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Co–operative programme for monitoring and evaluation of the long–range transmissions of air pollutants in Europe
Life

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
39th Meeting of the Task Force on Integrated Assessment Modelling

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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. This report provides an initial analysis for discussion at the 39th Meeting of the Task Force on Integrated Assessment Modelling. A full assessment for presentation to the Working Group on Strategies will require further refinements, based on feedbacks from the Task Force.

For a Europe-wide coherent projection of economic activities, the analysis envisages considerable changes in the structure of economic activities. Together with progressing 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 4.6 months, there will be more than 26,000 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, although such improvements would come at substantial costs. 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 0.4 to 9.8 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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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.

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 'GOTH_RevFeb2011':

Data for the year 2000 that are used for this report are available as the 'GOTH_Nat10_Feb2011' scenario. The policy scenarios for 2020 can be retrieved, following the naming conventions of this report, as:

GOTH_PRIMESBL2009_baseline
GOTH_PRIMESBL2009_LOW
GOTH_PRIMESBL2009_Low*
GOTH_PRIMESBL2009_MID
GOTH_PRIMESBL2009_High*
GOTH_PRIMESBL2009_HIGH
GOTH_PRIMESBL2009_MFR

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. Distinguishing country-specific application rates of available emission control technologies, GAINS uses emission factors that 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.

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. 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 constraint or in a multi-objective fashion. For this purpose the radiative forcing transfer coefficients and related 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 r is the receptor region, s the source region, p the relevant pollutants, $\mathrm{Em}_{\mathrm{s,p}}$ the emissions of pollutant p in source region s, with transfer matrix $\mathrm{T}_{\mathrm{r,s}}^{\mathrm{RF,p}}$ and constants $\mathrm{k}_{\mathrm{r}}^{\mathrm{RF}}$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:

$$C - Dep_r = \sum_s \sum_p T_{r,s}^{C-Dep,p} \cdot Em_{s,p} + k_r^{C-Dep}$$

where the relevant set of pollutants here only includes BC and OC, and only three distinct receptor regions are considered (the Alps, 70+ degree arctic region, and 60+ degree arctic region). 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 17 countries as well as a set of Europe-wide projections that have been compiled from various international sources. The resulting two sets of activity scenarios, i.e., a set of Europe-wide consistent scenarios 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 a national scenario that reflects the perspectives of individual governments, however without any guarantee for international consistency (Table 2.1).

Table 2.1: Sources of activity projections

	Europe-wide PRIMES 2009 scenario	*National scenario*
Energy projections		
PRIMES 2009 baseline	EU-27, MK, NO	
National projections	CH	AT, CR, CZ, DK, FI, GR, IE, IT, NL, NO, PT, ES, SE, CH, UK
PRIMES 2008 C&E		BE, BG, CY, EE, FR, DE, HU, MK, LV, LT, LU, MT, PL, RO, SK, SI
IEA WEO 2009	AL, BY, BA, CR, 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 recent 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 calculated 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

17 Parties of the Convention on Long-range Transboundary Air Pollution submitted their most recent governmental projections of future economic development, energy use and agricultural activities to CIAM. 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. In some cases these projections date back before the economic crisis. As these projections reflect perspectives of individual national governmental, they are not necessarily internationally consistent in their assumptions on future economic development, energy prices and climate policies. 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 30% between 2005 and 2020, while total energy use is assumed to increase by only three percent. Non-EU countries anticipate, for constant population, GDP growing in this period by two thirds, 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 9% in the transport sector up to 2020 (relative to 2005), and by 3% 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.

Calculations of urban air quality do not (yet) include for the non-EU countries the urban increments that have been calculated with the City-Delta methodology (Thunis *et al.*, 2007) to reflect the additional population exposure in urban centres from low-level sources. These urban increments have been estimated for the EU countries before, and work on the extension of this approach to non-EU countries has been started. However, inconsistencies in the available land use and population data between EU and non-EU countries prevented the use of results for 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 this 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_Nat10_Feb2011' scenario.

Emission estimates are based on the amount of fuel sold within a country.

2.3 Changes since last report

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

2.3.1 New information on ammonia

Following a request of the WGSR, the Task Force on Reactive Nitrogen (TFRN) is preparing a revision of Annex IX to the Gothenburg protocol, taking into account the latest scientific and technological information. As one item to that task, 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 TFRN-5 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 presentations held at the expert workshop.

Improved cost information made available at that workshop allowed revision of the cost calculation of ammonia abatement measures in GAINS. The original methodology had been developed during the 1990's and has since experienced a number of adaptations as a consequence of 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 current changes in GAINS, opened for review to the expert of TFRN, constitute an important improvement over the previous situation.

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

- Average farm sizes were reassessed excluding hobby farms and subsistence farms of less than 15 livestock units (LSU). This has the effect that measures that will be prohibitively more expensive on small farms (and will not be taken anyway) are now considered “not applicable”, and instead only “industrial farms” are being considered for applying ammonia abatement measures. As a consequence of this exclusion, average farm sizes (and associated costs for measures) even in countries where the “subsistence” share is very large (Poland, Bulgaria, Romania) become more comparable to the other countries, which more adequately represents the real situation where industrial farms on a comparable level exist in all countries, albeit at a different share.
- Additional costs incurred due to low protein feed were strongly decreased as a consequence of the workshop discussions. Resulting costs in term of emission were in the range of 0.5 €/kg NH_3-N abated, depending on some further country- and animal specific assumptions.
- Purification of exhaust air to animal houses now is based on a different technique, acid scrubbers instead of biofilters. This strongly decreases costs, which still are high at 10 €/kg NH_3-N saved. Other housing costs were not changed.
- Costs of manure storage options also remained unchanged.
- Costs for manure spreading were reassessed assuming that contractors would be able to operate much cheaper, as their investment would pay off much easier. 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, at (country-specific) fertilizer prices near 1 €/kg N abated emissions, costs in some cases may become negative, i.e., it is economically sound to prevent manure N from being lost into the atmosphere in form of NH_3. Emission estimates and cost curves

2.3.2 Updates of input data and mitigation potentials

Compared to the CIAM 1/2010 report, there a few differences in emission levels for the baseline scenario and the MTFR scenario, as a results of two updates. First, while in previous analysis measures in SNAP sector 8 (Off-Road) were excluded from the optimization, now these measures can be part of a cost-optimal portfolio of measures. This has significant implications for the potential reductions of SO_2, NO_x, and PM. Second, it was found that the maximum application rates for NH_3 measures had been ignored in the previous work, which led to an overestimation of the reduction potential. Finally, a revision of the cost information for NH_3 measures resulted in a re-interpretation of the implementation rates of measures in the baseline scenario, and thus a revision of the baseline emissions.

3 Scope for further environmental improvements in 2020

3.1 The scope for further emission reductions

The GAINS model estimates baseline 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 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 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 (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 25% relative to 2000. Even larger potentials are revealed for primary emissions of PM2.5 and NH_3 (40 to 45% of emissions of the year 2000), while for NO_x further technical measures could cut total emissions by another 15%. In total, these measures would cut SO_2, NO_x, PM2.5 and VOC emissions by up to 60% compared to the levels in 2000, while for ammonia a 40% potential is estimated. 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.

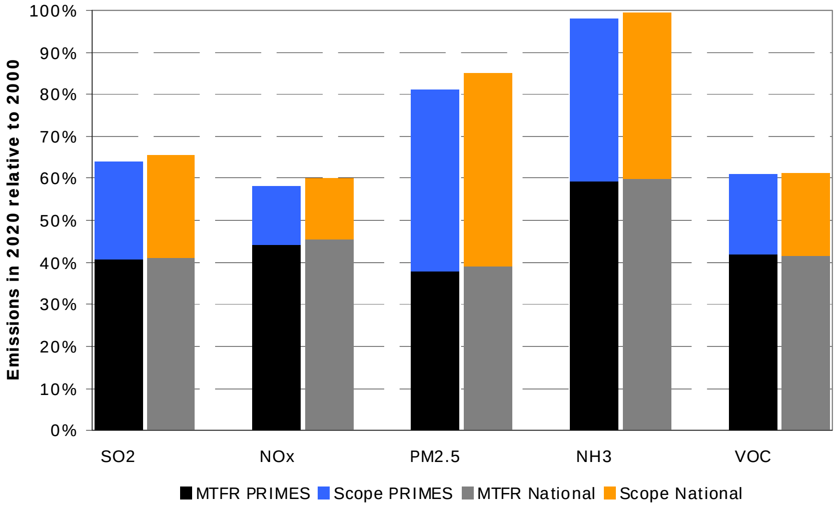


Figure 3.1: Baseline projections of emissions in 2020 and the scope for reductions through technical measures, relative to 2000.

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	80	94	84
Belgium	176	81	62	77	58	337	168	138	155	131
Bulgaria	888	132	80	138	51	158	68	52	74	57
Cyprus	47	5	2	5	1	22	13	8	11	7
Czech Rep.	294	106	93	101	90	308	150	110	139	96
Denmark	29	11	10	18	14	217	84	64	100	72
Estonia	85	16	12	16	9	33	21	12	21	14
Finland	77	42	37	61	53	221	123	103	125	100
France	633	199	132	192	138	1548	568	444	581	460
Germany	619	329	300	400	364	1707	707	601	753	640
Greece	543	112	45	100	41	330	235	174	224	156
Hungary	452	64	30	55	19	177	86	63	86	61
Ireland	144	28	20	16	12	141	68	52	73	58
Italy	774	234	117	308	127	1433	677	505	735	556
Latvia	11	4	3	6	4	37	22	19	29	21
Lithuania	52	15	7	29	12	54	28	23	32	24
Luxembourg	2	1	1	2	1	44	17	16	18	16
Malta	24	1	1	1	1	9	3	3	3	2
Netherlands	72	32	30	49	42	416	169	138	206	174
Poland	1490	468	299	471	287	823	426	342	434	340
Portugal	285	64	33	68	32	269	104	83	115	88
Romania	776	145	76	157	69	265	155	100	202	130
Slovakia	121	42	22	47	23	102	57	39	63	42
Slovenia	100	17	13	13	9	48	27	24	22	19
Spain	1433	311	168	315	138	1416	689	521	706	488
Sweden	45	29	28	29	28	238	95	78	101	75
UK	1193	227	149	290	196	1859	655	439	716	506
Albania	11	10	5	10	5	17	18	14	18	14
Belarus	172	89	34	89	34	181	150	91	150	91
Bosnia-H.	193	44	22	44	22	38	22	14	22	14
Croatia	75	20	8	44	19	67	46	29	68	42
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	87	147	93
Russia	2022	1832	412	1816	391	3009	2144	1221	2118	1198
Serbia	452	92	55	92	55	137	91	63	91	63
Switzerland	17	13	10	13	10	94	44	39	44	39
Ukraine	1349	1099	143	1145	144	912	646	380	651	380
EU-27	10398	2732	1783	2982	1835	12407	5511	4233	5819	4416
Non-EU	4436	3245	719	3298	710	4717	3337	1964	3348	1961
Total	14834	5977	2502	6280	2545	17123	8848	6197	9167	6377

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	57	36	58	37
Belgium	32	20	15	20	14	84	75	67	74	67
Bulgaria	47	33	9	42	11	69	58	51	58	51
Cyprus	3	1	1	1	1	6	5	4	5	4
Czech Rep.	34	25	13	19	11	86	65	50	65	50
Denmark	25	19	8	20	8	91	52	46	52	46
Estonia	20	7	3	8	3	11	11	6	11	6
Finland	32	21	9	22	12	35	29	24	29	25
France	365	206	106	227	109	703	597	387	597	388
Germany	140	83	62	86	67	626	598	371	599	371
Greece	55	33	16	33	14	54	49	37	49	37
Hungary	45	22	10	21	8	77	61	42	62	42
Ireland	14	8	6	6	5	132	98	77	107	83
Italy	160	81	61	123	74	420	383	229	374	226
Latvia	17	15	3	14	3	13	11	9	11	9
Lithuania	14	10	3	11	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	124	112	130	118
Poland	132	96	68	91	55	315	353	248	353	249
Portugal	95	58	15	56	13	71	67	43	67	43
Romania	141	106	20	144	24	167	143	90	198	123
Slovakia	24	10	6	11	6	30	22	13	26	16
Slovenia	9	6	3	6	2	20	16	11	16	11
Spain	142	89	53	82	50	372	361	210	349	203
Sweden	32	19	14	20	14	54	45	35	43	34
UK	115	53	41	53	43	328	265	221	281	231
	0	0	0	0	0					
Albania	8	8	2	8	2	18	23	15	23	15
Belarus	46	48	15	48	15	117	150	102	150	102
Bosnia-H.	15	13	5	13	5	17	19	11	19	11
Croatia	19	14	4	17	6	29	33	16	35	17
FYROM	14	7	2	7	2	10	9	6	9	6
R Moldova	10	9	2	9	2	16	16	10	16	10
Norway	61	31	15	42	15	24	21	13	21	13
Russia	717	778	186	741	151	552	555	316	555	315
Serbia	70	48	14	48	14	65	55	30	55	30
Switzerland	11	7	4	7	4	51	51	40	56	43
Ukraine	357	368	69	366	69	292	285	176	285	176
EU-27	1743	1052	567	1150	574	4018	3599	2450	3668	2499
Non-EU	1328	1330	319	1306	284	1191	1218	736	1224	740
Total	3071	2381	886	2456	859	5210	4817	3186	4893	3238

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					*Total emission control costs*				
	2000	2020				2000	2020			
		PRIMES		National			PRIMES		National	
		BL	MTFR	BL	MTFR		BL	MTFR	BL	MTFR
Austria	184	111	73	114	73	849	1845	2702	1752	2663
Belgium	215	128	108	125	104	1317	2297	2945	2178	2818
Bulgaria	130	79	40	90	46	246	1314	2101	1207	2134
Cyprus	11	5	4	5	4	22	319	452	309	356
Czech Rep.	218	147	81	132	74	984	2291	3365	1901	2884
Denmark	141	73	44	74	46	615	1191	2082	1164	2143
Estonia	44	21	14	22	13	96	363	587	332	569
Finland	163	71	52	73	58	689	1129	2124	1367	2324
France	1706	714	472	748	479	3113	10707	19021	11206	20346
Germany	1490	867	579	852	575	9527	15564	20594	16918	21373
Greece	296	146	87	150	87	611	2088	3192	2184	3421
Hungary	168	104	59	99	54	251	1439	2181	1153	1848
Ireland	78	49	29	51	30	278	795	1277	761	1302
Italy	1580	772	615	818	603	4446	8925	12456	10294	15672
Latvia	71	49	18	44	17	84	364	1143	412	1017
Lithuania	81	53	29	52	29	58	453	998	468	978
Luxembourg	20	7	6	7	5	99	417	452	371	409
Malta	5	3	2	4	3	16	65	81	161	176
Netherlands	249	155	122	161	129	1427	3146	4177	3967	5081
Poland	616	339	218	341	208	2502	8871	13440	8632	13624
Portugal	276	175	115	161	104	333	1504	2523	1896	2929
Romania	437	300	128	340	134	478	2459	5827	2430	6873
Slovakia	73	56	38	54	35	192	696	1124	574	1090
Slovenia	57	30	16	30	15	124	614	751	454	593
Spain	1042	642	461	603	429	1965	9403	14369	8175	12409
Sweden	256	119	93	116	90	803	1964	2543	1931	2471
UK	1330	669	487	663	488	2573	7138	10594	8874	11917
Albania	29	19	10	19	10	36	148	391	148	390
Belarus	210	184	108	184	108	49	343	1866	343	1751
Bosnia-H.	49	29	13	29	13	66	255	600	255	602
Croatia	101	70	43	65	36	77	419	772	502	919
FYROM	28	14	8	14	8	45	127	270	127	260
R Moldova	25	25	14	25	14	7	56	324	56	264
Norway	381	85	65	88	66	283	1193	1984	1261	2269
Russia	3140	2516	1472	2516	1472	536	5549	17154	5562	15902
Serbia	132	113	50	113	50	176	771	2055	771	2043
Switzerland	146	80	52	80	52	476	1245	1700	1249	1785
Ukraine	636	536	312	536	312	389	1532	6292	1541	6263
EU-27	10938	5886	3989	5930	3931	33699	87362	133103	91070	139419
Non-EU	4876	3673	2146	3669	2140	2141	11637	33406	11814	32447
Total	15814	9559	6135	9599	6071	35840	98999	166510	102884	171866

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 base by about 40%, 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 25% 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 55% 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 4.6 months, there will be more than 25,000 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.

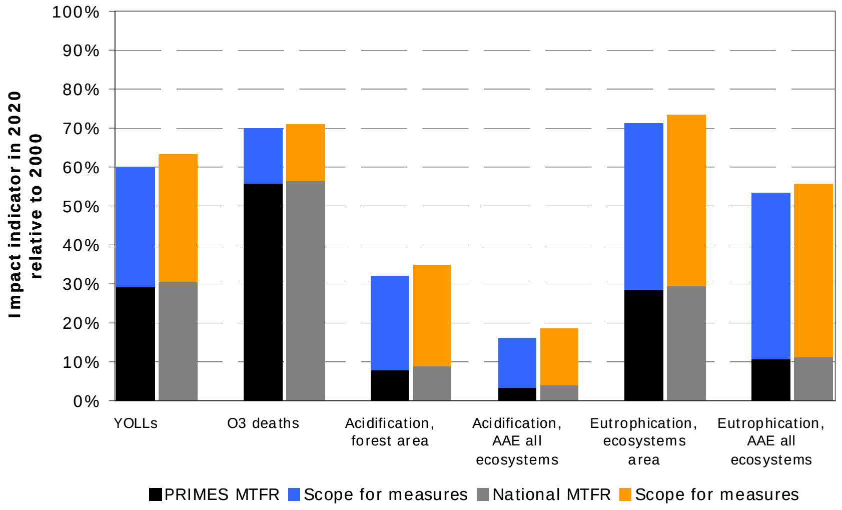


Figure 3.2: Impact indicators in 2020 compared to the levels in the year 2000, for the baseline cases (total bars) and the maximum technical feasible reductions (MTFR)

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 45% compared to the baseline case, and the number of premature deaths from ozone by 15%. These measures could also reduce ecosystems area threatened from excess nitrogen deposition by another 40%, and forest area endangered by acidification by 65% compared to the baseline situation expected for 2020.

Table 3.4: Impact indicators related to human health, for the PRIMES and the national (NAT) scenarios

	Loss in average life expectancy due to PM2.5 (months)					*Premature deaths attributable to ozone (cases/yr)*				
		Baseline 2020		MTFR 2020			Baseline 2020		MTFR 2020	
	2000	PRIMES	NAT	PRIMES	NAT	2000	PRIMES	NAT	PRIMES	NAT
Austria	7.9	3.6		2.4		472	279		233	
Belgium	13.7	6.5		4.8		526	335		287	
Bulgaria	8.3	3.9		1.8		550	365		288	
Cyprus	4.5	3.6		3.3		28	26		25	
Czech Rep.	9.6	4.6		3.0		670	367		291	
Denmark	7.1	3.6		2.4		222	150		130	
Estonia	5.6	3.1		1.4		25	18		16	
Finland	3.2	1.9		1.0		61	46		40	
France	8.2	3.8		2.5		2975	1841		1608	
Germany	10.2	4.8		3.4		4706	2954		2541	
Greece	8.1	4.0		2.6		657	499		427	
Hungary	11.5	5.2		2.8		853	509		400	
Ireland	4.3	1.9		1.4		99	79		74	
Italy	8.2	4.0		2.8		5084	3325		2875	
Latvia	6.0	3.9		1.7		60	42		35	
Lithuania	6.2	3.6		1.8		91	62		50	
Luxembourg	10.1	4.7		3.3		42	22		18	
Malta	5.9	4.2		3.7		29	19		17	
Netherlands	13.0	6.1		4.7		520	332		279	
Poland	10.2	5.1		3.2		1678	1007		809	
Portugal	6.7	3.5		1.9		600	445		402	
Romania	9.6	4.8		1.9		1208	791		601	
Slovakia	9.9	4.5		2.7		296	163		123	
Slovenia	8.8	4.1		2.5		131	73		58	
Spain	4.9	2.4		1.8		2117	1533		1383	
Sweden	3.8	2.0		1.3		223	159		140	
UK	7.9	3.3		2.4		2180	1662		1508	
EU-27	8.6	4.1		2.7		26101	17104		14659	
Albania	5.3	2.7		1.6		129	90		75	
Belarus	6.9	4.5		2.0		322	222		169	
Bosnia-H.	5.9	2.8		1.6		253	148		113	
Croatia	8.5	4.1		2.4		356	217		174	
FYROM	6.2	2.7		1.5		98	74		65	
R Moldova	8.1	4.7		1.8		182	127		97	
Norway	2.5	1.3		0.8		99	81		75	
Russia	7.5	6.7		2.2		4702	3905		3192	
Serbia	8.1	3.6		1.8		499	346		285	
Switzerland	6.5	2.9		2.0		400	244		212	
Ukraine	9.2	6.6		2.2		2543	1893		1503	
Non-EU	7.7	6.0		2.1		11613	8971		7364	
Total	8.3	4.6		2.5		37714	26075		22023	

Note: Impacts for the national scenario will be provided later

Table 3.5: Impact indicators related to ecosystems, for the PRIMES and the national (NAT) scenarios

	Ecosystems area with nitrogen deposition exceeding critical loads [1000 km^2]						*Forest area with acid deposition exceeding critical loads [1000 km^2]*					
	Total	2000	Baseline 2020		MTFR 2020		Total	2000	Baseline 2020		MTFR 2020	
	area		PRIMES	NAT	PRIMES	NAT	area		PRIMES	NAT	PRIMES	NAT
Austria	40.3	40.2	27.4		3.8		35.7	0.6	0.0		0.0	
Belgium	6.3	6.2	5.1		3.1		6.3	1.9	0.9		0.5	
Bulgaria	48.3	45.3	27.4		8.2		48.3	0.0	0.0		0.0	
Cyprus	2.5	1.6	1.6		1.4		1.2	0.0	0.0		0.0	
Czech Rep.	27.6	27.6	27.6		27.5		21.6	7.5	5.0		3.1	
Denmark	3.6	3.6	3.6		3.6		2.3	1.8	0.3		0.2	
Estonia	24.7	16.8	7.9		2.4		18.4	0.0	0.0		0.0	
Finland	240.4	112.9	61.9		26.6		240.4	5.9	1.8		1.0	
France	180.1	176.2	151.9		90.5		170.7	18.5	4.5		1.4	
Germany	102.9	87.7	64.8		36.4		99.8	61.6	20.0		6.2	
Greece	52.9	52.6	51.6		44.8		17.6	1.4	0.2		0.0	
Hungary	20.8	20.8	19.6		12.9		13.5	5.6	0.7		0.0	
Ireland	2.4	2.2	1.9		1.7		4.3	1.9	0.4		0.2	
Italy	124.8	87.9	61.3		26.6		88.9	0.0	0.0		0.0	
Latvia	35.8	35.6	32.8		21.7		22.4	7.2	1.2		0.0	
Lithuania	19.0	19.0	19.0		18.1		14.4	6.3	5.7		1.8	
Luxembourg	1.0	1.0	1.0		1.0		0.7	0.2	0.1		0.0	
Malta	0.0	0.0	0.0		0.0		0.0	0.0	0.0		0.0	
Netherlands	4.4	4.2	3.8		3.6		5.3	4.8	4.3		4.1	
Poland	90.3	90.2	88.7		79.0		87.6	72.4	33.5		15.9	
Portugal	31.0	29.9	18.9		5.1		17.8	3.0	0.9		0.1	
Romania	98.0	19.5	1.0		0.0		98.0	52.7	4.1		0.1	
Slovakia	20.5	20.5	20.5		19.8		17.0	3.7	1.4		0.0	
Slovenia	11.0	10.7	6.1		0.1		10.8	0.8	0.0		0.0	
Spain	187.1	176.9	165.1		114.2		69.5	5.4	0.0		0.0	
Sweden	150.7	83.0	54.8		39.3		150.7	27.5	2.2		0.8	
UK	92.0	23.8	13.8		9.2		19.7	10.9	2.5		1.4	
Albania	17.0	16.9	16.7		13.3		6.5	0.0	0.0		0.0	
Belarus	64.0	63.9	62.0		49.5		57.9	11.9	4.7		0.0	
Bosnia-H.	31.9	28.2	22.8		14.1		20.0	3.8	0.0		0.0	
Croatia	31.7	31.7	31.1		28.0		17.8	1.3	0.5		0.0	
FYROM	13.9	13.9	13.9		10.1		7.2	1.6	0.0		0.0	
R Moldova	3.5	3.4	3.2		2.0		1.7	0.1	0.0		0.0	
Norway	135.3	27.6	11.8		4.7		0.0	0.0	0.0		0.0	
Russia	1821.6	454.8	180.4		41.7		1821.6	22.7	14.9		2.2	
Serbia	41.1	39.6	31.8		15.6		26.8	7.5	0.0		0.0	
Switzerland	9.6	9.5	9.0		4.5		9.6	0.7	0.2		0.1	
Ukraine	72.2	72.2	72.2		64.6		71.1	5.7	1.0		0.0	
EU-27	1618.4	1195.9	939.0		600.8		1283.0	301.6	89.6		36.8	
Non-EU	2241.7	761.7	454.9		247.9		2040.2	55.3	21.3		2.3	
Total	3860.1	1957.6	1393.9		848.7		3323.2	356.9	110.9		39.1	

Note: Impacts for the national scenario will be provided later

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 67 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 quantifications of preference structures for the various parties, even if such preference structures are used in a hidden way.

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 where the health impact indicator is actually improved.

4.2 Eutrophication

For eutrophication, the impact indicator accumulated 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. 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*. The gap closure approach thus also addresses the transboundary effects. Its country-specific specification guarantees that improvements in local biodiversity are achieved in each country, and not traded across Europe involving very different ecosystems involved. The AAEs are represented 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 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 function that quantify associations between ozone exposure and premature mortality. Based on this indicator, the gap closure concept is applied for each country, 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.

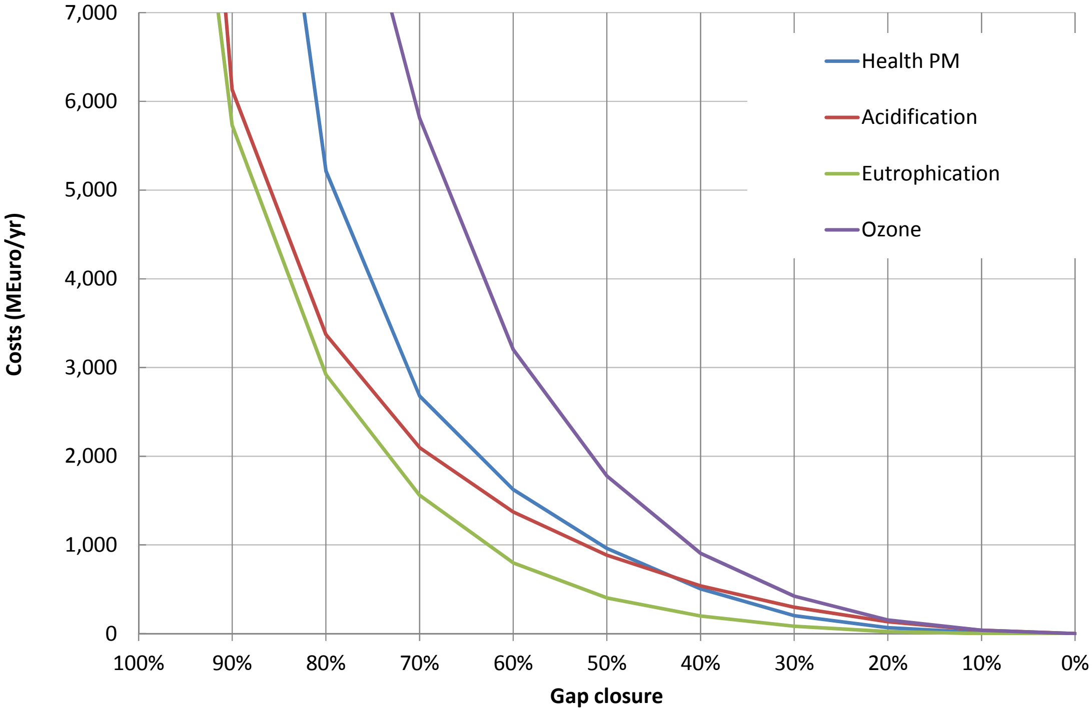
5 Exploring three ambition levels

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 rationale 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 one billion €/yr in the entire modelling domain. 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) 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 one billion €/yr (in addition to the baseline costs), a cost-effectiveness optimization that fulfills these targets for all effects simultaneously implies costs of 1.8 billion €/yr.



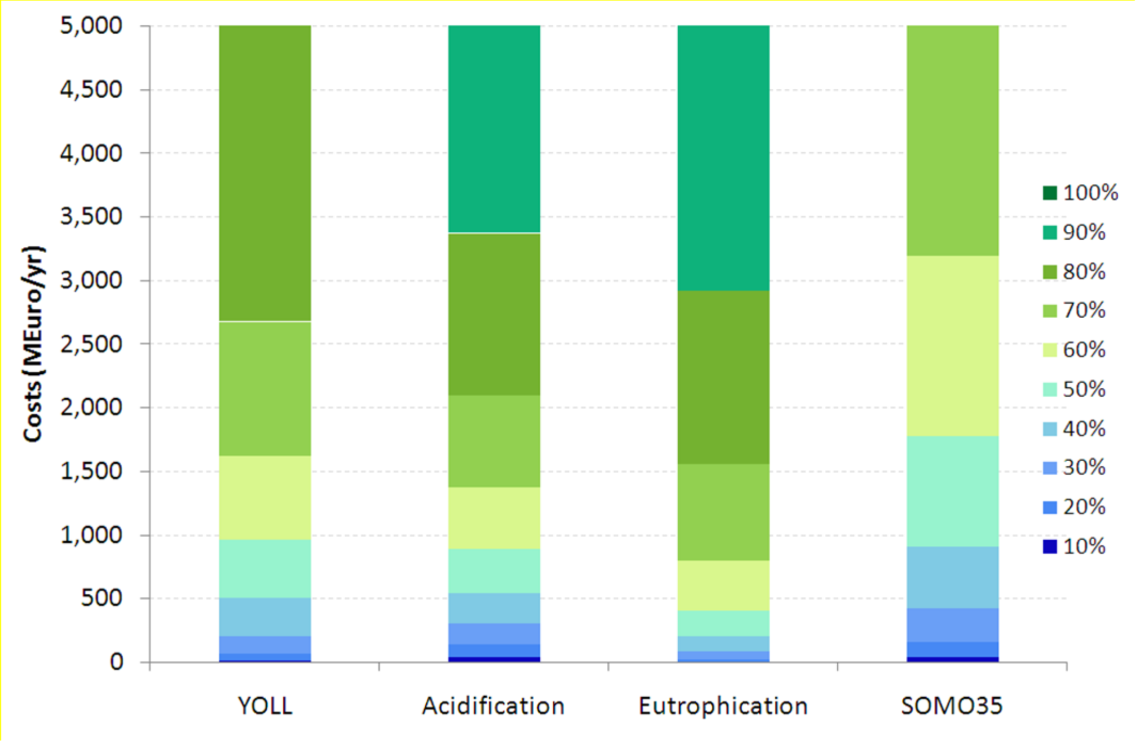


Figure 5.1: Top: Emission control costs for gap closure targets, to be achieved for the different effects individually. Bottom: Gap-closure percentages for the different effects that could be achieved for the same amount of money

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, 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 1.8 to 2.6 billion €/yr, i.e., by about 40%. Similarly, relaxing the gap closure target for ozone by 10 percentage points would lower costs from 1.8 to 1.5 billion €/yr, i.e., by about 18%. 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 emphasis attributed to ground-level ozone.

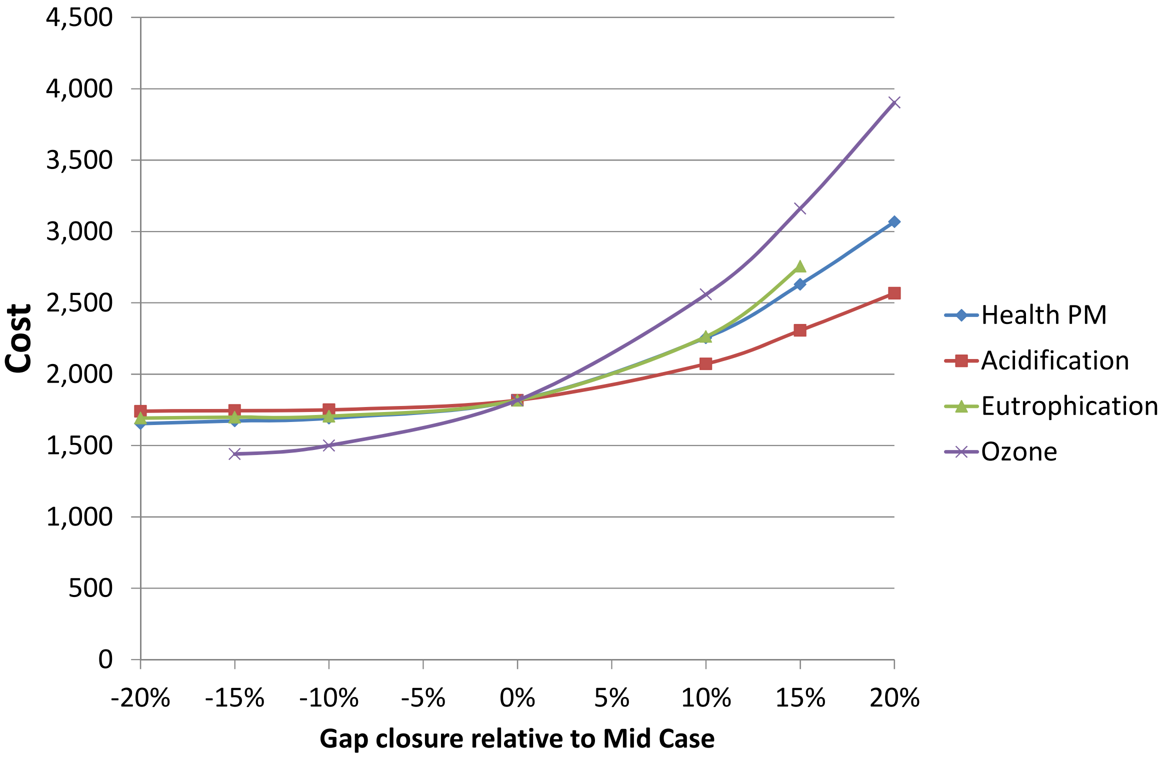


Figure 5.2: Costs for solutions in which the gap closure target for a single effect is modified while targets for the three other effects are kept at the mid case (i.e., 50% for health effects and eutrophication, 60% for acidification, 40% for ozone). Costs in billion €/yr.

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 costs for the entire modelling domain of 0.4 and 9.8 billion €/yr, respectively (compared to 1.8 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 against the ambition for ozone (Figure 5.3).

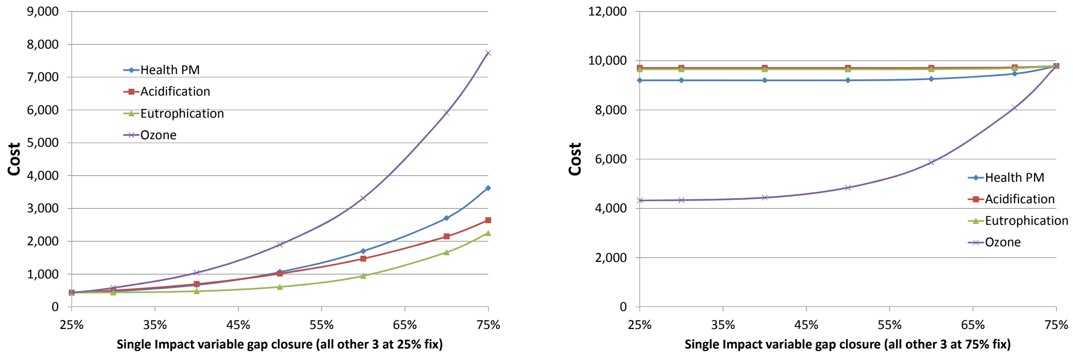


Figure 5.3: Costs for solutions in which the gap closure target for a single effect is modified while targets for the three other effects are kept. Left: variation from a 25% gap closures for all effects (LOW case); right: variation from a 75% gap closure for all effects (HIGH case)

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 0.4 to 0.6 billion €/yr for the low case, and from 9.8 to 4.8 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 scenario span a cost range from 0.4 (LOW case) over 0.6 (Low* case), 1.8 (Mid case), 4.8 (High* case) to 9.8 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, 52-60% of total costs emerge in the EU-27 (0.2 billion €/y in the LOW case, 1.0 billion in the mid case, and 5.9 billion €/yr in the HIGH case. In contrast, costs in the non-EU countries account for 40-48% 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 0.04% 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	6.4	7.8	13.4	31.2	82.1
Belgium	7.6	4.7	49.8	90.4	192.5
Bulgaria	0.9	1.5	4.7	42.1	44.8
Cyprus	0.6	1.6	3.5	6.4	6.7
Czech Rep.	10.3	10.4	20.9	55.5	176.3
Denmark	3.9	7.0	13.1	40.1	58.0
Estonia	3.3	4.7	7.8	10.1	9.4
Finland	4.5	29.3	30.2	60.4	27.9
France	23.3	42.2	110.5	342.8	919.5
Germany	31.3	51.8	161.7	269.7	970.2
Greece	4.4	8.4	13.3	31.4	104.4
Hungary	4.2	4.4	12.5	48.8	78.1
Ireland	2.9	5.6	13.8	37.4	137.1
Italy	11.9	18.9	77.9	240.1	643.6
Latvia	0.8	2.0	3.2	5.9	11.2
Lithuania	2.1	9.0	27.7	55.4	64.9
Luxembourg	0.2	0.5	0.9	1.5	15.9
Malta	0.0	0.0	0.1	0.3	2.5
Netherlands	5.5	5.9	54.3	138.9	398.8
Poland	26.7	27.1	113.0	251.1	328.1
Portugal	1.6	2.4	11.1	38.4	92.4
Romania	9.0	16.1	30.3	87.6	177.5
Slovakia	2.7	3.5	9.8	38.8	50.0
Slovenia	2.1	2.3	2.8	6.9	25.2
Spain	24.0	33.9	89.0	283.9	503.4
Sweden	11.9	8.0	17.8	37.1	29.9
UK	23.7	35.3	110.1	310.8	764.7
Albania	0.7	1.8	3.1	7.6	7.8
Belarus	13.4	38.7	63.7	141.7	224.9
Bosnia-H.	0.6	2.2	3.3	26.1	25.8
Croatia	6.1	6.7	13.2	23.8	55.1
FYROM	0.7	1.1	2.0	5.2	17.1
Moldova	1.1	2.1	4.3	9.1	14.7
Norway	6.5	11.9	18.2	70.0	90.1
Russia (EMEP)	144.3	144.3	401.3	1,198.1	2,453.4
Serbia-M.	3.4	4.6	17.4	60.2	104.0
Switzerland	2.8	4.1	5.6	25.4	46.0
Ukraine	29.1	45.9	282.1	714.3	828.1
EU-27	226	344	1,003	2,563	5,915
Non-EU	209	263	814	2,281	3,867
TOTAL	435	608	1,817	4,844	9,782

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%	0.00%	0.01%	0.03%
Belgium	0.00%	0.00%	0.01%	0.02%	0.05%
Bulgaria	0.00%	0.00%	0.01%	0.12%	0.13%
Cyprus	0.00%	0.01%	0.02%	0.03%	0.03%
Czech Rep.	0.01%	0.01%	0.01%	0.04%	0.11%
Denmark	0.00%	0.00%	0.01%	0.02%	0.02%
Estonia	0.02%	0.03%	0.05%	0.07%	0.06%
Finland	0.00%	0.01%	0.02%	0.03%	0.01%
France	0.00%	0.00%	0.01%	0.02%	0.04%
Germany	0.00%	0.00%	0.01%	0.01%	0.04%
Greece	0.00%	0.00%	0.00%	0.01%	0.04%
Hungary	0.00%	0.00%	0.01%	0.04%	0.07%
Ireland	0.00%	0.00%	0.01%	0.02%	0.06%
Italy	0.00%	0.00%	0.00%	0.01%	0.04%
Latvia	0.00%	0.01%	0.02%	0.03%	0.06%
Lithuania	0.01%	0.03%	0.09%	0.18%	0.21%
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%	0.02%	0.06%
Poland	0.01%	0.01%	0.03%	0.06%	0.08%
Portugal	0.00%	0.00%	0.01%	0.02%	0.05%
Romania	0.01%	0.01%	0.02%	0.06%	0.13%
Slovakia	0.00%	0.00%	0.01%	0.05%	0.07%
Slovenia	0.00%	0.01%	0.01%	0.02%	0.06%
Spain	0.00%	0.00%	0.01%	0.02%	0.04%
Sweden	0.00%	0.00%	0.00%	0.01%	0.01%
UK	0.00%	0.00%	0.00%	0.01%	0.03%
Albania	0.01%	0.02%	0.03%	0.07%	0.07%
Belarus	0.03%	0.09%	0.15%	0.33%	0.53%
Bosnia-H.	0.00%	0.01%	0.02%	0.17%	0.17%
Croatia	0.01%	0.01%	0.03%	0.05%	0.12%
FYROM	0.01%	0.01%	0.02%	0.06%	0.21%
Moldova	0.03%	0.05%	0.10%	0.22%	0.35%
Norway	0.00%	0.00%	0.01%	0.02%	0.03%
Russia (EMEP)	0.02%	0.02%	0.05%	0.14%	0.29%
Serbia-M.	0.01%	0.01%	0.04%	0.15%	0.26%
Switzerland	0.00%	0.00%	0.00%	0.01%	0.01%
Ukraine	0.02%	0.04%	0.24%	0.61%	0.70%
EU-27	0.00%	0.00%	0.01%	0.02%	0.04%
Non-EU	0.01%	0.01%	0.04%	0.12%	0.21%
TOTAL	0.00%	0.00%	0.01%	0.03%	0.06%

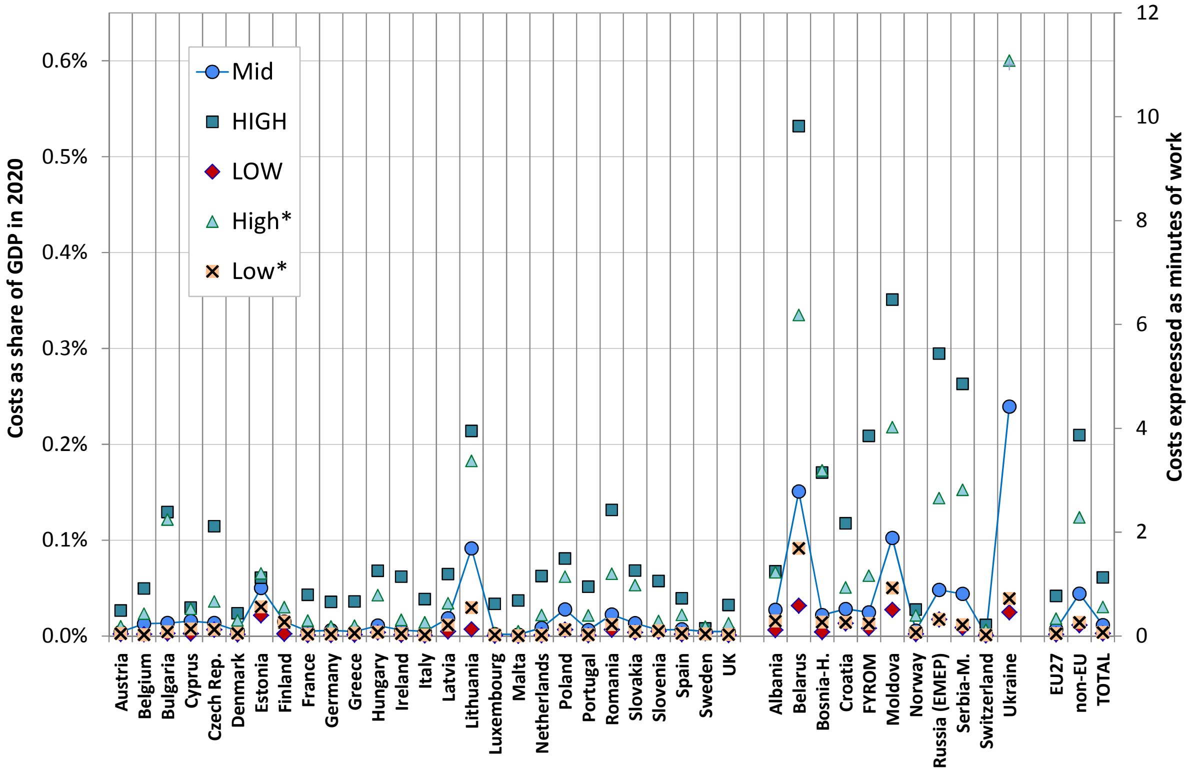


Figure 5.4: Additional air pollution control costs (on top of baseline), as a percentage of GDP in 2020, and in work time required

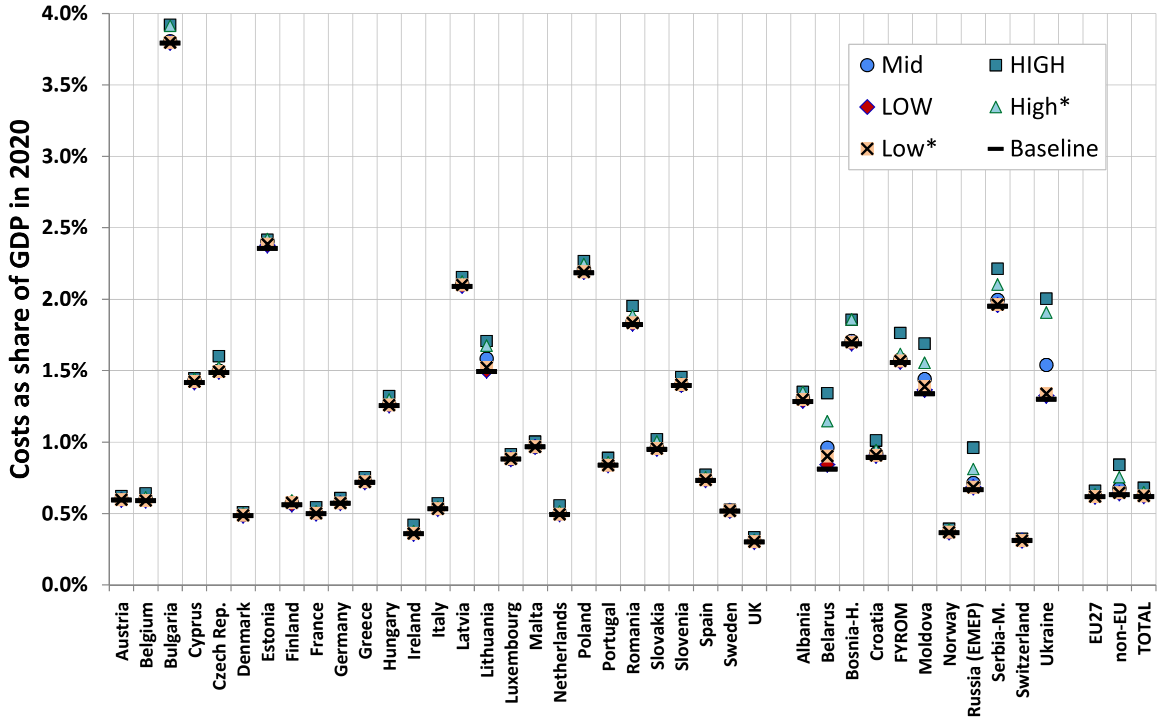


Figure 5.5: Total air pollution control costs (including current legislation) as percentage of GDP in 2020

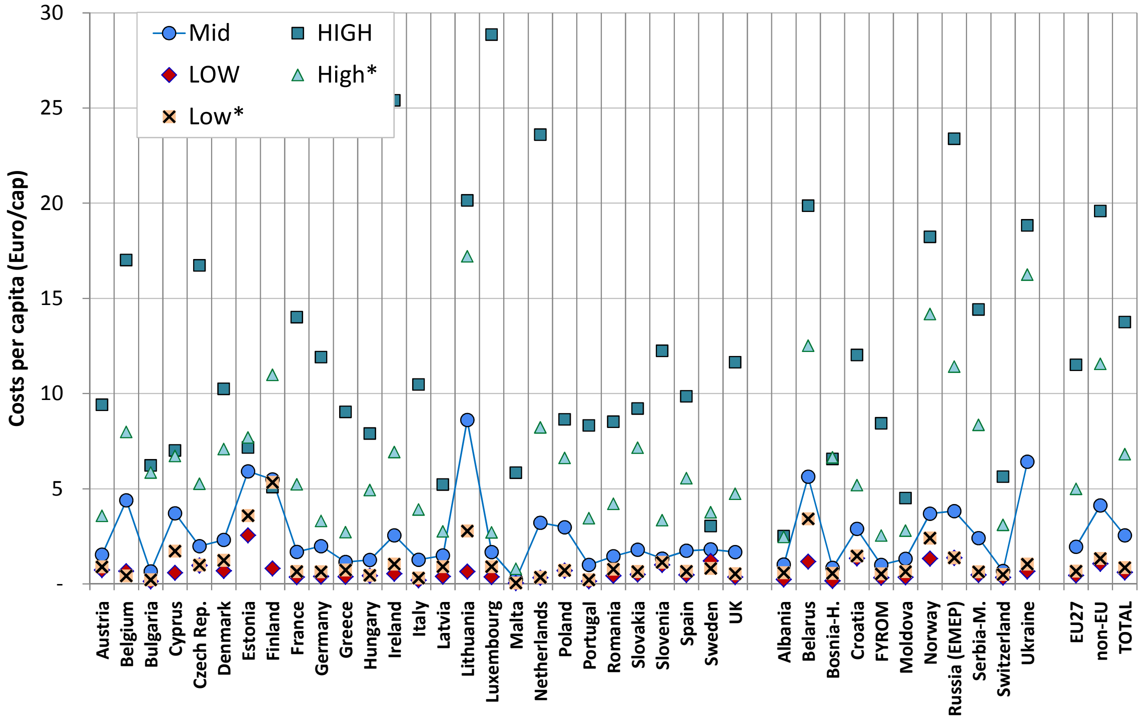


Figure 5.6: Air pollution control costs (on top of the costs for the baseline), on a per-capita basis (€/cap/yr)

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 6% (in relation to year 2000 emissions), depending on the ambition level. NO_x emissions are between 2 and 8% lower, PM2.5 emissions 6-12%, NH_3 emissions 10-21%, 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 7-45% below the baseline level, NO_x by 6-25%, PM2.5 by 29-64%, NH_3 by 9-22%, and VOC by 10-19% (Figure 5.7).

Results for individual countries are provided in Table 5.5 to Table 5.9.

Table 5.4: Change in emission levels for the emission control scenarios

		Ambition level				
	Baseline	LOW	Low*	Mid	High*	HIGH
EU-27						
SO_2	-74%	-74%	-74%	-76%	-80%	-79%
NO_x	-56%	-58%	-59%	-61%	-62%	-64%
PM2.5	-40%	-46%	-45%	-48%	-52%	-52%
NH_3	-10%	-20%	-28%	-30%	-33%	-31%
VOC	-46%	-50%	-49%	-51%	-51%	-55%
Non-EU countries						
SO_2	-27%	-34%	-34%	-51%	-75%	-72%
NO_x	-29%	-35%	-35%	-40%	-46%	-54%
PM2.5	0%	-29%	-23%	-53%	-67%	-64%
NH_3	2%	-11%	-19%	-22%	-29%	-24%
VOC	-25%	-35%	-35%	-38%	-38%	-44%

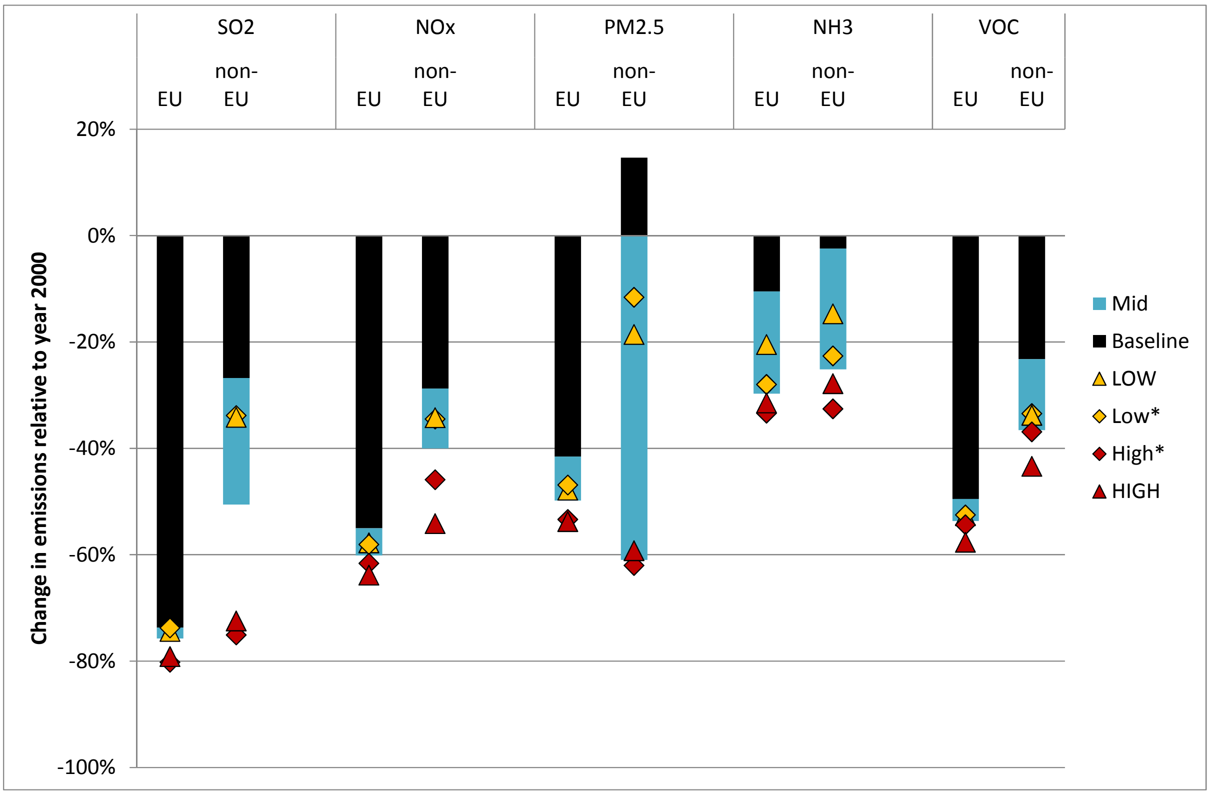


Figure 5.7: Change in emissions relative to the year 2000 for the different ambition levels

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	66	66	62
Bulgaria	888	132	132	132	132	86	127	80
Cyprus	47	5	5	5	5	5	5	2
Czech Rep.	294	106	106	106	101	95	98	93
Denmark	29	11	11	11	11	10	11	10
Estonia	85	16	14	16	14	14	14	12
Finland	77	42	41	41	39	41	40	37
France	633	199	198	198	193	148	149	132
Germany	619	329	328	329	326	318	323	300
Greece	543	112	111	111	111	107	111	45
Hungary	452	64	59	64	59	32	34	30
Ireland	144	28	27	28	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	9	9	9	7
Luxembourg	2	1	1	1	1	1	1	1
Malta	24	1	1	1	1	1	1	1
Netherlands	72	32	32	32	32	31	31	30
Poland	1490	468	443	467	372	311	338	299
Portugal	285	64	63	63	63	44	48	33
Romania	776	145	144	144	144	86	95	76
Slovakia	121	42	41	41	41	24	28	22
Slovenia	100	17	17	17	17	14	15	13
Spain	1433	311	288	310	261	208	205	168
Sweden	45	29	28	29	29	29	29	28
UK	1193	227	220	227	204	166	173	149
Albania	11	10	10	10	10	6	10	5
Belarus	172	89	82	89	73	48	50	34
Bosnia-H.	193	44	44	44	43	26	31	22
Croatia	75	20	20	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	1525	1521	1311	669	759	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	237	143
EU27	10398	2732	2654	2726	2518	2052	2166	1,783
Non-EU	4436	3245	2916	2931	2191	1103	1220	719
Total	14834	5977	5570	5657	4709	3155	3386	2,502

Table 5.6: NO_x emissions by country (kilotons)

			Ambition level					
	2000	2020 BL	LOW	Low*	Mid	High*	HIGH	MTFR
Austria	195	94	90	90	89	88	83	80
Belgium	337	168	162	162	154	150	148	138
Bulgaria	158	68	66	66	63	58	53	52
Cyprus	22	13	12	12	11	10	9	8
Czech Rep.	308	150	139	140	135	129	115	110
Denmark	217	84	74	73	69	67	66	64
Estonia	33	21	16	15	15	15	15	12
Finland	221	123	119	113	113	108	111	103
France	1,548	568	529	530	504	490	455	444
Germany	1,707	707	693	692	654	645	613	601
Greece	330	235	203	202	197	193	179	174
Hungary	177	86	80	80	76	73	70	63
Ireland	141	68	62	62	59	57	52	52
Italy	1,433	677	633	632	594	576	523	505
Latvia	37	22	21	21	20	20	20	19
Lithuania	54	28	27	26	25	25	24	23
Luxembourg	44	17	17	17	17	17	16	16
Malta	9	3	3	3	3	3	3	3
Netherlands	416	169	160	160	157	155	155	138
Poland	823	426	405	408	381	367	350	342
Portugal	269	104	99	100	94	93	85	83
Romania	265	155	140	141	129	123	110	100
Slovakia	102	57	53	53	49	46	43	39
Slovenia	48	27	25	25	25	25	25	24
Spain	1,416	689	642	641	613	576	528	521
Sweden	238	95	86	86	82	80	79	78
UK	1,859	655	613	586	553	512	499	439
Albania	17	18	16	15	14	14	14	14
Belarus	181	150	129	119	119	116	95	91
Bosnia-H.	38	22	21	20	20	15	14	14
Croatia	67	46	37	37	35	34	30	29
FYROM	33	19	18	18	17	16	14	14
Moldova	21	19	17	17	17	16	15	14
Norway	207	136	104	103	99	90	87	87
Russia (EMEP)	3,009	2,144	2,031	2,032	1,841	1,659	1,351	1,221
Serbia-M.	137	91	85	85	79	70	64	63
Switzerland	94	44	43	43	42	40	40	39
Ukraine	912	646	579	576	527	463	424	380
EU27	12,407	5,511	5,170	5,134	4,882	4,701	4,429	4,233
Non-EU	4,717	3,337	3,079	3,066	2,809	2,534	2,147	1,964
Total	17,123	8,848	8,249	8,200	7,691	7,235	6,576	6,197

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	12	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	23	23	22	21	13
Denmark	25	19	19	19	19	17	16	8
Estonia	20	7	6	6	6	6	5	3
Finland	32	21	21	21	21	19	18	9
France	365	206	195	196	190	176	175	106
Germany	140	83	79	80	79	76	76	62
Greece	55	33	25	26	25	25	24	16
Hungary	45	22	19	19	19	18	17	10
Ireland	14	8	8	8	8	7	7	6
Italy	160	81	76	76	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	15	15	14	14	13
Poland	132	96	90	90	88	86	85	68
Portugal	95	58	48	49	34	28	28	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	5	3	3
Spain	142	89	75	75	75	71	71	53
Sweden	32	19	19	19	19	18	19	14
UK	115	53	51	51	50	45	46	41
Albania	8	8	6	6	6	6	5	2
Belarus	46	48	31	33	30	28	28	15
Bosnia-H.	15	13	11	12	11	10	10	5
Croatia	19	14	10	10	9	7	7	4
FYROM	14	7	5	6	5	4	4	2
Moldova	10	9	4	6	4	4	3	2
Norway	61	31	30	30	30	29	29	15
Russia (EMEP)	717	778	517	561	330	227	228	186
Serbia-M.	70	48	38	39	37	31	32	14
Switzerland	11	7	6	6	6	6	5	4
Ukraine	357	368	286	315	154	90	120	69
EU27	1,743	1,052	937	954	902	838	831	567
Non-EU	1,328	1,330	944	1,025	622	440	473	319
Total	3,071	2,381	1,881	1,979	1,525	1,279	1,304	886

Table 5.8: NH_3 emissions by country (kilotons)

			Ambition level					
	2000	2020 BL	LOW	Low*	Mid	High*	HIGH	MTFR
Austria	60	57	55	48	47	42	44	36
Belgium	84	75	71	71	70	69	69	67
Bulgaria	69	58	56	54	54	53	55	51
Cyprus	6	5	5	4	4	4	4	4
Czech Rep.	86	65	57	54	53	52	53	50
Denmark	91	52	51	50	49	48	49	46
Estonia	11	11	7	7	6	6	7	6
Finland	35	29	26	25	25	24	26	24
France	703	597	553	483	467	435	447	387
Germany	626	598	491	428	418	407	411	371
Greece	54	49	47	41	40	38	42	37
Hungary	77	61	55	51	50	45	46	42
Ireland	132	98	92	87	85	82	83	77
Italy	420	383	325	299	287	255	273	229
Latvia	13	11	11	9	9	9	9	9
Lithuania	37	45	40	35	33	29	30	24
Luxembourg	6	5	5	5	5	4	4	4
Malta	2	2	2	2	2	2	2	2
Netherlands	150	124	123	120	119	115	115	112
Poland	315	353	309	279	279	271	279	248
Portugal	71	67	62	58	54	49	49	43
Romania	167	143	129	106	105	103	105	90
Slovakia	30	22	19	16	15	15	15	13
Slovenia	20	16	15	14	13	12	13	11
Spain	372	361	311	276	264	245	256	210
Sweden	54	45	39	39	39	36	39	35
UK	328	265	244	236	232	228	228	221
Albania	18	23	21	19	18	17	18	15
Belarus	117	150	142	123	119	111	117	102
Bosnia-H.	17	19	17	14	14	13	14	11
Croatia	29	33	24	22	20	19	20	16
FYROM	10	9	8	7	7	7	7	6
Moldova	16	16	15	13	12	11	12	10
Norway	24	21	20	17	17	15	16	13
Russia (EMEP)	552	555	466	448	434	375	409	316
Serbia-M.	65	55	45	40	38	35	36	30
Switzerland	51	51	49	46	45	43	43	40
Ukraine	292	285	257	217	210	195	210	176
EU27	4,018	3,599	3,197	2,895	2,825	2,677	2,755	2,450
Non-EU	1,191	1,218	1,064	966	934	841	900	736
Total	5,210	4,817	4,261	3,861	3,760	3,518	3,656	3,186

Table 5.9: VOC emissions by country (kilotons)

			Ambition level					
	2000	2020 BL	LOW	Low*	Mid	High*	HIGH	MTFR
Austria	184	111	106	106	106	103	95	73
Belgium	215	128	124	124	118	117	110	108
Bulgaria	130	79	71	71	71	71	68	40
Cyprus	11	5	5	5	5	5	5	4
Czech Rep.	218	147	137	137	136	134	109	81
Denmark	141	73	71	71	69	68	61	44
Estonia	44	21	20	20	20	20	19	14
Finland	163	71	69	69	69	69	65	52
France	1,706	714	699	700	686	667	621	472
Germany	1,490	867	771	774	748	733	660	579
Greece	296	146	134	135	134	134	117	87
Hungary	168	104	94	94	93	93	87	59
Ireland	78	49	47	48	43	43	34	29
Italy	1,580	772	752	752	750	742	716	615
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	3	2	2
Netherlands	249	155	151	152	143	137	124	122
Poland	616	339	319	323	314	314	293	218
Portugal	276	175	159	159	154	154	139	115
Romania	437	300	268	268	264	262	229	128
Slovakia	73	56	55	56	54	54	51	38
Slovenia	57	30	29	29	29	29	21	16
Spain	1,042	642	615	615	596	593	591	461
Sweden	256	119	114	114	112	112	111	93
UK	1,330	669	602	607	586	567	518	487
Albania	29	19	17	17	17	17	17	10
Belarus	210	184	166	167	165	165	145	108
Bosnia-H.	49	29	27	27	27	27	24	13
Croatia	101	70	60	60	60	60	51	43
FYROM	28	14	13	13	13	13	12	8
Moldova	25	25	20	20	20	20	19	14
Norway	381	85	80	82	77	76	75	65
Russia (EMEP)	3,140	2,516	2,147	2,155	2,026	2,011	1,800	1,472
Serbia-M.	132	113	101	102	101	101	92	50
Switzerland	146	80	70	70	70	70	64	52
Ukraine	636	536	464	467	458	458	407	312
EU27	10,938	5,886	5,516	5,534	5,403	5,321	4,937	3,989
Non-EU	4,876	3,673	3,167	3,182	3,034	3,017	2,707	2,146
Total	15,814	9,559	8,683	8,715	8,437	8,338	7,644	6,135

5.4 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 overachieved (if this 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 Table 5.13 provide results for all countries.

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

			Ambition level				
	2000	2020 BL	LOW	Low*	Mid	High*	HIGH
Austria	7.9	3.6	3.4	3.3	3.1	2.9	2.8
Belgium	13.7	6.5	6.1	6.1	5.8	5.4	5.3
Bulgaria	8.3	3.9	3.5	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	4.2	4.2	3.9	3.5	3.5
Denmark	7.1	3.6	3.3	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	3.5	3.5	3.3	3.1	3.0
Germany	10.2	4.8	4.5	4.4	4.2	3.9	3.8
Greece	8.1	4.0	3.8	3.8	3.6	3.2	3.3
Hungary	11.5	5.2	4.6	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	3.7	3.7	3.5	3.2	3.2
Latvia	6.0	3.9	3.5	3.5	3.2	2.8	2.8
Lithuania	6.2	3.6	3.2	3.1	2.8	2.4	2.3
Luxembourg	10.1	4.7	4.4	4.3	4.1	3.8	3.8
Malta	5.9	4.2	4.2	4.2	4.1	3.9	3.9
Netherlands	13.0	6.1	5.8	5.7	5.5	5.2	5.1
Poland	10.2	5.1	4.7	4.7	4.2	3.8	3.8
Portugal	6.7	3.5	3.1	3.2	2.7	2.4	2.4
Romania	9.6	4.8	4.2	4.3	3.7	3.0	3.0
Slovakia	9.9	4.5	4.1	4.1	3.7	3.2	3.2
Slovenia	8.8	4.1	3.7	3.7	3.4	3.1	2.9
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	3.0	2.9	2.7	2.7
Albania	5.3	2.7	2.4	2.5	2.3	2.0	2.0
Belarus	6.9	4.5	3.9	3.8	3.2	2.6	2.6
Bosnia-H.	5.9	2.8	2.5	2.5	2.3	2.0	2.0
Croatia	8.5	4.1	3.7	3.7	3.4	2.9	2.9
FYROM	6.2	2.7	2.4	2.5	2.2	1.9	1.9
R Moldova	8.1	4.7	4.0	4.1	3.2	2.4	2.4
Norway	2.5	1.3	1.2	1.2	1.1	1.1	1.1
Russia	7.5	6.7	5.3	5.4	4.1	2.9	2.9
Serbia	8.1	3.6	3.2	3.2	2.9	2.4	2.4
Switzerland	6.5	2.9	2.7	2.7	2.6	2.3	2.3
Ukraine	9.2	6.6	5.7	5.8	4.0	2.8	3.0
EU-27	8.6	4.1	3.8	3.7	3.5	3.2	3.2
Non-EU	7.7	6.0	4.9	5.0	3.8	2.7	2.8
Total	8.3	4.6	4.1	4.1	3.6	3.0	3.0

Table 5.11: Forest area with acid deposition exceeding critical loads [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	0.6	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	4.3	3.7	3.5	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	1.4	1.2	1.2
France	170.7	18.5	4.5	3.9	3.4	2.9	1.9	2.0
Germany	99.8	61.6	20.0	14.6	12.3	10.9	9.2	9.2
Greece	17.6	1.4	0.2	0.1	0.1	0.1	0.0	0.0
Hungary	13.5	5.6	0.7	0.6	0.5	0.4	0.1	0.1
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	4.3	4.3	4.3	4.2	4.2	4.2
Poland	87.6	72.4	33.5	28.8	27.5	23.7	19.2	20.5
Portugal	17.8	3.0	0.9	0.7	0.6	0.6	0.2	0.5
Romania	98.0	52.7	4.1	3.7	3.9	2.6	0.4	0.6
Slovakia	17.0	3.7	1.4	1.1	0.9	0.4	0.0	0.0
Slovenia	10.8	0.8	0.0	0.0	0.0	0.0	0.0	0.0
Spain	69.5	5.4	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	1.0	1.0
UK	19.7	10.9	2.5	2.2	2.1	1.9	1.6	1.6
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	1.8	0.6	0.1	0.1
Bosnia-H.	20.0	3.8	0.0	0.0	0.0	0.0	0.0	0.0
Croatia	17.8	1.3	0.5	0.4	0.1	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	22.7	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	0.7	0.2	0.2	0.2	0.1	0.1	0.1
Ukraine	71.1	5.7	1.0	0.8	0.7	0.0	0.0	0.0
EU-27	1283.0	301.6	89.6	75.7	70.6	60.9	47.5	49.9
Non-EU	2040.2	55.3	21.3	16.2	15.1	11.8	5.0	6.6
Total	3323.2	356.9	110.9	91.9	85.8	72.7	52.4	56.4

Table 5.12: Ecosystems area with nitrogen deposition exceeding critical loads [1000 km^2]

	Total area	2000	2020 BL	Ambition level LOW	Low*	Mid	High*	HIGH
Austria	40.3	40.2	27.4	20.4	14.1	11.5	8.0	8.0
Belgium	6.3	6.2	5.1	4.8	4.4	4.0	3.7	3.7
Bulgaria	48.3	45.3	27.4	18.3	16.6	15.9	13.8	12.9
Cyprus	2.5	1.6	1.6	1.6	1.5	1.4	1.4	1.4
Czech Rep.	27.6	27.6	27.6	27.6	27.5	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	16.8	7.9	5.4	4.8	4.2	3.7	3.5
Finland	240.4	112.9	61.9	51.8	45.8	42.9	34.4	33.6
France	180.1	176.2	151.9	139.3	128.2	120.6	108.5	108.4
Germany	102.9	87.7	64.8	55.0	48.1	45.5	43.1	42.5
Greece	52.9	52.6	51.6	50.2	48.9	48.1	47.1	46.8
Hungary	20.8	20.8	19.6	18.5	17.1	15.8	14.3	14.0
Ireland	2.4	2.2	1.9	1.8	1.8	1.8	1.8	1.7
Italy	124.8	87.9	61.3	47.4	41.2	38.9	33.9	34.7
Latvia	35.8	35.6	32.8	30.6	28.9	28.0	26.2	25.6
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	3.6	3.6
Poland	90.3	90.2	88.7	86.3	84.1	83.0	81.8	81.8
Portugal	31.0	29.9	18.9	14.5	12.7	10.9	9.1	8.8
Romania	98.0	19.5	1.0	0.4	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	10.7	6.1	3.5	1.6	0.7	0.4	0.4
Spain	187.1	176.9	165.1	157.7	151.8	146.2	135.8	135.8
Sweden	150.7	83.0	54.8	49.2	47.2	45.6	43.1	43.1
UK	92.0	23.8	13.8	12.6	11.8	11.2	10.6	10.5
Albania	17.0	16.9	16.7	16.1	15.7	15.2	14.7	14.4
Belarus	64.0	63.9	62.0	58.8	55.7	54.6	52.8	52.8
Bosnia-H.	31.9	28.2	22.8	20.5	19.1	18.1	16.1	15.7
Croatia	31.7	31.7	31.1	30.9	30.7	30.4	30.1	29.8
FYROM	13.9	13.9	13.9	13.5	12.5	11.7	11.1	10.8
R Moldova	3.5	3.4	3.2	3.2	2.6	2.3	2.2	2.1
Norway	135.3	27.6	11.8	9.1	7.5	6.8	6.2	6.0
Russia	1821.6	454.8	180.4	123.9	108.2	87.8	68.4	62.7
Serbia	41.1	39.6	31.8	26.4	22.3	19.9	17.4	17.2
Switzerland	9.6	9.5	9.0	8.0	7.4	6.9	6.7	6.5
Ukraine	72.2	72.2	72.2	72.2	72.0	71.8	71.3	71.0
EU-27	1618.4	1195.9	939.0	844.3	785.0	750.6	695.0	691.7
Non-EU	2241.7	761.7	454.9	382.5	353.8	325.7	297.0	289.0
Total	3860.1	1957.6	1393.9	1226.8	1138.8	1076.3	992.0	980.7

Table 5.13: Premature deaths attributable to ozone (cases/yr)

			Ambition level				
	2000	2020 BL	LOW	Low*	Mid	High*	HIGH
Austria	472	279	268	268	261	256	245
Belgium	526	335	323	323	316	311	299
Bulgaria	550	365	346	346	334	324	306
Cyprus	28	26	26	26	26	26	26
Czech Rep.	670	367	348	348	336	327	307
Denmark	222	150	144	144	141	139	135
Estonia	25	18	18	18	17	17	16
Finland	61	46	45	44	44	43	42
France	2975	1841	1783	1783	1748	1723	1666
Germany	4706	2954	2851	2851	2785	2748	2644
Greece	657	499	477	477	469	462	445
Hungary	853	509	481	481	464	451	427
Ireland	99	79	78	78	77	76	75
Italy	5084	3325	3212	3212	3145	3100	2987
Latvia	60	42	40	40	39	38	37
Lithuania	91	62	59	59	57	56	53
Luxembourg	42	22	21	21	21	20	19
Malta	29	19	19	19	18	18	17
Netherlands	520	332	319	319	311	306	292
Poland	1678	1007	957	957	922	898	853
Portugal	600	445	434	434	428	424	413
Romania	1208	791	743	743	714	691	649
Slovakia	296	163	153	153	146	141	132
Slovenia	131	73	69	69	66	65	61
Spain	2117	1533	1496	1495	1473	1451	1416
Sweden	223	159	154	153	151	149	145
UK	2180	1662	1617	1619	1599	1585	1547
Albania	129	90	86	86	84	82	78
Belarus	322	222	208	207	200	194	180
Bosnia-H.	253	148	139	139	133	128	120
Croatia	356	217	205	205	198	194	183
FYROM	98	74	72	72	71	69	67
R Moldova	182	127	120	120	115	111	105
Norway	99	81	79	79	78	78	77
Russia	4702	3905	3727	3727	3621	3550	3370
Serbia	499	346	331	331	322	313	299
Switzerland	400	244	236	236	232	228	220
Ukraine	2543	1893	1793	1791	1735	1688	1600
EU-27	26101	17104	16480	16480	16108	15844	15256
Non-EU	11613	8971	8563	8559	8320	8138	7751
Total	37714	26075	25043	25039	24428	23982	23007

5.4.1 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 5.8). For comparison, radiative forcing of the long-lived Kyoto greenhouse gases is currently estimated at around 2.7 W/m^2 (IPCC AR4).

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.

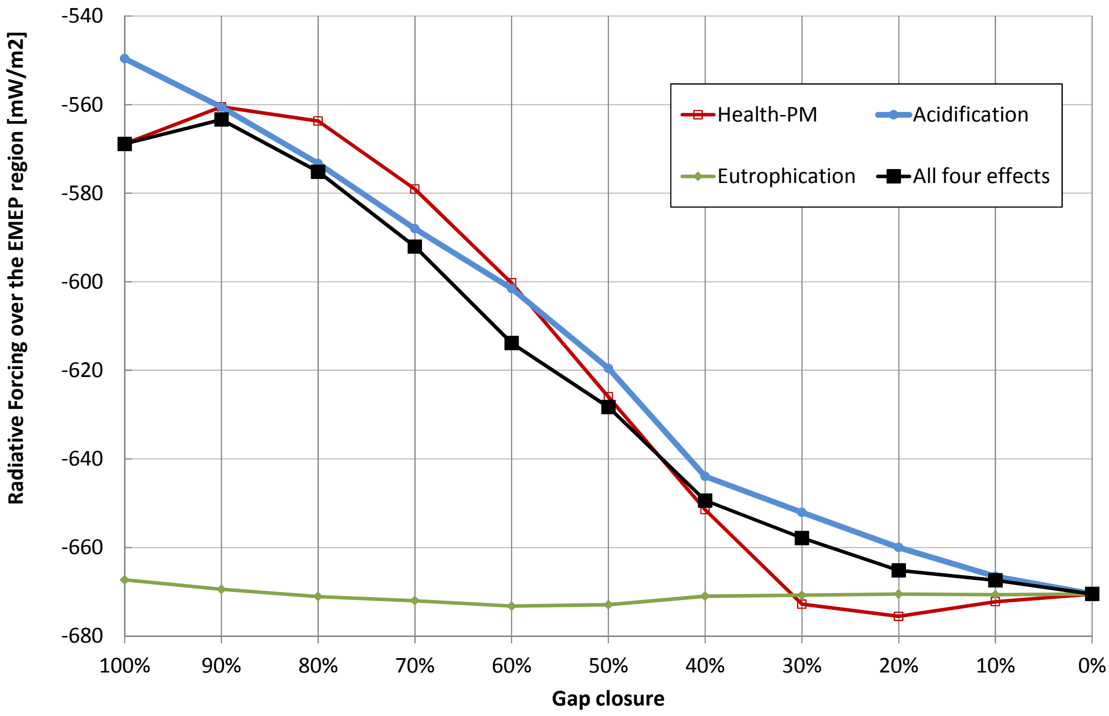


Figure 5.8: Side-effects on instantaneous radiative forcing over the EMEP region from the scenarios optimized for the air pollution targets.

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 5.14). 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 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 5.14: 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	-493
EMEP domain	-671	-662	-664	-631	-577	-583	-569	-696
Arctic > 60°	-110	-109	-109	-106	-99	-100	-100	-115
Arctic > 70°	-48	-49	-49	-47	-45	-45	-46	-53
Radiative Forcing - for the EMEP domain, by component [mW/m^2]								
Total	-671	-662	-664	-631	-577	-583	-569	-696
BC	134	121	123	121	120	119	96	97
OC	-35	-29	-30	-29	-29	-28	-22	-24
SO_4	-723	-709	-713	-680	-626	-634	-604	-723
NO_3	-46	-44	-44	-43	-42	-40	-39	-46
Total carbon deposition (BC and OC, dry and wet) [mg/m^2.yr]								
Arctic > 60°	4.9	4.3	4.4	4.3	4.3	4.2	3.5	3.7
Arctic > 70°	1.3	1.2	1.2	1.2	1.2	1.2	1.0	1.0
Alps	59.6	55.5	55.6	55.3	54.3	53.0	39.0	43.5

6 Sensitivity analyses

6.1 Alternative projections of economic activities

To come later ….

6.2 Low-cost options to reduce radiative forcing

The preceding section 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. In particular, 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 6.1).

Compared to the pure cases where impacts of radiative forcing are completely ignored, consideration of near-term climate impacts would gradually relax pressure on SO_2 emission (Figure 6.2. Instead, primary emissions of PM2.5 and of NH_3 are reduced more, while 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.

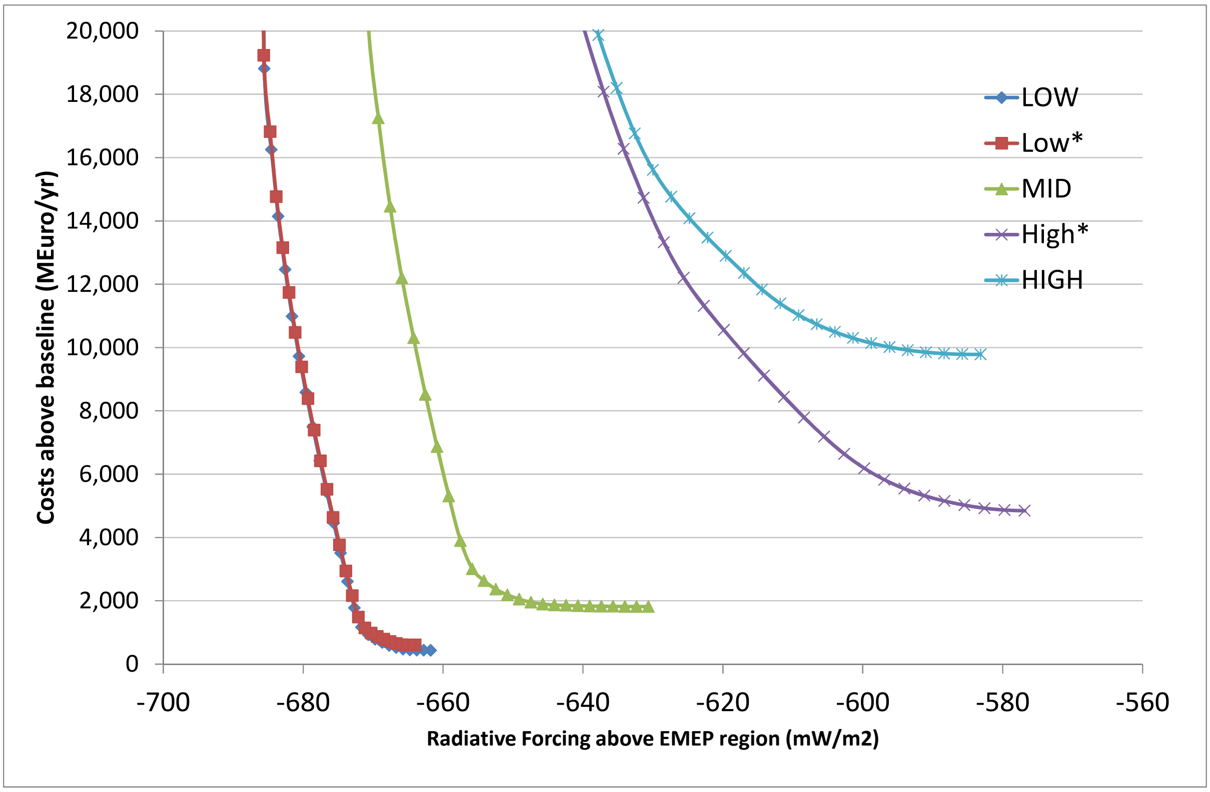


Figure 6.1: Emission control costs (above the baseline) for additional reductions of instantaneous reductions of radiative forcing for the five cost-optimized scenarios that address the four air quality impacts.

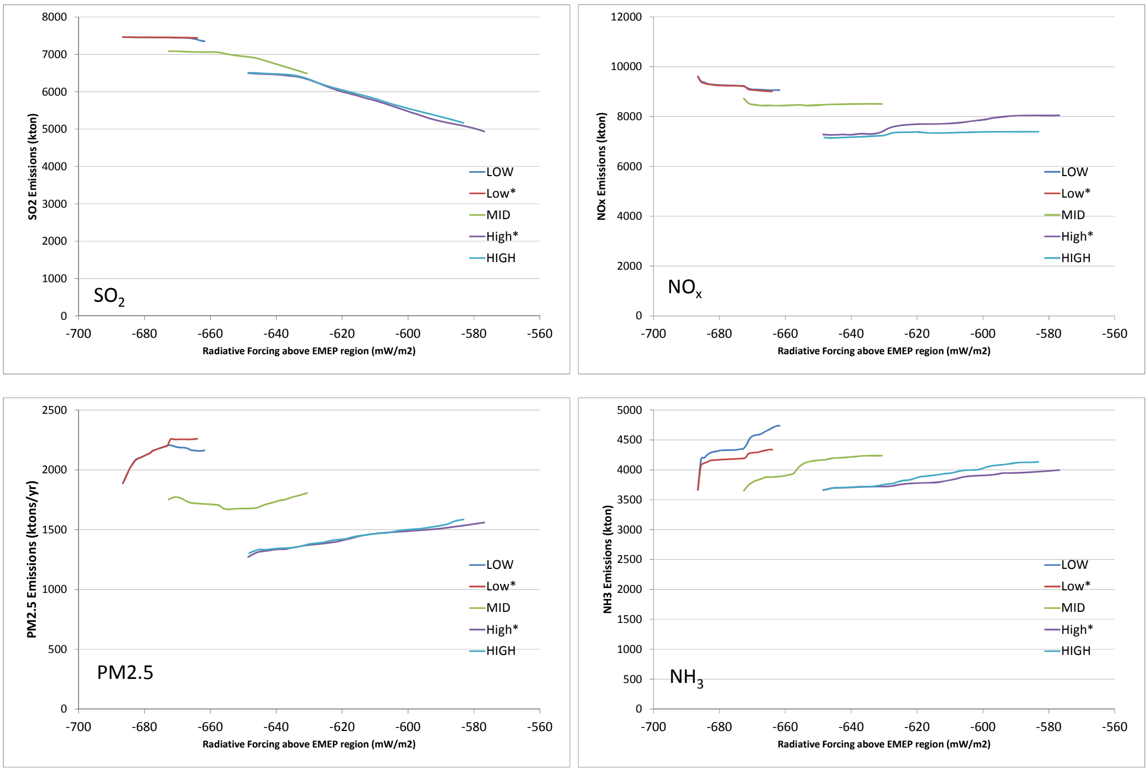


Figure 6.2: Cost-effective changes in emissions for reducing radiative forcing, in addition to the targets for air quality impacts. Note that, as this preliminary analysis addresses only radiative forcing from aerosols, changes in VOC emissions occur only at stringent reductions.

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. 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 a least-cost optimization results 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: million of years of life lost)

	Baseline	Target	MTFR
Mid case (original)	193.5	151.1	108.6
Sensitivity case without urban increment	187.7	146.2	104.7

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)	2,518	4,882	902	188	238
Sensitivity case without urban increment	2,515	4,883	905	188	238
Difference (absolute)	2	-1	-3	0	0
Difference (%)	0.09%	-0.02%	-0.32%	-0.02%	-0.04%

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 as 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 emission 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. The report provides an initial analysis for discussion at the 39th Meeting of the Task Force on Integrated Assessment Modelling. A full assessment for presentation to the Working Group on Strategies will require further refinements, based on feedbacks from the Task Force.

For a Europe-wide coherent projection of economic activities, the analysis envisages considerable changes in the structure of economic activities. Together with progressing 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 4.6 months, there will be more than 26,000 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, although such improvements would come at substantial costs. Cost-effective emission control scenarios are presented that achieve 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 0.4 to 9.8 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 impose 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.

The results presented in this report should serve as a background to the discussions of the 39th Session of the Task Force on Integrated Assessment Modelling. A full analysis that also responds to the other questions of the Working Group on Strategies, inter alia, on the analysis of specific measures that would be cost-effective to achieve the identified emission ceilings in the various countries, requires more work that could not be completed in time for this report. Furthermore, it might be interesting to explore options for achieving a more uniform distribution of emission control costs across the EMEP domain. Such analyses, together with feedbacks from the Task Force, will be incorporated into the final report of CIAM to the 48th Session of the Working Group on Strategies in April 2011.

References

Amann M. et al., (2010). Cost-effective emission reductions to improve air quality in Europe in 2020. CIAM Report 1/2010, EMEP Centre for Integrated Assessment Modelling, International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria

Capros, P., L. Mantzos, V. Papandreou and N. Tasios (2008). European Energy and Transport Trends to 2030 — Update 2007. European Commission Directorate-General for Energy and Transport, Brussels, Belgium

CEC (2007a). Euro VI - emissions from heavy duty vehicles. Commission of the European Communities, Brussels, Belgium

CEC (2007b). Commission Staff Working Document Accompanying the Document to the Proposal for a Directive of the European Parliament and of the Council on Industrial Emissions (Integrated Pollution Prevention and Control). Impact Assessment. Commission of the European Communities Brussels, Belgium

DieselNet (2009). Emission Standards. Summary of worldwide diesel emission standards.

EMEP (2010). Transboundary acidification, eutrophication and ground level ozone in Europe in 2008. EMEP Report 1/2010, Norwegian Meteorological Institute, Oslo, Norway

FAO (2003). World Agriculture: towards 2015/2030. FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, Rome

Gkatzoflias D., Ntziachristos L., Samaras Z. (2007). COPERT 4. Computer programme to calculate emissions from road transport - Users Manual. European Environment Agency, European Topic Centre on Air Air and Climate Change (ETC-ACC), Copenhagen

Hettelingh, J.-P., M. Posch and J. Slootweg (2008). CCE Status Report 2008: Critical Load, Dynamic Modelling and Impact Assessment in Europe. Coordination Centre for Effects, Netherlands Environmental Assessment Agency, Bilthoven, Netherlands, http://www.pbl.nl/en/themasites/cce/publications/cce-status-report-2008/index.html

IEA (2009). World Energy Outlook 2009. OECD/International Energy Agency, Paris, France

IEACCC (2009). Coal Power Database. IEA Clean Coal Centre, London, UK

Myhre, G., T. F. Berglen, M. Johnsrud, C. R. Hoyle, T. K. Berntsen, S. A. Christopher, D. W. Fahey, I. S. A. Isaksen, T. A. Jones, R. A. Kahn, N. Loeb, P. Quinn, L. Remer, J. P. Schwarz and K. E. Yttri (2009). Modelled radiative forcing of the direct aerosol effect with multi-observation evaluation. Atmospheric Chemistry and Physics **9**(4): 1365-1392.

OJ (2001a). Directive 2001/81/EC of the European Parliament and of the Council of 23 October 2001on national emission ceilings for certain atmospheric pollutants. Official Journal of the European Union OJ L2001/309/22.

OJ (2001b). Directive 2001/80/EC of the European Parliament and of the Council of 23 October 2001 on the limitation of emissions of certain pollutants into the air from large combustion plants. Official Journal of the European Union OJ L2001/309/1

OJ (2003). Directive 2003/17/EC of the European Parliament and of the Council of 3 March 2003 amending Directive 98/70/EC relating to the quality of petrol and diesel fuels Official Journal of the European Union, OJ L 2003/76/10.

OJ (1999). Council Directive 1999/32/EC of 26 April 1009 relating to a reduction in the sulphur content of certain liquid fuels and amending directive 93/12/EEC. Official Journal of the European Union OJ:L 1999/121/13.

OJ (2009a). Regulation (EC) No 595/2009 of the European Parliament and of the Council of 18 June 2009 on type-approval of motor vehicles and engines with respect to emissions from heavy duty vehicles (Euro VI) and on access to vehicle repair and maintenance information and amending Regulation (EC) No 715/2007 and Directive 2007/46/EC and repealing Directives 80/1269/EEC, 2005/55/EC and 2005/78/EC. Official Journal of the European Union OJ L/2009/188/1.

OJ (2009b). Directive 2009/30/EC of the European Parliament and of the Council of 23 April 2009 amending Directive 98/70/EC as regards the specification of petrol, diesel and gas-oil and introducing a mechanism to monitor and reduce greenhouse gas emissions and amending Council Directive 1999/32/EC as regards the specification of fuel used by inland waterway vessels and repealing Directive 93/12/EEC. Official Journal of the European Union OJ L 2009/140/88

OJ (2010). Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control). Official Journal of the European Union, OJ L 2010/334/17.

Riahi, K., A. Gruebler and N. Nakicenovic (2007). Scenarios of long-term socio-economic and environmental development under climate stabilization. Technological Forecasting and Social Change **74**(7): 887-935.

Thunis, P., L. Rouil, C. Cuvelier, R. Stern, A. Kerschbaumer, B. Bessagnet, M. Schaap, P. Builtjes, L. Tarrason, J. Douros, N. Moussiopoulos, G. Pirovano and M. Bedogni (2007). Analysis of model responses to emission-reduction scenarios within the CityDelta project. Atmospheric Environment **41**(1): 208-220.

Tsyro, T., D. Simpson, L. Tarrason, Z. Klimont, K. Kupiainen, C. Pio and K. Yttri (2007). Modeling of elemental carbon over Europe. Journal of Geophysical Research **112**.

Wagner, F., M. Amann and W. Schoepp (2007). The GAINS optimization module as of 1 February 2007. Interim Report IR-07-004, International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria, http://www.iiasa.ac.at/Admin/PUB/Documents/IR-07-004.pdf