Co-benefits of climate policy

Background Studies

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Co-benefits of climate policy

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J.C. Bollen, C.J. Brink, H.C. Eerens, A.J.G. Manders

Contact:
Johannes Bollen
PBL/MNP/KMD
johannes.bollen@pbl.nl

Netherlands Environmental Assessment Agency (PBL)
PO Box 303
3720 AH Bilthoven
The Netherlands
T: +31 (0)30 274 2745
F: +31 (0)30 274 4479
E: info@pbl.nl
www.pbl.nl/en

About this report

Global climate policy will reduce outdoor air pollution

A stringent global climate policy will lead to considerable improvements in local air quality and consequently improves health. Measures to reduce emissions of greenhouse gases to 50% of 2005 levels, by 2050, can reduce the number of premature deaths from the chronic exposure to air pollution by 20 to 40%. Climate policy will already generate air quality improvements in the OECD countries (particularly in the US) in the mid-term, whereas in developing countries these benefits will only in the longer run show to be significant. This is the main message of a report published by the Netherlands Environmental Assessment Agency (PBL), titled 'Co-benefits of climate policy' that was carried out for the OECD.

Synergy between air pollution and climate policies

Combustion of fossil energy leads to climate change and air pollution. The OECD, therefore, posed the question if a global climate policy could bring additional benefits by reducing outdoor air pollution, with the associated positive effects on public health. The potential additional benefits can be an extra incentive for countries to participate in a future climate agreement. The study by the Netherlands Environmental Assessment Agency (PBL) indicates that there is indeed a synergy between these policy areas. An integrated strategy tackling climate change and air pollution will reduce the policy costs and generate a net welfare benefit at the global level.

The co-benefits of uniform carbon prices around the world will in the medium term become visible in the rich OECD countries, and in the longer run in non-OECD countries. In these latter countries, however, the costs of such a uniform global climate policy would initially outweigh the benefits of better air quality. Moreover, the PBL report reveals that in developing countries these air quality improvements can be achieved more cheaply by pursuing a directed air quality policy.

Insufficient incentive

Although the indirect benefits of climate policy – improved air quality and public health – could be an additional incentive for countries to participate in a future climate convention, they are too small to outweigh the costs of climate policy. For example, in 2050, the costs of such a climate policy in China – under which greenhouse gas emissions are 80% lower than the baseline trend without that policy – will amount to 6.5% of the country's GDP. Meanwhile, the benefits will be equivalent to 4.5% of GDP. However, these benefits could also be achieved through a more targeted air quality policy. In China, such a targeted air quality policy could achieve the same air quality improvements by 2050, at a cost of 1.8% of GDP.

Stringent air pollution policy This study also shows that a stringent air quality policy can lead to a reduction in emissions of greenhouse gases. For example, if China pursues a stringent air policy to reduce the number of premature deaths from chronic exposure to outdoor air pollution by 70%, by 2050 (compared with a baseline trend without policy), this policy will lower GDP in 2050 by 7%. The air quality benefits would be equivalent to 7.5% of GDP, while greenhouse gas emissions would be 40% lower.

Keywords: climate change, air pollution, integration, damage valuation, costbenefit analysis

Rapport in het kort

Mondiaal klimaatbeleid leidt tot verbetering van luchtkwaliteit

Streng mondiaal klimaatbeleid leidt tot een forse verbetering van de lokale luchtkwaliteit en daarmee tot minder gezondheidsverlies. Maatregelen om in 2050 de wereldwijde uitstoot van broeikasgassen te verlagen tot 50% van het niveau in 2005 kunnen de vroegtijdige sterfte door chronische blootstelling aan luchtvervuiling verminderen met 20-40%. De verbetering van de luchtkwaliteit als gevolg van klimaatbeleid zal sneller zichtbaar zijn in de OESO-landen (vooral in de VS) en pas later in ontwikkelingslanden. Dat blijkt uit deze studie, die is uitgevoerd in opdracht van de OESO.

Synergie tussen luchtvervuiling en klimaatverandering

De verbranding van fossiele energie leidt tot klimaatverandering én luchtvervuiling. De OESO veronderstelt daarom dat een mondiaal klimaatbeleid bijkomende voordelen zou kunnen hebben voor de vermindering van luchtvervuiling en de daarmee gepaard gaande positieve gevolgen voor de gezondheid. Die mogelijke bijkomende voordelen kunnen landen een extra prikkel geven om mee te doen aan een toekomstig klimaatverdrag. Uit de studie van het Planbureau voor de Leefomgeving blijkt dat er inderdaad synergie bestaat tussen de beleidsterreinen. Een geïntegreerde aanpak van klimaatverandering en luchtvervuiling vermindert de kosten van beleid, en leidt tot een netto welvaartswinst op mondiaal niveau.

De voordelen van wereldwijde uniforme klimaatbeprijzing zullen op de middellange termijn al zichtbaar zijn in de rijke, OESO-landen en op de wat langere termijn ook buiten de OESO. In ontwikkelingslanden echter wegen de kosten van zo'n wereldwijd uniform klimaatbeleid vooralsnog niet op tegen de baten van luchtkwaliteit. Dit rapport laat bovendien zien dat in deze landen de luchtkwaliteit goedkoper verbeterd kan worden door gericht streng luchtbeleid.

Prikkel onvoldoende

Ofschoon de indirecte baten van klimaatbeleid – namelijk een verbetering van de luchtkwaliteit en gezondheid – een extra prikkel zouden kunnen zijn voor landen om mee te doen aan een toekomstig klimaatverdrag, zijn deze te klein om de kosten van het klimaatbeleid te overtreffen. In China zullen bijvoorbeeld de kosten van het klimaatbeleid in 2050 – leidend tot een 80% vermindering van broeikasgassen ten opzichte van het basispad zonder beleid - gelijk zijn aan 6,5% van het BBP. Terwijl de luchtbaten dan gelijk zullen zijn aan 4,5% van het BBP. Wel moet aangetekend worden dat deze baten via een meer gericht luchtbeleid ook gerealiseerd kunnen worden. In China kan in 2050 met 1,8% van het BBP dezelfde luchtbaten worden behaald door gericht luchtbeleid.

Streng luchtbeleid

Deze studie laat ook zien dat streng luchtbeleid op zijn beurt kan leiden tot vermindering van de uitstoot broeikasgassen. Als in China bijvoorbeeld zo'n streng luchtbeleid erop gericht is om in 2050 70% van de vroegtijdige sterfgevallen door luchtvervuiling te vermijden (ten opzichte van een basispad zonder beleid), dan zal dit beleid het BBP in 2050 met 7% verlagen. De luchtbaten zijn in dat geval gelijk aan 7,5% van het BBP, terwijl de uitstoot van broeikasgassen in dat geval 40% lager uitvallen.

Trefwoorden: klimaatverandering, luchtvervuiling, integratie, schadekosten,
kosten-baten analyse

Contents

Summary

Policy perspectives on Climate Change and Air Pollution

This report investigates the consequences of the interrelationship between global climate change (GCC) and local air pollution (LAP). The major connection between these environmental problems is the combustion of fossil fuels. As a consequence, policies aiming to mitigate one of these environmental problems potentially have large effects on the other. For example, climate policy may reduce the demand for coal in the electricity sector, which lowers emissions that contribute to local air pollution.[1] From an efficiency point of view, it is important to take into account these co-effects when deciding on appropriate policy actions in response to one of these problems. Also for a country's decision to participate in an international environmental agreement (for example on climate change), the incentive not only depends on the direct costs and benefits of this policy strategy, but also on the co-effects of the policy under consideration.

The present study investigates the interrelations between policies for climate change and policies for local air pollution from three different perspectives or windows (see Figure 1, based on Bollen et al., 2009):

i. *Climate change window:* policies primarily aiming at the mitigation of global climate change not only reduce emissions of greenhouse gases (Impact 1), but also reduce emissions of air pollutants (Additional impact 1), which yields co-benefits in terms of reduced local air pollution;
ii. *Air pollution window:* policies primarily aiming at the mitigation of local air pollution not only reduce emissions of air pollutants (Impact 2), but also reduce emissions of greenhouse gases (Additional impact 2), yielding co-benefits in terms of reduced global climate change;
iii. *Integrated approach:* policies are simultaneously aiming at the mitigation of global climate change (Impact 1 + Additional impact 2) and local air pollution (Impact 2 + Additional impact 1), yielding an optimised combination of reductions in emissions of greenhouse gases and air pollutants.

In this report, the costs and benefits (including the co-benefits) are estimated for different environmental policies. In the climate change window and the air pollution window, co-benefits are calculated in two alternative ways. First, co-benefits are calculated as the monetary value of the avoided disutility (compared with the Business-As-Usual (BAU) scenario) associated with the damage from local air pollution (premature deaths) and global climate change (temperature rise), respectively. Second, co-benefits are calculated as the avoided costs and benefits of alternative policy packages that would yield the same co-benefit (i.e. reduction in premature deaths and greenhouse gas emissions, respectively) at minimum cost. The reason to do so is that, although co-benefits calculated in the first way may be substantial, if these benefits can be achieved at lower cost by an alternative policy package (i.e. co-benefits calculated in the second way are lower than calculated in the first way), this is a more appropriate figure to evaluate whether co-benefits form an incentive to participate in an international agreement. Indeed, for example in the climate window, the number of premature deaths prevented through the climate policy can also be achieved through more cost-effective options to mitigate the impacts of local air pollution (mostly end-of-pipe control measures).

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[1] In this study LAP represents outdoor air pollution and focuses on the impacts related to the mortality from long-term outdoor exposure to particulate matter (with a diameter no larger than 2.5 μm, further referred to as $PM_{2.5}$).

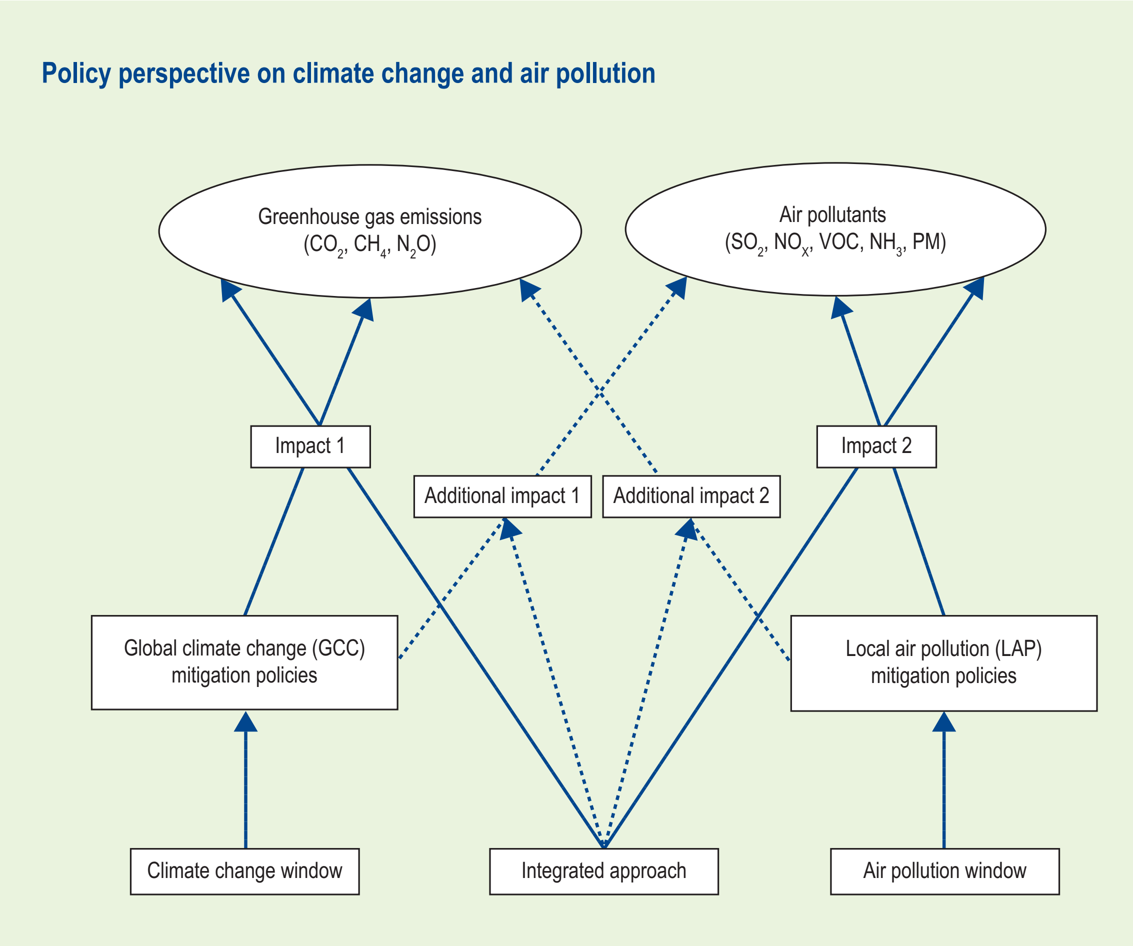

Figure 1 Three perspectives on the analysis of co-benefits

Table 1 summarizes the impacts of different variants of mitigation policies representing the three perspectives in Figure 1. All numbers refer to percentage deviations from the Business-As-Usual (BAU) scenario in the year 2050 for the OECD, China and India and also for the world as a whole. The assumptions of the BAU scenario are described in OECD (2008). Table 1 presents both the number of premature deaths and CO_2 eq. emissions and the monetized impacts (GDP losses from abatement, benefits of prevented damage from global climate change and local air pollution).

In the climate change window, the policy package provides a cost-effective way of reducing global CO_2 eq. emissions in 2050 to 50% below the 2005 level (equal to a 73% reduction of the BAU emission level in 2050). In the air pollution window, the policy package aims to reduce the global number of premature deaths caused by chronic exposure to outdoor $PM_{2.5}$ concentrations in rural and urban areas by 25% of the 2005 level.[2] In the integrated approach the model is used to determine the policy package that maximizes global welfare, given the cost of mitigation and the disutility associated with global climate change and local air pollution (and hence the benefits of mitigation).

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[2] This global figure is based on the aggregation of regional figures derived as uniform percentage deviation from a time profile of the integrated approach (see Appendix II).

Table 1 Main results in 2050 of different windows of policies (% change compared with BAU)

		World	OECD	China	India
Climate change window					
climate policy	CO_2 eq mitigation (%)	73	74	81	77
	PM-death reduction (%)	42	34	45	40
	GDP (%)	-2.2	-0.8	-6.4	-3.6
	GCC benefits (% GDP)	0.1	0.2	0.0	0.0
	LAP benefits (% GDP)	1.8	1.4	4.6	3.5
	benefits – GDP loss (% GDP)	-0.2	0.8	-1.8	-0.2
alternative air policy	benefits – GDP loss (% GDP)	1.1	1.0	2.8	1.8
Incentive power	climate policy – alternative air policy (% GDP)	-1.3	-0.2	-4.5	-2.0
Air pollution window	CO_2 eq mitigation (%)	40	38	42	61
Air policy	PM-death reduction (%)	71	65	70	74
	GDP (%)	-2.3	-1.0	-6.9	-7.5
	GCC benefits (% GDP)	-0.1	-0.1	-0.1	0.0
	LAP benefits (% GDP)	3.2	2.5	7.3	6.8
	benefits – GDP loss (% GDP)	0.9	1.6	0.3	-0.8
alternative climate policy	benefits – GDP loss (% GDP)	-0.1	0.2	-0.7	-0.3
Incentive power	air policy - alternative climate policy (% GDP)	1.1	1.4	1.0	-0.5
Integrated approach	CO2 eq mitigation (%)	59	70	56	58
	PM-death reduction (%)	67	74	65	62
	GDP loss (%)	2.9	1.5	7.4	5.8
	LAP benefits (%GDP)	3.3	2.9	6.7	5.6
	benefits – GDP loss (% GDP)	0.5	1.4	-0.6	-0.2

Co-benefits are calculated as the monetary value of the disutility it causes (as % GDP), and also as the avoided costs of an alternative policy achieving the same co-benefit at the lowest possible cost. Within the climate change window and the air pollution window, net benefits are calculated for both types of policies. The difference between these two figures, referred to as the ‘incentive power’, represents the net benefits of climate or air policies when considering co-benefits as avoided cost instead of monetized disutility. If the incentive power is a positive number, the benefits and co-benefits (avoided costs) together are large enough to compensate the cost of the policy.

In the integrated approach, no distinction is made between primary benefits and co-benefits. All effects are included and weighed against each other in order to determine an optimal policy, maximizing global welfare.

Scope of the study

There have been several assessments focusing on the interactions between policies for global climate change and local air pollution. As the notion of co-benefits originated in climate policy discussions, most of these assessments have focused on the co-benefits in terms of a reduction in local air pollution that stem from GHG mitigation policies (like in the *climate change window*). A key conclusion is that GHG mitigation could yield large near-term co-benefits in terms of reduced risks to human health (OECD, 2008). Moreover, in developing countries, the number of premature deaths will increase over time because of urbanization and the increasing share of the elderly in the population, despite that local air pollutant control measures will come into effect. Furthermore, the ratio between co-benefits related to local air pollution and the marginal costs of GHG mitigation are greater in developing than in developed countries, partly due to higher increase in air pollution in the former group of countries.

There are only a few analyses that investigate the co-benefits of climate policies from the point of view of avoided cost of air pollution policies. Moreover, there are not many studies that look at the interrelations between global climate change and local air pollution through the air pollution window or in an integrated approach. In this report, these issues are explicitly addressed through simulations that were made with an extension to the Model for Evaluating the Regional and Global Effects of GHG Reduction Policies (MERGE) to include outdoor local air pollution. The model takes into account the main pollutants that have an impact on human health, except for the impact of ozone. The extended model was used to simulate the costs and benefits of mitigating global climate change and local air pollution in a general equilibrium, dynamic, multi-regional and multi-sectoral framework.

The climate window

Co-benefits of climate policies are significant and increase over time
Simulations in the climate window show that GHG mitigation policies result in a reduction in the number of premature deaths due to air pollution compared with the BAU scenario by around 40% globally in 2050 (Table 1). In the OECD this percentage is smaller than in India and China.

This is partly because local air pollution in the OECD countries is mainly driven by the demand for transport services, whereas outside the OECD a major driving force is coal burning by households. This analysis includes the impact of emissions from household energy consumption on outdoor pollution, but not from indoor pollution. In the next 20 years, cheap GHG abatement opportunities in developing countries are more in the electricity than in transport sector, at least compared with OECD countries. Thus, the resulting emission reductions have less impact on local air pollution in the former than in the latter.

Furthermore, exposure to local air pollution is usually higher when pollution results from many small sources in transport and domestic sources than from large-scale power plants. However, as illustrated in Table 1, the co-benefits are higher in non-OECD than in OECD countries for more stringent emission reductions or over longer time scale. This is the case when relatively cheap CO_2 abatement opportunities in the electricity sector in non-OECD countries are exhausted, and OECD countries run out of options to reduce local air pollution through GHG mitigation policies.

Beyond 2050, however, co-benefits tend to stabilise and even decline slightly in terms of number of deaths as well as in monetary terms. The main reason is that the non-energy related local air pollution substances such as NH_3 become a more dominant source of pollution than energy combustion so that climate policy can no longer significantly reduce emissions responsible for local air pollution. Hence, the co-benefits do not increase further and may even decrease.

Co-benefits of climate policies will increase in the longer term only in non-OECD countries
Aging and strong urbanisation result in a more vulnerable population in non-OECD regions. Therefore, the co-benefits in terms of prevented deaths increase over time. To compare co-benefits with the cost of mitigation policies, the number of prevented premature deaths is multiplied

by the value of a statistical life. The value of a statistical life is assumed to be proportional to GDP per capita in a region. High economic growth and a resulting high value of a statistical life will therefore boost the co-benefits in non-OECD countries further. Finally, with the assumed uniform CO_2 eq. price, emission reductions would be higher in non-OECD than in OECD countries. When expressed as percentage of GDP, co-benefits are also larger in non-OECD than in OECD countries.

Up until 2050, the co-benefits of climate policies alone will probably not provide sufficient incentive to participate in climate mitigation strategies.
It appears that co-benefits can cover a significant part of the costs. The extent to which co-benefits of climate mitigation policies offer economic incentive for countries to participate in climate policies depends on two factors. First, the extent and the value of the co-benefits is important. In 2050, in the OECD the benefits of air pollution are large enough to totally compensate for the GDP loss of the GHG mitigation policies. In India and China and also for the world as a whole, this is not the case, although the benefits to a large extent compensate for the mitigation cost. Second, it is also important to consider the cost of achieving the same level reduction of local air pollution through direct policies. If these costs of direct policies are less than the monetized air pollution benefits, these should be considered as the co-benefits achieved. For all regions this implies that indeed the co-benefits increase the incentive to participate in a climate agreement up to 2050, but they are not enough to fully compensate for the cost of mitigation policies. After 2050, the gains from GHG mitigation are expected to become large and to outpace the mitigation costs.

Air pollution window

The co-benefits of stringent air pollution policies are significant, and provide an incentive for many regions to pursue this air pollution strategy.
In many regions, there are large incentives for countries to directly control local air pollution (or to go through *the air pollution window*). Local air pollution could be effectively reduced by add-on control technologies, which would not reduce GHG emissions. Significant reductions in the level of local air pollution, as shown in Table 1, however result in substantial reductions in GHG emissions, indicating that structural energy adjustments are pursued.

In all three regions, total benefits of reduced air pollution outweigh total cost in the long run. In the short-term, net benefits are only found in the OECD, whereas in China, local air pollution policies are profitable from 2030 and in India this is not the case until 2050. Because of the relatively high reduction in emissions of air pollutants and a high energy intensity in India, the country is confronted with high GDP losses offsetting air pollution benefits. As a result, the reduction in emissions of CO_2 is also relatively high in India.

Although GHG emissions are substantially reduced as a co-benefit of air pollution policies, until 2080 this does not result in a reduction in global average temperature rise. In the long run (2100-2150), global temperature stabilizes at a level well below the long term global temperature level in the baseline. The counterintuitive development in global temperature is the result of the cooling effect of SO_2. Due to the reduction target for air pollution, SO_2 emissions are reduced significantly (worldwide over 80%). As a result, the cooling effect of sulphate aerosols, which in total is estimated to reduce global average temperature by about 0.7 degrees, disappears rapidly. In 2050 the global climate change co-benefits are negative.

Integrated approach

The integrated long-term cost-benefit approach balances the means to lower simultaneously the adverse impacts of climate change and air pollution and shows significant climate benefits only after 2050.

In summary, these simulations and results from the literature review suggest that for countries giving priority to GHG mitigation, the local air pollution co-benefits provide an additional incentive by off-setting a proportion of the GHG mitigation costs. These co-benefits could be larger than currently estimated since most estimates omit the possible co-effects of GHG mitigation on indoor air pollution, which is expected to be large in countries such as India and China (IPCC, 2007). Still, it remains to be seen whether these indoor induced co-benefits are large. As already stated, the GHG mitigation strategy reduces CO_2 emissions from households only in the more stringent cases, and in the longer term. In addition, the carbon price will likely yield only small co-benefits in terms of reduced indoor air-pollution as there may be a switch from coal to biomass. Keep in mind that the burning of biomass also generates emissions of particulate matter.

Moreover, the outdoor air pollution benefits could also be higher, if the baseline PM_{10} emissions were higher. If so, the reductions in CO_2 eq. emission would go hand in hand with higher reductions in $PM_{2.5}$ emissions.[3] However, the co-benefits could also be lower if the attributive risk parameter - linking average concentrations of $PM_{2.5}$ to the number of deaths – is lower.[4] The literature is not conclusive on this issue. With lower attributive risk parameters, the damage of local air pollution in the baseline and the co-benefits of the GHG mitigation strategy will also be lower.

However, for countries that give priority to air pollution control over climate change policy, co-benefits of climate policies are still positive but unlikely to provide sufficient incentive to participate in a climate agreement. Local air pollution control policies give a higher return on investment. This result is independent of any assumption on the value of a statistical life, because the co-benefit of climate policy is offset by the direct benefit of the much cheaper air pollution policy.

Nonetheless, countries that plan to significantly control local air pollution would de facto reduce GHG emissions. Finally, as local air pollution and global climate change are both driven by fossil fuel combustion, there are synergies and higher returns on controlling both GHG and local air pollution (*integrated approach*). Hence for countries that give priority to mitigate the adverse impacts of local air pollution, there is an incentive to also invest in mitigation policies and to maximise benefits across these areas. The synergies can be seen to especially depend on the

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[3] In this sense, the co-benefits are relatively low because of the relatively low emissions in the BAU scenario. This is consistent with the recent dynamics in the regulation of LAP substances in China. In 2007, the annual rise in CO_2emissions was 8%, whereas SO_2emissions fell by 10% (MNP, 2008).

[4] More deaths are estimated in this analysis than in the OECD environmental outlook. The main reasons are firstly, the anthropogenic contribution to pollution is higher, and hence the number of premature deaths are based on concentrations larger than 0 μg/m^3, instead of the approach based on WHO (2004) for urban areas to measure only the number of deaths above 7 ug/m3. Secondly, the number of diseases assumed to be relevant not only concerns mortality from cardiopulmonary disease and lung cancer, but is includes all mortality impacts from exposure to local air pollutants.

level of value of a statistical life, but even the climate sensitivity parameter. If the value of a statistical life is high, then the co-benefits are also high, and vice versa.

Finally, this report demonstrates that the benefits of local air pollution reduction significantly outweigh those of global climate change mitigation in the integrated approach. The benefits of prevented climate damages only show to be significant beyond 2070. Hence, the discounted benefits of local air pollution certainly outweigh those of global climate change. Still, it is not argued to only restrict energy policy making today to what should be the first priority, local air pollution control, and wait with the reduction of greenhouse gas emissions, but instead to design policies that simultaneously address both these issues, as their combination also creates an additional climate change bonus. It seems from the analysis of this report that climate change mitigation proves to be an ancillary benefit of air pollution reduction, rather than the other way around.

1 Introduction

There are strong linkages between global climate change (GCC) and local air pollution (LAP). Emissions from the combustion of fossil fuels contribute significantly to both GCC and LAP. These key environmental issues are discussed extensively in the international political arena: the first notably in the United Nations Framework Convention on Climate Change (UNFCCC) and the second in, for instance, the United Nations Economic Commission for Europe's task-force on Long-Range Transboundary Air Pollution (UNECE-LRTAP).

Options to mitigate GCC may show strong co-benefits in terms of less LAP and vice versa. For example, policies to limit transport emissions and congestion will both improve air quality and simultaneously have positive consequences on GHG emissions. However, this is not always the case. Greenhouse gas (GHG) emissions can be cut by equipping fossil fuel power plants with CO_2 Capture and Storage (CCS) technology only addresses greenhouse gases and usually not emissions of air pollutants. CCS equipment installed in isolation therefore alleviates GCC but not LAP. End-of-pipe abatement techniques reduce emissions of local air pollutants (SO_2, NO_x, NH_3, or particulates) Their application thus contributes to diminishing LAP but not to GCC.

Policies neglecting these co-benefits may be sub-optimal. An integrated analysis of GCC and LAP was carried out to determine the extent to which the co-benefits of climate mitigation policies offer economic incentive for countries to participate in a global agreement to mitigate GHG emissions. The analysis also provides insight into the co-benefits of air pollution policies to offer economic incentive to further reduce on the emissions of air pollutants.

The main issue analysed was the extent to which GHG mitigation costs are covered by the co-benefits in terms of less local air pollution. It seems that climate mitigation costs would be partially covered by the co-benefits if the world community could agree a uniform carbon price. Further, GHG mitigation policies will only increase co-benefits outside the OECD region in the longer term or by means of stringent policies. A related question is the impact of policy design (such as CO_2 eq. emissions trading) on these co-benefits.

For this analysis of the dual GCC-LAP problem, the global top-down model MERGE was used. MERGE (Model for Evaluating the Regional and Global Effects of greenhouse gas reduction policies) has been developed by Manne and Richels (1995). This climate change model includes sufficient bottom-up technology features. For the purpose of this study, the model was expanded with a module dedicated to local air pollution including mathematical expressions for:

- Emissions of local air pollutants (SO_x, NO_x, NH_3 and primary PM) in all sectors,
- Chronic exposure of the population to increased lAP (concentration of pollutants),
- Premature deaths from chronic LAP-exposure in urban and rural areas,
- Monetary estimates for damage resulting from premature LAP deaths.

The LAP module was calibrated to estimates from studies by the World Health Organization (WHO, 2002; 2004) and the RAINS consortium (Amman *et al.*, 2004), as well as several other sources (Pope *et al.*, 2002; Holland *et al.*, 2004). Since cost estimates of GCC and LAP damage as well as most of our other modelling assumptions are subject to uncertainties, a sensitivity analysis was performed on key modelling assumptions. These include discounting assumptions, the number of premature LAP-related deaths, and monetary valuation of these deaths.

The welfare benefits from preventing LAP-related damage are important in the modified version of MERGE used in this study. Benefits can be realized by reducing emissions of SO_2, NO_x, NH_3, or particulates. Emission reductions involve end-of-pipe abatement measures, or a switch from fossil fuels to cleaner forms of energy. When benefits exceed costs, an incentive is created for reducing emissions of local air pollutants. A similar and synchronous balancing between costs and benefits occurs for CO_2 emission reductions. At the same time, a balancing occurs between the incentive to act on LAP respectively GCC, while interactions and spillovers between these two add to the overall optimisation process.

The analysis employed a stylised version of LAP which is restricted to outdoor health impacts of air pollutants and excludes acidification and indoor air pollution. There are also several abstractions in this analysis:

- The focus is on emissions from fossil fuel combustion in the electricity and non-electricity sectors, and process emissions for all substances as these impact exposure to $PM_{2.5}$ but are also the main source of GHG emissions, and thus the principal driver of both GCC and LAP.
- The focus is on fine PMs with a diameter of less than 2.5 μm (referred to as $PM_{2.5}$) which are responsible for deaths from particulates in the ambient air.
- The transboundary aspects of secondary aerosol formations are disregarded because inter-regional transport of these pollutants would need to be addressed, and thus require a more in-depth version of an air-transport model. This is beyond the scope of this analysis.
- Whereas theoretically PM can travel thousands of kilometres, the major contribution to local PM concentrations is from emissions close to the source. The high concentrations of primary PM in cities and densely populated urban areas mostly result from transport systems and power plants in the vicinity. Thus, the assumption can be made that reductions in regional PM emissions contribute to a decrease in PM concentrations within the region under consideration only, especially in the light of the very large area modelled.. [5]

There are also a set of significant approximations.

- We modelled LAP at a highly aggregated level because this enabled LAP and GCC to be integrated into a single modelling framework. The drawback is that modelling of local air pollutants is more rudimentary than for instance in RAINS. The detailed bottom-up abatement cost for EU countries has been reduced to only a few sectors and regions. This approach, however, has the advantage that the economic aspects are more realistic than in RAINS, because the simplification enables simulation of time-dependent abatement technology costs.
- The impact on mortality is higher with $PM_{2.5}$ concentration than with PM_{10} concentration. As very little $PM_{2.5}$ data are available and PM_{10} data are readily available, these data were used as proxy for $PM_{2.5}$ data, as in WHO (2006).
- There is probably only a linear relationship between PM emissions and concentrations at intermediate emission levels. The PM concentration depends not only on regionally produced air pollution, but also on local factors such as meteorology. However, at low emission levels, the increase in LAP emissions alters the concentration of $PM_{2.5}$ very little and thus is mainly determined by regional PM background values. Nevertheless, this analysis was restricted to a linear dose-response relationship.

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[5] Regions in MERGE are USA, Western Europe, Japan, Canada/Australia/New Zealand, Eastern Europe and the former Soviet Union, China, India, MOPEC, and the rest of the world. The model employs a time horizon of 150 years (up to 2150) with time steps of ten years.

- The valuation of premature deaths from chronic exposure to PM concentrations is a contentious issue because there are basically two approaches: Value of a Statistical Life (VSL) and Value of a Life Year (VOLY) multiplied by the number of Years of Life Lost' (YOLL). For the CAFE program, the European Commission decided to adopt the precautionary principle, and used the VSL approach [REFERENCE]. It was also argued that VSL is more statistically reliable than VOLY. This study used the VSL approach but also tested the robustness of the major conclusions on sensitivity/ uncertainty analysis.

Even though a stylised version of LAP, the model is a starting point for exploring and testing the potential significance of synergy between GCC- and LAP-policies. The study provides a cost-benefit framework that derives economically optimal pathways for CO_2 and emissions of air pollutants, given parameter values and specific modelling assumptions. These pathways are based on a trade-off between costs of mitigation efforts and benefits of preventing mid-term air pollution and long-term climate change damage.

An overview of the adapted version of MERGE is presented in Chapter 2. This chapter focuses on the adaptation of the original MERGE model with respect to air pollution, as far as it may give rise for a sensitivity analysis of the main findings of the report.

Chapter 3 discusses the perspective of the climate window by exploring the co-benefits of climate mitigation policies, and the perspective of the air pollution window is presented in Chapter 4 by analysing the co-benefits of mitigation policies of air pollution. The broader integrated perspective of addressing LAP and GCC simultaneously is taken in Chapter 5 which also addresses the spillovers of CO_2 emissions trading on air pollution policies. The robustness of the main findings is tested in Chapter 6 and main conclusions and recommendations are presented in Chapter 7.

2 Model approach

Quantifying the co-benefits and the incentive power of participating in a global GCC mitigation strategy were analysed with model simulations using the extended peer-reviewed MERGE model. MERGE was originally developed and applied to simulate the impacts on the regional economy, to estimate global and regional effects of greenhouse gas (GHG) emissions and the costs of the emission reductions (Manne and Richels, 2004). The MERGE model was modified (Bollen *et al,.*2007) to simulate the impacts of outdoor local air pollution (LAP) and for this study LAP was refined to describe the emissions and impacts of primary PM emissions and to take accountof the health impacts of secondary aerosol formation by simulating regional patterns of SO_2, NO_x, and NH_3 emissions. The model can simulate the costs and benefits of GCC and LAP policies in a dynamic and multi-regional context.

In MERGE, the domestic economy of each region is represented by a Ramsey-Solow model of optimal long-term economic growth, in which inter-temporal choices are made on the basis of a utility discount rate. Response behaviour to price changes is introduced through an overall economy-wide production function. The output of the generic consumption depends, as in other top-down models, on the inputs of capital, labour and energy. CO_2 emissions are linked to energy production in a bottom-up perspective, and separate technologies are defined for each main electric and non-electric energy option. The amount of CO_2 emitted in each simulation period is translated into an addition to the global CO_2 concentration and a matching global temperature increment.

The analysis has global coverage and nine geopolitical regions are distinguished. In each region, production and consumption opportunities are negatively affected by damage (or disutility) generated by either GCC or LAP. The cases analysed by MERGE and the solutions obtained assume Pareto-efficiency. Abatement can be optimally allocated with respect to the dimensions of time (when), space (where) and pollutants (what). [6]

2.1 Cost-benefit mode

In Chapters 3 and 4 the cost effectiveness mode of the model is applied by having the model calculate the cheapest way to meet some imposed target, such as CO_2 eq. emissions (at the regional or global level) or the regional number of premature deaths. However in chapter 5 the cost-benefit (CB) mode of the model is applied. Here the equations are highlighted that are most relevant for the CB-mode. In each year and region an allocation of resources include those assigned to end-of-pipe abatement costs related to emissions of SO_2, NO_x, PM_{10},, and NH_3 :

$$Y_{t,r} = C_{t,r} + I_{t,r} + J_{t,r} + K_{t,r} + D_{t,r} + X_{t,r} \tag{1}$$

with Y representing output or Gross Domestic Product (GDP) aggregated in a single good or *numéraire*, C consumption of this good, I the production reserved for new capital investments, J the costs of energy, K the end-of-pipe abatement costs as added with respect to the original

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[6] Energy saving is one of the more expensive means to mitigate climate change but it will also reduce the LAP emissions intensity.

MERGE formulation, D the output required to compensate for GCC-related damages, and X the net-exports of the numéraire good. The subscripts t and r refer to time and region, respectively. Solving the cost-benefit problem implies a control system that leads to lower temperature increases and avoided premature deaths. Together they minimise the discounted present value of the sum of abatement and damage costs.[7] There is disutility associated with the damages from GCC, and LAP. This is shown by the following relation expressing the objective function (maximand) of the total problem, being the Negishi-weighted discounted sum of utility:

$$\sum_r n_r \sum_t u_{t,r} \log\left(E_{t,r} F_{t,r} C_{t,r}\right) \tag{2}$$

with n representing the Negishi weights, u the utility discount factor, E the disutility factor associated with GCC, and F the disutility factor associated with LAP,. The loss factor E is:

$$E = (1 - (\Delta T / \Delta T_{cat})^2)^h \tag{3}$$

in which ΔT is the temperature rise of its 2000 level, and ΔT_{cat} the catastrophic temperature at which the entire economic production would be wiped out. The t-dependence is thus reflected in the temperature increase reached at a particular point in time, while the r-dependence is covered by the ‘hockey stick’ parameter h, which is assumed to be 1 for high-income regions, and takes values below unity for low-income regions. The GCC part of MERGE is kept unchanged in its original form, but for the part of this theory section below the focus is on the expanded MERGE model to account for (A) the chain of emissions of SO_2, NO_x, NH_3, and PM_{10} increasing their contribution to the $PM_{2.5}$ concentrations, (B) the increase of PM concentrations provoking premature deaths, and (C) the meaning of these deaths in terms of their monetary valuation.

2.2 Valuing Air pollution: VSL

Starting at the end of the impact pathway chain, the question is how should premature deaths resulting from chronic PM exposure be monetised. Holland et al. (2004) recommend using both VSL and VOLY, respectively, to value the deaths incurred from PM exposure. The differences between these two approaches are smaller than the values shown in Table 2.1 suggest. Much of the difference disappears when the VOLY values are multiplied by the number of life years lost. Typically for Europe, an average of 10 life years lost under current PM exposure levels can be assumed. In this case, the VOLY approach at median estimates results in a valuation of death approximately 50% lower than in the VSL approach. In this study, the median estimate of the VSL approach in 2000 has been assumed as the benchmark case.

As shown in Table 2.1, VSL in Europe for the base year 2000 is about US$. 1.06 million (2000). The following equation holds for the monetised damage (F) from LAP:

$$F_{t,r} = 1 - \frac{1.06 N_{t,r}}{C_{t,r}} \left(\frac{Y_{t,r} / P_{t,r}}{Y_{2000,weur} / P_{2000,weur}} \right) \tag{4}$$

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[7] Y is ‘fixed’. It is equal to the sum of a production function of a new vintage and a fixed old vintage. With respect to the new vintage, there is a putty-clay CES formulation of substitution between new capital, labour, electric and non-electric energy in the production of the composite output good . With respect to the old vintage, it is assumed that there is no substitution between inputs. New capital is a distributed lag function of the investments of a certain year and a previous time step. K is equal to the costs of end-of-pipe abatement, and just one of the claimants of production, and therefore if K increases, then C reduces (which itself is part of the maximand).

Table 2.1 Valuation of PM deaths in million 2000 US$. Source: Holland et al. (2004)

	VSL	VOLY
Median	1.061	0.056
Mean	2.165	0.130

in which N is the number of premature death from chronic exposure to PM, and P the exogenous number of people in a given population.

For non-European regions, VSL is determined by multiplying VSL for Western Europe (WEUR) with the ratio of these respective regions GDP per capita. For future years, VSL is assumed to rise with the growth rate of per capita GDP (income elasticity is one).

The European Commission decided to use the VSL approach instead of the VOLY method for the CAFE program. The VOLY approach latter can be argued to be less statistically reliable while the VSL also better reflects the precautionary principle. This study tested the robustness of the major conclusions through an uncertainty analysis by applying the 56000 of a VOLY times the average number of 10 life-years gained. The valuation of the mortality impacts decline by about 50%.

Finally, a sensitivity analysis was conducted of the model simulations with an income elasticity of 0.5 as opposed to that employed in the benchmark case (see Viscusi and Aldy, 2003). The counter-intuitive result emerging from this alternative assumption is that low-income countries will have a larger VSL in the short to medium term, whereas in the long term the VSL will be lower that the base case for all countries.

2.3 From emissions to concentrations to deaths

The concentration in each region is derived from the substance-specific contribution of emissions to the ambient concentration. Both rural and urban concentrations are added to the regional average. Equation (2) summarizes the relationship between the average yearly $PM_{2.5}$ concentration in µg/m³ in year t and region r:

$$G_{t,r} = \sum_{s \in S} H_{s,t,r} \tag{5}$$

With s the index of substances SO_2, NO_x, PM_{10}, and NH_3, and H the substance-specific contribution to the regional yearly $PM_{2.5}$ concentration, which is based on the weighted mean of urban and rural concentrations in the following equation (3):

$$\begin{aligned} H_{s,t,r} &= u_{t,r}\left(C_{s,t,r,urb} + C_{s,t,r,rur}\right) + \left(1 - u_{t,r}\right)\left(C_{s,t,r,rur}\right) \\ &= u_{t,r}C_{s,t,r,urb} + C_{s,t,r,rur} \\ &= \Delta E_{s,t,r}\left(u_{t,r}\alpha_{s,r,urb} + \alpha_{s,r,rur}\right) \end{aligned} \tag{6}$$

With u the exogenous time series of the proportion of people living in urban areas in year t in region r, $\Delta E_{s,t,r}$ the growth of emissions of substance s at time t compared to the year 2000, and the substance-specific coefficient ⊠ in urban or rural areas to translate regional emission increases to the regional yearly average concentration of $PM_{2.5}$.

Equations (2) and (3) convert regional emissions of the different substances into $PM_{2.5}$ concentrations. The model is linear in emission changes and does not take account of transboundary aspects of air pollution. This simplifies the complex interactions between substances in heterogeneous areas. [8]

The number of deaths N is estimated from emissions of local air pollutants by assuming that the risk of death increases log-linearly with the ambient concentration of $PM_{2.5}$ Here, the method follows the approach used by the WHO to estimate total deaths, or years of life lost, from public PM exposure (WHO, 2002; 2004). One risk coefficient was applied, depending on the $PM_{2.5}$ concentration, which was multiplied by the population of a given region at a given time. The coefficient was derived from a large cohort study of adults in the USA (Pope et al., 2002). By using this coefficient, the analysis basically relies on fine PM of a diameter<2.5 μm, or $PM_{2.5}$. Thus the equation added to MERGE is:

$$N_{t,r} = \frac{(1.059\text{-}1)G_{t,r}}{(1.059\text{-}1)G_{t,r}+1} P_{t,r} c_{t,r} \tag{7}$$

in which G is the $PM_{2.5}$ concentration in units of 10 μg/m³, P the population of the region , and c the crude death rate.

Holland et al. (2005) were followed by estimating all deaths above the nil-effect bottom-line of 0 μg/m³. [9] The values adopted for the regional crude death rates are based on Hilderink (2003) and take account of relatively more deaths in aging societies and should thus be represented by higher values of c. As expressed in equation (1) with increasing levels for c, the phenomenon of ageing increased the number of premature deaths from PM at a fixed concentration level.

The population will increase over the coming 50 years (globally by +50% and in the OECD region by +20%). Also, regions will be confronted with the issues of an ageing population, and hence the crude death rate will increase (globally by +12% and in the OECD by +8% compared to 2000). This implies that at constant emissions, more people will die prematurely from long-term exposure to $PM_{2.5}$ concentration driven by the population growth and composition. If

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[8] The model only relates annual regional emission changes to annual average concentrations. If the transboundary aspects are taken into account, impact would be small on the simulation results because discounted errors in the damage valuation of LAP are small (see Appendix 2). There are several reasons for this. Firstly, the discount rate is on average 3% on the mid-term, hence damage valuation errors will have little impact on the choice variables in the optimsation mode of MERGE. Secondly, the regions are quite large and hence impacts in border locations have a limited impact on the regional average concentration estimate. Thirdly, the regional reduction profiles of emissions are significant in all regions, and thus border location impacts will only affect regional averages if emission reductions differ between two neighbouring regions. Fourthly, although secondary aerosol formation is transboundary, this is not so for primary PM emissions which are one of the main sources for the concentration of $PM_{2.5.}$ Primary PM remains in the vicinity of its source.

[9] As opposed to WHO (2004), which measured the number of deaths above a threshold concentration level (7.5 μg/m³), an upper boundary was applied by calculating only the contribution to the number of premature deaths from $PM_{2.5}$ concentrations.

emissions of LAP substances remain constant, then deaths will rise by 25% in 2050 in the OECD region (globally by +70%).

Moreover, sustained growth of income will result in an increased movement to urban areas. The urbanisation dynamics will also increase the number of people affected by LAP, see equation (3). If emissions are constant from now onwards, then the number of deaths will increase by between 5 and 10% in the OECD, and by 30% outside the OECD. In summary, in the BAU scenario, besides growth in LAP substances, population growth, ageing population, and urbanisation will increase the number of deaths in 2050 by at least 30% within the OECD, and outside the OECD this will be more than double.

2.4 Implementing the BAU

The mains characteristics of the BAU scenario are growth in population and regional economies, evolution of emission levels of all greenhouse gases (GHGs), which is described in OECD (2008a). The regional time profiles of the LAP substances (SO_2, NO_x and NH_3) follow the OECD Environmental Outlook (OECD, 2008b), and the regional time profile of primary PM is based on emission intensities from Bollen et al. (2007). [10]

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[10] The results beyond 2050 are based on an extrapolation of trends of exogenous region and time-specific GDP per capita growth rate. For more details on the numbers, see Appendix I, Table I.1 and I.5.

3 Climate change window

The main question to be analyzed here will be how much of the of the GHG mitigations costs will be covered by the co-benefits.

This chapter focuses on the GCC50 variant. The main assumption is that global CO_2 eq. emissions are reduced in 2050 to 50% of the 2005 level. This GCC50 variant has policy relevance, given the discussion by the G8 and the European Climate strategies. Other variants considered in this study are GCC25 and GCC35 (for more information on the CO_2 eq. emission profile, see Appendix II, Table 1). Simulations have been done for the OECD region, India and China. Comparing the OECD region with two newly industrialising countries is of particular interest because of the tremendous differences in local air quality and the dramatic economic growth in these countries.

Firstly, the monetised impacts of climate action are presented in terms of mitigation cost of GHG emissions, benefits of less global warming and the health co-benefits of improving local air quality (Section 3.1). next, we take a step down and focus on the physical impacts of climate policy: the impacts on GHG emissions and the impacts on air pollutants are presented in Section 3.2 and Section 3.3, respectively. Section 3.4 links co-benefits in physical terms (emissions of air pollutants) to health impacts (deaths) and monetary aspects. Finally, co-benefits are presented as opportunity costs.

3.1 Co-benefits of climate policy

Costs and benefits of climate policy - GCC50 - are presented in Figure 3.1 These include mitigation costs of climate action, the benefits of less global warming and the co-benefits of improved local air quality in the GCC50 variant for the OECD, India and China. Also, the total costs and benefits are given as percentage deviations of GDP from the baseline (BAU).

There is a large time lag between mitigation costs and reaping the benefits from less global warming (“first the pain, then the gain”). Regions suffer an income loss (CMIT) in the first half of the century, and climate benefits (BGCC) only become apparent after 2050.

Co-benefits from better local air quality (BLAP) accrue much earlier but tend to flatten out over time. Air quality improves rapidly with increasing reduction efforts and stabilises in the second half of the century. Mitigation options with a high co-benefit for LAP are relatively cheap and are taken first, for instance, in transport. Only after some time, when greater reductions have to be achieved is attention given to measures with a small impact on air quality such as power generation.

In all three regions, the total of costs and benefits turn positive over time, with mitigation costs declining driven by the reducing cost of the currently expensive technologies of LBDN and LBDE as the global CO_2 eq. restriction is greater than 65%. However, this can only be achieved by 2050 with substantial penetration of the learning technologies. The cost decreases in the electricity sector from EUR 50 to 10 mills per kwH, whereas the more traditional options are relatively more expensive, EUR 40 to 45 mills per kwH.

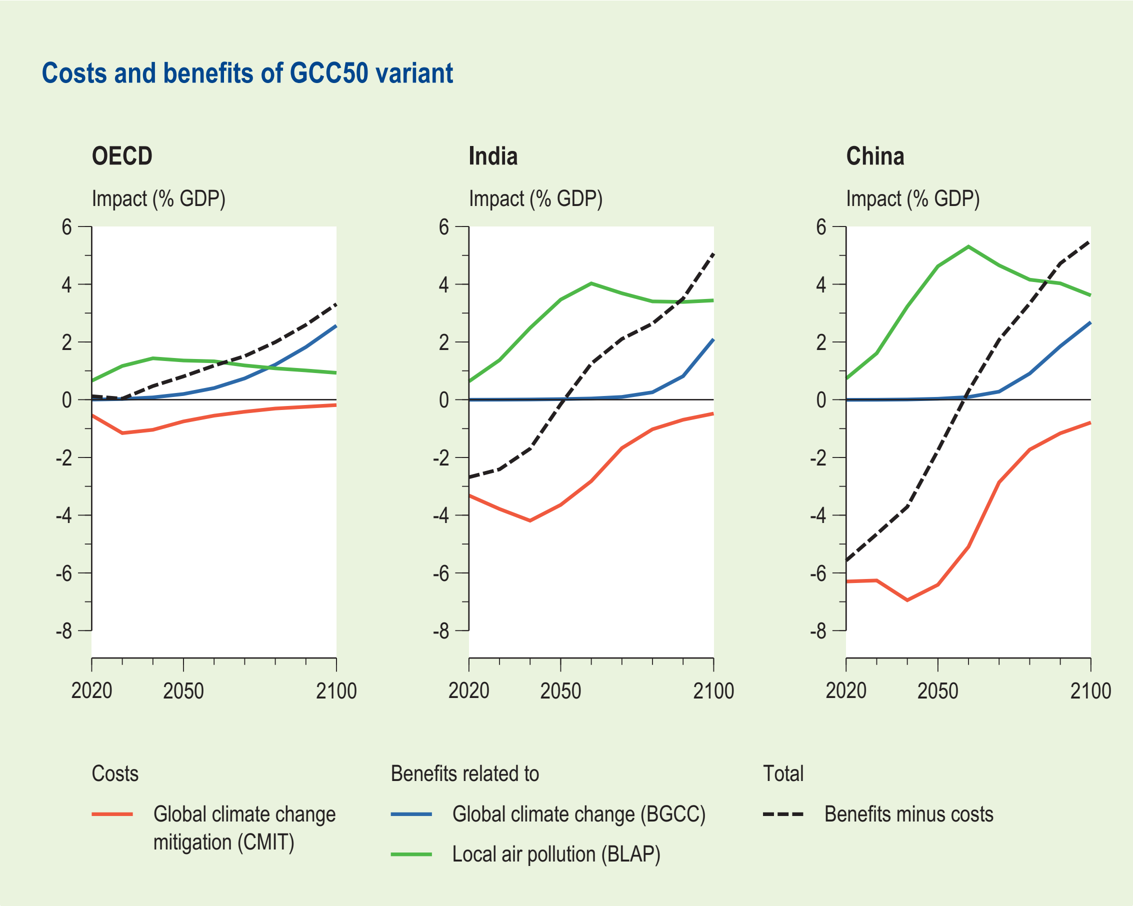

Figure 3.1 Costs and benefits of climate policy, GCC50

There are striking differences between the regions. Mitigation costs (CMIT) and co-benefits (BLAP) are much higher in India and China than in the OECD (See Sections 3.2 and 3.4). Net benefits outweigh the mitigation cost after 2030 in the OECD countries, and after 2050 outside the OECD. CMIT is much higher because of the higher energy intensity in those countries (see Section 3.2). The high co-benefits in India and China are due to the high LAP in the baseline, urbanisation. OECD already has a LAP in place. An aging population (see Appendix I: population dynamics), urbanisation and increasing VSL values make India and China more vulnerable for local air pollution.

3.2 GHG-emission reductions by sector and region

GHG emissions for the OECD region, India and China are presented in Figure 3.2. Four sources are distinguished: power generation (electricity); transport; household demand and heat generation; and processes. Emission profiles are given for the business-as-usual (BAU) scenario and the GCC50 variant.

Currently, emissions from the OECD region are dominant but China will rapidly catch up in the next 20 years, and by the end of this century emissions will be more than three times that in the OECD. India is also growing rapidly but its increasing contribution to global emissions lags behind China and the OECD. Despite the high growth rate, emissions from India are less than China and by 2100 emissions are comparable with the OECD.

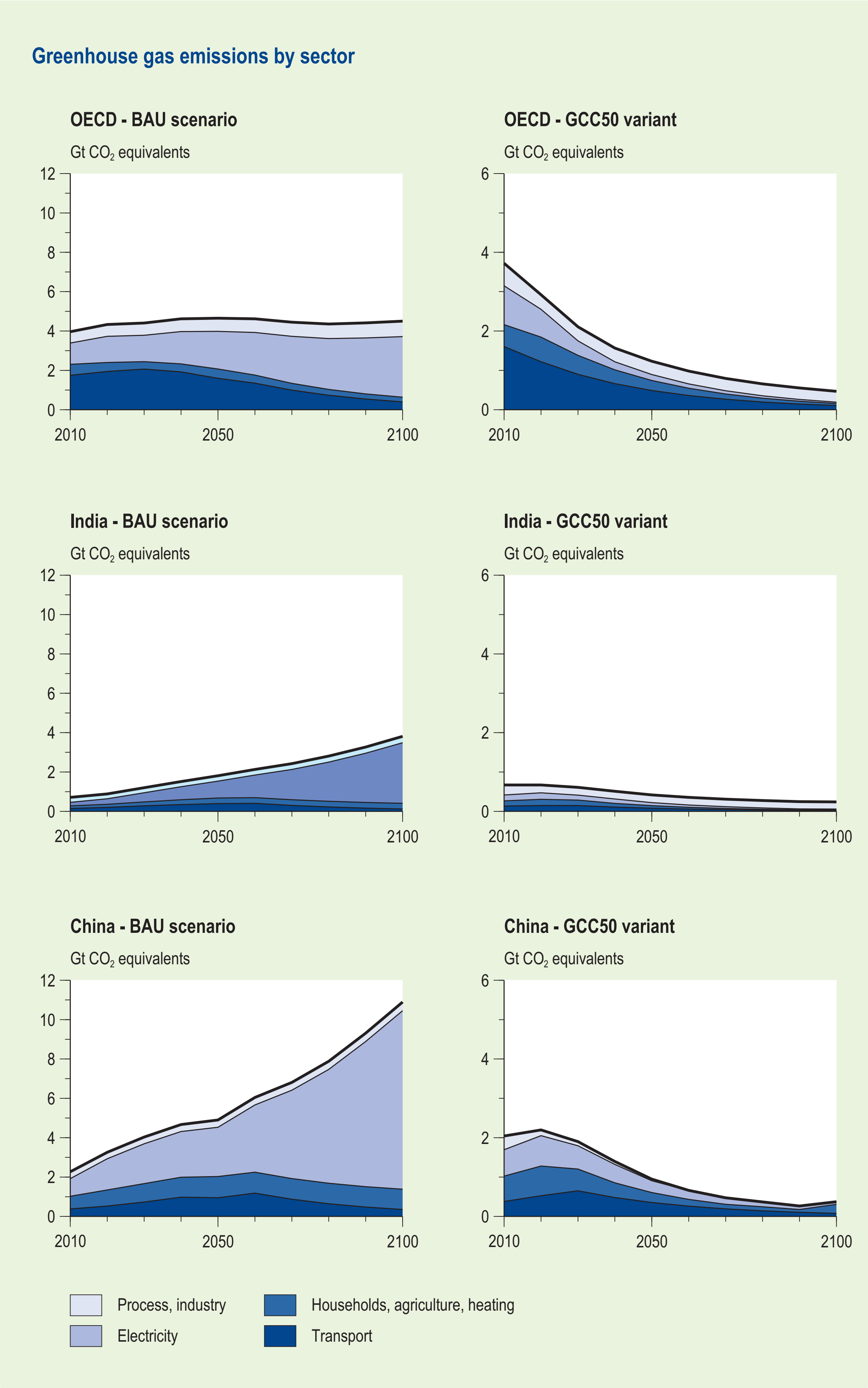

Figure 3.2 GHG-emissions by region and sector in BAU and CC50.

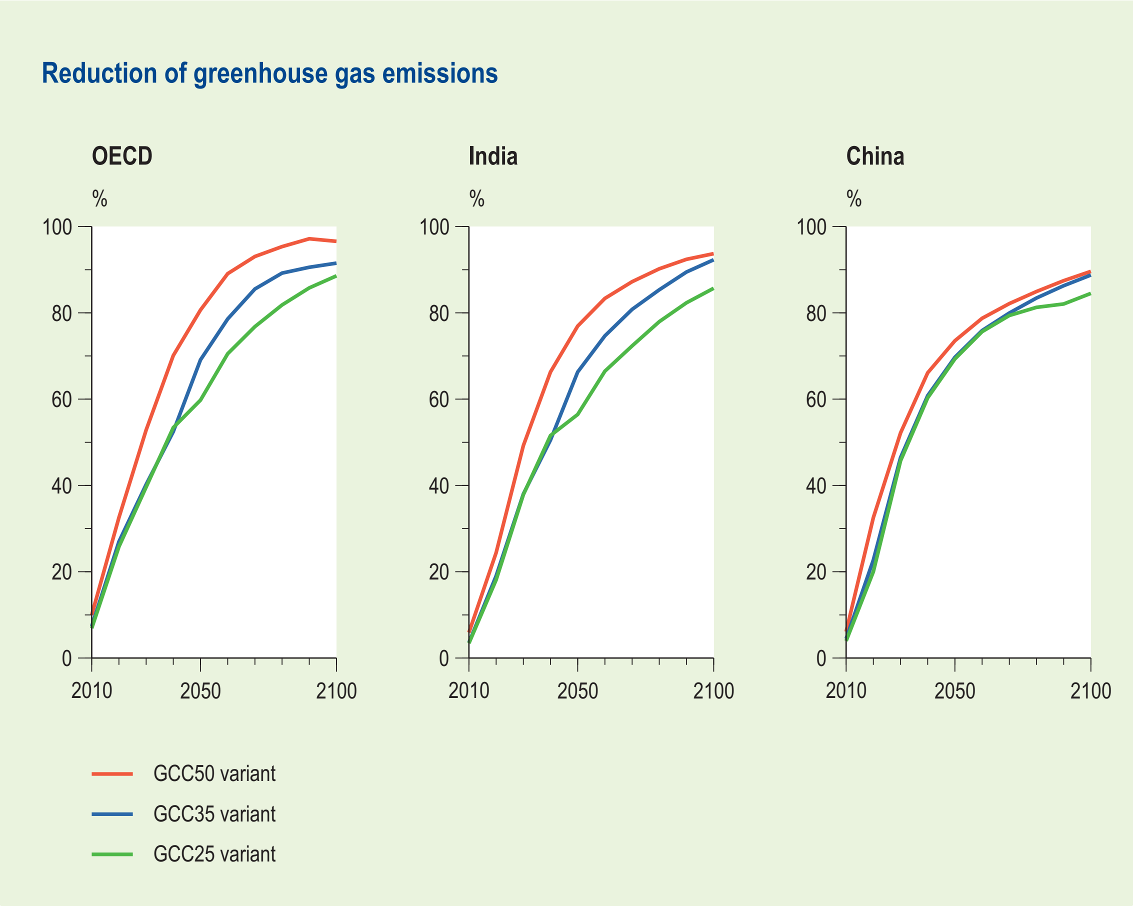

Figure 3.3 Emission reductions in GCC25, GCC35 and GCC50.

In all regions, emissions from power generation dominate over time. In OECD, emissions from transport are still significant but will dwindle in the course of the century with oil depletion.

In the GCC50 variant, GHG emissions reduce considerably. Global emissions in 2030 are 40% below baseline, in 2050 emissions are about 75 % below the BAU scenario and in 2100 there are virtually no GHG emissions (reduction is more than 90% below BAU). Reductions in China and India are higher than in the OECD region. In 2050, the emission reduction by the OECD is 74%, while reduction in India and China is 79% and 80%, respectively. In 2100, the OECD emissions in GCC50 are 14% of emissions in the BAU scenario, while in India, emissions are 9% of baseline values and in China only 4%. Differences across regions are driven by differences in marginal abatement costs. An efficient global climate regime is assumed. Reductions take place where abatement options are cheapest. Cheap options lie outside the OECD.

With the high energy intensity in India and China compared to the OECD, any reduction percentage hits harder in these countries; mitigation costs as percentage of GDP (CMIT) are much higher (see Figure 3.1). In all regions, CMIT increases up to 2050 and thereafter declines because of learning-by-doing. Despite the higher reduction efforts, mitigation costs less because of a forced lock-in of LBDE and LBDN technologies. The reduction percentages are high throughout the century, because the emissions in the BAU scenario increase rapidly, which explains the small differences between regional reductions effort.

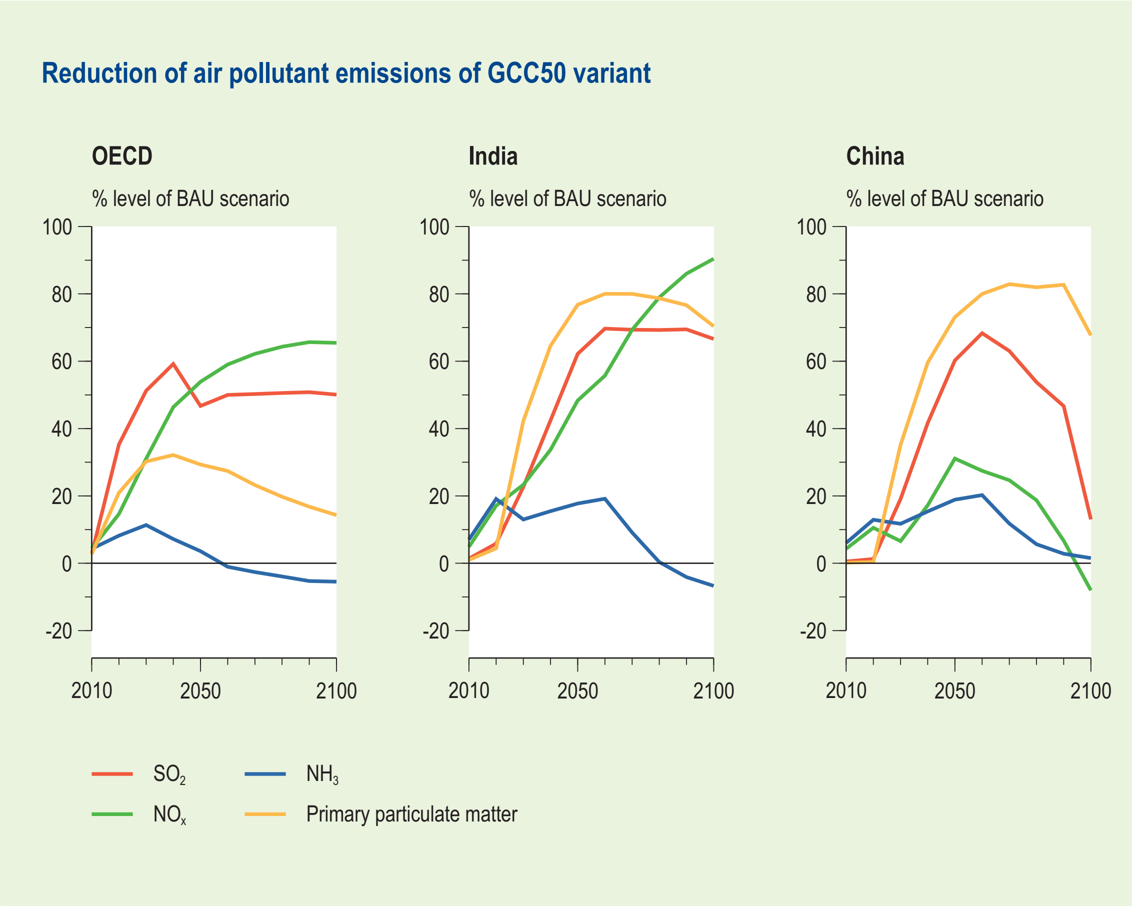

Figure 3.4 Reduction of air pollutant emissions of GCC50 variant

In both absolute and relative terms, reductions are highest in power generation (electricity). Emission reduction from household heat generation and from processes and non-CO_2 are relatively low. But by the end of the century, emissions have to be reduced to such an extent that emissions from these sources are also considerable.

The situation is similar in the other variants GCC35 and GCC50, and reductions relative to the BAU are similar. Emission profiles in BAU, GCC25, GCC35 and GCC50 for the OECD, China, and India are presented in Figure 3.3.

As can be seen, the emission reductions compared to the BAU are large. Reduction by 2050 is 60 to 75%, and increasing to 85 to 98% by the end of this century.

3.3 Emission reductions of LAP

Emissions reductions of SO_2, NO_x, NH_3 and particulate matter in relation to baseline for the three regions - the OECD, India and China – are presented in Figure 3.4. SO_2 reductions are relatively high in the OECD in the first 20 years. OECD relies heavily on measures that affect small point sources such as household heating and energy for transport services, which have a large impact on SO_2 emissions. Oil combustion is the only source of SO_2 emissions (see Table I.6 in Appendix I for emission coefficients of the various technologies).

Reducing particulate matter (primary $PM_{2.5}$) is important in India and China in the latter half of the century when measures in transport are inevitable. PM reductions in the OECD are relatively small given the fact that in the baseline, PM emissions are low due to air quality policies in the past.

3.4 Reduction of LAP, health and income effects

PM reductions (PM sum), reduction in deaths due to local air pollution and the associated income effects of a lower mortality (BLAP) are presented in Figure 3.4. Outcomes of the GCC50 variant are shown for the OECD, India and China. PMsum is a proxy for LAP and is the weighed sum of emissions of SO_2, NO_x, NH_3 and primary Particulate Matter (de Leeuw, 2002).

Health impacts of climate action – fewer deaths due to a better local air quality (LAP deaths) - are closely linked to reductions in PM sum (reducing PM sum also reduces LAP deaths). Compared to India and China, the population in the OECD is relatively old and more vulnerable. For any given reduction percentage, the impact on LAP deaths is thus higher in the OECD. For example, in 2030 the reduction in PM sum relative to BAU is 24% and the corresponding LAP deaths in 21% lower. In India, in 2030 PM sum is 20% lower but LAP deaths are only 13% lower. As their population ages, India and China become more vulnerable to LAP.

Reduction in PM sum and LAP deaths diverge over time. PM sum is not a perfect proxy of LAP deaths. Reductions in PM sum reflect a regional average. Improvement in urban air quality is better, due to a relative high reduction in PM10. This is not reflected in the regional average. This mismatch becomes more prominent with increasing urbanisation over time. The weighing in PM sum is based on regional average. The divergence is not due to a decline in population, which is assumed to be constant after 2050.

Co-benefits become apparent a little earlier in the OECD region. In these countries, LAP pollutants affect CO_2 eq. emission reductions especially in the transport sector. In non-OECD countries, measures in power generation are taken at first with somewhat lower LAP benefits. Only in the longer term in non-OECD countries do the CO_2 eq. emission reductions concern the small point sources such as transport.

Preventing LAP generates in the long run a much higher welfare gain in India and China than in the OECD. In India and China, the benefits in 2050 is 4 to 5% of GDP as a result of less LAP, while in the OECD the accrued benefits are about 1% of GDP. There are two reasons for this. Firstly, a much higher proportion of the population is exposed to LAP. In 2050, mortality due to LAP is higher than 0.2% in India and China, and below 0.1% in the OECD. Secondly, in the long run the percentage reduction in the weighted sum of LAP emissions due to climate action is higher.

The increase in income effects in India and China over time is also driven by the assumption that VSL rises proportionally with income (elasticity is one). With the dramatically high growth in India and China, VSL also explodes. By the end of the century, VSL in India and China is even higher than in the OECD. This is based on the assumption that in 2005, VSL in India and China *per unit of output* was much higher than in the OECD region.

Reduction of emissions, premature deaths, and avoided damages of local air pollution of GCC50 variant

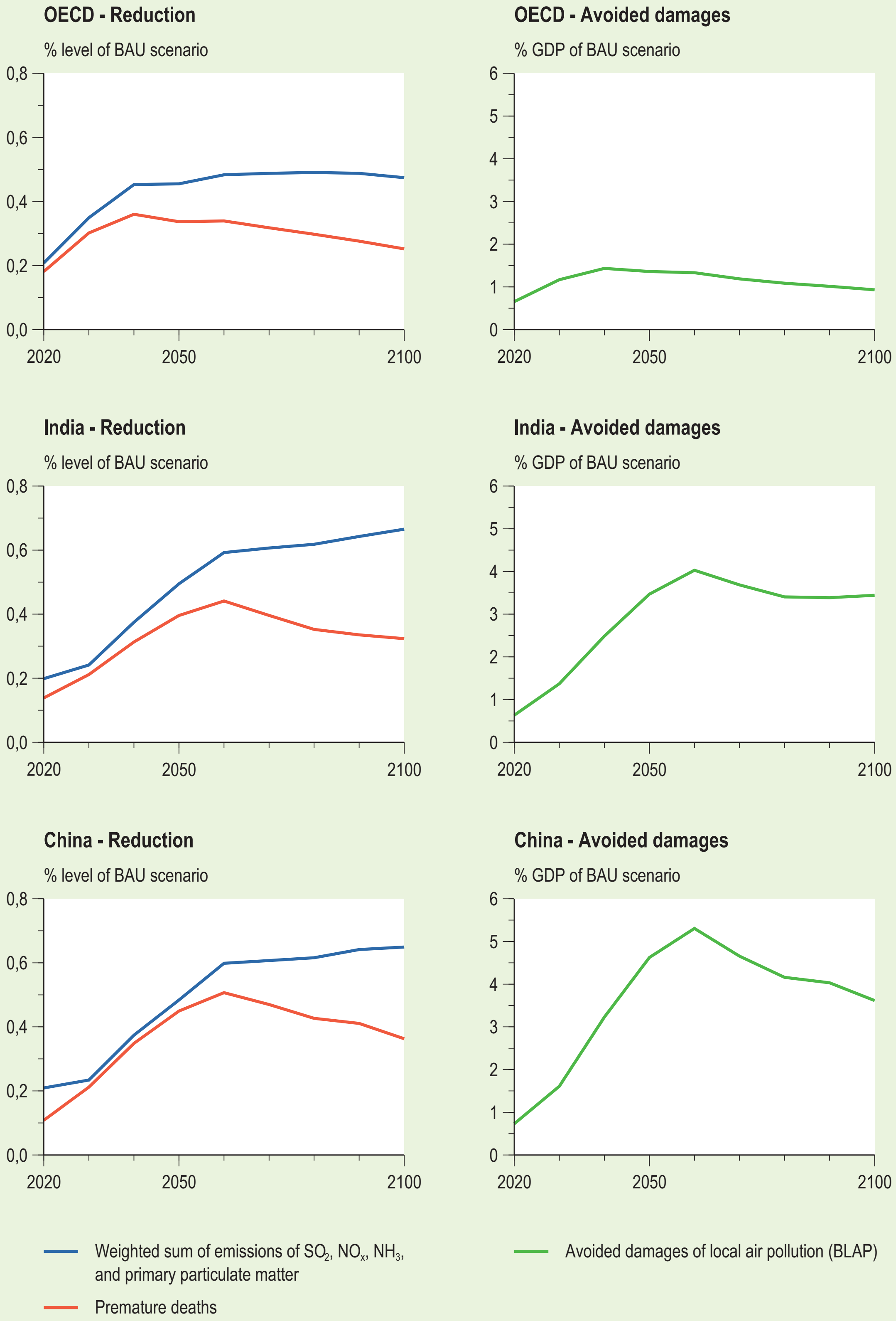

Figure 3.5 Reduction of emissions, premature deaths, and avoided damages of local air pollution of GCC50 variant

3.5 Avoided cost versus air pollution benefits

As described above, LAP co-benefits of climate mitigation policies provide an additional economic incentive for countries to participate in a global agreement to mitigate GHG emissions. In fact, a decrease in health damage due to reduction in emissions of air pollutants partly offsets the costs of climate policies. From 2050 onwards, the global total of local air pollution benefits from climate mitigation policies exceeds the cost. This implies that even leaving aside the benefits of a reduction in the climate change, climate mitigation is beneficial.

However, the extent to which the co-benefits are an incentive for GHG mitigation not only depends on the size of the co-benefits, but also on the cost of achieving the same level of reduction in LAP through direct policies. If this can be achieved at lower cost, the co-benefits of climate policies are not sufficient incentive to pursue climate policies. In the absence of climate policies, countries are likely to pursue policies to reduce LAP. In general, marginal benefits of reduced LAP exceed the marginal cost at current BAU emission levels (see also Section 4.2 4).

Therefore, instead of valuing LAP co-benefits in terms of premature deaths prevented, they should be valued at the cost of prevented air pollution policies that would otherwise have been implemented. To determine these costs, the model was used to calculate the minimum cost of achieving the same reduction in health damage as achieved as a co-benefit of the climate policy variants described in the previous section Model runs were performed on regions in which the number of premature deaths is the same as in the appropriate climate policy variants. This variant is referred to as LAP(GCC50).

In these model runs, mitigation options were implemented that reduce emissions of air pollutants to meet these restrictions at the least cost, regardless of the impact on the climate system. Assuming that this reduction in air pollution would occurs (because it is beneficial for a region), the co-benefits of climate mitigation imply that this cost is prevented in the presence of climate policies. The co-benefits of GCC50 should not be valued in terms of reduced premature LAP deaths which are the same in GCC50 and LAP(GCC50), but as the avoided cost of LAP mitigation. The higher the cost of policies primarily aimed at LAP, the higher the level of avoided cost and consequently, the higher the incentive power of co-benefits for climate policies.

The costs and primary benefits of climate mitigation (as in Figure 3.1) are presented for the OECD, India and China in Figure 3.5. The co-benefits included are the avoided cost of LAP mitigation instead of the value of prevented premature deaths. The total impact of the sum of costs and benefits is also shown.

Cost of mitigation policies

In all three regions, the avoided costs of LAP policies are much lower than the benefits of reduced air pollution as presented in Figure 3.1. Obviously, there are alternative mitigation options to achieve the same level of reduction in air pollution at much lower costs. In general, premature deaths can be reduced by relatively low-cost, end-of-pipe control technologies, reducing emissions of SO_2, NO_x, NH_3 and PM. In India and China, mitigation costs increase substantially up to 2050 and then decrease. Moreover, climate benefits are mainly achieved after 2050. As a result, the total costs and benefits become net returns only in the longer term: in 2060 in the OECD and in 2090 in India and China.

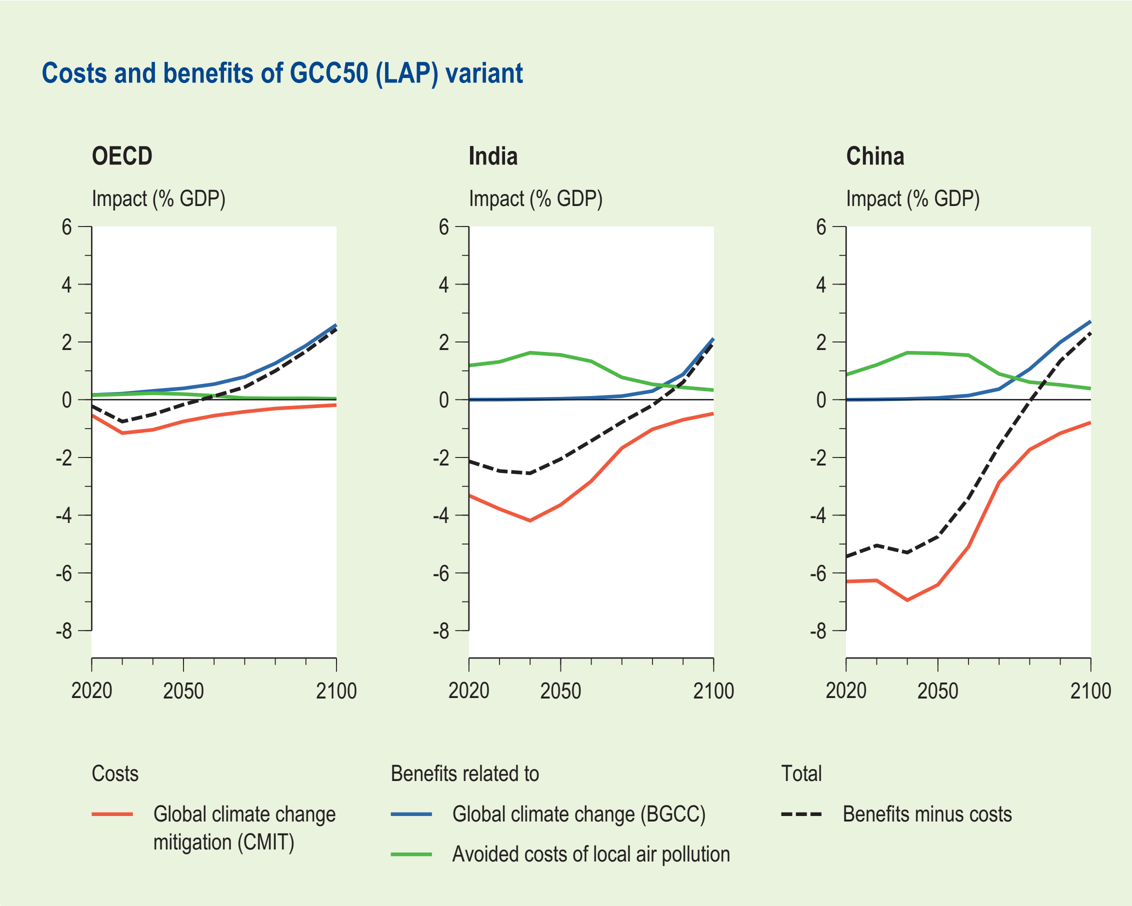

Figure 3.6 Costs, benefits and avoided LAP mitigation cost in GCC50 variant

The air pollution policies in LAP(GCC50) also have limited impact on climate change. Damage due to climate change increases with respect to the baseline because of the effect of SO_2 and its ambiguous role in climate change and air pollution. However, SO_2 emissions contribute to air pollution, while SO_2 has a cooling effect on climate change. This means a reduction in SO_2 emissions because of the harmful effect on human health, while GHG emissions remain unchanged causing global temperature to increase at a higher rate. The calculations show that in the LAP(GCC50) variant, the damage resulting from climate change increases as a result of reductions in SO_2 emissions. This is apparently a cost-effective means of reducing air pollution damage. At the same time, GHG emissions are reduced with the reduction in air pollutants. The beneficial consequences of this for the climate (reduction in increasing global temperature) is camouflaged by the climate impact of a reduction in SO_2 emissions. The net effect of these two opposite effects is a limited but negative climate benefit with respect to the baseline. In Figure 3.5, these damage costs are added to the avoided cost of LAP policies.

Overall picture

Taking all benefits and costs (climate benefits and avoided costs)) together, there are no net benefits in China and India until 2090, while in the OECD, net benefits appear from 2060 onwards. In the short term (up until 2050), the co-benefits do not provide sufficient incentive to make climate policies beneficial in these regions.

In fact, this is not the entire story because it depends on the assumption that reduction in the level of air pollution is in itself a welfare improvement. The optimal level of reduction depends on the marginal costs and benefits of reduction in exposure to air pollution. These benefits are based on the number of prevented deaths resulting from reduced air pollution multiplied by the value of a statistical life (VSL, see Section 2). With the valuation used in this study, for most regions and also globally the benefits of air pollution reduction are higher than the cost of mitigation for the entire time period.

4 Air pollution window

The calculations in Chapter 3 show that the benefits of climate policies are mainly the co-benefits of local air pollution (LAP). Moreover, the analyses show that policies primarily aimed at reduction in air pollution yield the same LAP benefits at much lower cost, while having an impact on climate change. In this chapter, the impact of LAP policies on climate change is discussed in terms of the extent to which climate co-benefits of LAP policies provide incentive (in addition to the large benefits of reducing LAP within the region itself) for LAP policies.

The analysis focused on the co-benefits of air pollution mitigation in terms of reduced climate change, and the extent to which mitigations costs are covered by these co-benefits.

A variant was formulated to analyse the impact of air pollution policies on climate change (LAP25), simulating a reduction of 25% of premature deaths as a result of air pollution in 2050 compared to the 2005 level. 11)

4.1 The costs and benefits of air pollution policies

Figure 4.1 presents the costs and benefits of air pollution policies for the OECD, India and China. These include mitigation cost of air pollution policies (LMIT), the benefits as a reduction in premature deaths with respect to the baseline (BLAP), and the co-benefits as a result of the impact air pollution policies have on climate change (BGCC). The sum of the costs and benefits are also presented as percentage deviations of GDP from the baseline (BAU).

In all three regions, total benefits outweigh total cost in the long term. Mitigation costs differ per region and are much higher in India and China than in the OECD. In the three regions, the mitigation costs (LMIT) as well as the benefits of reduced air pollution (BLAP) increase between 2020 and 2050. In the OECD, the benefits exceed the cost, leading to net benefits over the entire time period. In China, LAP policies are profitable from 2030, while in India this is not the case until 2050. After 2050, the benefits of reduced air pollution exceed the cost substantially in all three regions. From 2090, there are also co-benefits from less global warming (BGCC).
These results show the costs and benefits in these regions in a situation where in all world regions policies are pursued resulting in the same relative reduction in air pollution. A 'solo effort' by the OECD was not investigated, but this would likely result in higher costs because of other effects on competitiveness and resulting changes in international trade.

4.2 Emission reductions by sector and region

The LAP25 variant implies a substantial reduction in premature deaths (65 to 74%), as a result of reductions in emissions of SO_2, NO_x, NH_3 and particulates (PM). In the OECD, emissions of these air pollutants are reduced by about 40% to 70% in 2050 and in India and China by about 60% to almost 100% (Table 4.1). In India and China, the first decades show in particular a

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[11] This reduction level was chosen on the basis of the outcome of optimal variant (see Chapter 5).

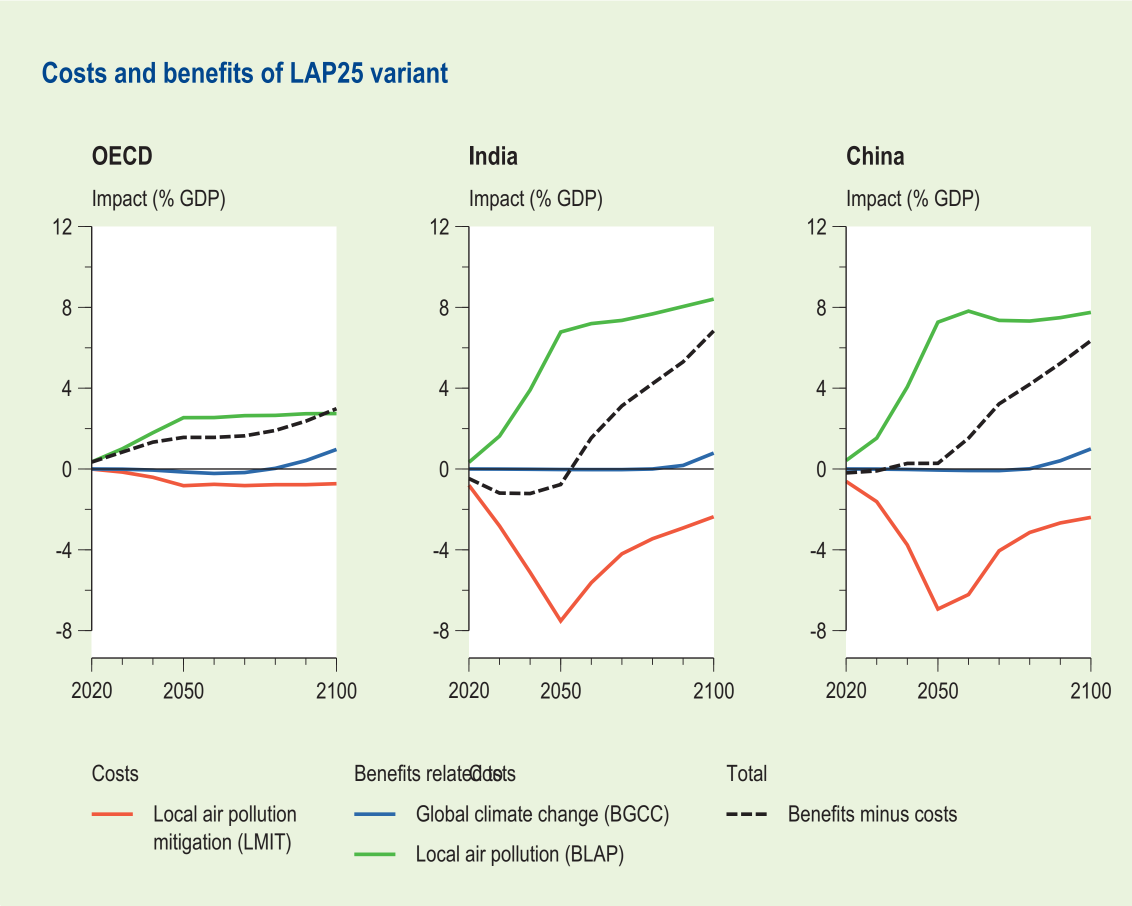

Figure 4.1 Costs and benefits of LAP policy, LAP-25

substantial reduction in primary particles emissions, whereas in the OECD the reduction in SO_2 emissions is relatively high in the short term. In the longer term, reduction percentages are high for all air pollutants, except for NH_3. Emission reduction percentages are highest in India, because as a result of relatively high rates of ageing and urbanization, India faces a relatively high growth rate for the number of premature deaths in the baseline (see appendix I, Table I.4).

Figure 4.2 shows emissions of air pollutants (as a weighted sum of SO_2, NO_x, NH_3 and primary PM; see also Chapter 3) by sector in the BAU scenario and the LAP25 variant for the OECD and India (China is not included in the figure because emissions have the same pattern as in India). In all three regions, the relative emission reduction levels are highest in the transport sector and for emissions from households and heating (80-90%).

Table 4.1 Reduction in air pollution and GHG emissions in LAP25 compared to baseline (BAU) levels for the OECD, India and China in 2050

	SO_2	NO_x	NH_3	Primary PM	Premature deaths	GHG (CO_2-eq.)	CO_2
OECD	73	65	43	72	65	38	44
India	88	79	66	97	74	61	71
China	78	60	57	95	70	42	45

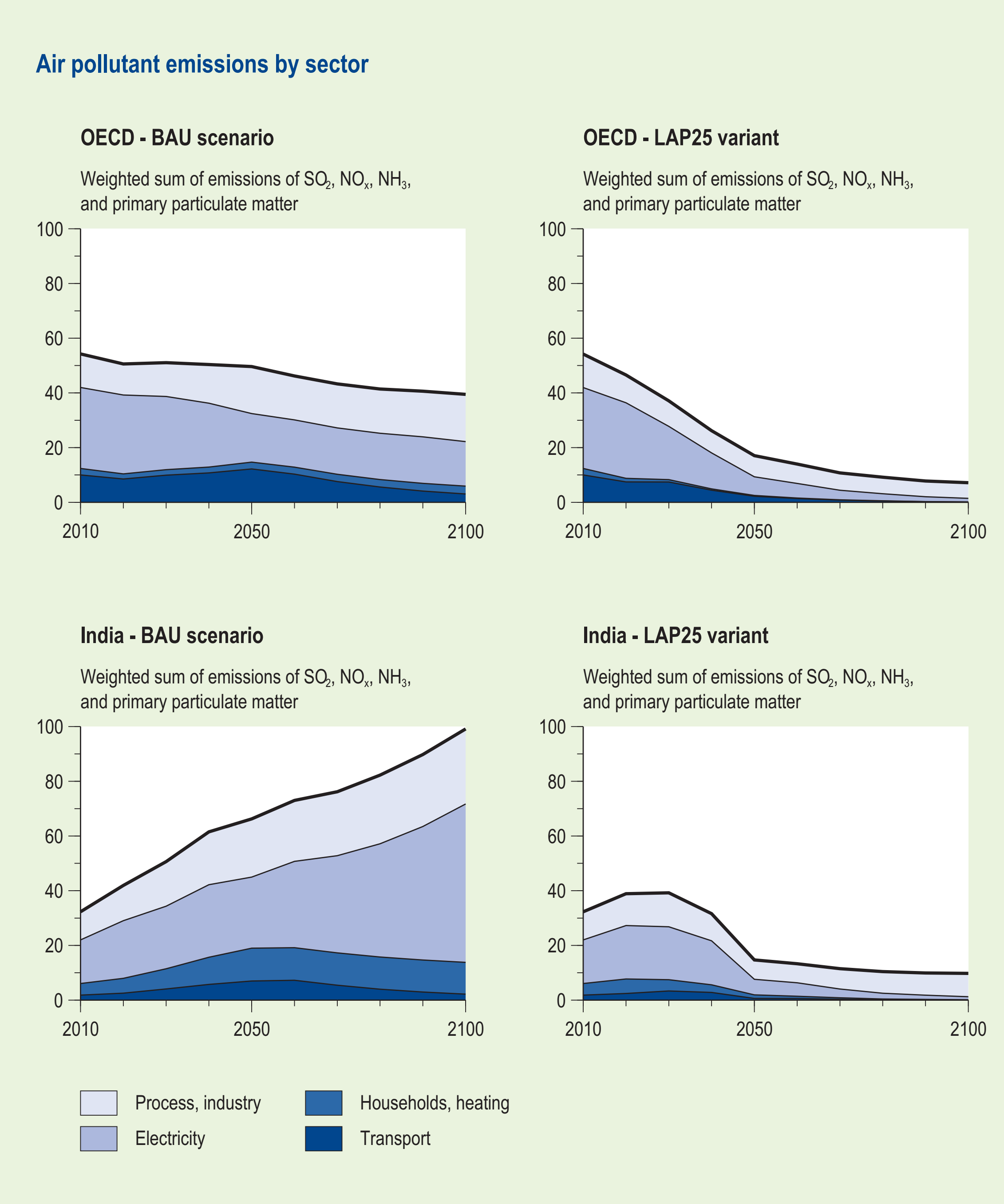

Figure 4.2 Emissions of air pollutants by sector for the period 2010-2100 in two regions (OECD and India)

4.3 Co-benefits of LAP policies for GCC

Table 4.1 also presents the change in GHG emissions that results from the air pollution policies. These co-benefits are the highest in India (60%), followed by China and the OECD (40%). GHG emission reductions only concern emissions of CO_2, emissions of other greenhouse gases are not affected. Because of the relatively high reduction in emissions of air pollutants in India, the reduction in emissions of CO_2 is also relatively high in India.

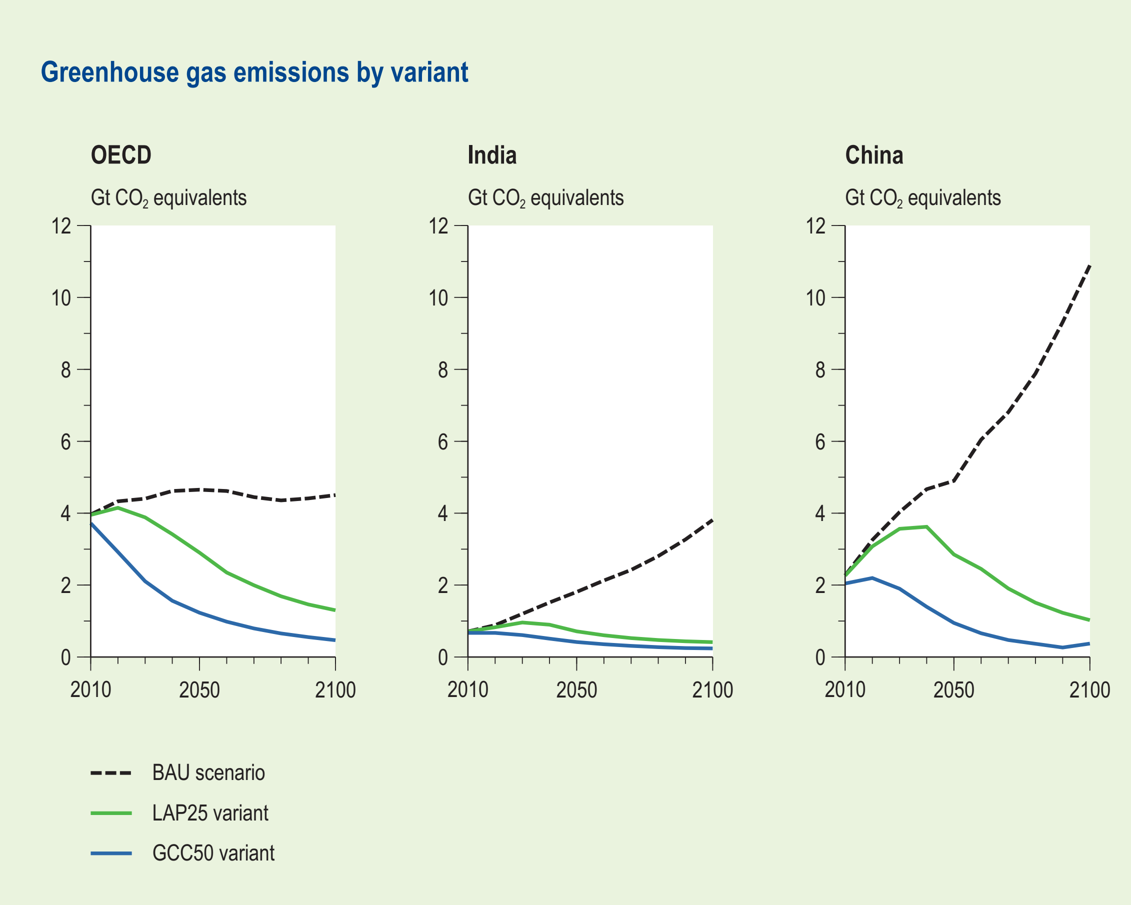

Figure 4.3 Greenhouse gases by variant for the period 2010-2100 for three regions (OECD, China, and India)

Figure 4.3 shows the development of GHG emissions (CO_2-equivalents) over time in the baseline (BAU), the GHG reduction variant presented in the Chapter 3 (GCC50) and the air pollution mitigation variant (LAP25). In 2100, CO_2-eq. emissions are substantially lower in LAP25 than in the baseline (70% in the OECD, and 90% in India and China). In 2050, total global CO_2-eq. emissions are reduced by 40%, i.e. from 80% above the 2005 level in the baseline to 10% above the 2005 level in LAP25. By 2100, the reduction is even more pronounced, from 20% above the 2005 level in the baseline to 40% below the 2005 level in LAP25.

Compared to the reduction in GHG emissions resulting from policies primarily aimed at climate change mitigation (see Chapter 3), in 2050 just over 50% of the GHG reduction in variant GCC50 is achieved as a co-benefit of the air pollution policies in the LAP25 variant. However, in contrast with the GCC50 variant, the GHG emission reduction in LAP25 does not result in the same reduction in global temperature as in the GCC50 variant (see Figure 4.4). Indeed, until 2080 LAP25 faces a higher global average temperature rise than the baseline. In the long run (2100-2150), global temperature more or less stabilizes at about 3 degrees above the 2000 level in LAP25, which is below the long term global temperature level in the baseline. The counterintuitive development in global temperature is the result of the cooling effect of SO_2 (see also chapter 3). Due to the reduction target for air pollution in the LAP25 variant, SO_2 emissions are reduced significantly (worldwide over 80%), compared with a reduction of about 50% in the climate change policy variant (GCC50). As a result, the cooling effect of sulphate

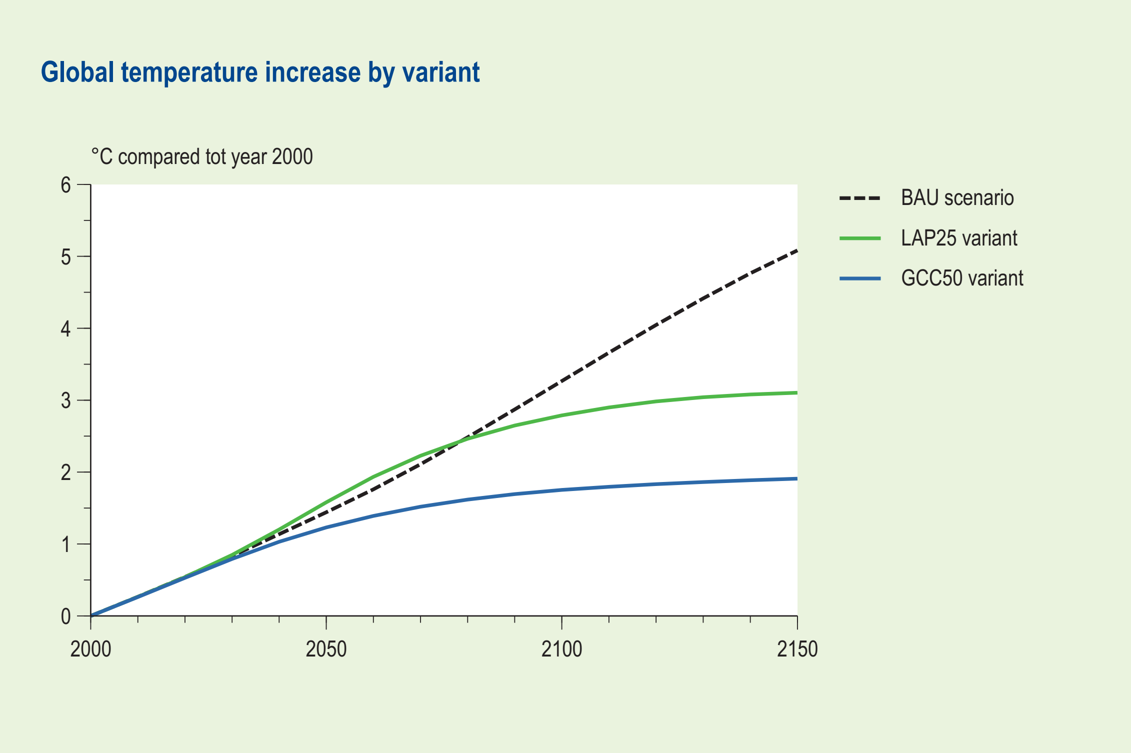

Figure 4.4 **Global temperature increase by variant for the period 2010-2150**

aerosols, which in total is estimated to reduce global average temperature by about 0.7 degrees, disappears rapidly.

4.4 Reduction of LAP, health and income effects

The LAP policies yield large benefits in preventing premature deaths from chronic exposure to PM_{25} concentrations. The benefits of air pollution policies are the highest in India, followed by China and then OECD (figure 4.1). The costs and benefits for China and India (7 to 8% of GDP) differ greatly from the OECD region (0.5 to 2%).

These differences can be explained by several factors. The energy intensity in China and India is higher than in the OECD region. Because of the lower energy prices in India and China, the relative cost increase due to LAP policies is higher in these regions. With an increasing share of the elderly people and the urban people in total population in India and China, the benefits of air emission reduction are will be increasing compared to the base year. Moreover, the existing stringency of the LAP policies in the OECD limit the potential gains of additional policy efforts.

4.5 Incentive power co-benefits

As shown in Figure 4.2, GHG emissions decrease substantially together with the abatement of air pollutants. LAP policies therefore substantially contribute to the target of current climate policies (for instance, Kyoto, EU target): a reduction in emissions of CO_2-equivalent GHG. Hence, this might yield an additional incentive for action to reduce LAP, not so much because of the benefits of preventing climate damage (which do not occur until 2080), but in terms of avoided

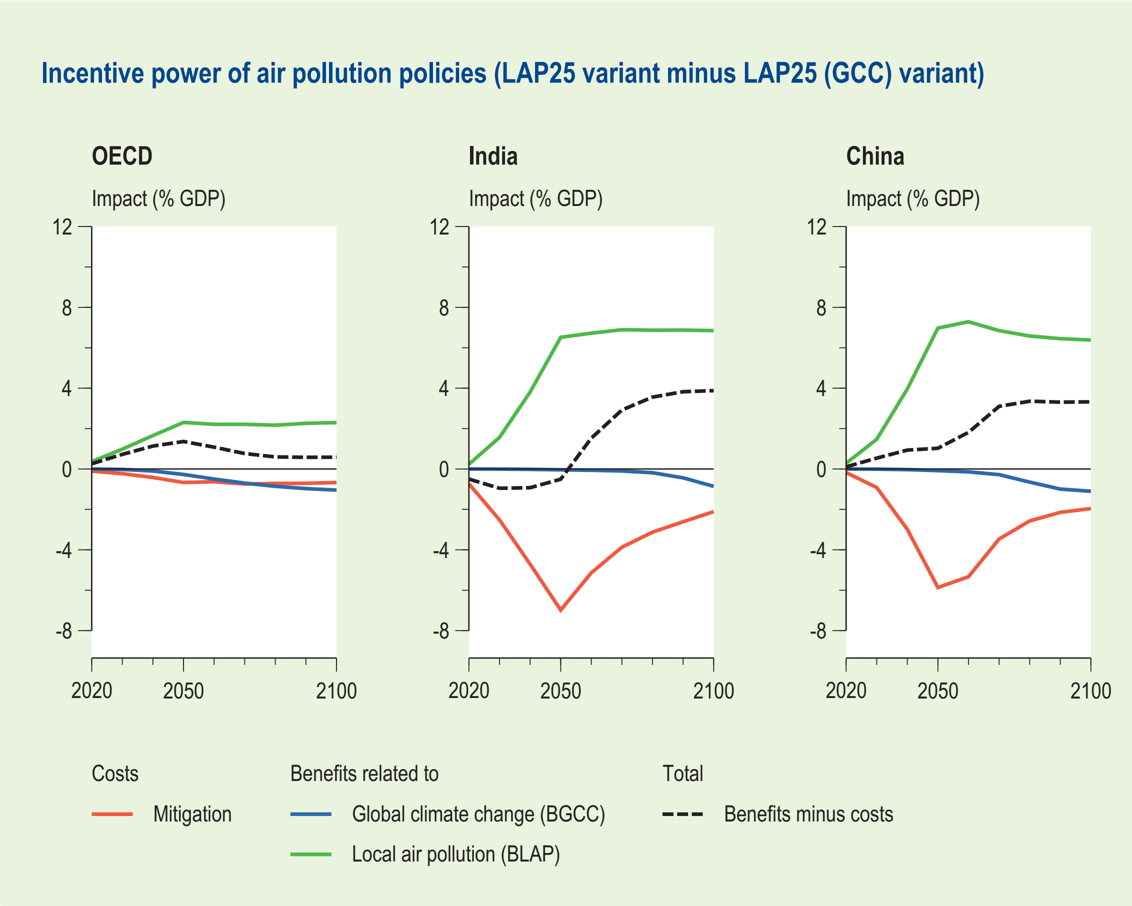

Figure 4.5 Costs and benefits of LAP policies including avoided cost of GHG reduction as co-benefits

cost of GHG emission reduction (given the policy targets in the world). To determine the avoided cost, the model simulated for each region the least-cost solution to achieve the same reduction in GHG emissions as achieved in the LAP-25 variant. Figure 4.5 presents the differences in costs and benefits between this least cost GHG reduction (LAP25(GCC) and LAP25. Comparing the sum of the costs and benefits in Figure 4.5 with those in Figure 4.1 shows that in China this sum changes from limited net costs in the first decades (Figure 4.1) to net benefits over the entire period (Figure 4.5). Although for the OECD and India the magnitude of the net cost (until 2050 in India) and the net benefits decreases, the sign of the sum of costs and benefits does not change.

5 Integrated approaches and policy design

In this chapter the integrated approach will be described, and also some indication will be given on the relevance of the policy design of climate mitigation.

5.1 The integrated window

The integrated approach fully internalises the externalities of LAP and GCC in the economies in the three regions. Thus, the external cost (or environmental dual prices) is included in the prices of energy services and consumer goods. These external costs are set at zero in the BAU scenario, and also in the scenarios presented in Chapter 3 and Chapter 4. Restrictions – either on global CO_2 eq. emissions or regional premature deaths from $PM_{2.5}$ exposure - are imposed in order to analyse the impacts on markets. The co-benefits are ex-post valuations of physical impacts, such as premature deaths and global temperature increase. These restrictions are not arbitrary but an integrated scenario approach may give more guidance on less costly emission reduction profiles with very little increase monetary terms. The integrated scenario (CBALL) internalises GCC and LAP damage, yielding energy technology implementation paths that account for all costs and benefits of CO_2 and LAP reduction efforts. Thus the resources for energy system adjustments and end-of-pipe abatement technologies are balanced.

Figure 5.1 presents the results of the scenario addressing both externalities up to the point where marginal discounted losses of consumption from mitigation are equal to the marginal discounted avoided damage of LAP and GCC (Cost and Benefits of All externalities, CBALL). The impacts are evaluated against the BAU scenario (the baseline scenario without any policies). All indicators are plotted for the period 2020-2100 and refer to the mitigation costs (through energy adjustments and use of EOP abatement measures), the benefits of preventing LAP (BLAP) and GCC (BGCC), and the net impact (SUM). The three regions presented are the OECD, China and India..

Striking the balance between the two externalities yields globally more LAP benefits than either the climate or the air pollution window do. The former yields less LAP benefits because resources are not spent on EOP abatement that reduces LAP more effectively, and the latter also yields less benefits because LAP externality is not fully resolved. There is also extra climate damage from SO_2 emission reduction that generates LAP benefits. The optimal case is superior to all cases analysed previously in both physical and monetary terms.

In CBALL, the OECD region generates more costs from mitigation but this goes hand in hand with higher LAP benefits. The net impact is positive and increases with time, which after 2050 is driven by prevented damage of GCC. China can also reduce expenditure on energy adjustments as to lower the peaking costs, recall that in the climate window, GDP losses may accrue to 7.3% in 2050, while these are lowered to 5% in the CBALL case. There will be little gains in LAP compared to the scenarios driven from the air pollution window.

In summary, China will benefit in the CBALL case compared to the climate window, and loose in air pollution window perspective. The net impact will be greater than zero from 2040 onwards. The driving force for CO_2 eq. emission reduction leading to net losses up to 2040 come from the long-term benefits related to GCC, not only to China but also the other regions. A similar line of reasoning applies to India.

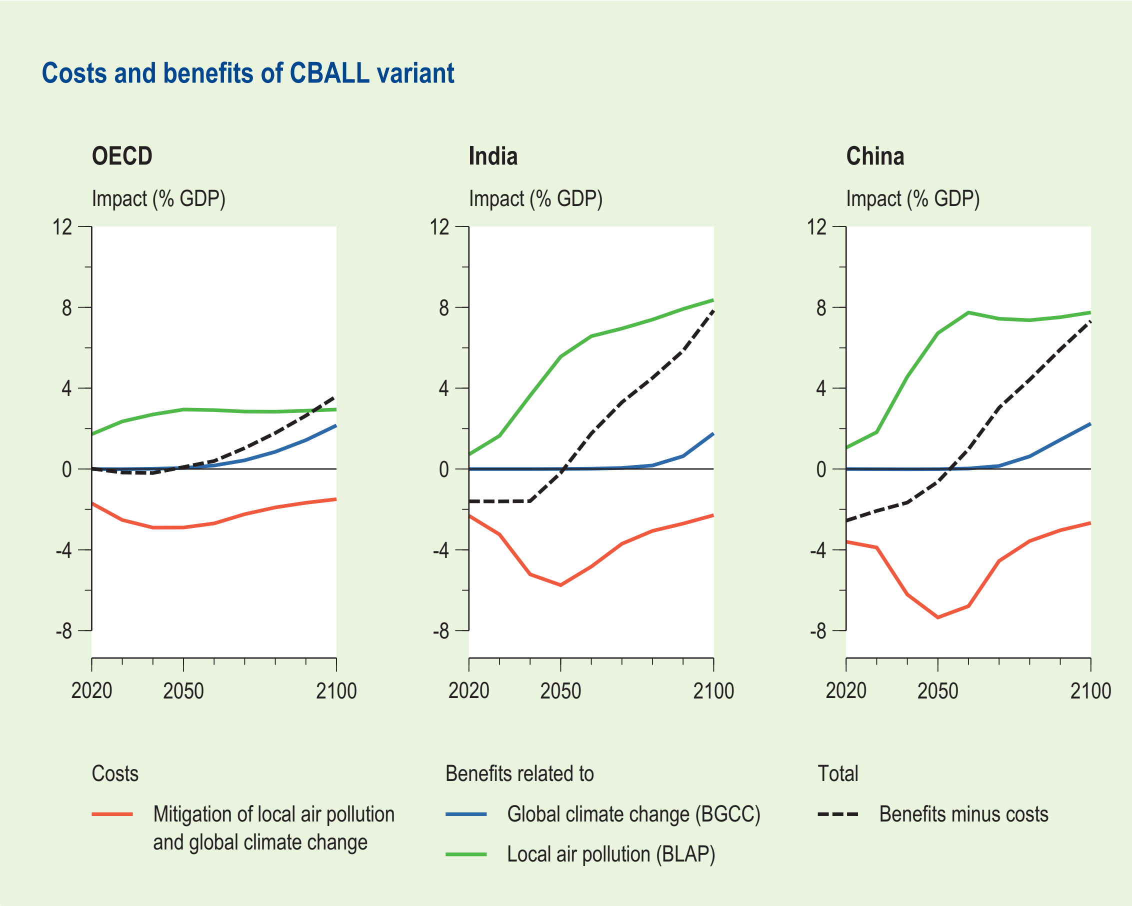

Figure 5.1 Costs and benefits of CBALL scenario

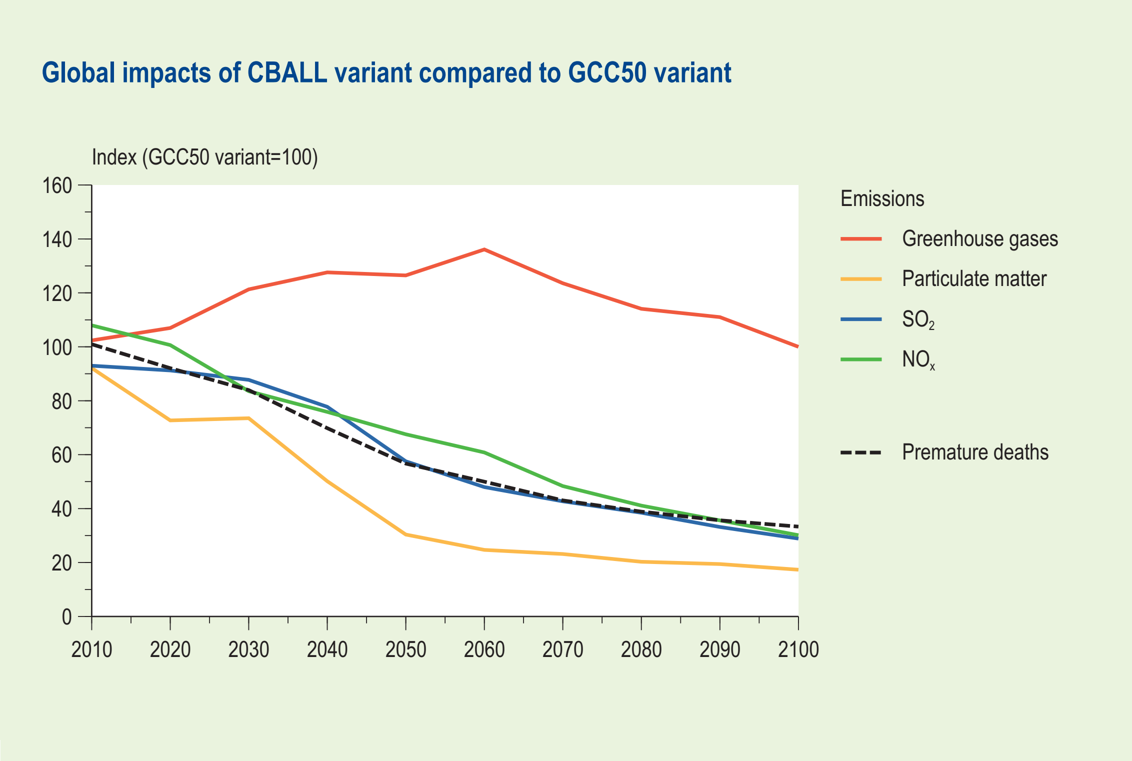

Figure 5.2 Global impacts CBALL compared to CC50 (index CC50=100)

Table 5.1 Carbon prices and shadow prices of air pollution in different variants

Variant name	Year	usa	weur	japan	canz	eefsu	china	india	mopec	Row
Carbon Prices in 2000 US$ / tC										
BASE	2020	84	342	87	88	75	75	75	0	0
	2050	132	615	136	159	136	117	117	101	101
GTBS	2020	57	57	57	57	57	57	57	57	57
	2050	187	187	187	187	187	187	187	187	187
GTALL	2020*	0	0	0	0	0	0	0	0	0
	2050	71	71	71	71	71	71	71	71	71
Air Pollution Prices in thousands 2000 US$ / (µg/m³ $PM_{2.5}$)										
GTALL	2020	31	34	13	3	3	7	3	3	18
	2050	66	57	18	6	11	31	19	15	69

Note: * the carbon price in 2020 in the GTALL is zero, because CO_2 emissions decline below the level of the BASE case (synergy from simultaneously tackling air pollution and climate change).

Figure 5.1 shows the changes in emissions in the CBALL compared to the GCC50 scenario (and not BAU). EOP abatement leads to greater reductions in emission of SO_2, NO_x, NH_3, and PM at the expense of the stringent CO_2 abatement effort in the GCC50 case. As stated above, the higher CO_2 emissions and the lower SO_x emissions to reduce the $PM_{2.5}$ concentration increase global warming slightly. Hence, compared to the GCC50 scenario, there is less expenditure on energy and more on EOP abatement leading to slightly increasing climate damage offset by a larger reduction in LAP damage.

5.2 Relevance of policy design in climate policy for the co-benefits

The interactions between CO_2 emissions trading and air pollution policies are discussed. The marginal costs of abatement of the three variants are presented in Table 5.1.

The BASE case assumes a carbon price in Western Europe to meet emission targets in 2020 and 2050. These targets are 20%, 50%, and 80% reduction on 1990 emissions in 2020, 2050, and 2100 respectively. Japan and EEFSU start with a lower carbon price in 2020 than in Western Europe, but the price increases by 2% per year.. USA and CANZ also start with a lower carbon price which increases by 1.5% per year. The other non-Annex I countries start at US$ 75 (2000) per tonne of carbon in 2030, and increases by 1.5% per year up to 2050. Beyond 2050, the carbon price increases by 2% per year in all regions, except Western Europe.

The following two cases give insight into the co-benefits and the policy design of permit prices.

1. The first is an alternative to the BASE case and assumes a theoretical global emissions trading system with permits allocated according to emissions in the BASE case (GTBS).
2. The second is the GTALL and is the same as GTBS but in this simulation the air pollution externality is fully internalised in the regions' decisions.

Figure 5.3 illustrates the impacts of the BASE case, GTBS, and GTALL to support the argument that policy design is relevant to estimates of co-benefits. The information concerns discounted changes in the flow of costs and benefits of the policy variants compared to the BAU. The compliance costs measure the discounted changes in annual consumption (and not GDP as in the

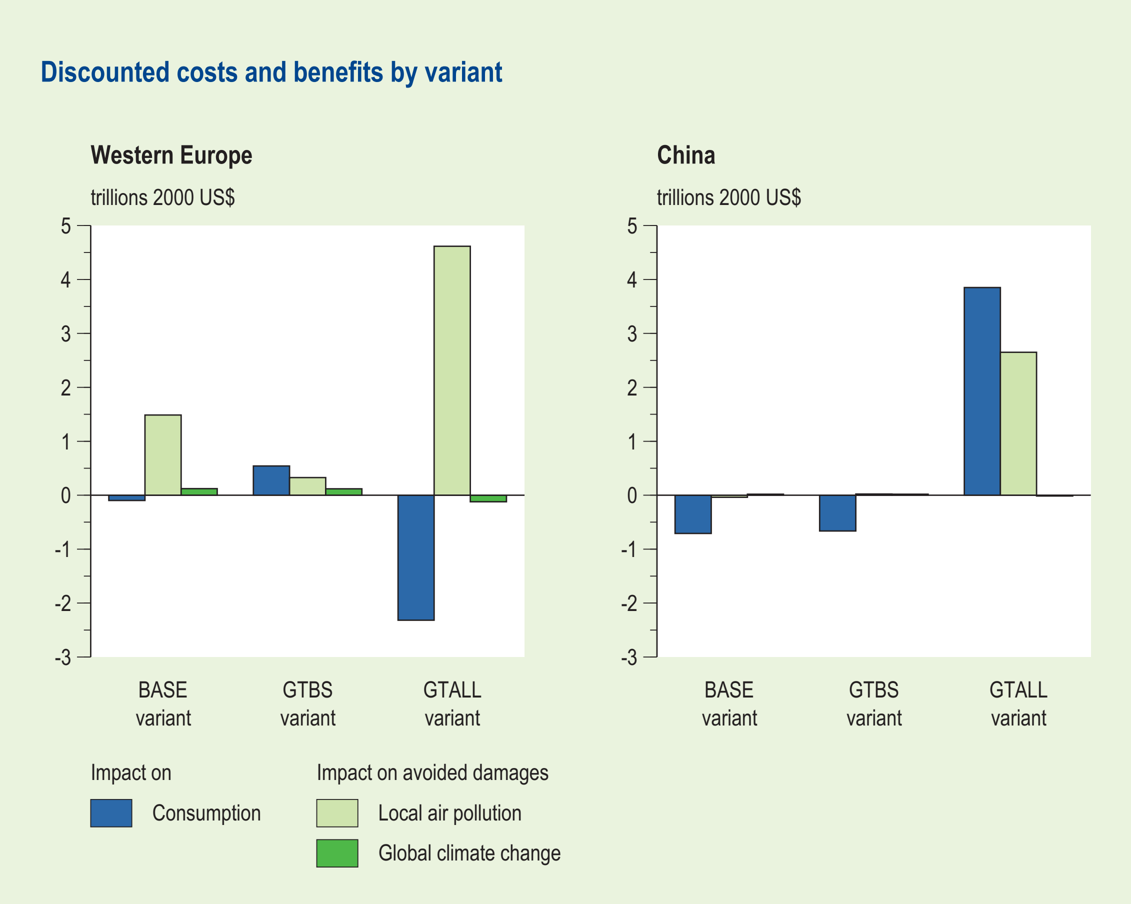

Figure 5.3 Discounted impacts in Europe and China of Global Emissions Trading or optimal air pollution policies on private consumption, and damages from air pollution and climate change (all measured in discounted trillion 2000 US$)

previous chapters) over the entire time horizon in trillions of US dollars at 2000. Likewise, the benefits of the policies concern the discounted sum of annual changes in damage associated with either LAP or GCC compared to the BAU scenario. The discount rates in these calculations are 4% in 2000, linearly declining to 2% in 2100.

The costs in Europe vary in each of the three variants. If Europe aims to comply with the -20%, -50% CO_2 emission targets, energy-intensive industries can pass on the higher costs of production. A terms-of-trade gain is the result that reduces the mitigation costs. The CO_2 emissions in China will be lower than in the BAU scenario, and hence mitigation costs are significant. However, the air pollution and climate benefits are almost zero as opposed to significant numbers in the Climate Change window (Chapter 3) and Air Pollution window (Chapter 4). The reason is that the CO_2 eq. emission reduction is 50% lower than in the GCC50 case, with emissions by 2050 in the GCC50 case about one-third of the BASE case. LAP concentrations are little affected because emissions are only reduced from large point sources that have a relatively small impact on LAP exposure. Then the argument of catching up on the monetised benefits of prevented damage is less pronounced and decline to zero.

The GTBS case lowers the co-benefits more than the decline in mitigation costs. The reason is twofold. Firstly, increasing mitigation efforts in the poorer Southern countries, which are paid by the Northern countries, reduce the burden of mitigation for the northern countries. Hence, the small loss in consumption becomes a gain in consumption in Western Europe because terms-of-trade gains are smaller than in the BASE case, but expected to be greater than zero. Secondly, the mitigation costs decline in Europe because smaller CO_2 emission reduction are paid for, for example in China. However, the host countries gain from emissions trading, although as illustrated in Figure 5.3, there is little change in consumption in China.

The GTALL case boosts the prevented damages related to air pollution in all regions. In Europe, the costs may increase to almost US$ 2.5 trillion (2000) but will be smaller globally. The extra costs compared to the BASE case result from the net impact of gains from emissions trading and the allocation of resources to end-of-pipe abatement measures. However, the benefits of prevented air pollution damage will be greater in Europe and in other OECD counties.

The discounted impacts of the three variants are presented in Figure 5.3. In the GTBS case, the OECD region changes from a net-importer of CO_2 permits to a net-exporter in the GTALL case, and vice-versa for China and India. The reason is that simultaneously tackling the adverse impacts of climate change and air pollution is more likely to occur in richer countries with resources to do so. The synergy of both environmental issues in the rich OECD countries magnifies the CO_2 abatement, and hence results in a zero price for carbon in 2020 as the demand for permits declines.

In Europe as well as in other OECD countries, there are additional losses in consumption from higher abatement costs but these are more than outweighed by the prevented pollution damage. The world can generate a lock-in to energy extensive consumption patterns (in the coming 20 years under BAU, the demand for energy-intensive goods is dominated by the OECD). Hence, China also turns the consumer losses to gains in the GTALL case. The simulations show that in China – at least up to 2050 - production declines with lower investments by expanding on consumption that only beyond 2050.

Thus, the policy assumptions of climate mitigation are important. Emissions trading without any additional LAP policy response may yield lower co-benefits. The CO_2 emission reductions are moved to areas that yield less LAP benefits, that is abatement is moved from transport in the OECD region to the electricity sector outside the OECD. However, if there are also LAP policies that fully internalise the regional externality in the prices of goods, more CO_2 emission reductions may be yielded in high-cost abatement countries (OECD countries where VSL is five to ten times higher than in countries outside the OECD. Hence, there are many more synergies with LAP policies in the OECD countries. The synergy is driven by unresolved externality of LAP that increases extra CO_2 abatement. The drive to pursue extra CO_2 abatement is magnified by the chance to switch resources from EOP abatement of LAP to extra CO_2 abatement. OECD countries may become net-exporters of CO_2 permits, whereas CO_2 abatement is much cheaper in non-OECD countries.

6 Sensitivity analysis

Co-benefits and incentive power of the GCC50 variant are evaluated against the following alternative assumptions:

High Value-of-Statistical Life (VSL)
In the literature, there are indications that VSL should reach higher values (doubling the base case). Assumptions regarding VSL are the key to cost-benefit analyses. The upper limit is US$ 2.1 million, corresponding to the estimate for VSL in the USA (US-EPA, 1999). [12]

Using these higher VSL values gives a reason to spend more on EOP emissions abatement in the CBALL variant so that more LAP damage is prevented. The synergy of tackling both externalities increases and hence reduces the global optimal CO_2 eq. emission from 6.3 to about 6 Gt CO_2 eq.

Accounting for the co-benefits of preventing LAP from climate policy and considering the opportunity costs of the same physical benefits within the regions gives an indication of the incentive power of co-benefits to join a GHG mitigation strategy. The incentive power at global level from the climate perspective will change little as the benefits from LAP policy are the same but the costs are much lower than the climate policy. Only in China are there fewer disincentives to participate the GCC50 abatement coalition. In 2050, the incentive power increases from minus 4.6 to minus 4.2% of GDP.

Value-Of-LifeYears (VOLY) approach
The synergy of tackling both externalities reduces and hence increases the global optimal CO_2 eq. emission level from 6.3 to 7.5 Gt CO_2 eq. Accounting for the co-benefits of preventing LAP from climate policy and considering the opportunity costs of achieving the same physical benefits within the regions gives an indication of the incentive power of co-benefits to join a GHG mitigation strategy. The incentive power globally from the climate perspective will change little as the benefits from LAP policy are the same but costs are much lower than the climate policy. Only in China are there more disincentives to join the GCC50 abatement coalition. In 2050, the incentive power increases from -4.6 to -4.7% of GDP.

Impact of various health end points on premature deaths
In this study the effects of air pollution on health has been derived from epidemiological studies that showed a relationship between total mortality and particulate matter in air. Epidemiological studies also found significant correlation with other health points, such as the effect on cardio-vascular diseases, lung cancer and pulmonary infection by children under 5 years. The number of deaths derived from the relation with cardio-vascular diseases shows, on the average higher values at low concentration and lower values at high concentration. Also in space and time the ratio with the outcome of total mortality differ, in 2000 the percentage of people dying from cardio-vascular diseases varied from 16% (Africa) till 42% (North-America), these percentage are expected to convergence and grow gradually, by 2150 this results in percentages between 41% (Africa) and 48% (North-America). On the average the number of calculated deaths are the same order of magnitude, although a higher number in OECD countries and somewhat lower in the rest of the world.

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[12] This 'environmental' VSL is one-third of the total VSL and the same rule is adopted as applied in Holland et al. (2004).

Lower income elasticity

Income elasticity of 0.5 as apposed to 1 implies high VSL for low-income countries, but lower VSL over time. VSL for non-OECD countries is much higher, and increases by a factor of 2.5 to 4. But over time, VSL does not rise as rapidly as assumed in the base case, and in non-OECD countries, is 25 to 40% higher than the base case. In China, VSL is 25% higher than in the BASE case. As already stated, doubling the VSL has little impact on incentive power. There could be an impact in China, but then again 25% is much lower than VSL high. Hence, there is no impact on the incentive power.

Higher discount rate

Higher discount rate are in line with marginal productivity of capital. One of the main reasons that in all the sensitivity scenarios the prevented damage (or benefits) from GCC policy is significantly lower than those from LAP policy is that GCC is intrinsically a long-term problem. Both climate damage and the effects of climate change mitigation only become manifest in the long term, and are thus discounted accordingly, at a rate that determines the present-day valuation of these impacts.

The consequences of two opposing views on discounting were explored. The utility discount factor, used in the goal-function of the maximand, is the difference between the Marginal Productivity of Capital (MPC) and the per capita growth rate of GDP. In the base case, a prescriptive view of discounting is adopted, with a MPC of 4% in 2000 that declines linearly to 2% in 2100 (see Weitzmann, 2001). For the descriptive case, a value of 5% declining to 4% in 2100 for MPC is assumed. Switching to this descriptive approach, reduces the importance of long-term GCC damage, and thus reduces climate change mitigation. The discounted damage of LAP will also be lower but becomes more important than energy switches to a low-carbon economy. Overall, by 2050 emissions will increase to about 7 Gt CO_2 eq. (as opposed to 6.3 Gt CO_2 eq.). There are no impacts on the incentive power as presented in this report because discounting does not play a role in this variable.

Adding an externality related to energy security

There is disutility associated with the damages from GCC, LAP, and low values of energy related SOS. This is shown by the following relation expressing the objective function (maximand) of the total problem, being the Negishi-weighted discounted sum of utility:

$$\sum_r n_r \sum_t u_{t,r} \log\left(E_{t,r} F_{t,r} S_{t,r} C_{t,r}\right), \tag{8}$$

with *n* representing the Negishi weights, *u* the utility discount factor, *E* the disutility factor associated with GCC, *F* the disutility factor associated with LAP, and *S* the disutility factor associated with damages from a low SOS.Finally, the argument *S* is added to account for disutility, associated with a low energy related SOS:

$$S_{t,r} = 1 - \sum_{f \in \{oil, gas\}} IMP_{f,t,r} \ , \tag{9}$$

in which IMP is the penalty function for oil and gas, resembling the willingness-to-pay in order to avoid a lack in SOS (% consumption) related to one of these types of energy. A low value for oil and gas security translates into high values for IMP and lower values for *S*.

Analytical supply-of-security expressions can be added to the model for oil and gas (for an extensive analysis of this issue, see Bollen (2008). Adding this energy-security externality causes a delay in global demand for oil in scenarios without explicit climate change and air pollution policy. Even so, oil resources are eventually completely depleted in this case. With additional climate change policy, oil resources do not deplete, and when complemented by air pollution policy (CBALL variant), reserves of oil remain larger. There is a 20% reduction in cumulative demand (over the coming 150 years) for oil compared to the CBALL variant. Emissions decline to 6 Gt CO2 eq., which is close the climate ambitions of G-8. In the mid-term, there are substantial CO2 emission reductions in the OECD region. This is induced by energy exporters, expanding on combustion of their own abundant (and cheaper) gas and oil resources. In turn, this implies that energy importing regions increase CO2 emission reductions, thus minimising the damage caused by climate change.

7 Conclusions

Two major interrelated environmental policy issues with significant transboundary aspects are global climate change and local air pollution. These issues are extensively discussed in the international political arena: the first notably in the United Nations Framework Convention on Climate Change (UNFCCC), and the second in for instance the United Nations Economic Commission for Europe's task-force on Long-Range Transboundary Air Pollution (UNECE-LRTAP).

Emissions from combustion of fossil fuels contribute significantly to global climate change and local air pollution. Options to mitigate these environmental problems are typically chosen to address each exclusively. For example, to achieve emission reductions of SO_2, NO_x, NH_3, or particulates, end-of-pipe abatement techniques are used which are dedicated to these respective effluents and not to the mitigation of the greenhouse gases (GHG). Their application thus only contributes to diminishing local air pollution and not global climate change. Alternatively, one of the ways to reduce GHG emissions is to equip fossil-fuel power plants with CO_2 Capture and Storage (CCS) technology. This technology only addresses this greenhouse gas and usually not emissions of air pollutants. CCS equipment installed in isolation, therefore, alleviates global climate change but not local air pollution. Still, policies to limit transport emissions and congestion will also improve air quality, and have positive effects on GHG emissions.

The analysis here aimed to determine the extent to which co-benefits of climate mitigation policies offer economic incentive for countries to participate in a global agreement to mitigate GHG emissions by addressing the extent to which mitigation cost can be compensated by co-benefits. While the analysis was restricted to outdoor air pollution (indoor air pollution was excluded), the analysis shows that the co-benefits, in either physical or monetary terms, are substantial and increase over time. However, in the coming 20 years, the co-benefits are larger for OECD countries than for non-OECD countries. From 2050 onwards, the air quality improvements from a global cost-effective GHG mitigations strategy also outside the OECD generate rapidly rising co-benefits. Further, the cost of climate policy appears to be high compared to air policies that also yields high benefits, thus indicating that the "incentive power" of co-benefits (to participate in a climate mitigation agreement) is not very great.

The reason is that in the OECD, one of the major contributors to local air pollution is the combustion of oil for transport use. Outside the OECD, income growth especially spurs the demand for coal for heating purposes, thus driving deterioration of air quality. However, a global effort to cost-effectively reduce GHG emissions in the next 20 years is likely be motivated by OECD countries through a reduction of oil, thus significantly affecting local air pollution. However, in non-OECD countries, GHG mitigation strategy will mainly affect demand for coal in electricity markets ("low-hanging fruit" options). Although this will significantly reduce CO_2 emissions, it will be less effective in air quality improvement. The main reason is that in the BAU scenario, newly installed coal-fired power plants in these regions are likely have low emission intensities of the substances relevant for local air pollution anyway.

The co-benefits of air pollution policy, however, are potentially very large, and may yield large reductions in CO_2 emissions if the adverse health impacts are significantly reduced worldwide. The co-benefits of policy simulations through one of the windows indicate the dilemma and the priority for environmental policy: global climate change versus local air pollution.

The extent to which the adverse health impacts of local air pollution are reduced depends on the costs of emission abatement of substances affecting air quality, but also the benefits associated with prevented damage of these policies. The mitigation costs are for either application of end-of-pipe techniques, and/or structural energy adjustments (partly making end-of-pipe techniques redundant). The prevented damage depends on the assumptions in valuing the physical improvements. In this analysis, it is represented by the number of premature deaths prevented from chronic exposure to $PM_{2.5}$ concentration.

A premature death from long-term exposure to $PM_{2.5}$ concentrations is valued in Europe as US$ 1 million (with an income elasticity of 1 for other regions and future years). The integrated approach to tackle global climate change and local air pollution simultaneously may argue for substantial GHG emission reductions in the short and medium term. Hence, it is not argued to restrict energy policy-making today to the first priority of local air pollution control and to delay reduction of GHG emissions. Policies need to be designed to simultaneously address both issues, because the combination creates an additional climate change bonus. As such, climate change mitigation will prove to be an ancillary benefit of air pollution reduction, rather than the other way around.

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Appendix I Main Assumptions

I.1 Assumptions related to Business As Usual (BAU) scenario

Table 1.1 Urban share of population UN projections medium variant (up to 2050)

	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
usa	0.81	0.83	0.84	0.86	0.88	0.90	0.90	0.91	0.91	0.92	0.92
weur	0.73	0.74	0.75	0.77	0.78	0.79	0.79	0.79	0.79	0.79	0.79
japan	0.70	0.73	0.75	0.78	0.80	0.83	0.84	0.85	0.86	0.87	0.88
canz	0.70	0.71	0.72	0.73	0.74	0.76	0.76	0.75	0.75	0.75	0.75
eefsu	0.77	0.79	0.82	0.84	0.86	0.88	0.89	0.90	0.90	0.91	0.92
china	0.45	0.53	0.61	0.69	0.77	0.85	0.87	0.88	0.89	0.90	0.92
india	0.31	0.36	0.42	0.47	0.53	0.58	0.61	0.65	0.68	0.71	0.74
mopec	0.66	0.68	0.69	0.71	0.72	0.74	0.75	0.75	0.76	0.76	0.77
row	0.52	0.56	0.60	0.64	0.69	0.73	0.75	0.77	0.79	0.81	0.83
oecd	0.75	0.77	0.78	0.80	0.82	0.84	0.87	0.86	0.86	0.85	0.85
non-oecd	0.50	0.54	0.59	0.64	0.69	0.73	0.76	0.80	0.83	0.86	0.89
world	0.53	0.57	0.61	0.65	0.70	0.74	0.78	0.81	0.83	0.86	0.88

Table 1.2 Urban share of population UN projections medium variant (up to 2050)

	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
usa	0.81	0.83	0.84	0.86	0.88	0.90	0.90	0.91	0.91	0.92	0.92
weur	0.73	0.74	0.75	0.77	0.78	0.79	0.79	0.79	0.79	0.79	0.79
japan	0.70	0.73	0.75	0.78	0.80	0.83	0.84	0.85	0.86	0.87	0.88
canz	0.70	0.71	0.72	0.73	0.74	0.76	0.76	0.75	0.75	0.75	0.75
eefsu	0.77	0.79	0.82	0.84	0.86	0.88	0.89	0.90	0.90	0.91	0.92
china	0.45	0.53	0.61	0.69	0.77	0.85	0.87	0.88	0.89	0.90	0.92
india	0.31	0.36	0.42	0.47	0.53	0.58	0.61	0.65	0.68	0.71	0.74
mopec	0.66	0.68	0.69	0.71	0.72	0.74	0.75	0.75	0.76	0.76	0.77
row	0.52	0.56	0.60	0.64	0.69	0.73	0.75	0.77	0.79	0.81	0.83
oecd	0.75	0.77	0.78	0.80	0.82	0.84	0.87	0.86	0.86	0.85	0.85
non-oecd	0.50	0.54	0.59	0.64	0.69	0.73	0.76	0.80	0.83	0.86	0.89
world	0.53	0.57	0.61	0.65	0.70	0.74	0.78	0.81	0.83	0.86	0.88

Table 1.3 Crude death rates (pro mills of population), based on PHOENIX (2004)

	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
usa	8.2	8.9	9.7	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4
weur	11.0	11.0	10.9	10.9	10.8	10.7	10.6	10.6	10.5	10.5	10.4
japan	10.0	10.5	10.9	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4
canz	6.6	6.8	7.1	7.3	7.8	8.3	8.6	9.0	9.3	9.7	10.0
eefsu	12.3	12.3	12.3	12.2	12.2	12.2	12.1	12.1	12.1	12.0	12.0
china	7.6	8.2	8.9	9.5	11.0	12.4	12.4	12.4	12.4	12.4	12.4
india	8.6	9.9	11.1	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4
mopec	5.5	5.5	5.5	5.5	5.6	5.6	6.9	8.2	9.4	10.7	12.0
row	9.6	9.5	9.4	9.2	8.9	8.7	9.7	10.7	11.8	12.8	13.8
oecd	9.7	9.9	10.2	10.5	10.5	10.5	10.9	10.8	10.6	10.6	10.5
non-oecd	8.7	9.0	9.3	9.6	9.7	9.8	10.6	11.4	12.3	13.2	14.0
world	8.8	9.1	9.4	9.7	9.8	9.8	10.6	11.4	12.1	12.9	13.6

Table 1.4 Indexed growth of exposure from urbanization and population dynamics (ageing+growth)

	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
usa	1	1.2	1.4	1.7	1.7	1.8	1.8	1.8	1.8	1.8	1.8
weur	1	1.0	1.0	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0
japan	1	1.1	1.1	1.2	1.2	1.1	1.1	1.1	1.1	1.2	1.2
canz	1	1.1	1.3	1.4	1.6	1.8	1.9	2.0	2.0	2.1	2.2
eefsu	1	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9
china	1	1.3	1.6	1.9	2.4	2.8	2.8	2.9	2.9	2.9	3.0
india	1	1.5	2.1	2.7	3.1	3.5	3.6	3.8	3.9	4.1	4.2
mopec	1	1.2	1.4	1.6	1.8	1.9	2.5	3.1	3.7	4.3	5.0
row	1	1.2	1.5	1.7	1.9	2.1	2.5	2.9	3.3	3.7	4.1
oecd	1	1.1	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
non-oecd	1	1.2	1.5	1.8	2.0	2.2	2.5	2.8	3.1	3.4	3.7
world	1	1.2	1.5	1.7	1.9	2.0	2.3	2.5	2.7	2.9	3.2

Table 1.5 Emission Coefficients

Technology Name	Identification/Examples	Costs in 2000 $/GJ	Carbon (C.) t/GJ	SO$_2$ gr/GJ	NOx gr/GJ	primPM gr/GJ
CLDU	Coal-direct use	2.5	0.024	0,3378	0,2177	0,1212
OIL-1-10	Oil 1-10 cost categories	3.0-5.3	0.020	0,1512	0,0349	0,0167
GAS-1-10	Gas 1-10 cost categories	2.0-4.3	0.014	0,0000	0,3518	0,0000
RNEW	Renewables	6	0	0,0000	0,0000	0,0112
LBDN	Carbon free: learning by doing	14 / 6	0	0,0000	0,0000	0,0000

Table 1.6 The characteristics of the technologies used in the BAU inside and outside the electricity sector and the differences between countries

Technology Name (earliest possible year of introduction)	Identification/Examples	Costs in 2000 Mills/kWh	Carbon (C.) Bn tons/TWH	SO_2 Mt/TWh	NOx Mt/TWh	primPM Mt/TWh
HYDRO	Hydroelectric and geothermal	40	0	0,0000	0,0000	0,0000
NUC	Remaining initial nuclear	50	0	0,0000	0,0000	0,0000
GAS-R	Remaining initial gas fired	36	0.14	0,0000	0,2572	0,0000
OIL-R	Remaining initial oil fired	38	0.21	1,8744	0,3952	0,0108
COAL-R	Remaining initial coal fired	20	0.25	0,9949	0,4198	0,0125
GAS-N (2010)	Advanced combined cycle	13	0.09	0,0000	0,2304	0,0000
GAS-A (2020)	Gas fuel cells + capture & sequestration	30	0	0,0000	0,0000	0,0000
COAL-N (2010)	Pulverized coal without CO_2 recovery	41	0.20	0,0000	0,3472	0,0000
COAL-A (2050)	Fuel cells with CCS - coal fuel	56	0.01	0,0287	0,0120	0,0003
IGCC (2030)	Integrated Gasification + CCS - coal	62	0.02	0,0358	0,2259	0,0012
LBDE (2010)	Carbon-free: learning by doing	100 / 50	0	0,0000	0,0000	0,0000

I.2 Air Pollution modeling

Table I.7 shows the values of exogenous parameters (see also chapter 2) mentioned in equation 1 and 2 below.

The equations summarize the relation between the average yearly $PM_{2.5}$ concentration in µg/m³ in year *t* and region *r*:

$$G_{t,r} = \sum_{s \in S} H_{s,t,r} \,, \tag{1}$$

With *s* the index referring to the substances SO_2, NO_x, PM_{10}, and NH_3, and *H* the substance-specific contribution to the regional yearly $PM_{2.5}$ concentration, which is based on the weighted mean of urban and rural concentrations following equation (2):

$$\begin{aligned} H_{s,t,r} &= u_{t,r}\left(C_{s,t,r,urb} + C_{s,t,r,rur}\right) + \left(1 - u_{t,r}\right)\left(C_{s,t,r,rur}\right) \\ &= u_{t,r} C_{s,t,r,urb} + C_{s,t,r,rur} \\ &= \Delta E_{s,t,r}\left(u_{t,r}\alpha_{s,r,urb} + \alpha_{s,r,rur}\right) \end{aligned} \tag{2}$$

The values of α are derived from the 2000 emission situation and the modeled (EMEP, 2007) impact of these emissions on the PM concentration in WEU. Substances specific correction factor were introduced for each region to account for differences in meteorological situations and the average density (inhabitants/km²) of the urban population. Table I.7: shows the relative impact of 1 kg emissions per capita relative to primary particulate emissions, due to the relative slow conversion of SO_x, NO_x and NH_3. The values for the regional level are in good agreement with de values used by de Leeuw (2002). The table shows that the urban increase of $PM_{2.5}$ is domi-

Table 1.7 Values of exogenous parameters mentioned in equation 2.

		OECD*	China	India
α_{urban}	SO_x	3.8	1.5	5.3
	NO_x	5.9	2.5	8.8
	NH_3	1.7	1.6	1.2
	PM_{10}	2.5	1.1	1.9
α_{rural}	SO_x	3.2	2.1	3.6
	NO_x	2.1	1.4	2.4
	NH_3	4.4	8.9	5.8
	PM_{10}	6.2	6.6	13.1
U	2000	0.75	0.45	0.31
	2030	0.80	0.69	0.47
	2050	0.84	0.85	0.58
	2100	0.85	0.92	0.74
Relative regional contribution of 1 kg/cap emission compared to 1 kg/capita PMprim emission				
	SO_2	0.50	0.50	0.50
	NO_x	0.82	0.82	0.82
	NH_3	0.40	0.40	0.40
Relative urban contribution of 1 kg/cap emission compared to 1 kg/capita PMprim emission				
	SO_2	0.05	0.05	0.05
	NO_x	0.02	0.02	0.02
	NH_3	0.10	0.10	0.10
Relative urban density/meteorological correction factor compared to weu				
		0.3-USA 0.7-CANZ 2-Jap	2	2

Note: OECD numbers are population weighted averages of the regions usa, weur, canz, and japan

nated by the contribution of primary particulate emissions. Globally the largest urban population density and adverse weather conditions are found in Japan, China and India.

Figure I.1 illustrates how the concentration exposure is modelled for a generic area. Emissions of SO_x and NO_x and NH_3 contribute secondary aerosol formation to the background concentrations of $PM_{2.5}$. By moving upwards from one source category to another, the local contribution of emissions to ambient concentration increases, and thus the transboundary aspect of emissions declines. These types of concentrations are mostly characterised by local emissions.

Although sulphates and nitrates add mostly to the background contribution of $PM_{2.5}$concentration, secondary aerosols are only part of the problem (see also EPA, 2004). [13] Our analysis includes all energy-related primary PM, which is dominated by concentrations in urban and rural areas.

The contribution of the PM precursor to $PM_{2.5}$ exposure is different from the proportion of emissions of that particular substance compared to the other precursors (SOx, NOx, and NH3). Thus attaining a health improvement does not imply that the contribution to average concentrations

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[13] In urban areas, $PM_{2.5}$ concentrations correlate with black and organic carbon, which depends on primary and secondary PM_{10} emissions, see EPA (2004), CANADA-United States – Transboundary PM – Science Assessment, see http://www.msc-smc.ec.gc.ca/saib.

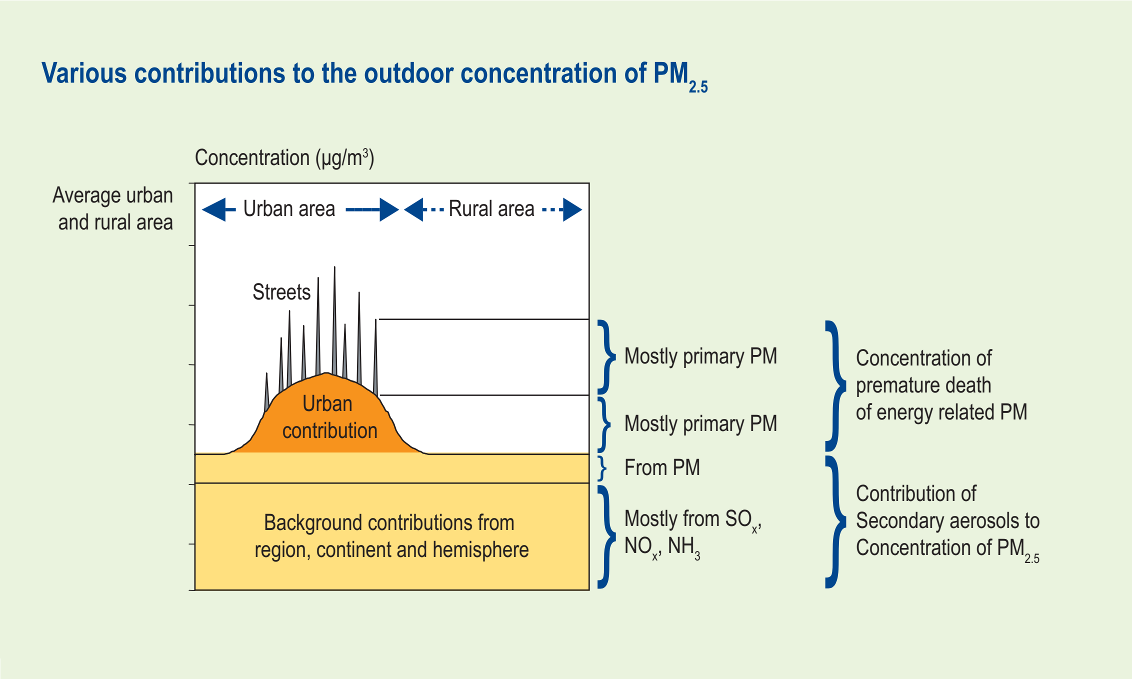


Figure I.1 $PM_{2.5}$ concentrations and sources in urban and rural areas in generic world regions
Source: derived from OECD (2008)

(ug/m³) and also emissions (tonnes) can be used to claim that sulphur emission reductions are more effective (leaving aside the differences in marginal abatement costs of specific substances). To illustrate this, sulphur tends to be emitted by large point sources in suburban areas and to disperse over larger areas, whereas PM_{10} emissions are also emitted in urban areas and remain for quite some time. From examining the options to optimally reduce average exposure to ambient urban $PM_{2.5}$, the more effective response is to reduce energy-related PM emissions rather than to reduce sulphur emissions. This point certainly holds for the EU countries (see also model simulations by Amman et al., 2004), but can also be shown to hold for the USA, although historically there are fewer SO_2 mitigation programs than in the EU.

In addition, the assumption that substances in LAP affect air quality only in that local region may seem unfortunate. However, this simplification does not lead to significant errors in the simulations, because

1. Calculations refer to averages over one region. The regions are large, and cover urban and rural areas. Thus, air quality in border areas does affect the average, but does not fully represent the average concentration in a region.
2. Average contributions in the base year are dominated by urban concentrations. Transboundary issues related to urban-dominated concentrations are less important. Thus, any error may be small. Emissions of primary PM remain close to the source as compared to SO_2 emissions and its conversion to sulphates which is actually substance contributing to the exposure of $PM_{2.5}$ concentrations, mainly because the height of emissions of SO_2 is on average larger than for PM. Careful checking of the RAINS model regard to SO_2 emissions shows the following:

    a. 80% emissions in Western Europe contribute to air quality in this region, and on average, 20% leaks to central European countries (as part of eefsu in MERGE).
    b. Only 5% of emissions in Central Europeleak to Western Europe.

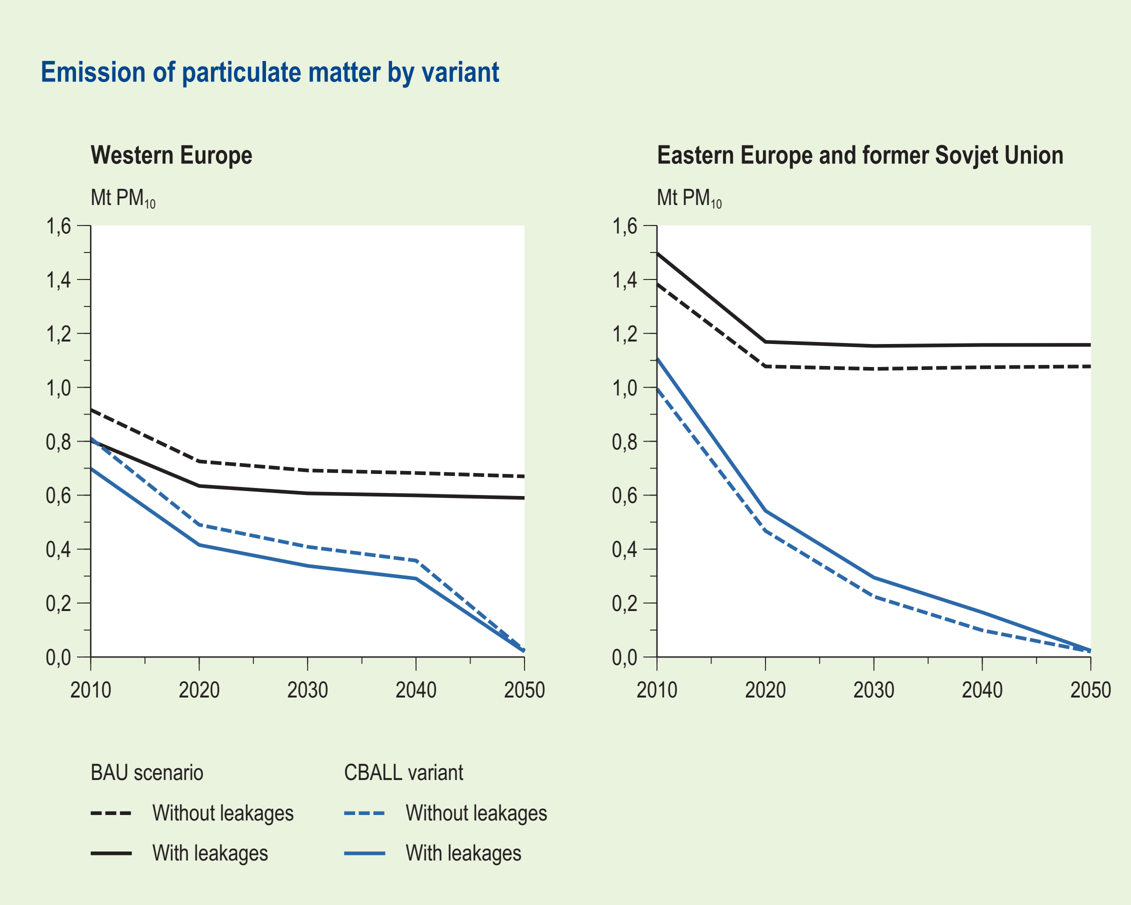


Figure I.2 Emissions of PM_{10} for two regions (OECD-EU and EEFSU) and two scenarios (BAU and GCC&LAP) with and without leakages.

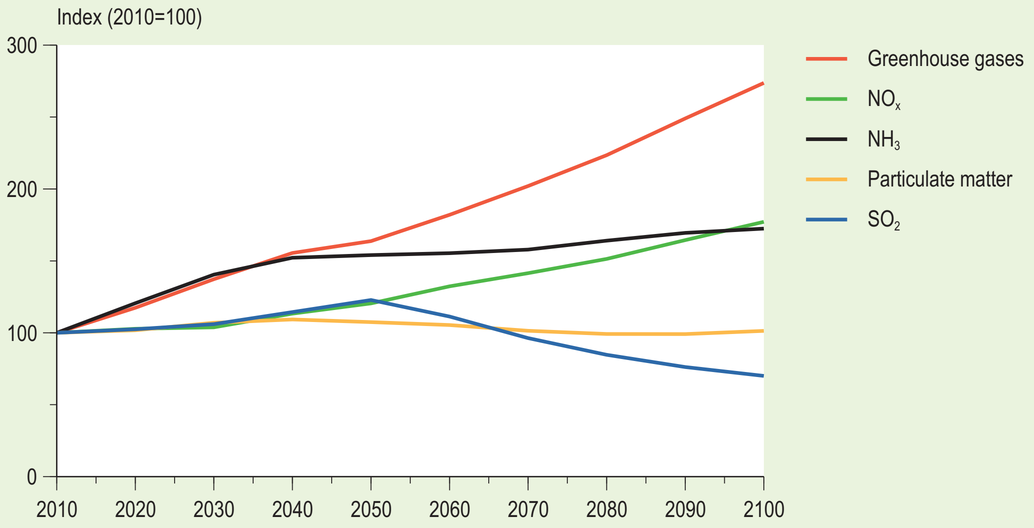
This could serve as an extreme upper estimate for leakage of energy-related primary PM, but should be interpreted as maximum estimate.. Figure 2 shows how the assumption for SO_2 leakages applied to PM affects the net emissions of Western Europe and EEFSU.

It can be seen that when transboundary aspects are not included the number of premature deaths in OECD-Europe is overestimated by 11% in 2010, and 20% in 2040. At the same time, the number of premature deaths in EEFSU is underestimated by up to 9%.. This suggests – with a linear impact on concentrations, premature deaths, and monetisation - an even smaller error in the damage valuations (including discounting) relevant for utility that may lead to relocation of resources for CO2 abatement (in Westerne Europe, 3% in 2010 and 2% in 2040; and for EEFSU, 1%).The errors in the global estimates are even smaller, because other regions are even larger than Western Europe and EEFSU, and also leakages are cancelled out (an increase in one region is a reduction in the other) thus leading much lower leakages.

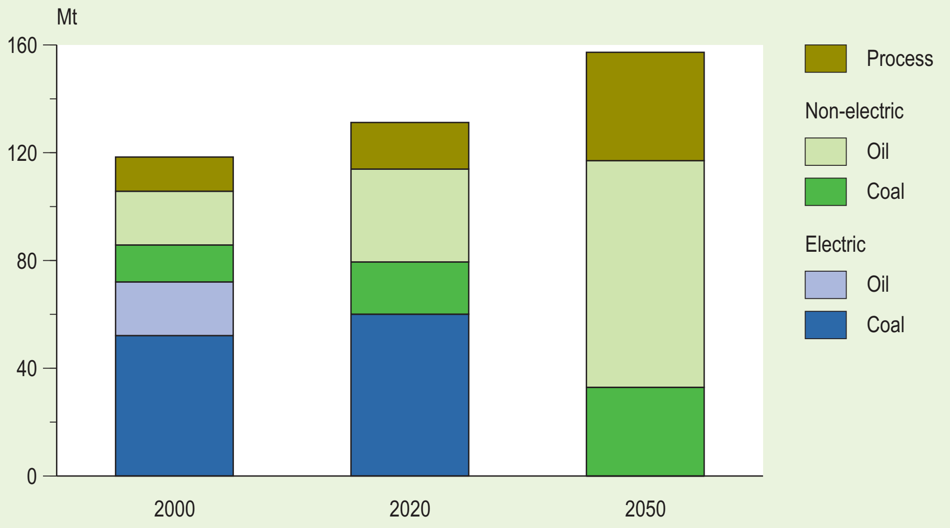
In conclusion, as regions are large, leakages and transboundary air quality impacts are limited. The transboundary aspects of sulphur emissions are larger than for PM_{10} emissions, as shown in Figure 1. Errors resulting from not including transboundary air pollution on discounted welfare changes at the regional level are less than 3%, and thus our approximation is not likely to have a significant impact on the optimal regional emissions of CO_2 and PM_{10} or on reallocation of resources.

I.3 Assumptions emissions of GHG and air pollutants

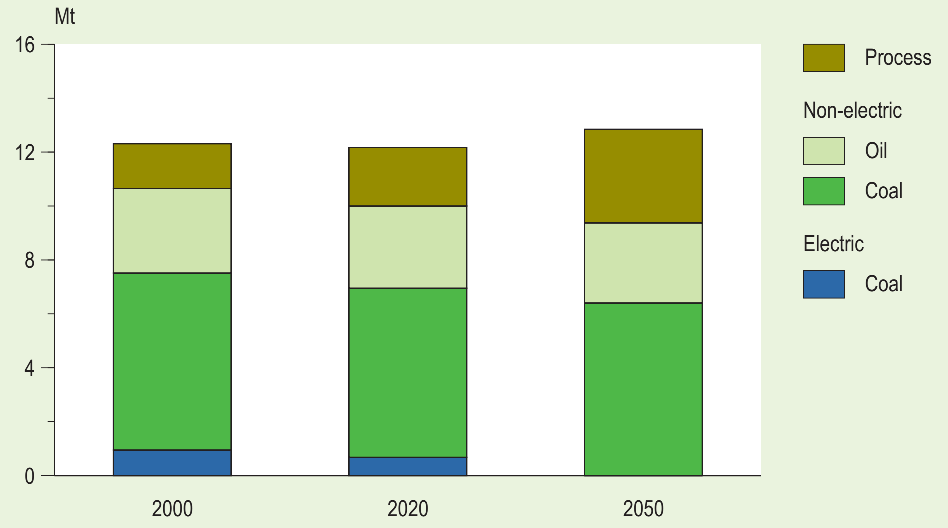
Global emissions of BAU scenario



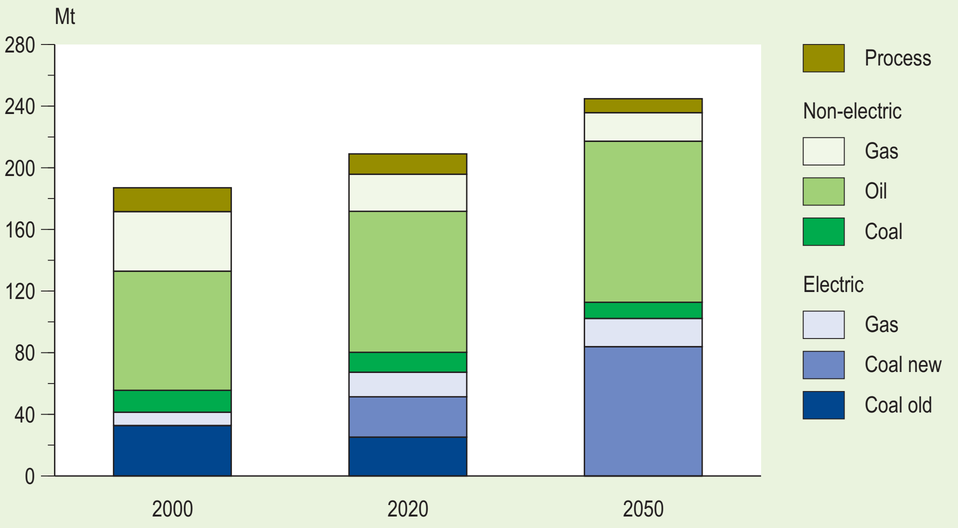
Global SO_2 emissions of BAU scenario by source



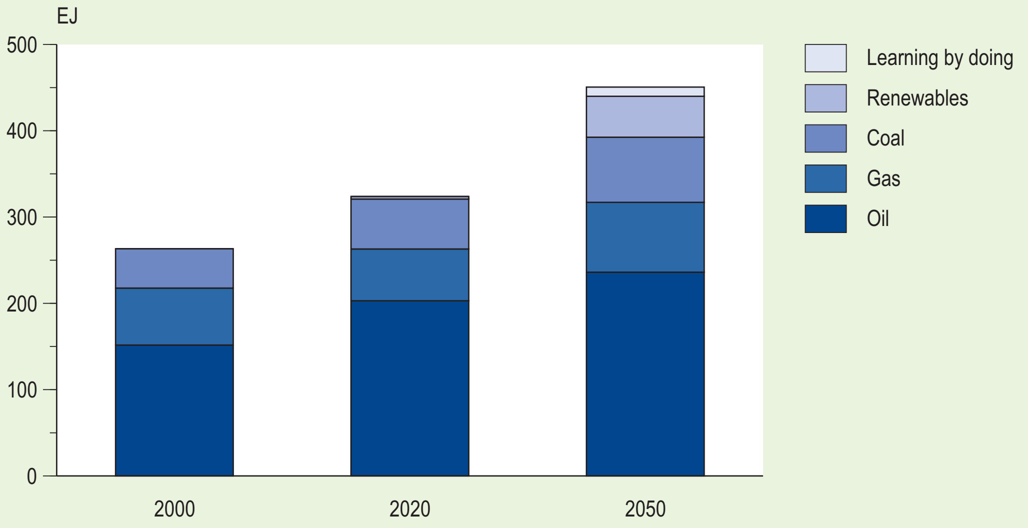
Global PM_{10} emissions of BAU scenario by source



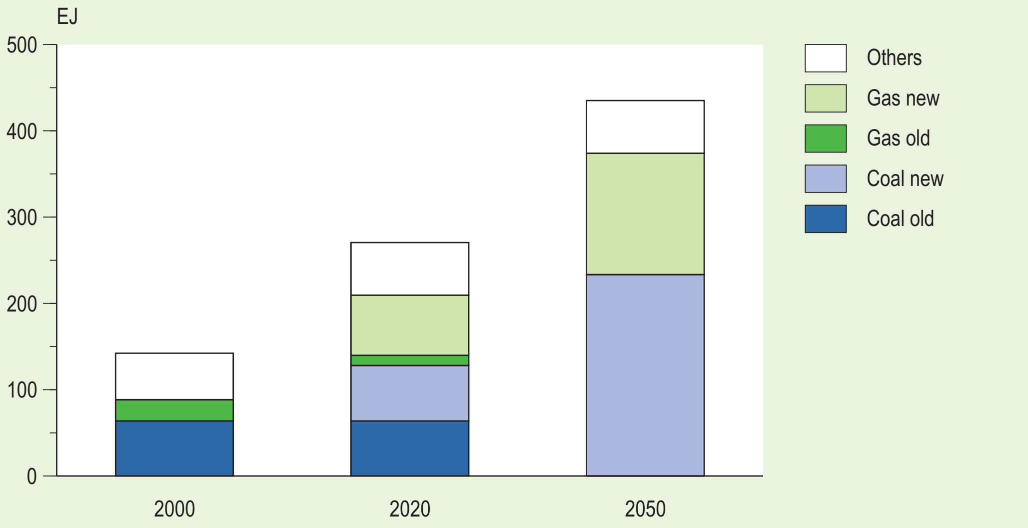
Global NO_x emissions of BAU scenario by source



Global non-electric energy of BAU scenario by source



Global electric energy of BAU scenario by source



Appendix II More detailed results of variants

Table II.1 presents the CO_{2eq} emissions for the regions and scenario's discussed in the previous chapters. The BAU scenario is consistent with OECD baseline of the recently published 2050 OECD Outlook. The CBall scenario is the optimal (minimal damage by climate change and air pollution and maximum economic growth) outcome of the MERGE model. The climate change policy scenarios are based on a pre determined 2050 global emission reduction (compared to 2005). For the period 2020-2040 the climate change reduction scenarios follow an optimal global reduction path based on gradually increase of the permit price (see table II.3) for $CO_{2eq.}$

Table II.2 presents the premature deaths for the regions and scenario's discussed in the previous chapters. The CBall scenario is the optimal (minimal damage by climate change and air pollution and maximum economic growth) outcome of the MERGE model. The Air pollution scenario is based on a pre determined regional premature death reduction (25% in 2050 compared to 2005). The premature death reduction was based on the ratio of CO_{2eq} reduction for

Table II.1 Green house gas emissions of the climate and Air pollution policy scenarios (GCC25, GCC35, GCC50, AP25, CBall)

GT CO_2 eq	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Global											
BAU	8.7	11.2	13.1	15.4	17.4	18.3	20.4	22.6	25	27.9	30.7
GCC25	8.7	10.7	10.7	9.7	8.4	7.5	6.4	5.8	5.4	5.2	5.1
GCC35	8.7	10.7	10.5	9.4	8.3	6.5	5.5	4.6	3.9	3.5	3.2
GCC50	8.7	10.5	9.5	8	6.4	5.0	3.6	3.2	2.9	2.5	2.4
AP25	8.7	11.2	10.5	10.3	9.1	7.5	6.3	5.6	5.1	4.8	4.6
CBAll	8.7	10.7	10.2	9.7	8.2	6.3	4.9	4.0	3.3	2.8	2.4
OECD											
BAU	3.6	4.0	4.3	4.4	4.6	4.7	4.6	4.5	4.4	4.4	4.5
GCC25	3.6	3.8	3.5	2.4	1.8	1.4	1.1	0.92	0.82	0.79	0.70
GCC35	3.6	3.8	3.4	2.4	1.8	1.4	1.1	0.89	0.72	0.60	0.51
GCC50	3.6	3.7	2.9	2.1	1.6	1.2	0.98	0.79	0.66	0.55	0.47
AP25	3.6	4.0	3.3	2.7	2.0	1.5	1.2	1.0	0.8	0.7	0.7
CBAll	3.6	3.3	2.8	2.3	1.8	1.4	1.1	0.88	0.72	0.59	0.50
China											
BAU	1.1	2.3	3.3	4.0	4.7	4.9	6.1	6.8	7.9	9.3	10.9
GCC25	1.1	2.1	2.4	2.4	2.2	2.0	1.8	1.6	1.4	1.3	1.2
GCC35	1.1	2.1	2.4	2.4	2.2	1.5	1.3	0.99	0.85	0.88	0.92
GCC50	1.1	2.0	2.2	1.9	1.4	0.95	0.66	0.47	0.37	0.26	0.37
AP25	1.1	2.2	2.5	2.5	2.4	1.9	1.6	1.6	1.4	1.4	1.3
CBAll	1.1	2.3	2.6	2.5	2.0	1.4	0.96	0.69	0.50	0.36	0.26
India											
BAU	0.48	0.71	0.89	1.2	1.5	1.8	2.1	2.4	2.8	3.3	3.8
GCC25	0.48	0.69	0.73	0.75	0.73	0.79	0.71	0.67	0.62	0.58	0.55
GCC35	0.48	0.69	0.72	0.75	0.75	0.61	0.54	0.47	0.41	0.34	0.29
GCC50	0.48	0.67	0.67	0.61	0.51	0.42	0.35	0.31	0.28	0.25	0.24
AP25	0.48	0.71	0.73	0.77	0.80	0.76	0.67	0.53	0.61	0.57	0.54
CBAll	0.48	0.72	0.72	0.74	0.64	0.49	0.40	0.34	0.30	0.26	0.24

the GCC25 variant in relation to the BAU and CBall emissions, the same ratio was applied for the premature death reduction.

Table II.2 Premature deaths of the climate and air policy scenarios (GCC25, GCC35, GCC50, AP25, CBall)

millions	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Global											
BAU	4.5	5.8	7.5	9.4	11.5	13.0	14.0	14.7	15.6	16.6	17.6
GCC25	4.5	5.7	6.9	8.4	9.3	10.5	10.6	11.1	11.7	12.3	13.2
GCC35	4.5	5.6	6.9	8.4	9.5	9.2	9.2	9.6	10.1	10.6	11.1
GCC50	4.5	5.6	6.5	7.3	7.6	7.6	7.6	8.2	8.9	9.5	10.3
AP25	4,5	5,7	6,9	8,4	9,3	10	11	11	12	12	13
CBall	4.5	5.6	6.0	6.1	5.3	4.3	3.8	3.5	3.5	3.4	3.4
OECD											
BAU	0.88	0.77	0.80	0.88	0.92	0.94	0.92	0.91	0.91	0.93	0.94
GCC25	0.88	0.75	0.72	0.63	0.62	0.65	0.63	0.64	0.67	0.75	0.78
GCC35	0.88	0.75	0.69	0.62	0.61	0.65	0.62	0.63	0.64	0.68	0.71
GCC50	0.88	0.74	0.65	0.62	0.59	0.63	0.61	0.62	0.64	0.67	0.71
AP25	0,88	0,75	0,72	0,63	0,62	0,65	0,63	0,64	0,67	0,75	0,78
CBall	0.88	0.60	0.42	0.34	0.28	0.24	0.22	0.21	0.20	0.20	0.19
China											
BAU	0.93	1.6	2.2	2.5	3.1	3.4	3.6	3.6	3.6	3.7	3.8
GCC25	0.93	1.6	2.0	2.4	2.8	3.1	3.1	3.1	3.1	3.2	3.2
GCC35	0.93	1.6	2.0	2.4	2.9	2.6	2.4	2.4	2.5	2.7	2.9
GCC50	0.93	1.6	1.9	2.0	2.0	1.9	1.8	1.9	2.1	2.2	2.4
AP25	0,93	1,6	2,0	2,4	2,8	3,1	3,1	3,1	3,1	3,2	3,2
CBall	0.93	1.6	1.8	1.9	1.6	1.2	0.99	0.93	0.93	0.91	0.89
India											
BAU	0.46	0.84	1.5	2.2	3.0	3.4	3.7	3.8	4.0	4.3	4.5
GCC25	0.46	0.82	1.3	2.1	2.5	3.1	3.1	3.4	3.5	3.6	3.8
GCC35	0.46	0.82	1.3	2.1	2.6	2.6	2.6	2.8	3.0	3.1	3.2
GCC50	0.46	0.81	1.3	1.8	2.0	2.1	2.1	2.3	2.6	2.8	3.1
AP25	0,46	0,82	1,3	2,1	2,5	3,1	3,1	3,4	3,5	3,6	3,8
CBall	0.46	0.85	1.2	1.7	1.6	1.3	1.1	1.0	1.0	0.99	1.0

Table II.3 Permit price for the climate policy scenarios (GCC25, GCC35, GCC50, CBall)

	2010	2020	2030	2040	2050
Euro/ton C_{eq}					
GCC25	0	118	207	258	262
GCC35	0	131	228	363	610
GCC50	0	166	340	584	965
CBall	64	95	131	184	251
Euro/ton CO_{2eq}					
GCC25	0	32	56	70	71
GCC35	0	36	62	99	166
GCC50	0	45	93	159	263
CBall	17	26	36	50	68

Global climate policy will reduce outdoor air pollution

A stringent global climate policy will lead to considerable improvements in local air quality and consequently improves human health. Measures to reduce emissions of greenhouse gases to 50% of 2005 levels, by 2050, can reduce the number of premature deaths from the chronic exposure to air pollution by 20 to 40%. Climate policy will already generate air quality improvements in the OECD countries (particularly in the USA) in the mid-term, whereas in developing countries these benefits will only in the longer run show to be significant. This is the main message of this report that was carried out for the OECD.

Netherlands Environmental Assessment Agency, February 2009