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Cost-effective Emission Reductions to Improve Air Quality in Europe in 2020

Scenarios for the Negotiations on the Revision of the Gothenburg Protocol under the Convention on Long-range Transboundary Air Pollution

Background paper for the
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Executive Summary

The Convention on Long-range Transboundary Air Pollution has embarked on the revision of its Gothenburg multi-pollutant/multi-effect protocol. To inform negotiations about the scope for further cost-effective measures, this report presents a series of emission control scenarios that illustrate options for cost-effective improvements of air quality in Europe.

Europe-wide coherent projections of economic activities envisage considerable changes in the structure of economic activities. Together with continuing implementation of already agreed emission control legislation, these would lead to significant impacts on future air pollution emissions. In 2020 baseline SO_2 emissions in the EMEP modelling domain are expected to be approximately 35% lower than in 2000; NO_x and VOC emissions would be 40% and PM2.5 emissions 20% lower. However, no significant changes emerge for NH_3 emissions in Europe. Despite these cuts in emissions, negative impacts of air pollution remain considerable: In 2020, air pollution would still shorten statistical life expectancy by 4.7 months, there will be more than 24,000 cases of premature deaths every year caused by ground-level ozone, bio-diversity of 1.4 million km^2 of European ecosystems will be threatened by high levels of nitrogen deposition, and more than 110,000 km^2 of forests will continue to receive unsustainable levels of acid deposition.

There remains substantial scope for further environmental improvement through additional technical emission reduction measures. Cost-effective emission control scenarios are presented for five different sets of environmental targets on air quality. These targets cover a range from 25% to 75% of the feasible improvements for each effect, and they involve additional emission control costs of 0.6 to 10.6 billion €/yr over the entire modelling domain (on top of the costs of the baseline scenario). Between 50 and 60% of the costs emerge for the EU-countries. However, since the EU-27 includes 72% of total population and 88% of GDP in the modelling domain, these scenarios imply higher relative efforts for some non-EU countries.

Sensitivity analyses explore the robustness of optimization results against modifications in the ambition levels for individual effects, finding that different targets on ozone would have largest impacts on emission control costs.

As a new element, the analysis estimates impacts of the control scenarios on instantaneous radiative forcing and, for the Arctic and Alpine glaciers, on carbon deposition. The analysed scenarios tend to reduce the negative forcing (and thus increase radiative forcing) in the EMEP domain by up to 0.1 W/m^2 (compared to a current total forcing from long-lived greenhouse gases of about 2.7 W/m^2) as a consequence of cuts in cooling emissions. A sensitivity analysis demonstrates that low cost options are available that could reduce this negative impact on near-term climate change to some extent.

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Acknowledgements

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1 Introduction

The Convention on Long-range Transboundary Air Pollution has embarked on the revision of its Gothenburg multi-pollutant/multi-effect protocol with the aim to finalize a revision by the end of 2011 (ECE/EB.AIR/106). It has been agreed that the new protocol should follow an effects-based approach and should include meaningful measures designed to increase the possibility for ratification by more Parties. To inform negotiations on the revision of the protocol about the scope for further cost-effective measures, this report presents a series of emission control scenarios that illustrate options for cost-effective improvements of air quality in Europe.

These scenarios employ the cost-optimization mode of the GAINS (Greenhouse gas – Air pollution Interactions and Synergies) model, which identifies least-cost solutions to achieve exogenously established targets on air quality. Environmental targets are represented as constraints in the optimization problem, and have dominant influence on overall costs of a cost-effective solution and their distribution across different countries and economic sectors.

CIAM report 1/2010 presented four alternative options for setting environmental targets to the negotiators of the 47th Session of the Working Group on Strategies in August 2010. Based on this input, the Working Group, inter alia,

- *"… supported the effects-based approach for target setting and concluded that in particular the national and Europe-wide gap closure and optimization options […] should be further explored, as well as the option for achieving equal ecosystem improvements across countries;*
- *invited the Task Force on Integrated Assessment Modelling and CIAM to further explore the "hybrid" scenarios of options 3 and 4, combined with some aspects of the option 2; and to provide further information on other gap closure percentages (in the range of 25 to 75 per cent), for presentation at the 48th session of the Working Group in April 2011;*
- *invited the Task Force on Integrated Assessment Modelling and CIAM to analyse the sensitivity of scenario results for different assumptions on baseline developments … and to publish on the Internet all relevant input data and scenario results for each country;*
- *With reference to the key technical measures for emission reduction in the countries with economies in transition that had been proposed by CIAM at the forty-first session of the Working Group in 2008, invited CIAM together with the Task Force on Integrated Assessment Modelling to further assess the measures that could contribute to the achievement of cost-effective emission reduction strategies."*

In response to these requests, this report presents a range of scenarios of cost-effective emission reductions in 2020 that simultaneously address human health, acidification, eutrophication and ground-level ozone. As a new element, the analysis explores the impacts of these emission changes on radiative forcing. Version 1 of this report has been discussed at the 39th Meeting of the Task Force on Integrated Assessment Modelling (Stockholm, February 23-25, 2011). In response to issues raised at this meeting, the report has been updated and is now presented as Version 2 as a background paper to the 48th Session of the Working Group on Strategies and Review (Geneva, April 11-14, 2011).

The remainder of the report is organized as follows: Section 2 provides a brief account of the modelling methodology, summarizes the changes that have been introduced since CIAM Report 1/2010, and describes assumptions and boundary conditions that have been used for the analysis in this report. Section 3 reviews the scope for further emission reductions under two different baseline projections and explores the scope for environmental improvements that could be achieved through available emission control measures. Section 4 recalls alternative options for target setting in a cost-effectiveness analysis. Section 5 presents least-cost scenarios for five alternative sets of environmental targets, and provides for all countries emission control costs, emission reductions and their environmental impacts. Section 6 introduces three sensitivity analyses, which explore the robustness of the cost-optimized solutions against different baseline activity projections, different quantifications of the impact of urban emissions, and the scope for additional improvements of radiative forcing that could be achieved at low costs. Conclusions are drawn in Section 7.

All detailed input data and results for all Parties are accessible through the online version of the GAINS model (http://gains.iiasa.ac.at), version GAINS-Europe, scenario group 'CIAM 1/2011 - March:

The policy scenarios can be retrieved, following the naming conventions of this report, as:

- Data for the year 2000: GOTH_2000

- PRIMES baseline: GOTH_PRIMESBL2009_baseline_rev1
- LOW case: GOTH_PRIMESBL2009_LOW_rev1
- Low* case: GOTH_PRIMESBL2009_Low-star_rev1
- Mid case: GOTH_PRIMESBL2009_MID_rev1
- High* case: GOTH_PRIMESBL2009_High-star_rev1
- High case: GOTH_PRIMESBL2009_HIGH_rev1
- Maximum feasible reductions: GOTH_PRIMESBL2009_MFR_rev1

- National projections, baseline: GOTH_NAT_baseline_rev1
- Maximum feasible reductions: GOTH_NAT_MFR_rev1

2 Methodology, input data and assumptions

2.1 Methodology

2.1.1 The GAINS model

To identify cost-effective measures to further improve air quality in Europe, this report employs the GAINS (Greenhouse gas – Air Pollution Interactions and Synergies) model developed by the International Institute for Applied Systems Analysis (IIASA).

The GAINS (Greenhouse gas-Air Pollution Interactions and Synergies) model explores cost-effective multi-pollutant emission control strategies that meet environmental objectives on air quality impacts (on human health and ecosystems) and greenhouse gases. GAINS, developed by the International Institute for Applied Systems Analysis (IIASA) in Laxenburg (Austria), brings together data on economic development, the structure, control potential and costs of emission sources, the formation and dispersion of pollutants in the atmosphere and an assessment of environmental impacts of pollution. GAINS addresses air pollution impacts on human health from fine particulate matter and ground-level ozone, vegetation damage caused by ground-level ozone, the acidification of terrestrial and aquatic ecosystems and excess nitrogen deposition to soils, in addition to the mitigation of greenhouse gas emissions. GAINS describes the interrelations between these multiple effects and the pollutants (SO_2, NO_x, PM, NMVOC, NH_3, CO_2, CH_4, N_2O, F-gases) that contribute to these effects at the European scale (Figure 2.1).

	PM (BC, OC)	SO_2	NO_x	VOC	NH_3	CO	CO_2	CH_4	N_2O	HFCs PFCs SF_6
Health impacts: PM (Loss in life expectancy)	√	√	√	√	√					
O_3 (Premature mortality)			√	√		√		√		
Vegetation damage: O_3 (AOT40/fluxes)			√	√		√		√		
Acidification (Excess of critical loads)		√	√		√					
Eutrophication (Excess of critical loads)			√		√					
Climate impacts: Long-term (GWP100)							√	√	√	√
Near-term forcing (in Europe and global mean forcing)	√	√	√	√	√	√				
Black carbon deposition to the arctic	√									

Figure 2.1: The multi-pollutant/multi-effect approach of the GAINS model to find cost-effective solutions to control air pollution and climate impacts

GAINS assesses, for each of the 43 countries in Europe, more than 2000 measures to control emissions to the atmosphere. It computes the atmospheric dispersion of pollutants and analyzes the costs and environmental impacts of pollution control strategies. In its optimization mode, GAINS identifies the least-cost balance of emission control measures across pollutants, economic sectors and countries that meet user-specified air quality and climate targets. A full technical documentation of the methodology of the GAINS model is available at http://gains.iiasa.ac.at/index.php/documentation-of-model-methodology/supporting-documentation-europe.

GAINS calculates future emissions for the baseline activity data on energy use, transport, and agricultural activities that have been projected by the PRIMES, TREMOVE and CAPRI models. Together with country-specific application rates of available emission control technologies, the GAINS emission factors reproduce emissions reported by countries to the UNFCCC and the Convention on Long-range Transboundary Air Pollution. Most recently, the GAINS model has been reviewed under the EC4MACS project (www.ec4macs.eu/home/review-agenda.html) and the EMEP Steering Body (ECE/EB.AIR/GE.1/2009/2).

2.1.2 Radiative forcing from short-lived substances

As a new element, climate impacts from aerosol air pollutants in form of their radiative forcing have been included in the GAINS model as an additional impact (Figure 2.1). This extension has been used for this report to explore impacts on near-term climate change of the emission control scenarios that are discussed in Sections 5 and 6.

In this new version of GAINS, radiative forcing from short-lived substances (i.e., SO_2, NO_x, BC and OC implied in the reduction of PM2.5 emissions) is calculated on the basis of source-receptor relationships, which quantify the impacts of changes in emissions in each country on instantaneous radiative forcing over the EMEP domain as well as carbon deposition in the Arctic and on Alpine glaciers. The calculation of radiative forcing from ozone, however, has not been finalized in time for this report, and is therefore not considered here. It is expected that these impacts could be included in further analyses in the course of 2011.

Source-receptor relationships for radiative forcing and carbon deposition

The global version of the Unified EMEP model has been used to calculate tropospheric aerosol burdens and the contributions of emissions from individual EMEP countries to the column burdens. Further details of the EMEP model set-up and specific information on the modelling of aerosols (see also Tsyro *et al.*, 2007) can be found in EMEP, 2010.

These SLCF model runs used a new global emission data set with a resolution of 1° x 1°. For European sources the EMEP emission inventory for 2006 was employed. These data, which include $PM_{2.5}$ and PM_{10} emissions, were supplemented by estimates of OC, BC and their ratios to $PM_{2.5}$, so that the necessary BC and OC inputs would be available to the model. The BC and OC data were generated with the GAINS model, and provided by IIASA at the SNAP1 sector level for each European country. For emission sources outside Europe the EMEP calculations made use of data from the RCP 8.5 scenario (Riahi *et al.*, 2007) for 2005 that have been developed for the IPCC scenario exercise. Calculations were carried out using the meteorological conditions of 2006.

Source-receptor calculations were performed to assess the influence of emissions from each European country on global aerosol loading. For each source region in turn, a set of four reduction scenarios was carried out, in each of which emissions of one pollutant, or set of pollutants, was reduced by 15%. The pollutants considered in this way were SO_2, NH_3 and VOC taken individually, and NO_x, BC and OC where the emission reductions could be made simultaneously because of the lack of interaction between them in the model.

The results of such model calculations, involving some fifty separate European source regions, have been made available to IIASA on a 1° x 1° grid covering the globe. The model outputs provided cover a wide range of parameters in addition to the relevant surface concentrations and column burdens, and have been given as both annual and monthly values.

Normalised radiative forcing factors, i.e., the radiative forcing (Wm^{-2}) divided by the total column burden of a species (gm^{-2}), can be used to estimate radiative forcing from the column burden results of the EMEP model. Such factors can be calculated using radiative transfer models developed over several years at University of Oslo/CICERO. Results have been provided by CICERO for BC, OC, SO_4 and NO_3 components – so far as annual averages – on a 1° x 1° grid corresponding to the global EMEP model output. These data are based on calculations with the global chemical transport model OsloCTM2, described by Myhre *et al.*, 2009.

Radiative forcing as an additional constraint in the GAINS optimization

The GAINS optimization framework has been extended to include radiative forcing as an additional effect of air pollutants and greenhouse gases, so that near-term radiative forcing can be addressed within the optimization process – in addition to the existing health and environmental impacts – either as an extra environmental constraint in the single-objective (cost-minimizing) optimization or in a multi-objective fashion. For this purpose the radiative forcing transfer coefficients and related constants have been derived as described below.

Radiative forcing of the short-lived aerosol forcers is calculated – as all other environmental impacts – as linear functions of the relevant pollutants, using matrix source-receptor relationships derived from a set of full EMEP model runs. The relevant precursor emissions for the radiative forcing calculation are SO_2, NO_x, BC and OC. Emissions from all regions in the EMEP domain are used as input to the forcing calculation, contributions from other source regions are absorbed into constants. The relative magnitude of these constants can be significant, owing to the fact that the background contribution can be dominant:

$$RF_r = \sum_s \sum_p T_{r,s}^{RF,p} \cdot Em_{s,p} + k_r^{RF}$$

where $\mathbf{r}$ is the receptor region, $\mathbf{s}$ the source region, $\mathbf{p}$ the relevant pollutants, $\mathbf{Em_{s,p}}$ the emissions of pollutant $\mathbf{p}$ in source region $\mathbf{s}$, with transfer matrix $\mathbf{T_{r,s}^{RF,p}}$ and constants $\mathbf{k_r^{RF}}$ for radiative forcing. The average forcing is calculated for four distinct receptor regions (EMEP domain, Northern Hemisphere, 70+ degree arctic region, and 60+ degree arctic region).

Carbon deposition on snow-covered regions is calculated as:

$$Cdep_r = \sum_s \sum_p T_{r,s}^{Cdep,p} \cdot Em_{s,p} + k_r^{Cdep}$$

where the relevant set of pollutants here only includes BC and OC, and only three distinct receptor regions are considered (the Alps, Arctic north of 70 degree, Arctic north of 60+ degree). Constraints on these impact indicators can now be combined with other target setting approaches in the GAINS model to calculate joint optimized scenarios. The targets are linked through the above equations to the cost function through the emissions and costs for emission reduction measures.

2.2 *Input data and assumptions*

The analysis reported in this paper builds on the baseline projections of economic activities that have been provided by Parties to CIAM. These projections include the national energy and agricultural scenarios submitted by 18 countries as well as a set of Europe-wide projections that have been compiled from various international sources (Table 2.1). The resulting two sets of activity scenarios, i.e., a set of Europe-wide consistent projections and a set of national scenarios, have been accepted by the Working Group on Strategies at its 46th Session as a basis for the further cost-effectiveness analysis.

2.2.1 Activity projections

The central analysis in this report employs a Europe-wide coherent picture on future economic, energy and agricultural development and comprises projections from international sources. A sensitivity analysis is carried out for the national scenarios to reflect the perspectives of individual governments, however without any guarantee for international consistency.

Table 2.1: Sources of activity projections

	Europe-wide PRIMES 2009 scenario	*National scenario*
Energy projections		
PRIMES 2009 baseline	EU-27, CR, MK, NO	BE, BG, CY, EE, FR, DE, HU, MK, LV, LT, LU, MT, PL, RO, SK, SI
National projections	CH	AT, CR, CZ, DK, FI, GR, IE, IT, NL, NO, PT, ES, SE, CH, UK
IEA WEO 2009	AL, BY, BA, MD, RU, RS, UA	AL, BY, BA, MD, RU, RS, UA
Agriculture		
CAPRI 2009	EU-27, AL, BA, CR, MK, NO, RS	AL, BA, BG, CY, CZ, DK, EE, FR, DE, GR, HU, LV, LT, LU, MK, MT, NO, PL, PT, RS, SL
National projections	CH	AT, BE, CR, FI, IE, IT, NL, RO, SK, ES, SE, CH, UK
FAO 2003	BY, MD, RU, UA	BY, MD, RU, UA

A Europe-wide coherent scenario

The Europe-wide scenario employs for the 27 EU countries and the Former Yugoslav Republic of Macedonia energy projections that have been developed with the PRIMES model in 2009 for the European Commission (i.e., updates of scenarios presented in Capros et al., 2008). This scenario includes the effects of the financial crisis. Detailed activity projections are available at the IIASA

GAINS web site (http://gains.iiasa.ac.at). For non-EU countries, the scenario employs energy projections of the International Energy Agency published in their World Energy Outlook 2009 (IEA, 2009). This scenario envisages significant changes for the fuel mix of the EU-27. Compared to 2005, current policies for renewable energy sources are expected to increase biomass use by 45% in 2030, and to triple energy from other renewable sources (e.g., wind, solar). In contrast, coal consumption is expected to decline by 17% by 2030, and oil consumption is estimated to be 10% lower than in 2005.

Future agricultural activities are derived for the EU countries and Norway from CAPRI model calculations. Detailed data on future animal numbers and fertilizer use are available from the on-line version of the GAINS model (http://gains.iiasa.ac.at). For Switzerland, a recent national projection was found most coherent with the scenarios of other countries. For all other countries, animal projections published by the Food and Agricultural Organization (FAO) have been employed (FAO, 2003).

A set of national activity projections

18 Parties of the Convention on Long-range Transboundary Air Pollution submitted their most recent governmental projections of future economic development, energy use and/or agricultural activities to CIAM (in some cases the national projections date back before the economic crisis). As these projections reflect perspectives of individual national governments, they are not necessarily internationally consistent in their assumptions on future economic development, energy prices and climate policies. In order to arrive at a data set that covers all of Europe, projections for other countries were taken from the World Energy Outlook 2009 (IEA, 2009) and the PRIMES model (the 2009 baseline). Detailed activity data can be retrieved from the GAINS online model (http://gains.iiasa.ac.at).

For the 27 EU countries, these national projections assume GDP to increase by about 35% between 2005 and 2020, while total energy use is assumed to grow by only two percent. Non-EU countries anticipate, for constant population, GDP growing in this period by about 60 percent, associated with a 12% increase in energy use. Thus, governments imply a clear decoupling between GDP growth and primary energy consumption, as a consequence of the economic restructuring towards less energy-intensive sectors, autonomous technological progress and dedicated energy policies that promote energy efficiency improvements. However, different trends are expected for different economic sectors. In the EU-27 energy demand is expected to increase by 7% in the road transport sector up to 2020 (relative to 2005), and by 2% for households and industry. In contrast, fuel input to the power sector will decline up to 2020. Abolition of the milk quota regime in the EU will most likely lower the number of dairy cows and other cattle, but there will be more pigs and poultry.

2.2.2 Assumptions

This report presents, for the two alternative baseline emission projections, calculations of the resulting air quality impacts. These calculations have been carried out with IIASA's GAINS model and employ a set of exogenous assumptions that are important when interpreting results.

To reflect the additional population exposure in urban centres from low-level sources, GAINS employs for PM2.5 'urban increments' that have been calculated with the City-Delta methodology

(Thunis *et al.*, 2007) for the EU countries. While work on the extension of this approach to non-EU countries has started, inconsistencies in the available land use and population data between EU and non-EU countries prevented the use of results for the non-EU countries in this report. A sensitivity analysis has been carried out which explored the impacts of such 'urban increments' on optimized emission ceilings (Section 6.3)

The quantification of excess of critical loads for eutrophication employs ecosystems-specific deposition estimates. As earlier calculations for the NEC directive have used grid-average deposition, results are not directly comparable.

For the impact assessment, the 2008 database on critical loads of the Coordination Centre for Effects (Hettelingh *et al.*, 2008) has been used. Again, this is different from earlier NEC calculations that employed the 2006 version of the database.

The calculation of years of life lost (YOLLs) that can be attributed to the exposure to fine particulate matter is based on actual population numbers for the years under consideration. This means that for the year 2000 calculations employ population numbers of 2000, while for 2020 the population size projected for that year is used.

For marine sources, calculations assume implementation of the recent IMO57 agreements on emission reductions.

Costs are reported in Euros of 2005, which is different to earlier NEC analyses that used Euros of 2000 as the currency unit.

Emission estimates for the year 2000 are based on activity statistics published by EUROSTAT. For some countries this results in slight discrepancies to national estimates that rely on national statistics. On the GAINS online version, data for the year 2000 that are used for this report are made available as the 'GOTH_2000' scenario.

National emissions are estimated based on the amount of fuel sold within a country.

2.3 Changes since the last reports

Since the CIAM 1/2010 report (Amann et al., 2010), the following changes have been implemented:

Following a request of the WGSR, the Task Force on Reactive Nitrogen (TFRN) is preparing a revision of an Annex IX to the Gothenburg protocol, taking into account the latest scientific and technological information. As a preparation, costs of ammonia abatement options were reassessed in an expert workshop 'Costs of ammonia abatement and the climate co-benefits' held adjacent to and reporting back to the Task Force on Reactive Nitrogen (TFRN) meeting in Paris, Oct 27, 2010. Details are covered in the chairmen's report submitted to the 48th session of the WGSR in April, 2011 (document draft ECE/EB.AIR/WG.5/2011/xx dated Jan 11, 2011), and are also available at TFRN's web page (www.clrtap-tfrn.org), which also includes background material and the presentations held at the expert workshop.

The improved information on ammonia emission control costs that emerged at that workshop allowed revision of the cost calculation in GAINS. The original GAINS methodology has been developed during the 1990's, and was repeatedly modified to include outcomes from country consultations, questionnaires sent to and responses received from country experts, and expertise made available in the framework of the ammonia expert group, a predecessor of TFRN. The recent changes in GAINS have been discussed with experts of TFRN, and constitute an important improvement over the previous situation.

In brief, the following changes were introduced (a more comprehensive documentation is in preparation – a draft is available upon request):

- Average farm sizes were reassessed, and hobby and subsistence farms of less than 15 livestock units (LSU) were excluded. Thereby, measures that are prohibitively expensive on small farms are now considered as “not applicable, and ammonia abatement measures are only considered for farms with more than 15 LSU. As a consequence, the potential for and costs of ammonia control are more accurately estimated, particularly in countries with a large share of small “subsistence” farms (e.g., Poland, Bulgaria, Romania).
- Additional costs for low protein feed were strongly decreased to about 0.5 €/kg NH_3-N abated, based on the evidence presented at the workshop.
- Costs and efficiencies of purification of exhaust air from animal houses are now based on acid scrubbers instead of biofilters. This results in a strong cost decrease to about 10 €/kg NH_3-N saved. Other housing costs were not changed.
- Costs of manure storage options remained unchanged.
- Costs for manure spreading were reassessed based on the assumption that contractors would be able to operate much more cheaply, as their investment would pay off more readily. Reported costs are below 1 €/kg NH_3-N abated, with high efficiency measures being cheaper in abatement-related costs. Considering that any nitrogen not emitted as NH_3 would contribute to soil fertilization and save the application of mineral fertilizer, with (country-specific) fertilizer prices of about 1 €/kg N, total abated costs may become negative in some cases, i.e., it can be economically sound to prevent manure N from being lost into the atmosphere in form of NH_3.

Country-specific details can be extracted from the GAINS online version.

Compared to the CIAM 1/2010 report, emission levels for the baseline and the MTFR scenarios have been slightly modified for some countries to reflect recent information, e.g., on maximum application rates for NH_3 measures, and on the implementation of ammonia measures in the baseline.

In addition, the following changes have been introduced since draft version 1.0 of this CIAM 1/2011 report that has been presented to the 39th Meeting of the Task Force on Integrated Assessment Modeling in February 2011:

- In response to comments from several EU countries who have not supplied national energy projections to CIAM, the set of national projections includes now for these countries the 2009 PRIMES energy scenario instead of the 2008 scenario that has been used before, as the 2009 version comes much closer to their national expectations than the 2008 baseline scenario did.

- For the off-road sector, the analysis considers the options of low sulfur heavy fuel oil and low sulfur diesel (compared to what was assumed in the CIAM report 1/2010). However, compared to version 1 of CIAM report 1/2011, no accelerated introduction of Euro-standards to the off-road sector is considered in this report.

- For Switzerland, the national activity projection that has been supplied to CIAM has been incorporated. Furthermore, emission factors and control strategies for cattle have been updated to reflect current legislation.
- VOC control strategies for the solvent sectors have been updated for Russia, Balkan and Former Soviet Union countries.
- NH_3 emission factors for mineral fertilizers and applicability constraints have been updated for the UK in response to comments from national experts.

3 Scope for further environmental improvements in 2020

3.1 The scope for further emission reductions

As a reference point, the baseline projection proposes future emissions as they would emerge for 2020 from the assumed evolution of economic activities and progressive implementation of emission control legislation. These baseline projections have been described in detail in CIAM Report 1/2010.

For EU countries the baseline projection assumes (i) the implementation of all emission control legislation as laid down in national laws, (ii) compliance with the existing National Emission Ceilings Directive (OJ, 2001), as well as (iii) the implementation of emission control measures for heavy duty vehicles (EURO-VI, OJ, 2009a), and for stationary sources the newly adopted Directive on Industrial Emissions (OJ, 2010) – see Box 1. Implementation of EURO-VI standard is assumed from 2014 onwards. Emission factors for road vehicles used in GAINS are consistent with COPERT IV factors (Gkatzoflias et al., 2007)

However, the analysis does not consider the impacts of other legislation for which the actual impacts on future activity levels cannot yet be quantified. This includes compliance with the air quality limit values for PM, NO_2 and ozone established by the new Air Quality Directive, which could require, inter alia, traffic restrictions in urban areas and thereby modifications of the traffic volumes assumed in the baseline projections. Although some other relevant directives such as the Nitrates Directive are part of current legislation, there are some uncertainties as to how their impacts can be quantified.

For the non-EU countries the baseline scenario considers an inventory of current national legislation in the various countries. Assumptions about emission controls in the power sector have been cross-checked with detailed information from the database on world coal-fired power plants (IEACCC, 2009). The database includes information on types of control measures installed on existing plants as well as on plants under construction. Recently several non-EU countries (Albania, Bosnia and Herzegovina, Kosovo, Croatia, Macedonia, Montenegro and Serbia) signed the treaty on the European “Energy Community”. Under this treaty, signatories agree to implement selected EU legislation, including the Large Combustion Plants Directive (LCPD; 2001/80/EEC) from 2018 onwards and the Directive on Sulphur Content in Liquid Fuels (1999/32/EC; OJ, 1999) from 2012 onwards. For countries that have currently only observer status within the Energy Community (Moldova, Turkey, Ukraine) only national legislation has been implemented.

The implementation schedule of measures to control emissions from mobile sources has been compiled for each country based on national information (where available) and international surveys (DieselNet, 2009). According to these surveys, emission limit values up to the Euro 4/5 standards for light-duty vehicles and Euro IV/V for heavy-duty vehicles will be implemented in non-EU countries with five to ten years delay compared with the EU.

Box 1: Legislation considered for air pollutant emissions for EU countries

SO_2:

- Directive on Industrial Emissions (OJ, 2010)
- Directive on the sulphur content in liquid fuels (OJ, 2009b)
- Directives on quality of petrol and diesel fuels (OJ, 2003), as well as the implications of the mandatory requirements for renewable fuels/energy in the transport sector
- IPPC requirements for industrial processes
- Sulphur content of gasoil used by non-road mobile machinery and inland waterway vessels (reduction from 1000 ppm to 10 ppm) according to the Directive 2009/30/EC (OJ, 2009c)
- National legislation and national practices (if stricter)

NO_x:

- Directive on Industrial Emissions
- EURO-standards, including adopted EURO-5 and EURO-6 for light duty vehicles
- EURO-standards, including adopted EURO V and EURO VI for heavy duty vehicles
- EU emission standards for motorcycles and mopeds up to Euro 3
- Legislation on non-road mobile machinery
- Higher real-life emissions of EURO-II and EURO-III for diesel heavy duty and light duty diesel vehicles compared with the test cycle
- IPPC requirements for industrial processes
- National legislation and national practices (if stricter)

NH_3:

- IPPC Directive for pigs and poultry production as interpreted in national legislation
- National legislation including elements of EU law, i.e., the nitrates and water framework directives
- Current practice including the code of good agricultural practice

VOC:

- Stage I directive (liquid fuel storage and distribution)
- Directive 96/69/EC (carbon canisters)
- EURO-standards, including adopted EURO-5 and EURO-6 for light duty vehicles
- EU emission standards for motorcycles and mopeds up to Euro 3
- Fuel directive (RVP of fuels)
- Solvents directive
- Products directive (paints)
- National legislation, e.g., Stage II (gasoline stations)

PM2.5:

- Directive on Industrial Emissions
- EURO-standards, including the adopted EURO-5 and EURO-6 standards for light duty vehicles
- EURO-standards, including adopted EURO V and EURO VI for heavy duty vehicles
- Legislation on non-road mobile machinery
- IPPC requirements for industrial processes
- National legislation and national practices (if stricter)

This legislation, combined with the anticipated changes in the structure of economic activities, will have significant impacts on future air pollution emissions. In 2020 baseline SO_2 emissions in the modelling domain are expected to be approximately 60% lower than in 2000; NO_x 50%, VOC 40%, and PM2.5 emissions 20% lower. However, only minor changes (-6%) emerge for NH_3 emissions in Europe (Figure 3.1).

At the same time, there is further scope for the mitigation of air pollutant emissions. Full application of the technical measures that are considered by GAINS could reduce SO_2 emissions in Europe by another 20% relative to 2000. Even larger potentials are revealed for primary emissions of PM2.5 and NH_3 (50 to 35% of emissions of the year 2000), while for NO_x further technical measures could cut total emissions by another 15%. It is noteworthy that, at the aggregated European level, these potentials are rather similar for both projections of economic activities. Maximum technically feasible reduction measures (MTFR) do not include changes in consumer behaviour, structural changes in transport, agriculture or energy supply or additional climate policies.

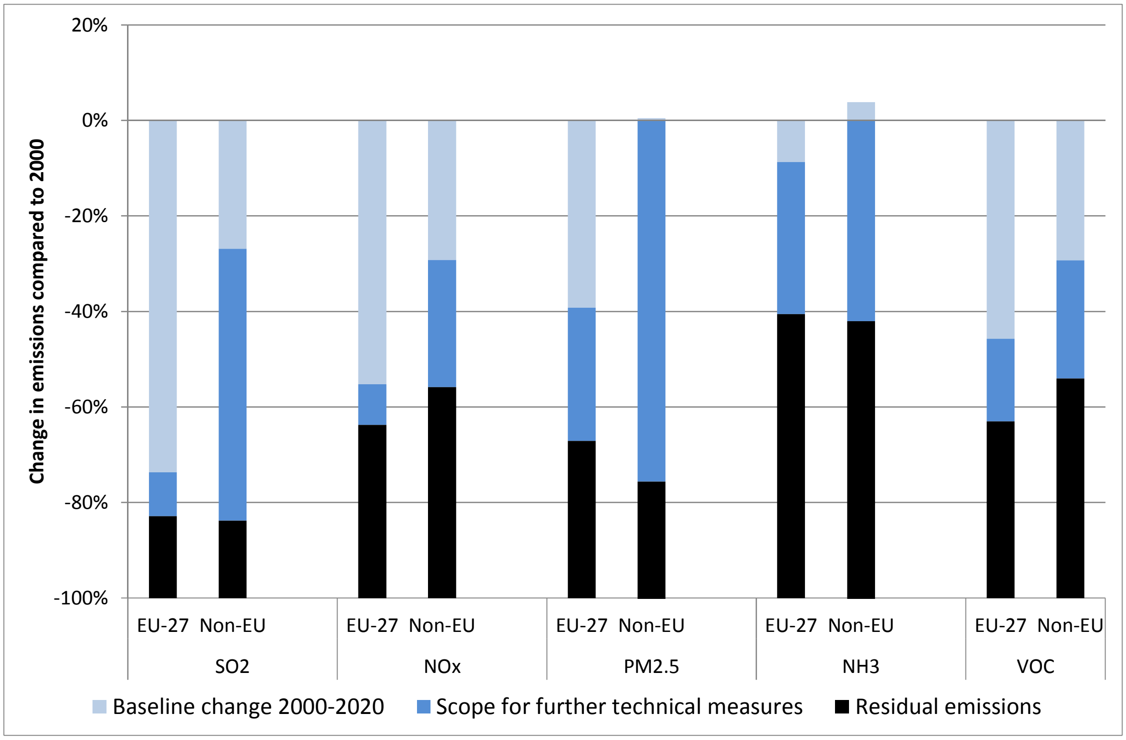


Figure 3.1: Baseline projections of emissions in 2020 and the scope for reductions through technical measures, relative to 2000.

Table 3.1: Emissions of SO_2 and NO_x: Estimates for 2000 and 2020. The table lists baseline projections (BL) and the Maximum Technically Feasible Reductions (MTFR) cases, for the PRIMES and national scenarios, respectively (in kt)

	SO_2					NO_x				
	2000	2020				2000	2020			
		PRIMES		National			PRIMES		National	
		BL	MTFR	BL	MTFR		BL	MTFR	BL	MTFR
Austria	32	19	16	18	16	195	94	81	95	86
Belgium	176	81	62	81	62	337	170	142	170	142
Bulgaria	888	132	80	132	80	158	68	53	68	53
Cyprus	47	5	2	5	2	22	13	8	13	8
Czech Rep.	294	106	93	101	90	308	151	113	140	99
Denmark	29	11	10	18	14	217	85	74	101	82
Estonia	85	16	12	16	12	33	21	13	21	13
Finland	77	42	37	61	53	221	125	110	127	107
France	633	199	132	199	132	1548	572	472	572	472
Germany	619	329	300	329	300	1707	708	609	708	609
Greece	543	112	45	100	41	330	242	199	232	181
Hungary	452	64	30	64	30	177	86	64	86	64
Ireland	144	28	20	16	12	141	69	53	73	59
Italy	774	234	117	308	127	1433	679	548	763	612
Latvia	11	4	3	4	3	37	22	19	22	19
Lithuania	52	15	7	15	7	54	29	24	29	24
Luxembourg	2	1	1	1	1	44	17	16	17	16
Malta	24	1	1	1	1	9	3	3	3	3
Netherlands	72	32	30	49	42	416	170	150	207	186
Poland	1490	468	299	468	299	823	429	353	429	353
Portugal	285	64	33	68	32	269	106	87	117	91
Romania	776	145	76	145	76	265	156	104	156	104
Slovakia	121	42	22	42	22	102	57	39	57	39
Slovenia	100	17	13	17	13	48	27	25	27	25
Spain	1433	311	168	315	138	1416	695	553	708	545
Sweden	45	29	28	29	28	238	97	87	103	84
UK	1193	227	149	290	196	1859	663	499	723	564
Albania	11	10	5	10	5	17	18	15	18	15
Belarus	172	89	34	89	34	181	150	96	150	96
Bosnia-H.	193	44	22	44	22	38	22	14	22	14
Croatia	75	20	8	44	19	67	46	30	69	46
FYROM	109	15	8	15	8	33	19	14	19	14
R Moldova	9	5	2	5	2	21	19	14	19	14
Norway	26	24	20	24	21	207	136	110	148	119
Russia	2022	1832	412	1832	412	3009	2144	1294	2144	1294
Serbia	452	92	55	92	55	137	91	63	91	63
Switzerland	17	13	10	13	10	94	44	40	44	40
Ukraine	1349	1099	143	1099	143	912	646	393	646	393
EU-27	10398	2732	1783	2889	1828	12407	5553	4495	5767	4639
Non-EU	4436	3245	719	3268	730	4717	3337	2083	3371	2107
Total	14834	5977	2502	6157	2558	17123	8891	6578	9139	6746

Table 3.2: Emissions of PM2.5 and NH$_3$: Estimates for 2000 and 2020. The table lists baseline projections (BL) and the Maximum Technically Feasible Reductions (MTFR) cases, for the PRIMES and national scenarios, respectively (in kt)

	PM2.5					*NH$_3$*				
	2000	2020				2000	2020			
		PRIMES		National			PRIMES		National	
		BL	MTFR	BL	MTFR		BL	MTFR	BL	MTFR
Austria	22	13	8	15	9	60	55	35	56	36
Belgium	32	20	15	20	15	84	75	67	77	68
Bulgaria	47	33	9	33	9	69	60	50	60	50
Cyprus	3	1	1	1	1	6	6	4	6	4
Czech Rep.	34	25	13	19	11	86	68	49	68	49
Denmark	25	19	8	20	9	91	52	46	52	46
Estonia	20	7	3	7	3	11	11	6	11	6
Finland	32	21	10	22	12	35	30	24	30	24
France	365	207	107	207	107	703	621	358	621	358
Germany	140	83	63	83	63	626	601	365	601	365
Greece	55	33	16	33	15	54	52	37	52	37
Hungary	45	22	10	22	10	77	70	40	70	40
Ireland	14	8	6	7	6	132	98	76	106	82
Italy	160	81	61	125	72	420	384	224	375	221
Latvia	17	15	3	15	3	13	12	9	12	9
Lithuania	14	10	3	10	3	37	45	24	45	24
Luxembourg	3	2	2	2	2	6	5	4	5	4
Malta	1	0	0	0	0	2	2	2	2	2
Netherlands	27	16	13	17	14	150	125	112	131	117
Poland	132	96	69	96	69	315	355	247	355	247
Portugal	95	62	15	62	14	71	69	42	69	42
Romania	141	106	20	107	20	167	150	90	204	122
Slovakia	24	10	6	10	6	30	24	13	28	15
Slovenia	9	6	3	6	3	20	16	11	16	11
Spain	142	90	54	82	51	372	364	208	352	200
Sweden	32	19	15	20	15	54	45	34	43	33
UK	115	53	42	53	43	328	270	214	285	223
Albania	8	8	2	8	2	18	24	15	24	15
Belarus	46	52	16	52	16	117	150	100	150	100
Bosnia-H.	15	13	5	13	5	17	19	11	19	11
Croatia	19	14	5	18	6	29	33	16	36	17
FYROM	14	7	2	7	2	10	9	6	9	6
R Moldova	10	9	2	9	2	16	17	10	17	10
Norway	61	31	15	42	15	24	22	13	23	13
Russia	717	778	194	778	194	552	555	314	555	314
Serbia	70	48	14	48	14	65	56	30	56	30
Switzerland	11	7	4	7	4	51	65	48	65	48
Ukraine	357	368	70	368	70	292	285	172	285	172
EU-27	1743	1059	572	1095	580	4018	3668	2389	3734	2434
Non-EU	1328	1334	330	1349	331	1191	1236	735	1239	737
Total	3071	2393	903	2443	911	5210	4904	3125	4973	3171

Table 3.3: Emissions of VOC and total emission control costs for all pollutants: Estimates for 2000 and 2020. The table lists baseline projections (BL) and the Maximum Technically Feasible Reductions (MTFR) cases, for the PRIMES and national scenarios, respectively (in kt and million €/yr)

	VOC					*Emission control costs (total for all pollutants)*				
	2000	2020				2000	2020			
		PRIMES		National			PRIMES		National	
		BL	MTFR	BL	MTFR		BL	MTFR	BL	MTFR
Austria	184	111	73	115	74	837	1848	2681	1758	2644
Belgium	215	129	108	129	108	1371	2305	2943	2305	2943
Bulgaria	130	79	40	79	40	249	1314	2066	1314	2066
Cyprus	11	5	4	5	4	21	322	374	322	374
Czech Rep.	218	148	82	133	75	1012	2309	3769	1906	2841
Denmark	141	74	45	75	47	614	1200	2090	1181	2058
Estonia	44	21	14	21	14	92	366	585	366	585
Finland	163	90	56	93	63	633	1090	2250	1316	2442
France	1706	720	480	720	480	3356	10749	18946	10749	18946
Germany	1490	870	583	870	583	10058	15606	20669	15606	20669
Greece	296	147	88	151	89	555	2149	3139	2211	3268
Hungary	168	104	59	104	59	244	1442	2140	1442	2140
Ireland	78	49	30	52	31	278	800	1275	759	1229
Italy	1580	777	622	833	606	3943	8966	12402	10326	15816
Latvia	71	49	18	49	18	78	377	1105	377	1105
Lithuania	81	53	29	53	29	51	453	975	453	975
Luxembourg	20	7	6	7	6	102	418	451	418	451
Malta	5	3	2	3	2	14	69	84	69	84
Netherlands	249	156	125	162	131	1705	3161	4133	3977	5028
Poland	616	343	223	343	223	2484	8935	12566	8935	12566
Portugal	276	176	115	162	104	299	1505	2482	1897	2895
Romania	437	301	129	301	129	450	2517	6232	2524	6232
Slovakia	73	56	38	56	38	157	701	1174	705	1174
Slovenia	57	31	17	31	17	124	615	739	615	739
Spain	1042	646	468	608	436	1919	9457	13792	8234	12280
Sweden	256	120	95	117	91	797	1992	2440	1949	2489
UK	1330	673	494	668	495	2748	7178	10180	8922	11407
Albania	29	27	12	27	12	36	112	421	112	421
Belarus	210	178	108	178	108	49	324	1768	324	1768
Bosnia-H.	49	30	13	30	13	66	220	560	220	560
Croatia	101	70	44	66	37	76	426	758	517	758
FYROM	28	14	8	14	8	45	129	261	129	261
R Moldova	25	26	14	26	14	7	56	266	56	266
Norway	381	86	65	88	67	273	1223	1999	1269	1999
Russia	3140	2307	1562	2307	1562	536	5339	15191	5339	15191
Serbia	132	113	50	113	50	176	761	2055	761	2055
Switzerland	146	81	52	81	52	578	1288	1793	1288	1793
Ukraine	636	514	313	514	313	389	1493	6139	1493	6139
EU-27	10938	5939	4045	5941	3994	34187	87845	131683	90637	135449
Non-EU	4876	3446	2241	3444	2236	2232	11370	31211	11508	31211
Total	15814	9385	6286	9385	6230	36419	99215	162893	102145	166660

3.2 *The scope for further environmental improvements*

For 2020 the baseline emission projections suggest significant improvements in the impact indicators of all environmental effects that are considered in the analysis (Figure 3.2). Over the entire model domain, years of life lost (YOLLs) attributable to fine particulate matter would decrease in the baseline case by about 40% compared to the year 2000, and the number of premature deaths that can be linked to the exposure to ground-level ozone by about 30%. The area of ecosystems that face unsustainable conditions from air pollutant deposition would decline by about 70% for acidification, and by 30% for eutrophication. In mass terms, the amount of pollutant deposition in excess of critical loads will decrease even more, i.e., by more than 80% for acidification and by 50% for eutrophication. While this indicates significant improvements compared to the current situation, impacts remain considerable in absolute terms: In 2020, air pollution would still shorten statistical life expectancy by 4.7 months, there will be more than 24,000 cases of premature deaths every year caused by ground-level ozone, bio-diversity of 1.4 million km^2 of European ecosystems will be threatened by high levels of nitrogen deposition, and 110,000 km^2 of forests will continue to receive unsustainable levels of acid deposition.

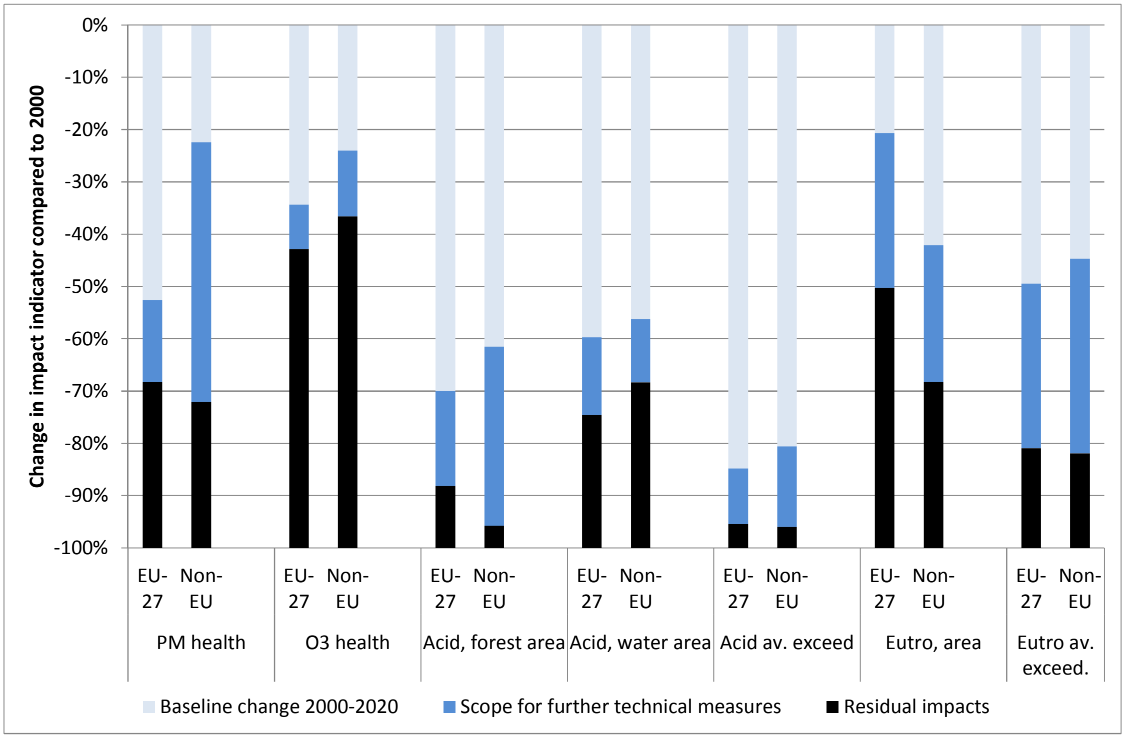


Figure 3.2: Scope for further improvements of the impact indicators in 2020

However, the analysis also demonstrates that a host of concrete measures will be still available that could further improve the situation in 2020. With these measures loss in life expectancy could be reduced by another 25% compared to the baseline case, and the number of premature deaths from ozone by 10%. These measures could also reduce ecosystems area threatened from excess nitrogen deposition by another 30%, and forest area endangered by acidification by 20% compared to the baseline situation expected for 2020.

Table 3.4: Health impact indicators related to exposure to PM2.5, for the PRIMES and the national scenarios, for the baseline (BL) and the maximum feasible reduction cases (MTFR). These calculations include the urban increments for EU countries, Norway and Switzerland.

	Loss in average life expectancy due to PM2.5 (months)					*Years of life lost (million years)*				
	2000	2020				2000	2020			
		PRIMES		National			PRIMES		National	
		BL	MTFR	BL	MTFR		BL	MTFR	BL	MTFR
Austria	7.9	3.7	2.4	3.8	2.5	3.40	1.77	1.17	1.85	1.21
Belgium	13.7	6.6	4.9	6.8	5.1	7.49	3.94	2.92	4.08	3.04
Bulgaria	8.3	3.9	1.8	4.0	1.8	3.49	1.61	0.75	1.64	0.76
Cyprus	4.5	3.6	3.3	3.6	3.3	0.14	0.17	0.16	0.17	0.16
Czech Rep.	9.6	4.6	3.0	4.6	3.0	4.87	2.70	1.75	2.67	1.73
Denmark	7.1	3.6	2.5	3.7	2.6	2.01	1.08	0.74	1.12	0.77
Estonia	5.6	3.1	1.5	3.1	1.5	0.39	0.22	0.10	0.22	0.10
Finland	3.2	1.9	1.0	2.0	1.1	0.85	0.58	0.31	0.60	0.33
France	8.2	3.8	2.5	3.9	2.5	24.90	13.12	8.50	13.42	8.69
Germany	10.2	4.9	3.5	5.0	3.5	47.15	23.91	16.96	24.51	17.40
Greece	8.1	4.0	2.6	4.1	2.6	4.62	2.73	1.77	2.77	1.76
Hungary	11.6	5.2	2.8	5.4	2.9	5.88	2.91	1.59	2.99	1.63
Ireland	4.3	1.9	1.5	2.0	1.5	0.71	0.48	0.36	0.49	0.38
Italy	8.2	4.0	2.8	4.7	3.1	26.46	13.94	9.95	16.29	10.70
Latvia	6.0	3.9	1.7	4.0	1.7	0.73	0.47	0.21	0.48	0.21
Lithuania	6.2	3.7	1.9	3.7	1.9	1.08	0.65	0.33	0.66	0.34
Luxembourg	10.1	4.7	3.3	4.9	3.4	0.23	0.13	0.09	0.14	0.09
Malta	5.9	4.3	3.7	4.4	3.7	0.11	0.11	0.09	0.11	0.09
Netherlands	13.0	6.2	4.7	6.5	5.0	10.89	5.75	4.42	6.04	4.66
Poland	10.2	5.1	3.2	5.2	3.3	18.09	10.91	6.85	11.00	6.90
Portugal	6.7	3.6	1.9	3.6	1.8	3.56	2.21	1.16	2.23	1.12
Romania	9.6	4.8	1.9	5.0	2.0	10.10	5.65	2.26	5.79	2.34
Slovakia	10.0	4.5	2.7	4.6	2.7	2.43	1.37	0.80	1.40	0.82
Slovenia	8.8	4.1	2.6	4.4	2.7	0.90	0.49	0.31	0.53	0.33
Spain	4.9	2.4	1.8	2.4	1.7	10.30	6.59	4.81	6.49	4.63
Sweden	3.8	2.0	1.4	2.1	1.4	1.79	1.05	0.70	1.08	0.72
UK	7.9	3.3	2.5	3.5	2.6	24.09	11.45	8.45	12.11	9.01
Albania	5.3	2.7	1.6	2.7	1.6	0.73	0.37	0.22	0.38	0.23
Belarus	7.0	4.5	2.1	4.6	2.1	3.58	2.33	1.06	2.35	1.07
Bosnia-H.	6.0	2.8	1.6	2.9	1.7	1.36	0.64	0.37	0.67	0.38
Croatia	8.5	4.2	2.4	4.6	2.6	2.11	1.03	0.59	1.15	0.65
FYROM	6.2	2.7	1.5	2.8	1.5	0.64	0.28	0.15	0.28	0.15
R Moldova	8.1	4.8	1.8	4.8	1.9	1.59	0.94	0.36	0.95	0.37
Norway	2.5	1.3	0.8	1.5	0.8	0.58	0.34	0.21	0.39	0.22
Russia	7.6	6.7	2.3	6.7	2.3	54.85	48.72	16.35	48.83	16.42
Serbia	8.1	3.6	1.8	3.7	1.8	4.34	1.92	0.96	1.97	0.99
Switzerland	6.5	3.0	2.1	3.1	2.1	2.66	1.23	0.84	1.28	0.87
Ukraine	9.2	6.6	2.2	6.6	2.3	22.49	16.09	5.44	16.18	5.49
EU-27	8.6	4.1	2.7	4.3	2.8	216.65	115.99	77.53	120.88	79.92
Non-EU	7.7	6.0	2.2	6.0	2.2	94.94	73.89	26.57	74.44	26.84
Total	8.3	4.7	2.6	4.8	2.6	311.59	189.88	104.10	195.32	106.76

Table 3.5: Health impact indicators related to exposure to ozone human health, for the PRIMES and the national (NAT) scenarios, for the baseline (BL) and the maximum feasible reduction cases (MTFR).

	Premature deaths (cases per year)				
	2000	2020			
		PRIMES		National	
		BL	MTFR	BL	MTFR
Austria	472	280	238	284	241
Belgium	526	336	292	338	293
Bulgaria	550	365	295	367	296
Cyprus	28	26	25	26	25
Czech Rep.	670	367	298	367	296
Denmark	222	150	132	152	134
Estonia	25	18	16	19	16
Finland	61	46	41	47	41
France	2975	1846	1639	1857	1644
Germany	4706	2959	2577	2974	2586
Greece	657	501	438	502	435
Hungary	853	510	409	519	414
Ireland	99	79	74	80	75
Italy	5084	3331	2939	3435	2997
Latvia	60	42	36	42	36
Lithuania	91	62	52	62	52
Luxembourg	42	22	19	23	19
Malta	29	19	17	20	17
Netherlands	520	333	284	336	286
Poland	1678	1008	828	1014	831
Portugal	600	447	407	447	405
Romania	1208	791	615	797	618
Slovakia	296	163	126	165	127
Slovenia	131	73	60	76	62
Spain	2117	1538	1404	1544	1399
Sweden	223	159	143	161	144
UK	2180	1664	1520	1667	1523
Albania	129	91	77	92	78
Belarus	322	221	174	223	175
Bosnia-H.	253	148	117	155	121
Croatia	356	218	178	229	186
FYROM	98	75	66	75	66
R Moldova	182	127	100	128	100
Norway	99	81	76	81	77
Russia	4702	3848	3249	3853	3252
Serbia	499	346	290	351	292
Switzerland	400	245	216	248	218
Ukraine	2543	1882	1529	1890	1533
EU-27	26103	17135	14924	17321	15012
Non-EU	9583	7282	6072	7325	6098
Total	35686	24417	20996	24646	21110

Table 3.6: Impact indicators related to the eutrophication of ecosystems, for the PRIMES and the national scenarios, for the baseline (BL) and the maximum feasible reduction cases (MTFR).

	Ecosystems area with nitrogen deposition exceeding critical loads [1000 km2]					*Average accumulated excess deposition of nitrogen [eq/ha/yr]*				
	2000	2020				2000	2020			
		PRIMES		National			PRIMES		National	
		BL	MTFR	BL	MTFR		BL	MTFR	BL	MTFR
Austria	40.2	27.7	3.9	28.7	4.3	418.4	121.0	8.9	128.6	9.8
Belgium	6.2	5.2	3.0	5.4	3.2	959.6	396.3	188.0	423.4	203.8
Bulgaria	45.3	28.6	7.4	29.4	9.6	223.0	67.4	14.2	76.7	15.8
Cyprus	1.6	1.6	1.3	1.6	1.3	114.6	121.1	91.0	121.5	90.9
Czech Rep.	27.6	27.6	27.5	27.6	27.5	1055.2	652.5	381.3	657.4	383.6
Denmark	3.6	3.6	3.6	3.6	3.6	1125.9	630.9	475.4	649.8	490.6
Estonia	16.9	8.0	2.5	8.3	2.5	86.2	26.4	6.7	27.9	6.9
Finland	113.6	63.4	27.1	65.7	28.0	55.2	18.5	6.2	19.3	6.4
France	176.3	154.9	86.2	155.3	87.7	584.1	272.4	79.3	277.4	81.9
Germany	87.9	65.9	36.4	66.6	37.2	658.0	299.4	92.0	307.5	96.2
Greece	52.6	51.8	45.7	51.9	45.6	276.6	187.9	97.2	191.1	96.5
Hungary	20.8	20.5	12.6	20.7	12.7	549.7	301.1	102.1	326.7	111.3
Ireland	2.2	1.9	1.7	1.9	1.8	668.8	332.8	192.8	379.0	225.0
Italy	87.9	61.5	26.9	64.4	27.5	367.1	160.1	31.2	164.2	33.8
Latvia	35.6	32.9	21.8	33.0	22.1	267.4	151.4	55.9	155.8	57.7
Lithuania	19.0	19.0	18.1	19.0	18.1	491.5	380.8	163.3	386.7	166.8
Luxembourg	1.0	1.0	1.0	1.0	1.0	1121.1	660.4	375.1	674.6	387.2
Malta										
Netherlands	4.2	3.8	3.6	3.9	3.6	1493.7	893.3	602.0	965.3	663.3
Poland	90.2	88.9	78.7	89.2	79.0	732.1	492.4	234.3	500.6	238.7
Portugal	29.9	19.1	3.7	19.4	3.6	163.2	50.4	4.0	52.7	4.0
Romania	20.1	1.6	0.0	9.8	0.0	23.0	0.9	0.0	6.5	0.0
Slovakia	20.5	20.5	19.8	20.5	19.8	649.3	367.9	148.5	395.3	162.6
Slovenia	10.8	6.3	0.1	7.3	0.2	373.0	65.4	0.6	82.3	0.8
Spain	176.9	165.5	114.4	165.2	111.2	321.9	185.4	63.5	181.3	60.2
Sweden	83.1	55.3	40.1	56.4	40.8	134.8	62.0	33.9	64.2	35.1
UK	23.8	14.3	9.3	15.6	10.3	146.9	46.7	19.4	54.5	23.7
Albania	16.9	16.7	13.3	16.7	13.5	302.5	232.5	93.5	239.8	96.6
Belarus	63.9	62.0	49.4	62.1	49.6	390.1	311.4	116.2	316.4	118.6
Bosnia-H.	28.2	23.0	14.0	23.5	14.6	267.0	132.2	40.3	143.6	44.9
Croatia	31.7	31.2	28.5	31.3	29.5	534.9	310.4	104.1	341.3	123.5
FYROM	13.9	13.9	10.1	13.9	10.3	311.0	188.4	73.3	193.5	74.3
R Moldova	3.4	3.2	1.9	3.2	2.0	333.4	227.1	89.8	255.4	98.5
Norway	27.7	12.3	5.1	13.4	5.6	28.0	6.7	2.2	7.6	2.5
Russia	483.9	181.1	43.5	182.7	43.9	29.9	11.1	3.0	11.3	3.0
Serbia	39.7	32.9	15.4	34.3	15.8	289.7	138.8	41.7	149.3	44.7
Switzerland	9.6	9.2	6.3	9.2	6.5	692.9	407.9	104.7	413.2	108.9
Ukraine	72.2	72.2	63.8	72.2	66.7	507.4	337.6	113.2	352.6	121.6
EU-27	1197.9	950.3	596.2	971.5	602.3	334.0	168.8	63.6	173.4	65.4
Non-EU	790.9	457.8	251.4	462.5	258.0	77.8	43.0	14.1	44.8	14.9
Total	1988.9	1408.1	847.5	1434.0	860.3	185.2	95.8	34.8	98.7	36.1

Table 3.7: Impact indicators related to the acidification of forest soils, for the PRIMES and the national scenarios, for the baseline (BL) and the maximum feasible reduction cases (MTFR).

	Forest areas with acid deposition exceeding critical loads [1000 km2]					*Average accumulated excess deposition of acidifying compounds [eq/ha/yr]*				
		PRIMES 2020		National 2020			PRIMES 2020		National 2020	
	2000	BL	MTFR	BL	MTFR	2000	BL	MTFR	BL	MTFR
Austria	0.6	0.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0
Belgium	1.9	0.9	0.5	1.0	0.6	568.6	98.1	40.2	112.1	47.2
Bulgaria	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cyprus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Czech Rep.	7.5	5.0	3.0	5.0	3.0	372.9	94.1	31.3	94.8	31.0
Denmark	1.8	0.3	0.2	0.5	0.2	649.4	30.6	10.0	37.7	11.8
Estonia	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0
Finland	5.9	1.8	1.0	2.0	1.1	4.5	0.8	0.3	0.9	0.4
France	19.5	4.6	0.9	4.7	1.0	58.3	9.0	0.7	9.4	0.7
Germany	61.8	20.6	6.1	21.5	6.6	467.8	67.5	12.4	72.6	14.0
Greece	1.5	0.2	0.0	0.2	0.0	45.6	1.0	0.1	1.0	0.1
Hungary	5.6	0.9	0.0	1.2	0.0	315.8	9.5	0.0	12.7	0.0
Ireland	1.9	0.4	0.2	0.4	0.2	245.6	18.9	5.5	19.0	5.5
Italy	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Latvia	7.2	1.2	0.0	1.3	0.0	70.6	5.9	0.0	6.3	0.0
Lithuania	6.3	5.7	1.8	5.7	1.8	294.6	105.8	7.2	108.8	7.8
Luxembourg	0.2	0.1	0.0	0.1	0.0	258.6	54.8	0.2	58.4	0.3
Malta	0.0	0.0	0.0	0.0	0.0					
Netherlands	4.8	4.4	4.1	4.4	4.2	2589.9	1116.6	735.0	1278.8	857.5
Poland	72.5	33.6	15.6	34.1	15.9	871.1	159.9	36.2	163.5	37.2
Portugal	3.0	0.9	0.1	0.9	0.1	124.8	7.8	0.3	9.8	0.3
Romania	53.0	4.2	0.1	5.4	0.1	282.7	2.6	0.0	4.3	0.0
Slovakia	3.7	1.4	0.0	1.5	0.0	132.3	11.7	0.0	14.4	0.0
Slovenia	0.8	0.0	0.0	0.0	0.0	38.3	0.0	0.0	0.0	0.0
Spain	5.5	0.0	0.0	0.0	0.0	48.3	0.3	0.1	0.3	0.0
Sweden	27.5	2.2	0.8	2.3	0.9	26.5	1.2	0.3	1.4	0.4
UK	10.9	2.6	1.4	3.1	1.7	551.6	51.6	20.4	67.8	27.3
Albania	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Belarus	11.9	4.7	0.0	4.8	0.0	66.3	8.3	0.0	8.9	0.0
Bosnia-H.	3.9	0.0	0.0	0.0	0.0	67.8	0.0	0.0	0.2	0.0
Croatia	1.3	0.5	0.0	0.5	0.0	48.9	4.1	0.0	8.1	0.0
FYROM	1.6	0.0	0.0	0.0	0.0	47.6	0.0	0.0	0.0	0.0
R Moldova	0.1	0.0	0.0	0.0	0.0	2.4	0.0	0.0	0.0	0.0
Norway	0.0	0.0	0.0	0.0	0.0					
Russia	22.8	14.9	2.2	15.0	2.2	2.3	1.1	0.0	1.1	0.0
Serbia	7.5	0.0	0.0	0.0	0.0	88.4	0.0	0.0	0.0	0.0
Switzerland	0.8	0.3	0.1	0.3	0.1	36.3	9.5	1.9	9.9	2.0
Ukraine	5.9	1.0	0.0	1.0	0.0	24.1	1.9	0.0	1.9	0.0
EU-27	303.5	91.2	35.9	95.4	37.4	174.6	27.2	7.8	29.2	8.7
Non-EU	55.8	21.5	2.4	21.6	2.4	7.4	1.3	0.0	1.4	0.0
Total	359.2	112.7	38.3	117.0	39.7	72.0	11.3	3.0	12.1	3.4

Table 3.8: Impact indicators related to the acidification of freshwater bodies, for the PRIMES and the national scenarios, for the baseline (BL) and the maximum feasible reduction cases (MTFR).

	Catchment area with acid deposition exceeding critical loads [1000 km2]					*Average accumulated excess deposition of acidifying compounds [eq/ha/yr]*				
		PRIMES 2020		National 2020			PRIMES 2020		National 2020	
	2000	BL	MTFR	BL	MTFR	2000	BL	MTFR	BL	MTFR
Finland	1971	827	274	827	299	6.0	1.2	0.2	1.4	0.2
Italy	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
Sweden	44309	14822	9109	14954	9460	22.6	2.5	1.4	2.8	1.5
UK	7709	6090	4359	6122	5876	532.2	89.4	39.6	114.6	53.0
Norway	28026	12234	8843	12703	9263	46.2	10.1	5.0	11.2	5.6
Switzerland	146	100	67	105	71	603.0	245.9	93.0	260.2	97.3
EU-27	53989	21738	13741	21903	15635	43.4	6.2	2.9	7.6	3.6
Non-EU	28172	12334	8910	12808	9334	46.7	10.4	5.1	11.4	5.7
Total	82160	34072	22651	34711	24969	44.5	7.6	3.7	8.9	4.3

4 Target setting for cost-effective emission reductions

While there remains substantial scope for further environmental improvement through additional technical emission reduction measures, it is clear that such improvements would come at substantial costs. Over the whole modelling domain, for the maximum technically feasible reductions emission control costs would increase by 70% compared to the baseline case, i.e., by about 65 billion €/yr. These additional costs would represent in the EU-27 about 0.3% of GDP, and 1.2% in the non-EU countries.

The cost-effectiveness analysis of the GAINS model can identify portfolios of measures that lead to cost-effective environmental improvements. Thereby, such an analysis can identify those measures that attain a large share of the feasible environmental improvements at a fraction of the overall costs.

For this purpose the optimization feature of GAINS searches for the least-cost portfolio of measures that (i) minimize total emission control costs over Europe while (ii) satisfying a set of environmental constraints (Wagner *et al.*, 2007). Obviously, in such an optimization problem any cost-optimal solution is critically determined by the choice of environmental constraints, i.e., by the chosen ambition level of the environmental targets as well as by their spatial distribution across Europe. More stringent and more site-specific targets will result in higher costs. Targets that could usefully guide international negotiations on further emission reductions must fulfil two criteria:

- First, they must be achievable in all countries (otherwise no portfolio of measures would be available to achieve them), and
- second, they should result in internationally balanced costs and benefits, so that they could be politically acceptable by all Parties.

Ultimately, the choice of a set of environmental targets that could serve as a useful starting point for negotiations will require value judgments, and will therefore always remain a political task for negotiators. It cannot be replaced by scientific models unless they employ (implicit or explicit) quantifications of preference structures for the various parties.

To illustrate different policy options for choosing environmental targets for the revision of the Gothenburg Protocol, CIAM report 1/2010 has explored four different concepts:

Option 1: Targets based on *equal environmental quality* caps throughout Europe (uniform caps of environmental quality). Examples are the uniform air quality limit values that apply throughout Europe.

Option 2: Targets calling in all countries for equal relative improvements in environmental quality *compared to a base year* (a ‘gap closure’), e.g., a uniform relative (equal percentage) reduction of the area of ecosystems where critical loads were exceeded in a base year (such a gap closure concept has been employed for earlier protocols under the Convention).

Option 3: Targets aiming in all countries for equal relative improvements in environmental quality *compared to the available scope for additional measures*, i.e., equal environmental improvements between what would result from the baseline and from the MTFR scenario.

This concept has been employed by the Clean Air for Europe (CAFE) program for ecosystems-related targets (see Amann *et al.*, 2005).

Option 4: Least-cost achievement of environmental improvements for *Europe as a whole*, e.g., minimizing the total loss of life years for Europe (a Europe-wide approach). This concept has been employed by the CAFE program for health targets.

These alternative options were discussed at the 47th Session of the Working Group on Strategies, which in its conclusions:

- *"… supported the effects-based approach for target setting and concluded that in particular the national and Europe-wide gap closure and optimization options 3 and 4 should be further explored, as well as the option 2 for achieving equal ecosystem improvements across countries;*
- *invited the Task Force on Integrated Assessment Modelling and CIAM to further explore the "hybrid" scenarios of options 3 and 4, combined with some aspects of the option 2; and to provide further information on other gap closure percentages (in the range of 25 to 75 per cent), for presentation at the 48th session of the Working Group in April 2011."*

In response to these conclusions, the analysis in this report presents hybrid scenarios that combine the different target setting options for the individual impact categories in the following way:

4.1 Health impacts from fine particulate matter

The scenarios analysed in this report use as a health impact indicator the 'Years of Life Lost' (YOLL), which are essentially calculated as the product of the number of people exposed times the average concentration of PM2.5 they are exposed to times the concentration/response function. For the population size, the number of people that will be older than 30 years in 2020 is used.

Target setting and optimization employs the *European-wide* approach (Option 4 in the CIAM 1/2010 report): At the European scale first the indicator is calculated for the baseline and MTFR scenarios. The difference between these scenarios is considered the 'gap', i.e., the feasible space for improvements, and then the gap closure procedure is applied to this gap. In particular, there are no country-specific target values, and the optimization identifies the overall most-cost-effective solution independently of where the health impact indicator is actually improved.

4.2 Eutrophication

For eutrophication, the impact indicator accumulates for all ecosystems in a country the total amount of deposited nitrogen that exceeds critical loads (AAE). The gap closure procedure then is applied to this indicator in each country separately (option 3 in the CIAM 1/2010 report). This means that first the AAEs are calculated in the baseline scenario and the MTFR scenario, where in the MTFR scenario emissions are set at the lowest technically feasible level *in all countries*. As all calculations are related to impacts, the gap closure approach also addresses transboundary effects. Its country-specific application guarantees that improvements in local biodiversity are achieved in each country, and not traded across Europe involving very different ecosystems. The AAEs are approximated as piece-wise linear functions in the GAINS model so that cost optimization calculations can be performed very efficiently.

However, following common practice to facilitate communication to the general public and decision makers, progress in ecosystems protection is reported in terms of the area of ecosystems where deposition exceeds critical loads. This indicator is calculated by GAINS ex-post from the optimization results for each country.

4.3 Acidification

For acidification, the same concept as for eutrophication is used.

4.4 Ground-level ozone

The SOMO35 (sum of daily eight-hour mean ozone over a threshold of 35 ppb) indicator is used as a proxy for the health effects of human exposure to ground-level ozone, using concentration-response functions that quantify associations between ozone exposure and premature mortality. Based on this indicator, the gap closure concept is applied for each country (option 3 in the CIAM 1/2010 report), i.e., the same relative improvement (between baseline and MTFR) needs to be achieved in each country.

Damage from ground-level ozone on forest trees, semi-natural vegetation and agricultural crops will be explored in an ex-post analysis (based on the ozone flux approach) in cooperation with the Coordination Centre for Effects and the Working Group on Effects.

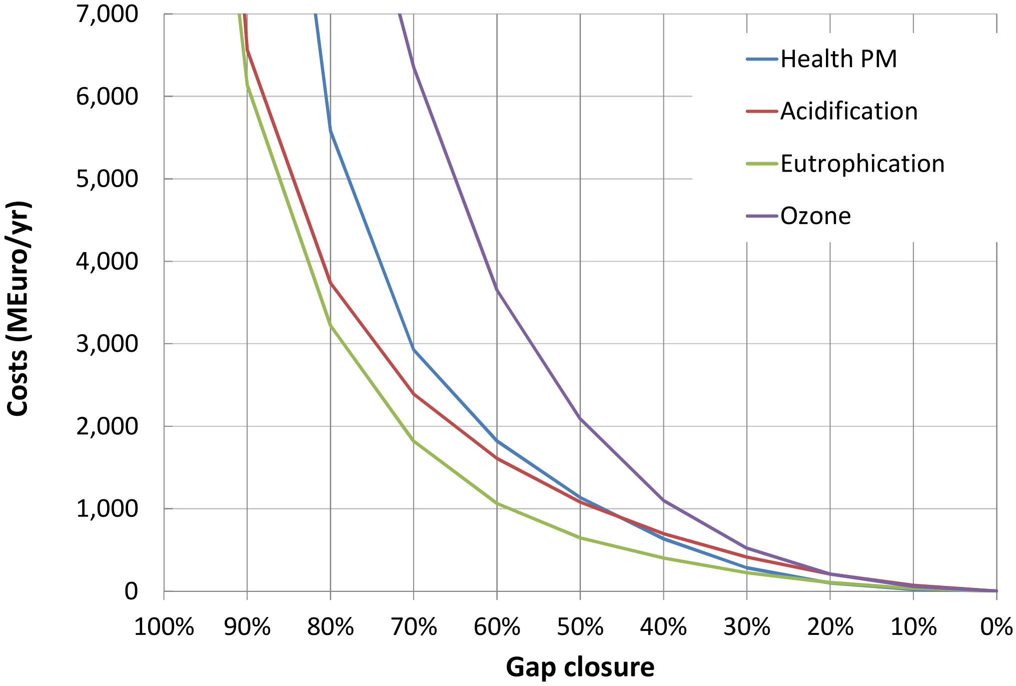
5 Exploring three ambition levels

5.1 Environmental targets

Accepting these choices on impact indicators and target setting options, appropriate ambition levels for the individual effects and their combination into a manageable set of meaningful policy scenarios remain to be decided. Obviously, combining ambition levels for different effect categories requires political value judgment of negotiators, and cannot be performed in an objective and unambiguous way by scientific models. (In principle, a strict cost-benefit analysis with full monetary quantifications of all health and environmental effects could provide a rational framework for relating ambition levels for different effects; however, in practice a precise monetary quantification of health and ecosystems benefits remains controversial.)

Given the invitation of the WGSR "… *to provide further information on other gap closure percentages (in the range of 25% - 75%)"*, this analysis has taken a pragmatic approach to define three different sets of ambition levels. Along this line, this report establishes for the initial round of negotiations a mid-ambition level employing the mid-range mentioned by WGSR, i.e., a 50% gap closure of health effects. This target would involve emission reduction costs of about 1.1 billion €/yr in the entire modelling domain (in addition to the costs of the current legislation baseline). Given this willingness to pay, analysis explored how much progress could be achieved for each of the other effects for the same amount of money. Opting for round numbers, this resulted in a 50% gap closure for acidification, 60% for eutrophication and 40% for ground-level ozone, respectively (Figure 5.1). It should be stressed that this choice of a 'mid ambition' level was a pragmatic decision of the modelling team in order to obtain a starting point (or straw-man proposal) for the cost-effectiveness analysis. Neither the modelling team nor its home Institute express with this mid case any value judgment about appropriate targets for negotiations.

While, individually, each of these targets could be achieved at about 1.1 billion €/yr (in addition to the baseline costs), a cost-effectiveness optimization that fulfills these targets for all effects simultaneously implies costs of 2.3 billion €/yr, as a consequence of the co-benefits of emission reductions on multiple environmental impacts.



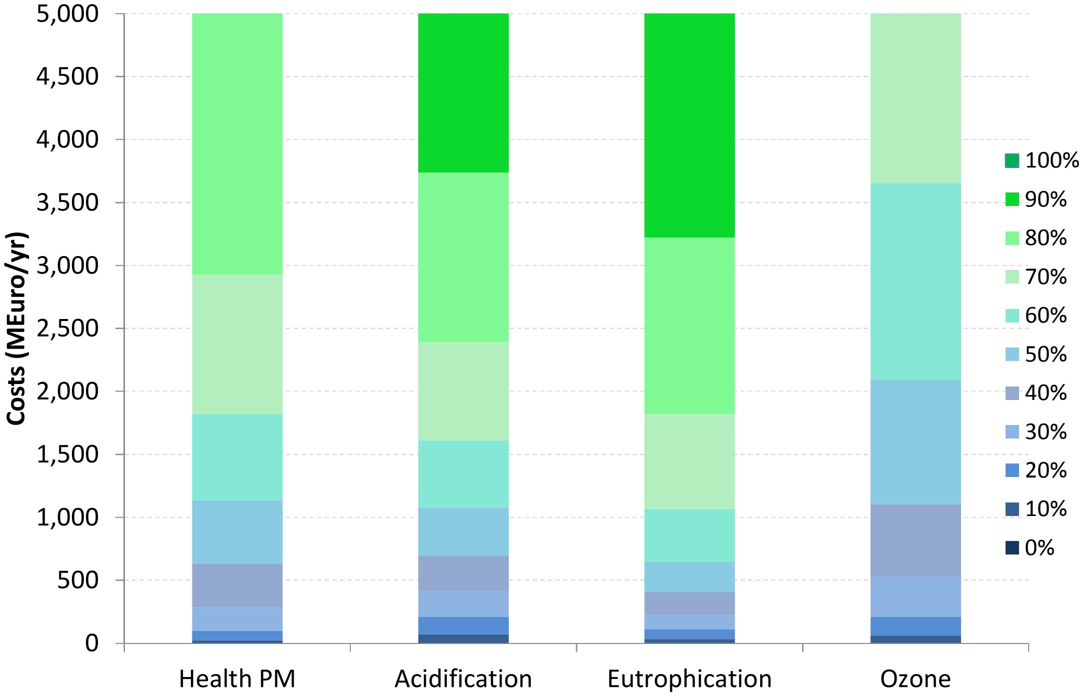


Figure 5.1: Top: Emission control costs for gap closure targets, to be achieved for the different effects individually. Bottom: Gap-closure percentages for the different effects that could be achieved for the same amount of money (for the single effect optimizations)

As the choice of a 50/50/60/40% gap closure combination for the different effects is an arbitrary decision of the modelling team, a sensitivity analysis was conducted to explore how modifications of ambition levels for individual targets would modify overall costs. For this purpose, (combined) optimization analyses have been performed for permutations of the individual ambition levels, and resulting costs are reported in Figure 5.2. It turns out that costs are most sensitive towards modifications of the gap closure target for ground-level ozone. For instance, tightening the gap closure target for ozone by 10 percentage points (and keeping targets for the other effects constant) increases costs from 2.3 to 3.2 billion €/yr, i.e., by about 40%. Similarly, relaxing the gap closure target for ozone by 10 percentage points would lower costs from 2.3 to 1.8 billion €/yr, i.e., by about 22%. In comparison, variations of the targets for other effects have much lower cost implications. Thus, when reviewing the mid set of targets, decision makers might critically consider the relative emphasis attributed to ground-level ozone in comparison to other health and environmental targets. However, it is also clear that the measures for ozone that are required to meet the original targets also yield additional co-benefits on the other effects.

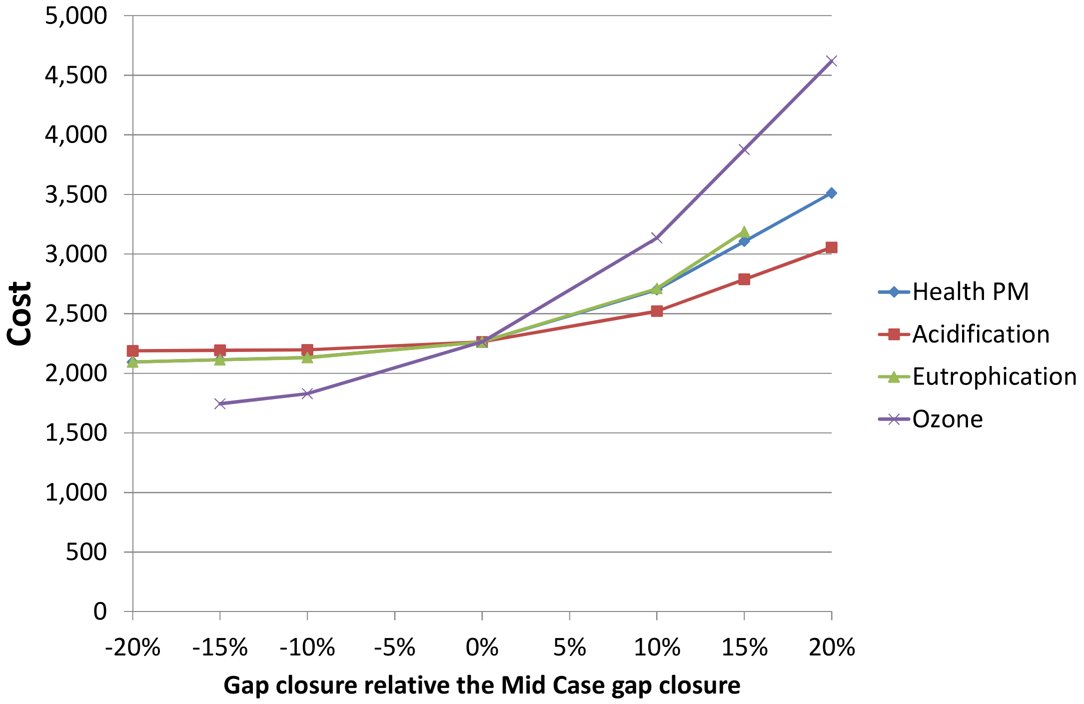


Figure 5.2: Costs for solutions in which the gap closure target for a single effect is modified while targets for the three other effects are kept at the mid case (i.e., 50% for health effects and eutrophication, 60% for acidification, 40% for ozone). Costs in billion €/yr.

With reference to the WGSR decision, the analysis adopted 25% and 75% gap closures as the low and high cases for all effects. Meeting these targets for all effects simultaneously would involve additional costs (beyond the baseline) for the entire modelling domain of 0.6 and 10.6 billion €/yr, respectively (compared to 2.3 billion €/yr for the mid case). Subsequently, a sensitivity analysis explored how costs would change if individual targets were modified. For the low case, costs increase most rapidly for increasing stringency of targets for ozone, and slowest for eutrophication. Also for the high case, costs are most sensitive to the ambition for ozone (Figure 5.3).

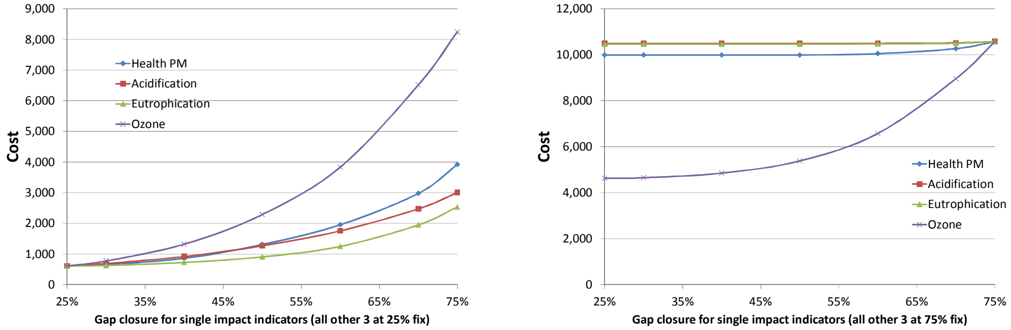


Figure 5.3: Costs for solutions in which the gap closure target for a single effect is modified while targets for the three other effects are kept. Left: variation from a 25% gap closures for all effects (LOW case); right: variation from a 75% gap closure for all effects (HIGH case)

Based on this sensitivity analysis, in addition to the 'pure' cases with uniform 25% and 75% gap closures, two variants have been developed that increase for the low case the ambition level for eutrophication to 50%, and reduce for the high case the ambition level for ozone to 50% (Table 5.1). These modified cases are indicated as high* and low* cases, in contrast to the HIGH and LOW cases that refer to the unmodified targets. Emission control costs change from 0.6 to 0.9 billion €/yr for the low case, and from 10.6 to 5.4 billion €/yr for the high case.

Table 5.1: Summary of gap closure percentages for the impact indicators for the scenarios discussed

	Health-PM	Acidification	Eutrophication	Ozone
HIGH	75%	75%	75%	75%
High*	75%	75%	75%	50%
Mid	50%	50%	60%	40%
Low*	25%	25%	50%	25%
LOW	25%	25%	25%	25%

5.2 *Emission control costs*

The five scenarios span a cost range from 0.6 (LOW case) over 0.9 (Low* case), 2.3 (Mid case), 5.4 (High* case) to 10.6 billion €/yr (HIGH case) for the entire model domain, on top of the costs of the baseline scenario (Table 5.2). Depending on the case, 57 to 65% of total costs emerge in the EU-27 (0.4 billion €/y in the LOW case, 1.4 billion in the mid case, and 6.8 billion €/yr in the HIGH case). In contrast, costs in the non-EU countries account for about 35 to 43% of total European costs. However, as the non-EU countries cover only 28% of the population and 12% of the anticipated GDP, costs in the non-EU countries are higher in relative terms than in the EU-countries. This is a direct consequence of the more lenient baseline emission control legislation and lower GDP that prevails in most non-EU countries, so that in these countries higher efforts will be required to achieve comparable environmental improvements. For instance, in the mid case, emission control costs amount to about 0.01% of GDP in the EU-27, and to 0.05% of GDP in the non-EU countries (Figure

5.4). Costs for the modified high* case increase to 0.02% for the EU countries, and 0.12% for the non-EU countries (Table 5.3). For comparison, 0.01% of GDP corresponds to 10 minutes of work per year for each person (assuming 250 workdays per year with eight hours). At the same time, total air pollution control costs (including the costs of the baseline scenario) are comparable in relative terms (e.g., percentage as GDP) between EU and non-EU countries (Figure 5.5).

Table 5.2 Additional air pollution control cost above the baseline level (million €/yr).

	LOW	Low*	Mid	High*	HIGH
Austria	7.2	8.2	23.1	33.1	94.3
Belgium	10.5	9.3	51.6	93.5	194.1
Bulgaria	2.7	1.8	7.6	38.7	50.9
Cyprus	0.6	1.2	3.0	5.4	6.1
Czech Rep.	11.2	10.7	21.7	61.5	187.8
Denmark	3.6	9.8	12.9	48.7	98.6
Estonia	4.3	5.5	6.5	11.0	41.1
Finland	4.9	21.4	34.3	63.5	56.4
France	39.3	59.8	157.1	482.5	1088.2
Germany	51.5	124.2	251.2	380.8	1101.0
Greece	3.8	6.5	12.0	29.3	138.9
Hungary	5.7	5.3	12.6	50.6	84.5
Ireland	4.4	7.5	14.2	45.3	153.1
Italy	48.4	102.1	201.7	416.9	819.7
Latvia	1.4	2.1	2.9	5.2	16.6
Lithuania	3.4	6.2	26.3	53.6	67.3
Luxembourg	0.4	0.4	0.8	1.4	15.2
Malta	0.0	0.0	0.1	0.6	2.9
Netherlands	10.1	9.4	81.5	179.9	395.2
Poland	39.1	37.1	124.2	249.6	343.1
Portugal	2.0	4.3	10.6	48.8	111.4
Romania	12.1	18.3	34.7	88.1	190.5
Slovakia	6.3	5.1	11.6	34.8	60.9
Slovenia	1.5	1.7	3.5	19.8	32.5
Spain	43.1	69.8	147.1	294.5	544.2
Sweden	11.8	10.9	14.2	34.6	40.6
UK	36.2	46.8	131.3	321.2	829.6
Albania	0.7	2.1	3.7	7.3	12.1
Belarus	13.8	26.1	37.9	76.2	186.5
Bosnia-H.	0.9	2.6	13.2	25.2	27.8
Croatia	6.6	10.1	17.3	39.1	62.8
FYROM	1.1	1.5	2.9	4.8	17.4
Moldova	1.3	1.8	3.0	8.6	14.1
Norway	6.9	13.9	18.7	71.6	91.3
Russia (EMEP)	168.2	185.4	436.3	1234.8	2372.6
Serbia-M.	4.6	8.8	18.5	65.1	114.6
Switzerland	9.0	18.9	28.2	52.0	86.0
Ukraine	31.7	47.9	284.1	703.2	821.9
EU-27	365.5	585.5	1398.4	3092.7	6764.5
Non-EU	244.7	319.1	863.7	2287.7	3807.1
TOTAL	610.1	904.7	2262.1	5380.4	10571.6

Table 5.3: Additional air pollution control costs (on top of the baseline) as percentage of GDP in 2020

	LOW	Low*	Mid	High*	HIGH
Austria	0.00%	0.00%	0.01%	0.01%	0.03%
Belgium	0.00%	0.00%	0.01%	0.02%	0.05%
Bulgaria	0.01%	0.01%	0.02%	0.11%	0.15%
Cyprus	0.00%	0.01%	0.01%	0.02%	0.03%
Czech Rep.	0.01%	0.01%	0.01%	0.04%	0.12%
Denmark	0.00%	0.00%	0.01%	0.02%	0.04%
Estonia	0.03%	0.04%	0.04%	0.07%	0.27%
Finland	0.00%	0.01%	0.02%	0.03%	0.03%
France	0.00%	0.00%	0.01%	0.02%	0.05%
Germany	0.00%	0.00%	0.01%	0.01%	0.04%
Greece	0.00%	0.00%	0.00%	0.01%	0.05%
Hungary	0.00%	0.00%	0.01%	0.04%	0.07%
Ireland	0.00%	0.00%	0.01%	0.02%	0.07%
Italy	0.00%	0.01%	0.01%	0.02%	0.05%
Latvia	0.01%	0.01%	0.02%	0.03%	0.10%
Lithuania	0.01%	0.02%	0.09%	0.18%	0.22%
Luxembourg	0.00%	0.00%	0.00%	0.00%	0.03%
Malta	0.00%	0.00%	0.00%	0.01%	0.04%
Netherlands	0.00%	0.00%	0.01%	0.03%	0.06%
Poland	0.01%	0.01%	0.03%	0.06%	0.08%
Portugal	0.00%	0.00%	0.01%	0.03%	0.06%
Romania	0.01%	0.01%	0.03%	0.07%	0.14%
Slovakia	0.01%	0.01%	0.02%	0.05%	0.08%
Slovenia	0.00%	0.00%	0.01%	0.04%	0.07%
Spain	0.00%	0.01%	0.01%	0.02%	0.04%
Sweden	0.00%	0.00%	0.00%	0.01%	0.01%
UK	0.00%	0.00%	0.01%	0.01%	0.03%
Albania	0.01%	0.02%	0.03%	0.06%	0.11%
Belarus	0.03%	0.06%	0.09%	0.18%	0.44%
Bosnia-H.	0.01%	0.02%	0.09%	0.17%	0.18%
Croatia	0.01%	0.02%	0.04%	0.08%	0.13%
FYROM	0.01%	0.02%	0.04%	0.06%	0.21%
Moldova	0.03%	0.04%	0.07%	0.20%	0.34%
Norway	0.00%	0.00%	0.01%	0.02%	0.03%
Russia (EMEP)	0.02%	0.02%	0.05%	0.15%	0.28%
Serbia-M.	0.01%	0.02%	0.05%	0.16%	0.29%
Switzerland	0.00%	0.00%	0.01%	0.01%	0.02%
Ukraine	0.03%	0.04%	0.24%	0.60%	0.70%
EU-27	0.00%	0.00%	0.01%	0.02%	0.05%
Non-EU	0.01%	0.02%	0.05%	0.12%	0.21%
TOTAL	0.00%	0.01%	0.01%	0.03%	0.07%

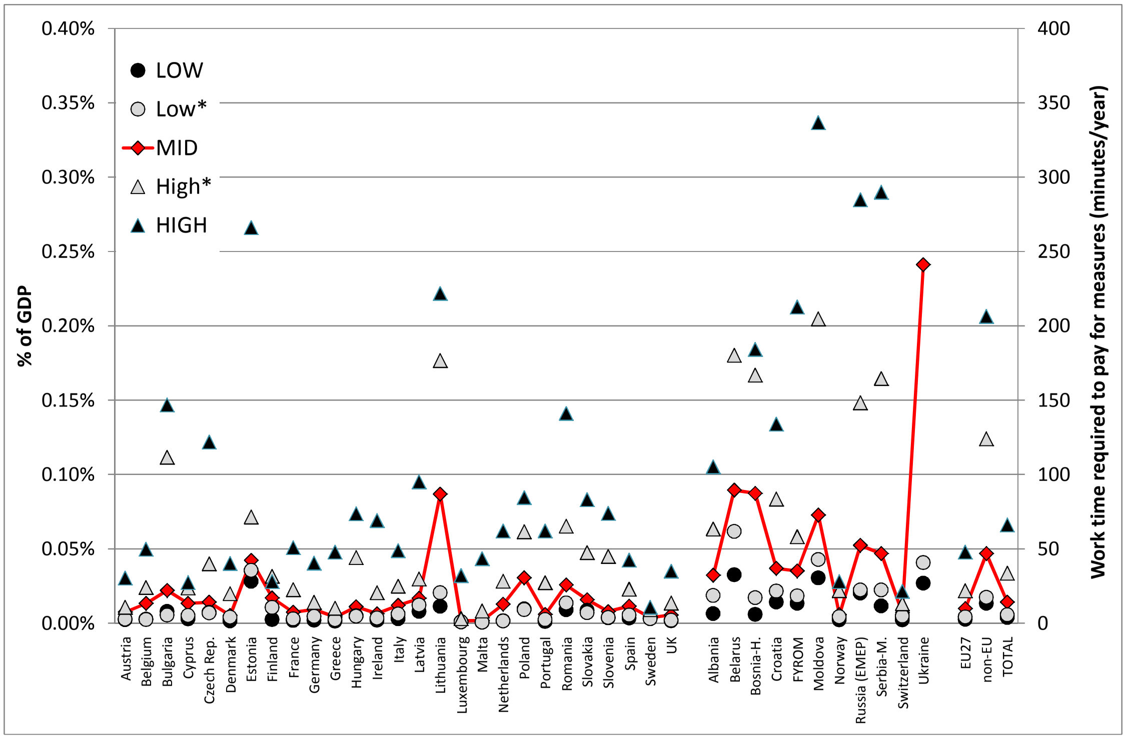


Figure 5.4: Additional air pollution control costs (on top of baseline), as a percentage of GDP in 2020, and expressed as work time required to pay for the measures (minutes per year per person)

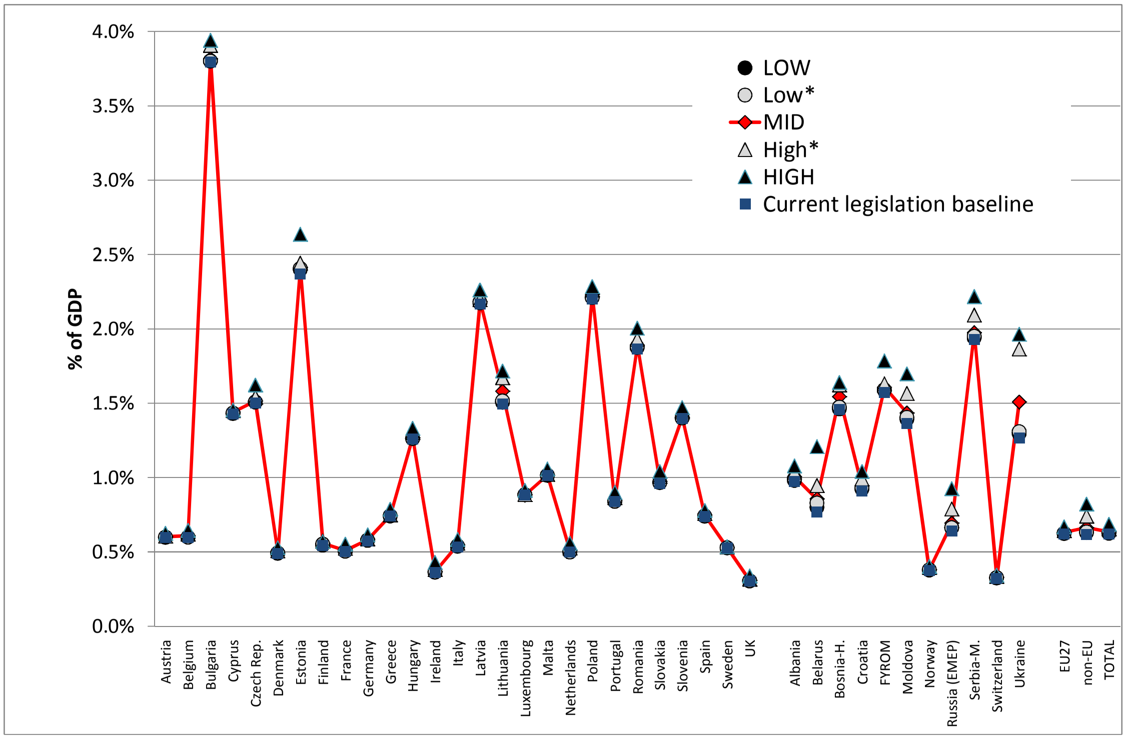


Figure 5.5: Total air pollution control costs (including current legislation) as percentage of GDP in 2020

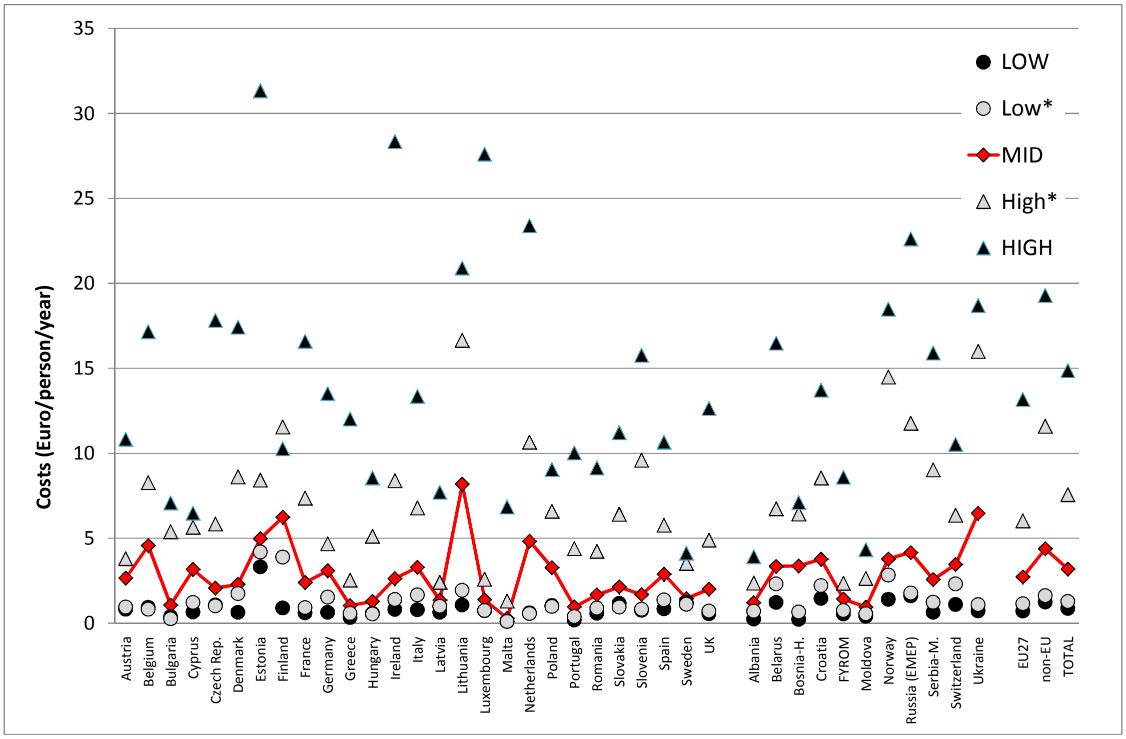


Figure 5.6: Air pollution control costs (on top of the costs for the baseline), on a per-capita basis (€/cap/yr)

5.3 Emissions

While the ambition levels were established with reference to the four environmental effects, the corresponding changes in emissions are a result of the cost-optimization of the GAINS model. For the EU-27, cuts in SO_2 emissions beyond the baseline projection range between 0 and 7% (in relation to year 2000 emissions), depending on the ambition level. NO_x emissions are between 2 and 9% lower, PM2.5 emissions 7-13%, NH_3 emissions 9-24%, and VOC emissions 4-11%. (Table 5.4).

Larger relative changes evolve for the non-EU countries, where SO_2 emissions would be cut by 7-46% below the baseline level, NO_x by 7-23%, PM2.5 by 22-66%, NH_3 by 9-33%, and VOC by 8-16% (Figure 5.7).

Results for individual countries are provided in Table 5.5 to Table 5.9. It is noteworthy that in some cases emission reduction requirements do not increase monotonously with tightening environmental ambition, particularly between the LOW and Low*, and the High* and HIGH scenarios. This is a consequence of changes in the ambition levels for ozone, which influence the requirement for NO_x controls. As a knock-on effect of tightened NO_x reductions, NH_3 measures can be relaxed if total nitrogen deposition is to be kept constant (and vice versa).

Table 5.4: Change in emission levels for the emission control scenarios compared to the year 2000

		Ambition level					
	Baseline	LOW	Low*	Mid	High*	HIGH	MTFR
EU-27							
SO_2	-74%	-75%	-74%	-76%	-80%	-79%	-83%
NO_x	-55%	-57%	-58%	-59%	-60%	-62%	-64%
PM2.5	-39%	-46%	-45%	-48%	-52%	-52%	-67%
NH_3	-9%	-18%	-27%	-30%	-35%	-32%	-41%
VOC	-46%	-49%	-49%	-50%	-51%	-55%	-63%
Non-EU countries							
SO_2	-27%	-34%	-34%	-51%	-75%	-73%	-84%
NO_x	-29%	-34%	-35%	-39%	-44%	-52%	-56%
PM2.5	0%	-30%	-22%	-53%	-66%	-64%	-75%
NH_3	4%	-5%	-19%	-18%	-29%	-24%	-38%
VOC	-29%	-38%	-37%	-40%	-40%	-45%	-54%

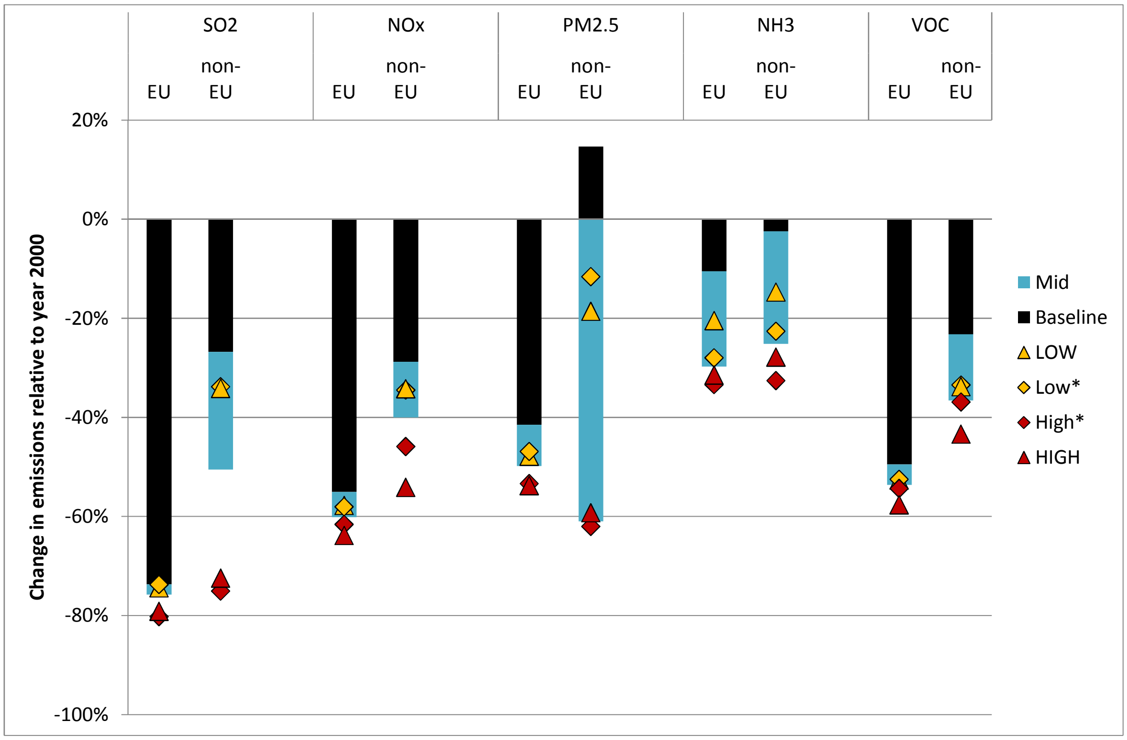


Figure 5.7: Change in emissions relative to the year 2000 for the different ambition levels

Table 5.5: SO_2 emissions by country (in kilotons)

			Ambition level					
	2000	2020 BL	LOW	Low*	Mid	High*	HIGH	MTFR
Austria	32	19	19	19	19	18	18	16
Belgium	176	81	76	81	70	67	66	62
Bulgaria	888	132	132	132	132	93	123	80
Cyprus	47	5	5	5	5	5	5	2
Czech Rep.	294	106	106	106	100	95	98	93
Denmark	29	11	11	11	11	10	10	10
Estonia	85	16	14	16	14	14	14	12
Finland	77	42	41	41	40	41	40	37
France	633	199	195	198	193	148	149	132
Germany	619	329	324	329	324	318	319	300
Greece	543	114	113	113	113	113	113	45
Hungary	452	64	59	64	59	32	34	30
Ireland	144	28	27	27	26	22	22	20
Italy	774	234	234	234	234	160	171	117
Latvia	11	4	3	4	3	3	3	3
Lithuania	52	15	13	15	11	9	9	7
Luxembourg	2	1	1	1	1	1	1	1
Malta	24	3	3	3	3	1	1	1
Netherlands	72	32	32	32	32	31	31	30
Poland	1490	468	431	466	364	311	338	299
Portugal	285	64	63	63	63	45	48	33
Romania	776	145	144	144	144	86	95	76
Slovakia	121	42	41	41	41	27	28	22
Slovenia	100	17	17	17	17	14	15	13
Spain	1433	311	275	310	259	206	203	168
Sweden	45	29	28	29	29	29	29	28
UK	1193	227	212	227	203	166	168	149
Albania	11	10	10	10	10	7	10	5
Belarus	172	89	82	86	74	48	50	34
Bosnia-H.	193	44	44	44	43	27	31	22
Croatia	75	20	18	20	18	12	12	8
FYROM	109	15	15	15	15	14	15	8
Moldova	9	5	5	5	5	4	4	2
Norway	26	24	24	24	24	23	23	20
Russia (EMEP)	2022	1832	1521	1523	1307	672	757	412
Serbia-M.	452	92	92	92	89	64	69	55
Switzerland	17	13	13	13	13	11	11	10
Ukraine	1349	1099	1085	1097	589	225	232	143
EU27	10398	2736	2619	2727	2508	2068	2153	1783
Non-EU	4436	3245	2910	2930	2188	1107	1213	719
Total	14834	5980	5529	5656	4696	3175	3366	2502

Table 5.6: NO_x emissions by country (kilotons)

			Ambition level					
	2000	2020 BL	LOW	Low*	Mid	High*	HIGH	MTFR
Austria	195	94	91	91	89	89	85	81
Belgium	337	170	165	163	158	153	152	142
Bulgaria	158	68	65	66	63	59	54	53
Cyprus	22	13	12	12	11	10	9	8
Czech Rep.	308	151	140	141	137	132	117	113
Denmark	217	85	81	79	78	76	74	74
Estonia	33	21	16	15	15	15	13	13
Finland	221	125	123	119	118	114	114	110
France	1548	572	540	541	520	501	476	472
Germany	1707	708	695	695	662	646	624	609
Greece	330	242	224	224	218	212	200	199
Hungary	177	86	80	80	78	74	71	64
Ireland	141	69	62	62	60	58	53	53
Italy	1433	679	644	644	617	603	561	548
Latvia	37	22	21	21	21	21	20	19
Lithuania	54	29	26	26	26	26	24	24
Luxembourg	44	17	17	17	17	17	16	16
Malta	9	3	3	3	3	3	3	3
Netherlands	416	170	170	170	169	168	168	150
Poland	823	429	411	410	387	378	361	353
Portugal	269	106	102	101	97	91	88	87
Romania	265	156	138	138	131	126	112	104
Slovakia	102	57	50	53	49	46	42	39
Slovenia	48	27	26	26	26	26	25	25
Spain	1416	695	644	642	610	606	559	553
Sweden	238	97	91	91	90	88	87	87
UK	1859	663	635	627	596	571	548	499
Albania	17	18	17	17	16	16	15	15
Belarus	181	150	129	129	123	121	100	96
Bosnia-H.	38	22	21	21	15	15	14	14
Croatia	67	46	38	38	36	33	31	30
FYROM	33	19	17	17	16	16	14	14
Moldova	21	19	18	18	17	17	15	14
Norway	207	136	125	125	123	114	111	110
Russia (EMEP)	3009	2144	2025	2009	1858	1698	1431	1294
Serbia-M.	137	91	85	85	80	70	63	63
Switzerland	94	44	43	43	42	41	40	40
Ukraine	912	646	585	586	540	484	439	393
EU27	12407	5553	5273	5256	5046	4909	4656	4495
Non-EU	4717	3337	3103	3087	2866	2625	2275	2083
Total	17123	8891	8376	8343	7912	7534	6931	6578

Table 5.7: PM2.5 emissions by country (kilotons)

			Ambition level					
	2000	2020 BL	LOW	Low*	Mid	High*	HIGH	MTFR
Austria	22	13	12	12	12	12	11	8
Belgium	32	20	19	19	19	16	16	15
Bulgaria	47	33	26	29	25	18	18	9
Cyprus	3	1	1	1	1	1	1	1
Czech Rep.	34	25	23	24	23	22	21	13
Denmark	25	19	19	19	18	17	16	8
Estonia	20	7	6	6	6	6	5	3
Finland	32	21	21	21	21	19	18	10
France	365	207	195	196	191	176	176	107
Germany	140	83	79	81	79	77	76	63
Greece	55	33	26	26	25	25	24	16
Hungary	45	22	19	19	19	18	17	10
Ireland	14	8	8	8	8	7	8	6
Italy	160	81	77	77	75	70	71	61
Latvia	17	15	13	13	13	13	13	3
Lithuania	14	10	7	7	7	7	6	3
Luxembourg	3	2	2	2	2	2	2	2
Malta	1	0	0	0	0	0	0	0
Netherlands	27	16	15	16	15	15	15	13
Poland	132	96	90	90	89	86	85	69
Portugal	95	62	48	50	34	28	26	15
Romania	141	106	74	83	65	58	59	20
Slovakia	24	10	8	9	8	8	8	6
Slovenia	9	6	5	5	5	4	3	3
Spain	142	90	76	76	76	71	71	54
Sweden	32	19	19	19	19	18	18	15
UK	115	53	52	52	51	46	47	42
Albania	8	8	6	6	6	6	6	2
Belarus	46	52	32	34	31	29	29	16
Bosnia-H.	15	13	11	12	11	10	10	5
Croatia	19	14	10	11	10	7	7	5
FYROM	14	7	5	6	5	4	4	2
Moldova	10	9	4	6	4	4	4	2
Norway	61	31	31	31	30	29	29	15
Russia (EMEP)	717	778	498	566	331	234	236	194
Serbia-M.	70	48	38	39	37	31	32	14
Switzerland	11	7	6	6	6	6	5	4
Ukraine	357	368	287	314	155	92	122	70
EU27	1743	1059	941	958	907	842	832	572
Non-EU	1328	1334	928	1030	626	451	483	330
Total	3071	2393	1868	1989	1532	1293	1315	903

Table 5.8: NH_3 emissions by country (kilotons)

			Ambition level					
	2000	2020 BL	LOW	Low*	Mid	High*	HIGH	MTFR
Austria	60	55	50	49	46	43	44	35
Belgium	84	75	71	71	69	68	69	67
Bulgaria	69	60	58	57	55	53	54	50
Cyprus	6	6	5	4	4	4	4	4
Czech Rep.	86	68	61	60	59	51	52	49
Denmark	91	52	51	49	49	47	48	46
Estonia	11	11	7	6	6	6	7	6
Finland	35	30	26	25	24	24	26	24
France	703	621	558	482	461	398	424	358
Germany	626	601	535	439	414	407	412	365
Greece	54	52	48	42	41	39	43	37
Hungary	77	70	52	51	48	43	43	40
Ireland	132	98	91	86	85	81	82	76
Italy	420	384	346	298	286	252	269	224
Latvia	13	12	11	9	9	9	9	9
Lithuania	37	45	41	36	33	29	30	24
Luxembourg	6	5	5	5	5	4	4	4
Malta	2	2	2	2	2	2	2	2
Netherlands	150	125	120	119	118	114	114	112
Poland	315	355	309	282	280	271	279	247
Portugal	71	69	62	56	56	48	48	42
Romania	167	150	139	112	105	104	104	90
Slovakia	30	24	20	16	15	15	15	13
Slovenia	20	16	15	15	13	12	13	11
Spain	372	364	328	281	268	244	254	208
Sweden	54	45	38	37	37	36	38	34
UK	328	270	251	234	231	224	228	214
Albania	18	24	22	19	19	17	18	15
Belarus	117	150	139	113	113	107	113	100
Bosnia-H.	17	19	18	14	15	14	14	11
Croatia	29	33	30	23	21	19	19	16
FYROM	10	9	8	7	7	7	7	6
Moldova	16	17	15	13	13	11	12	10
Norway	24	22	19	16	16	14	15	13
Russia (EMEP)	552	555	513	449	465	381	410	314
Serbia-M.	65	56	50	41	39	35	36	30
Switzerland	51	65	60	57	55	53	52	48
Ukraine	292	285	262	217	209	192	208	172
EU27	4018	3668	3301	2921	2819	2628	2718	2389
Non-EU	1191	1236	1136	970	972	851	906	735
Total	5210	4904	4437	3891	3791	3479	3624	3125

Table 5.9: VOC emissions by country (kilotons)

			Ambition level					
	2000	2020 BL	LOW	Low*	Mid	High*	HIGH	MTFR
Austria	184	111	107	107	102	101	93	73
Belgium	215	129	123	124	118	117	111	108
Bulgaria	130	79	71	71	70	70	68	40
Cyprus	11	5	5	5	5	5	5	4
Czech Rep.	218	148	137	137	137	134	110	82
Denmark	141	74	72	72	71	70	59	45
Estonia	44	21	20	20	20	20	19	14
Finland	163	90	88	88	88	88	77	56
France	1706	720	705	705	693	672	629	480
Germany	1490	870	774	774	747	738	657	583
Greece	296	147	136	136	135	134	116	88
Hungary	168	104	94	94	94	92	85	59
Ireland	78	49	44	44	43	41	33	30
Italy	1580	777	757	758	748	737	710	622
Latvia	71	49	46	46	44	44	41	18
Lithuania	81	53	49	49	49	49	45	29
Luxembourg	20	7	6	6	6	6	6	6
Malta	5	3	3	3	3	2	2	2
Netherlands	249	156	151	152	142	135	126	125
Poland	616	343	322	322	320	319	295	223
Portugal	276	176	160	160	157	154	139	115
Romania	437	301	268	268	261	259	227	129
Slovakia	73	56	55	55	54	54	51	38
Slovenia	57	31	29	29	29	23	20	17
Spain	1042	646	619	619	600	600	589	468
Sweden	256	120	115	115	114	114	110	95
UK	1330	673	607	607	588	571	525	494
Albania	29	27	25	25	25	25	22	12
Belarus	210	178	160	162	160	159	141	108
Bosnia-H.	49	30	28	28	27	27	24	13
Croatia	101	70	60	60	59	58	51	44
FYROM	28	14	13	13	13	13	12	8
Moldova	25	26	21	21	21	21	20	14
Norway	381	86	78	81	77	77	74	65
Russia (EMEP)	3140	2307	2039	2054	1941	1937	1793	1562
Serbia-M.	132	113	102	102	102	102	92	50
Switzerland	146	81	70	70	70	70	64	52
Ukraine	636	514	439	444	437	437	392	313
EU27	10938	5939	5566	5569	5437	5351	4949	4045
Non-EU	4876	3446	3035	3061	2930	2925	2686	2241
Total	15814	9385	8601	8629	8367	8276	7635	6286

5.4 Cost-effective emission control measures

For each country, the GAINS model considers costs and impacts of about 2000 individual emission reduction measures, and determines cost-effective portfolios of emission control measures that achieve the prescribed environmental quality targets at least cost. In this cost-minimization approach the application rates of all 2000 measures serve as decision variables, and thus the cost-optimal solution specifies the implementation rates for each measure, between the current legislation baseline and the maximum feasible reduction cases.

Figure 5.8 to Figure 5.13 summarize the specific emission control measures that are included in the cost-optimal solutions for the Low*, mid and High* cases, respectively. For readability, these graphs present group measures by sector. Detailed measures that are included for each sector in each country are available on the Internet via http://gains.iiasa.ac.at/Goth_data, or directly at http://gains.iiasa.ac.at/gains/download/Gothenburg/CIAM1-2011-measures-MID_case.xlsx.

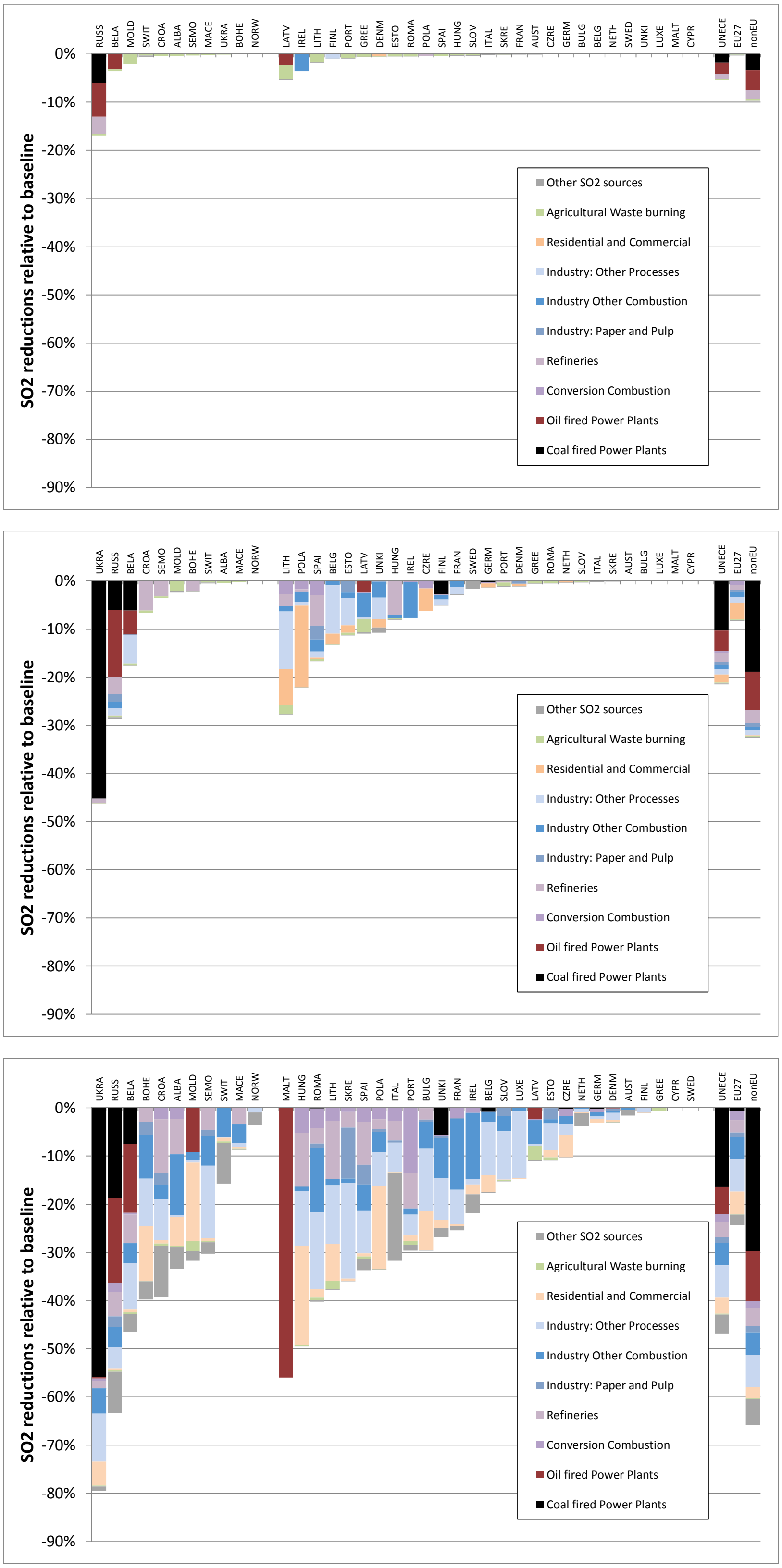


Figure 5.8: Further reductions of SO_2 emissions (beyond the baseline) for the Low* (upper panel), mid (central panel) and High* (lower panel) cases, by sector

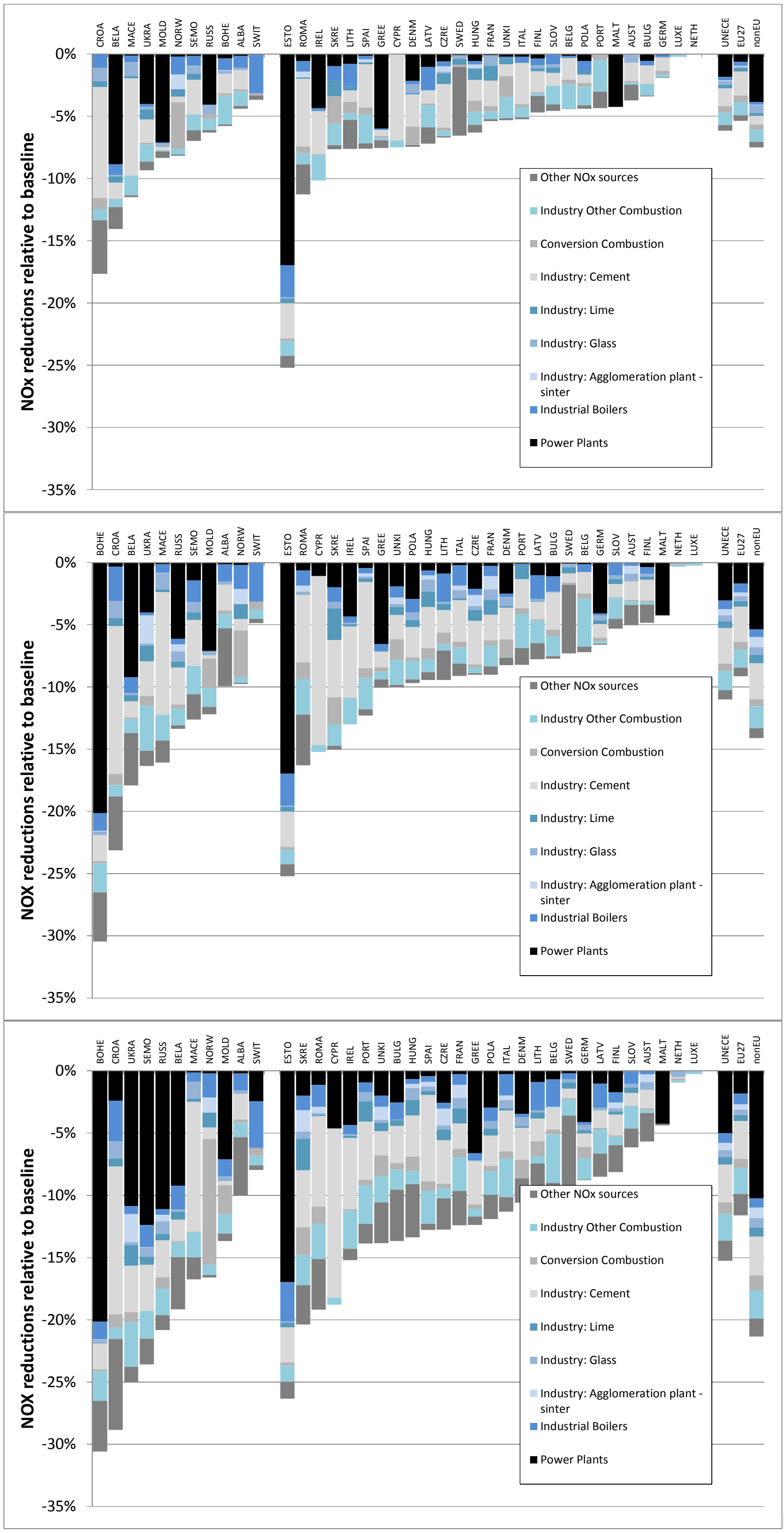


Figure 5.9: Further reductions of NO$_x$ emissions (beyond the baseline) for the Low* (upper panel), mid (central panel) and High* (lower panel) cases, by sector

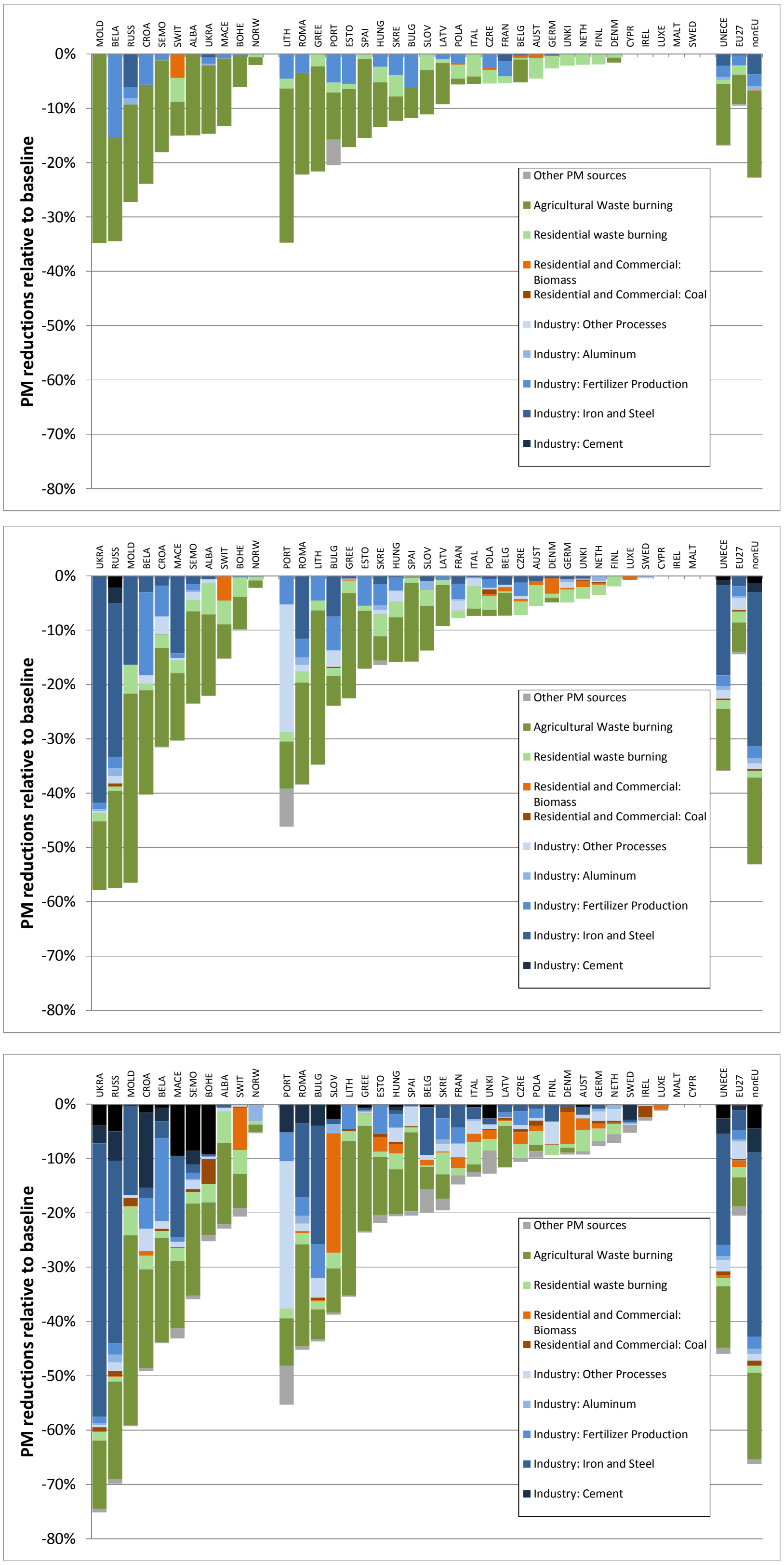


Figure 5.10: Further reductions of PM2.5 emissions (beyond the baseline) for the Low* (upper panel), mid (central panel) and High* (lower panel) cases, by sector

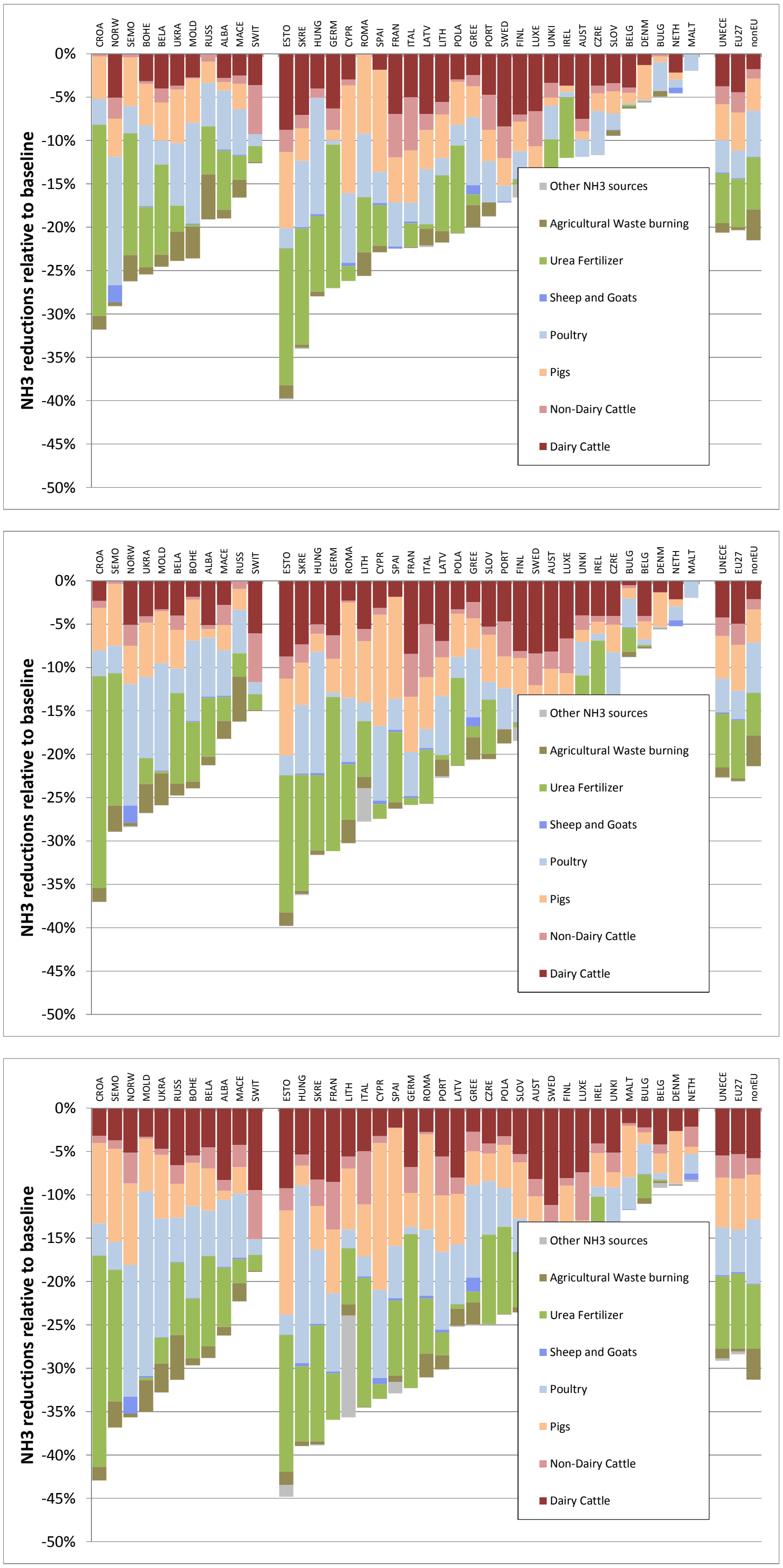


Figure 5.11: Further reductions of NH_3 emissions (beyond the baseline) for the Low* (upper panel), mid (central panel) and High* (lower panel) cases, by sector

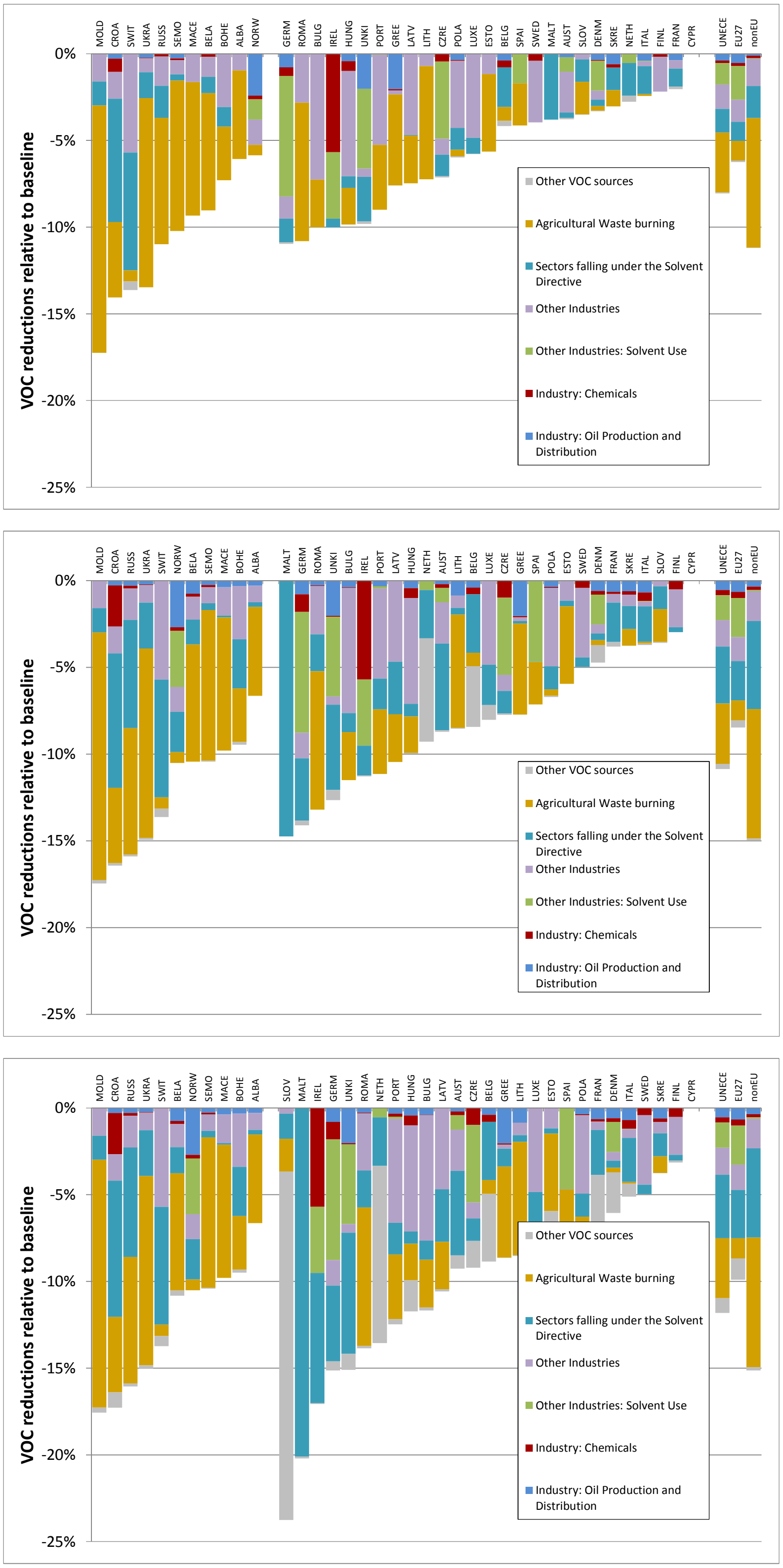


Figure 5.12: Further reductions of VOC emissions (beyond the baseline) for the Low* (upper panel), mid (central panel) and High* (lower panel) cases, by sector

5.5 Impact indicators

As mentioned above, impact indicators have been specified as constraints to the optimization, and therefore are fully achieved by the optimized scenarios. However, in some cases targets for individual countries will be over-achieved (if this is required to fulfil a more stringent target in a neighbouring country) and, as explained before, the health targets do not specify in which countries environmental improvements need to be made, as long as the overall progress in the entire model domain is achieved. Thus, impact indicators for the different effects, and their changes for the different scenarios, vary from country to country. Table 5.10 to **Error! Reference source not found.** provide results for all countries.

Table 5.10: Loss of average life expectancy due to PM2.5 (months)

			Ambition level				
	2000	2020 BL	LOW	Low*	Mid	High*	HIGH
Austria	7.9	3.7	3.4	3.4	3.2	2.9	2.8
Belgium	13.7	6.6	6.2	6.1	5.9	5.5	5.4
Bulgaria	8.3	3.9	3.6	3.6	3.2	2.6	2.6
Cyprus	4.5	3.6	3.6	3.6	3.5	3.4	3.4
Czech Rep.	9.6	4.6	4.3	4.2	3.9	3.6	3.5
Denmark	7.1	3.6	3.4	3.3	3.1	2.9	2.9
Estonia	5.6	3.1	2.7	2.7	2.4	2.1	2.0
Finland	3.2	1.9	1.7	1.7	1.6	1.3	1.3
France	8.2	3.8	3.6	3.5	3.4	3.1	3.0
Germany	10.2	4.9	4.6	4.4	4.2	3.9	3.9
Greece	8.1	4.0	3.8	3.8	3.6	3.3	3.3
Hungary	11.6	5.2	4.7	4.6	4.2	3.6	3.6
Ireland	4.3	1.9	1.8	1.8	1.7	1.6	1.6
Italy	8.2	4.0	3.8	3.7	3.6	3.2	3.2
Latvia	6.0	3.9	3.5	3.5	3.2	2.9	2.8
Lithuania	6.2	3.7	3.2	3.2	2.8	2.4	2.3
Luxembourg	10.1	4.7	4.4	4.3	4.1	3.8	3.8
Malta	5.9	4.3	4.2	4.2	4.1	3.9	3.9
Netherlands	13.0	6.2	5.9	5.8	5.6	5.2	5.2
Poland	10.2	5.1	4.7	4.7	4.2	3.8	3.8
Portugal	6.7	3.6	3.1	3.2	2.7	2.4	2.3
Romania	9.6	4.8	4.3	4.3	3.7	3.0	3.0
Slovakia	10.0	4.5	4.1	4.1	3.7	3.2	3.2
Slovenia	8.8	4.1	3.8	3.7	3.5	3.0	3.0
Spain	4.9	2.4	2.3	2.3	2.2	2.0	2.0
Sweden	3.8	2.0	1.9	1.8	1.7	1.6	1.6
UK	7.9	3.3	3.1	3.1	2.9	2.7	2.7
Albania	5.3	2.7	2.5	2.5	2.3	2.0	2.1
Belarus	7.0	4.5	3.9	3.8	3.3	2.7	2.6
Bosnia-H.	6.0	2.8	2.6	2.5	2.3	2.0	2.0
Croatia	8.5	4.2	3.8	3.7	3.4	2.9	2.9
FYROM	6.2	2.7	2.5	2.5	2.3	1.9	1.9
R Moldova	8.1	4.8	4.0	4.1	3.2	2.5	2.5
Norway	2.5	1.3	1.2	1.2	1.1	1.1	1.1
Russia	7.6	6.7	5.2	5.4	4.1	2.9	3.0
Serbia	8.1	3.6	3.2	3.2	2.9	2.4	2.4
Switzerland	6.5	3.0	2.8	2.7	2.6	2.4	2.3
Ukraine	9.2	6.6	5.7	5.8	4.1	2.9	3.0
EU-27	8.6	4.1	3.8	3.8	3.5	3.2	3.2
Non-EU	7.7	6.0	4.9	5.0	3.8	2.8	2.8
Total	8.3	4.7	4.1	4.1	3.6	3.1	3.1

Table 5.11: Years of life lost (million YOLLs). Note that this calculation includes for the EU countries, Norway and Switzerland the urban increments, but not for the non-EU countries

			Ambition level				
	2000	2020 BL	LOW	Low*	Mid	High*	HIGH
Austria	3.40	1.77	1.65	1.63	1.53	1.40	1.37
Belgium	7.49	3.94	3.72	3.69	3.52	3.28	3.24
Bulgaria	3.49	1.61	1.48	1.49	1.32	1.08	1.09
Cyprus	0.14	0.17	0.17	0.17	0.17	0.16	0.16
Czech Rep.	4.87	2.70	2.50	2.47	2.29	2.08	2.05
Denmark	2.01	1.08	1.01	0.99	0.94	0.88	0.87
Estonia	0.39	0.22	0.19	0.19	0.17	0.15	0.14
Finland	0.85	0.58	0.52	0.52	0.47	0.40	0.40
France	24.90	13.12	12.31	12.05	11.53	10.52	10.46
Germany	47.15	23.91	22.43	21.80	20.61	19.36	19.14
Greece	4.62	2.73	2.57	2.58	2.43	2.22	2.23
Hungary	5.88	2.91	2.60	2.59	2.35	2.03	2.00
Ireland	0.71	0.48	0.45	0.44	0.43	0.40	0.40
Italy	26.46	13.94	13.22	13.03	12.51	11.30	11.25
Latvia	0.73	0.47	0.43	0.42	0.39	0.34	0.34
Lithuania	1.08	0.65	0.57	0.56	0.50	0.43	0.42
Luxembourg	0.23	0.13	0.12	0.12	0.11	0.11	0.11
Malta	0.11	0.11	0.11	0.11	0.10	0.10	0.10
Netherlands	10.89	5.75	5.47	5.40	5.17	4.88	4.84
Poland	18.09	10.91	9.99	9.95	8.96	8.06	8.03
Portugal	3.56	2.21	1.94	1.98	1.70	1.49	1.45
Romania	10.10	5.65	4.96	5.02	4.29	3.52	3.49
Slovakia	2.43	1.37	1.24	1.23	1.10	0.96	0.96
Slovenia	0.90	0.49	0.45	0.45	0.42	0.36	0.36
Spain	10.30	6.59	6.15	6.19	5.90	5.49	5.46
Sweden	1.79	1.05	0.97	0.96	0.90	0.82	0.83
UK	24.09	11.45	10.80	10.58	10.11	9.37	9.35
Albania	0.73	0.37	0.34	0.34	0.32	0.28	0.28
Belarus	3.58	2.33	1.99	1.98	1.68	1.37	1.36
Bosnia-H.	1.36	0.64	0.58	0.57	0.53	0.45	0.46
Croatia	2.11	1.03	0.93	0.92	0.85	0.72	0.72
FYROM	0.64	0.28	0.25	0.25	0.23	0.20	0.20
R Moldova	1.59	0.94	0.80	0.81	0.63	0.48	0.48
Norway	0.58	0.34	0.32	0.31	0.30	0.28	0.28
Russia	54.85	48.72	37.97	39.29	29.70	21.08	21.41
Serbia	4.34	1.92	1.71	1.70	1.54	1.27	1.28
Switzerland	2.66	1.23	1.14	1.12	1.07	0.98	0.96
Ukraine	22.49	16.09	13.97	14.23	9.93	7.02	7.34
EU-27	216.65	115.99	108.02	106.59	99.89	91.17	90.52
Non-EU	94.94	73.89	60.01	61.53	46.78	34.14	34.77
Total	311.59	189.88	168.03	168.13	146.66	125.31	125.28

Table 5.12: Premature deaths attributable to ozone (cases/yr)

			Ambition level				
	2000	2020 BL	LOW	Low*	Mid	High*	HIGH
Austria	472	280	269	269	263	259	249
Belgium	526	336	325	325	318	314	303
Bulgaria	550	365	347	347	337	328	312
Cyprus	28	26	26	26	26	26	26
Czech Rep.	670	367	350	350	340	332	313
Denmark	222	150	146	145	143	141	137
Estonia	25	18	18	18	17	17	16
Finland	61	46	45	45	44	44	42
France	2975	1846	1794	1794	1763	1740	1690
Germany	4706	2959	2864	2863	2804	2768	2672
Greece	657	501	484	484	476	470	454
Hungary	853	510	483	484	469	456	434
Ireland	99	79	78	78	77	77	76
Italy	5084	3331	3233	3233	3175	3135	3037
Latvia	60	42	40	40	39	39	37
Lithuania	91	62	59	59	58	56	54
Luxembourg	42	22	22	22	21	21	20
Malta	29	19	19	19	18	18	18
Netherlands	520	333	320	320	313	308	296
Poland	1678	1008	963	963	933	912	869
Portugal	600	447	436	435	430	427	417
Romania	1208	791	743	745	720	700	659
Slovakia	296	163	153	154	148	143	134
Slovenia	131	73	69	69	67	66	63
Spain	2117	1538	1500	1499	1476	1468	1435
Sweden	223	159	155	155	153	151	147
UK	2180	1664	1622	1622	1605	1592	1556
Albania	129	91	87	87	85	84	80
Belarus	322	221	209	208	202	197	184
Bosnia-H.	253	148	140	140	134	130	123
Croatia	356	218	206	207	200	196	187
FYROM	98	75	72	72	71	70	68
R Moldova	182	127	120	120	116	113	106
Norway	99	81	80	80	79	78	77
Russia	4702	3848	3698	3698	3608	3548	3399
Serbia	499	346	332	332	324	316	303
Switzerland	400	245	237	237	233	230	223
Ukraine	2543	1882	1789	1790	1741	1700	1618
EU-27	26103	17135	16563	16563	16233	16008	15466
Non-EU	9583	7282	6970	6971	6793	6662	6368
Total	35686	24417	23533	23534	23026	22670	21834

Table 5.13: Ecosystems area with nitrogen deposition exceeding critical loads [1000 km^2]

	Total			Ambition level				
	area	2000	2020 BL	LOW	Low*	Mid	High*	HIGH
Austria	40.3	40.2	27.7	21.4	15.5	11.8	8.3	8.4
Belgium	6.3	6.2	5.2	4.9	4.5	4.1	3.6	3.6
Bulgaria	48.3	45.3	28.6	19.4	18.2	15.9	13.8	12.9
Cyprus	2.5	1.6	1.6	1.6	1.4	1.4	1.4	1.4
Czech Rep.	27.6	27.6	27.6	27.6	27.6	27.5	27.5	27.5
Denmark	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6
Estonia	24.7	16.9	8.0	5.6	4.8	4.4	3.7	3.7
Finland	240.4	113.6	63.4	53.2	47.0	43.7	36.7	35.8
France	180.1	176.3	154.9	140.7	128.8	120.7	100.9	104.4
Germany	102.9	87.9	65.9	59.1	50.2	46.3	43.6	43.6
Greece	52.9	52.6	51.8	50.9	49.7	48.7	47.8	47.4
Hungary	20.8	20.8	20.5	18.5	17.1	15.6	14.0	13.9
Ireland	2.4	2.2	1.9	1.8	1.8	1.8	1.8	1.8
Italy	124.8	87.9	61.5	53.9	43.0	39.4	34.2	34.9
Latvia	35.8	35.6	32.9	30.9	28.9	28.2	26.3	25.8
Lithuania	19.0	19.0	19.0	18.9	18.7	18.7	18.5	18.5
Luxembourg	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Malta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Netherlands	4.4	4.2	3.8	3.7	3.7	3.7	3.7	3.7
Poland	90.3	90.2	88.9	86.6	84.3	83.2	81.7	81.8
Portugal	31.0	29.9	19.1	14.6	11.6	10.8	7.2	6.9
Romania	98.0	20.1	1.6	0.5	0.2	0.1	0.1	0.1
Slovakia	20.5	20.5	20.5	20.2	20.0	19.9	19.9	19.9
Slovenia	11.0	10.8	6.3	4.3	2.2	0.7	0.5	0.5
Spain	187.1	176.9	165.5	159.9	152.0	147.0	135.7	135.6
Sweden	150.7	83.1	55.3	50.4	47.8	46.4	44.1	44.1
UK	92.0	23.8	14.3	12.8	12.0	11.7	10.8	10.8
Albania	17.0	16.9	16.7	16.4	15.9	15.6	14.8	14.7
Belarus	64.0	63.9	62.0	59.1	55.1	54.4	52.5	52.7
Bosnia-H.	31.9	28.2	23.0	21.5	19.4	18.4	16.2	15.9
Croatia	31.7	31.7	31.2	31.0	30.9	30.6	30.2	30.1
FYROM	13.9	13.9	13.9	13.8	13.0	12.0	11.3	11.2
R Moldova	3.5	3.4	3.2	3.2	2.7	2.3	2.1	2.1
Norway	135.3	27.7	12.3	9.6	8.1	7.1	6.4	6.4
Russia	1821.6	483.9	181.1	144.5	108.2	95.8	71.3	65.7
Serbia	41.1	39.7	32.9	28.4	23.2	20.7	17.5	17.2
Switzerland	9.6	9.6	9.2	8.8	8.2	8.0	7.3	7.4
Ukraine	72.2	72.2	72.2	72.2	72.0	71.8	71.6	71.1
EU-27	1618.4	1197.9	950.3	866.1	795.4	756.4	690.3	691.5
Non-EU	2241.7	790.9	457.8	408.5	356.7	336.8	301.3	294.5
Total	3860.1	1988.9	1408.1	1274.6	1152.1	1093.2	991.6	986.0

Table 5.14: Average accumulated excess deposition of nitrogen loads [eq/ha/yr]

			Ambition level				
	2000	2020 BL	LOW	Low*	Mid	High*	HIGH
Austria	418.4	121.0	72.8	43.9	31.4	21.5	21.6
Belgium	959.6	396.3	323.4	278.3	254.7	225.4	226.2
Bulgaria	223.0	67.4	50.2	40.0	32.0	24.9	23.0
Cyprus	114.6	121.1	112.8	104.3	101.7	97.5	98.1
Czech Rep.	1055.2	652.5	568.4	516.8	488.2	442.7	438.8
Denmark	1125.9	630.9	592.0	553.1	537.6	514.3	514.3
Estonia	86.2	26.4	16.1	12.8	11.3	9.2	9.0
Finland	55.2	18.5	13.4	11.2	10.0	8.3	8.3
France	584.1	272.4	216.1	163.7	144.4	108.4	115.2
Germany	658.0	299.4	231.4	160.5	138.3	125.2	125.0
Greece	276.6	187.9	163.3	141.3	132.3	118.9	119.1
Hungary	549.7	301.1	211.8	178.2	157.8	132.3	129.8
Ireland	668.8	332.8	288.3	261.4	247.5	226.7	226.8
Italy	367.1	160.1	118.5	82.5	70.6	49.7	54.3
Latvia	267.4	151.4	120.7	97.5	88.6	75.7	74.1
Lithuania	491.5	380.8	323.8	270.9	249.2	216.7	216.8
Luxembourg	1121.1	660.4	570.0	505.0	476.8	435.0	439.3
Malta							
Netherlands	1493.7	893.3	806.7	746.1	717.1	667.5	667.2
Poland	732.1	492.4	399.0	341.1	321.4	293.7	295.8
Portugal	163.2	50.4	32.9	20.8	18.1	9.3	8.8
Romania	23.0	0.9	0.3	0.1	0.1	0.0	0.0
Slovakia	649.3	367.9	293.6	248.7	226.9	198.3	194.3
Slovenia	373.0	65.4	29.8	10.4	4.7	2.3	2.4
Spain	321.9	185.4	151.8	119.6	107.2	89.7	89.8
Sweden	134.8	62.0	51.4	46.7	44.2	40.2	40.3
UK	146.9	46.7	38.1	31.9	29.2	25.3	25.3
Albania	302.5	232.5	196.3	160.6	146.7	126.0	126.3
Belarus	390.1	311.4	258.4	196.6	183.9	158.1	159.3
Bosnia-H.	267.0	132.2	104.8	79.5	70.4	57.7	56.7
Croatia	534.9	310.4	258.1	206.0	180.9	151.1	147.4
FYROM	311.0	188.4	156.2	125.0	113.5	97.5	98.0
R Moldova	333.4	227.1	183.8	142.4	129.9	113.4	114.2
Norway	28.0	6.7	5.0	4.0	3.6	3.0	3.0
Russia	29.9	11.1	8.5	6.7	6.2	4.5	4.2
Serbia	289.7	138.8	106.9	78.9	69.9	57.0	56.1
Switzerland	692.9	407.9	317.1	246.7	216.1	168.2	168.1
Ukraine	507.4	337.6	280.8	224.0	201.4	167.6	167.6
EU-27	334.0	168.8	134.8	107.8	97.6	83.1	84.1
Non-EU	77.8	43.0	34.8	27.3	24.8	20.2	19.9
	185.2	95.8	76.7	61.1	55.3	46.6	46.8

Table 5.15: Forest area with deposition exceeding critical loads for acidification [1000 km^2]

	Total area	2000	2020 BL	Ambition level LOW	Low*	Mid	High*	HIGH
Austria	35.7	0.6	0.0	0.0	0.0	0.0	0.0	0.0
Belgium	6.3	1.9	0.9	0.8	0.8	0.7	0.7	0.6
Bulgaria	48.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cyprus	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Czech Rep.	21.6	7.5	5.0	4.5	4.4	3.7	3.4	3.5
Denmark	2.3	1.8	0.3	0.3	0.2	0.2	0.2	0.2
Estonia	18.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Finland	240.4	5.9	1.8	1.5	1.5	1.5	1.3	1.3
France	170.7	19.5	4.6	3.9	3.3	2.5	1.5	1.5
Germany	99.8	61.8	20.6	16.3	12.9	11.1	9.3	9.4
Greece	17.6	1.5	0.2	0.1	0.1	0.1	0.0	0.0
Hungary	13.5	5.6	0.9	0.6	0.5	0.4	0.0	0.0
Ireland	4.3	1.9	0.4	0.4	0.4	0.3	0.3	0.3
Italy	88.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Latvia	22.4	7.2	1.2	1.0	0.9	0.6	0.1	0.1
Lithuania	14.4	6.3	5.7	5.4	5.3	4.9	3.7	4.2
Luxembourg	0.7	0.2	0.1	0.1	0.1	0.1	0.1	0.1
Malta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Netherlands	5.3	4.8	4.4	4.3	4.3	4.2	4.2	4.2
Poland	87.6	72.5	33.6	28.9	27.6	23.5	19.2	20.4
Portugal	17.8	3.0	0.9	0.7	0.6	0.6	0.1	0.2
Romania	98.0	53.0	4.2	3.7	3.9	2.6	0.4	0.6
Slovakia	17.0	3.7	1.4	1.1	0.9	0.3	0.0	0.0
Slovenia	10.8	0.8	0.0	0.0	0.0	0.0	0.0	0.0
Spain	69.5	5.5	0.0	0.0	0.0	0.0	0.0	0.0
Sweden	150.7	27.5	2.2	1.7	1.6	1.3	1.1	1.1
UK	19.7	10.9	2.6	2.2	2.1	1.9	1.7	1.7
Albania	6.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Belarus	57.9	11.9	4.7	2.6	1.5	0.6	0.1	0.1
Bosnia-H.	20.0	3.9	0.0	0.0	0.0	0.0	0.0	0.0
Croatia	17.8	1.3	0.5	0.5	0.2	0.1	0.0	0.0
FYROM	7.2	1.6	0.0	0.0	0.0	0.0	0.0	0.0
R Moldova	1.7	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Norway	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Russia	1821.6	22.8	14.9	12.3	12.3	11.0	4.7	6.3
Serbia	26.8	7.5	0.0	0.0	0.0	0.0	0.0	0.0
Switzerland	9.6	0.8	0.3	0.2	0.2	0.2	0.2	0.2
Ukraine	71.1	5.9	1.0	0.8	0.7	0.0	0.0	0.0
EU-27	1283.0	303.5	91.2	77.7	71.5	60.7	47.1	49.4
Non-EU	2040.2	55.8	21.5	16.4	14.9	11.8	5.0	6.6
Total	3323.2	359.2	112.7	94.1	86.4	72.5	52.1	55.9

Table 5.16: Average accumulated excess deposition for acidification in forests [eq/ha/yr]

			Ambition level				
	2000	2020 BL	LOW	Low*	Mid	High*	HIGH
Austria	4.0	0.0	0.0	0.0	0.0	0.0	0.0
Belgium	568.6	98.1	80.2	80.1	65.1	51.7	51.6
Bulgaria	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cyprus	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Czech Rep.	372.9	94.1	73.8	65.0	54.3	42.5	43.1
Denmark	649.4	30.6	24.4	20.5	17.3	14.1	13.9
Estonia	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Finland	4.5	0.8	0.6	0.6	0.5	0.4	0.4
France	58.3	9.0	6.1	3.7	2.8	1.3	1.6
Germany	467.8	67.5	48.2	33.0	25.9	20.5	20.7
Greece	45.6	1.0	0.6	0.5	0.4	0.2	0.2
Hungary	315.8	9.5	4.3	3.3	1.5	0.0	0.0
Ireland	245.6	18.9	14.6	12.9	11.1	8.1	8.1
Italy	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Latvia	70.6	5.9	3.6	2.5	0.9	0.1	0.1
Lithuania	294.6	105.8	79.3	63.7	41.7	18.3	20.5
Luxembourg	258.6	54.8	34.8	24.5	16.8	2.3	3.0
Malta							
Netherlands	2589.9	1116.6	1012.8	963.6	908.9	828.2	828.0
Poland	871.1	159.9	118.3	109.8	76.1	52.5	58.7
Portugal	124.8	7.8	6.2	5.4	5.0	0.5	0.6
Romania	282.7	2.6	2.1	2.2	1.4	0.1	0.2
Slovakia	132.3	11.7	5.3	3.2	0.9	0.0	0.1
Slovenia	38.3	0.0	0.0	0.0	0.0	0.0	0.0
Spain	48.3	0.3	0.3	0.3	0.2	0.1	0.1
Sweden	26.5	1.2	0.9	0.8	0.6	0.5	0.5
UK	551.6	51.6	41.9	38.4	33.3	26.5	26.7
Albania	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Belarus	66.3	8.3	4.4	2.3	0.9	0.1	0.2
Bosnia-H.	67.8	0.0	0.0	0.0	0.0	0.0	0.0
Croatia	48.9	4.1	2.1	0.6	0.3	0.0	0.0
FYROM	47.6	0.0	0.0	0.0	0.0	0.0	0.0
R Moldova	2.4	0.0	0.0	0.0	0.0	0.0	0.0
Norway							
Russia	2.3	1.1	0.7	0.7	0.5	0.1	0.1
Serbia	88.4	0.0	0.0	0.0	0.0	0.0	0.0
Switzerland	36.3	9.5	6.9	5.4	4.7	3.4	3.2
Ukraine	24.1	1.9	1.2	1.0	0.0	0.0	0.0
EU-27	174.6	27.2	20.8	18.1	14.1	10.6	11.1
Non-EU	7.4	1.3	0.9	0.8	0.5	0.1	0.1
Total	72.0	11.3	8.6	7.4	5.7	4.1	4.4

Table 5.17: Catchment area with deposition exceeding critical loads for acidification [km^2]

			Ambition level				
	2000	2020 BL	LOW	Low*	Mid	High*	HIGH
Finland	1971	827	654	654	522	397	397
Italy	0	0	0	0	0	0	0
Sweden	44309	14822	13478	13665	10696	9527	9956
UK	7709	6090	6058	6052	6045	5168	5168
Norway	28026	12234	11401	10879	10242	9593	9593
Switzerland	146	100	92	80	80	76	78
EU-27	53989	21738	20190	20371	17263	15092	15520
Non-EU	28172	12334	11493	10959	10322	9669	9671
Total	82160	34072	31683	31330	27585	24762	25192

Table 5.18: Average accumulated excess deposition of acidifying substances for freshwater ecosystems [eq/ha/yr]

	Total			Ambition level				
	area	2000	2020 BL	LOW	Low*	Mid	High*	HIGH
Finland	33231	6.0	1.2	0.8	0.8	0.6	0.3	0.3
Italy	6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sweden	292479	22.6	2.5	2.2	2.3	1.9	1.6	1.6
UK	14987	532.2	89.4	75.0	71.7	62.2	48.3	49.3
Norway	177108	46.2	10.1	8.7	8.0	7.2	6.1	6.1
Switzerland	180	603.0	245.9	205.9	173.4	159.2	124.1	129.3
EU-27	340703	43.4	6.2	5.3	5.2	4.4	3.5	3.6
Non-EU	177288	46.7	10.4	8.9	8.2	7.4	6.3	6.3
Total	517991	44.5	7.6	6.5	6.2	5.4	4.4	4.5

5.6 Side-effects on radiative forcing

As a new element in the analysis of air pollution control scenarios, this report examines impacts of reductions of aerosol air pollutants on radiative forcing. The recent extension of the GAINS model quantifies impacts of reductions of SO_2, NO_x, NH_3, PM and VOC on instantaneous radiative forcing over the EMEP domain and on carbon deposition in the Arctic and Alpine glaciers (see Section 2.1).

With this extension it is now possible to assess the relationship between air quality improvements targeted at the individual effects and radiative forcing. It is noteworthy that for the baseline case in 2020 air pollutants emitted in the EMEP region are estimated to cause a negative forcing of -670 mW/m^2 over the EMEP domain (Figure 5.13). For comparison, radiative forcing of the long-lived Kyoto greenhouse gases is currently estimated at around 2.7 W/m^2 (IPCC AR4).

In a single-effect optimization, cost-effective strategies with low ambition levels for health effects from fine particles would slightly decrease radiative forcing, as they include low cost measures directed at black carbon. However, beyond a 30% gap closure, such strategies involve to a growing degree measures for SO_2 to reduce secondary particles, and thereby increase radiative forcing (or reduce the negative forcing). For instance, a 90% gap closure would increase radiative forcing by about 100 mW/m^2. Only the most expensive measures that are taken beyond the 90% gap closure level would again lower radiative forcing to some extent.

Cost-effective improvements of acidification will always lead to higher radiative forcing, as they always involve measures to reduce SO_2 emissions. In contrast, strategies aimed at eutrophication will hardly influence radiative forcing. Note that the current implementation of the radiative forcing module in GAINS does not yet quantify radiative impacts from ground-level ozone. A combined strategy which simultaneously addresses all four effects in the most cost-effective way would also lead to higher radiative forcing, as the acidification targets need to be fulfilled.

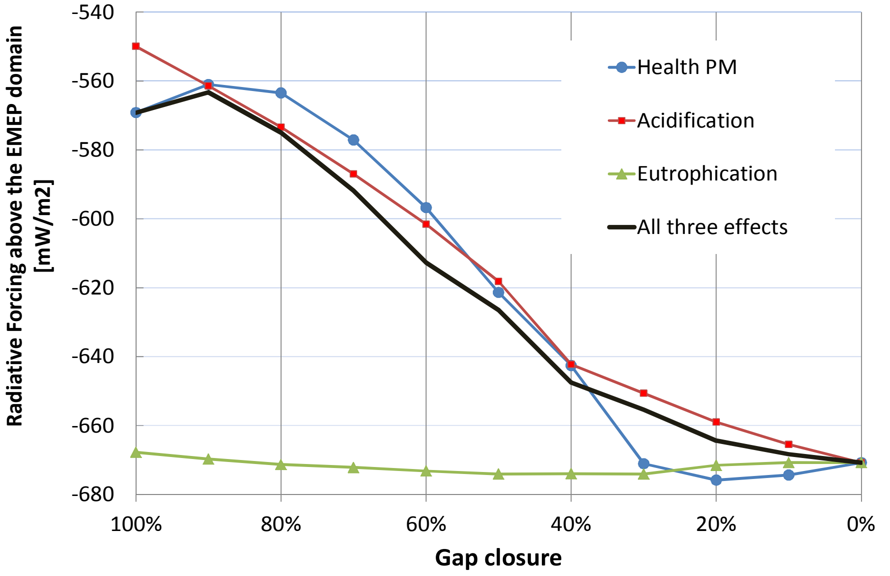


Figure 5.13: Side-effects on instantaneous radiative forcing over the EMEP region from the scenarios optimized for the air pollution targets.

The scenarios analysed in this report combine different gap closure targets for the individual effects. In total, they increase radiative forcing in the EMEP domain from the considered substances by up to 13%. Full application of the maximum feasible emission reductions would increase instantaneous forcing by 15%, while a selective strategy that would aim solely at the reduction of radiative forcing could reduce forcing by about 5% (Table 5.19). These scenarios would reduce carbon deposition in the Arctic (north of 60°) by up to 15%, but cause only little changes in carbon deposition to Alpine glaciers. Strategies that target carbon deposition, however, could cut carbon deposition by about 20%.

All these strategies have been designed employing a cost-effectiveness rationale focused on air quality impacts. This means they minimize costs to achieve the given environmental targets, but do not take into account implications on radiative forcing or carbon deposition. The scope for low cost options to minimize negative impacts on radiative forcing of such air pollution oriented strategies is discussed in Section 6.2.

Table 5.19: Impacts of the emission control scenarios on radiative forcing and carbon deposition

	Baseline	LOW	Low*	Middle	High*	HIGH	MTFR	Lowest RF
Radiative forcing from emissions in the EMEP domain [mW/m^2]								
Northern Hemisphere	-488	-487	-487	-482	-473	-474	-472	-492
EMEP domain	-671	-660	-664	-630	-577	-583	-569	-695
Arctic > 60°	-110	-109	-109	-106	-99	-100	-99	-115
Arctic > 70°	-48	-49	-49	-47	-45	-45	-46	-52
Radiative Forcing - for the EMEP domain, by component [mW/m^2]								
Total	-671	-660	-664	-630	-577	-583	-569	-695
BC	134	122	124	122	121	120	97	98
OC	-35	-29	-30	-29	-29	-28	-22	-24
SO_4	-723	-708	-713	-679	-627	-633	-604	-723
NO_3	-46	-45	-45	-44	-43	-41	-40	-46
Total carbon deposition (BC and OC, dry and wet) [mg/m^2.yr]								
Arctic > 60°	4.9	4.4	4.4	4.3	4.3	4.3	3.6	3.7
Arctic > 70°	1.3	1.2	1.2	1.2	1.2	1.2	1.0	1.0
Alps	60.0	56.0	56.1	52.8	54.4	52.8	39.5	43.5

6 Sensitivity analyses

6.1 Alternative projections of economic activities

Different economic development may lead to different future activity levels and hence may require a different effort for achieving a given set of environmental objectives. Two critical questions arise:

- How much would it cost to achieve emission ceilings that have been determined based on the assumption of the PRIMES scenario, if the national scenarios materialized?
- How different would cost-effective emission ceilings be if they were calculated for the national scenario. i.e., how sensitive are cost-optimized emission ceilings towards the assumed projection of future economic activities?

Following the decision of the Working Group on Strategies, the central emission reduction scenarios presented above are based on a Europe-wide coherent set of the PRIMES energy and the CAPRI agricultural projections. Obviously, the assumptions and suggested future trends of these scenarios are associated with unavoidable uncertainties; while alternative projections of activities are available, they are loaded with uncertainties too. However, the specification of the environmental targets for the optimization scenarios as well as the scope for further measures is critically dependent on the underlying assumptions on future human activity levels.

In principle, different sensitivity analyses could be conducted to explore the implications of alternative assumptions on economic development on optimized results. For instance, different energy and agriculture projections imply different emission levels for the baseline and the maximum technically feasible reduction (MTFR) cases, and subsequently also different environmental targets for the optimization if they were derived based on the 'gap closure' concept (as the gaps between baseline and MTFR emissions are different for the different scenarios). Obviously, different environmental targets in absolute terms could result in different allocations of emission reductions.

Another sensitivity analysis could explore cost implications to countries if they would need to meet an emission ceiling that has been optimized for a different activity projection. In such cases, i.e., if economic activities would evolve differently from what has been assumed for the optimization, the original solution will no longer remain cost-minimal, although the changes in costs depend on the specific assumptions (i.e., costs might be higher for a scenario with higher economic activities, and lower for low-growth scenarios).

Most important, both for costs and compliance checking, however, will be whether emission ceilings that have been established based on the assumption of a certain economic development, would become unachievable under a different activity projection. To explore this aspect, a sensitivity analysis has been carried out for the mid case that checks whether the emission ceilings that have been established on the basis of the PRIMES energy scenarios would remain feasible if the national projections of economic activities (described in Section 2.21) materialized. For this purpose, the emission ceilings for the mid case presented above have been compared to the emission levels that emerge for the 'maximum technically feasible reduction' (MTFR) case for the national activity projections. While 15 countries have provided national projections, the mid-case ceilings for all five pollutants that have been optimized for the PRIMES scenario turn out to be lower than the maximum feasible levels of the national scenarios in eight cases (involving five countries). In three cases (Denmark, Finland, Netherlands and Croatia), emission ceilings for SO_2 would be unachievable If the national projections materialized (Figure 6.1); NO_x ceilings conflict in three cases

(Denmark, Netherlands and Croatia;

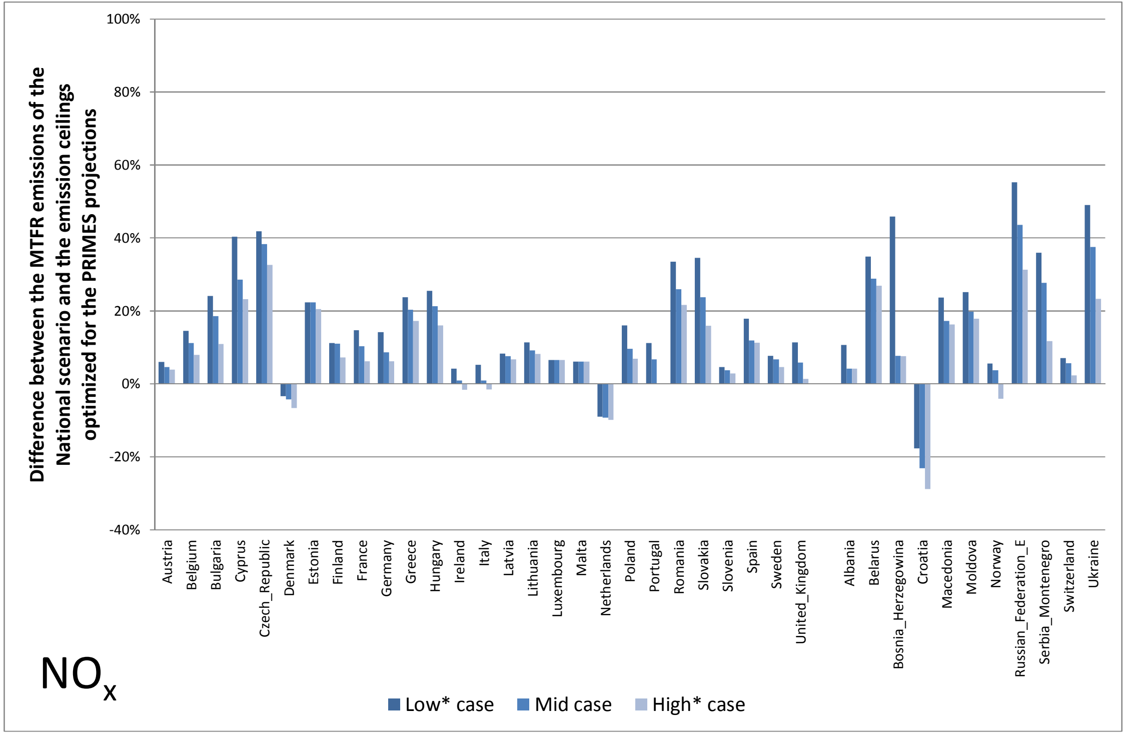


Figure 6.2), and the ammonia ceiling for Romania (Figure 6.4). Emission ceilings for PM2.5 and VOC appear as feasible in all cases. In the few cases where infeasibilities occur, the national scenarios employ very different assumptions on the future development in the various sectors. It will be important to identify the reasons for such conflicts for a final set of emission ceilings in more detail, and to develop a shared and more coherent perspective on the future economic development in these countries.

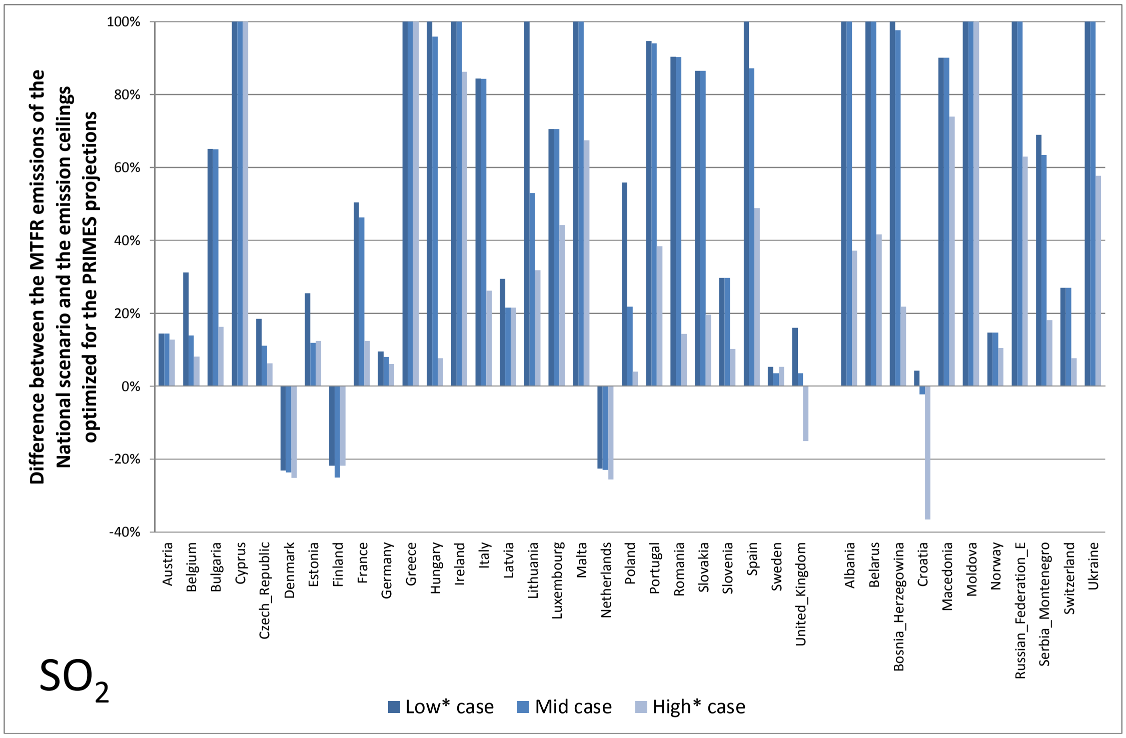


Figure 6.1: Comparison of the cost-optimal emission ceilings for SO2 for the PRIMES scenarios with the emission levels that could be achieved through application of the maximum technically feasible emission reductions for the National scenarios

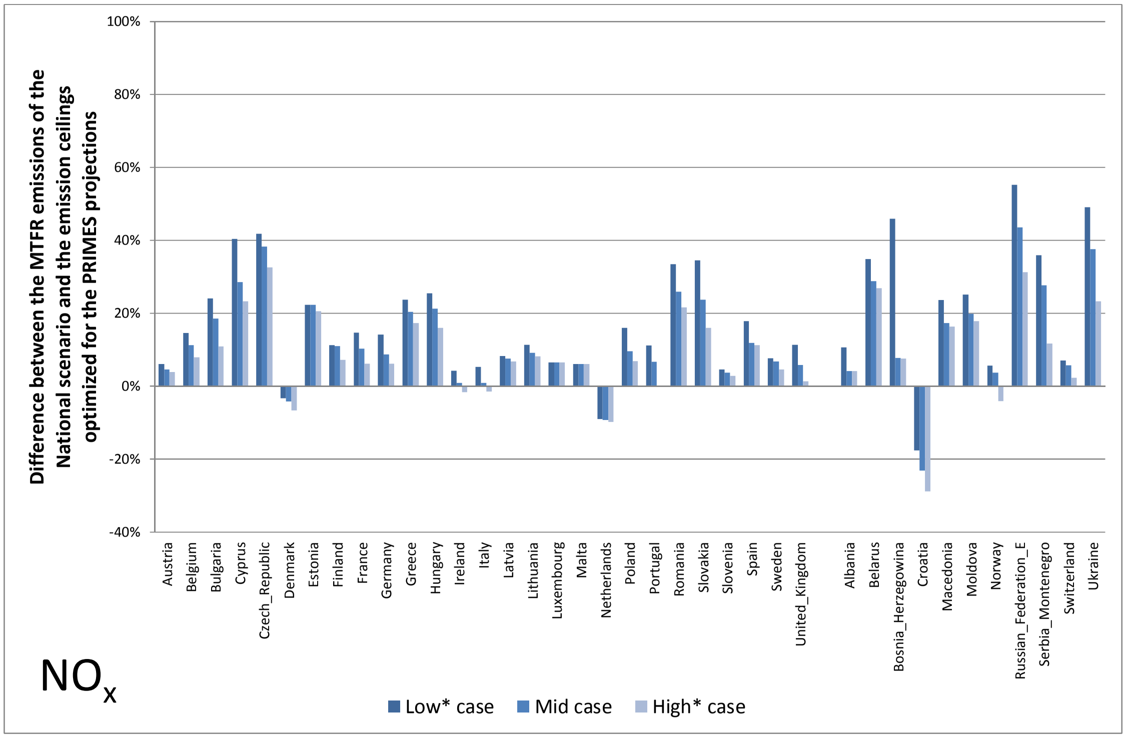


Figure 6.2: Comparison of the cost-optimal emission ceilings for NOx for the PRIMES scenarios with the emission levels that could be achieved through application of the maximum technically feasible emission reductions for the National scenarios

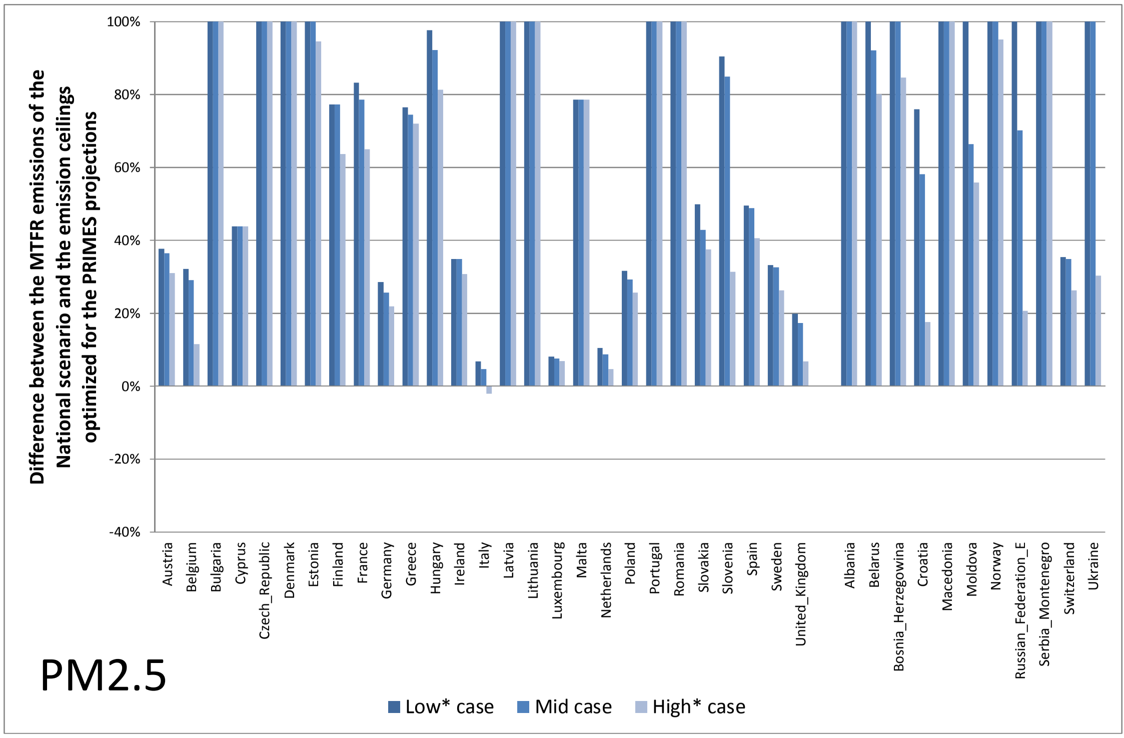


Figure 6.3: Comparison of the cost-optimal emission ceilings for PM2.5 for the PRIMES scenarios with the emission levels that could be achieved through application of the maximum technically feasible emission reductions for the National scenarios

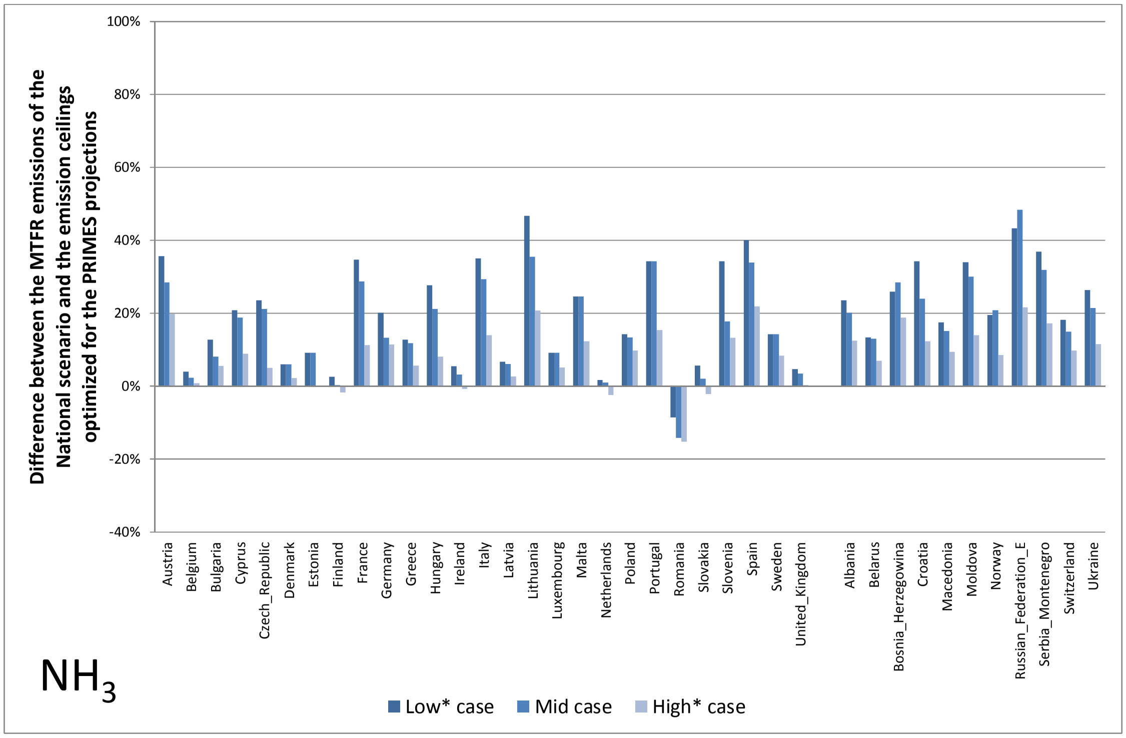


Figure 6.4: Comparison of the cost-optimal emission ceilings for NH3 for the PRIMES scenarios with the emission levels that could be achieved through application of the maximum technically feasible emission reductions for the National

scenarios

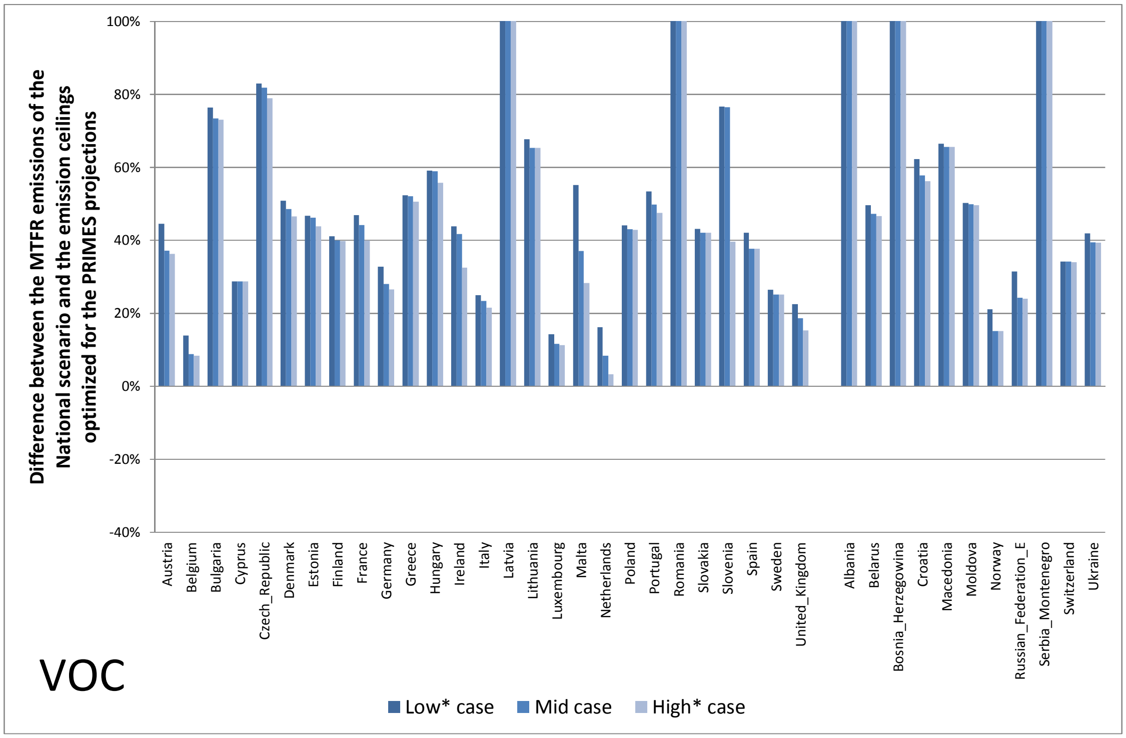


Figure 6.5: Comparison of the cost-optimal emission ceilings for VOC for the PRIMES scenarios with the emission levels that could be achieved through application of the maximum technically feasible emission reductions for the National scenarios

6.2 Low-cost options to reduce radiative forcing

Section 5.6 analysed the side-effects of achieving the air quality targets on instantaneous radiative forcing, demonstrating that the cuts in cooling agents (e.g., SO_2, OC) that are involved in cost-effective control strategies lead to increased forcing compared to the baseline case. The question arises to what extent radiative forcing could be reduced as well, in addition to the air quality targets, without imposing excessive costs. For this purpose, a series of sensitivity analyses has been carried out that maintain the environmental targets for the effects (as discussed in Section 4) and impose gradually tightened constraints on instantaneous forcing (over the EMEP region). It turns out that there exists a potential for measures that could reduce radiative forcing while still achieving the air quality targets without substantial increases in emission control costs. These measures are not cost-effective for meeting the conventional air quality targets for the four impacts; however, they emerge as cost-effective compromises if constraints on radiative forcing are to be met in addition. For the low ambition levels radiative forcing could be reduced by about 0.01 W/m^2 without excessive increase in costs, and for the mid case the potential grows to about 0.02 W/m^2. For the high ambition levels there is no clear threshold, although a low cost potential is available (Figure 6.6).

Compared to the cases where impacts of radiative forcing are completely ignored, consideration of near-term climate impacts would gradually relax pressure on SO_2 emissions (Figure 6.7). Thereby, radiative forcing is primarily reduced through less ambitious SO2 reductions, and the resulting increases in PM2.5 are compensated by additional measures for primary PM2.5 (though not specifically directed at black carbon) and of NH_3. Emissions of NO_x are hardly influenced. Note, however, that this preliminary analysis addresses only the radiative forcing from aerosols (ignoring the indirect forcing), and does not yet consider forcing resulting from tropospheric ozone.

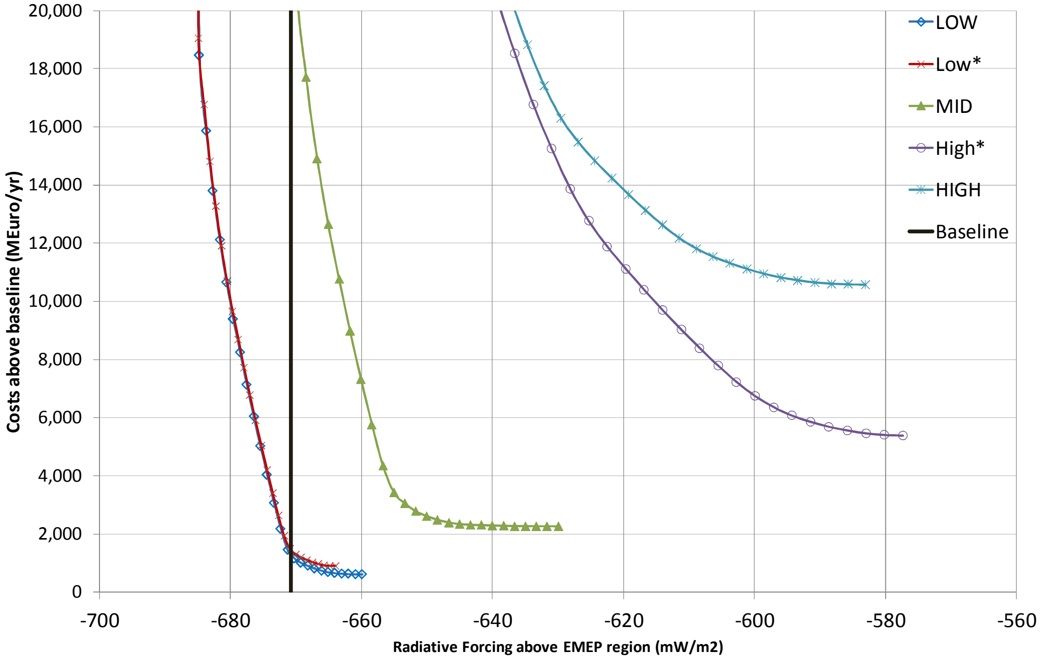
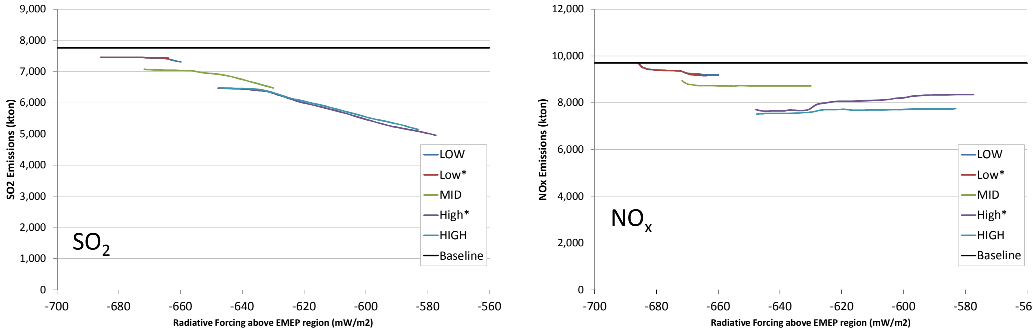


Figure 6.6: Emission control costs (above the baseline) for additional reductions of instantaneous reductions of radiative forcing for the five cost-optimized scenarios that address the four air quality impacts.



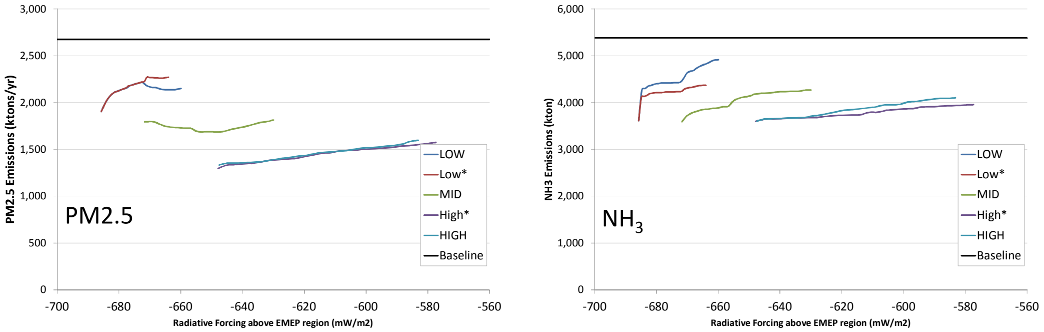


Figure 6.7: Cost-effective changes in emissions for reducing radiative forcing, in addition to the targets for air quality impacts. Note that, as this preliminary analysis addresses only radiative forcing from aerosols, changes in VOC emissions occur only at stringent reductions.

6.3 *Ignoring the larger intake fraction of urban emissions*

It has been demonstrated before that emissions from low-level sources within urban areas have a stronger impact on population exposure than emissions from high-level sources and sources that are remote from population centres. In the GAINS model this fact is considered through the ‘urban increment’ that is allocated to emissions from the domestic and transport sectors in urban areas when calculating health impacts of fine particulate matter. However, at this stage of the analysis the urban increments (as calculated with the City-Delta methodology) could only be applied to the EU27 member states (excl. Cyprus and Malta), Croatia, Norway, and Switzerland. For other countries the compilation and quality control of relevant data on land use, meteorology and demography could not be completed in time, so that calculations presented in this report do not consider the higher impact of urban PM emissions on population exposure in these countries. Thus, all results presented in this report need to be considered as provisional.

As different methodologies have been applied to EU and non-EU countries, results could potentially be biased. In order to estimate the potential bias of including the urban increment only for a subset of the total domain, a sensitivity analysis for the mid-ambition case has been conducted where the urban increment has been ignored for the EU countries as well.

Consideration of the urban increment delivers higher health impact estimates in absolute terms. However, in the context of the present study the question arises to what extent the results of a least-cost optimization based on a gap closure approach, which relates to the relative changes between the baseline and the maximum feasible reductions, would be affected. In such a situation, the gap closure would be applied to two references points (baseline and MTFR), which both ignore the urban increment. Thus the same target setting procedure as in the mid-ambition case has been applied to the exposure calculations without the urban increments, and the same gap closure percentages as in the mid-ambition case, i.e., 50/50/60/40% for the health PM, acidification, eutrophication and ozone indicators, respectively, have been used. For the health PM indicator this means that the absolute target is different than in the mid-ambition case, but for the other indicators the absolute targets are indeed identical to those in the mid-ambition case (Table 6.1).

Table 6.1: Health PM indicators for the mid case (central case with urban increment in the EU-27) and the variant without urban increment (Unit: months of statistical life expectancy lost)

	Baseline	Target	MTFR
Mid case (original)	4.49	3.52	2.55
Sensitivity case without urban increment	4.36	3.41	2.46

It turns out that in the optimized cases the differences between these two variants in terms of emissions are small. Even in the EU-27, where the cases employ different assumptions on the urban increments, emissions hardly differ (Table 6.2).

Table 6.2: Emissions in the EU-27 for the mid case and the variant without urban increment (kilotons)

	SO_2	NO_X	$PM_{2.5}$	NH_3	VOC
Mid case (original)	2508	5046	907	2819	5437
Sensitivity case without urban increment	2513	5046	910	2820	5436
Difference (absolute)	-5	0	-3	-2	0
Difference (%)	-0.18%	0.00%	-0.33%	-0.06%	0.00%

In summary, it can be concluded from this sensitivity run that cost-effective emission ceilings that are derived from gap closure approaches for target setting appear to be robust against the quantification of the incremental impacts of urban emissions on population exposure. This is a consequence of the relative nature of a gap closure target, i.e., that it refers to two reference points which are based on the same methodology. However, this does not mean that the calculation of the absolute levels of indicators for urban air quality and health impacts would not be influenced by the way urban emissions are considered. Similarly, emission ceilings that are based on absolute targets (e.g., compliance of air quality limit values) would strongly depend on the chosen methodology.

7 Conclusions

The Convention on Long-range Transboundary Air Pollution has embarked on the revision of its Gothenburg multi-pollutant/multi-effect protocol. To inform negotiations about the scope for further cost-effective measures, this report presents a series of emission control scenarios that illustrate options for cost-effective improvements of air quality in Europe.

Europe-wide coherent projections of economic activities envisage considerable changes in the structure of economic activities. Together with continuing implementation of already agreed emission control legislation, these would lead to significant impacts on future air pollution emissions. In 2020 baseline SO_2 emissions in the EMEP modelling domain are expected to be approximately 35% lower than in 2000; NO_x and VOC emissions would be 40% and PM2.5 emissions 20% lower. However, no significant changes emerge for NH_3 emissions in Europe. Despite these cuts in emissions, negative impacts of air pollution remain considerable: In 2020, air pollution would still shorten statistical life expectancy by 4.7 months, there will be more than 24,000 cases of premature deaths every year caused by ground-level ozone, bio-diversity of 1.4 million km^2 of European ecosystems will be threatened by high levels of nitrogen deposition, and more than 110,000 km^2 of forests will continue to receive unsustainable levels of acid deposition.

There remains substantial scope for further environmental improvement through additional technical emission reduction measures. Cost-effective emission control scenarios are presented for five different sets of environmental targets on air quality. These targets cover a range from 25% to 75% of the feasible improvements for each effect, and they involve additional emission control costs of 0.6 to 10.6 billion €/yr over the entire modelling domain (on top of the costs of the baseline scenario). Between 50 and 60% of the costs emerge for the EU-countries. However, since the EU-27 includes 72% of total population and 88% of GDP in the modelling domain, these scenarios imply higher relative efforts for some non-EU countries.

A sensitivity analysis explores the robustness of optimization results against modifications in the ambition levels for individual effects, finding that different targets on ozone would have largest impacts on emission control costs.

As a new element, the analysis explores the impacts of the controls scenarios on instantaneous radiative forcing and, for the Arctic and Alpine glaciers, on carbon deposition. The analysed scenarios tend to reduce the negative forcing (and thus increase radiative forcing) in the EMEP domain by up to 0.1 W/m^2 (compared to a current total forcing from long-lived greenhouse gases of about 2.7 W/m^2) as a consequence of cuts in cooling emissions. A sensitivity analysis demonstrates that low cost options are available that could reduce these negative impact on near-term climate change to some extent.

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