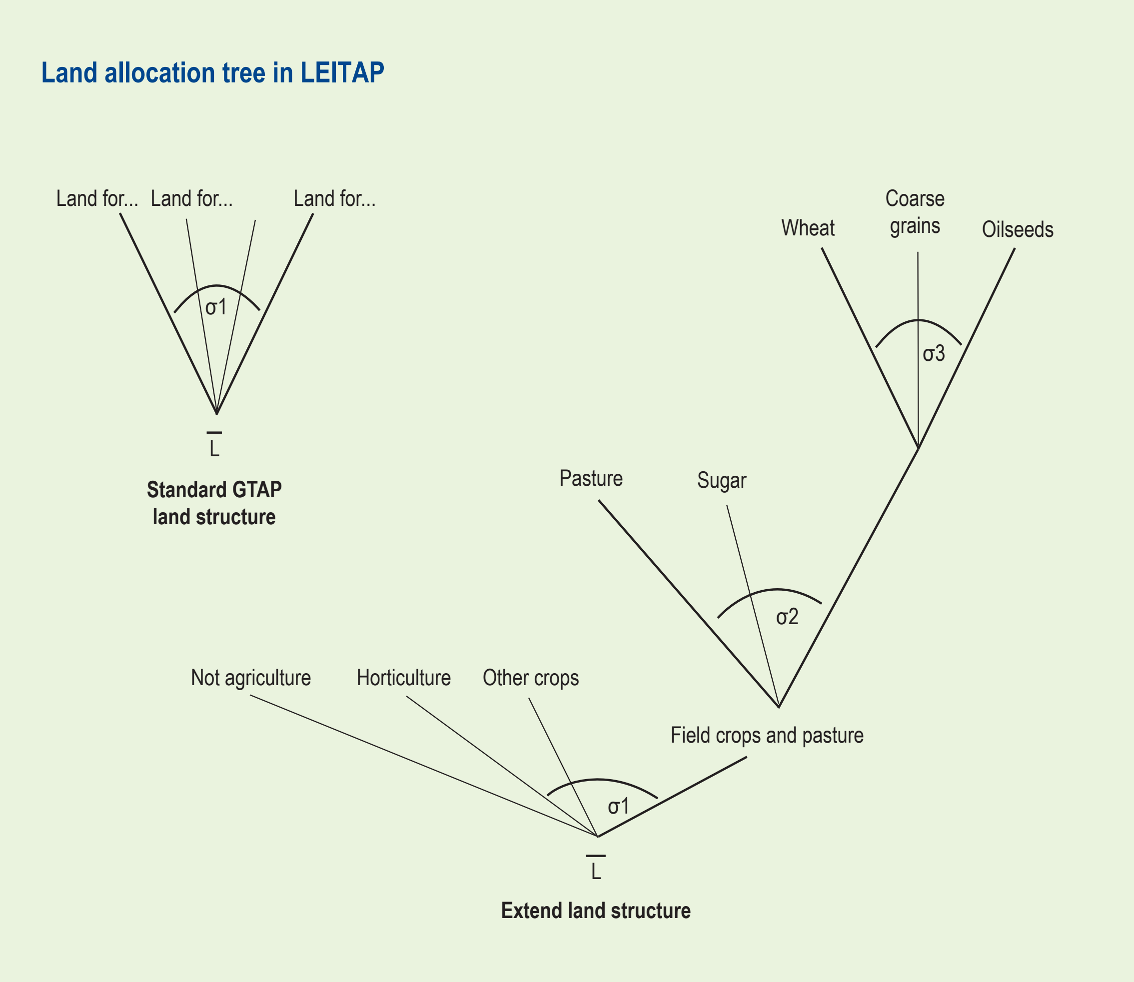


Figure 3.4 Land allocation tree within LEITAP
(088s_oec08)

However, when almost all agricultural land is in use, an increase in demand for agricultural land will mainly lead to high increase of the land rental rates (land becomes scarce, see right part of the curves in *Figure 3.5*). In this case land conversion is difficult to achieve and therefore the elasticity of land supply in respect to land rental rates is low as well. This situation is described by points situated on the right steep part of the land supply curve.

The land supply curve is derived and estimated using biophysical data from the IMAGE modelling framework (Alcamo et al., 1998, see section 3.1.5). IMAGE takes into account marginal lands and changes in the potential land productivity due to changes in land use and climate change. In the IMAGE model, climate and soil conditions determine the crop productivity on a grid scale of 0.5 by 0.5 degrees, allowing the feedback of heterogeneous information of land productivity to the economic framework.

Land supply curves have been derived by using the IMAGE land productivity curve describing the potential crop productivity (for an average crop) as a function of the accumulated land area. This productivity curve can be translated into land supply curve under the assumption that the land price is a function of the inverse of the land productivity. It can be described by the following mathematical equation:

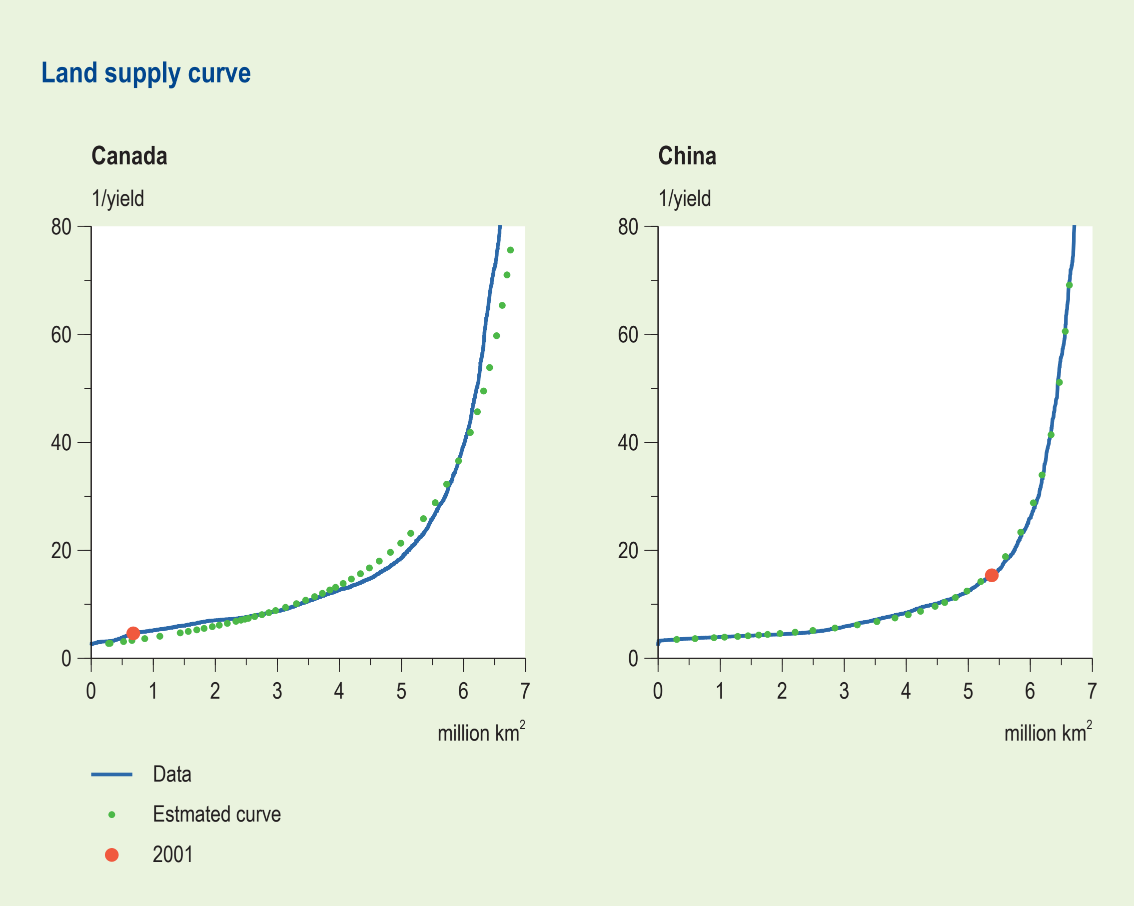


Figure 3.5 Land supply curve for Canada and China
(155x_oec08)

$$\text{Land supply} = a - b/f(1/y) \qquad [1]$$

where, “a” (>0) is an asymptote interpreted as the maximal potentially available agricultural land and “b” is a positive parameter and f(1/y) is a non-increasing function of the inverse of land productivity y.

Asymptote “a” of the land supply curve is provided by IMAGE and equal to available land per world region minus urban area, protected bio-reserves, ice and tundra and so on. When the potential land productivity is close to the observed land productivity, the asymptote (simultaneously with other parameters of the land supply curve) is estimated by using only observations concerning the accumulated land area lower then the currently observed agricultural area. This method was used the EU15 countries rest of the Western Europe and Japan. Land supply curves have been estimated for 25 regions and were implemented into GTAP model.

Land supply functions differ per region *(Figure 3.5)*. For instance, the current position of Canada on their land supply curve indicates that the agricultural land in Canada can still be expanded without a high increase in the rental land price in this region. The opposite situation is observed for China or EU15. Small expansion in the agricultural land in China or EU15 will lead to a high increase in real land prices, therefore stimulating intensification processes in agricultural practices.

Factor market segmentation

If labour were perfectly mobile across domestic sectors, we would observe equalized wages throughout the economy for workers with comparable endowments. This is clearly not supported by evidence. Wage differentials between agriculture and non-agriculture can be sustained in many countries (especially developing countries) through limited off-farm labour migration (De Janvry et al., 1991). Returns to assets invested in agriculture also tend to diverge from returns of investment in other activities.

To capture these stylized facts, segmented factor markets for labour and capital have been incorporated by specifying a CET structure that transforms agricultural labour (and capital) into non-agricultural labour (and capital) (Hertel and Keening, 2003). This specification has the advantage that it can be calibrated to available estimates of agricultural labour supply response. In order to have separate market clearing conditions for agriculture and non-agriculture, we need to segment these factor markets, with a finite elasticity of transformation. We also have separate market prices for each of these sets of endowments. The economy-wide endowment of labour (and capital) remains fixed, so that any increase in supply of labour (capital) to manufacturing labour (capital) has to be withdrawn from agriculture, and the economy-wide resources constraint remains satisfied. The elasticities of transformation can be calibrated to fit estimates of the elasticity of labour supply from OECD (2003).

Agricultural production quotas

An output quota places a restriction on the volume of production. If such a supply restriction is binding, it implies that consumers will pay a higher price than they would pay in case of an unrestricted interplay of demand and supply. A wedge is created between the prices that consumers pay and the marginal cost for the producer. The difference between the consumer price and the marginal costs is known as the tax equivalent of the quota rent. In our model both the EU milk quota and the sugar quota are implemented at the national level. Technically, this is achieved by formulating the quota as a complementarity problem. This formulation allows for endogenous regime switches from a state when the output quota is binding to a state when the quota becomes non-binding. In addition, changes in the value of the quota rent are endogenously determined. If t denotes the tax equivalent of the quota rent, and r denotes the difference between the output quota $\bar{q}$ and output q, then the complementary problem can be written as:

$$r = \bar{q} - q \qquad [2]$$

and

either $t > 0$ and $r = 0$ the quota is binding
or $t = 0$ and $r =\geq 0$ the quota is not binding.

Some assumptions in the LEITAP model

Production, trade and consumption of agricultural products

Future production, trade and consumption of agricultural products are calculated by the GTAP model, and are driven by population growth, economic growth, and technological improvement. Therefore assumptions on these parameters have a major impact on GTAP results. Assumptions within the GTAP model are made with respect to the elasticities, which are very difficult to estimate, and which are known to have a major impact on model results. Furthermore, is assumed that today’s elasticities are constant over time. Although there are no data or methods to do otherwise, it is very likely that elasticities will change over time.

Another crucial assumption is the parameterisation of the land supply curve, which is related to the inverse of yields calculated by IMAGE (see above). Although this is generally well in line with Ricardo's Principles of Political Economy and Taxation (Ricardo, 1817), the strong impact of the land supply curve on model results would ask for a further empirical verification.

Agricultural productivity

Intensification of agricultural production was based on FAO projection of population and food production for 2000-2050 (Bruinsma, 2003; FAO, 2006). While increase in crop productivity can be derived directly from this source, the procedure is more complicated for livestock, as FAO does not provide data on grassland, which contributes a large share of the total feed required for the production of beef, sheep, goats, and milk. Global livestock production systems are very diverse, and they differ in terms of animals used, their productivity, their land requirements, their feed, their excretion and emissions and the manure management. Based on the FAO projections, and by assuming that the area of global grasslands remains stable, a reference scenario of crop and livestock production was developed, which is consistent with FAO projections. Results from this reference scenario were also used to derive the total land and feed requirements of animal products between 2000 and 2050, which was then used as external technological improvement in the LEITAP model (see section on model coupling).

3.1.3 IMAGE Energy (the TIMER model)

The global energy system model TIMER (Targets IMage Energy Regional Model) has been developed to simulate (long-term) energy baseline and mitigation scenarios. The model describes the investments in, and the use of, different types of energy options influenced by technology development (learning-by-doing) and resource depletion. Inputs to the model are macro-economic scenarios and assumptions on technology development, preference levels and restrictions to fuel trade, in this study from ENV-Linkages. 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 utilization, cost indicators and greenhouse gas and other emissions. In TIMER, implementation of mitigation is generally modeled 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, and investments in bio-energy, 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 optimization) (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 *(Figure 3.6)*. The steps are connected by demand for energy (from left to right) and by feedbacks, mainly in the form of energy prices (from right to left). The TIMER model has three types of submodels: (i) the energy demand model; (ii) models for energy conversion (electricity and hydrogen production), and (iii) models for primary energy supply. Some assumptions for the different sources and technologies are listed in *Table 3.1*.

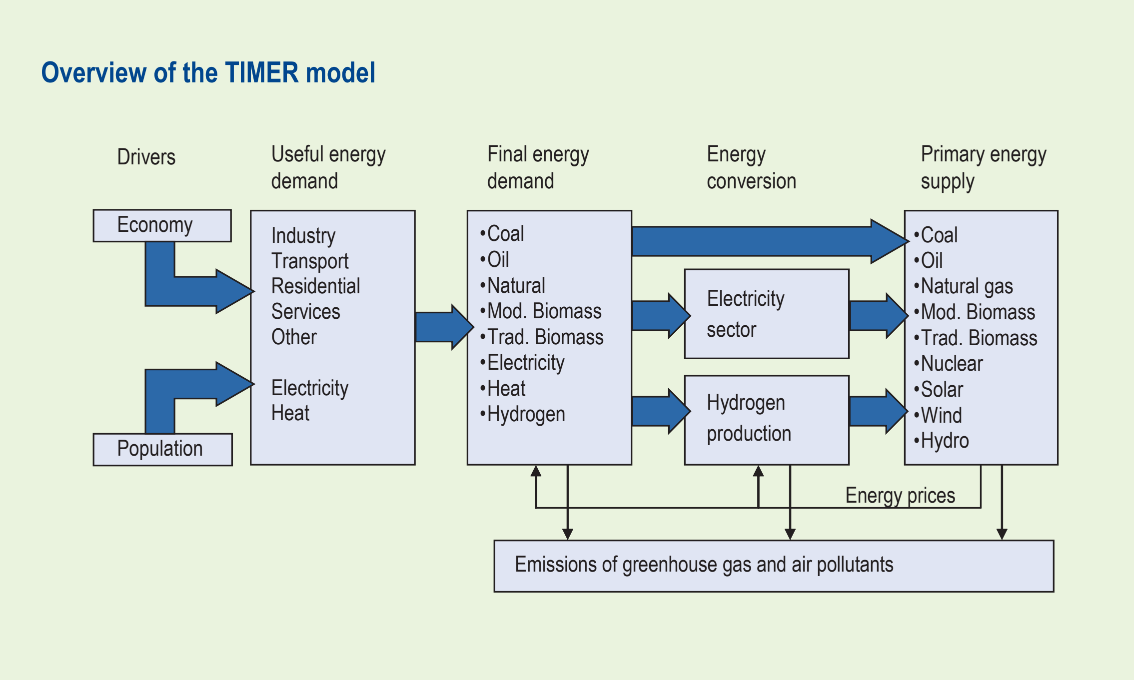


Figure 3.6 The chain from demand for energy services to related emissions as modelled by TIMER
(091s_oec08)

3.1.4 IMAGE emissions database ('EDGAR')

To provide the input data for TIMER and IMAGE on energy use and historic emissions EDGAR has been used. The EDGAR (Emission Database for Global Atmospheric Research) information system is a joint project of MNP, Bilthoven (The Netherlands), TNO, Apeldoorn (The Netherlands) and JRC, Ispra (Italy). EDGAR stores global emission inventories of direct and indirect greenhouse gases from anthropogenic sources including halocarbons and aerosols both on a per country and region basis as well as on grid. EDGAR serves as reference database, worldwide, for policy applications as well as for scientific studies by providing gridded emissions as input for atmospheric models (Olivier and Berdowski, 2001; www.mnp.nl/edgar).

EDGAR includes the following sources: (a) fossil-fuel related sources and (b) biofuel combustion, both on a per country basis; (c) industrial production and consumption processes (including solvent use) also on a per country basis; (d) landuse-related sources, including waste treatment, partially on a grid basis and partially on a per country basis; and (e) selected natural sources on a grid basis. The level of detail per source is generally defined by the available international statistics (e.g. for fuel combustion the many fuel types and economic subsectors distinguished by the IEA statistics).

The inventories are not stored as emissions but are calculated per source category, firstly at country level by multiplication of (a) activity data (in general international statistics) and (b) emission factors (for greenhouse gases in general IPCC default values). Subsequently, emissions at a 1x1 degree grid may be generated from the emissions at country level using source-specific global grid maps as proxy for the spatial distribution of emissions within countries. Aircraft emissions are also calculated at 1 km altitude bands. The EDGAR system can generate global, regional and national emissions data in various formats for any definition of source categories.

Table 3.1 Main assumptions in the TIMER model

Option	Assumptions	References
Fossil fuels	Regional resources and production costs for various qualities; the ultimate coal, oil and natural gas resources equal 300, 45, and 117 ZJ, respectively. In time, depletion leads to price increases, while technology change reduces prices. Under a medium scenario (B2) global average crude energy prices in 2050 are around 1.4, 5.1 and 4.4 1995US$ / GJ for coal, oil and natural gas, respectively. In 2000, these prices are 1.1, 3.0 and 2.3 1995US$ / GJ.	Rogner (1997), TNO (2006)
Carbon capture and storage (CCS)	Regional reservoir availability and storage costs for various options (different categories of empty oil and natural gas reservoirs, coal reservoirs, coal-bed methane recovery, aquifers). Total capacity equals 1500 GtC. Transport and storage costs range, depending on category and region, from 10 to 150 US $/tC.	Hendriks et al. (2002)
Power plant efficiency and investment costs	Power plant efficiency and investment costs for 20 types of thermal power plants (coal, oil, natural gas, biomass) including carbon capture and storage defined over time.	Hendriks et al. (2004)
Energy crops	Potential and costs for energy crops defined by region on the basis of IMAGE 2 maps (including abandoned agricultural land, natural grasslands and savannah). Primary biomass can be converted into liquid biofuels (for transport) and solid bio-energy (for electricity). Technology development is based on learning-by-doing. Under a medium (B2) scenario, maximum potential equals 230 EJ in 2050 and 600 EJ in 2100. Production costs for liquid fuels varies from 12 to 16 US $/GJ in 2000 to 8-12 US $/GJ in 2050 (depending on scenario). Production costs for solid fuels varies around 4 US $/GJ.	Hoogwijk (2004)
Solar / wind power	Solar and wind power based on studies that assess global potential on the basis of 0.5 x 0.5 degree maps. Costs change over time as a result of depletion, learning-by-doing and grid penetration (declining capacity credit and excess electricity production).	Hoogwijk (2004)
Nuclear power	Investment costs of nuclear power based on available information in the literature (most important references indicated). Investment costs are assumed to decrease over time. Fuel costs increase over time as a result of depletion.	MIT (2003); Sims et al. (2003)
Hydrogen	Hydrogen modelled on the basis of production from fossil fuels, bio-energy, electricity and solar power (including carbon capture and storage).	Van Ruijven et al. (in press)
Energy demand	Parameters for autonomous and price-induced efficiency improvement, and structural change, are mostly based on model calibration.	De Vries et al. (2001)

Activity data were mostly taken from international statistical data sources and emission factors were selected mostly from international publications to ensure a consistent approach across countries (Olivier et al., 2006; Olivier et al., 2005, Van Aardenne et al., 2001).

All activity data are available in detail for 1970-2000 (annually) and at more aggregate level for 1880-1990 (per 10 year). Emission factors also cover these periods, except for air pollutants (NO_x, CO, NMVOC, SO_2) for which no detailed factors are available for 1970-1985. For all compounds and standard source categories emissions were calculated for 1990, 1995 and 2000. For greenhouse gases data are available for the 1970-2000 period.

The uncertainty in the resulting dataset at national level may be substantial, especially for methane and nitrous oxide, and even more so for the F-gases. The uncertainty is caused by the limited accuracy of international activity data used and in particular of emission factors selected for calculating emissions on a country level. However, since methods used are comparable with IPCC methodologies and global totals comply with budgets used in atmospheric studies and the data were based on international information sources, this dataset provides a sound basis for comparability. Details on uncertainty and caveats identified in the dataset, as well as more detailed source category estimates are available at the website (see also: Olivier et al., 2001, and Olivier and Peters, 2002).

3.1.5 IMAGE overall; and terrestrial module

The Integrated Model to Assess the Global Environment (IMAGE) has initially been developed as an integrated assessment model to study anthropocentric climate change (Rotmans, 1990). Later it was extended to include a more comprehensive coverage of global change issues in an environmental perspective (Alcamo et al. 1994, IMAGE team, 2001). The current main objectives of IMAGE are to contribute to scientific understanding and support decision-making by quantifying the relative importance of major processes and interactions in the society-biosphere-climate system. (see further: www.mnp.nl/image)

IMAGE provides a dynamic and long-term assessment of the systemic consequences of global change up to 2100. The model was set up to give insight into causes and consequences of global change up to 2100 as a quantitative basis for analyzing the relative effectiveness of various policy options for addressing global change. *Figure 3.7* provides an overview of the IMAGE modelling framework used in this analysis.

In earlier studies two models associated with, but not integrated in IMAGE, were used to provide basic drivers for the IMAGE model. These are the general equilibrium economy model, WorldScan (CPB, 1999), and the population model, PHOENIX (Hilderink, 2000). The WorldScan model provides input for IMAGE on economic developments, and PHOENIX provides input on demographic developments for both IMAGE and WorldScan.

For the *OECD Environment Outlook*, the population projection is taken from the UN directly and is one of the inputs for the OECD ENV-Linkages model. The economic results from the ENV-linkages model are used as drivers to produce the detailed, physically oriented projections for the energy and land-use sectors by various model in the IMAGE framework. As described in section 3.1.2, IMAGE uses agricultural demand, production and trade as calculated by the LEITAP model. More aspects of the linkage between the two models are described in section 3.1.6.

The TIMER model (see section 3.1.3) provides regional energy consumption, energy efficiency improvements, fuel substitution, supply and trade of fossil fuels and renewable energy technologies. On the basis of energy use and industrial production TIMER computes emissions of greenhouse gases (GHG), ozone precursors and acidifying compounds.

The Terrestrial Environment System (TES) of IMAGE computes land-use changes based on regional production of food, animal feed, fodder, grass and timber, with consideration of local climatic and terrain properties, and changes in natural vegetation due to climate change. Consequently, emissions from land use changes, natural ecosystems and agricultural production systems, and the exchange of carbon dioxide between terrestrial ecosystems and the atmosphere are calculated. The Atmospheric Ocean System (AOS) part of IMAGE calculates changes in atmospheric composition using the emissions from the TIMER model and TES, and by taking oceanic carbon dioxide uptake and atmospheric chemistry into consideration. Subsequently, AOS computes changes in climatic properties by resolving the changes in radiative forcing caused by greenhouse gases, aerosols and oceanic heat transport (see Eickhout et al., 2004).

This description now zooms in on the Terrestrial Environment System TES and its sub-systems, as the geographically explicit modelling of land-use is one of the outstanding characteristics of IMAGE. The Terrestrial Vegetation Model (TVM) simulates the potential distribution of natural vegetation and crops on the basis of climate conditions and soil characteristics on a

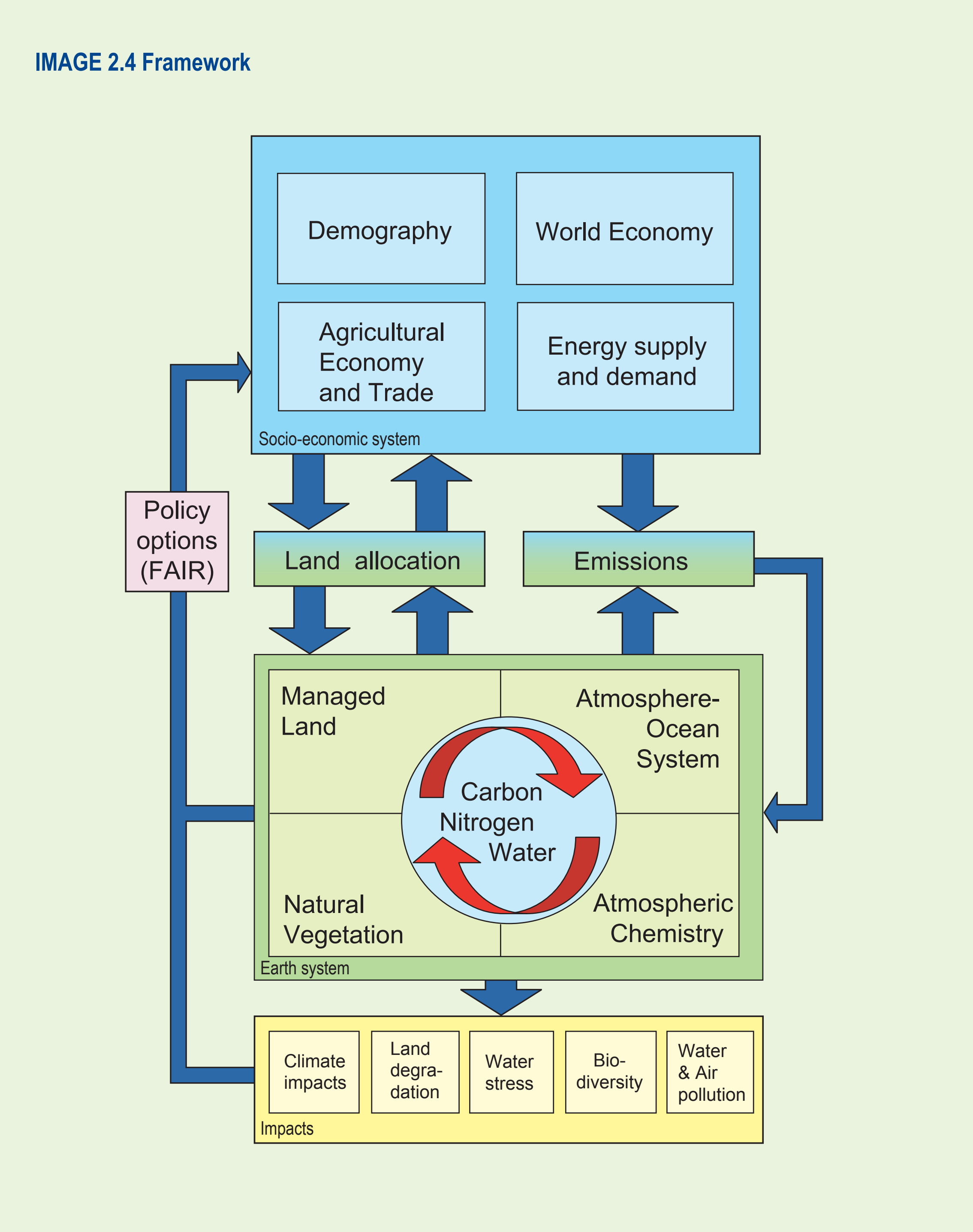


Figure 3.7 Schematic diagram of IMAGE 2.4
(102s_oec08)

spatial resolution of 0.5 degree latitude by 0.5 degree longitude. It also estimates potential crop productivity, which is used by Land Cover Model (LCM), to determine the allocation of the cropland to different crops. First, TVM calculates 'constraint-free rain fed crop yields' accounting for local climate and light attenuation by the canopy of the crop considered (FAO, 1981). The climate-related crop yields are adjusted for grid-specific conditions by a soil factor with values ranging from 0.1 to 1.0. This soil factor takes into account three soil quality indicators: (1) nutrient retention and availability; (2) level of salinity, alkalinity and toxicity;

and, (3) rooting conditions for plants. The adjustment factor is calibrated using historical productivity figures and also includes the fertilization effect of changes in the atmospheric concentration of carbon dioxide. The carbon dioxide fertilization is determined by the Terrestrial Carbon Model (TCM) that distinguishes different parameter settings per land cover type (Leemans et al., 2002). The resulting crop productivity, called 'reduced potential productivity of crops', is used in the land cover model.

The objective of the Land Cover Model (LCM) is to simulate global land use and land cover changes by reconciling the land use demand with the land potential. The basic idea of LCM is to allocate crop production on grid cells within a world regions until the total demand for this region is satisfied. The results depend on changes in the demand for food and feed as computed by GTAP. The allocation of land use types is done at grid cell level on the basis of specific land allocation rules like crop productivity, distance to existing agricultural land, distance to water bodies and a random factor (Alcamo et al., 1998).

IMAGE uses the historical data for the 1765-1970 period to initialize the carbon cycle and climate system. Actual simulations cover the period 1970-2050. Data for 1970-2000 are used to calibrate the IMAGE model against FAO data. For the period 2001-2050 the simulations are driven by the input from the TIMER model and LEITAP, and by additional scenario assumptions on e.g. technology development, yield improvements and efficiencies of animal production systems.

Food security may be threatened by loss of soil productivity as a result of human-induced land degradation. Water erosion is the most important cause of land degradation, and its effects are irreversible. IMAGE includes a qualitative approach to assess the land's sensitivity to water erosion. A qualitative approach is most appropriate, because it is impossible to estimate soil loss rates and effects on plant productivity for different water erosion processes at the scale of the IMAGE model (0.5 by 0.5 degree). A modified version of the Universal Soil Loss Equation (USLE) (Wischmeier, 1978) was used to computed erosion hazard on the basis of the terrain erodibility index (considering slope and soil type), rainfall erosivity and land use/cover. The terrain erodibility index is composed of the soil erodibility index and relief index. The rating of soil characteristics is referred to as soil erodibility, based on soil texture and soil depth. The relief index is a landform characterization derived from a digital elevation model (based on differences in elevation within grid cells). The calculation of the rainfall erosivity is based on the maximum mean monthly rainfall intensity calculated from monthly precipitation and the number of wet days. The land use pressure is based on the land cover simulations of the IMAGE model using index values specific for each crop or land cover type.

The actual land degradation strongly depends on the conservation measures taken to prevent soil erosion. The results of the land-degradation model of IMAGE can therefore only be used to identify regions where problems of water erosion may present and where they may be most severe, and how the land's sensitivity to water erosion may change in the future under scenarios of population growth, economic growth, technological development and climate change.

Some assumptions on constant and model parameters in IMAGE

There are a number of parameters which are assumed to be constant in the IMAGE simulation. On the consumption side, it is assumed that the relative contribution of commodities not covered by the IMAGE crop and animal product groups to the diet remains constant. With respect to agricultural management, it is assumed that the fraction of fallow land within a region remains constant after 2000. There may be reasons for both an increase or a decrease in cropping intensity, but projections can hardly be made due to lack of knowledge and data. We also assume no change in irrigated areas, knowing that this might lead to underestimating future yields in some regions, while overestimating them in other regions.

Furthermore, there are a number of assumptions inherent to the current IMAGE 2.4 model version. The parameterisation of the climate model still follows the IPCC's third assessment report (IPCC, 2001), therefore climate sensitivity is set to 2.5 degree, while it should be increase to 3.0 according to the fourth assessment report (IPCC, 2007). However, until 2050 this modification hardly affects the results.

Concerning the terrestrial carbon cycle, the parameterisation of the IMAGE 2.4 model follows recommendations of IPCC (2007), with the fertilization factor of natural vegetation being reduced to 0.35, while the fertilization factor for agriculture remains at 0.7.

3.1.6 Coupling of LEITAP and IMAGE

Figure 3.8 shows the methodology of iterating the extended version of GTAP (LEITAP) with IMAGE. The output of LEITAP is, among others, sectoral production growth rates, land use, and a yield factor describing the change in land productivity because of technology improvements and the degree of land intensification. The degree of intensification is modelled endogenously by LEITAP, while the technology improvement is assumed exogenously using information from FAO's study 'World Agriculture towards 2015/2030' (Bruinsma, 2003).

The output from LEITAP is used by the IMAGE model to calculate change in crop productivity, the demand for land, feed efficiency rates and environmental indicators. This procedure delivers adjustments to the achieved changes in yields and changes in feed conversion, which are given back to LEITAP. Through this procedure comparable land foresights are simulated in both models.

Yields

In the adjusted GTAP model yield depends on a trend factor and prices. The production structure used in this model implies that there are substitution possibilities among production factors. If land gets more expensive, the producer uses less land and more other production factors such as capital. The impact of a higher land price is that land productivity or yields will increase. Consequently, yield is dependent on an exogenous part - the trend component - and on an endogenous part with relative factor prices, which is the management component.

The exogenous trend of the yield is taken from the FAO study 'Agriculture towards 2030' (Bruinsma, 2003) where macro-economic prospects were combined with local expert knowledge. This approach led to best-guesses of the technological change for each country for the coming 30 years. Given the scientific status of the FAO-work these data were used as exogenous input for a first model run with the adjusted GTAP model. However, many studies indicated this change in productivity are enhanced or reduced by other external factors, of which climate change is mentioned most often (Rosenzweig et al., 1995; Parry et al., 2001; Fischer et al., 2002). These studies indicated increasing adverse global impacts because of climate change will be encountered with temperature increases above 3 to 4°C compared to pre-industrial levels. These productivity changes need to be included in a global study. Moreover, the amount of land expansion or land abandonment will have an additional impact on productivity changes, since land productivity is not homogenously distributed over each region.

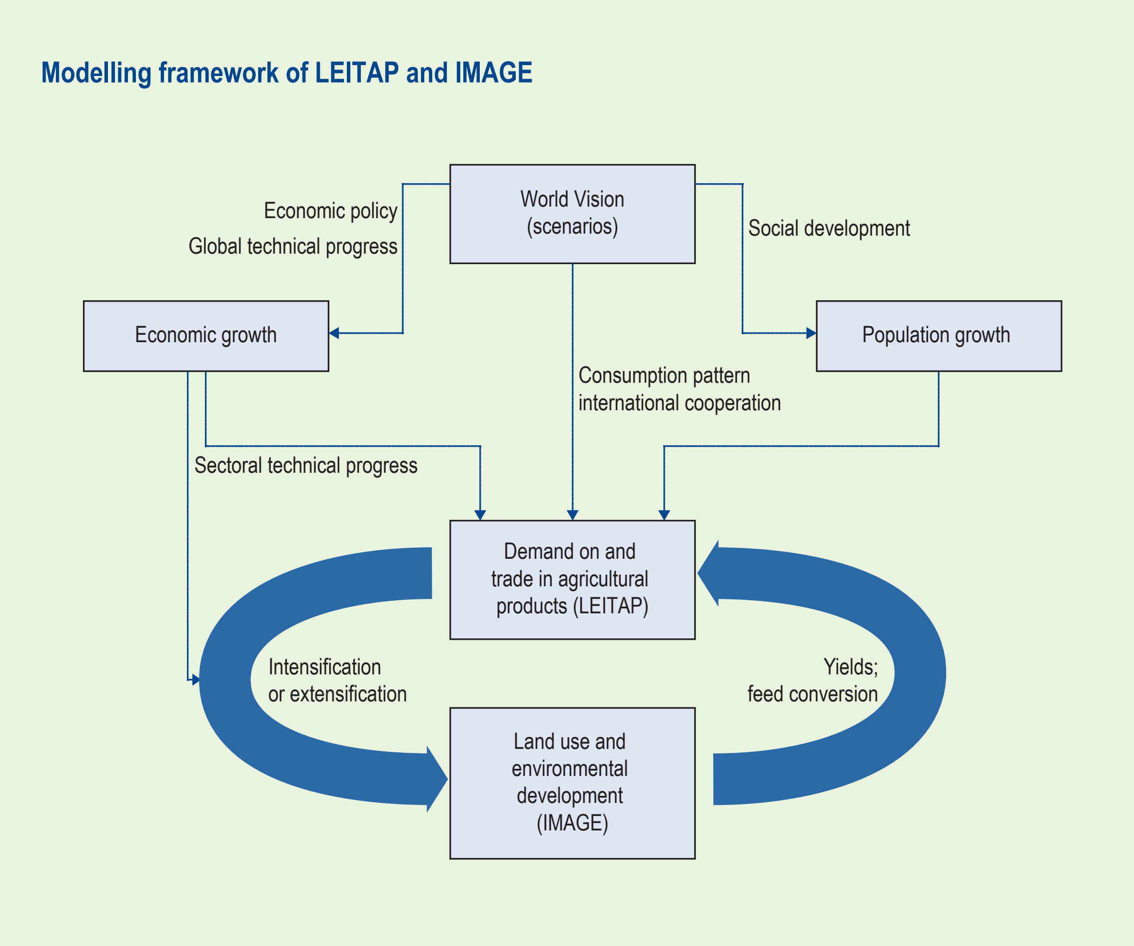


Figure 3.8 LEITAP and IMAGE coupling
(092s_oec08)

In our approach, the exogenous part of the yield was updated in an iterative process with the IMAGE model (see *Figure 3.8*). The output of LEITAP used for the iteration with IMAGE is sectoral production growth rates and a management factor describing the degree of land intensification. Next, the IMAGE model calculates the yields, the demand for land and the environmental consequences of crop growth productivity. IMAGE simulates global land-use and land-cover changes by reconciling the land-use demand with the land potential. The basic idea is to allocate gridded land cover within different world regions until the total demands for this region are satisfied. The results depend on changes in the demand for food and feed and a management factor as computed by LEITAP. The allocation of land-use types is done at grid cell level on the basis of specific land allocation rules like crop productivity, distance to existing agricultural land, distance to water bodies and a random factor (Alcamo et al., 1998). This procedure delivers an amount of land needed per world region and the coinciding changes in yields, because of changes in the extent of used land and climate change. Next, these additional changes in crop productivity are given back to LEITAP. A general feature is that yields decline if large land expansions occur since marginal lands are taken into production. In the near term, these factors are more important than the effects of climate change.

Feed conversion in livestock
The intensification of livestock production systems also influences the composition of the feed required by livestock production systems. In general, intensification is accompanied by decreas-

ing dependence on open range feeding and increasing use of concentrate feeds, mainly feed grains, to supplement other fodder. At the same time improved and balanced feeding practices and improved breeds in ruminant systems enabled more of the feed to go to meat and milk production rather than to maintenance of the animals. This has led to increasing overall feed conversion efficiency (Seré and Steinfeld, 1996). In the IMAGE model, the production of animal products is used as input to simulate the number of animals required for this production. For this conversion, the animal productivity is taken from Bruinsma (2003) including the future developments until 2030. The calculation of total feed required in dairy and beef production were modified from EPA (1994). In this approach the net energy requirements for dairy cattle are divided into maintenance, feeding, lactation and pregnancy (Bouwman et al., 2005b). Based on the animal diets, the intake of crops and grass/fodder are calculated to feed the animals. The feed composition in 2000 is modified from Bouwman et al. (2005). In the future, the intensification, ant thereby shift to more concentrate feeds (maize and soy beans) will continue. On the basis of these feed diets the demand for grass and fodder was calculated, assuming that grazing animals such as cattle, goats and sheep depend mainly on pasture and fodder species, while pigs and poultry rely primarily on crops. Hence, the importance of food crops in the animal diet increases at the cost of pasture and fodder species and crop residues, along with increasing intensity of production on the basis of recent trends observed. More details of the IMAGE grazing simulation were described in Bouwman et al. (2005). This procedure delivers feed conversion or efficiency rates for the livestock sectors that were used as input for the LEITAP modelling framework. Additionally, just like or crops, substitution between inputs is possible, so that LEITAP calculates endogenously intensification of animal production by using less land but more capital input.

Feed demand in food processing industry
As noted above, developments in livestock are important for the demand for feed crops. In many countries feed crops are delivered to the feed-processing industry and this sector adds value and delivers it to the livestock sectors. The feed-processing sector in LEITAP is a part of a very heterogeneous food processing sector which causes the problem that feed demand is determined by the growth of this larger food processing sector and only indirectly by the growth of the livestock sectors. (In the aggregation used in this report the problem is more serious because it separates only a very aggregated food-processing sector where the feed processing industry is only a minor part.) Given the importance of crop feed demand for land use we adjust this aggregation issue by creating a direct link between feed demand in agro-food processing sector ("agro") and the growth of the livestock complex. Demand for feed crops in food processing sector is a sales weighted average of growth of livestock sectors:

$$qf(i,"agro"r) = \sum_{k=livestock} \frac{VFA("agro",k,r)}{\sum_{m=livestock} VFA("agro",m,r)} * \left(qo(k,r) - af(i,k,r)\right) \qquad [3]$$

where qf (i, "agro", r) is growth rate of industry demand in food processing sector (agro) for intermediate feed crop input i in region r, VFA ("agro",k,r) is producer expenditure of k industry on sales from food processing industry (agro) in region r, qo(k,r) is production growth in sector k in region r, sector k is a livestock sector, and af(i,k,r) is the feed efficiency rate in livestock sector k in region r. This efficiency rate af(i,k,r) is provided by IMAGE.

Illustrating the risk of desertification: combining IMAGE and LEITAP projections
Desertification is defined as the degradation of land in arid, semi-arid, and dry sub-humid areas (MEA, 2005). Direct drivers of desertification include overcultivation, overgrazing, deforestation,

and poor irrigation. These drivers can be traced back to a range of economic and social pressures, ignorance, war, and natural climate fluctuations like drought.

Drylands — arid, semi-arid and dry sub-humid — comprise some 41% of global lands (MEA, 2005). It is thought that at least a quarter of drylands are already degraded and heading toward desertification (Safriel, 1997). In general, desertification results in a lower biodiversity and shifts in species composition and natural areas, and in lower productivity in cultivated area (MEA, 2005).

The United Nation's Convention to Combat Desertification (CCD) takes the ratio of mean annual precipitation to mean annual potential evapotranspiration to identify drylands. They include arid, semi-arid, and dry sub-humid areas (in other than polar and sub-polar regions) in which this ratio ranges from 0.05 to 0.65. This definition has been used to identify the total amount of dryland areas and their changes over time using the IMAGE 2.2 model. As for the risk of desertification, the increase in arid areas is less important than the nature of the pressure on these areas, the next step was to overlay the data on the future extent of arid areas with the future agricultural use including the free ranging livestock. This resulted in the projected increase of arid areas devoted to agriculture (see *Figure 2.14*). In reality, the desertification risks are more complex and numerous, but they are difficult to depict in a global model.

3.1.7 FAIR 2.1

The policy decision-support tool 'Framework to Assess International Regimes for the differentiation of commitments' (FAIR) has been developed to explore and evaluate the environmental and abatement cost implications of various international regimes for differentiation of future commitments for meeting long-term climate targets, such as stabilization of the atmospheric greenhouse gas concentrations (Den Elzen, 2005). The model aims to support policy makers by quantitatively evaluating the environmental and costs implications of a range of approaches and linking these to targets for global climate protection. The model was also used to support dialogues between scientists, NGOs and policy makers. To this end the model is set up as an interactive tool with a graphical user interface, allowing for interactive changing and viewing model input and output. A demonstration version of the model can be downloaded at: www.mnp.nl/fair.

The FAIR model consists of three linked models, including a climate model, an emission allocation model and an abatement costs model. The climate model calculates the climate impacts of global emission profiles and emission scenarios, and determines the global emission reduction objective based on the difference between the global emissions scenario (without climate policy) and a global emission profile (including climate policy). The emission allocation model calculates the regional greenhouse gas (GHG) emission allowances for different regimes for the differentiation of future commitments within the context of the global reduction objective from the climate model. The abatement costs model calculates the regional abatement costs and emission levels after trading on the basis of the emission allowances coming from the emission allocation model following a least-cost approach. The model makes full use of the flexible Kyoto mechanisms as emissions trading and substitution of reductions between the different gases and sources.

The model calculations are done at the level of 24 IMAGE world regions. The GHG emissions are converted to carbon dioxide equivalent, similar to those in the Kyoto Protocol, i.e. the sum of the Global Warming Potential weighted emissions of the six GHGs or groups of GHGs specified in the Kyoto Protocol. Various data sets of historical emissions, baseline scenarios, emission profiles and marginal abatement cost (MAC) curves are included in the model framework to assess the sensitivity of the outcomes to variation in these key inputs.

There have been five main developments since the FAIR 2.0 model, which is extensively described in Den Elzen and Lucas (2005), i.e. (i) the development of multi-gas emission pathways (and envelopes) corresponding to a stabilization of GHG concentration at levels of about 450, 550 and 650 ppm carbon dioxide equivalent (Den Elzen et al., 2007c; Den Elzen and Van Vuuren, 2007); (ii) abatement cost calculation for mitigation scenarios based on updated MAC curves for all GHG emissions from the TIMER 2.0 model and IMAGE 2.3 model (Den Elzen et al., 2005a; Den Elzen et al., 2007c); (iii) updated climate attribution calculations (Den Elzen et al. 2005b); (iv) an updated Triptych approach at the level of countries (Den Elzen et al., 2007b), and two additional post-2012 regimes for post-2012 commitments (i.e. Common-but-differentiated convergence (Höhne et al., 2006) and the South–North Dialogue Proposal (Den Elzen et al., 2007a)); and (v) country-scale calculation of emission allowances and abatement costs, referred to as the FAIR-world model (Den Elzen, 2005).

3.1.8 WaterGAP

WaterGAP is global model for estimating water availability and water use. The aim of the model is to provide a basis: (i) to compare and assess current water resources and water use in different parts of the world, and (ii) to provide an integrated long-term perspective of the impacts of global change on the water sector.

WaterGAP comprises two main components, a Global Hydrology Model and a Global Water Use Model. The Global Hydrology Model simulates the macroscale behaviour of the terrestrial water cycle to estimate water resources, while the Global Water Use Model computes water use for the domestic, industrial, irrigation and livestock sectors. Both water availability and water use computations cover the entire land surface of the globe (except the Antarctic) and are performed for cells on a 0.5° by 0.5° spatial resolution.

The WaterGAP-Global Hydrology Model calculates a daily vertical water balance for both land area and open water bodies in each 0.5°-cell. The sum of runoff produced within a cell plus the upstream discharge into a cell is transported through groundwater, lakes, reservoirs and wetlands to rivers. Finally, the river discharge is routed to the next downstream cell according to a global drainage direction map (Döll and Lehner, 2002). This allows performing calculations for more than 10 000 ‘first-order’ rivers (i.e. rivers that drain into the ocean or into inner continental sinks) covering the entire land surface of the earth. The calculated total discharge has been tuned to measured values (from GRDC, 2000) for 724 drainage basins worldwide, covering half the global land area, except the Antarctic. For 50% of these stations, the tuning of one model parameter is sufficient to achieve that simulated and observed long-term average annual discharge agree within 1 per cent, while for the rest additional corrections have to be applied. For drainage basins without measured discharge data, runoff factors are regionalized by applying a multiple regression approach (Döll et al., 2003).

The WaterGAP-Global Water Use Model computes water withdrawals and consumptive water use for the main water-use sectors: domestic, industry, irrigation and livestock. Each sector’s water use is computed as a function of ‘water-use intensity’ multiplied by the most important 'driving forces' of water use (e.g. population, national electricity production, area of irrigated land, number of livestock).

Variables representing 'water-use intensity' are per capita water withdrawals (domestic), water withdrawals per unit of produced electricity (industry), gross irrigation water requirement per unit of irrigated area (irrigation) and per-animal drinking-water use (livestock). Water intensities change over time due to 'structural' and 'technological changes'. For the domestic and industrial sector, historical structural changes correlate with income, and trends are based on data provided by Shiklomanov (1997, 2000) for 26 different world regions. To be able to compute scenarios of country-specific future water use in these two sectors, assumptions on regional, structural and technological changes are applied to country estimates for recent (i.e. 1995) sectoral water use (Shiklomanov, 2000; WRI, 2000). These country-specific values are finally distributed to grid cells according to the spatial distribution of population, and information on urbanization and access to safe drinking water. Computations for the irrigation sector rely on an irrigation sub-model, which calculates irrigation water requirements by cell, reflecting an optimal supply of water to irrigated crops (Döll and Siebert, 2001). The water withdrawals by livestock are assumed to be equal to their consumptive use and are computed by multiplying the number of livestock by their water consumption per head and year (for ten different varieties of livestock).

Water use in the domestic, industrial and livestock sectors is computed annually, while for the irrigation sector, the sub-model operates on a daily basis.

Once the water-use intensities have been determined for each sector, total water use is obtained by multiplying water-use intensities by the respective 'driving forces'. The corresponding driving forces for each sector are country-level scenarios for population (domestic), electricity production (industry), irrigated area (irrigation) and number of livestock (livestock).

The water stress indicator 'withdrawal-to-availability ratio' combines information from both sub-models by comparing the water availability in each cell with the water withdrawals. The concept of 'water stress' is often used for assessing the status of the world water situation. It indicates the intensity of pressure put on the water resources. More detailed descriptions of the model components are also provided by Alcamo et al., 2000, Alcamo et al., 2003, and Lehner et al., 2001.

3.1.9 Air pollutant emissions

The *OECD Environmental Outlook* addresses several aspects of conventional air pollution including emissions of sulphur dioxide, nitrogen oxides, airborne particulate matter and ground level ozone. The focus is on what the Baseline and policy measures mean for urban air quality worldwide.

Ambient particulate matter is partly directly emitted into the atmosphere (dominant sources are fossil fuel use, wood burning and road transport); partly it is formed in the atmosphere from precursor gases (sulphur dioxide, nitrogen oxides, ammonia and, to a lesser extent, volatile organic compounds). Ground-level ozone is a secondary pollutant: it is not directly emitted but formed in the atmosphere. Important precursors of ozone are nitrogen oxides, volatile organic compounds, methane and carbon monoxide.

Future emissions of sulphur dioxide, nitrogen oxides, methane and carbon monoxide from the energy system are calculated by IMAGE/TIMER using a system of sector/region/substance specific emission coefficients (based on the EDGAR database), calibrated to historic trends and reflecting assumptions of the policy packages (see sections 3.1.3 and 3.1.4) . Land use related emissions are calculated in a similar manner based on the land use and agricultural parameters included in IMAGE (see section 3.1.5).

Based on published cost curves, a default long-term ambition level was set relative to maximum feasible reductions (Cofala et al., 2005). The reason is to exclude the last and steep part of the cost curve and thus limit the additional costs. This long term ambition emission level lies between 4 and 13% above what can be achieved with maximum feasible reductions. The pathway towards this long-term ambition was differentiated by region, in function of the regional GDP per capita as projected with ENV-Linkages (and interpreted to be equivalent to purchasing power parity). A further differentiation was applied by sector. Emissions from international shipping were addressed separately. For the policy simulations, is assumed that emission control targets for sulphur dioxide from marine shipping will be internationally agreed, with noticeable decreases in emissions by 2020 and full implementation by 2035. The first stage is assumed to be a reduction in maximum sulphur content of fuel to 1% (averaged over regulated and non-regulated sea areas) with a further tightening at a second stage to 0.4%. Currently, the global maximum sulphur content under MARPOL is 4.5% - outside special areas - and the average sulphur content in heavy fuel oil bunkers is approximately 2.7% (BMT, 2006).

3.1.10 Air Quality models

Methodology Air Quality

Urban air quality, in particular ozone (O_3) and particulate matter (PM_{10} that is, particulate matter with an aerodynamic diameter of < 10 µm) has been assessed in more than 3000 cities worldwide with populations greater than 100 000. Given concentration-response function from epidemiological studies, the health impacts from ambient air pollution have been estimated in terms of attributable deaths and DALYs.

Urban agglomerations

A database of the major world cities has been taken from a recent study of the World Bank (Pandey et al., 2007). Projections of the population in each of the cities the period 2000-2030 are based on the average annual rate of change of the urban population at the national level (UN, 2006). Cities currently smaller than 100 000 inhabitants and fast growing cities which cross the 100 000 inhabitant threshold during the period up to 2030 are not included in the database. This implies that when in the *OECD Environmental Outlook* quantitative results are presented, these results refer 'only' to the total urban population in the cities included in the model calculations (see *Figure 3.9*). Depending on the regional cluster 55-100% of the urban population as given in the World Urbanisation Prospects (UN, 2006) is included in the calculation. With respect to the total (rural and urban) population the coverage is 20-70 % (in 2000) and 25-75% (in 2030).

Urban air quality

For estimating PM_{10} concentrations starting point was the urban GMAPS model (Global Model of Ambient Particulates, developed by the World Bank, see Pandey et al., 2006; WHO 2004). This empirical model incorporates information on factors such as energy mix, level of economic development, demographics and meteorology. The model has been parameterised on monitoring data, mostly for the period 1996-1999, for urban background locations in more then 300 cities

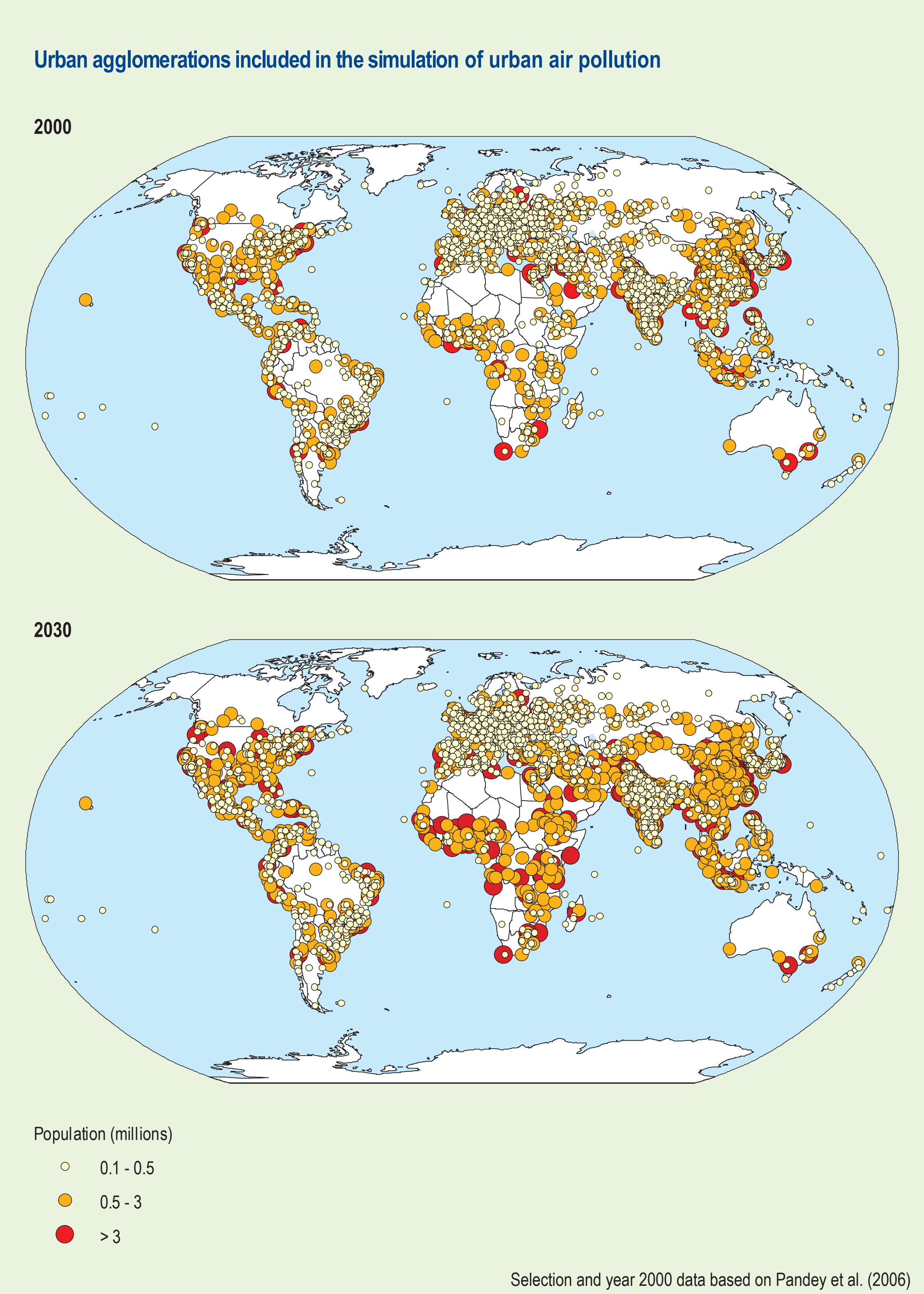
Table 3.2 Assumed introduction period for enhanced emission control for conventional macro air pollutants in the power and industry sectors

	Start of introduction of enhanced air pollution policies	Completion of introduction of enhanced air pollution policies
Canada	2015	2030
USA	2015	2030
Japan	2015	2030
Western Europe	2015	2030
Oceania	2015	2030
Central Europe	2015	2030
Turkey	2015	2030*
Russia & Caucasus	2015	2030
Mexico	2015	2030*
Republic of South Africa	2015	2035
Korea Region	2015	2030
Ukraine Region	2020	2040
China Region	2020	2040
Brazil	2020	2050
Middle East	2020	2050
Rest of South America	2020	2050
STANs	2030	2050
Central America & Caribbean	2030	2050[a)]
India	2030	2050
Indonesia	2030	2050
North Africa	2030	2050
Rest of South East Asia	2030	2050
South Asia except India	2040	2070
Southern Africa except RSA	2040	2070
West Africa	2050	2070
East Africa	2050	2070

a) The projected GDP/cap under baseline conditions of three regions does not quite match the threshold of the group they are placed in. These are Turkey, Mexico and Central America and the Caribbean. For the purpose of this exercise it is assumed that regional collaboration will enable these regions to implement air emission controls.

in 55 countries. In preliminary calculations the model was run using IMAGE-results to define the necessary input (that is, GDP, energy use, and fuel mix, where needed the data has been down-scaled at the national level). These preliminary runs resulted in an unrealistic outlook for the 2030 situation. As GMAPS relates drivers (economy, energy demand) to ambient air quality it is not able to predict a decoupling between economic growth and environmental state and impact. Moreover, the fact that it has been parameterised on a relatively short period (1996-1999), makes the model less suitable for scenario outlooks over 30 years.

Based on the original model, a version, called GUAM (Global Urban Air quality Model) has been developed. As GMAPS, GUAM includes demographic, geographic and meteorological conditions but instead of drivers, emissions as modelled by IMAGE (see section 3.1.5 and 2.2.3) are used directly.



Urban agglomerations included in the simulation of urban air pollution

2000

2030

Selection and year 2000 data based on Pandey et al. (2006)

Figure 3.9 Urban agglomerations included in the simulations
(027x_oec08)

PM_{10} concentrations for each city are calculated according to:

$$\log\left[PM10_{ijkt}\right] = \sum_{d=1}^{D} \beta_{E,d} E_{d,k,t} + \sum_{f=1}^{F} \beta_{U,f} U_{f,j,k,t} + \beta_N N_{j,k,t} + \beta_P P_{j,k} + \sum_{g=1}^{G} \beta_{Mg} M_{g,j,k} + \beta_{c,k} \qquad [4]$$

where:

- $E_{d,k,t}$ is log of emission density of pollutant *d* for country *k* at time *t*. In the current application emissions of carbon monoxide and secondary-PM precursors are included. The sec-PM emissions is the weighted sum of SO_2 and NO_x emissions; the weight factor accounts for the fraction of precursor which is in the atmosphere oxidized to secondary aerosol (De Leeuw, 2002). Total emissions (including contributions from natural and land use emissions) at the regional level are derived from IMAGE; the split of the regional emissions into national totals depends on the actual national emissions as given by EDGAR and on the relative changes in economy (expressed by their GDP per capita derived from IMAGE) in the respective countries.
- $U_{f,j,k,t}$ is log of the effective local emission of pollutant *f* in city *j* in country *k* at time *t*. In the current application this term is limited to effective secPM-emissions. Only emissions related to energy use and to industrial processes are considered here; land-use related emissions are assumed not to give a substantial contribution in the urban area. The effective emission is defined as the urban emission density, *Q*, scaled by the residence time of an air parcel over the city, that is, $U = Q \cdot l / w$ where *l* is a typical length ($l = \sqrt{urban\_area}$) and *wv* is the wind velocity.
- $N_{j,k,t}$ is log of population of city *j* in country *k* at time *t*
- $P_{j,k}$ is log of local population density of city *j* in country *k*. The population density is assumed to be constant in time, that is, the urban area increases linear with increasing population.
- $M_{g,j,k}$ is log of a meteorological or geographic factor for city *j* in country *k* describing the local dispersion condition. The following factors (annual mean and standard deviation of monthly data) are included: mean temperature, diurnal temperature range mean precipitation, vapour pressure, wind speed, cloud cover and the frequency of wet, sunny and frosty days (New et al., 1999). Additional factors include heating and cooling degrees-days and two topographical factors: distance from city centre to nearest coast line and city elevation. All $M_{g,j,k}$ factors have been taken from GMAPS. The meteorological factors are constant in time.
- $\beta_{c,k}$ is a country specific constant term.

The β-coefficients have been parameterised using the results of the original GMAPS model as secondary standard. Parameterisation based on monitoring data would be preferable but a monitoring data base with sufficient global and temporal coverage is not available at this moment. The correlation between the results of GUAM with the original GMAPS is high ($R^2 = 0.97$) although GUAM tends do give higher results, especially for concentrations above 100-150 µg/m³.

Background concentrations of ozone have been obtained from a global chemical tracer model (the TM3-model, Dentener et al., 2005; 2006). The emissions which are used in these model calculations are based on the Current Legislation (CLE) and Maximum Feasible reduction (MFR) scenarios developed by IIASA and JRC-Ispra (Dentener et al., 2005). Emissions calculated from the OECD Baseline are in agreement with but slightly higher than the CLE emission scenario: anthropogenic NO_x emissions are 36.5 and 35.4 Tg N/yr for 2030 in CLE and OECD baseline, respectively. Methane and carbon monoxide emissions for 2030 are according to the OECD baseline: 485 Tg methane per year and 430 Tg carbon monoxide per year; according to the CLE scenario it is 478 Tg methane per year and 416 Tg carbon monoxide per year. The results of the CLE scenario calculations have been used in the OECD Outlook. As the ozone concentration is a rather robust quantity (when the sensitivity of ozone for small changes in precursor emissions is relatively small) it is expected that the uncertainties introduced by this way are relatively small, certainly when compared to the uncertainties in the health impact assessment. The background concentrations will be used as proxy for the concentration in the urban areas. This might result in a small overestimation of ozone levels as ozone concentrations tends to be lower in urbanized area due to a chemical interaction with freshly emitted nitrogen oxides.

Health Impact Assessment

Estimation of population exposure for health impact assessments is based on the assumption 'one population – one average exposure level'. This means that it the exposure of the urban population is estimated as the modelled average urban concentration. Concentration gradients within the city (e.g. hot-spots), different exposure for neither different population classes nor indoor pollution have been considered. The assessment does not incorporate the effects of ambient air pollution on the population living in with less then 100 000 inhabitants and on the rural population.

For quantifying the effect of air pollution, the relative risk (RR) in a population whose exposure is estimated by an average concentration C is given by the concentration-response function:

$$RR = \exp\left[B\left(C - C_0\right)\right] \qquad [5]$$

where C_0 is a reference concentration (the background concentration that would exist without any man-made pollution determined by natural sources or a concentration below which no health effects are to be expected). B is the estimated effect of the pollutant on the health outcome (e.g. mortality from cardiopulmonary diseases) and is given as an increase in incidence per unit increase in concentration, see *Table 3.3*.

The composition of the particulate matter will be different in the regional clusters and with changing emissions in precursors and primary PM its composition will change over time. However, we have assumed that the factors given in *Table 3.3* have no temporal or spatial dependence.

Once the relative risks have been determined, the fraction (AF) of health effects from air pollution for the exposed population is:

$$AF = \sum P_i\left(RR_i - 1\right) / \sum P_i RR_i \qquad [6]$$

where

- P_i = the proportion of the population at exposure category *i* including the unexposed
- RR_i = the relative risk in exposure category *i*

When the total population is considered with only one exposure level, this simplifies to:

$$AF = \left(RR - 1\right) / RR \qquad [7]$$

The expected total number of cases of premature mortality due to air pollution is given by:

$$E = AF \cdot MR \cdot Pop \qquad [8]$$

Table 3.3 Estimates of relative risk of mortality, coefficients of concentration response function (B)

Health outcome	Exposure metric	Relative risk per 10 $\mu g/m^3$ (95% CL)	Reference
Mortality from cardiopulmonary disease, adults > 30 year	$PM_{2.5}$	1.059 (1.015-1.105)	Pope et al., 2002
Mortality for lung cancer, adults > 30 year	$PM_{2.5}$	1.082 (1.011 – 1.158)	Pope et al., 2002
Mortality from acute respiratory infection, children aged 0-4 year	$PM_{2.5}$	1.010 (0.991 – 1.031)	WHO, 2004
Total mortality, adults > 30 year; excluding violent death	PM_{10}	1.043 (1.026-1.061)	Kunzli et al., 2000
Total mortality, adults > 30 year, excluding violent death	ozone	1.003 (1.001 – 1.004)	WHO, 2006

where

- *E* is the expected number of deaths due to outdoor air pollution,
- *MR* is the population incidence of the given health effect (i.e. deaths per 1000 people per year) and
- *Pop* is the relevant exposed population for the health effect.

In the impact assessment a constant $PM_{2.5}/PM_{10}$ ratio of 0.5 was adopted (Cohen et al., 2004). The reference concentration C_0, the theoretical minimum concentration below which there is no excess risk, is set at 15 µg/m³ for PM_{10} and 7.5 µg/m³ for $PM_{2.5}$. It is further assumed that for PM_{10} concentrations above 150 µg/m³ there is no further increase in excess risk.

Demographic data (total population and age distribution per country) for the period 2000-2030 has been taken from the medium fertility variant of the World Population Prospects (UN, 2005). Similar age distributions for urban and total population have been assumed. Information on baseline incidences is obtained from the WHO Burden of Disease project (Mathers and Loncar, 2006).

As a consequence of the uncertainties in this assessment, the quantitative results obtained cannot be confidently extrapolated to smaller geographical areas like countries or cities. Results are therefore only presented at the larger scale of regional country groupings.

3.1.11 Modelling of the fate of nutrients

Point sources

Figure 3.10 visualizes the factors influencing the amount of nitrogen compounds in sewage, as described in section 2.1.8. Of the total population, the urban population is considered. A part of the urban population has access to improved population. A part of this group has connection to public sewerage. Of the sewage carried by public sewerage, a part is discharged without treatment. Of the sewage treated, the effluent still contains a part of the nitrogen load.

A conceptual relationship of per capita N emission and per capita income is used to calculate urban waste water N discharge (modified from Van Drecht et al. (2003), Bouwman et al. (2005)):

$$N_{em} = 8 + 8(GDP_{ppp} / 33{,}000)^{0.5} \qquad [9]$$

where N_{em} is the per capita daily N emission (g per person per day) and GDP_{ppp} is the Purchasing Power Parity based national annual per capita gross domestic product (exchange rate based GDP expressed 1995 US dollar). N-emission is calculated as annual mean per capita and country. We assume N-emission varies with GDP only. Low-income countries have per capita N emissions of about 10 g per day and industrialized countries are between 15 and 18 g per day. For this study we recalibrated equation [9] to obtain a better match with available data on N-emissions from raw urban waste water of a number of Western European countries compared to the original studies Van Drecht et al. (2003) and Bouwman et al. (2005). Furthermore, the equation was changed by using Purchasing Power Parity based GDP instead of a market exchange rate based GDP as in the original studies. For a number of Eastern European countries and for China daily N emissions, calculated with equation [9] resulted in better estimates; see also the Danube Applied Research Program (1997).

The amount of N that is actually discharged to surface water is calculated as follows:

$$N_{sw} = (1\text{-}R)\ D\ (0.365\ N_{em}) \qquad [10]$$

where N_{sw} is the net nitrogen emission to surface water (kg per person per year), R is the removal of N in waste water treatment plants expressed as a fraction of the N-emission in raw waste water (N-effluent/N-influent concentration ratio), and D is the fraction of the total population connected to (public) sewerage systems. Population connected to public sewerage is part of the WHO/UNICEF definition of 'improved sanitation' WHO/UNICEF (2000). However, this definition includes connection to a public sewer, septic systems, simple pit latrines, pour-flush, and ventilated improved pit latrines. Van Drecht et al. (2003) used regional estimates of the contribution of each system to obtain an estimate of D (source: WHO/UNICEF, 2000). To improve this approach, here we use country data for D based on WHO/UNICEF (2000, 2001b, 2001a, 2003) and European Environmental Agency (EEA) (1998, 2003). D is known from literature for most OECD countries for the 1970–2000 period. For countries where no data are available, D is calculated as follows:

$$D = C\ U\ Su \qquad [11]$$

where C is a dimensionless correction factor; U is the population in urban areas as fraction of total population; and Su is the urban population with access to 'improved sanitation' as fraction of the urban population. Hence, where D, U and Su are known for e.g. the year 2000, the correction factor C can be calculated. We applied this calibrated value of C for 2000 for other years, so that a trend for D can be obtained from the available trends in U and Su. If no data on D are available in the literature, we use the regional estimate for C.

By using equation [11] we neglected waste water N emissions from rural populations. The access to improved sanitation differs between rural and urban populations. For industrialized countries the access is generally 100% for both rural and urban populations. However, in transition and developing countries the access to improved sanitation is much lower for the rural than for the urban population. For example, WHO/UNICEF (2000) reports for Romania for the mid-1990s that 86% of the urban - and only 10% of the rural population is served with access to 'improved sanitation'. Outside Europe public sewerage systems in rural areas are rare. Particularly in the rural areas of many developing countries, the human waste is commonly collected in latrines or septic tanks; we assume that this does not enter the surface water. However, in densely populated developing countries in the tropics with a high proportion of the population living in rural areas, we think the contribution of sewage nitrogen to surface water pollution can be significant. We do not account for coastal areas with direct discharge to the sea as far as this practice is not included in the no-treatment class.

Table 3.4 Types of sewage treatment distinguished and their nitrogen removal rates

	This study	Kristensen et al. (2004)
	%	
None	0	0
Mechanical	10	20 - 25
Biological	35	36 - 55
Advanced	80	45 - 83

For the removal of nitrogen (R), different types of waste water treatment are distinguished *(Table 3.4)*. The value for R is calculated as the weighted average of no treatment, mechanical, biological, and advanced treatment. Data on the distribution over the different types of treatment are known for most European countries (EEA, 1998). (Eurostat data from http://epp.eurostat.ec.europa.eu). Data for many other countries rely on various sources. For countries where no data were found to estimate R we use regional estimates, primarily on the basis of the WHO/UNICEF Joint Monitoring Program (WHO/UNICEF, 2000). In most developing countries the overall N removal rate is low because advanced and biological treatment are not widespread. Errors in the estimated N discharge from sewerage systems are, therefore, small. Projections for waste water treatment for 2030 are not available. We assumed that a doubling of the N-removal percentage in the period 1995-2030 must be possible (see *Table 3.5*). We assumed a maximum N-removal of 80%, based on current treatment technology.

Nonpoint sources

Each IMAGE agricultural 0.5 by 0.5 degree gridcell consists of four aggregated agricultural land uses, including grassland, wetland rice, leguminous crops (pulses, soybeans) and other upland crops *(Figure 3.12)*. The annual surface nitrogen balance includes the nitrogen inputs and outputs for each land use type. Nitrogen inputs include biological nitrogen fixation (N_{fix}), atmospheric nitrogen deposition (N_{dep}), application of synthetic nitrogen fertilizer (N_{fert}) and animal manure (N_{man}). 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 (N_{exp}). The surplus of the surface nitrogen balance (N_{sur}) is calculated as follows:

$$N_{\text{sur}} = N_{\text{fix}} + N_{\text{dep}} + N_{\text{fert}} + N_{\text{man}} - N_{\text{exp}} \tag{12}$$

The different input and output terms of the surface balance are discussed in detail in various publications (Bouwman, 2006; Bouwman, 2005). N_{sur} is subject to NH_3 volatilization, denitrification and leaching from the root zone to the upper groundwater. NH_3 volatilization

Table 3.5 Assumptions for access to improved sanitation, population with sewerage connection and nitrogen removal in sewage treatment systems

	Baseline	pp Global
S_u, access to improved sanitation (fraction of urban population)	S_u is constant, i.e. fraction of population with improved sanitation grows at the same rate as urbanization	50% of the gap between $S_{u,2000}$ and S_u=100% is closed in 2030
D, population connected to public sewerage (fraction of urban population)	*D* is constant, i.e. urban population with sewerage connection is a constant fraction of S_u	50% of the gap between D_{2000} and 100% connection in urban areas is reached in 2030
R, removal of nitrogen in sewage treatment plants (%)	50% of the gap between 2000 and the target is closed. Target is twice that in 2000 ($R_{2030}=2R_{2000}$)$^{a)}$.	100% of the gap between 2000 and the target is closed. Target is twice that in 2000 ($R_{2030}=2R_{2000}$)$^{a)}$.

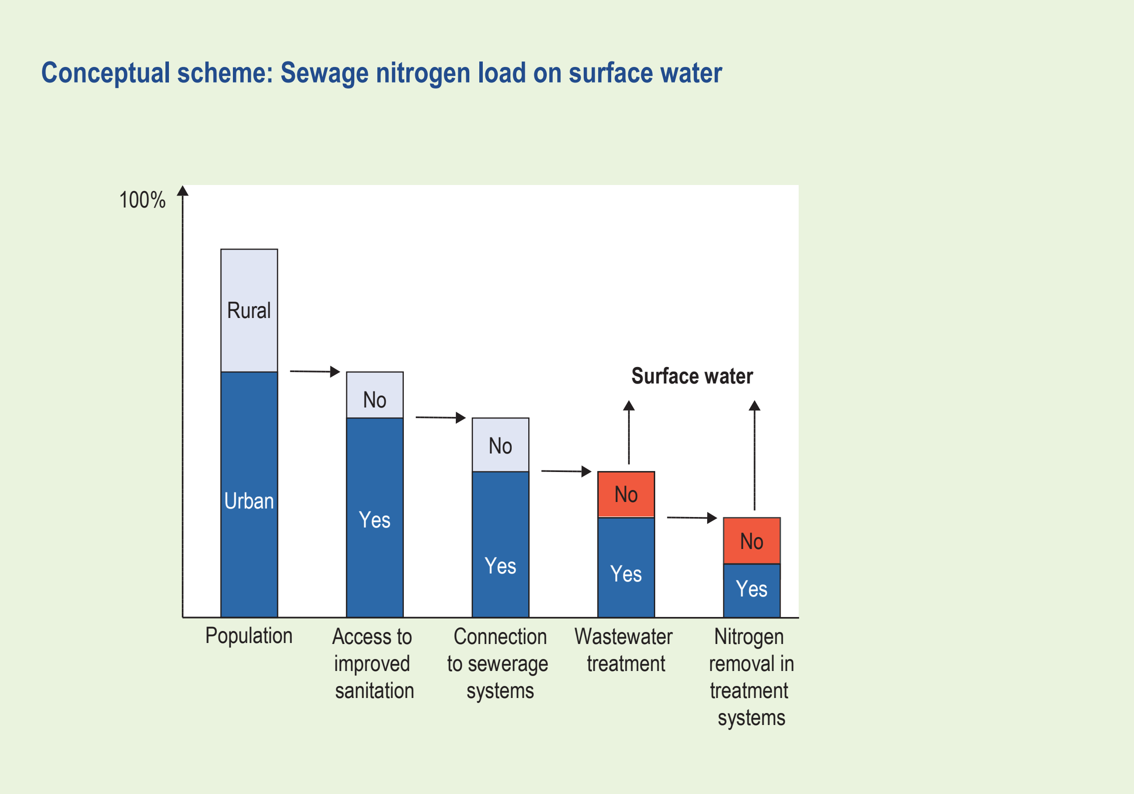


Figure 3.10 Scheme of estimation of sewage nitrogen effluent to surface water
(096g_oec08)

is based on different approaches for animal houses and manure storage systems, grazing and spreading of manure as described in various papers (Bouwman, 1997; Bouwman, 2005). For leaching and denitrification we developed a model for soils under rainfed crops that combines the effect of temperature, crop type, soil properties and hydrological conditions on annual mean nitrate leaching and denitrification rates (Van Drecht, 2003).

The groundwater flowing into draining surface water is a mixture of water with varying residence times in the groundwater system. The nitrate concentration in groundwater depends on the historical year of water infiltration into the saturated zone and the denitrification loss during its transport. Two groundwater subsystems are distinguished, i.e. shallow groundwater with rapid transport of nitrate in surface runoff and flow through shallow groundwater to local water courses and deep groundwater with slow transport through deep groundwater towards larger streams and rivers *(Figure 3.12)*. Shallow groundwater both recharges the deep groundwater layer and discharges into local water courses.

River nitrogen transport

The total nitrogen from point sources, direct atmospheric deposition and nitrate flows from shallow and deep groundwater form 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, atmosphere or stream sediments. We use a global river-export coefficient of 0.7 (implying retention and loss of 30% of the nitrogen discharged to streams and rivers) which represents a mean of a wide variety of river basins in Europe and the USA used by Van Drecht et al. (2003).

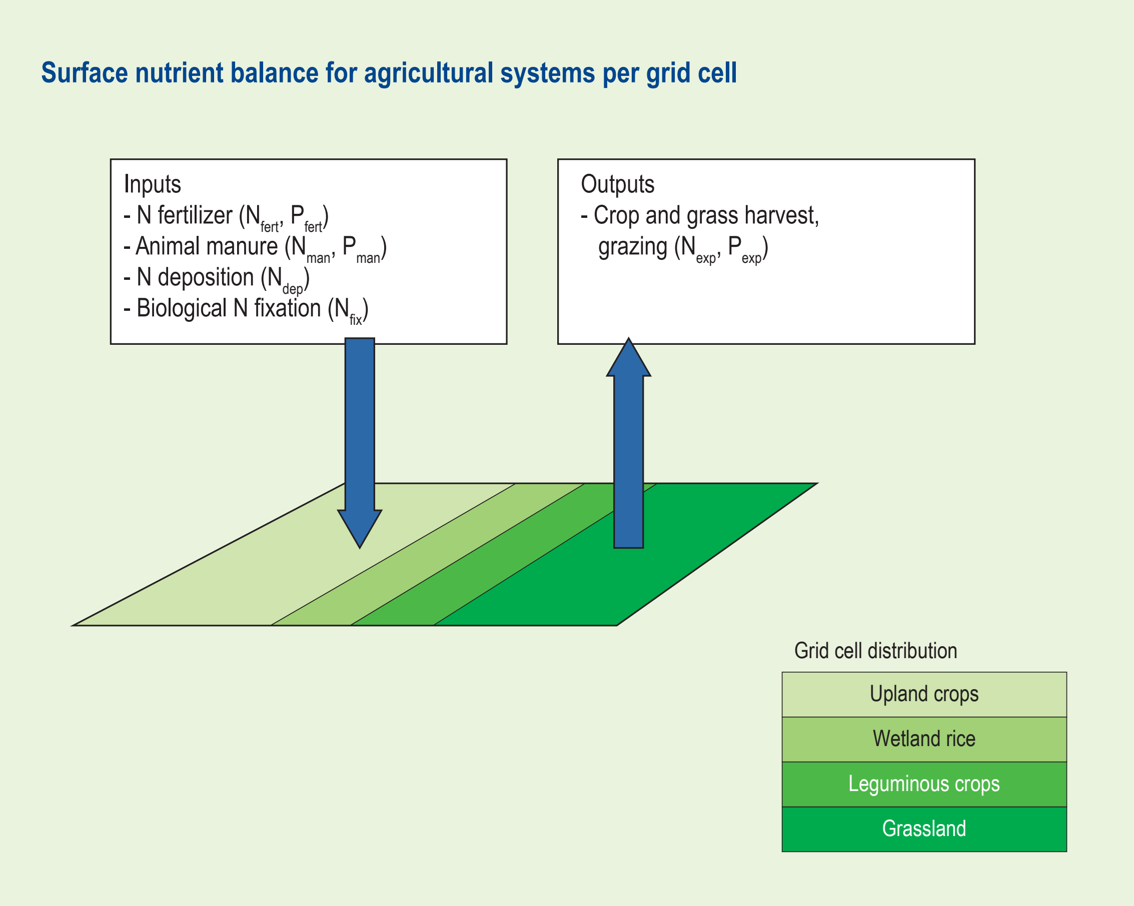


Figure 3.11 Scheme of surface nitrogen balance for agricultural systems
(097s_oec08)
Applied within each 0.5 by 0.5 degree grid cell in IMAGE 2.4.
Nsur is defined as the difference between nitrogen inputs and outputs according to equation (3).
Nsur is subject to ammonia volatilization, denitrification or leaching.

3.1.12 Biodiversity Indicator and Modelling

According to the Convention on Biological Diversity (CBD), biodiversity encompasses the overall variety found in the living world and includes the variation in genes, populations, species and ecosystems. Several complementary indices are used within the CBD framework. In this document biodiversity loss has been expressed for each biome in the mean relative abundance of the original species (MSA). In this index, the abundances of individual species are compared to their abundances in the natural or low-impacted state. Therefore, this aggregated indicator can be interpreted as a measure of 'naturalness' or 'intactness', and is similar to the Biodiversity Intactness Index BII (Scholes and Biggs, 2005).

The Biodiversity indicator MSA
Mean species abundance is not an absolute measure of biodiversity. If the indicator value is 100%, the biodiversity is similar to the natural or low-affected state. If the indicator value is 50%, the average abundance of original species is 50% of the natural or low-affected state, and so on. By definition, the abundance of exotic or invasive species is not included in the indicator, but their impact shows by the decrease in the abundance of the original species they replace.

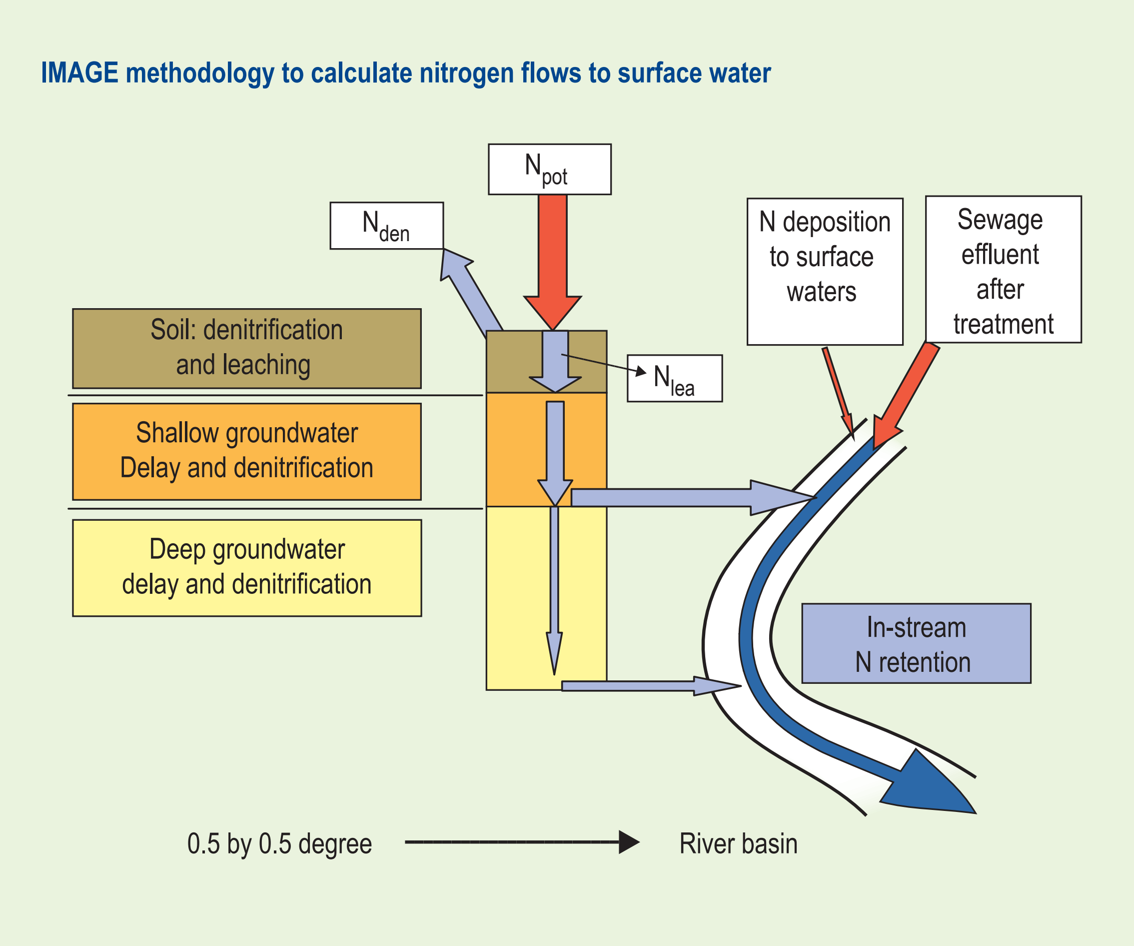


Figure 3.12 IMAGE 2.4 calculation of river nitrogen load from nitrogen leaching, atmospheric nitrogen deposition and sewage nitrogen effluent

Based on Van Drecht et al. (2003) (098s_0ec08)

As a result of human activities, different ecosystem types are often becoming more and more alike. This is sometimes referred to as 'levelling out' or 'homogenisation' of biodiversity (Ten Brink, 2000; Pauly, 1998; Scholes and Biggs, 2005; MEA, 2005). Strongly expanding species, which may sometimes even become plagues in terms of invasions and infestations, are a signal of both biodiversity loss and decreasing populations. *Figure 3.13* illustrates the difference between an intact, rich ecosystem (left) and a degraded ecosystem (right). The individual species abundances in the left hand graph reflect the (indexed) natural population sizes for a variety of species that span the range for an intact system (shaded area). In contrast, the abundance of most species in the middle and right hand graphs have dropped below this range, reflecting a loss of species and a skewed distribution of population sizes. The calculated MSA indicator values (red horizontal lines) drop from left to right, reflecting the homogenisation process.

MSA can be specified for geographical regions and different nature types (or biomes). The MSA values at the global and regional levels are the sum of the underlying biome values (in km²) in which the abundances for each biome are equally weighted (Ten Brink, 2000; UNEP, 2003 and 2004).The contribution of different causes of loss can be distinguished, which offers the opportunity to assess the effects of policy options targeted at pressures. The indicator is very suitable for use in comparing different future projections that give developments in direct and indirect drivers related to the distinguished pressures (CBD & MNP, 2007).

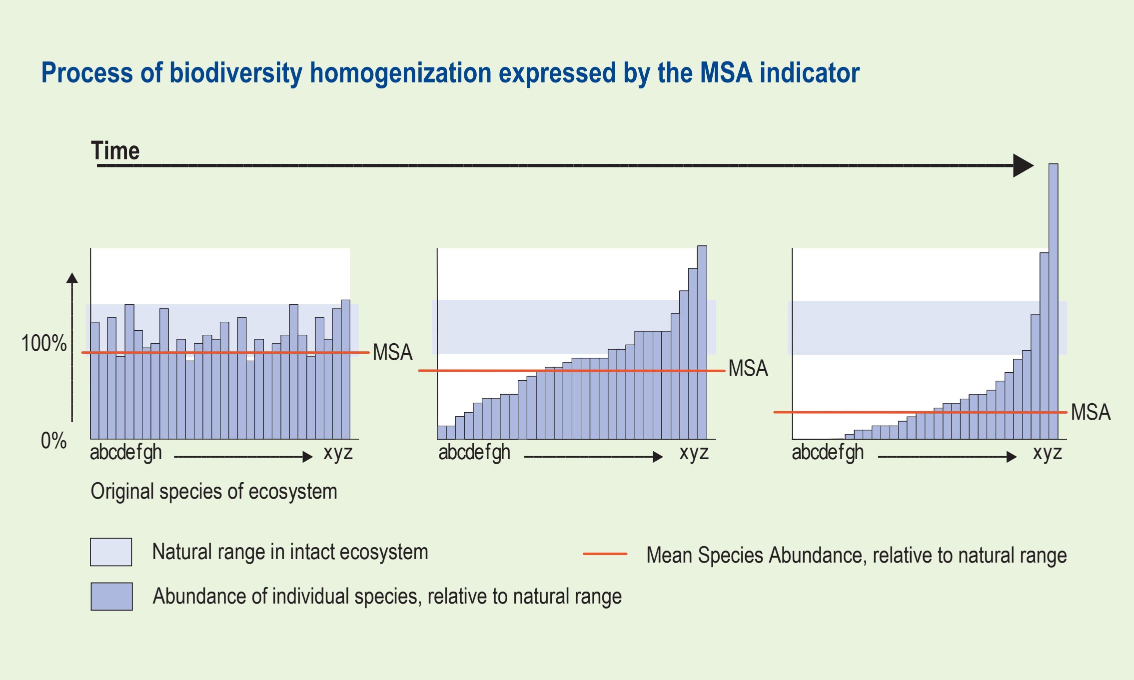


Figure 3.13 Homogenization process and mean species abundance (conceptual scheme)
(093x_oec08)

The various nature types in the world, also called 'biomes' vary greatly in the number of species, their species composition and their species abundance. Obviously a tropical rainforest is entirely different from tundra or polar systems. A key feature is that the indicator treats the biodiversity value of all ecosystems alike, whether tundra or tropical rainforest. Thus, the indicator allows aggregation and projection into the future only because it is a crude measure.

By equally weighing, no additional value is assigned to endangered ecosystems. The MSA indicator is not intended to highlight individual species under threat. Lastly, aggregation across regions may also mask differences between regions or biomes by averaging.

It should be emphasized that the presented results are rough estimates only and based on pressures that are model outcomes in themselves, instead of monitored pressures. In reality, impacts of the various pressures are probably not independent but are interacting. Furthermore, effects related to climate change are long-term, i.e. the consequence of slowly changing species composition. In fact, in ecosystems in the northern regions, which are at present already under significantly large pressure from the current rate of climate change, the modeled climate change effects have not yet materialized (Ten Brink, 2000).

Vice versa, when pressures decrease, the model will show a fast recovery in biodiversity. In reality, restoration will take a considerable amount of time. Analysis of the GLOBIO literature database on secondary forest growth showed that a full recovery of biodiversity (in MSA) is not likely within 50 years, with distinct differences in species groups (birds, plants, insects). In 50 years, biodiversity converges to an MSA value around 0.5. The recovery of specific canopy species will take more than 100 years. This long period for full recovery is the consequence of the complex vertical layered structure of especially tropical forests, and the slow growth rates of trees that dominate the climax situation (Peña-Claros, 2003).

Complete recovery in abandoned agricultural areas to natural grassland ecosystems may be faster than for forests, as their vertical structure is less complex. Restoration of low productive heathlands on former agricultural fields was especially difficult for rare plant species, while insects responded much more quickly (Verhagen, 2007).The recovery process could not be completely analysed with the literature contained in the current GLOBIO database.

The Biodiversity model GLOBIO3

One of the advantages of 'mean species abundance' is that it can be measured and modeled relatively easily. In a straightforward multiplicative approach, the MNP GLOBIO3 model (Alkemade et al., 2006) combines estimates for key pressures on biodiversity. These pressures include climate change, nitrogen deposition, land-use change (agriculture, forestry, urban), fragmentation, infrastructure and human settlement.

The core of GLOBIO3 is a set of regression equations describing the impact on biodiversity of the degree of pressure using dose-response relationships. These dose-response relationships are derived from a database of observations of species response to change. The database includes separate measures of MSA, each in relation to different degrees of pressure exerted by various pressure factors or driving forces. The entries in the database are all derived from studies in the peer-reviewed literature, reporting either on change through time in a single plot, or on response in parallel plots undergoing different pressures.

The current version of the database includes data from approximately 500 peer-reviewed studies, about 140 studies on the relationship between species abundance and land cover or land use, 50 on atmospheric nitrogen deposition (Bobbink, 2004), over 300 on impacts of infrastructure (UNEP, 2001) and several literature studies on minimal area requirements of species. Dose-response relationships for climate change are based on model studies (Bakkenes et al., 2002; Leemans and Eickhout, 2004)

The pressures on biodiversity considered with GLOBIO3 include land cover change (quantification taken from IMAGE), land use intensity (partly taken from IMAGE), atmospheric nitrogen deposition (see section 3.11), infrastructure development (as applied in GLOBIO2), fragmentation and climate change (both taken from IMAGE).

Indirect drivers of biodiversity change, such as human population density and energy use, are not used explicitly in the GLOBIO3 framework, but they impact biodiversity through their influence on other, direct, drivers. For example, changes of the direct drivers (land use, climate, atmospheric nitrogen deposition and forestry) due to changing demography and socio-economic developments are calculated with IMAGE (Bouwman et al., 2006). Changes of infrastructure are calculated with the GLOBIO2 model (UNEP, 2001).

For land-use change, the MSA value of a human influenced land-cover type depends on to the local pristine or reference situation. For instance, a forest converted to intensively used grassland has a lower remaining MSA than a natural grassland converted to the same land-cover, as the converted grassland resembles the original situation more. The fragmentation effect is related the size of natural continuous land-cover types, and their capacity to sustainably house viable populations of species (Smout et al. in prep). The combination of the multiple impacts results in estimates for changes in species abundance and extent of natural areas on a detailed spatial grid (0.5 x 0.5 degree, conform to IMAGE).

The effect of infrastructure is based on the GLOBIO2 model (UNEP & RIVM 2004), which treats infrastructure as a proxy for a range of pressure factors. The GLOBIO3 model treats the pressure factors independently, but still uses the infrastructure knowledge base of GLOBIO2 to estimate the impact of infrastructure expansion. Therefore, the infrastructure effect is most probably overestimated. Improvements of the GLOBIO3 model to solve this are under development.

3.1.13 Connections between the models

Whereas each of the models used for the *OECD Environmental Outlook* has been applied before, or is derived from a model that has been applied before, the precise way these models have been combined is unique to this study. Therefore this section presents three diagrams depicting the flow of information between the models.

Figure 3.14 provides an overview. Important characteristics are the following.

The overall logic of the model network is linear causality, from driving forces, to environmental pressures, to environmental changes and impacts, to responses that act on various links in the chain. Thus, the economic modelling estimates driving forces of environmental change. Subsequently, integrated assessment modelling with an environmental focus estimates the consequences.

Further to the principal scheme of *Figure 3.1*, energy and land-related modelling form an important ‘bridge’ between the economic model and modelling of environmental changes and further impacts for the *OECD Environmental Outlook* to 2030.

As described in section 3.1.1, the environmental results are not fed back to the economic and demographic assumptions, in the sense that they would for example negatively impact economic development.

One important flow of information looping back from the environmental to the economic modelling is cost of environmental protection measures to be evaluated for their impact on GDP. This information flow existed in two forms. Either, estimates for direct abatement cost were generated by the environmental modelling, as in cost of air pollution control measures, and then fed the economic modelling. Or, as in energy-related emissions of carbon dioxide, estimations for the required decrease in pressure on the environment were fed to the economic modelling which then had to find the corresponding carbon price path and hence the impact on value added, by sector, by region and over time.

An important limitation of the network needs to be mentioned, namely that agricultural production and water quantity issues have been analysed with separate models. The agricultural projections, such as production volumes per commodity, precise location, crop area and assumed irrigation, have been set as conditions for the water use modelling. This ensures consistency under otherwise equal conditions. But it does answer the question whether the Baseline development in water management will provide enough water for the ongoing improvement in agricultural efficiency which has been assumed in the Baseline. (Global agricultural production increasing more than 50% while the agricultural area increases only 10%, by 2030.)

Figures 3.15 and *3.16* provide close-ups for the model connections on urban air quality and its impacts on population health and for projections of the load of nitrogen compounds on the

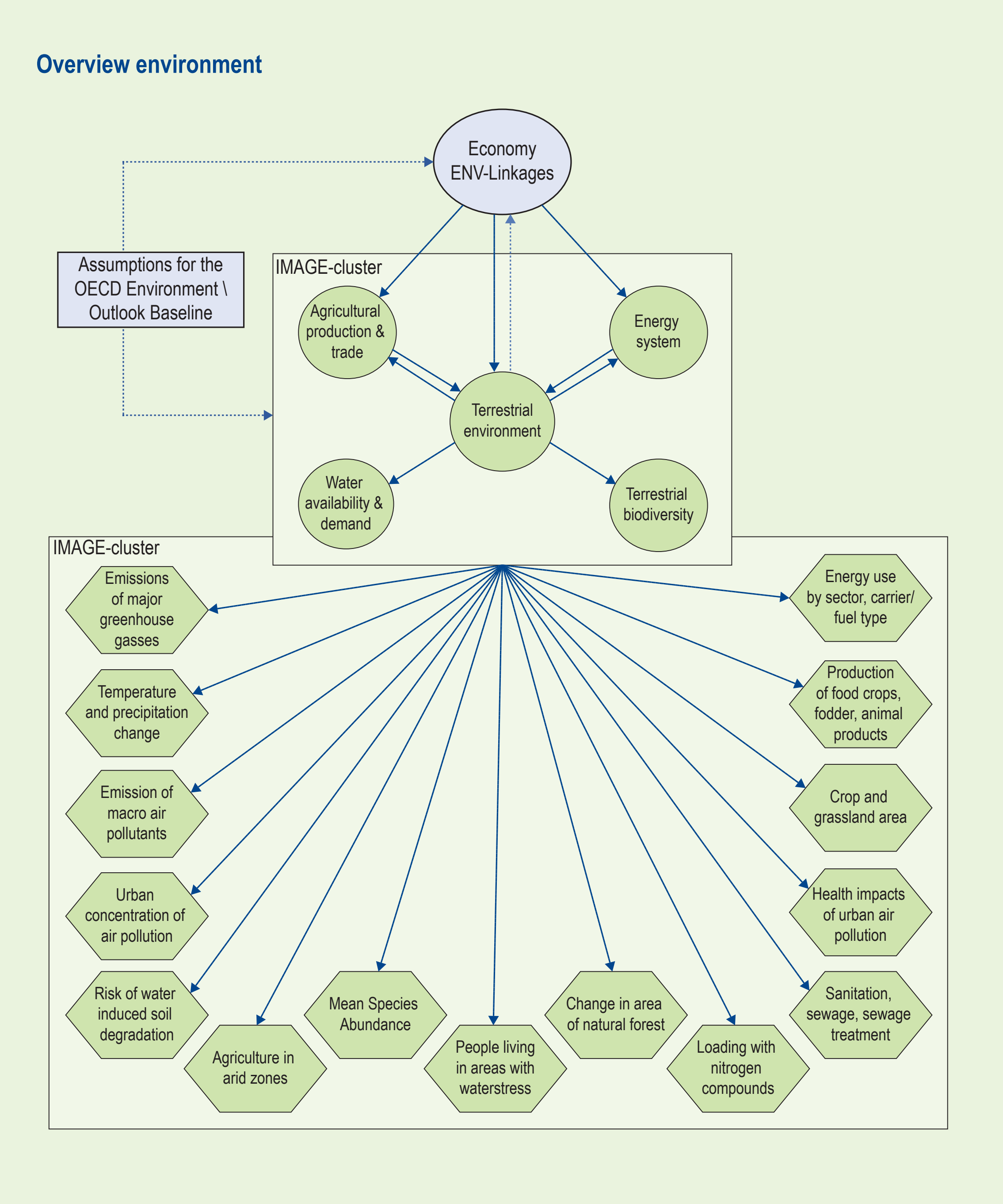


Figure 3.14 Dataflow overview environment
(099s_oec08)

environment. For both issues, two flows through the environment are modelled and the estimates combined.

The projections of urban air quality consider particulate matter, influenced by local and regional emissions. They also consider groundlevel ozone, product of relatively complicated atmospheric chemistry and influenced by local and regional emissions as well as emissions around the globe on the Northern hemisphere. The projections of concentrations and exposure for these two pollutants are handled by separate strands of modelling. Subsequently, for both pollutants the future impacts on population health are estimated using the respective routines of the WHO Comparative Risk Assessment. The methodology is described in section 3.1.10.

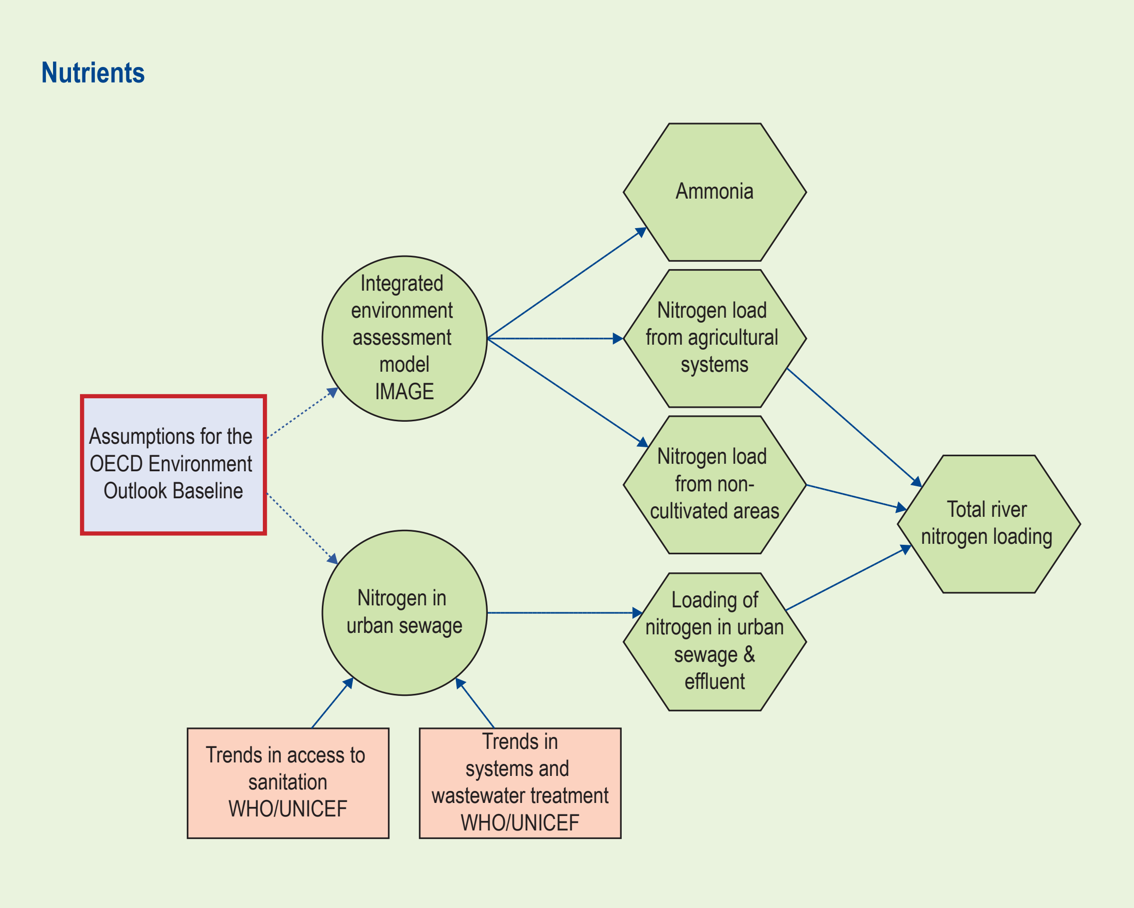


Figure 3.15 Dataflow nutrients
(100s_oec08)

The load of nitrogen compounds on surface water combines estimates for non-point sources (dominated by agriculture) and point sources (focusing on sewage and sewage treatment effluent). The methodology is described in section 3.1.11.

Last but not least, an important information flow that runs in parallel to the data being passed on from model team to model team is the general understanding of the baseline and the policy cases. *Figure 3.14* shows this under the broad term of 'assumptions'. For example, precisely how is the 'no new policies' principle to be understood in each sector.

3.2 Uncertainty issues and limitations

3.2.1 Introduction

The outcomes of the analysis in the *OECD Environmental Outlook* are conditional on the numerous choices and assumptions made in working out the Baseline and the associated policy packages (see the introductions to sections 2.1 and 2.2). In addition, there are many sources of uncertainty and other limitations that can influence these results, including problem framing; the preselection of issues for the Outlook to focus on; indicator selection; data quality and imprecisions, model restrictions and characteristics; baseline assumptions; and the status of the under-

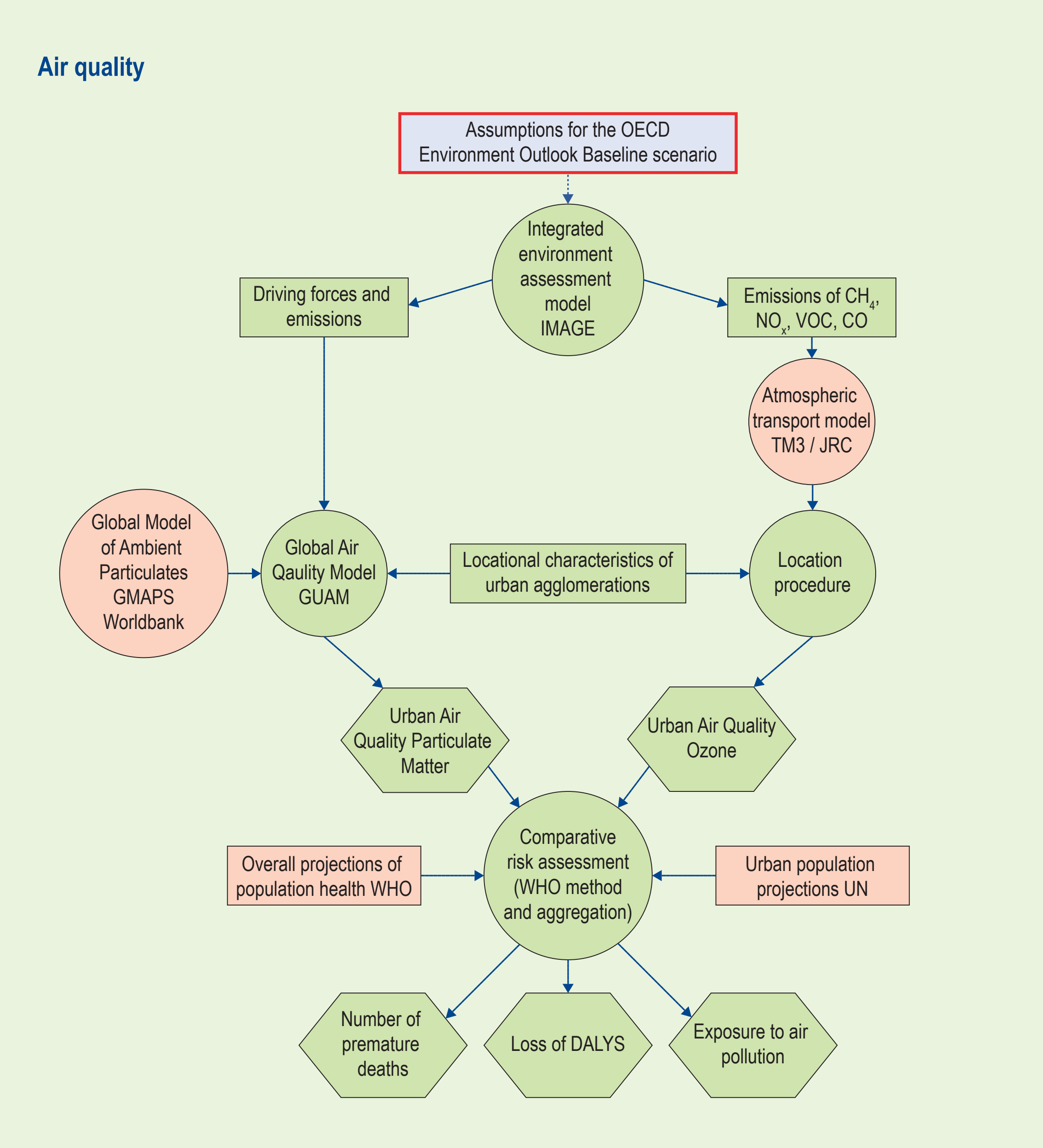


Figure 3.16 Dataflow air quality
(101s_oec08)

standing and knowledge about the way the environment reacts to various pressures (Janssen et al., 2005).

Given practical restrictions, these aspects could only be partially dealt with in the *OECD Environmental Outlook*. However, most chapters in the Outlook and this background report identify and briefly discuss key uncertainties. Moreover, the final pages of the Outlook (pages 512-515) provide a short overview of its model-related uncertainties. In the current chapter this picture is complement by briefly listing and discussing some central issues pertaining to uncertainties and by commenting on the main substantive findings in the light of these uncertainties.

In doing so, one should bear in mind that, inevitably, there will always be uncertainties involved which are – for the time being - not or not completely known. As Liu et al. (2007) argue, in integrated studies of coupled human and natural systems new and complex patterns and processes will occur, which are not evident when studied from a single (social science or natural science) perspective. Every assessment runs the risk of missing some of these features, due to a lack of knowledge on mechanisms involved, and due to practical restrictions in modeling and data. This will inevitably contribute to the uncertainty in the results.

3.2.2 Sources of uncertainty

Framing of the study
Returning to a discussion of specific sources of uncertainty, one of the basic choices and limitations lies in the framing of the study.

Scope of the OECD Environmental Outlook
The present *OECD Environmental Outlook to 2030* is a follow-up of the 2001 *OECD Environmental Outlook* with updated projections and new policy simulations, centering especially around the critical ('red light') issues in the *OECD Environmental Outlook* (2001) and in the *OECD Environmental Strategy for the First Decade of the 21st Century*. These include the priority issues of climate change, biodiversity loss, and water scarcity, considering key sectors like agriculture, energy and transport. Other sectors, which strongly affect natural resource use or pollution, such as fisheries or chemicals, and selected industries (steel, cement, pulp and paper, tourism and mining) have also been included. In addition, a new priority issue was studied on the health impacts of the build-up of chemicals in the environment. Not all of these issues have been analysed in the modelling exercise reported here.

The above choices have been made partly on practical grounds to limit the extent of the investigation, while it was judged that the overall conclusions would not be drastically different if these factors would have been included. One should however realise that, for instance, excluding vulnerability aspects and adaptation capabilities from analysis of the quantitative simulations, might lead to underestimation of the burden of environmental change, especially in the Rest of the World group.

Baseline
Another important issue in framing concerns the choice of the Baseline, which serves as the backbone of the *OECD Environmental Outlook*. Other recent integrated assessments, like IPCC and GEO 4, use multiple – typically four - scenarios to account for uncertainties involved in future developments. The *OECD Environmental Outlook* has taken another stance and uses one baseline as a reference path into the future. The *OECD Environmental Outlook* has taken another stance and uses one baseline as a reference path into the future, as part of the policy-focus of the Outlook as this enables a clear analysis of the differences between the baseline and the specific policies and policy packages simulated. As a consequence, the model-based *OECD Environmental Outlook* has uncertainties concerning future developments not integrated in the sense of contrasting scenarios. Rather, uncertainties stemming from the baseline are addressed by added analysis of economic variants and sensitivity runs. Therefore, the conclusions concerning the baseline developments and the effects of policy options should always be viewed conditional on the employed assumptions and settings.

The Baseline is not to be viewed as the most plausible description of future development. Rather, it renders a somewhat synthetic reference projection of current trends and developments, essentially assuming there to be 'no new policies' in the areas under study which go beyond the currently agreed upon policy plans for the future (for example, for trade liberalisation and agricultural subsidies). Moreover, unforeseen disturbances are also excluded from the Baseline. The function of the Baseline lies principally in signalling potential needs for new policies, and in serving as a counterfactual reference situation for assessing the needs for and the potential effects of future new policy options.

Some sensitivity analysis was performed, and a few variations to the baseline were developed in which a number of key assumptions in the economic drivers underlying the model ENV-Linkage, has been varied in the Baseline. For example, taking the higher growth of the recent 2001-2005 time period as indicative for medium-term productivity growth rates, instead of the more conservative growth trend in the historical 1981-2001 time period. This sensitivity analysis is reported in Chapter 6 of the Outlook. In essence, it shows that the uncertainty in the baseline lies asymmetrically on the
side of more activity and more pressure on the environment, in particular in dynamic new economies such as BRIC.

Compared to other major environmental analyses that look to the future (for instance, the IPCC Fourth Assessment Report) in terms of GDP per capita, energy use and agricultural production, the Baseline of this Outlook can be positioned as a kind of Business-as-Usual scenario. For example, new Doha Round agreements are excluded. The energy system, specifically, might develop in very different ways. This is illustrated by the IPCC SRES scenarios (IPCC, 2000). Although the population and economic assumptions are very similar for two of the IPCC scenarios (A1 and B1), these scenarios develop in very different ways, depending on assumptions on lifestyle and technology. Van Vuuren (2007) gives an illustration of how the emissions – even for tightly defined storylines - can still widely vary as a result of uncertainties in energy resources, technology development and structural economic changes.

Technologic development in the Baseline is intended to give a realistic future projection under 'no new policy', and is similar to what specialiced bodies like IEA and FAO report. However, comparing the Baseline to the outcomes of simulations reflecting new policy, its results should not be misinterpreted as a minimum quality or lower end limit. Situations could worsen under new policy, as exemplified by the liberalisation of the agricultural policy. On the one hand, for example, agricultural productivity could increase due to efficiency improvements (intensification) while, on the other hand, production area could increase (extensification), leading to considerable more land use and associated deterioration of biodiversity. Similarly, although in line with the IEA projections, Baseline assumptions about a cleaner fuel mix in future emissions for countries like Russia, may be far too optimistic. Namely, the situation could work out quite differently if Russia - as seems more in line with reality - decides to use gas primarily for export, and coal-fired plants and nuclear energy for the internal market.

This discussion shows, that in using the Baseline for policy analysis one should, preferably, focus more on describing effects in terms of general patterns and trends, instead of adhering too much value to overly specific descriptions of illusively precise amounts and spatial details.

Policy options

Similar to the choice of the Baseline, the choice of the policy options to be evaluated is also an important aspect of the framing of the study. As described in parts 1 and 2, the centrepiece of the policy analysis for the Outlook is formed by three policy packages. The results are described in this report, in addition to a relatively large number of variants supporting a closer look at climate policies – variants on timing, burden sharing and ambition. Finally, reported in the Outlook, but not in this background report, are theme-specific stand-alone analyses. These analyses have been performed with only part of the model suite, for instance, the economic model, and, therefore, they render only a partial picture of the issues at hand.

Practicality and the interests expressed in delegation meetings during the preparation of the *OECD Environmental Outlook*, have been leading in chosing the policy packages for the integrated analysis. The focus of these packages is to study how timing and intensity of cooperation between OECD and non-OECD countries will affect the results. This is applied to a selected set of issues, namely agricultural liberalisation, climate change policies, air pollution and sewage treatment. Other urgent issues, like biodiversity protection or water use have not been explicitly addressed in this integrative policy package analysis. Therefore, the assessment is tilted away from these issues. One should be aware of this when interpreting the results of the *OECD Environmental Outlook*. For instance, the effect of the considered policy packages on the biodiversity indicator is in most cases rather insignificant. This e absence should not be interpreted as a failure of biodiversity policies, because these were simply not included in the policy packages. Rather, the simulation results for biodiversity reflect the policies that were included (climate change mitigation, air pollution control). These produce ancillary benefits to the biodiversity target but these effects are small. Moreover, the fact that the 450 ppm multigas policy case results in improved biodiversity is not to be considered a result of climate policy, but rather of the assumed agricultural setting (compact agriculture).

In addition to the above framing issues concerning the choice of the Baseline and of the policy packages involved, some other relevant uncertainty issues are briefly discussed, point by point.

The modelling framework

Obviously, the various model components used for this *OECD Environmental Outlook*, as well as the way they are combined, contribute to the uncertainty and limitations of its findings. To further identify the sources of uncertainty and the limitations, this section discusses the main components of the modelling framework. It does so model by model. In addition, Annex B of the Outlook itself provides a somewhat shorter overview, theme by theme (energy, land, …).

Environment-economy feedbacks

The model system used in the *OECD Environmental Outlook*, despite its state-of-the-art character for integrated assessment studies, has its limitations in describing the mechanisms and couplings in the interaction between the environment and the socio-economic system. For instance, although it shows the impact of the global economy's development on the environment, it does not allow for a direct feedback of the environmental impacts on economy and demography. That might even be outside the remit of the Outlook, aiming for a simple and straightforward story. As a consequence the Baseline does not reflect GDP loss from environmental damage, or sectoral shifts to accommodate it. The immediate consequence is that GDP projections may be higher than justified – to which degree will probably differ between regions. Moreover, due to this missing feedback, environmental policy will always be portrayed as involving a loss of GDP, which misleadingly implies that environmental policy always decreases welfare.

General Equilibrium modeling

One of the primary drivers of the IMAGE model and its associated components is found in the economic results, provided by the general equilibrium model ENV-linkages. The agriculture-related results given by the agro-economic LEITAP model, are also based on a general equilibrium model. The popularity of general equilibrium modelling does not stem from its ability to provide accurate predictions – its limitations are well known and have been discussed by economists for some time (for recent critiques see, Scrieciu, 2007, Köhler et al., 2006, Taylor and von Arnim, 2006). Rather, the popularity of general equilibrium models rests on their underpinnings in principles of economic analysis, which many analysts and policymakers find valuable for sifting through the interlinkages in modern economies. Many of the characteristics do not conform to the day-to-day economy that most people experience, but they are long-term principles of observed economic behaviour which policy ignores at its peril. These characteristics are sometimes seen as a weaknesses in the general equilibrium approach (e.g. assumptions on (nearly) perfect foresight and competition, on representative and rational agents, on elasticities, exchange rates, causalities and endogenisation of technical change. The classical example of economic policy that ignored principles of economic behaviour, was the stagflation of the 1970s - which is generally viewed as having been caused by policies pursued during the 1960s. Nonetheless, since these models are founded on the notion of complete markets, they have difficulty assessing the non-marketed issues that most environmental policy is intended to address. Thus, they provide a limited partial picture of the impact of policy, unless coupled with alternative models that can better capture aspects of the physical world that people care about.

The IMAGE model

With respect to the IMAGE model itself, no comprehensive and systematic exploration of key uncertainties has been performed, and of how they are propagated throughout the entire IMAGE model to influence the final results. What has been done, for many aspects, is an analysis of uncertainties of underlying data and model formulations in subsystems of the overall framework, thus providing partial sensitivity analyses for the IMAGE 2.4 framework. An overview of the available sensitivity studies for the main modules has been presented in a recent publication (Bouwman et al., 2006). To stress the importance of a detailed documentation of model uncertainties, this section is cited here, with some additions.

Energy modelling

An earlier version of the TIMER energy and emissions model was systematically examined to establish the most important parameter settings and model assumptions influencing model results. This exploration uses the NUmeral Spread Assessment Pedigree (NUSAP) system (Van der Sluijs et al., 2005). Input variables and model components most sensitive to projected carbon dioxide emissions, were population and economic growth; shifts in economic structure; technology improvement factors; fossil and renewable resource cost/supply curves; and autonomous and price-induced efficiency gains. Combined with the outcome of expert appraisal of the parameter 'pedigree', estimates of the 'strength' of the parameters were added to their sensitivity.

Emission data

Obviously, any projection of future environmental conditions rests critically on the underlying emission factors and their relationship with relevant human activities or drivers. The IMAGE model has incorporated the most recent and authoritative sources. Despite ongoing efforts to collect data and enhance statistical procedures and modelling, many emission sources of greenhouse gases and other anthropogenic trace gases remain uncertain. Van Aardenne et al. (2001) have overviewed the qualitative analysis of activity data, emission factors and grid maps as in IMAGE. As a rule, emissions from large point sources, such as power plants, tend to be of acceptable quality, while smaller and dispersed sources are typically poor to very poor. Global or large-scale regional aggregate budgets are generally fairly certain whereas the contribution of sectors and activities by geographic location is for the most part much more uncertain. Emission factors that depend on fuel properties, like carbon dioxide and sulphur dioxide, can be estimated within narrow ranges, but other emissions are very sensitive to technological details, local conditions like soil properties, and management practices. This induces not only uncertainties in the initial inventories, but also in future emission projections.

Agricultural economy

In the coupled application of the agro-economic GTAP model and IMAGE, land supply curves play a crucial role in establishing agricultural demands, production and trade flows. Derived from biophysical properties in IMAGE, land supply curves are used in GTAP, to find solutions of equilibrium for agricultural land volumes and the associated land rental rate (see chapter 4 of Bouwman et al., 2006). To test the sensitivity, simulation experiments were run with the asymptote 2.5% lower and 2.5% higher than the central estimate. In addition, the impacts on model results for land supply, the real land rental rate and production changes were investigated (Tabeau et al., 2006). Analyses show, that changing the asymptote of the land supply function leads to significant changes of land supply for countries where agricultural land is relatively scarce. However, the induced production changes are rather low. The aggregated agricultural production elasticity, with respect to the asymptote change, varies from 0.1 for countries where agricultural land is abundant to 0.5 for countries where agricultural land is scarce. This means that the simulation results for production development are rather robust with regard to the estimated land supply curve parameters.

Ammonia

The sensitivity of ammonia volatilisation in agricultural production systems, to variation in input parameters, was researched by Bouwman et al. (2006). Various parameters were selected, including nitrogen excretion per head, animal stocks, the distribution of production over pastoral, mixed and landless systems, fertiliser inputs and the ammonia emission factors for animal housing, etc. A consolidated assessment of these uncertainties in ammonia emissions from agricultural systems is provided by Beusen et al. (in press). The results suggest that on the global scale, the most important parameters in the model are excretion of nitrogen per head, and animal stocks. However, the importance of the various parameters varies among world regions and countries. For example, in China fertiliser use is a far more important determinant for total ammonia loss than in other world regions, while in India the use of manure as fuel is a very important process. The overall conclusion is that the spatial modelling of nutrient use with IMAGE, allows for analysis of various policy alternatives and consequences for the nitrogen cascade.

Carbon cycle

The terrestrial carbon cycle model, implemented in the IMAGE framework, has been subjected to a thorough evaluation (Van Minnen, 2008), which has shown it to be suitable for simulating global and regional carbon pools and fluxes. Sensitivity analysis shows that uncertainties in the response of the biosphere to climate and land use change are crucial to understanding the global carbon cycle. A dominant factor at both the global and regional scales is the reaction of the biosphere to increasing concentrations of carbon dioxide. There are other uncertainties. For example, the role of nitrogen limitation in temperate ecosystems is not included, and this may cause smaller carbon dioxide uptake than currently thought. Although, in large parts of the tropics nitrogen is not limiting, so the carbon dioxide sink may be underestimated. Overall, the IMAGE modelling of carbon dioxide fertilisation in terrestrial systems is based on up-to-date knowledge. Regarding the oceanic carbon sink, IMAGE is also based on currently available knowledge, and results are within the range of uncertainty at the global scale (IPCC, 2007a).

Climate system
With regard to the climate system's response to changes in atmospheric composition and associated radiative properties, two core aspects were tested. The first parameter addressed was climate sensitivity. This parameter describes by how many degrees Celsius the equilibrium global mean temperature will rise if the concentration of greenhouse gases in the atmosphere doubles, in carbon dioxide equivalents, compared to the pre-industrial level. The simple climate model in the Atmosphere-Ocean System (AOS) of IMAGE 2 is attuned to represent the generally accepted central estimate for the climate sensitivity of 2.5 degrees. This model was adjusted to explore a range from 1.5 to 4.5 degrees. As expected, this greatly amplified or reduced all climate-related impacts for any given emission projection. For climate change impacts, however, global mean effects are of limited significance. Therefore, a second sensitivity analysis addressed the spatial patterns of temperature and precipitation projections. IMAGE employs exogenous patterns from complex climate models (GCMs) to scale the impacts of the endogenously derived global mean temperature change. The robustness of regional impacts to different GCM patterns was reported by UNEP and RIVM (2004). Results indicate that, while GCM outcomes for some regions are fairly consistent, for other regions the temperature effect is very different. With regard to annual precipitation the disagreement between models is even stronger. In some regions, for example in South America, they do not even agree on the direction of change.

Mitigation scenarios
Estimates of the costs of emission reductions, even within a well-defined scenario context, are subject to considerable uncertainties, as the potential contribution and cost of abatement options are spread across wide ranges. A sensitivity analysis was performed for a scenario that stabilises at 550 ppm carbon dioxide equivalent (Van Vuuren et al., 2006c) to identify for which abatement options the alternative assumptions had a significant impact on overall abatement costs. Selected options were tested not only one by one, but also all together and simultaneously. Most individual options did not affect the total abatement costs by more than 10% (up or downwards) until 2050, with the exception of energy crops. Accepting the high end of the literature estimates on the supply potential, and introducing the option to capture and store carbon dioxide from bioenergy, costs dropped by up to 40%. However, the compounded effect of all options, together, results in 40% less to almost 100% more costs in 2050. Beyond 2050, the impact of uncertainties in options increases even further. This applies particularly to options that are expected to become viable on a large scale in the longer term, such as hydrogen (± 20% in 2100). By 2100, the compounded effect of all options considered collectively falls into the range of -40% to +250%.

Scale-issues (temporal and spatial)

The *OECD Environmental Outlook* considers gradual (incremental) changes. The policy horizon is 2030, and the impact horizon for slow-changing phenomena is 2050. This is not uncommon in worldwide environmental outlooks. However, for phenomena which exhibit slow dynamics and long-term effects, or for more abrupt, radical and catastrophic shifts, this focus may be too restricted. It may lead to an underestimation of the risks associated with these phenomena, most important of wich, climate change. For example, differences between the baseline and 450 ppm multigas simulation are still small in 2050, but become large when extended until 2100. This is not only due to further emission reductions, but is also a result of emissions during 2000-2050 and climate system inertia.

The modelling for the Outlook is relatively detailed, in terms of space. For example, water stress in modelled using WaterGAP at the level of a drainage basin (6000 drainage basins, globally). This is where the availability of and the demand for water meet physically. Any coarser unit would underestimate the problem, implicitly assuming that rainfall at one end of a large country would satisfy the water demand at the other end – which is unlikely unless costly infrastructure is in place. Or, as another example, the biodiversity modelling with the GLOBIO model operates at the level of frequency distributions within each of the 60 000 global grid cells. Thus, the modelling for the Outlook allows checking distribution pattern a few levels deeper than reported, thus adding to the confidence in the identified patterns.

Obviously, the level of detail of the IMAGE cluster is also a compromise. The common designation for this level of detail in earth sciences is 'medium complexity': providing a feel for reality in the projections, while keeping it manageable. Implicitly, the compromise means that within the smallest unit (a region, for most driving forces) linearity of effects is assumed. Aggregation to large geographical units (such as 'Rest of the World') sometimes means that developments of opposite sign, such as gains and losses of biodiversity, cancel out. However, this is questionable – the loss may be immediate and certain, while the gain might be uncertain and spread over half a century. For the Outlook, these heterogeneities have not been studied and, in this respect, the report relies on review.

A specific source of fuzziness between the Outlook's text and the model-based quantification is that the text sometimes speaks about BRIICS (Brazil, Russia, India, Indonesia, China and the Republic of South Africa) as the new economic and environmental players, while the standard aggregation of modelling results speaks of OECD, BRIC and Rest of the World. As the economic and the environmental modelling has been carried out with a regional detail that distinguishes these countries individually, it is possible to inspect the differences. Therefore it can be concluded that it is improbable that the main messages of the Outlook would be any different, if its projections had been aggregated using BRIICS instead of BRIC (compare *Table 3.6*). The increases in resource use look even more dynamic in BRIIC than in BRIC. Moreover, with BRIICS as a key grouping, the Outlook would have featured one emerging player on the African continent.

Indicator choice and presentation

In environmental assessments, the relevant quantitative features of the problem under study are expressed in terms of indicators and target variables. The selection and design of indicators are important steps in shaping a study. The limitations and uncertainties of a number of the indicators used in the model-based contribution to the *OECD environmental Outlook*, are discussed below.

Economic indicators

The set of indicators used to express macroeconomic developments and impacts, as estimated with ENV-Linkages (GDP and sectoral values added), are based on measures of market interac-

Table 3.6 BRIICS versus BRIC

		Population	GDP	GDP/cap	GHG emissions	Primary energy use	Final energy use	Energy production	Crop area	Forest area
	Index 1970 = 1									
BRIC	1970	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
BRIICS	1970	1.1	1.1	1.0	1.1	1.1	1.1	1.1	1.3	1.1
BRIC	2030	2.1	18.8	9.0	4.0	4.4	3.7	6.8	1.4	0.8
BRIICS	2030	2.3	20.1	8.9	4.5	4.8	4.0	7.3	1.9	0.9

BRIC: Brazil, Russia, India, China
BRIICS: Brazil, Russia, India, Indonesia, China, South Africa
Sources: historic data from UN, IEA, World Bank, FAO and projections fromOECD Environmental Outlook modelling suite, final output from IMAGE cluster

tions. They are not intended to give precise welfare measures (for example, indicators of well-being). Market transactions in the presence of externalities are known to be imperfect indicators of welfare.

Biodiversity and Mean Species Abundance (MSA)

Biodiversity is a complex phenomenon, that can only be described by a set of complementary indices (see CBD, 2006). Not all of these indices can be incorporated in modelling frameworks. The used biodiversity indicator ‘Mean Species Abundance’ (MSA) cannot give information on all aspects, for instance the special value of protected areas for certain target species is not included, and neither is the value of semi-natural (human altered) landscapes, which are high in agro-biodiversity (Hoogeveen et al., 2004). MSA enables comparisons over time and between regions, and of the balance between different pressures. The effects of future developments on MSA are obtained on the basis of quantitative dose-response relationships, which evaluate the effects of the driving forces under certain conditions. As explained in section 3.1.12, one should keep in mind that this indicator treats the biodiversity value of all ecosystems alike, whether tundra, grassland or tropical forest. There are limitations and uncertainties in the employed dose-response relationships, the driving forces considered and the underlying data on land use and land conversion, which are needed to evaluate the MSA (see also section 10.4 in Bouwman et al. 2006).

A full uncertainty analysis of the GLOBIO model has not been performed yet, but information on the underlying relations is available. The GLOBIO model includes dose-response relationships for stresses, such as land use, fragmentation and nitrogen-loading, which are all well studied. Statistical uncertainties are known and described in reviews of existing literature. For land use, the uncertainty in biodiversity effects is in the order of a few percent only (Alkemade et al., submitted). Infrastructure effects are also described in literature, but are conceptually diverse, which deserves further attention and dissemination (direct and indirect effects) to effectively formulate policies. Climate change effects are mostly based on modelling exercises and contain considerable conceptual uncertainty.

Additionally, the current GLOBIO model does not capture the fact that biodiversity is usually lost quickly and regained or restored only slowly. Therefore, like all highly aggregate indicators, the overall totals may underestimate the amount of change. Consequently, the rate of biodiversity decline can be underestimated in dynamic situations, like in the global shift of agricultural production to non-OECD countries.

Water stress; risk of water-induced soil degradation

The indicators for water-induced soil degradation and for water stress refer to the change in risk for the physical system. Whether degradation or water shortages will indeed manifest themselves, depends on societal responses in the concerning regions. In fact, more resourceful communities have a better chance of countering increases in these risks. Either way, increases in water or soil-related problems and increased efforts to counter them both, mean an increase in pressure on the community. Vulnerability and adaptability aspects of regions have not been considered in the quantification. Therefore, the projections for these issues tend to be more sombre than experienced on the ground in high-income regions, in terms of actual water shortage or soil degradation. At the same time, they are thought to provide a more or less adequate outlook for developments elsewhere.

Climate Change

The most commonly used indicator for climate change is the increase in global mean temperature above the pre-industrial level, which is the compounded effect of more radiative forcing agents in the atmosphere and cooling from, for instance, direct and indirect sulphur aerosols. It must be noted, that the magnitude of temperature change, associated with a given increase in greenhouse gas concentration (‘climate sensitivity’), is still very uncertain (Roe and Baker, 2007). Therefore, future temperatures may end much higher or lower than projected here, where a more central estimate of the climate sensitivity is used of 2.5°C per doubling of equivalent carbon dioxide concentration in the atmosphere. This factor alone represents a crucial uncertainty for both impacts and policy response analyses. Moreover, IPCC has concluded in the meantime, that a sensitivity of 3.0°C is the ‘best’ estimate, and thus the use of 2.5°C is likely to underestimate the climate impacts of the projected greenhouse gas emissions (IPCC, 2001 and 2007).

To assess climate impacts, shifts in global mean indicators are not very helpful because, for example, the change of global mean temperature is neither distributed evenly over the Northern and Southern hemispheres, nor over the continents. A general trend observed in all climate models is that the increase is concentrated on the Northern Hemisphere, where most of the landmass is situated, and is stronger at higher latitudes. This poses a particular threat to vulnerable systems at high latitudes, including tundra and boreal forests and, potentially, it may induce large negative feedback. Dwindling sea-ice cover, changes in the regional albedo (reflectivity of the Earth surface) and enhanced methane emissions from melting permafrost soils, may all accelerate climate change.

Climate change is also associated with changes in precipitation, since the hydrological cycle is intensified with higher temperatures, which is due to an increase in evaporation and results in more precipitation. Again, like the temperature pattern, the effect is very unevenly distributed and many areas may become even dryer than they are today. Evaporation and precipitation, typically, do not balance locally and moist air is transported over long distances through the atmosphere.

The spatial distribution of changes in temperature and precipitation, at any given global mean, are also subject to large uncertainties, and state-of-the-art climate models produce very different patterns than the ones shown in this report, even including differences in the sign of precipitation changes.

Climate change indicators, reported in this study, all relate to shifts in annual mean numbers, but obviously an indicator like the (seasonal) mean precipitation only renders limited knowledge on the variability of precipitation. For example, whether it snows or rains during winter in the hills of a certain watershed - for instance the Rhine - makes a great difference to the people living and working in that area, but this is not reflected in the indicator of total precipitation.

Health impacts of air pollution

Health impacts of, for example, urban air pollution are expressed in terms of (i) excess mortality and (ii) loss of disability adjusted life years (DALYs), including mortality loss. As explained in section 3.1.10, the Outlook's quantification of the health impact of airborne particulate matter - judged to be the major cause of health loss from air pollution – is based on two extensive epidemiological studies carried out under North American city conditions. It is difficult to judge whether these studies can simply be extrapolated to situations where different conditions apply. These differences could be in population health, nutritional status, lifestyle, demographic variables, genetic disposition, exposure to multiple stressors (psychosocial as well as environmental), or particle composition of the air pollution mix etc. However, in line with the current best practice and WHO-methods worldwide, risk factors have been calculated on the basis of these epidemiological results. Limitations of this approach are rather well known and apparently widely accepted.

Moreover, in evaluating the health impacts, key uncertainties in the sulphur and nitrogen oxide emissions have to be dealt with. These uncertainties, particularly, include the future use of coal worldwide - quantity as well as technology -, the use or non-use of existing abatement equipment in power plants in China, and industrial emissions from metallurgic industry in Russia. In fact, the concentrations from energy use in Russia and the Ukraine are also likely to be underestimated in the Baseline. Actually, it is expected that more coal will be used to supply energy for the domestic market, while more natural gas will probably be destined for export.

Traffic-light method

Evaluating a multi-dimensional issue, by means of a judging traffic light, has proved a valuable communication method, as the reception of the 2001 *OECD Environmental Outlook* showed. In fact, it is an expert assessment of the urgency of issues. A combination of factors is considered (the direction and rate of change of the development; the distance to target or desirable value; the presence of hotspots), making a certain degree of subjectivity inevitable. Besides, the simplicity of the traffic light scheme comes at a price, in terms of sensitivity. For example, one can imagine that policy options with very different rates of decrease in greenhouse gas emissions are all awarded a red light, since none of them may be sufficient. Moreover, the differences between situations may be large, but will only become clearly visible after the 2050 impact horizon of the *OECD Environmental Outlook*. All in all, the traffic lights are more suitable as a method to indicate the urgency of issues, than as an adequate means to compare the effects of policy options as in *Table 1.2* of this report.

3.2.3 Implications for the robustness of the main conclusions

For this discussion, the focus is on themes in the key messages throughout the Outlook, regarding:

- Cost of Policy inaction (what, where, how much)
- Policy measures (effect, type, by whom, when, level of effort)
- Priority problems and interconnections between them.

Economic sectors, such as transport, fisheries and chemical industry are also a subject of the key messages. However, apart from energy and agriculture, it is mostly based on other sources than the integrated assessment modelling reported here. Therefore, statements on sectoral priorities are not discussed.

Cost of policy inaction

- Which issues make up the cost of policy inaction?
  There is no indication that the Outlook missed important issues. Of course, the design of these broad assessments in practice can never begin completely 'open'. There has to be some preselection of issues, in order to initiate a process of scoping which expands or shrinks the selection of issues and prioritizes analytical resources. For the *OECD environmental outlook to 2030*, the responses to the previous outlook (OECD, 2001) fulfilled this priming role. The skeptical observer may suspect that the Outlook focuses on those topics that the analysts were best at. This is a valid concern. However, the Outlook does cover a wide range of issues. What is more, the review process and comparison with recent other assessments provided no indication that the Outlook, as a whole, missed key issues to the extent that this would have changed the overall story.

  To the hypothetical reader who sees the number of tables and graphs on an issue as a first indicator of its importance, the quantification in the Outlook would underemphasise some issues of international and long-term importance, while emphasising some issues of a more immediate and local character, the latter of which would be less obvious agenda items for international policy. In this sense, persistent toxic chemicals as well as fisheries would be seen as underemphasised, and urban air pollution and nitrogen loading as overemphasised. However, the summaries and key message sections of the Outlook rectify this.

- Where do the consequences of inaction land?
  The Outlook is strong in regionalisation. The modelling of most environmental impacts is, in one way or another, spatially explicit. But this deepest layer is not shown, in most cases, avoiding the illusion of being simultaneously precise for 25 or 50 years into the future, as well as on the map. Thus, the Outlook is probably balanced in its statements on where the environment changes least or most.

  However, it is important to realise that the Outlook quantification does not account for differences in vulnerability, including those in response capacity, between and within countries. If this had been done, the projected consequences of policy inaction would have been quantified as somewhat less serious in high-income countries, and much more serious in low-income countries and for vulnerable groups. At a verbal level, this inequality in impacts is correctly stated in the executive summary key messages.

- How large will the consequences of inaction be?
  Here, the largest uncertainty stems from the baseline. The uncertainties around the baseline are asymmetrically distributed: the chances of overestimating the problems (future activity volumes, resource use, technology mix) are smaller than of underestimating them. In other words, the consequences of inaction are rather conservatively estimated. This is especially so in BRIC and Rest of the World, as well as for global issues that depend on pressures from the BRIC and ROW groups.

Policy measures

Level of effort involved

What level of effort would be involved in the environmental protection measures that were analysed? Most of the uncertainties point to an underestimation (-), more so than to an overestimation (+). The following factors are important.

(-) The carbon price trajectory for the 450 ppm multigas case, as reported in the Outlook, assumes that decision makers will steer decisions (investments and behaviour) sufficiently to achieve a timely and significant renewal of capital goods, such as power stations and buildings - as well as early emission decreases. Critically, this policy change has already impacts between 2010. Modelling of the energy system as undertaken with TIMER and by the IEA (IEA, 2007) suggests that the turnaround between 2010 and 2030 requires a large effort. This is not reflected in the carbon price trajectory over time as published in the outlook.

(-) The large items in the policy packages have been costed, but not for everything. Costed were: mitigation of energy-related emissions of carbon dioxide; abatement of emissions of sulphur dioxide and nitrogen oxides. Included in the simulation results, but not costed: mitigation of non-energy related emissions of carbon dioxide and of other greenhouse gases (Kyoto gases), and enhancing sewage treatment. Furthermore, a quick reader may think that costs mentioned in the Outlook cover actions for the other priority items, such as biodiversity. But this is not the case. Identified as ‘red light’ issues in the Outlook’s key messages, but excluding the simulation of measures and therefore not costed: biodiversity; forests; water use and scarcity; groundwater quality; specific waste issues; chemicals.

(+/-) Costs as estimated with a general equilibrium model generally do not cover friction costs. An example of this is the early retirement of capital stock in the energy sector. However, such estimations do not show potential employment benefits of environment policies.

(-) More generally, the cost estimates assume perfect implementation of policies, which is not necessarily how things would go in the real, molre complex world.

(+) European studies conclude that ex-ante estimates, when afterwards compared with realisation, tend to overestimate costs of environmental protection (SEI, 1999; Oosterhuis, 2006). The findings vary between subject areas but, by and large, suggest caution with projections of large costs. One factor is that the potential for innovation is underestimated.

Timing of action

The Outlook and accompanying presentations emphasise the need for early action – that is, in the next ten years. This is corroborated by the modelling. Climate change policy has been elaborated on most extensively and thus provides most evidence in this respect. It comes in the form of the timing variants and in the results of the 450 ppm multigas case, as elaborated with the energy model TIMER. The policy packages for other themes, such as sewage treatment, do not systematically compare early and delayed action but they do imply timely investment in infrastructure. In contrast, the air policy package features a very gradual increase in effort. This is a direct reflection of the assumption that, in this policy package, currently low-income countries would engage in ambitious air pollution control policy, as soon as a certain income level would be reached.

Benefits of new environmental policies
What would be the benefits of the analysed policy packages?
At an overall level, across the environmental issues, there are no indications of bias in the difference that the policy packages make, in relation to the baseline. At this level, two opposing uncertainties can be identified. On the one hand, for the cost aspect perfect implementation was assumed. For example, it was assumed that policies would be instrumented in such a way that no 'take-back' occurs (demand would increase, due to more efficient technologies and, thus, resources would become cheaper). Uncertainty here could lead to an overestimation of benefits. On the other hand, as the policy packages simply stacked measures for the four policy areas concerned without optimisation, potential synergies between them would mostly be obscured.

Benefits of joint action
All in all, the Outlook's quantitative projections might underrepresent the need to start policy efforts early. This is particularly true if the ENV-Linkages carbon price, or its effect on GDP, is taken as an indicator for effort level in the early years of implementation. In that case, the message on timing of climate policies could easily be misunderstood.

Priority problems

Land
Land use changes are a cross-cutting issue in the Outlook. They play a role in many of the discussed issues, such as future agriculture, trade, biodiversity, urban sprawl and biofuels. But they are not quantified as rigorously as the energy-climate-air domain. In particular, the dynamics in space (global shifts of agricultural production) and over time (as the global population grows to 9 billion people) may be somewhat underemphasised, in comparison with the better-established environmental agenda.

Climate change
The Outlook's identification of climate change as a priority problem rests for the most part on the projected emissions of greenhouse gases. The resulting climate change and, in turn, its consequences, can only be fully appreciated by looking beyond the 2030/2050 horizon – further than the outlook projections themselves go. In addition, long-term climate change projections are beset with uncertainties. But these uncertainties are extensively reviewed and reported, above all by the IPCC. On these grounds, there is no reason to doubt the identification as such of climate change as a priority problem.

There are uncertainties of some consequence for the Outlook's messages. To begin with, the Outlook may somewhat underestimate the climate change that would follow from the projected greenhouse gas emissions, because a somewhat conservative climate sensitivity was used, and because some impacts do not show up at the spatial resolution of the analysis. Also, the interaction between climate change policies and future serious air pollution control policies in BRIC and ROW, is not well understood. Finally, the precise spatial distribution of changes in precipitation is uncertain.

Air pollution health impact
Although state of the art, the projections of premature mortality come with a fundamental caveat, as the only firm epidemiological basis is that for North America. From a public health perspective, the projections would perhaps look unsurprising; as people are getting older, they become more vulnerable to all sorts of things, including air pollution. Moreover, a public

health perspective would place the increased premature mortality from air pollution, in a wider context of the consequences of changing lifestyles and aging. Such a perspective would put less emphasis on mortality and more on loss of healthy life time. The latter is measured in DALYs. However, it must be said that the results of the Outlook's air pollution projections in DALYs included in this background report, exhibit the same patterns, allowing for changes in age composition of the populations, as those of its projections in premature mortality. Thus, the messages on the issue of urban air pollution seem robust, namely that health damage from air pollution will increase in many regions of the world, and that urbanisation, ageing and hemispheric circulation of air pollution will complicate the task of air quality managers.

Biodiversity
In the Outlook, biodiversity loss is regarded through the lens of the specific indicator that enables the projections into the future, namely mean species abundance. As explained in section 3.1.12, a decrease in this indicator cannot be equated with extinction of species, which is apparently what part of the audience understands as concrete biodiversity. Rather, mean species abundance is a more nuanced measure reflecting the species composition of each grid cell as influenced by a range of pressure factors. The closest layman's translation would be naturalness.

The account of sources of uncertainty in this report does not alter the overall pattern as projected. That is, terrestrial biodiversity keeps declining; by 2050, biodiversity will have declined significantly everywhere, but least so in nature areas, away from people: deserts, ice, mountain areas and boreal forest.

The projections do not account for the fact that biodiversity is usually lost quickly, but regained slowly. Thus, they do not reflect that the spatial shifts in agriculture, as projected in the baseline and in the policy packages (for example, from North and South America as a result of liberalisation and within North America as a result of climate change), would, for the first decades, mean a net loss in naturalness. At any rate, this does not change the assessment of the baseline (unchecked decline). If the modelling had captured this effect, the biodiversity results for *ppGlobal* and *ppOERD+BRIC* would have been more negative, especially in Brazil and Other Latin America.

Along these lines, in the integrated modelling of *ppOECD+BRIC* and *ppGlobal*, the liberalisation of agricultural production and trade stimulates this production, outside OECD countries. But, at the same time, the carbon price limits the modelled increase in demand for agricultural products outside OECD. Therefore, in these cases, the agricultural impact on biodiversity is attenuated.

Together, these model characteristics probably mask the negative effect of the policy packages. Importantly, the policy packages do not comprise biodiversity policies for biodiversity outside OECD countries.

Water
The Outlook's messages related to water, are made up of three different strands. In terms of uncertainty, they can be annotated as follows.

- Water use in relation to availability
  In the projections for the Outlook, water use in relation to availability is quantified by a rating of water stress. The main uncertainty in these projections is how the results should

be interpreted. The Outlook does not provide this explanation. The results have been sometimes misinterpreted following release of the Outlook (i.e. understood as too alarming, or too alarming for the wrong regions).

- Sanitation
  Assumptions, for the evolution up to 2030, of access to improved sanitation and connection to sewerage, were input for the Outlook's modelling of nutrient loading caused by sewage. However, in the Outlook these assumptions were positioned as important aims for the proposed package of enhanced environmental policies. Although not intended in the modelling, the resulting presentation is probably in keeping with the Outlook's emphasis on collaboration between OECD countries and non-OECD countries. However, the cost of expanding access to improved sanitation and connection to sewerage, in the spirit of the Millennium Development Goals, is considerable and not included in the Outlook's estimation of the cost of action.

- Nutrient loading
  Nutrient loading is modelled as a function of agricultural practices, sanitation and sewerage, and developments in deposition of nitrogen compounds from the air. The nitrogen load is dominated by agricultural developments, and the effects of uncertainties in the modelling were researched relatively well.

  The main limitation, that should probably be highlighted, is that the results obtained for nitrogen compounds only partly apply to all nutrient pollution, including phosphorus. However, this does not affect the key messages on nutrient pollution. At a more specific level, if projections for phosphorus pollution had been included, then the global increase and spread of the use of dishwasher machine detergents would have been pointed out as part of the future problem. In particular, this would have shown a larger problem in OECD countries, spreading elsewhere.

Robustness of the Outlook's Executive Summary
What does this discussion of uncertainties and limitations in the model-based assessment mean for the overall key messages of the Outlook, as presented in the Executive Summary?

In a nutshell, the essence of the Executive Summary is found to be robust, even if based on a partial quantification of the world's environment to 2030 / 2050. However, in light of the reported modelling in this report, specific comments are as follows.

(1) The consequences of inaction, and therefore the need for more ambitious international environmental policy, are probably underestimated.

(2) The cost of future action, is probably underestimated, too, or only partly covered, but so are the benefits. Among other things, the cost estimates assume that implementation will be perfect. On the benefit side, the picture is especially lacking in co-benefits.

However, these two points hardly affect the overall stance of the Executive Summary.

(3) The Outlook emphasises the need for early action to be taken on climate change. However, a reader who would only consider the carbon price applied in the early years for the most ambitious climate policy case (450ppm multigas), might not immediately draw this conclusion.

At the same time, the Outlook, as well as its underlying energy modelling and parallel modelling by the International Energy Agency, emphasises that the first ten years are critical to avoid dangerous global warming at reasonable cost.

(4) Arguably the most important point made by the Outlook is the necessity, as well as the opportunity, for new economic players such as Brazil, India, China and Russia to join international policy action on the identified priority themes. The outlook underpins this with three policy packages, showing the effect of stepwise inclusion of BRIC and Rest of the World. The policy packages cover liberalisation of agricultural production and trade; climate change mitigation; air pollution; water pollution. The Executive Summary states the necessity and urgency of collaboration although it does not link to the supporting modelling results in the main text.

Annexes

Regional classification

The economic analysis in ENV-Linkages covered 34 regions and the analyses in the IMAGE-framework covered 24 regions, not counting Antarctica and Greenland and not counting the further subdivision of the India region and Southern Africa which is done for energy-specific analyses. For most graphs, 24 regions are too many to show. Therefore, regional results have been aggregated in most cases into 13 regional clusters or into three groups (OECD, BRIC, Rest of the World). *Table A.1* and *Figure A.1* show how this aggregation works.

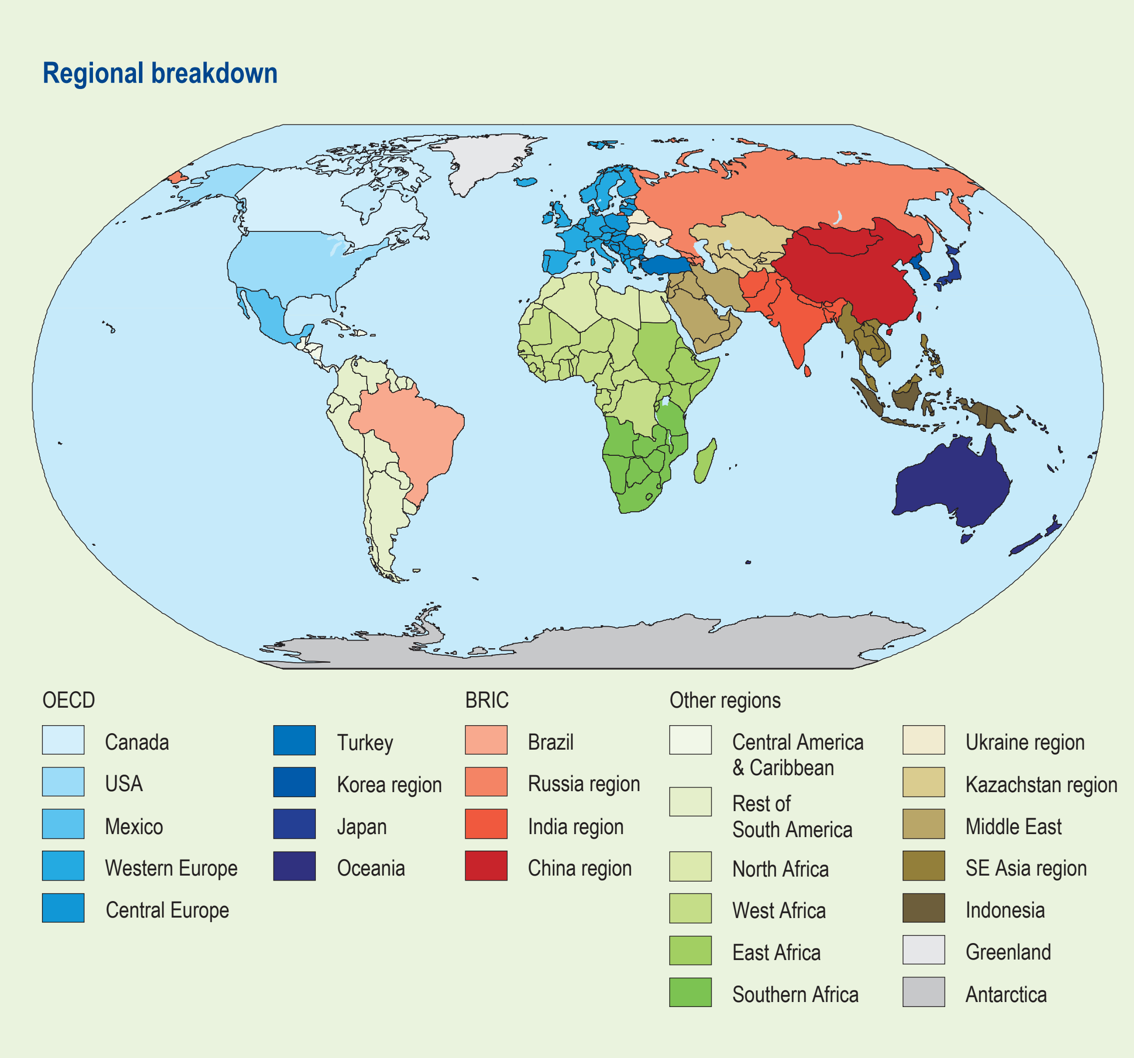


Figure A.1 Map of regions used in environmental modelling for the OECD Environmental Outlook
(103k_oec08)

Table A.1 Clustering of model results for presentation in the OECD Environmental Outlook

ENV-Linkages 34 regions	**IMAGE results 24 regions**	**Default presentation in tables and graphs in the outlook**				
				3 groups		
		13 clusters		Current OECD	BRIC	Rest of world
Canada	Canada	North America	NAM	X		
USA	USA					
Mexico	Mexico					
France	Western Europe	OECD Europe	EUR	X		
Germany						
UK						
Italy						
Spain						
Rest of EU 15						
Iceland, Norway, Switzerland						
Poland	Central Europe					
Czech, Slovak, Hungary						
EU non OECD						
Central Europe						
Turkey	Turkey					
Japan	Japan	OECD Asia	JPK	X		
Korea	Korea region					
Australia/ NZL	Oceania	OECD Pacific	ANZ	X		
Brazil	Brazil	Brazil	BRA		X	
Russia	Russia & Caucasus	Russia & Caucasus	RUS		X	
India	South Asia[a)]	South Asia	SOA		X	
South Asia						
China	China Region	China Region	CHN		X	
Chinese Taipei						
Middle East	Middle East	Middle East	MEA			X
Indonesia	Indonesia	Other Asia	OAS			X
Rest SE Asia	SE Asia					
Other ex-Soviet Union	Ukraine Region	Eastern Europe & Central Asia	ECA			X
	STANs					
Central America & Caribbean	Central America & Caribbean	Other Latin America & Caribbean	OLC			X
Rest South America	Rest South America					
North Africa	North Africa	Africa	AFR			X
Rest of Africa	West Africa					
	East Africa					
South Africa	Southern Africa[b)]					
Rest of Southern Africa						
	Greenland					
	Antarctica					

Notes: [a)] For energy-related analyses further subdivided into India and Other South Asia. [b)] For energy-related analyses further subdivided into South Africa (Republic of) and Other Southern Africa.

Overview of key variables per theme

Table A.2 Overview of key variables per theme

Theme	Variables	Tools used	Basis of estimation	Elementary unit of analysis	For what cases?
Climate change	Emissions of major greenhouse gases *up to 2050*	FAIR, TIMER and IMAGE-land use	Physical activity parameters in the energy/agricultural system Emission coefficients evolving over time Response of energy production and use to carbon tax	Total of Kyoto gases, in carbon dioxide equivalent Energy-related carbon dioxide emissions also available separately Five-year steps, by region, by sector/fuel/process + land use change	- Baseline - Baseline variation - pp OECD - pp OECD + BRIC - pp global - 450 PPM - climate policy variations
	Annual average air temperature and rate of change *up to 2050*	IMAGE	Concentrations of major greenhouse gases + cooling effect of aerosols	Five-year steps, 1/2x1/2 degree longitude latitude grid cells, global mean	- Baseline - Baseline variation - pp OECD - pp OECD + BRIC - pp global
	Change in annual total precipitation *up to 2050*	IMAGE	Concentrations of major greenhouse gases; cooling effect of aerosols	Five-year steps, 1/2x1/2 degree longitude latitude grid cells, global mean	- Baseline - Baseline variation - pp OECD - pp OECD + BRIC - pp global
Air pollution	Emissions of sulphur dioxide, nitrogen oxides, primary particulates, methane and carbon monoxide *up to 2050*	FAIR, TIMER and IMAGE-land use	EDGAR: emission coefficients Cost curves; distinction between end-of-pipe and integrated measures (Bollen et al., 2007)	Region, pollutant, broad sectors including marine shipping, five-year steps	- Baseline - pp OECD - pp OECD + BRIC - pp global
	Urban concentrations of particulate matter and ground level ozone Exposure of urban populations to particulate matter and ground level ozone, by severity class	TM3 of JRC Ispra for projection of hemispheric transport of air pollution including ozone and its precursors GMAPS of World Bank for urban local contribution 1995 and 2000 Projection of urban population (UN; disaggregated) IMAGE cluster (GUAM model) for projection of concentration of PM_{10}	TM3: atmospheric dispersion and chemistry modelling GMAPS: statistical correlation GUAM: scaling of urban concentrations and population exposure in function of regional emissions and urban growth	3265 urban agglomerations worldwide	- Baseline (particulates and ozone) - pp global (particulates)
Land degradation risk	Risk of water-induced soil degradation	IMAGE	Land cover; hilliness; precipitation	1/2x1/2 degree longitude latitude grid cells	- Baseline - pp OECD - pp OECD + BRIC - pp global
	Agriculture in arid zones	IMAGE	Overlay	1/2x1/2 degree longitude latitude grid cells	- Baseline

Theme	Variables	Tools used	Basis of estimation	Elementary unit of analysis	For what cases?
Terrestrial biodiversity	Mean species abundance (= change of mean abundance of selected species relative to the undisturbed original situation) *up to 2050*	IMAGE cluster (GLOBIO model)	Changes in land use categories and key pressures; spatially explicit	By region, biome and pressure factor, 1/2x1/2 degree longitude latitude grid cells For discrete years: 1970, 2000, 2030, 2050	- Baseline - pp OECD - pp OECD + BRIC - pp global - 450 ppm
Freshwater resources	People living in areas with water stress	WaterGAP	Balance between projected availability and use	Drainage basin (approx 6 000 basins) Use categories: domestic; electricity production; irrigation; livestock; manufacturing. Calculated for 2005 and 2030. Results expressed in classes of water stress: ratio of water use over available water	- Baseline - pp global
Forest	Change in area of natural forest, excluding regrowth	IMAGE	Agricultural land expansion and abandonment; wood demand; taking into account location & plantations; excluding regrowth after clearcutting in the scenario period	Region and spatial grid; five-year time steps; forest types (boreal, temperate, tropical)	- Baseline - pp OECD - pp OECD + BRIC - pp global - 450 ppm
Coastal marine ecosystems	Loading with nitrogen compounds	IMAGE (+ check against OECD/TAD country nitrogen balances for the present)	Agricultural balance. Estimate is for the flow at the river mouth, taking into account retention and denitrification	Region (with underlying country detail); source: nitrogen compounds from sewage and sewage treatment; deposition from the air; flow from natural systems Estimated for 1970, 2000, 2030	- Baseline - pp global
	Nitrogen balance agricultural land	IMAGE (nutrient module)	Crop and husbandry nutrient balances	Per region, crop type, animal class, five-year time steps	- Baseline - Baseline variation - pp OECD - pp OECD + BRIC - pp global
	Nitrogen compounds from sewage	IMAGE (added module)	Developments in access to improved sanitation and access to sewerage; urban sewerage is considered; developments in sewage treatment	Region; treatment type	- Baseline - pp global
Human health & the environment	Health impacts from urban air pollution. Excess mortality as well as DALYs lost	Comparative risk assessment (WHO) applied to exposed urban population as estimated with IMAGE/GUAM and projection of overall health status to 2030 by WHO	Relative increase in mortality and loss of healthy life expectancy, derived from US-based epidemiological studies	3 265 urban agglomerations; ground level ozone (Baseline only) and fine particles	- Baseline - pp global

References

Abler D. (2003) Adjustment at the Sectoral Level. An IAPRAP workshop on Policy Reform and Adjustment. The Wye Campus of Imperial College, October 23-25. http://agadjust.aers.psu.edu/Workshop_files/Abler_presentation.pdf. Visited 20 March 2008.

Alcamo J. [Ed.] et al. (1994) IMAGE 2.0: Integrated modeling of global change. Kluwer Academic Publishers, Dordrecht, 318 pp.

Alcamo, J., ed. (2003) Ecosystems and Human Well-Being: a framework for assessment. Island Press, Washington.

Alcamo J., R. Leemans, G.J.J. Kreileman (1998) Global change scenarios of the 21st century. Results from the IMAGE 2.1 model. Elsevier Science, London, 296 pp.

Alcamo, J., T. Henrichs, T. Rösch, (2000) World Water in 2025 – Global modeling and scenario analysis for the World Water Commission on Water for the 21st Century. (Kassel World Water Series 2). Kassel: Center for Environmental Systems Research, University of Kassel. Available from: http://www.usf.uni-kassel.de. Visited 20 March 2008.

Alcamo, J., P. Döll, T. Henrichs, F. Kaspar, B. Lehner, T. Rösch, S. Siebert (2003) Development and Testing of the WaterGAP 2 Global Model of Water Use and Availability Hydrological Science, 48 (3) 317-337.

Alkemade, J.R.M., et al. (2006) GLOBIO 3: Framework for the Assessment of Global Terrestrial Biodiversity, in A.F. Bouwman, T. Kram & K. Klein Goldewijk (eds.), Integrated Modelling of Global Environmental Change. An Overview of IMAGE 2.4, Netherlands Environmental Assessment Agency (MNP), Bilthoven, The Netherlands.

Amann M. et al., (2005) CAFE Scenario Analysis Report Nr. 4: Target Setting Approaches for Cost-effective Reductions of Population Exposure to Fine Particulate Matter in Europe, Background paper for the CAFE Steering Group, International Institute for Applied Systems Analysis (IIASA), February 13, 2005, Laxenbourg, Austria.

Andersen D., M., P.M. Gilbert, J.M. Burkholder (2002) Harmful algal blooms and eutrophication: nutrient sources, composition, and consequences. Estuaries, 25: 704-726.

Bagnoli, P., J. Chateau, S. Sahin (2006) Structural change and PPP measures of income, paper presented at OECD Workshop on Global Convergence Scenarios: Structural and Policy Issues, 16 January 2006, Paris.

Bakkenes M., J.R.M. Alkemade, F. Ihle, R. Leemans, J.B. Latour (2002) Assessing effects of forecasted climate change on the diversity and distribution of European higher plants for 2050. Global Change Biology, 8:390-407.

Beusen A.H.W., Bouwman A.F., Heuberger P.S.C., Van Drecht G. and Van Der Hoek K.W. (in press) Uncertainty On Global Ammonia Emissions From Global Agricultural Production Systems. Atmospheric Environment (accepted)

BMT (2006) Shipping Emissions Abatement and Trading. Sulphur Emissions Offsetting Pilot. Final Report. Prepared by Dr. ME Davies for SEAaT. BMT Ltd.

Bobbink R. (2004) Plant species richness and the exceedance of empirical nitrogen critical loads: an inventory. Utrecht University, Utrecht.

Bollen, J., B. van der Zwaan, C. Brink, H. Eerens, (2007) Local Air Pollution and Global Climate Change: A Combined Cost-Benefit analysis. MNP-Report no. 500116002. Also submitted to Analysis Resource and Energy Economics 3-2007.

Bouwman A.F., D.S. Lee, W.A.H. Asman, F.J Dentener., K.W. van Der Hoek and J.G.J.Olivier (1997) A global high-resolution emission inventory for ammonia. Global Biogeochemical Cycles, 11:561-587.

Bouwman A.F., G. Van Drecht, K.W. Van der Hoek (2005a) Nitrogen surface balances in intensive agricultural production systems in different world regions for the period 1970-2030. Pedosphere, 15(2): 137-155.

Bouwman A.F., K.W. van Der Hoek, B. Eickhout, I. Soenario (2005b) Exploring changes in world ruminant production systems. Agricultural Systems, 84(2):121-153.

Bouwman A.F., T. Kram, K. Klein Goldewijk (2006) Integrated modelling of global environmental change. An overview of IMAGE 2.4. Netherlands Environmental Assessment Agency, Bilthoven, The Netherlands, 228 pp. pp.

Brink, B.J.E. ten (2000) Biodiversity Indicators for the OECD Environmental Outlook and Strategy, a Feasibility Study. RIVM National Institute for Public Health and the Environment, in co-operation with WCMC, Cambridge/Bilthoven.

Brooks, T.M., R.A. Mittermeier, G.A.B. da Fonseca, J. Gerlach, M. Hoffmann, J.F. Lamoreux, C.G. Mittermeier, J.D. Pilgrim, A.S.L. Rodrigues (2006) Global Biodiversity Conservation Priorities. Science 313, 58-61.

Bruinsma J.E. (2003) World agriculture: towards 2015/2030. An FAO perspective. Earthscan, London, 432 pp.

Burniaux, J.-M., G. Nicoletti, J. Oliveira Martins (1992) GREEN: A Global Model for Quantifying the Costs of Policies to Curb CO_2 Emissions, OECD Economic Studies, 19 (Winter).

Burniaux, J.-M., (2002) A Multi-Gas Assessment of the Kyoto Protocol, OECD Economics Department Working Papers No. 270, OECD, Paris.

CBD (2006) Global Biodiversity Outlook 2. Secretariat of the Convention on Biological Diversity, Montreal, Canada..

CBD and MNP (2007) Cross-roads of Life on Earth — Exploring Means to meet the 2010 Biodiversity Target, Solution-oriented Scenarios for Global Biodiversity Outlook 2. Secretariat of the Convention on Biological Diversity and Netherlands Environmental Assessment Agency, Technical Series no. 31. Secretariat of the Convention on Biological Diversity, Montreal.

Cofala, J., M. Amann, Z. Klimont, W. Schop, (2005) Scenarios of World anthropogene emissions of SO_2, NOx and CO up to 2030. International Institute for Applied Science, Laxenburg, Austria.

Cofala, J., et al., (2007) Analysis of Policy Measures to Reduce Ship Emissions in the Context of the Revision of the National Emissions Ceilings Directive, Contract No 070501/2005/419589/MAR/C1. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria, <http://ec.europa.eu/environment/air/pdf/06107_final.pdf>. Visited 20 March 2008.

Cohen A.J. H.R. Anderson, B. Ostro, K.D. Pandey, M. Krzyzanowski, N. Kuenzli, K. Guttschmidt, C.A. Pope, I. Romieu, J.M. Samet, K.R. Smith (2004) Mortality impacts of urban air pollution. In Comparative quantification of health risks: Global and regional burden of disease due to selected major risk factors. Eds. M. Ezzatti, A.D. Lopez, A. Rodgers, and C.U.J.L. Murray, vol 2, pp1353-1433. Geneva, World Health Organisation.

CPB (1999) WorldScan: the core version. Netherlands Bureau for Economic Policy Analysis (CPB), The Hague, 137 pp.

Crafts N.F.R. (2003) Quantifying the Contribution of Technological Change to Economic Growth in Different Eras: A Review of the Evidence. London School of Economics Working Paper 79/03, pp 31.

Danube Applied Research Program (1997) Nutrient Balances for Danube Countries – Final Report. Institute for Water Quality and Waste Management, Vienna University of Technology and Department of Water and Wastewater Engineering, Budapest University of Technology.

De Janvry A., M. Fafchamps, E. Sadoulet (1991) Peasant household behavior with missing markets: Some paradoxes explained. Economic Journal, 101:1400-17.

De Leeuw F.A.A.M. (2002) A set of emission indicators for long-range transboundary air pollution. Environmental Science and Policy 5, 135-145.

Dentener F., D. Stevenson, J. Cofala, R. Mechler, M. Amann, P. Bergamaschi, F. Raes, R. Derwent (2005) The impact of air pollutant and methane emission controls on tropospheric ozone and radiative forcing: CTM calculations for the period 1990-2030. Atmos. Chem. Phys., 5, 1731-1755.

Dentener F. et al. (2006) The global atmospheric environment for the next generation. Environ Sci Technol, 40, 3586/3594.

Den Elzen M.G.J. (2005) Analysis of future commitments and costs of countries for the South-North Dialogue. Proposal using the FAIR 2.1 world model. Report 728001032, Netherlands Environmental Assessment Agency (MNP), Bilthoven, The Netherlands.

Den Elzen M.G.J. and P. Lucas (2005) The FAIR model: a tool to analyse environmental and costs implications of climate regimes. Environmental Modeling and Assessment, 10(2):115-134.

Den Elzen M.G. J., D. P. van Vuuren (2007) Peaking profiles for achieving long-term temperature targets with more likelihood at lower costs. PNAS, vol. 104, no. 46, pp 17931–17936. < www.pnas.org/cgi/doi/10.1073/pnas.0701598104>. Visited 20 March 2008.

Den Elzen M.G.J., J.S. Fuglestvedt, N. Höhne, C.M. Trudinger, J. Lowe, B.J.H. Matthews, B. Romstadt, C. Pires De Campos, N. Andranova (2005a) Analysing countries' contribution to climate change: Scientific uncertainties and methodological choices. Environmental Science Policy, 8:614-636.

Den Elzen M.G.J., P. Lucas, D.P. van Vuuren (2005b) Abatement costs of post-Kyoto climate regimes. Energy Policy, 33(16):2138-2151.

Den Elzen, M.G.J., P. Lucas, D.P. Van Vuuren (2007) Regional abatement costs and options under allocation schemes for emission allowances for low CO_2-equivalent concentrations. Submitted.

Den Elzen, M.G.J., M. Meinshausen, D.P. van Vuuren, (2007) Multi-gas emission envelopes to meet greenhouse gas concentration targets: costs versus certainty of limiting temperature increase. Global Environmental Change, 17: 260–280.

Den Elzen, M.G.J., N. Höhne, S. Moltman (2008) The Triptych approach revisited: a staged sectoral approach for climate mitigation. Energy Policy 2008; 36(3): 1107-1124.

DICTUC (2000) Social benefits of the reduction of ambient concentrations of atmospheric pollutants in the Metropolitan Region of Santiago. Technological and Scientific Research Department, Pontificia Universidad Católica de Chile, Santiago.

Döll, P., F. Kaspar and B. Lehner, (2003) A global hydrological model for deriving water availability indicators – model tuning and validation. Journal of Hydrology, 270 (1-2), 105-134.

Döll, P., and B. Lehner, (2002) Validation of a new global 30-min drainage direction map. Journal of Hydrology, 258, pp. 214-231.

Döll, P., and S. Siebert, (2001) Global modeling of irrigation water requirements (10.1029/2001WR000355). Water Resources Research, 38(4), 8.1-8.10.

EEA (1998) A report on the changes in the pan-European environment as a follow-up to 'Europe's Environment: The Dobris Assessment' (1995) requested by the environment Ministers for the whole of Europe to prepare for the fourth ministerial conference in Aarhus, Denmark, June 1998. European Environment Agency, Copenhagen.

EEA (2006) Air Pollution by Ozone in Europe in Summer 2005, Technical report No 3/2006, European Environment Agency, Copenhagen.

Eickhout B., M. den Elzen, E. Kreileman (2004) The atmosphere-ocean system in IMAGE 2.2. Report 481508017, National Institute for Public Health and the Environment, Bilthoven, The Netherlands.

EPA (1994) International anthropogenic methane emissions: estimates for 1990. Report EPA 230-R-93-010, U.S. Environmental Protection Agency, Washington, D.C., USA.

ETC/ACC (2007) European Exchange of Monitoring Information and State of the Air Quality in 2005, European Topic Centre on Air and Climate Change Technical Paper 2007/1.

FAO (1981) Reports of the Agro-Ecological Zones Project. World Soil Resources Project No. 48, Vol. 3 - South and Central America. Food and Agriculture Organization of the United Nations, Rome.

FAO (2006) World Agriculture: Towards 2030/2050. Interim Report. Prospects for food, nutrition, agriculture and major commodity groups, Global Perspectives Studies Unit. Food and Agriculture Organization of the United Nations, Rome 71 pp.

Fischer G., M. Shah, H. van Velthuizen (2002) Climate Change and Agricultural Vulnerability. Special report prepared for the World Summit on Sustainable Development, Johannesburg 2002, International Institute of Applied Systems Analysis, Vienna, Austria, 152 pp.

Ghauri, B., A. Lodhi, M. Mansha (2007) Development of Baseline (air quality) data in Pakistan, Environ. Monit. Assess. 127, 237-252.

GRDC (2000) Observed river discharges. Koblenz: Global Runoff Data Centre.

GTZ and DME (2004) Challenges and Achievements of the Solar Cooker Field Test in South Africa. Deutsche Gesellschaft für Technische Zusammenarbeit and Department of Minerals and Energy. <http://www.cef.org.za/about/edc/solarcook.htm, Accessed 4 November 2005>

Hansen, J., M. Sato, R. Ruedy, A. Lacis, V. Oinas (2000) Global warming in the twenty-first century: an alternative scenario. Proceedings of the National Academy of Sciences of the United States of America, 97(18), pp. 9875-9880.

Hendriks C., W. Graus, F. van Bergen (2002) Global carbon dioxide storage potential and costs, Report EEP-02001, Ecofys, Utrecht.

Hendriks C., M. Harmelink, K. Burges K. Ransel (2004) Power and heat productions: plant developments and grid losses, Report EEP-03038, Ecofys, Utrecht.

Hertel T.W., R. Keeney (2003) Assessing the impact of WTO reforms on world agricultural markets: A new approach. Paper presented at the Conference on New Developments in Commodity Market Research, December 15- 16, Food and Agriculture organization of the United Nations, Rome.

Hertel T.W. (1997) Global Trade Analysis. Modelling and Applications. Cambridge University Press, 403 pp.

Hertel, T.W., D. Hummels, M. Ivanic, R. Keeney (2003) "How Confident Can We Be in CGE-Based Assessments of Free Trade Agreements?" GTAP Working Paper No. 26, Center for Global Trade Analysis, Purdue University.

Hilderink H.B.M. (2000) PHOENIX pluss: the population user support system version 1.0, <http://www.mnp.nl/phoenix>. Visited 20 March 2008

Höhne, N., M.G.J. den Elzen, M. Weiss. (2006) Common but differentiated convergence (CDC), a new conceptual approach to long-term climate policy. Climate Policy Vol 6. nr 2, pp.181-199.

Hoogeveen, Y., J-A. Petersen, K. Balazs, I. Higuero. (2004) High nature value farmland – Characteristics, trends and policy challenges. EEA report 1-2004, European Environment Agency, Copenhagen. <http://reports.eea.europa.eu/report_2004_1/en, accessed 20 Febr.2008>

Hoogwijk M. (2004) On the global and regional potential of renewable energy sources, PhD thesis, Utrecht University, Utrecht, The Netherlands, 256 pp.

Huang H., F. van Tongeren, F. Dewbre, H. van Meijl (2004) A New Representation of Agricultural Production Technology in GTAP. Paper presented at the Seventh Annual Conference on Global Economic Analysis, June, Washington, USA.

IMAGE-team (2001) The IMAGE 2.2 implementation of the SRES scenarios. A comprehensive analysis of emissions, climate change and impacts in the 21st century. CD-ROM publication 481508018, National Institute for Public Health and the Environment, Bilthoven.

IPCC (2000) Special Report on Emission scenarios. Nakicenovic, N. and Swart, R. eds. Cambridge University Press, Cambridge United Kingdom and New York.

IPCC (2001) Climate Change 2001, The Scientific Basis. Houghton J.T., Ding Y., Griggs D.J., Noguer M., Van Der Linden P.J., Dai X., Maskell K., Johnson C.A. [Eds.]. Cambridge University Press, Cambridge, UK.

IPCC (2007a) Climate change 2007. The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (edited by Solomon, S., Chin, D., Manning, M., Marquis, M., Averyt, K., Tignor, M.M.B., Le Roy Miller jr., H., Chen, Z.). Cambridge University Press, New York,.

IPCC (2007b) Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Parry, M., O. Canziani, J. Palutikof, C. Hanson (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Janssen, P.H.M., A.C. Petersen, J.P. van der Sluijs, J.S. Risbey, J.R. Ravetz (2005) A guidance for assessing and communicating uncertainties. Water Science & Technology, Vol 52 No 6 pp 125–131.

Jorgensen, D. and P. Wilcoxen (1990) Environmental Regulation and US Economic Growth, RAND Journal of Economics, 21 (2) Summer 1990.

Köhler, J., M. Grubb, D. Popp, O. Edenhofer (2006) The transition to endogenous technical change in climate–economy models: a technical overview to the innovation modeling comparison project. The Energy Journal 27, pp. 17–56.

Kristensen P., B. Fribourg-Blanc, S. Nixon (2004), Outlooks on Nutrient Discharges in Europe from Urban Waste Water Treatment Plants, Final Draft, EEA European Topic Centre on Water.

Künzli N., R. Kaiser, S. Medina, M. Studnicka, O. Chanel, P. Filliger, M. Herry, F. Horak, V. Puybonnieux-Texier, P. Quenel, J. Schneider, R. Seethaler, J-C. Vergnaud, H. Sommer (2000) Public health impact of outdoor and traffic related air pollution: a European assessment Lancet, 356, 795-801.

Leemans R., and B. Eickhout (2004) Another reason for concern: regional and global impacts on ecosystems for different levels of climate change. Global Environmental Change, 14:219-228.

Leemans R., B.J. Eickhout, B. Strengers, A.F. Bouwman, M. Schaeffer (2002) The consequences for the terrestrial carbon cycle of uncertainties in land use, climate and vegetation responses in the IPCC SRES scenarios. Science in China, 43:1-15.

Lehner, B., et al., (2001) EuroWasser – Model-based assessment of European water resources and hydrology in the face of global change. (Kassel World Water Series 5). Kassel: Center for Environmental Systems Research, University of Kassel. <www.usf.uni-kassel.de>. Visited 20 March 2008.

Li Y., J. Zhang (1999) Agricultural diffuse pollution from fertilizers and pesticides in China. Water Science and Technology, 39: 25-32.

Liu, J. Dietz, T., Carpenter S.R. et al. (2007) ”Complexity of Coupled Human and Natural Systems.” Science, Vol. 317, pp. 1513-1516.

Lutz, W., W.C. Sanderson, S. Scherbov, Eds. (2004) The End of World Population Growth in the 21st Century: New Challenges for Human Capital Formation and Sustainable Development. London: Earthscan.

Maddison, A. (2001) The World Economy: A Millennial Perspective OECD Development Centre, OECD, Paris.

Maddison, A. (2003) The World Economy: Historical Statistics, OECD Development Centre, OECD, Paris.

Mathers C.D. and D. Loncar (2006) Projection of global mortality and burden of disease from 2002 to 2030. PLoS Med 3(11) e442.

MEA (2005) Ecosystems and Human well-being: Synthesis of the Millennium Ecosystem Assessment. Island Press, Washington D.C.

Meinshausen M. (2006) On the risk of overshooting 2°C. In: Schellnhuber H.J., Cramer W., Nakicenovic N., Wigley T. and Yohe G. (Editors) Avoiding Dangerous Climate Change. Cambridge University Press, Cambridge, UK, pp. 265-281.

Mensbrugghe, D. van der (2003) Linkage Technical Reference Document Version 5.4, Development Prospects Group, World Bank, Washington DC.

MIT (2003) The future of nuclear power – an interdisciplinary MIT study, Massachusetts Institute of Technology, Cambridge, USA, 180 pp.

MNP (2007) Nederland en een duurzame wereld: armoede, klimaat en biodiversiteit. Tweede Duurzaamheidsverkenning (in Dutch). Report nr. 500084001, the Netherlands Environmental Assessment Agency (MNP), Bilthoven , the Netherlands.

Molden, D. (2007) Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture. London: Earthscan, and Colombo: International Water Management Institute.

New M., M. Hulme, P. Jones (1999) Representing twentieth-century space-time climate variability. Part I. Development of a 1961–90 mean monthly terrestrial climatology, Journal of Climate, 12:829–856.

OECD (2001) OECD Environmental Outlook. OECD, Paris

OECD (2003) Agricultural Policies in OECD Countries 2000. Monitoring and Evaluation. OECD, Paris.

OECD (2006) Working Party on Global and Structural Policies, Revised environmental baseline for the OECD environmental outlook to 2030, 20-21 November 2006, 24 October 2006, ENV/EPOC/GSP(2006)23.

OECD (2008) OECD *Environmental Outlook to 2030*. OECD, Paris.

Olivier, J.G.J. and J.J.M. Berdowski (2001) Global emissions sources and sinks. In: Berdowski, J., Guicherit, R. and B.J. Heij (eds.) The Climate System, pp. 33-78. A.A. Balkema Publishers/Swets & Zeitlinger Publishers, Lisse, The Netherlands. ISBN 90 5809 255 0.

Olivier, J.G.J. and J.A.H.W. Peters (2002) Uncertainties in global, regional and national emission inventories. In: Van Ham, J., A.P.M. Baede, R. Guicherit and J.F.G.M. Williams-Jacobse (eds.):‘Non-CO_2 greenhouse gases: scientific understanding, control options and policy aspects. Proceedings of the Third International Symposium, Maastricht, Netherlands, 21-23 January 2002’, pp. 525-540. Millpress Science Publishers, Rotterdam. ISBN 90-77017-70-4.

Olivier, J.G.J., J.J.M. Berdowski, J.A.H.W. Peters, J. Bakker, A.J.H. Visschedijk, J.-P.J. Bloos (2001) Applications of EDGAR. Including a description of EDGAR 3.0: reference database with trend data for 1970-1995. RIVM, Bilthoven. RIVM report no. 773301001/ NOP report no. 410200051.

Olivier, J.G.J., J.A. van Aardenne, F. Dentener, V. Pagliari, L.N. Ganzeveld, J.A.H.W. Peters (2005) Recent trends in global greenhouse gas emissions: regional trends 1970-2000 and spatial distribution of key sources in 2000. Env. Sc., 2 (2-3), 81-99. DOI: 10.1080/15693430500400345.

Olivier, J.G.J., T. Pulles, J.A. van Aardenne (2006) Part III: Greenhouse gas emissions: 1. Shares and trends in greenhouse gas emissions; 2. Sources and Methods; Greenhouse gas emissions for 1990, 1995 and 2000. In: “CO_2 emissions from fuel combustion 1971-2004”, 2006 Edition, pp. III.1-III.41. International Energy Agency (IEA), Paris. ISBN 92-64-10891-2 (paper) 92-64-02766-1 (CD ROM) (2006).

Oosterhuis, F. ed. (2006) Ex-post estimates of costs to business of EU environmental legislation, Contributions by: Véronique Monier and Cécile des Abbayes (BIO), Benjamin Görlach (Ecologic), Andrew Jarvis and James Medhurst (GHK) Onno Kuik (IVM), Robin Vanner and Paul Ekins (PSI), Jochem Jantzen and Henk van der Woerd (TME), Peter Vercaemst, D. Huybrechts and E. Meynaerts (VITO) Reviewed by Reyer Gerlagh (IVM), Amsterdam.

Pandey K.D., et al. (2006) Ambient Particulate Matter Concentrations in Residential Areas of World Cities: New Estimates Based on Global Model of Ambient Particulates (GMAPS,. The Development Research Group and the Environment Department, Washington, DC.

Pandey, K., D., D. Wheeler, B. Ostro, U. Deichmann, K. Hamilton, K. Bolt (2007) Ambient Particulate Matter Concentrations in Residential and Pollution Hotspot areas of World Cities: New Estimates based on the Global Model of Ambient Particulates (GMAPS), The World Bank Development Economics Research Group and the Environment Department Working Paper, The World Bank, Washington DC. (forthcoming). See also: <http://econ.worldbank.org/WBSITE/EXTERNAL/EXTDEC/EXTRESEARCH/0,,contentMDK:20785646~pagePK:64214825~piPK:64214943~theSitePK:469382,00.html>.

Parry M., N. Arnell, T. McMichael, R. Nicholls, P. Martens, S. Kovats, M. Livermore, C. Rosenzweig, A. Iglesias, G. Fischer (2001) Millions at Risk: Defining Critical Climate Change Threats and Targets. Global Environment Change, 11:1-3.

Pauly, D., V. Christensen, J. Dalsgaard, R. Froese, F.C.J.Torres (1998) Fishing down marine food webs. Science 279, 860-863.

Pena-Claros, M. (2003) Changes in Forest Structure and Species Composition during Secondary Forest Succession in the Bolivian Amazon. BIOTROPICA 35, 450-461.

Pope III C.A., R.T. Burnett, M.J. Thun, E.E. Calle, D. Krewski, K. Ito, G.D. Thurston (2002) Lung cancer, cardiopulmanory mortality, and long-term exposure to fine particulate air pollution J. Amer. Med. Assoc. 287, 1132-1141.

Ricardo, D. (1817) On the Principles of Political Economy and Taxation. John Murray, London.

Roe, G.H. and M.B. Baker (2007) Why is climate sensitivity so unpredictable? Science, Vol. 318, pp. 629-632.

Rogner H.H. (1997) An assessment of World Hydrocarbon Resources. Annual Review of Energy and the Environment, 22:217-262.

Rosenzweig C., M. Parry, G. Fischer (1995) World Food Supply. In: Strzepek, K.M. and Smith, J.B. (Editors), As Climate Changes: International Impacts and Implications. Cambridge University Press, pp. 27-56.

Rotmans, J. (1990) IMAGE. An Integrated Model to Assess the Greenhouse Effect, Kluwer Academic Publishers, Dordrecht.

Sala, O.E., F. Stuart Chapin III, J.J. Armesto, E. Berlow, J. Bloomfield, R. Dirzo., E. Huber-Sanwald, L.F. Huenneke, R.B. Jackson, A. Kinzig, R. Leemans, D.M. Lodge, H.A. Mooney, M. Oesterheld, N. LeRoy Poff, M.T. Sykes, B.H. Walker, M. Walker, D.H. Wall (2000) Global biodiversity scenarios for the year 2100. Science 287, 1770-1774.

Sala-i-Martin, X.X. (1996) Regional Cohesion: Evidence and Theories of Regional Growth and Convergence. European Economic Review, vol. 40, pp.1325-52.

Sala-i-Martin X.X. (1996) The Classical Approach to Convergence Analysis. Economic Journal vol. 106, no. 437, July 1996, pp. 1019-1036.

Schlesinger M.E., S. Malyshev, E.V. Rozanov,F. Yang., N.G. Andronova,B. de Vries,A. Grübler, K. Jiang, T. Masui, T. Morita., N. Nakicenovic., J. Penner., W. Pepper., A. Sankovski, Y. Zhang (2000) Geographical distributions of temperature change for scenarios of greenhouse gas and sulphur dioxide emissions. Technological Forecasting and Social Change, 65:167-193.

Scholes R.J. and R. Biggs (2005) A biodiversity intactness index. Nature, 434:45-49.

Scrieciu (2007) The inherent dangers of using computable general equilibrium models as a single integrated modelling framework for sustainability impact assessment. A critical note on Böhringer and Löschel (2006). Ecological Economics, Vol. 60, pp. 678-684.

Seré C. and H. Steinfeld (1996) World livestock production systems. Current status, issues and trends. Animal Production and Health Paper 127, Food and Agriculture Organization of the United Nations, Rome 83 pp.

Shiklomanov, I., (1997) Assessment of Water Resources and Water Availability of the World. Stockholm: Stockholm Environment Institute.

Shiklomanov, I. (2000) Appraisal and Assessment of World Water Resources, Water International, 25(1), pp 11-32.

Sims R.E.H., H.H. Rogner, K. Gregory (2003) Carbon emission and mitigation cost comparisons between fossil fuel, nuclear and renewable energy resources for electricity generation. Energy Policy, 31:1315–1326.

Smout, F.J.C., J. Clement, J.R.M. Alkemade, R. Reijnen. (in prep.) Minimum area requirement curve as a method for assessing the effect of fragmentation.

Tabeau A., B. Eickhout, H. van Meijl (2006) Endogenous agricultural land supply: Estimation and implementation in the GTAP model. Presented at the Ninth Annual Conference on Global Economic Analysis, June 2006, Addis Ababa, Ethiopia.

Taylor L. and R. von Arnim (2006) Modelling the Impact of Trade Liberalisation: A Critique of Computable General Equilibrium Models. Oxfam International Research Report, July 2006.

TNO (2006) Fossil Fuel Resource Estimates. TNO, The Netherlands.

UN (2005) United Nations, Department of Economic and Social Affairs, Population Division World Population Prospects: The 2004 Revision. CD-ROM Edition - Extended Dataset (United Nations publications, Sales No. E.05.XIII.12).

UN (2006) United Nations, Department of Economic and Social Affairs, Population Division (2006). World Urbanization Prospects : The 2005 Revision. CD-ROM Edition - Data in digital form (POP/ DB/WUP/Rev.2005).

UNEP (2001) GLOBIO. Global methodology for mapping human impacts on the biosphere. Report nr. UNEP/DEWA/TR 25, United Nations Environmental Programme, Nairobi.

UNEP (2003) An exploration on biological indicators relevant for the 2010 target. Report nr. UNEP/CBD/SBSTTA/9/inf/26, Convention on Biological Diversity, Montreal.

UNEP (2004) Report of the Ad Hoc Technical Expert Group on Indicators for assessing progress towards the 2010 target. Report nr. UNEP/CBD/SBSTTA/10/inf/7, Convention on Biological Diversity, Montreal.

UNEP (2006) Geo Yearbook 2006: An overview of our changing environment, UNEP, Nairobi, 2006, ISBN: 92-807-2668-4.

UNEP (2007) Global Environmental Outlook 4,, environment for development. United Nations Environmental Programme, Nairobi, Kenya, 540 pp.

UNEP/GPA (2006). The State of the Marine Environment: Trends and processes. UNEP/GPA, The Hague

UNEP/RIVM (Potting J., J. Bakkes Editors) (2004) The GEO-3 scenarios 2002-2032: Quantification and analysis of environmental impacts. Report UNEP/DEWA/RS.03-4 and RIVM 402001022, Division of Early Warning and Assessment (DEWA), United Nations Environment Programme (UNEP) / National Institute for Public Health and the Environment, Nairobi / Bilthoven, 216 pp.

Valenzuela, E., et al. (2007) Assessing Global CGE Model Validity Using Agricultural Price Volatility, American Journal of Agricultural Economics, vol. 89, no. 2, pp. 385-99.

Van Aardenne, J.A., F.J. Dentener, J.G.J. Olivier, C.G.M Klein Goldewijk, J. Lelieveld (2001) A 1γ x 1γ resolution dataset of historical anthropogenic trace gas emissions for the period 1890-1990. Global Biogeochemical Cycles,15(4), 909-928.

Van der Sluijs, J.P., M. Craye, S. Funtowicz, P. Kloprogge, J. Ravetz, J.Risbey (2005) Combining Quantitative and Qualitative Measures of Uncertainty in Model-Based Environmental Assessment: The NUSAP System. Risk Analysis 25 (2), 481–492. doi:10.1111/j.1539-6924.2005.00604.x.

Van Drecht G., A.F. Bouwman, J.M. Knoop, A.H.W. Beusen, C.R. Meinardi (2003) Global modeling of the fate of nitrogen from point and nonpoint sources in soils, groundwater and surface water. Global Biogeochemical Cycles, 17(4):1115, doi:10.129/2003GB002060.

Van Egmond K., T. Bresser, L. Bouwman (2002) The European nitrogen case. Ambio, 31: 72-78.

Van Minnen J.G. (2008) The terrestrial carbon cycle on the regional and global scale. Modeling, uncertainties and policy relevance. PhD thesis. Wageningen University Research Centre (WUR), Wageningen.

Van Ruijven B., D.P. van Vuuren, B. de Vries B. (2006) The potential role of hydrogen in energy systems with and without climate policy. International Journal of Hydrogen Energy 32 (12):1655-1672.

Van Vuuren D.P., B. Eickhout, P.L. Lucas, M.G.J. den Elzen (2006a) Long-term multi-gas scenarios to stabilise radiative forcing – exploring costs and benefits within an integrated assessment framework. The Energy Journal. Vol. Multi-Greenhouse Gas Mitigation and Climate Policy, Special Issue no. 3, pp.201-234.

Van Vuuren, D.P., M. Berk, J. Farla, R. de Vos (2006b) From climate objectives to emission reduction. Report nr. 500114003, the Netherlands Environmental Assessment Agency (MNP), Bilthoven, the Netherlands.

Van Vuuren, D.P., F. de al Chesnaye, J. Weyant (2006c) Multi-gas scenarios to stabilize radiative forcing. Energy Economics. 28 (1): 102-120.

Van Vuuren, D.P. (2007) Energy Systems and Climate Policy, PhD thesis, Utrecht University.

Van Vuuren, D.P., et al. (2007) Stabilizing Greenhouse Gas Concentrations at Low Levels: an Assessment of Reduction Strategies and Costs, Climatic Change 81: 2.119-159.

Van Vuuren, D.P., M. Meinshausen, G.-K. Plattner, F. Joos, K.M. Strassmann, S.J. Smith, T.M.L. Wigley, S.C.B. Raper, K. Riahi, F. de la Chesnaye, M. den Elzen, J. Fujino, K. Jiang, N. Nakicenovic, S. Paltsev, J.M. Reilly (forthcoming). Temperature increase of 21st century stabilization scenarios (submitted to PNAS).

Verhagen, R. (2007) Changing Land Use. Restoration perspectives of low production communities on agricultural fields after top soil removal. PhD-thesis, University of Groningen, Groningen, the Netherlands.

Vollenweider R.A. (1992) Coastal marine eutrophication: principles and control. Science of the Total Environment, Supplement 1992: 1-20.

Vries, H.J.M. de, et al. (2001) The Timer IMage Energy Regional (TIMER) Model, National Institute for Public Health and the Environment (RIVM), Bilthoven.

WHO (2004) Comparative quantification of health risks: global and regional burden of disease attributable to selected major risk factors. Ezzati M et al (eds). WHO.

WHO (2006). Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide - Global update 2005 - Summary of risk assessment. WHO regional office for Europe, Copenhagen, Denmark. <http://www.who.int/phe/health_topics/outdoorair_aqg/en/index.html>.

WHO/UNICEF (2000) Water supply and sanitation assessment 2000, report World Health Organization (WHO) / United Nations Children's Fund (UNICEF), Geneva. <www.childinfo.org/eddb/sani and www.who.int/docstore/water_sanitation_health/Globassessment/>.

Wigley, TM.L. (1991) Could reducing fossil-fuel emissions cause global warming. Nature. 349, p503-506.

Wischmeier W.H. and D.D. Smith (1978) Predicting rainfall erosion losses. A guide to conservation planning. USDA Agricultural handbook 537, United States Department of Agriculture, Washington, D.C.

WRI (2000) World Resources 2000-2001: People and Ecosystems, World Resources Institute, Elsevier Science, Oxford.

Abbreviations, units and conversions

AFR	Africa
ANZ	OECD Pacific (Oceania)
BRA	Brazil
BRIC	Brazil, Russia, India and China
BRIICS	Brazil, Russia, India, Indonesia, China and South Africa
cc	Climate policy variant
CBD	Convention on Biological Diversity
CCS	Carbon capture and storage
CFC	Chlorofluorocarbon
CH_4	Methane
CHN	China Region
C-eq	Carbon dioxide equivalents expressed as the carbon mass involved. One unit of C-equivalent corresponds to 3.67 (=44/12) units of carbon dioxide
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2-eq	Carbon dioxide equivalents. One unit of carbon dioxide-equivalent corresponds to 0.27 (=12/44) units of carbon involved
CSD	Commission on Sustainable Development
DALY	Disability-Adjusted Life Year
ECA	Eastern Europe & Central Asia (Ukraine Region, STANs)
EJ	Exajoule = 10^{18} Joules
EUR	OECD Europe (Western Europe, Central Europe, Turkey)
FAO	Food and Agriculture Organisation of the United Nations
GDP	Gross domestic product
GHG	Greenhouse gas
GJ	Gigajoule = 10^9 Joule
GMT	Global Mean Temperature
Gt	Gigatonne = 10^9 tonnes
GW	Gigawatt = 10^9 Watt
HFC	Hydrofluorocarbon
IIASA	International Institute for Applied Systems Analysis
IEA	International Energy Agency
IMAGE	Integrated Model to Assess the Global Environment
IPCC	Intergovernmental Panel on Climate Change
JPK	OECD Asia (Japan Korea region)

MDGs	Millennium Development Goals
MEA	Middle East
MJ	Megajoule = one million Joules
MNP	Netherlands Environmental Assessment Agency
MSA	Mean species abundance
Mt	Million tonnes
MWh	Megawatt-hour
N	Nitrogen
NAM	North America (Canada, USA, Mexico)
NH_3	Ammonia
NO_2	Nitrogen dioxide
N_2O	Nitrous oxide; dinitrogen oxide
NOx	Nitrogen oxides
NUR	Nitrogen Uptake Ratio
O_3	Ozone
OAS	Other Asia (Indonesia, Rest of SE Asia)
OLC	Other Latin America & Caribbean (Central America, Caribbean, South America apart from Brazil)
P	Phosphorus
PCC	Per capita convergence
PJ	petajoule = 10^{15} Joules
pp	policy package
ppb	Parts per billion
ppm	Parts per million
PFC	Perfluorocarbon
PM	Particulate matter
$PM_{2.5}$	Particulate matter, particles of 2.5 micrometres (µm) or less
PM_{10}	Particulate matter, particles of 10 micrometres (µm) or less
ROW	Rest of world
RUS	Russia & Caucasus
S	Sulphur
SO_2	Sulphur dioxide
SO_x	Sulphur oxides
SOA	South Asia
SF_6	Sulphur hexafluoride
Tg	Teragram = 10^{12} gram = 1 megatonne
TJ	Terajoule = 10^{12} Joules
TWh	Terawatt hour = 10^{12} Wh
UNFCCC	United Nations Framework Convention on Climate Change
VOC	Volatile organic compound
WHO	World Health Organization
WTO	World Trade Organization
ZJ	Zettajoule = 10^{21} Joules

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Background report to the OECD Environmental Outlook to 2030

Overviews, details, and methodology of model-based analysis

International environmental policy has a chance of succeeding if Brazil, Russia, India and China participate, and if swift action is taken. Then, serious climate policy will be affordable and feasible. The Netherlands Environmental Assessment Agency and OECD have assessed a package of policy measures in the area of free trade, climate, water and air. These analyses form the basis of the *OECD Environmental Outlook to 2030*.

Rapport de base des Perspectives de l’Environnement à l’Horizon 2030

Présentation, Détails et Méthodologie de l’Analyse Basée sur les Modèles

La politique environnementale internationale a une chance de réussir si le Brésil, la Russie, l’Inde et la Chine participent, et si une action rapide est prise. Alors, une politique climatique sérieuse sera abordable et faisable. L’Agence Néerlandaise d’Évaluation Environnementale (MNP) et l’OCDE ont évalué un ensemble de mesures de politique dans le domaine du libre échange, du climat, de l’eau et de l’air. Ces analyses forment la base des *Perspectives de l’Environnement de l’OCDE à l’horizon 2030.*

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