NEC Scenario Analysis Report Nr. 2

Emission control scenarios that meet the environmental objectives of the Thematic Strategy on Air Pollution

Markus Amann, Willem Asman, Imrich Bertok, Janusz Cofala, Chris Heyes,
Zbigniew Klimont, Max Posch, Wolfgang Schöpp, Fabian Wagner

International Institute for Applied Systems Analysis (IIASA)

with contributions from
Jean-Paul Hettelingh, Max Posch

Coordination Centre for Effects,
The Netherlands Environmental Assessment Agency (MNP)

IIASA
Science for
Global Insight

International Institute for Applied Systems Analysis
Schlossplatz 1 • A-2361 Laxenburg • Austria
Telephone: (+43 2236) 807 • Fax: (+43 2236) 807 533
E-mail: publications@iiasa.ac.at • Internet: www.iiasa.ac.at

Glossary of terms used in this report

CAFE	Clean Air For Europe Programme
CAP	Common Agricultural Policy
CAPRI	Agricultural model developed by the University of Bonn
CH_4	Methane
CLE	Current legislation
CO_2	Carbon dioxide
EEA	European Environment Agency
EFMA	European Fertilizer Manufacturer Association
EMEP	European Monitoring and Evaluation Programme
EU	European Union
GAINS	Greenhouse gas - Air pollution Interactions and Synergies model
GW	Gigawatt
IIASA	International Institute for Applied Systems Analysis
IPPC	Integrated Pollution Prevention and Control
kt	kilotons = 10^3 tons
Mt	megatons = 10^6 tons
N_2O	Nitrous oxide
NEC	National Emission Ceilings
NH_3	Ammonia
NO_x	Nitrogen oxides
O_3	Ozone
PJ	petajoule = 10^{15} joule
PM10	Fine particles with an aerodynamic diameter of less than 10 µm
PM2.5	Fine particles with an aerodynamic diameter of less than 2.5 µm
PRIMES	Energy Systems Model of the National Technical University of Athens
RAINS	Regional Air Pollution Information and Simulation model
SNAP	Sector aggregation system of the CORINAIR emission inventory
SO_2	Sulphur dioxide
SOMO35	Sum of excess of daily maximum 8-h means over the cut-off of 35 ppb calculated for all days in a year
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
VOC	Volatile organic compounds
WHO	World Health Organisation

Table of contents

1 Introduction

In its Thematic Strategy on Air Pollution, the European Commission outlined the strategic approach towards cleaner air in Europe (CEC, 2005a) and established environmental interim targets for the year 2020. As one of the main policy instruments, the Thematic Strategy announced the revision of the Directive on National Emission Ceilings (2001/81/EC) with new emission ceilings that should lead to the achievement of the agreed interim objectives.

In the meantime, the European Commission started the process to develop national ceilings for the emissions of the relevant air pollutants. The analysis started from an updated baseline projection of emissions and air quality impacts as it can be expected from the envisaged evolution of anthropogenic activities taking into account the impacts of the presently decided legislation on emission controls. These baseline projections have been presented to stakeholders in September 2006 (Amann *et al.*, 2006). In a further step, which is subject of this report, analysis explores sets of cost-effective measures that achieve the environmental ambition levels of the Thematic Strategy and examine their distributional implications on costs and benefits to the various Member States and economic sectors. The robustness of the identified emission ceilings against a range of uncertainties will be assessed in a third step.

The scenario analysis employs as the central analytical tool an extended version of the RAINS model called GAINS that allows, inter alia, studying of interactions between air pollution control and greenhouse gas mitigation. Part 1 of this report presents a concise summary of the features of the GAINS model that are used for the scenarios presented in Part 2 of this report.

Tables and figures in this report are based on EU-25. Future reports will take into account fully the accession of Bulgaria and Romania at 1 January 2007.

The remainder of the report is organized as follows: Section 2 provides a summary of concept and modelling tool that have been used for the development of the NEC baseline scenario. In particular, it introduces those elements of the GAINS model that have been used for this report. Section 3 reviews the changes that have been introduced into modelling methodology and data bases since the CAFE analysis and summarizes the validation process with experts from Member States and industry. Input assumptions on the driving forces for emissions, i.e., various projections of future energy use and agricultural activities, are presented in Section 4. Section 5 summarizes baseline emissions and the scope for further measures. Section 6 discusses how the environmental objectives of the Thematic Strategy have been applied for the NEC analysis. Optimization results in terms of emission reduction levels and involved control costs are presented in Section 7. Section 8 summarizes the findings of this report, but leaves conclusions up to the discussions of the stakeholders in the NECPI group.

2 Methodology

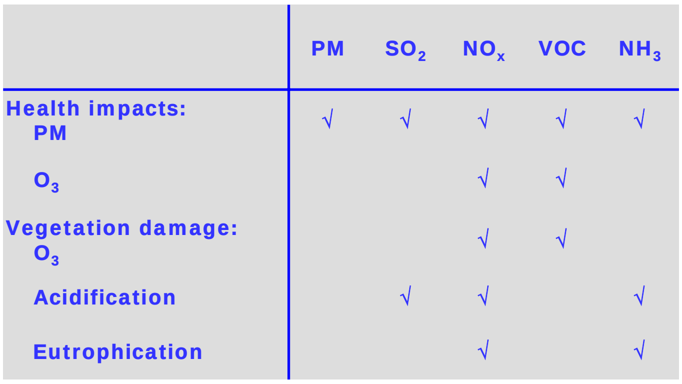
2.1 The RAINS and GAINS models

The integrated assessment conducted for the CAFE programme applied as a methodological tool the RAINS (Regional Air Pollution Information and Simulation) model, which describes the pathways of pollution from anthropogenic driving forces to various environmental impacts. In doing so, the model holds for all European countries databases with the essential information on the relevant aspects and links these data in such a way that the environmental implications of alternative assumptions on economic development and emission control strategies can be assessed.

For the revision of national emission ceilings, which is subject of this report, the analysis employs the air pollution-related features of the GAINS (Greenhouse gas – Air pollution Interactions and Synergies) model. GAINS constitutes an extended version of the RAINS model that can analyze, in addition to the existing features of the RAINS model, the interplay between air pollution control and greenhouse gas mitigation strategies. However, the cost-effectiveness analysis presented in this report utilizes only the air pollution related aspects and emission control options of the GAINS model, which are with the exception of the optimization approach identical to those of the RAINS model. Greenhouse gas-related features of GAINS, which include options to reduce greenhouse gases that also have impact on air pollution (e.g., fuel substitutions, energy conservation) will be only used for sensitivity analyses in the months to come. The following sections provide a brief summary of the RAINS model methodology and describe the methodological differences of GAINS that are relevant for the cost-effectiveness analysis presented in this report.

2.1.1 The RAINS model

The RAINS model, developed at the International Institute for Applied Systems Analysis (IIASA), combines information on economic and energy development, emission control potentials and costs, atmospheric dispersion and environmental sensitivities towards air pollution (Schöpp *et al.*, 1999). The model addresses the threats to human health posed by fine particulates and ground-level ozone as well as risk of ecosystems damage from acidification, excess nitrogen deposition (eutrophication) and exposure to elevated ambient levels of ozone. These air pollution-related problems are considered in a multi-pollutant context, quantifying the contributions of sulphur dioxide (SO_2), nitrogen oxides (NO_x), ammonia (NH_3), non-methane volatile organic compounds (VOC), and primary emissions of fine (PM2.5) and coarse (PM2.5-PM10) particles (Figure 2.1).



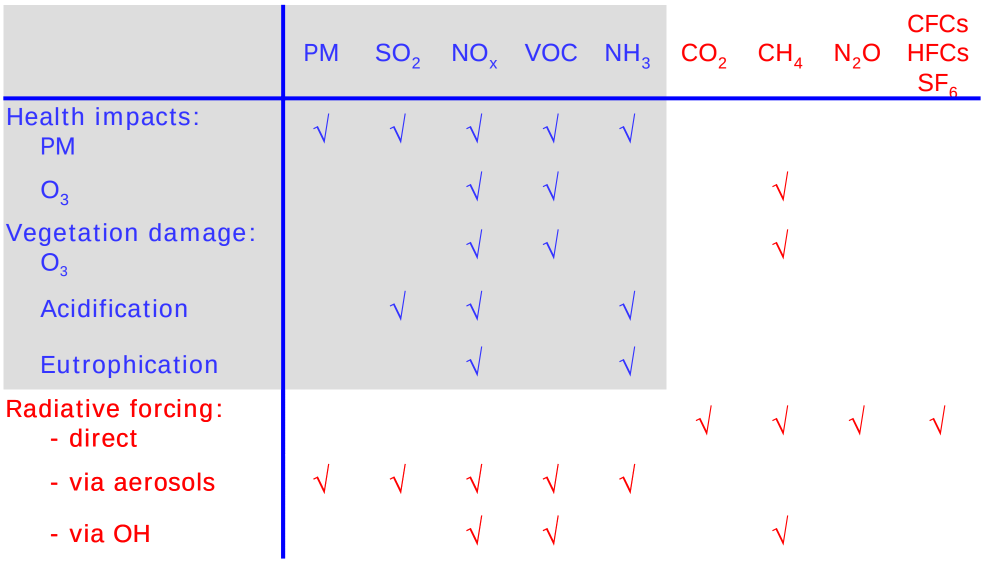
	PM	SO_2	NO_x	VOC	NH_3
Health impacts: **PM**	√	√	√	√	√
O_3			√	√	
Vegetation damage: **O_3**			√	√	
Acidification		√	√		√
Eutrophication			√		√

Figure 2.1: The multi-pollutant/multi-effect approach of the RAINS model

A detailed description of the RAINS model is provided in Amann *et al.*, 2004b. On-line access to the RAINS and GAINS model and to all input data is available at http://www.iiasa.ac.at/rains.

2.1.2 The GAINS model

Over the last few years the RAINS model has been extended to capture (economic) interactions between the control of conventional air pollutants and greenhouse gases. This GAINS (Greenhouse gas – Air pollution Interactions and Synergies) model includes, in addition to the air pollutants covered in RAINS, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and the F-gases (Klaassen *et al.*, 2004). Thereby, the traditional RAINS model constitutes the air pollution-related part of the GAINS model, while the GAINS extensions address the interactions between air pollutants and greenhouse gases.



	PM	SO_2	NO_x	VOC	NH_3	CO_2	CH_4	N_2O	CFCs HFCs SF_6
Health impacts: PM	√	√	√	√	√				
O_3			√	√			√		
Vegetation damage: O_3			√	√			√		
Acidification		√	√		√				
Eutrophication			√		√				
Radiative forcing: - direct						√	√	√	√
- via aerosols	√	√	√	√	√				
- via OH			√	√			√		

Figure 2.2: The GAINS multi-pollutant/multi-effect framework

However, for the analysis presented in this report use of the GAINS model was restricted to the air pollution related components. These are identical to those of the RAINS model with the only exception of the optimization approach. The optimization approach of RAINS has been reformulated from a conventional single-pollutant “cost curve” approach to a simultaneous “technology” approach to enable a correct assessment of the cost-effectiveness of emission control measures that affect more than one pollutant simultaneously.

2.2 Emission estimates

For each of the pollutants listed in Figure 2.2, GAINS estimates emissions based on activity data, uncontrolled emission factors, the removal efficiency of emission control measures and the extent to which such measures are applied:

$$E_{i,p} = \sum_{k} \sum_{m} A_{i,k} ef_{i,k,m,p} x_{i,k,m,p} \tag{1}$$

where:

i, k, m, p	Country, activity type, abatement measure, pollutant, respectively
$E_{i,p}$	Emissions of pollutant p (for SO_2, NO_x, VOC, NH_3, PM2.5, CO_2 , CH_4, N_2O, etc.) in country i
$A_{i,k}$	Activity level of type k (e.g., coal consumption in power plants) in country i
$ef_{i,k,m,p}$	Emission factor of pollutant p for activity k in country i after application of control measure m
$x_{i,k,m,p}$	Share of total activity of type k in country i to which a control measure m for pollutant p is applied.

This approach allows capturing critical differences across economic sectors and countries that could justify differentiated emission reduction requirements in a cost-effective strategy. It reflects structural differences in emission sources through country-specific activity levels. It represents major differences in emission characteristics of specific sources and fuels through source-specific emission factors, which account for the degrees at which emission control measures are applied. More detail is available in Cofala and Syri, 1998a, Cofala and Syri, 1998b, Klimont *et al.*, 2000, Klimont *et al.*, 2002, Klimont and Brink, 2006, Klaassen *et al.*, 2005, Höglund-Isaksson and Mechler, 2005, Winiwarter, 2005, Tohka, 2005. GAINS estimates future emissions according to Equation 1 by varying the activity levels along exogenous projections of anthropogenic driving forces and by adjusting the implementation rates of emission control measures.

2.3 Emission control measures and their costs

Basically, three groups of measures to reduce emissions can be distinguished:

- *Behavioral changes* reduce anthropogenic driving forces that generate pollution. Such changes in human activities can be autonomous (e.g., changes in life styles), they could be fostered by command-and-control approaches (e.g., legal traffic restrictions), or they can be triggered by economic incentives (e.g., pollution taxes, emission trading systems, etc.). The RAINS/GAINS concept does not internalize such behavioral responses, but reflects such changes through alternative exogenous scenarios of the driving forces.

- *Structural measures* that supply the same level of (energy) services to the consumer but with less polluting activities. This group includes fuel substitution (e.g., switch from coal to natural gas) and energy conservation/energy efficiency improvements. The GAINS model introduces such structural changes as explicit control options.

- A wide range of *technical measures* has been developed to capture emissions at their sources before they enter the atmosphere. Emission reductions achieved through these options neither modify the driving forces of emissions nor change the structural composition of energy systems or agricultural activities. GAINS considers about 1,500 pollutant-specific end-of-pipe measures for reducing SO_2, NO_x, VOC, NH_3 and PM emissions and several hundred options for greenhouse gases and assesses their application potentials and costs.

Any optimal allocation of emission control measures across countries and sectors is crucially influenced by differences in emission control costs across emission sources. It is therefore of utmost importance to systematically identify the factors leading to variations in emission control costs among countries, economic sectors and pollutants. Diversity is caused, i.a., by differences in the structural composition of existing emission sources (e.g., fuel use pattern, fleet composition, etc.), the state of technological development, and the extent to which emission control measures are already applied.

Assuming a free market for emission control technologies, the same technology will be available to all countries at the same costs. However, country- and sector-specific circumstances (e.g., size distributions of plants, plant utilization, fuel quality, energy and labor costs, etc.) lead to justifiable differences in the actual costs at which a given technology removes pollution at different sources. For each of the 1,500 emission control options, GAINS estimates their costs of local application considering annualized investments (I^{an}), fixed (OM^{fix}) and variable (OM^{var}) operating costs, and how they depend on technology m, country i and activity type k. Unit costs of abatement (ca), related to one unit of activity (A), add up to:

$$ca_{i,k,m} = \frac{I^{an}_{i,k,m} + OM^{fix}_{i,k,m}}{A_{i,k}} + OM^{var}_{i,k,m} . \qquad (2)$$

For the cost-effectiveness analysis, these costs can be related to the emission reductions achieved. The costs per unit of abated emissions (cn) of a pollutant p are calculated as:

$$cn_{i,k,m,p} = \frac{ca_{i,k,m}}{ef_{i,k,0,p} - ef_{i,k,m,p}} \tag{3}$$

where $ef_{i,k,0,p}$ is the uncontrolled emission factor in absence of any emission control measure (m=0).

2.3.1 Cost curves for emission controls

For its optimization routine the RAINS model produces cost curves for emission control, which provide for each country a ranking of the available emission control measures according to their marginal costs. If, for a given activity k, more than one control option is available, marginal costs (mc) for control option m for pollutant p in country i are calculated as:

$$mc_{i,k,m,p} = \frac{cn_{i,k,m,p} ef_{i,k,m,p} - cn_{i,k,m-1,p} ef_{i,k,m-1,p}}{ef_{i,k,m,p} - ef_{i,k,m-1,p}}. \tag{4}$$

Cost curves $f_{i,p}$ list for a country i for increasing levels of stringency the total costs $C_{i,p}^*$ of the least-cost combinations of the available abatement measures that reduce national total emissions of pollutant p to any technically feasible emission level $E_{i,p}^*$ $(E_{i,p\,min} < E_{i,p}^* < E_{i,p\,max})$:

$$C_{i,p}^* = f_{i,p}(E_{i,p}^*) = \sum_{s=1}^{S} \Delta E_{i,s,p} mc_{i,s,p} + \delta \cdot mc_{i,s+1,p} \tag{5}$$

where $mc_{i,s,p}$ are the marginal costs defined in Equation 4 and sorted over the activities k and measures m in such a way that $mc_{i,s,p} \leq mc_{i,s+1,p}$, $\Delta E_{i,s,p}$ are the corresponding emission reductions, and S is such that $E_{i,pmax} - \sum_{s=1}^{S} \Delta E_{i,s,p} > E_{i,p}^*$, but $E_{i,pmax} - \sum_{s=1}^{S+1} \Delta E_{i,s,p} \leq E_{i,p}^*$ and $\delta = E_{i,pmax} - \sum_{s=1}^{S} \Delta E_{i,s,p} - E_{i,p}^*$. Details on the cost calculations are provided in Cofala and Syri, 1998a, Cofala and Syri, 1998b, Klimont *et al.*, 2000, Klimont *et al.*, 2002.

2.3.2 The use of cost data in GAINS

In contrast to the single-pollutant cost curve approach used in RAINS, the optimization module of GAINS uses an explicit representation of technologies. While in RAINS the decision variables in the cost optimization are the segments of (independent) cost curves based on a fixed energy projection, in GAINS the decision variables are the activity levels of individual technologies themselves.

The advantages of this approach are fourfold:

- Multi-pollutant technologies are represented adequately in this approach. Multi-pollutant emission control technologies, such as those meeting the various Euro-standards for road vehicles, can be cost-effective in a multi-pollutant multi-objective regulatory framework, even though as single pollutant control technologies they may be not. Thus, while in a cost curve approach multi-pollutant technologies often do not appear to be cost effective, in the GAINS optimization these technologies are appraised on the basis their efficiency to meet (potentially) several environmental objectives simultaneously.

- GAINS allows for (limited) changes in the underlying energy system, primarily as possible measures to reduce greenhouse gas emissions. With each change in the energy system, however, the potential for air pollution control technologies may change, and thus in RAINS the individual cost curve would need to be recalculated for each change in the energy system. Using an explicit technology representation in the GAINS optimization avoids such a cumbersome procedure, as the model "sees" the available technologies and their potentials for their application *at every stage*.
- The GAINS approach fully integrates air pollution control and greenhouse gas mitigation measures so that it not only possible to address the two issues *sequentially*, as has been done in the past: with this tool both aspects of emission control can be addressed *simultaneously* to increase economic efficiency and environmental effectiveness.
- Emission control costs are directly associated with technologies, rather than with pollutants. For single pollutant technologies this difference is spurious, but both for multi-pollutant technologies and activities changes commonly considered as greenhouse gas mitigation options it is often inappropriate to attribute costs to the reduction of a single pollutant or to allocate the costs to individual pollutants. With the technology approach of GAINS no such allocation is needed, nor is it always possible.

Another important consequence of the technology representation in GAINS is the extension of the concept of maximum technically feasible reductions (MTFR). While in the RAINS approach the point of MTFR on a single pollutant cost curve was determined by the maximum application of end-of-pipe technologies, in GAINS further reductions can be achieved by changing the underlying activities, e.g., the energy mix for a given sub-sector. Thus, for example, a switch from coal to gas or to a renewable fuel will reduce emissions of particles below a level that could be achieved with filter technologies. Though a particular fuel switch may not be cost-effective as a control measure for a single air pollutant, it is important to take this additional potential for reduction into account when air pollution targets are discussed, particularly in a carbon constrained setting.

It is important to take note of the fact that the GAINS optimization module can still be used to construct single pollutant cost curves for individual countries if so desired. In this mode the GAINS model is allowed to use all add-on technologies for air pollution control like in the RAINS model, but fuel substitutions or efficiency improvement options are suppressed, i.e., are not available. Ignoring multi-pollutant technologies for the time being, the GAINS model in RAINS mode exactly reproduces the results of the original RAINS optimization approach.

Figure 2.3 shows the validation of the "RAINS-mode" operation of GAINS for a RAINS SO_2 cost curve for a single country. The curve connects bold squares that represent individual control technologies in the RAINS model. The curve is generated by ordering the individual control measures according to their marginal cost, taking into account maximum application rates. Each bullet is generated with the GAINS model by imposing an emission ceiling and optimizing for costs. It can be seen that the points calculated by GAINS all lie on the RAINS cost curve.

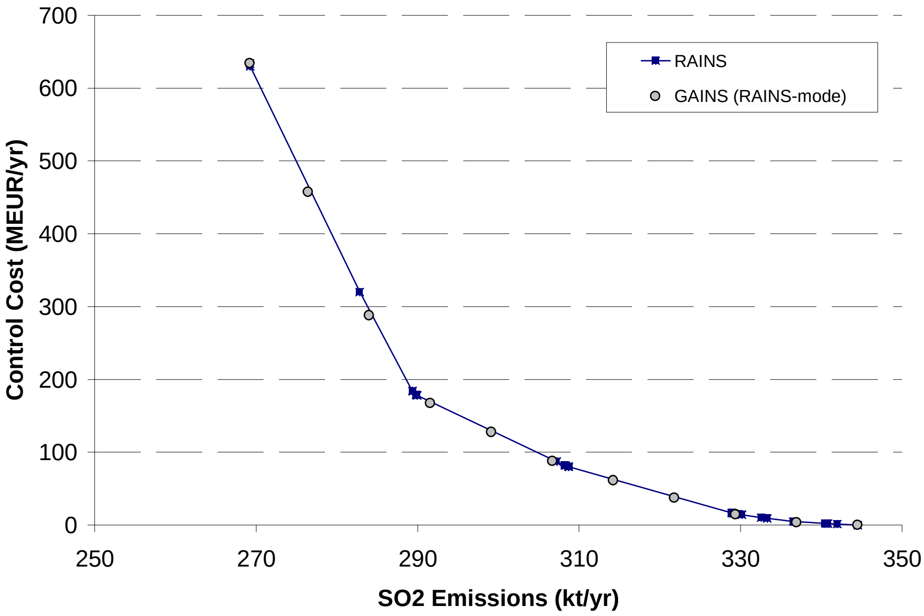


Figure 2.3: Validation of an original RAINS cost curve with the GAINS model operated in the "RAINS" mode

In contrast, when the restrictions on fuel substitutions and efficiency improvements are lifted and the GAINS model is allowed to use all available options, the "GAINS-mode" reveals a larger potential for emission reductions. In Figure 2.4, the thin line with bullets illustrates the single pollutant cost curve that is obtained with the GAINS model in RAINS mode. The curve begins at around 108 kt PM2.5 per year and ends at around 86 kt PM2.5 per year, which represents the maximum technically feasible reductions scenario generated with the RAINS model. Results emerging from the "GAINS mode" are indicated by the thin line with squares. This curve ends at around 79 kt PM2.5 per year with costs of around 7 billion €/yr (off the diagram). This cost estimate takes into account the change in the total system costs, i.e., costs of all fuel substitution options taken to achieve an emission level of 79 kt PM2.5 per year. If, however, only those costs are taken into account that are explicitly connected with PM2.5 end-of-pipe technologies, then the resulting costs in the MTFR scenario at 79 kt PM2.5 per year is lower than 1.6 billion €/yr, which is even below the level of the MTFR calculated in the RAINS mode (more than 1.6 billion €/yr). This is easily understood if one takes into account that the energy systems in the MTFR situations of the two cost curves are different: the bulleted line is constructed from a baseline scenario, whereas the endpoint of the second and third curves result from a scenario with less use of solid fuels – which means that there is less absolute amount of capacities that need to be controlled, which in turn implies smaller amounts of money spent on control equipment (dotted line with triangles).

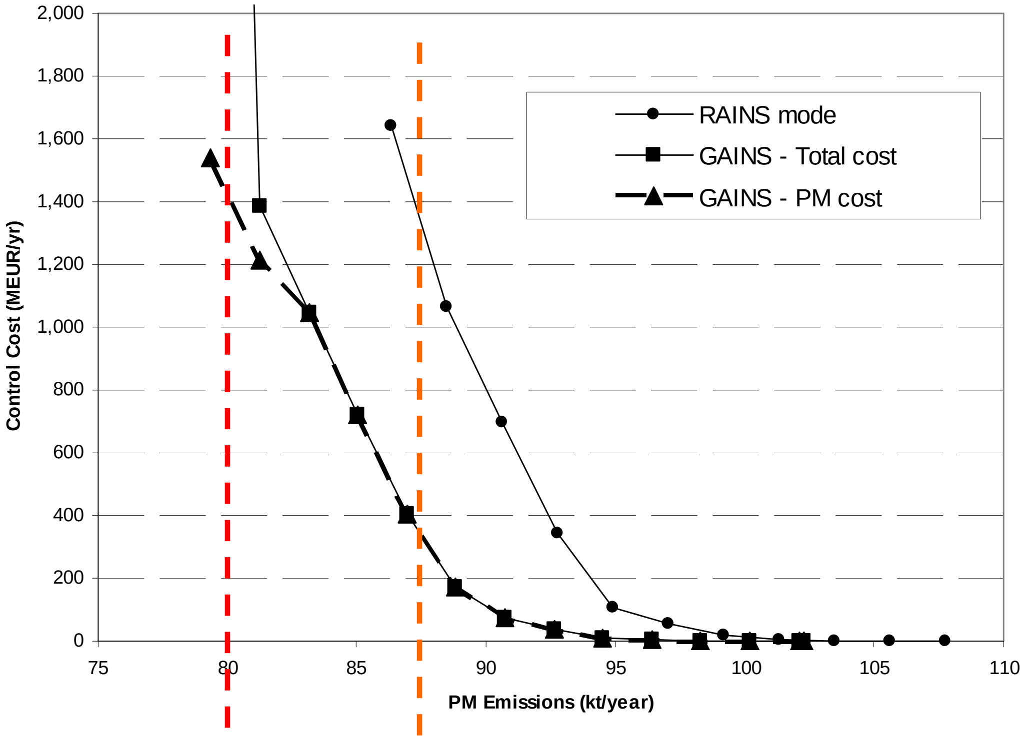


Figure 2.4: Single pollutant cost curves for PM2.5 in the year 2020. This illustrates the difference in maximum technically feasible reductions (MTFR) in the full GAINS model compared to the RAINS mode of GAINS. For details see text.

2.4 Atmospheric dispersion

An integrated assessment needs to link changes in the precursor emissions at the various sources to responses in impact-relevant air quality indicators *q* at a receptor grid cell *j*. Traditionally, this task is accomplished by comprehensive atmospheric chemistry and transport models, which simulate a complex range of chemical and physical reactions. The GAINS integrated assessment analysis relies on the Unified EMEP Eulerian model, which describes the fate of emissions in the atmosphere considering more than a hundred chemical reactions involving 70 chemical species with time steps down to 20 seconds including numerous non-linear mechanisms (Simpson *et al.*, 2003). This model was updated in August 2006. However, the joint analysis with economic and ecological aspects in the GAINS model, and especially the optimization task, calls for computationally efficient source-receptor relationships. For this purpose, an attempt has been made to describe the response surface of the impact-relevant air quality indicators through mathematically simple, preferably linear, formulations. Functional relationships have been developed for changes in annual mean PM2.5 concentrations, deposition of sulfur and nitrogen compounds as well as in long-term levels of ground-level ozone. The (grid- or country-specific) parameters of these relationships have been derived from a sample of several hundred runs of the full EMEP Eulerian model with systematically perturbed emissions of the individual sources. This "calibration sample" spans the policy-relevant range of emissions, i.e., taking the "current legislation" (CLE) emission projection as the upper limit and its "maximum technically feasible reduction" (MTFR) case as the lower end. While the optimization task in GAINS employs these fitted source-receptor relationships, policy-relevant scenario results are validated ex-post through runs of the full EMEP Eulerian model.

Source-receptor relationships have been developed for changes in emissions of SO_2, NO_x, NH_3, VOC and PM2.5 of the 25 Member States of the EU, Romania, Bulgaria, Croatia, Norway and Switzerland, and five sea areas, describing their impacts for the EU territory with the 50 km × 50 km grid resolution of the geographical projection of the EMEP model (see www.emep.int/grid/index.html).

2.4.1 Fine particulate matter – regional scale

The health impact assessment in GAINS relies on epidemiological studies that associate premature mortality with annual mean concentrations of PM2.5 monitored at urban background stations. Thus, the source-receptor relationships developed for GAINS describe, for a limited range around a reference emission level, the response in annual mean PM2.5 levels to changes in the precursor emissions SO_2, NO_x, NH_3 and primary PM2.5. The formulation reflects the interplay between SO_2, NO_x and NH_3 emissions in the formation of secondary sulfate and nitrate aerosols in winter. The almost linear response in annual mean PM2.5 produced by the EMEP Eulerian model towards changes in annual emissions of fine primary particulate matter (PM2.5) and of SO_2, as well as for changes in NO_x emissions during the summer, is represented as:

$$\begin{aligned} PM_j &= k_{0,j} + \sum_i pm_i PP_{ij}^A + \sum_i s_i S_{ij}^A + c_0 \left(\sum_i a_i A_{ij}^S + \sum_i n_i N_{ij}^S \right) + \\ &+ (1-c_0) \min\left\{ \max\left\{ 0, k_{1,j} + c_1 \sum_i a_i A_{ij}^W - c_2 \sum_i s_i S_{ij}^W \right\}, k_{2,j} + c_3 \sum_i n_i N_{ij}^W \right\} \end{aligned} \tag{6}$$

with

PM_j	Annual mean concentration of PM2.5 at receptor point j
s_i, n_i, a_i, pm_i	Emissions of SO_2, NO_x, NH_3 and primary PM2.5 in country i
A^X_{ij}, N^X_{ij}, S^X_{ij}, PP^X_{ij}	Matrices with coefficients for reduced (*A*) and oxidized (*N*) nitrogen, sulfur (*S*) and primary PM2.5 (*PP*), for season *X*, where *X*=*W* (winter), *S* (summer) and *A* (annual)
c_0, c_1, c_2, c_3, $k_{0,j}$, $k_{1,j}$, $k_{2,j}$	Model parameters.

While the above formulation with a computationally complex min-max formulation is required to capture changes in chemical regimes when ratios between the abundances of sulfur, nitrogen and ammonia in the atmosphere are changing due to different emission reduction rates of the pollutants involved, a simpler formulation appears to be sufficient when only limited changes in emissions around a reference point are considered. For such optimization problems, Equation 6 can be turned into a linear form:

$$PM_j = \sum_i pm_i \cdot PP_{ij}^A + \sum_i s_i \cdot S_{ij}^A + \sum_i a_i \cdot A_{ij}^A + \sum_i n_i \cdot N_{ij}^A + k_{0,j} \qquad (7)$$

For the CAFE programme, where the European Commission explored a wide range of alternative environmental targets implying large differences in emission reductions, the RAINS optimization applied the formulation of Equation 6. For the NEC analysis, however, where the general ambition level has been settled in the Thematic Strategy, the GAINS optimization problem uses Equation 7 with transfer coefficients which have been derived from permutations of emissions around the indicative target emissions levels outlined in the Thematic Strategy. Taking these target levels as the reference point, the GAINS optimization using local derivatives at this point results in a significantly more accurate representation of the underlying EMEP Eulerian model despite the simpler mathematical formulation.

This formulation only describes the formation of PM from anthropogenic primary PM emissions and secondary inorganic aerosols. It excludes PM from natural sources and primary and secondary organic aerosols due to insufficient confidence in the current modeling ability. Thus, it does not reproduce the full mass of PM2.5 that is observed in ambient air. Consequently, results of this approach need to be compared against observations of the individual species that are modeled. The health impact assessment in GAINS is consequently only conducted for *changes* in the specified anthropogenic precursor emissions, and excludes the (largely) unknown role of secondary organic aerosols and natural sources.

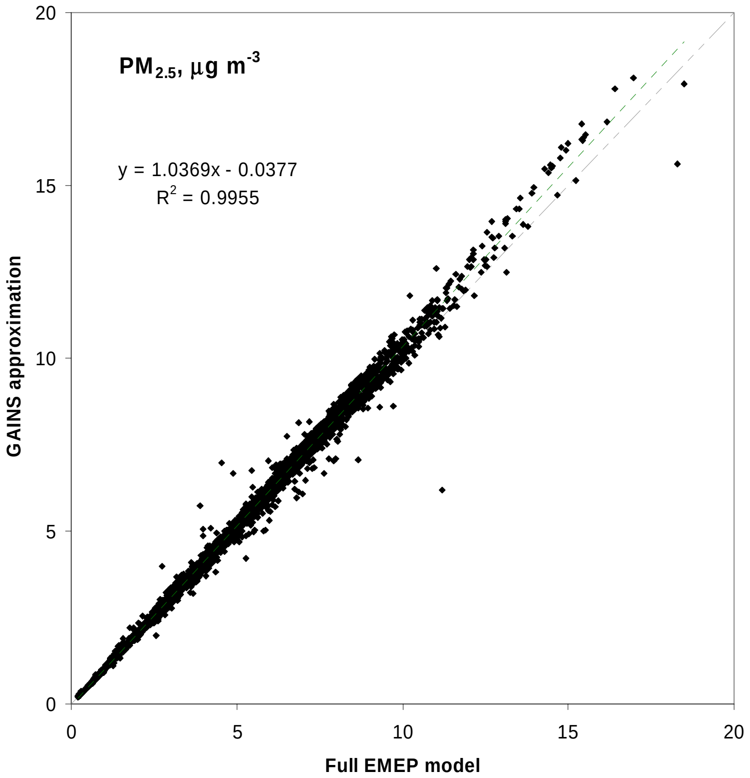


Figure 2.5: Validation of the GAINS approximations of the functional relationships against

computations of the full EMEP model around the emission levels outlined in the Thematic Strategy for Air Pollution.

2.4.2 Fine particulate matter – urban scale

In GAINS the regional-scale assessment is performed for all of Europe with a spatial resolution of 50 km × 50 km. Health impacts are, however, most pertinent to urban areas where a major share of the European population lives. Any assessment with a 50 km resolution will systematically miss out higher pollution levels in European cities. Based on the results of the City-delta model intercomparison, which brought together the 17 major European urban and regional scale atmospheric dispersion models (Thunis *et al.*, 2006), a generalized methodology was developed to describe the increments in PM2.5 concentrations in urban background air that originate – on top of the long-range transport component – from local emission sources.

These relationships associate urban increments in PM levels, i.e., incremental (PM2.5) concentrations in a city originating from emissions of the same city with the spatial variations in emission densities of low-level sources in that city and city-specific meteorological and topographic factors. In a second step, urban background PM2.5 concentrations within cities are then computed by correcting the PM concentration value computed by a 50*50 km regional dispersion model with a "city-delta", i.e., the local increase in concentration in the city due to emissions in the city itself. In the regional-scale calculations this contribution is smeared out over the whole 50*50 km grid element. In the City-delta approach the mass within the 50*50 km grid element is redistributed in such a way that the concentration in the city is increased by the "city-delta" increment, whereas the concentration in the country-side consequently is decreased. In this way mass is being conserved.

The GAINS/City-delta methodology starts from the hypothesis that urban increments in PM2.5 concentrations originate predominantly from primary PM emissions from low-level sources within the city. The formation of secondary inorganic aerosols, as well as the dispersion of primary PM2.5 emissions from high stacks, are reflected in the background computed by the regional-scale dispersion model.

Based on this hypothesis, urban increments have been derived with the following approach:

Step 1: Preparation of a data sample of model responses

Three urban dispersion models (Chimere, CAMx, REM3) have been used to generate a data sample with computed impacts of local emission control measures on urban PM2.5 concentrations for seven European cities with different characteristics (Berlin, Krakow, Lisbon, London, Milan, Paris, Prague). Scenarios have been computed for emissions in 2020 with and without urban emissions from low level sources, using the meteorological conditions of the year 2004.

Step 2: Hypothesis of local determinants and the functional forms for computing the urban increments

Based on atmospheric diffusion theory, potential determinants of urban increments and functional forms of their relationships have been hypothesized. Under neutral atmospheric conditions, the vertical diffusion of a non-reactive pollutant from a continuous point source can be described in general form through the following relationship (e.g., Seinfeld and Pandis, 1998):

$$\sigma_z^2 = \frac{2K_{zz}x}{U} \tag{8}$$

with σ_z^2 [m^2] indicating the variance of the vertical diffusion after a distance x [m] from the source, K as the Eddy diffusivity [$m^2\ s^{-1}$] and U [$m\ s^{-1}$] as the wind speed. For a homogenously distributed area source with source strength (emission rate) Q, the resulting concentration Δc of a pollutant due to emissions in the city can be derived from a spatial integration over the diameter of the city D [m] (Anton Eliassen, personal communication)

$$\Delta c = \frac{1}{2\sqrt{2}}\frac{1}{\sqrt{K_{zz}}}\left(\frac{D}{U}\right)^{1/2} Q\ . \tag{9}$$

The diffusivity K_{zz} as well as wind speeds and city diameters along the wind directions show variations over the year. In Equation 8 K_{zz} and U are constant with height. In reality and under neutral atmospheric conditions, K_{zz} increases approximately linearly with height, whereas U increases with the logarithm of the height. Moreover, at a relative short distance from the low source the plume is reflected at the earth's surface. Therefore only the general relation between Δc and $(D/U)^{0.5}$ is used in Equation 9, whereas all other effects are described by the diffusion characteristics of the city given by the constant α. Equation 10 shows that the urban concentration increments Δc can be described as a function of city diameter D, wind speed U, emission rates Q:

$$\Delta c = \frac{1}{2\sqrt{2}}\frac{1}{\sqrt{K}}\left(\frac{D}{U}\right)^{1/2} Q = \alpha \cdot \left(\frac{D}{U}\right)^{1/2} Q \tag{10}$$

In principle, the same type of model could also describe the relation under stable atmospheric conditions. However, it will be difficult to describe the situation for wind speeds below 0.5 – 1 $m\ s^{-1}$, as the flow will no longer be determined by the external wind speed, but by other effects such as differences in heating of the earth's surface and differences in terrain height.

Low wind situations in summer are different from low wind situations in winter. In summertime in a high pressure area during day time there are unstable conditions leading to a well-mixed atmosphere. In such situations the increase in concentration due to the low wind speed (causing less dilution) is partly compensated by a decrease in concentration due to better vertical mixing. In these situations a large fraction of the airborne aerosol does not directly come from nearby PM2.5 sources, but is generated by photochemical reactions by which so called secondary aerosols are formed. However, as mentioned above, there is insufficient confidence in the abilities of current atmospheric chemistry models to deliver reliable quantitative estimates for secondary organic aerosols. As a consequence, the current GAINS analysis excludes secondary organic aerosols altogether.

In winter, low wind speed conditions are mostly related to shallow boundary layers, in which emissions from local sources accumulate over time. Since process modelling of such conditions would require detailed meteorological information on the situation within cities that is usually unavailable for most European cities, a statistical approach has been adopted that builds upon model computations carried out by the City-delta models for the seven cities. Figure 2.6 indicates that winter days with wind speeds below 1.5 m/s make a stronger contribution to annual mean PM2.5 concentrations than days with higher wind speeds.

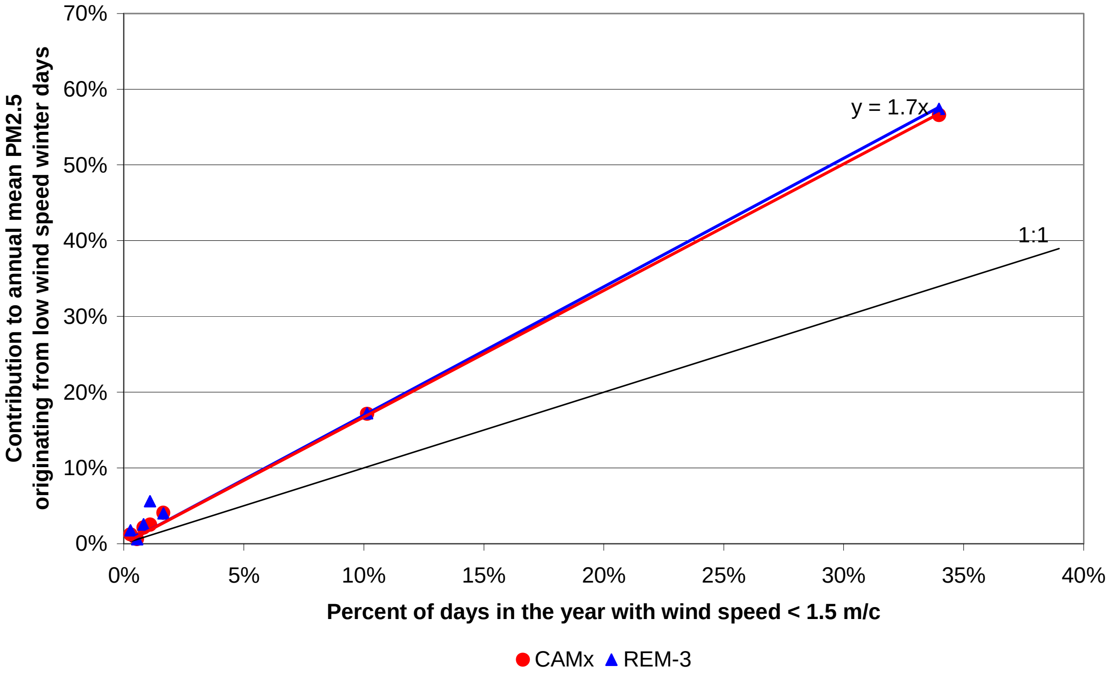


Figure 2.6: Contribution to annual mean PM2.5 concentrations originating from low wind speed days in winter, as computed by the CAMx and REM-3 models for the seven City-delta cities

As a pragmatic approach for determining the urban increments, the City-delta approach considers a second term that is related to the number of low wind speed days in winter (*d)*:

$$\Delta c = \alpha \cdot \left(\frac{D}{U} \right)^{1/2} Q + \beta \cdot \left(\frac{D}{U} \right)^{1/2} Q \cdot \frac{d}{365} \tag{11}$$

Step 3: Regression analysis for the seven cities

In a further step, a regression analysis estimated the regression coefficients α and β in Equation 11 from the data sample on Δc computed by the three urban dispersion models for the seven City-delta cities, with city-specific diameters *D*, wind speeds *U*, low wind speed days *d*, and changes in emission fluxes ΔQ. For concentration changes averaged over 10*10 km domains in the city centers, the regression analysis renders statistically significant values for α of 0.22 and for β of 0.48 with an R^2 of 0.89. With these coefficients, the functional relationships according to Equation 11 deliver for the seven sample cities urban increments that lie within the range produced by the three detailed urban dispersion models (Figure 2.7).

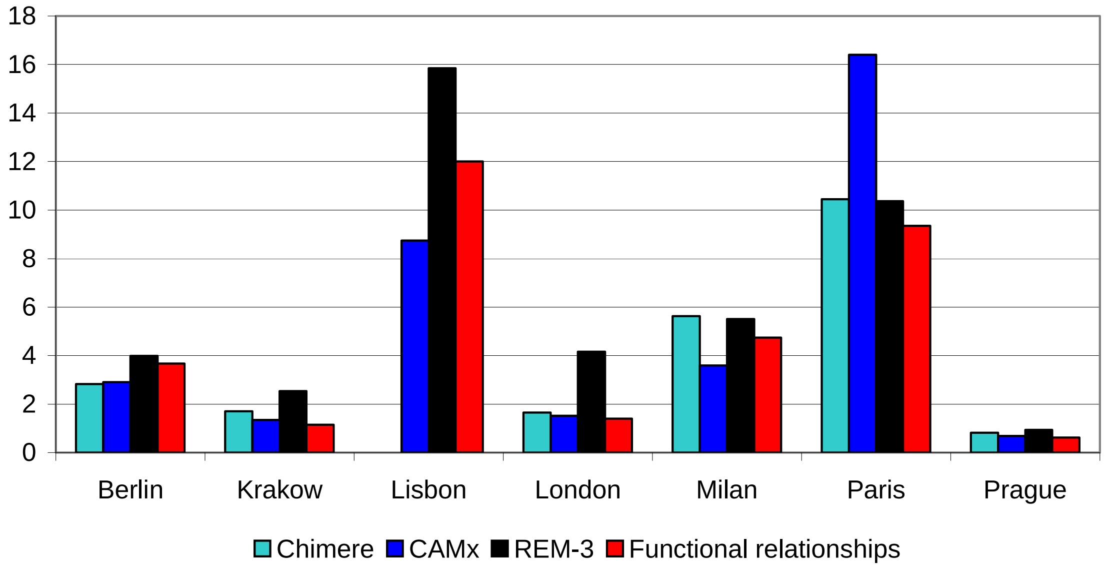


Figure 2.7: Urban increments of PM2.5 (in µg/m^3) computed by the three detailed urban dispersion models and the City-delta functional relationships for the seven City-delta cities, for the CAFE baseline emissions for 2020

Step 4: Extrapolation to all European cities

To estimate urban increments for all European cities based on the functional relationship identified in Equation 11, a database has been prepared with city-specific information on city area, city diameters, wind speeds, number of low wind days in winter for the 473 cities with more than 100,000 inhabitants.

Urban areas and diameters were derived from the JRC European population density data set and the *www.citypopulation.de* database using a special algorithm that associates populated areas with the individual urban agglomerations under consideration. Wind speed data have been extracted from the MARS meteorological database of JRC, which provides interpolated meteorological information derived from 2000 weather stations in Europe. Furthermore, local observations on wind speeds from a European database provided by the Free University Berlin have been used for German cities and other countries, when these data are more representative for city-centers than the interpolated MARS data (Figure 2.8, Figure 2.9).

With these data, the term $(D/U)^{1/2}$ in Equation 11 that reflects the influence of topography and meteorological conditions of a specific city on the dispersion characteristics of local emissions can be derived (Figure 2.10). This indicator displays a strong influence of the city size (shown by declining factors for the cities in each country, which are ranked by population) with the modifications of meteorological conditions.

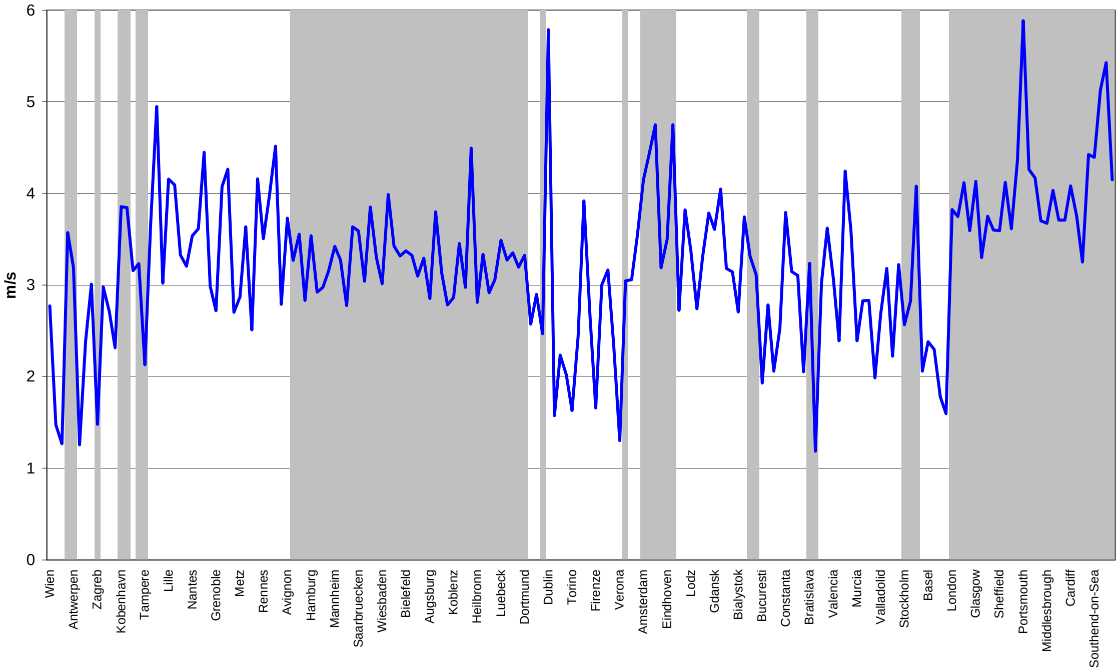


Figure 2.8: Mean annual wind speeds for the European cities with more than 250.000 inhabitants

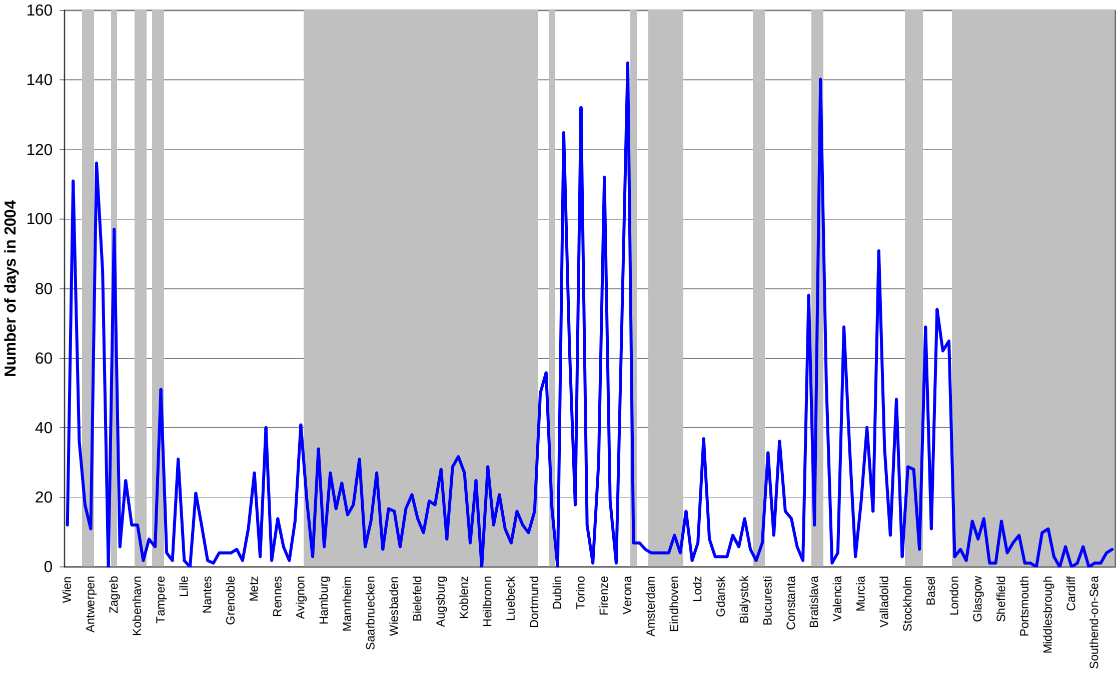


Figure 2.9: Number of days in winter with wind speeds below 1.5 m/s for cities with more than 250.000 inhabitants

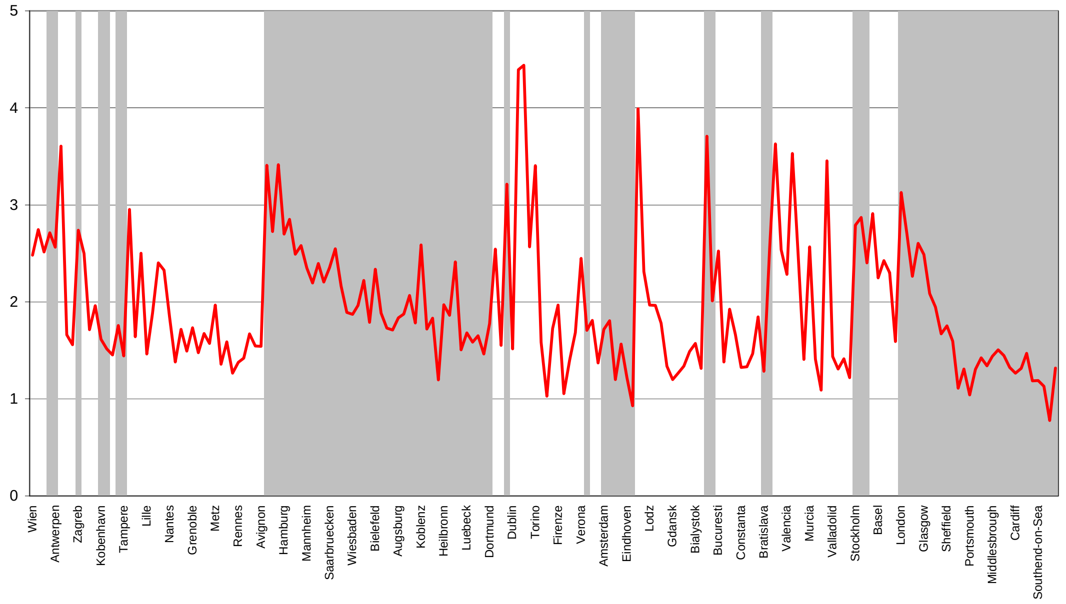


Figure 2.10: Topographic factors $(D/U)^{1/2}$ in Equation 11 that are proportional to the concentration increment (in $\mu g/m^3$) per ton PM2.5 emissions under neutral atmospheric conditions for the cities with more than 250.000 inhabitants

Special emphasis has been devoted to estimating urban emissions of low level sources. In the absence of city-specific emission inventories available at the European scale, urban emissions have been estimated on a sectoral basis (distinguishing the SNAP sectors) from the gridded emission inventory compiled for the calculations of the EMEP model. First, for each country, sectoral emissions reported in the EMEP database have been scaled to the estimates of the GAINS model, which have been recently agreed upon with national experts in the bilateral consultations with IIASA. In a second step, for each city, the sectoral emissions reported in the EMEP inventory for the specific grid cell (adjusted for the GAINS estimates) have been allocated to cities based on the distribution of urban and rural population within the grid cell. For splitting total emissions into low and high-level sources, the assumptions listed in Table 2.1 have been made. Essentially, it is assumed that all emissions of SNAP sector 2 (domestic and service sector), SNAP sector 4 (non-combustion related emissions from industrial processes, usually cold processes), SNAP sector 7 (traffic) and SNAP sector 8 (off-road sources, such as construction machinery, etc.) are emitted at low heights. Emissions from power stations (SNAP 1) and waste incineration plants (SNAP 9) are assumed to be high level, while in the absence of more city-specific information 50 percent of the PM2.5 emissions reported under SNAP 3 (industrial combustion and manufacturing) are assumed to be released into the surface layer.

It has to be mentioned that in the course of the bilateral consultations with national experts the RAINS estimates of sectoral PM2.5 emissions have been adjusted to match as far as possible the national inventories with plausible data on emission factors, removal efficiencies, activity rates and application rates of control measures.

Table 2.1: Assumptions about emission height for the SNAP sectors

SNAP sector		*Assumption about emission height*
1	Combustion in energy and transformation industries	0 % of emissions low level
2	Non-industrial combustion plants (domestic and service sector)	100 % of emissions low level
3	Combustion in the manufacturing industry	50 % of emissions low level
4	Production processes (e.g., diffusive emissions in industry, etc.)	100 % of emissions low level
5	Extraction and distribution of fossil fuels and geothermal energy	0 % of emissions low level
6	Solvent and other product use	Not relevant for PM2.5
7	Road transport	100 % of emissions low level
8	Other mobile sources and machinery	100 % of emissions low level
9	Waste treatment and disposal	0 % of emissions low level
10	Agriculture	Not relevant for urban PM2.5
11	Other sources and sinks including nature	Not relevant for urban PM2.5

However, it has to be mentioned that the information contained in the gridded EMEP emission inventory is burdened with uncertainties, since only few countries (Austria, Denmark, Spain, Finland, France and Lithuania) have provided information for PM2.5 and UK for PM10. For all other countries the spatial allocation of national PM2.5 emissions has been performed by EMEP based on surrogate indicators such as population densities.

A particular relevant source of uncertainties is related to emissions from wood burning. While a number of countries report rather high emissions from these activities, it is not always clear to what extent wood burning occurs within cities. There are indications that practices are different across countries, and gridded inventories that are not built upon bottom-up estimates but employ generic assumptions (like population-weighted spatial distributions) might results in serious over- or underestimates of urban PM2.5 emissions. However, there is little solid information on this subject available at this time at the European level that could allow further refinement of the current GAINS estimates.

There are striking differences in per-capita emissions and emission densities from urban low-level sources across the European cities. Differences in industrial emissions could be explained by the existence of specific plants in a given city, whose exact locations (i.e., within or outside the city boundaries) however would need to be validated on a case-by-case basis (Figure 2.12). Certain differences in the per-capita emissions from the domestic and service sector could potentially be related to different levels of wood burning, although the question to what extent wood burning takes place within cities needs further attention (Figure 2.11). Most strikingly, however, are variations in per-capita emissions from the transport sector across European countries (Figure 2.13). As a consequence, there are striking differences also in the spatial emission densities across European cities (Figure 2.14).

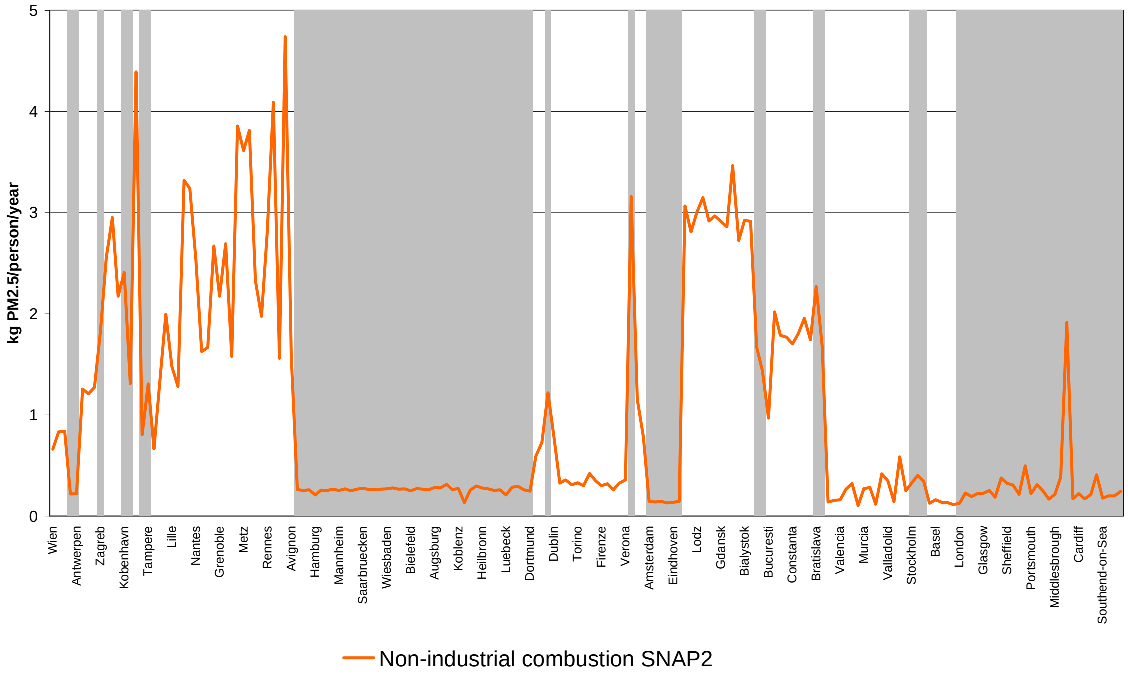


Figure 2.11: Urban per-capita emissions from non-industrial combustion (domestic and service sectors) – SNAP2 from the RAINS database for the year 2000, for the European cities with more than 250.000 inhabitants

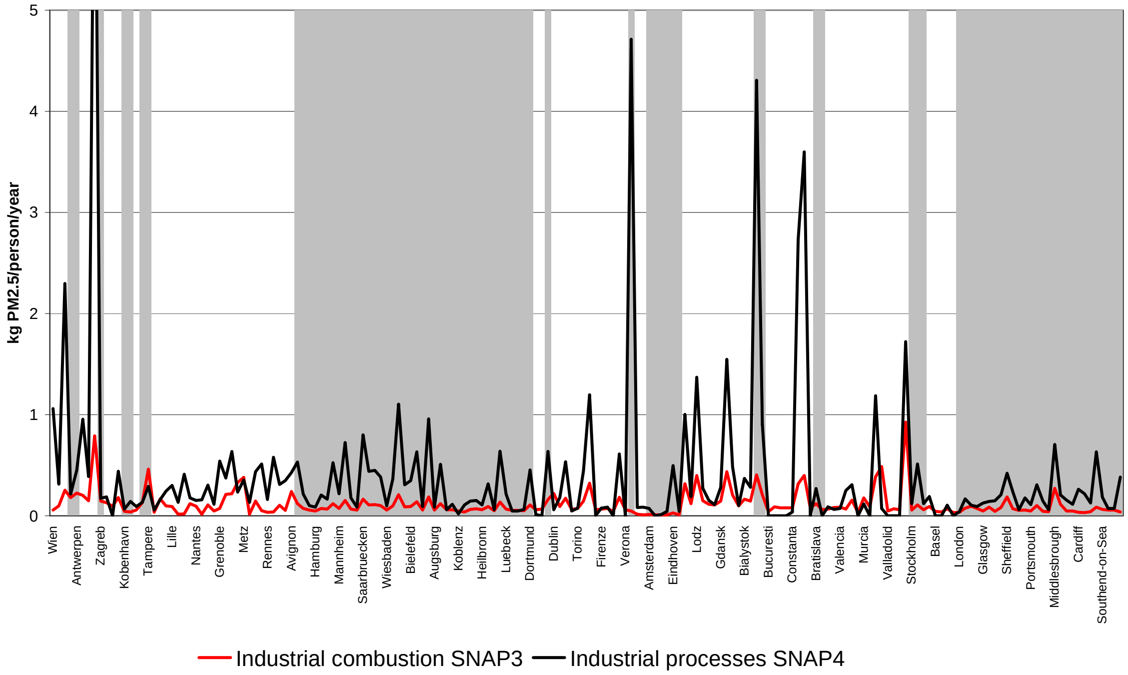


Figure 2.12: Urban per-capita emissions from industrial combustion (SNAP 3) and industrial processes (SNAP4) from the RAINS database for the year 2000, for the European cities with more than 250.000 inhabitants

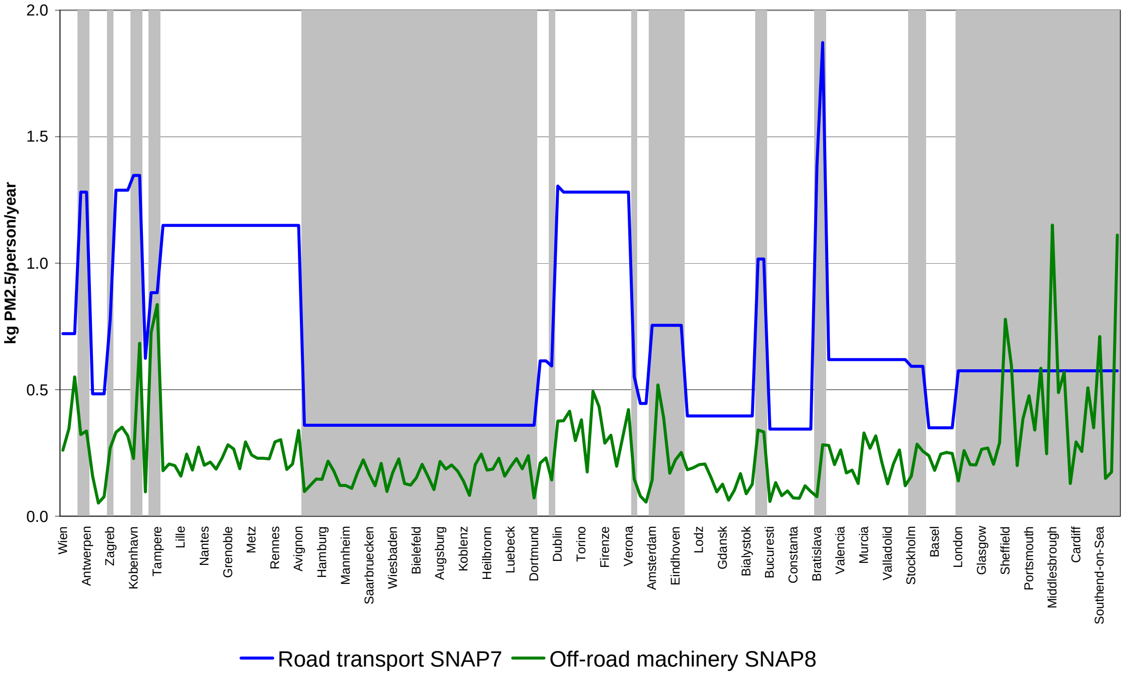


Figure 2.13: Urban per-capita emissions from road transport (SNAP 7) and off-road machinery (SNAP 8) from the RAINS database for the year 2000, for the European cities with more than 250.000 inhabitants

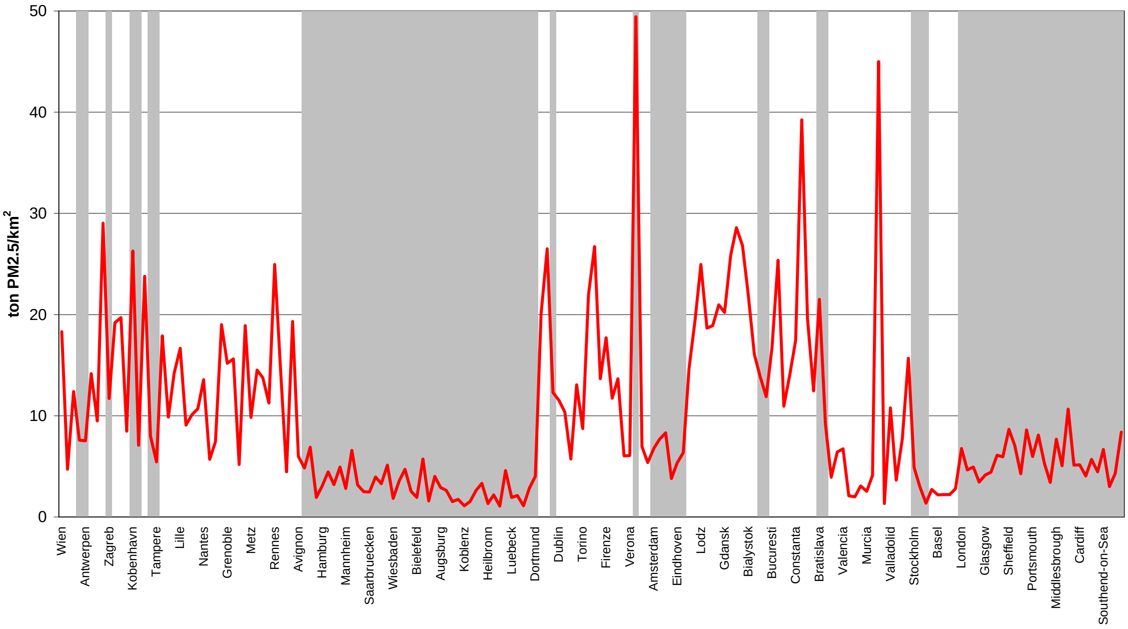


Figure 2.14: Emission densities of PM2.5 from urban low level sources (all sectors) for the European cities with more than 250.000 inhabitants

With all this information, urban increments have been estimated according to Equation 11 for the 473 European cities that have more than 100.000 inhabitants. Calculations show a wide spread across Europe, with peaks reaching between 15 and 19 µg/m^3 (Riga, Sofia, Milano, Athens, Katowice). Low emission densities in the UK and Germany (see Figure 2.14) result in comparably lower increments (e.g., London 4.8 µg/m^3, Sheffield 3.6 µg/m^3; Berlin 4.2 µg/m^3, Essen 4.1µg/m^3)

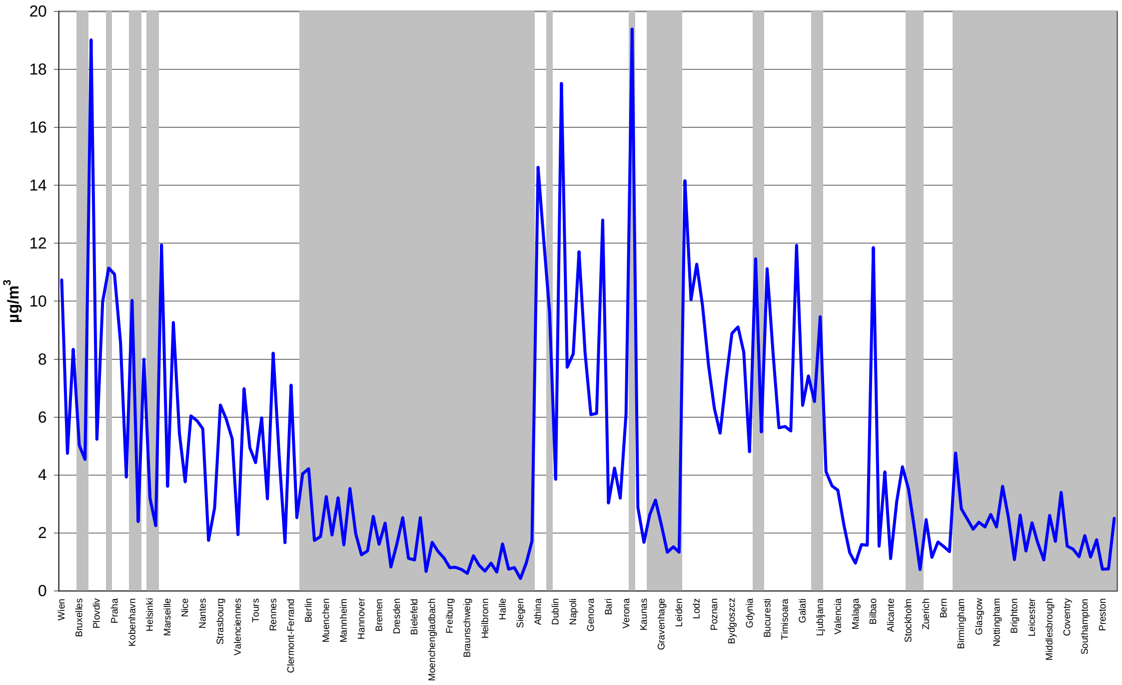


Figure 2.15: Computed urban increments for the year 2000 for the European cities with more than 250.000 inhabitants

Step 5: Calculations of the “city-deltas”

In a final step, the “city-deltas”, i.e., the correction factors that have to be applied to the results of the EMEP regional scale model calculations in order to derive estimates of urban air quality, have been developed. As a pragmatic solution double-counting of the urban emissions (i.e., in the regional scale EMEP calculations and the urban increments) has been avoided by estimating the PM increase from the urban emissions that is applied in the EMEP model. With some simplifying assumptions, the city-deltas *CD* compute as:

$$CD = \alpha \cdot \Delta Q . \frac{1}{\sqrt{U}} \cdot \left((1 + \beta \frac{d}{365}) \cdot \frac{\sqrt{D}}{A_C} - \frac{\sqrt[4]{A_E}}{A_E} \right) \qquad (12)$$

with the index *C* indicating city-related data and the index *E* values for the entire 50*50 km EMEP grid cell, and *A* relating to the respective areas .

The resulting city-delta CD_C can then be added to the EMEP regional scale results PM_{EMEP} to attain total PM concentrations in urban areas PM_C:

$$PM_c = PM_{EMEP} + CD_c \tag{13}$$

Step 6: Validation

Finally, the total PM2.5 concentrations computed along Equation 13 together with generic assumptions on the PM contribution from mineral dust and sea salt have been compared against available monitoring data. However, such a comparison is inherently difficult for two major reasons:

- First, the computed urban increment that reflects PM concentrations in urban background air is rather sensitive towards the target domain for which it is computed. Sensitivity analyses show that urban increments computed with the detailed urban dispersion models for 5*5 km, 10*10 km and 15*15 km domains differ typically by a factor of two to three. While the impact assessment in GAINS should ideally use a population-weighted change in concentrations to connect to the relative risk functions provided by epidemiological studies, it is not always clear for which domain size a given observation can be considered as representative.
- Second, there are significant uncertainties in the reported monitoring data for PM2.5, both about their representativeness within a given city as well as on monitoring techniques and applied correction factors in an international context. While it seems difficult to quantify the uncertainties around the available monitoring data, they establish a serious obstacle for a solid intercomparison between monitoring data and model results.

Figure 2.16 Figure 2.20 compare the contributions of mineral dust, the long-range component and the estimated city-delta to urban background PM2.5 with available measurements. For mineral dust, it has been assumed that concentrations range between 1 and 3 $\mu g/m^3$ as a function of geographical latitude. The long-range component represents the PM2.5 concentration computed by the EMEP Eulerian model (for primary PM and secondary inorganic aerosols) for the meteorology of the year 2004, while the city-deltas have been calculated according to the methodology outlined above. **Note that, compared to the provisional results presented at the Joint Workshop of the UNECE Task Forces on Integrated Assessment Modelling and on Measurements and Modelling on “Cost-effective control of urban air pollution” (IIASA, Laxenburg, November 16-17, 2006), estimates have changed due to improved meteorological information and new emission data.** Furthermore, the graphs provide measurement data extracted from the AIRBASE database and from other sources. Measurement data are displayed as contained in AIRBASE. They include, inter alia, different assumptions on correction factors or are uncorrected values, and the description of the station characteristics (urban background/traffic/etc.) is not always unambiguous.

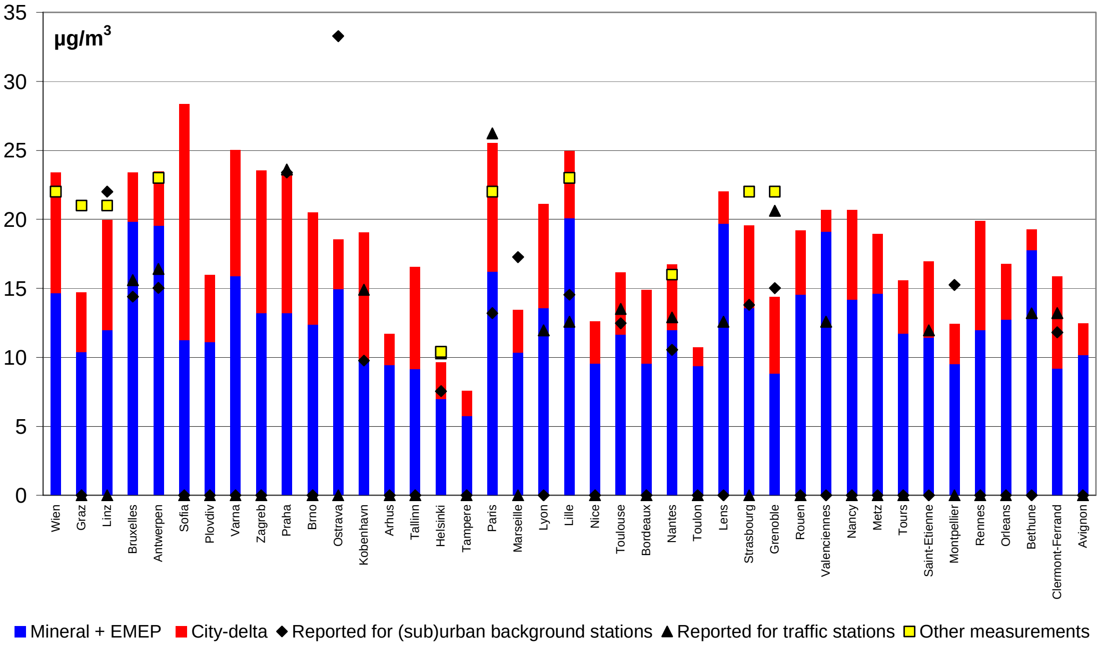


Figure 2.16: Contributions to urban background PM2.5 concentrations from mineral dust the long-range component computed by the EMEP model for the year 2004 and the estimated city-delta, compared to 2004 measurements reported in AIRBASE for urban background and traffic stations and from other sources, for Austria, Belgium, Bulgaria, Czech Republic, Denmark, Estonia, Finland, France.

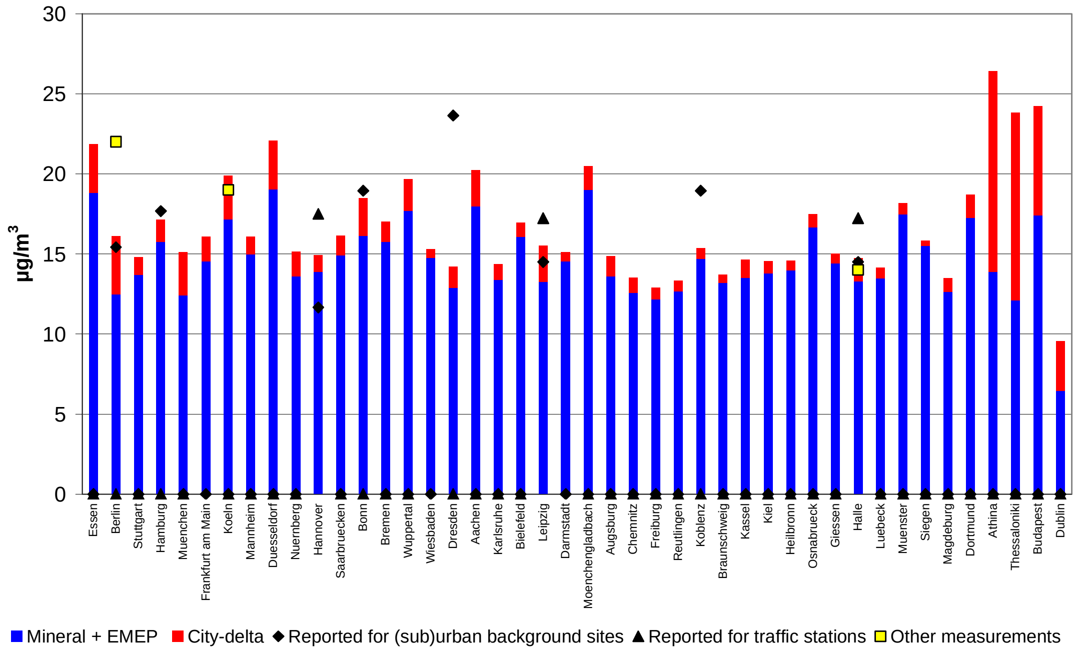


Figure 2.17: Contributions to urban background PM2.5 concentrations from mineral dust, the long-range component computed by the EMEP model for the year 2004 and the estimated city-delta, compared to 2004 measurements reported in AIRBASE for urban background and traffic stations and from other sources, for Germany, Hungary and Ireland.

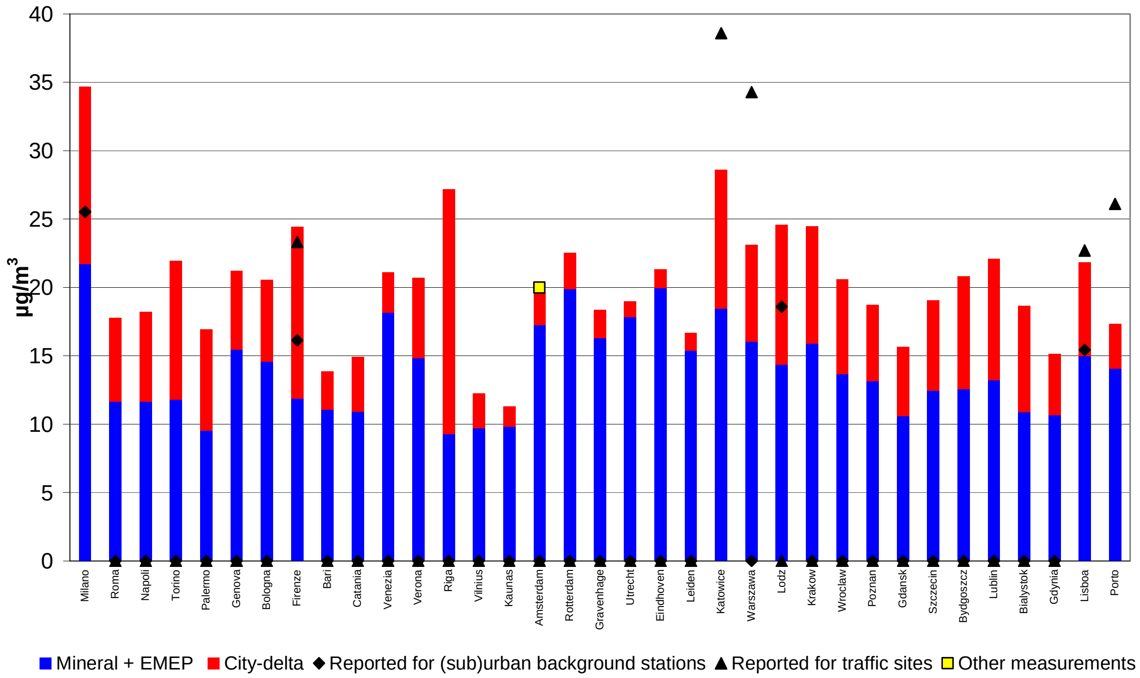


Figure 2.18: Contributions to urban background PM2.5 concentrations from mineral dust, the long-range component computed by the EMEP model for the year 2004 and the estimated city-delta, compared to 2004 measurements reported in AIRBASE for urban background and traffic stations and from other sources, for Italy, Latvia, Lithuania, Netherlands, Poland and Portugal.

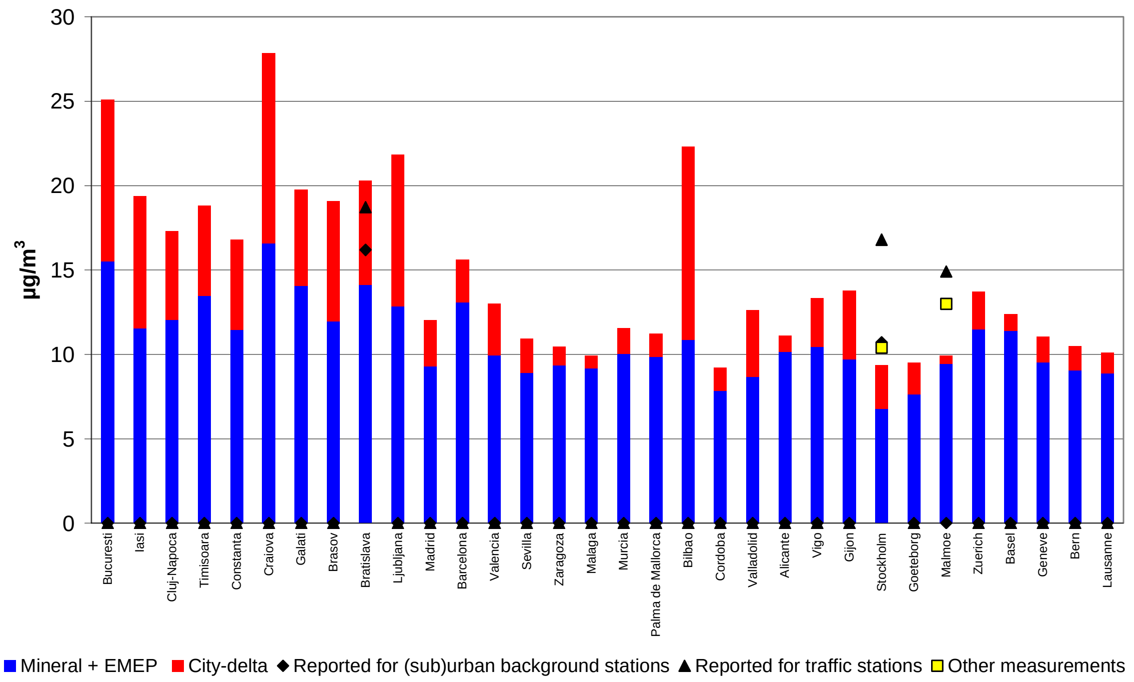


Figure 2.19: Contributions to urban background PM2.5 concentrations from mineral dust, the long-range component computed by the EMEP model for the year 2004 and the estimated city-delta, compared to 2004 measurements reported in AIRBASE for urban background and traffic stations and from other sources, for Romania, Slovakia, Slovenia, Spain, Sweden and Switzerland.

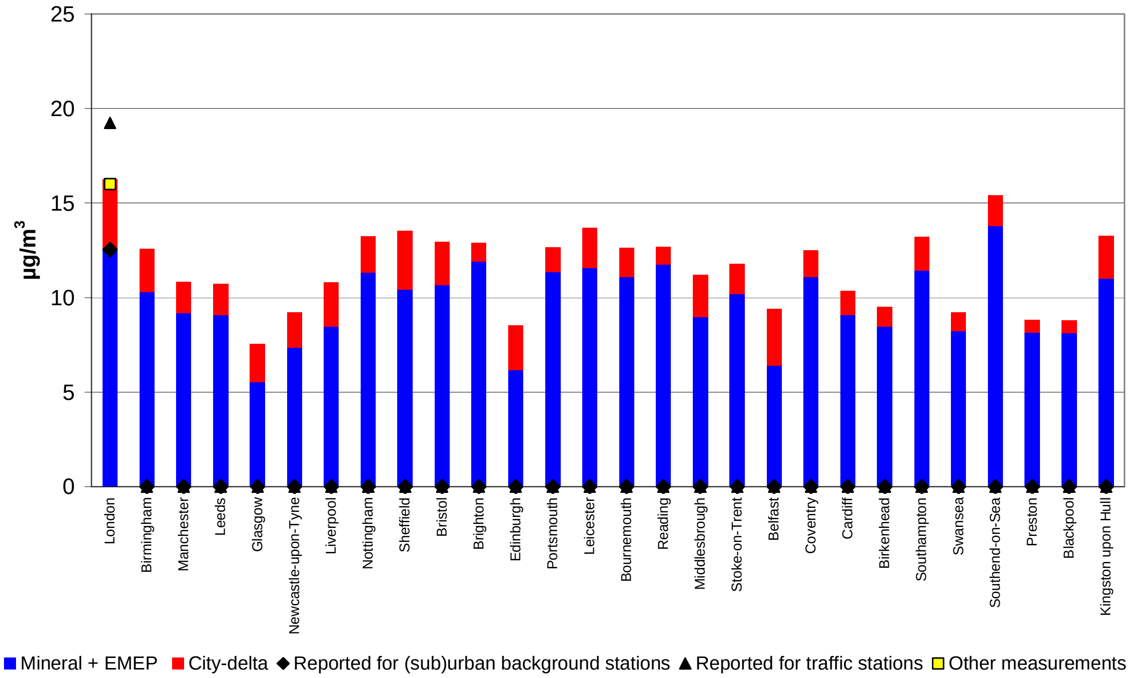


Figure 2.20: Contributions to urban background PM2.5 concentrations from mineral dust, the long-range component computed by the EMEP model for the year 2004 and the estimated city-delta, compared to 2004 measurements reported in AIRBASE for urban background and traffic stations and from other sources, for the United Kingdom.

Discussion

The urban increments derived with the methodology outlined above aim, for the purposes of a Europe-wide health impact assessment, at the quantification of the influence of urban emissions on health-relevant metrics of urban air quality. Since, from a health perspective, the endpoint of interest lies on a population-weighted long-term exposure of fine particles, the chosen metric (annual mean PM2.5 concentration in urban background air) cannot be directly compared with observations that are usually conducted to judge compliance with air quality limit values. Thus, the methodology is unable to provide meaningful information about PM concentrations over short time periods, for specific locations (e.g., hot spots, street canyons), and for other PM size fractions than PM2.5. Furthermore, measurements taken at such locations or taken for other size fractions (such as PM10) can be used for validation of the methodology to a limited extent.

Based on basic laws of atmospheric diffusion theory, the size of urban agglomerations, local wind speeds and the frequency of winter days with low ventilation, in addition to the emission densities of urban low-level emission sources, have been identified as critical factors that contribute to the “urban increments” in a given city. This information has been compiled from available sources for 473 European cities in Europe with more than 100.000 inhabitants. However, serious uncertainties that have critical influence on the estimated urban increments are associated with all these data. Most importantly, at the European level only limited information about the meteorological conditions within cities is available. Comparisons of local data with the information extracted from the Europe-wide databases reveals sometimes significant discrepancies. Furthermore, the available emission inventories for several source categories (e.g., road transport) exhibit substantial differences across countries which cannot always be explained to a satisfactory extent. Of particular relevance is the amount of fuel wood burned within cities, where the Europe-wide emission inventories provide only insufficient information.

Compared to the CAFE analysis, the revised methodology and data that are used for the NEC assessment result in higher urban increments of PM2.5. While a robust validation against the available measurements is burdened with high uncertainties, the comparably low increments computed, e.g., for Germany and the UK are mainly associated with the low densities of urban PM2.5 emissions that are used for the calculations, which are, however, in line with the nationally reported emission inventories. On the other hand, the uncertainties surrounding the issue of wood burning in cities might lead to potential overestimates of urban increments in countries with a high share of national total PM2.5 emissions from wood combustion (e.g., Austria, France). Furthermore, the lack of plant-specific specific information about the exact location and release height of industrial process emission sources might cause inaccuracies of the Europe-wide assessment for individual industrial cities.

More accurate information on city-specific meteorological data and information on the characteristics of local emission sources as well as improved monitoring data are important prerequisites for a further refinement of the methodology.

2.4.3 Deposition of sulfur and nitrogen compounds

The critical loads approach employed by the GAINS model for the quantification of ecosystems risks from acidification and eutrophication uses (ecosystem-specific) annual mean deposition of acidifying compounds (i.e., sulfur, oxidized and reduced nitrogen) as the impact-relevant air quality indicator. Significant non-linearities in the spatial source-receptor relationships due to co-deposition with ammonia have been found for the substantial emission reductions that have occurred over the last two decades (Fowler *et al.*, 2005). However, the EMEP Eulerian models suggests – for the technically feasible range of further emission reductions beyond the baseline projection considered by CAFE – nearly linear responses in annual mean deposition of sulfur and nitrogen compounds towards changes in SO_2, NO_x and NH_3 emissions:

$$Dep_{p,j} = Dep_{p,j,0} - \sum_i P_{i,j,p,0}(E_{i,p,0} - E_{i,p}) \tag{14}$$

with

$Dep_{p,j}$	Annual deposition of pollutant p at receptor point j
$Dep_{p,j,,0}$	Reference deposition of pollutant p at receptor point j
$E_{i,p}$	Annual emission of pollutant p (SO_2, NO_x, NH_3) in country i
$E_{i,p,0}$	Reference emissions of pollutant p in country i
$P_{i,\boldsymbol{j},\boldsymbol{p},0}$	Transfer matrix for pollutant p for emission changes around the reference emissions.

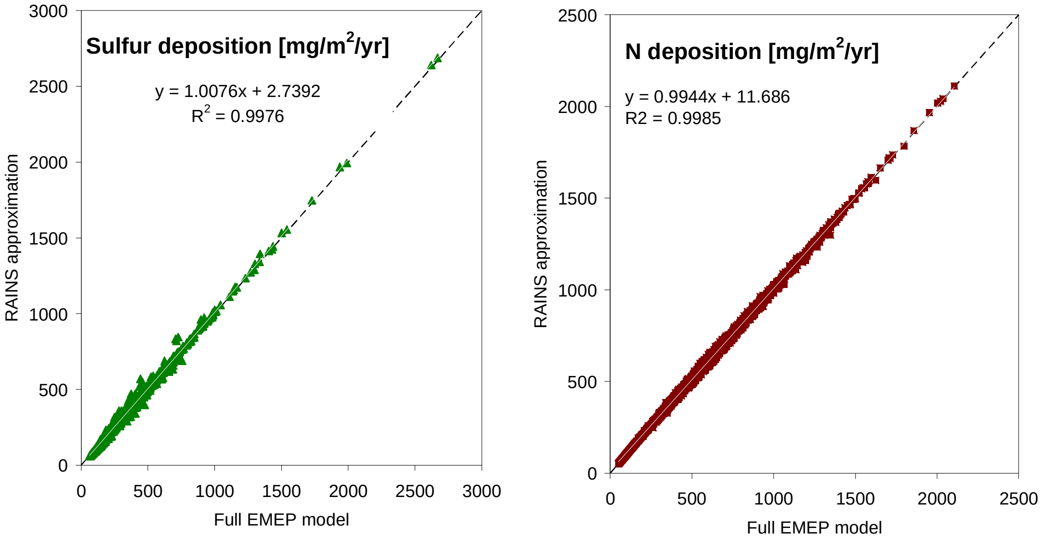


Figure 2.21: Comparison of the impact indicators calculated from the reduced-form approximations of the GAINS model with the results from the full EMEP Eulerian model, for the final CAFE scenario.

2.4.4 Formation of ground-level ozone – regional scale

The 2003 WHO systematic review of health aspects of air quality in Europe (WHO, 2003) emphasized that recent scientific studies have strengthened the evidence for health impacts from ozone not only from ozone peak episodes, but also from lower ozone concentrations as they occur throughout the year. The UNECE/WHO Task Force on Health recommended for health impact assessments the so-called SOMO35 as a relevant ozone indicator (UNECE/WHO, 2004). SOMO35 is calculated as the sum over the year of the daily eight-hour maximum ozone concentrations in excess of a 35 ppb threshold.

A wide body of scientific literature has highlighted important non-linearities in the response of ozone concentrations to changes in the precursor emissions, most notably with respect to the levels of NO_x emissions. It has been shown that, at sufficiently high ambient concentrations of NO and NO_2, lower NO_x emissions could lead to increased levels of ozone peaks. In earlier analyses for the negotiations of the Gothenburg multi-pollutant/multi-effect protocol in 1999, the RAINS model reflected this non-linear response through source-receptor relationships that describe the effect of NO_x emission reductions on accumulated ozone concentrations above 60 ppb in form of quadratic polynomials (Heyes *et al.*, 1996). A re-analysis of the latest Eulerian model results for the CAFE programme with a focus on the likely emission levels for the year 2020 suggests that such non-linearities will become less important for three reasons: (i) In 2020 "current legislation" baseline NO_x emissions are expected to be 50 percent lower than in the year 2000. (ii) The chemical processes that cause these non-linearities show less effect on the new long-term impact indicator (SOMO35) than for ozone peak concentrations; and (iii) such non-linearities diminish even further when population-weighted country-means of SOMO35 are considered. It was found that within the policy-relevant range of emissions (i.e., between the "CLE" and the "MTFR" levels anticipated for 2020), changes in the SOMO35 indicator could be described sufficiently accurate by a linear formulation:

$$O3_l = O3_{l,0} - \sum_i N_{i,l}(n_{i,0} - n_i) - \sum_i V_{i,l}(v_{i,0} - v_i) \tag{15}$$

where

$O3_l$	Health-relevant long-term ozone indicator measured as the population-weighted SOMO35 in receptor country l
$O3_{l,0}$	Population-weighted SOMO35 in receptor country l due to reference emissions n_0, v_0
n_i, v_i	Emissions of NO_x and VOC in source country i
$N_{i,l}$, $V_{i,l}$	Coefficients describing the changes in population-weighted SOMO35 in receptor country l due to emissions of NO_x and VOC in source country i.

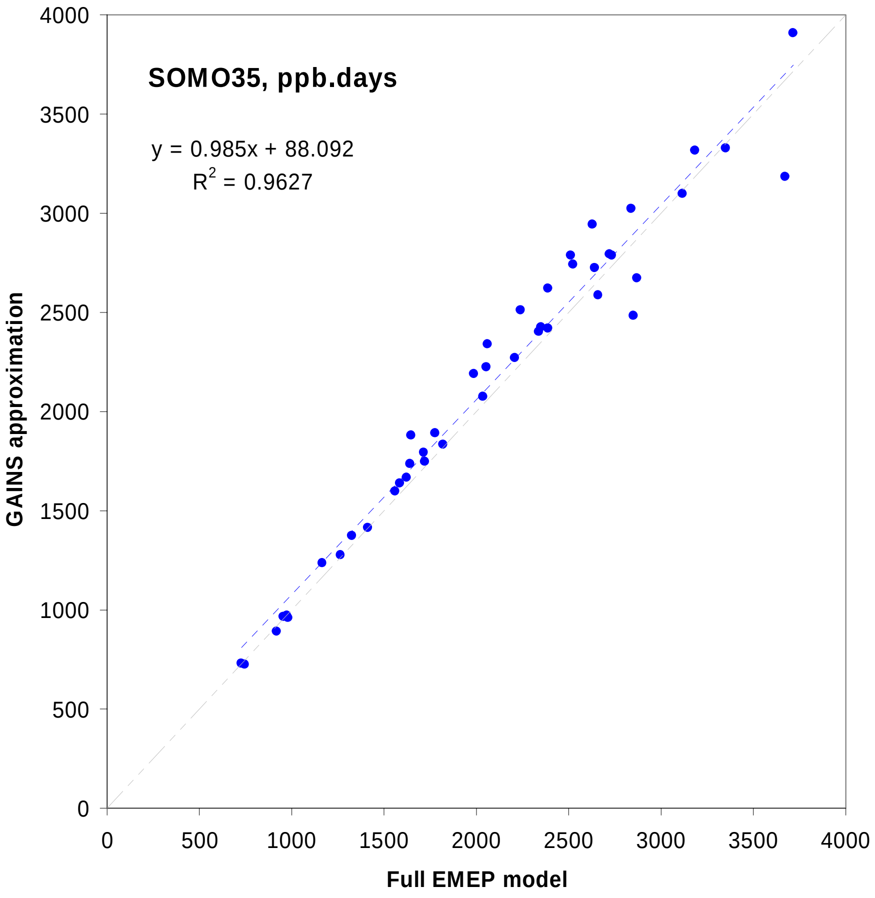


Figure 2.22: Comparison of the impact indicators calculated from the reduced-form approximations of the GAINS model with the results from the full EMEP Eulerian model, for the final CAFE scenario.

2.4.5 Formation of ground-level ozone – urban scale

As for fine particles, the GAINS analysis employs the EMEP regional scale Eulerian dispersion model with a 50*50 km resolution to compute regional scale changes in ozone that are thought to be representative for rural ozone levels. However, it is well understood that ozone within cities shows distinctive and systematic differences to rural levels, inter alia to the availability of local NO emissions in cities that cause a disappearance of ozone in urban areas. Analysis conducted within the City-delta project indicates in general that for reductions of urban NO_x emissions ozone concentration in cities increases because there is less NO released in the cities to react with ozone. This is e.g. reflected in the SOMO35 exposure measure (Figure 2.23). Within cities, these increases counteract reductions in ozone resulting from regional scale reductions of NO_x emissions.

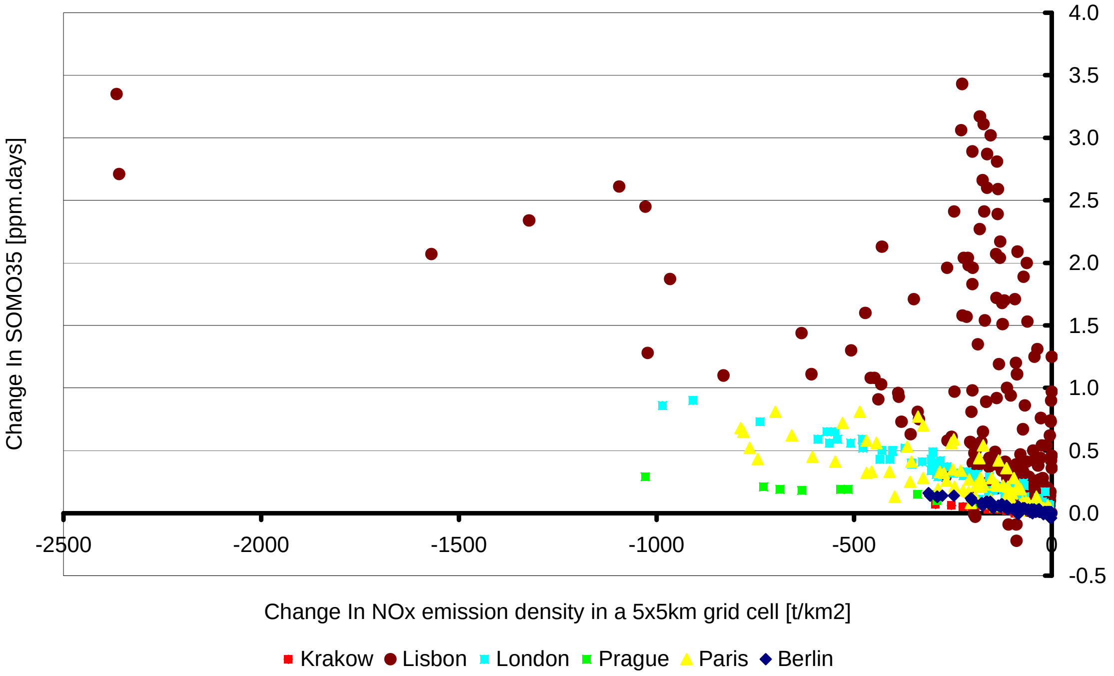


Figure 2.23: Change in the SOMO35 indicator in response to reductions of urban NO_x emissions as computed by the CAMx model for six European cities participating in the City-delta project.

While the existence of this inverse relation between the reductions of NO_x emissions and of urban ozone levels is widely acknowledged, the magnitude of this effect has not been quantified in a systematic ways for cities in different parts in Europe. It is clear from Figure 2.23 that ozone responds at different rates to emission reductions in the six cities analyzed, but the influence of the determining factors (such as meteorological conditions, emission densities, NO_x/VOC ratios, etc.) in a Europe-wide context has not been developed as yet.

In order to avoid that European emission control strategies focusing on health impacts are unduly driven by inaccurate representations of ozone formation for urban areas (e.g., by simply using results from regional scale dispersion models), a zero-order assumption has been made for the

GAINS computations that reductions in urban NO_x emissions would not lead to decreased ozone within cities.

In practice, based on the source-receptor relationships of Equation 15 derived from the regional scale model, for each country the changes of a population-weighted SOMO35 metric (which is proportional to the health impacts computed by GAINS) have been computed. Calculations have been done for the urban, rural and total populations, respectively, and for changes in NO_x and VOC emissions, respectively. In a second step, all improvements in the ozone indicator computed for the urban population in response to NO_x emission reductions have been set to zero, as a conservative reflection of the ozone chemistry within cities.

Furthermore, as indicated in Equation 15, the GAINS model applies a linear representation of ozone formation that is valid for limited variations from the reference (target) emission level. Obviously, such a formulation does not convey the important information of full ozone formation models to the optimizer that – at places with sufficiently high NO_x concentrations – larger reductions of NO_x emissions will lead to declining ozone, while smaller reductions will increase ozone. Without the information that larger reductions (beyond the analyzed emission range) will lead to declining ozone, a cost-minimizing optimization would tend to increase NO_x emissions in order to reduce ozone concentrations. Obviously, although such a solution constitutes a valid reaction on formal grounds, it is contrary to the objectives of European clean air policy. To avoid the GAINS optimization to be misled by incomplete information about ozone formation characteristics, all source-receptor relationships that indicate for the analyzed range of emission changes increases in the ozone health metric for the rural population due to reduced NO_x emissions have been set to zero.

In a third step, the resulting changes for urban and rural populations have been combined into single coefficients that reflect the collective response of total population to changes in NO_x and VOC emissions, respectively.

2.5 Air quality impacts

2.5.1 Health impacts from PM

Based on the findings of the WHO review on the health impacts of air pollution (WHO, 2003), the GAINS model quantifies for different emission scenarios premature mortality that can be attributed to long-term exposure to PM2.5, following the outcomes of the American Cancer Society cohort study (Pope *et al.*, 2002).

Cohort- and country-specific mortality data extracted from life table statistics are used to calculate for each cohort the baseline survival function over time. The survival function $l_c(t)$ indicates the percentage of a cohort c alive after time t elapsed since starting time w_0. $l_c(t)$ is an exponential function of the sum of the mortality rates $\mu_{a,b}$, which are derived from life tables with a as age and b as calendar time. As the relative risk function taken from Pope *et al.*, 2002 applies only to cohorts that are at least w_0=30 years old, younger cohorts were excluded from this analysis. Accordingly, for a cohort aged c, $l_c(t)$ is:

$$l_c(t) = \exp\left(-\sum_{z=c}^{t} \mu_{z,z-c+w_0}\right). \tag{16}$$

The survival function is modified by the exposure to PM pollution, which changes the mortality rate and consequently the remaining life expectancy (e_c). For a given exposure to PM2.5 (PM), life expectancy $\bar{l}_c$ is calculated as the integral over the remaining life time:

$$e_c = \int_c^{w_1} \bar{l}_c(t)\,dt = \int_c^{w_1} \exp\left(-RR_{PM}\sum_{z=c}^{t} \mu_{z,z-c+w_0}\right)dt \tag{17}$$

where w_1 is the maximum age considered and RR_{PM} the relative risk for a given concentration of PM2.5. With some simplifying assumptions and approximations (Vaupel and Yashin, 1985), the change in life expectancy per person (Δe_c) of a cohort c can be expressed as:

$$\Delta e_c = \beta PM \int_c^{w_1} l_c(t)\log l_c(t)dt \tag{18}$$

where – within the studied exposure range – RR_{PM} has been approximated as $RR_{PM} = \beta \cdot PM + 1$ with $\beta = 0.006$ as given in Pope *et al.*, 2002. For all cohorts in a country l the change in life years ΔL_l is then calculated as the sum of the change in life years for the cohorts living in the grid cells j of the country l:

$$\Delta L_l = \sum_{c=w_0}^{w_1} \Delta L_{c,i} = \beta \sum_{j\in l} PM_j \frac{Pop_j}{Pop_l} \sum_{c=w_0}^{w_1} Pop_{c,l} \int_c^{w_1} l_c(t)\log l_c(t)dt \tag{19}$$

where

$\Delta L_{c,l}$	Change in life years lived for cohort c in country l
$Pop_{c,l}$	Population in cohort c in country l
Pop_j	Total population in grid cell j (at least of age w_0=30)
Pop_l	Total population in country l (at least of age w_0=30).

2.5.2 Protection of ecosystems against acidification and eutrophication

The GAINS model applies the critical loads concept as a quantitative indicator for sustainable levels of sulfur and nitrogen deposition. Critical loads have been defined as the maximum input of deposition of sulfur and nitrogen compounds that does not, according to current scientific understanding, cause harmful effects in sensitive ecosystems in the long run (Nilsson and Grennfelt, 1988). The GAINS analysis employs the critical loads databases compiled by the Coordination Centre for Effects (CCE) of the UNECE Working Group on Effects. These critical loads have been computed by national focal centers using an internationally agreed methodology (Hettelingh *et al.*, 2004; UBA, 2004).

To evaluate the ecological impacts of emission control scenarios, GAINS compares computed deposition with these critical loads. GAINS uses the average accumulated exceedance (AAE) as a quantitative summary indicator for the excess of critical loads considering all ecosystems in a region. For the optimization mode of GAINS, the AAE for effect q in country l has been related to emissions by a linear model:

$$AAE_{q,l} = AAE_{q,l,0} - \sum_{p}\sum_{i} a_{i,l,p,q}(E_{i,p,0} - E_{i,p}) \tag{20}$$

where the sum is over all emitter regions i and all pollutants p contributing to critical load excess (sulfur and nitrogen species); as earlier, the index 0 refers to reference emissions. The so-called impact coefficients $a_{i,l,p,q}$ are derived at the CCE by first computing the depositions in one country from the emissions in another country via Equation (20) and then AAE from the individual critical loads according to:

$$AAE_{q,l} = \sum_{j\in l}\sum_{u} A_{q,j,u} \cdot \max\{Dep_{p,j} - CL_{q,j,u}, 0\} \Big/ \sum_{j\in l}\sum_{u} A_{q,j,u} \tag{21}$$

where $CL_{q,j,u}$ is the critical load of effect q for ecosystem u in grid j which has area $A_{q,j,u}$ and $Dep_{p,j}$ is the ecosystem-specific deposition onto that ecosystem of the relevant pollutant. The summation runs over all ecosystems within a grid cell j in country l. The 'maximum' in the equation makes sure that an ecosystem contributes zero to the AAE if the deposition is smaller than the critical load, i.e., if there is non-exceedance. This procedure is carried out for all country source-receptor combinations, resulting in a total of about 9,000 coefficients for acidification and eutrophication, of which, however, a large number is (close to) zero (Posch *et al.*, 2005). Equation 21 describes the AAE calculation for a single pollutant, such as total nitrogen for eutrophication. For acidification, the AAE calculations are more complicated since they include the effects of sulfur and nitrogen deposition (for technical details see Posch *et al.*, 2001, UBA, 2004). In the ex-post analysis of an optimization result, the AAE and protection percentages for the individual countries are directly and exactly computed from the individual critical load values.

2.5.3 Health impacts from ozone

Based on a comprehensive meta-analysis of time series studies conducted for the World Health Organization (Anderson *et al.*, 2004) and on advice received from the UNECE/WHO Task Force on Health (UNECE/WHO, 2004), the GAINS model quantifies premature mortality through an association with the so-called SOMO35 indicator for long-term ozone concentrations in ambient air. SOMO35 is calculated as the daily eight-hour maximum ozone concentrations in excess of a 35 ppb threshold, summed over the full year. In essence, the GAINS calculation estimates for the full year daily changes in mortality as a function of daily eight-hour maximum ozone concentrations, employing the concentration-response curves derived in the meta-analysis of Anderson *et al.*, 2004. The threshold was introduced (i) to acknowledge uncertainties about the validity of the linear concentration-response function for lower ozone concentrations, and (ii) in order not to overestimate the health effects. The annual cases of premature mortality attributable to ozone are then calculated as

$$Mort_l = \tfrac{2}{365} Deaths_l \cdot RR_{O3} \cdot O3_l \qquad (22)$$

where

$Mort_l$	Cases of premature mortality per year in country *l*
$Deaths_l$	Baseline mortality (number of deaths per year) in country *l*
RR_{O3}	Relative risk for one percent increase in daily mortality per µg/m^3 eight-hour maximum ozone concentration per day.

In addition to the mortality effects, there is clear evidence about acute morbidity impacts of ozone (e.g., various types of respiratory diseases). However, the GAINS model quantifies only mortality impacts of ozone, as they emerge as the dominant factor in any economic benefit assessment. Morbidity impacts will be quantified ex-post in the benefit assessment.

2.5.4 Vegetation impacts from ground-level ozone

Elevated levels of ozone have been shown to cause wide-spread damage to vegetation. In earlier policy analyses for the NEC Directive of the EU and the Gothenburg Protocol in 1999, RAINS applied the concept of critical levels to quantify progress towards the environmental long-term target of full protection of vegetation from ozone damage. The UNECE Working Group on Effects lists in its Mapping Manual critical levels for crops, forests and semi-natural vegetation in terms of different levels of AOT40 (UBA, 2004). This indicator is defined as the sum of hourly ozone concentrations above a threshold of 40 ppb, accumulated over the most sensitive vegetation period. After 1999, several important limitations and uncertainties of the AOT approach have been pointed out, inter alia a potential mismatch with critical features of important physiological processes. Alternative concepts, including the ozone flux concept, were developed and suggested as superior alternatives to the former AOT40 approach (Karlsson *et al.*, 2004).

While the theoretical advantage of the flux concept is widely accepted, the quantification of its critical parameters and their validation for economically and ecologically important vegetation types and plant species could not be completed in time for this analysis. Thus, for describing vegetation impacts of ozone the GAINS model cannot yet rely on a generally accepted methodology. It was found that the SOMO35 indicator as it is used by GAINS for quantifying health impacts is generally more sensitive than both the AOT40 and the currently available ozone flux indicators. Thus, it was concluded that progress on the SOMO35 scale will lead to at least equivalent progress on both scales that are currently discussed for vegetation impacts. Ozone vegetation impacts will be quantified ex-post in the benefit assessment.

2.6 Cost-effectiveness analysis

2.6.1 The RAINS optimization approach

As one of its most policy-relevant features, the optimization approach of the RAINS model allows a systematic search for cost-minimal combinations of emission control measures that meet user-supplied air quality targets, taking into account regional differences in emission control costs and atmospheric dispersion characteristics. In essence, RAINS formulates an optimization problem with the objective to minimize total European control costs (for all countries *i* and pollutants *p*):

$$\sum_i \sum_p C_{i,p} \rightarrow \min . \tag{23}$$

For each country *i* and pollutant *p*, emission control costs $C_{i,p}$ are represented in form of cost curves as described in Equation 5, i.e., as a function of national emissions $E_{i,p}$, which in turn are functions of the emission control measures $x_{i,k,m,p}$ in a country *i*:

$$C_{i,p} = f_{i,p}(E_{i,p}) = f_{i,p}(g_{i,p}(x_{i,k,m,p})) . \tag{24}$$

Optimal emission reductions are subject to environmental constraints for the various air quality problems *q* (i.e., health impacts from PM and ozone as well as ecosystems protection against acidification and eutrophication). Numerical values for these constraints are specified by the user (i.e., policy analyst) and reflect the environmental policy targets for which a least-cost emission control strategy should be explored. In the optimization problem, these environmental constraints (targets) are linked via the source-receptor relationships $h_{l/j,q}$ with emissions strengths ($E_{i,p}$) and thus with emission controls ($x_{i,k,m,p}$) at individual emission sources *m*:

$$Targ_{l|j,q} = h_{l|j,q}(E_{i,p}) = h_{l|j,q}(g_{i,p}(x_{i,k,m,p})) \tag{25}$$

Depending on user preferences, targets *Targ* for an effect *q* can be specified for individual grid cells *j*, countries *l*, or for the entire EU as receptor areas. To describe the relations $h_{l/j,q}$ between emission sources ($E_{i,p}$) and environmental impacts *q*, RAINS applies the source-receptor relationships and the quantifications of the various impacts as described in the preceding sections. The full mathematical formulation of the RAINS optimization approach as it was used for CAFE is provided in Wagner *et al.*, 2006.

2.6.2 The GAINS optimization

In GAINS there are two types of decision variables: (i) the activity variables $x_{i,k,m}$ for all countries *i*, activities *k*, and control technologies *m*, and (ii) the substitution variables $y_{i,k,k'}$ that represent fuel substitutions and efficiency improvements (replacing activity *k* by activity *k'*). The objective function that is minimized is the sum

$$C = \sum_{i,k} \left(\sum_{m} c^{x}_{i,k,m} \cdot x_{i,k,m} + \sum_{k'} c^{y}_{i,k,k'} y_{i,k,k'} \right) \tag{26}$$

where the first term represents the total end of pipe technologies cost, and the second term represents the total substitution/energy efficiency cost term. In order to avoid double counting the substitution cost coefficients $c^{y}_{ikk'}$ in the second term are calculated for uncontrolled activities, the difference in cost for control equipment for a fuel substitution is accounted for in the first term.

It is convenient to consider the activity data $x_{i,k}$, which are obtained from the variables $x_{i,k,m}$ by performing the appropriate sum over control technologies *m*. Activity data as well as the substitution variables may be constrained:

$$x^{\min}_{i,k,m} \le x_{i,k,m} \le x^{\max}_{i,k,m}, \; x^{\min}_{i,k} \le x_{i,k} \le x^{\max}_{i,k}, \quad y^{\min}_{i,k,k'} \le y_{i,k,k'} \le y^{\max}_{i,k,k'} \tag{27}$$

due to limitations in applicability or availability of technologies or fuel types.

The applicability of add-on technologies may be constrained by a maximum value:

$$x_{i,k,m} \le appl^{\max}_{i,k,m} x_{i,k}, \quad appl^{CLE}_{i,k,m} \le appl^{\max}_{i,k,m} \tag{28}$$

where the maximum application rate is at least as high as the application rate in the current legislation scenario. For ammonia (NH_3), technologies in the agricultural (livestock) sector are subdivided into technologies applying to different stages of manure treatment. For these technologies, application constraints are applied at a more aggregated level.

Emissions of pollutant *p* are calculated from the technology-specific activity data $x_{i,k,m}$ and their associated emission factors $ef_{i,k,m,p}$:

$$E_{i,p} = \sum_{k} \sum_{m} ef_{i,k,m,p} \cdot x_{i,k,m} \tag{29}$$

Since for no individual activity *k* emissions should increase above the current legislation level, it is further imposed that

$$\sum_{m} ef_{i,k,m,p} \cdot x_{i,k,m} \le IEF^{CLE}_{i,k,p} \cdot x_{i,k} \tag{30}$$

where $ef_{i,k,m,p}$ is the emission factor for pollutant *p* stemming from activity *k* being controlled by technology *m*, and $IEF_{i,k,p}^{CLE}$ is the implied, i.e., average emission factor for that pollutant from activity *k* in country *i* in the current legislation scenario.

Activity variables $x_{i,k,m}$ are linked to the substitution variables $y_{i,k,k'}$ via the balance equations

$$x_{i,k} + \sum_{k'} y_{i,k,k'} - \sum_{k'} \eta_{i,k,'k} \cdot y_{i,k,'k} = x^{CLE}_{i,k} \tag{31}$$

where $x^{CLE}_{i,k}$ is the activity *k* in country *i* in the current legislation scenario and $\eta_{i,k,k'}$ is the substitution coefficient that describes the relative efficiency change in the transition from activity *k'* to activity *k*. For example, in the energy sector this last equation is balancing the energy supply before and after a fuel substitution. There are also a number of constraints which ensure consistency across various levels of aggregations of sub-sectors and sub-activities.

3 Changes since the CAFE analysis

This section discusses the changes introduced for modelling methodology and databases since the CAFE analyses for the Thematic Strategy on Air Pollution. Details on each aspect are provided in the preceding sections.

3.1 Changes in the model structure

3.1.1 Road transport

Compared with calculations made for CAFE, the structure in the GAINS model of the transport sector has been extended to allow a separate treatment of cars, light-duty trucks, buses and heavy-duty trucks. Previously these categories were lumped into light-duty and heavy-duty vehicles. For countries and activity scenarios for which such a split was not available, light duty trucks are reported together with cars, and buses together with heavy-duty trucks.

For the national activity scenarios projection data were collected not only for fuel consumption but also for mileage (vehicle-kilometres) and vehicle numbers for each vehicle category. However, it has turned out that reported mileage data are not always consistent with the fuel consumption data provided in the associated energy forecasts. Thus exhaust emissions are calculated in GAINS still from fuel consumption, while information on mileage is used to calculate non-exhaust emission of PM (tyre and brake wear, road abrasion). Vehicle numbers are used for computing emission control costs. This new approach makes it possible for GAINS to model the effects of fuel efficiency improvement in GAINS. Since the PRIMES model does not provide information on mileage and vehicle numbers, corresponding data have been assessed by IIASA based on either national data or on international road statistics.

The emission characteristics of control technologies were modified to reflect the COPERT-IV emission factors (Samaras, 2006). COPERT-IV reflects recent measurements of emissions in real operating conditions, instead of data measured in test cycles. Real-life emission factors turned out for light-duty and heavy-duty diesel vehicles higher than factors measured during test cycle.

In addition, data on Euro-5 and Euro-6 for passenger cars and light-duty vehicles have been revised taking into account the current proposals prepared by the Commission (CEC, 2005b, CEC, 2006). At the time of writing of this report, European institutions are finalizing the agreement on the future standard on PM2.5 and NO_x and possibly other pollutants. Therefore, the NEC baseline includes the proposed new standard as it is likely to be concluded by the time the Commission launches the new NEC proposal. To the extent the approved new Euro-6 standard is different from the proposed standard the baseline will be adjusted to ensure full consistency. However, the implication in this adjustment is likely to be small. The overall implications of the inclusion of Euro-5 and Euro-6 standards to the NEC baseline for light duty vehicles will be reported transparently in the final version of the baseline report for NEC.

3.1.2 Representation of biomass and other renewable fuels

The new GAINS model incorporates a more detailed representation of the use of biomass, waste, and renewable energy sources. For biomass, 10 fuel types (inter alia, agricultural residuals, fuel wood, black liquor, waste fuels) are distinguished, for other renewables five new categories have been implemented (geothermal, small hydropower, solar photovoltaic, solar thermal, wind). This makes it possible to properly reflect the potentials for fuel substitution for each detailed category in the GAINS model. For the transport sector, the increased use of biofuels has been considered along the assumptions of the PRIMES and national energy projections, respectively.

3.1.3 Combustion in the domestic sector

Important changes have been made for small combustion installations in the domestic sector. The list of available boiler/stoves and control technologies in the VOC and PM modules has been unified and extended to better reflect emission factors and emission control possibilities. For biomass, emission factors and control costs depend now on fuel type. For stoves a separate set of emission factors and cost data has been prepared, distinguishing cooking and heating applications.

The choice of the representative techniques is based on information about national stocks of stoves and boilers and on analyses of their characteristics (Sternhufvud *et al.*, 2004, Johansson *et al.*, 2005, Haakonson and Kvingedal, 2001, Strehler, 2000, Wierzbicka *et al.*, 2005, Olsson *et al.*, 2003, Olsson, 2004, Broderick *et al.*, 2005, Henriksen, 2005). Apart from distinguishing between old and new installations, pellet stoves and boilers as well as ‘end-of-pipe’ options for controlling PM emissions from small domestic installations are explicitly distinguished in the model allowing for efficient emission abatement also in a shorter time perspective.

It is important to stress that the validation of cost data for these new boiler/stoves types is not yet finalized and might be revised in the coming months.

3.1.4 Computation of CO_2 emissions

The algorithm for calculating CO_2 emissions has been improved and aligned with the UNFCCC definitions. The new approach takes explicit account of the share of biofuels in liquid fuels used in transport. Emissions from aviation are calculated only for domestic flights. To reflect emissions from sectors/industrial products that are not included in GAINS a new emission sector (“Other CO_2 emissions”) has been introduced in order to better reproduce national inventory reports submitted to the UNFCCC. However, these changes do not affect the pollutants covered under the NEC directive.

3.1.5 VOC emitting sectors

Following the wealth of new information on the structure of VOC emitting activities and available emission control options, the GAINS structure was changed to incorporate the relevant features into the cost-effectiveness analysis. In particular, the old RAINS model structure has been changed to include coil coating activities (based on information provided by the European Coil Coating Association (ECCA) and more detailed mitigation options for emissions from the domestic use of solvents (BIPRO, 2002).

Other specific industrial activities, for which industrial associations have provided detailed information (e.g., marine coating, protective coating), constitute only a small share of European VOC emissions, and it is not foreseen that this share would substantially increase in the future. To maintain in the GAINS model the balance of details across sectors and pollutants, this information has been properly aggregated into larger categories. The representation of adhesive use in GAINS, formerly employing the findings of the EGTEI project, has been revised after discussions with industrial associations. For printing, a revised structure following the proposal of the EGTEI analysis is being incorporated into the GAINS model and will be available in the near future.

3.1.6 Agriculture

The calculation of ammonia emissions from dairy cows has been revised to take account of the impacts of increasing milk yield on nitrogen excretion that consequently lead to higher emission factors per animal. The relationship between milk yield and nitrogen excretion was derived from national studies (e.g., Haan, 2006; personal communication). Data on milk yield were extracted from the UNECE Expert Group on Ammonia Abatement questionnaire (Klimont *et al.*, 2005) and reviewed during the consultations with national experts.

3.1.7 The GAINS optimization routine

As discussed in the preceding section, the RAINS “cost curve” optimization approach has been replaced by the “technology approach” of the GAINS model. Detailed descriptions of the approaches, their differences and the comparison of their results are provided in Sections 2.3 and 2.6.

3.2 Updated emission inventories

Updated and sometimes more detailed information on activity statistics and the performance of emission control measures as well as revisions in national emission inventories caused changes in the emission estimates for the year 2000 compared the inventories used for the CAFE analysis. As illustrated in Figure 3.1 and Figure 3.2, national submissions of inventories for the same target year (2000) experienced sometimes considerable changes over time resulting from more in-depth assessments that have been conducted by countries for the preparation of the revised NEC directive.

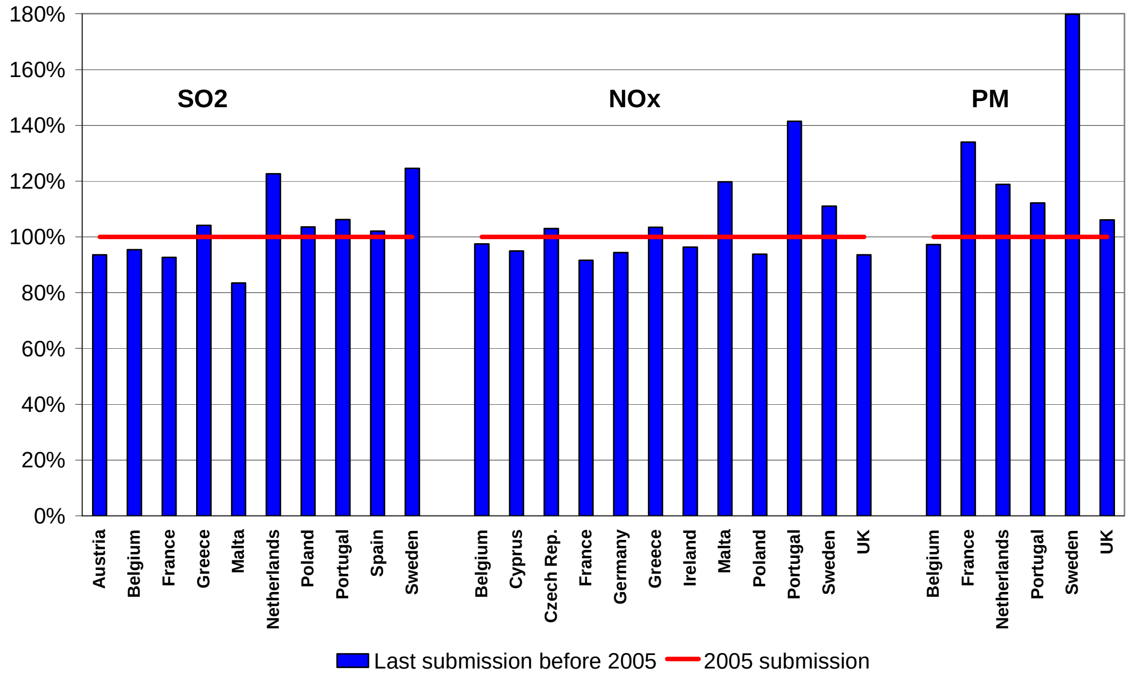


Figure 3.1: Comparison of national emission inventories of SO_2, NO_x and PM as reported to UNECE and/or EU for the year 2000 between the most recent official submission and earlier submissions

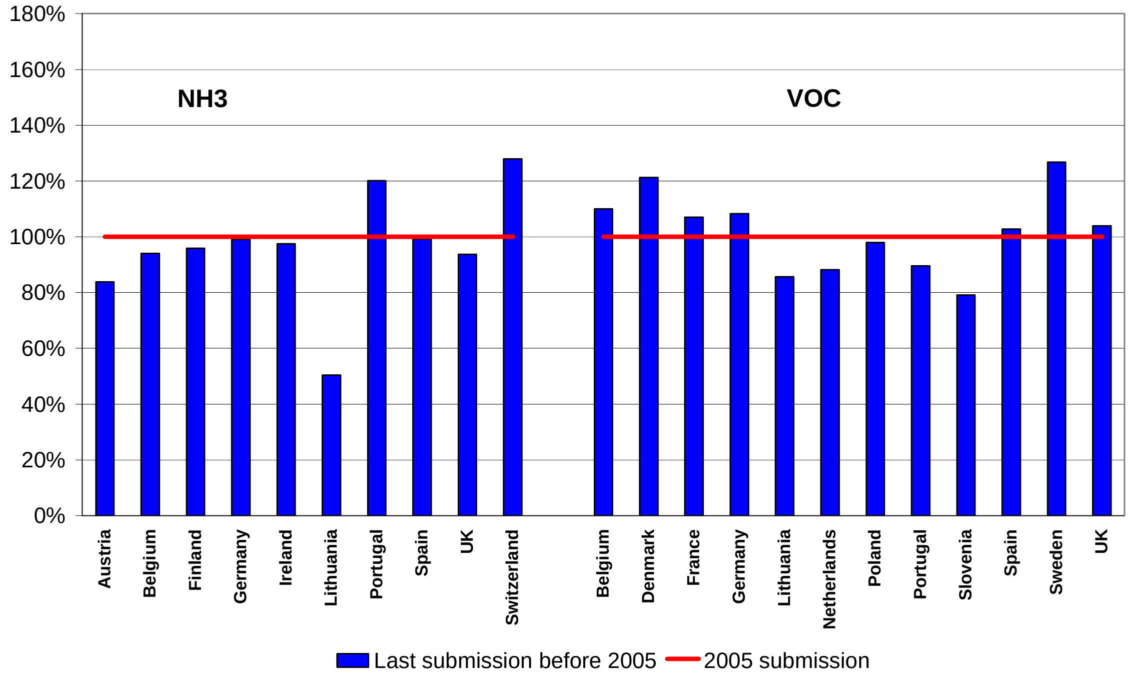


Figure 3.2: Comparison of national emission inventories of NH_3 and VOC as reported to UNECE and/or EU for the year 2000 between the most recent official submission and earlier submissions

Consequently, also the emission database in the GAINS model was updated to reflect this improved information and to match the most recent understanding of national emissions. The most important changes relate to:

- Penetration of emission control measures, where more information was provided by national experts and industrial associations in the course of the bilateral consultations.
- Modified emission factors for all Euro-standards for diesel vehicles reflecting the recent findings of the ARTEMIS project/COPERT-IV model.
- The representation of the residential sector in GAINS has been significantly modified to reflect more accurately emissions and control potentials from small combustion sources (see Section 3.4.4). Emissions from this sector have been in the centre of interest of the emission inventory community. While a substantial body of new data have been recently collected, especially with respect to emission characteristics, information on activity data is still uncertain. There are sometimes large differences between national and international assessments, in particular for the combustion of non-commercial biomass. The revision required additional data on combustion activities in this sector and a revised parameterization of the existing emission factors, and affects emissions of PM and VOC.
- Updated information on ammonia emissions, based on national information following the improved chapters on agriculture in the European Emission Inventory Guidebook.
- Update of ammonia emission factors for stationary combustion, especially for those NO_x emission control technologies that have potential impact on ammonia emissions.
- Improved treatment of VOC emissions from the coil sector, decorative paints, printing industry and vehicle refinishing. New information on current emission factors and their expected future development was provided by industrial associations.
- Incorporation of the findings of an EU-commissioned study (BIPRO, 2002)about the ‘domestic solvents’ sector and on possibilities for further emission abatement.
- Update of activity data on paint consumption and wood coating based on new information from industrial and national experts.

With this improved information it was possible to bring the emission estimates of the GAINS model in close agreement with the recent international submissions of national inventories, using internationally available activity statistics and plausible ranges of emission factors and penetration rates of emission control measures (Figure 3.3). With very few exceptions, for which clear explanations for the remaining differences in estimates have been identified, inventories for SO_2 and NO_x deviate typically by not more than two to three percent. Larger differences remain for the estimates of ammonia emissions, where recent methodological findings on emission factors and additional source categories have not always been incorporated in national estimates.

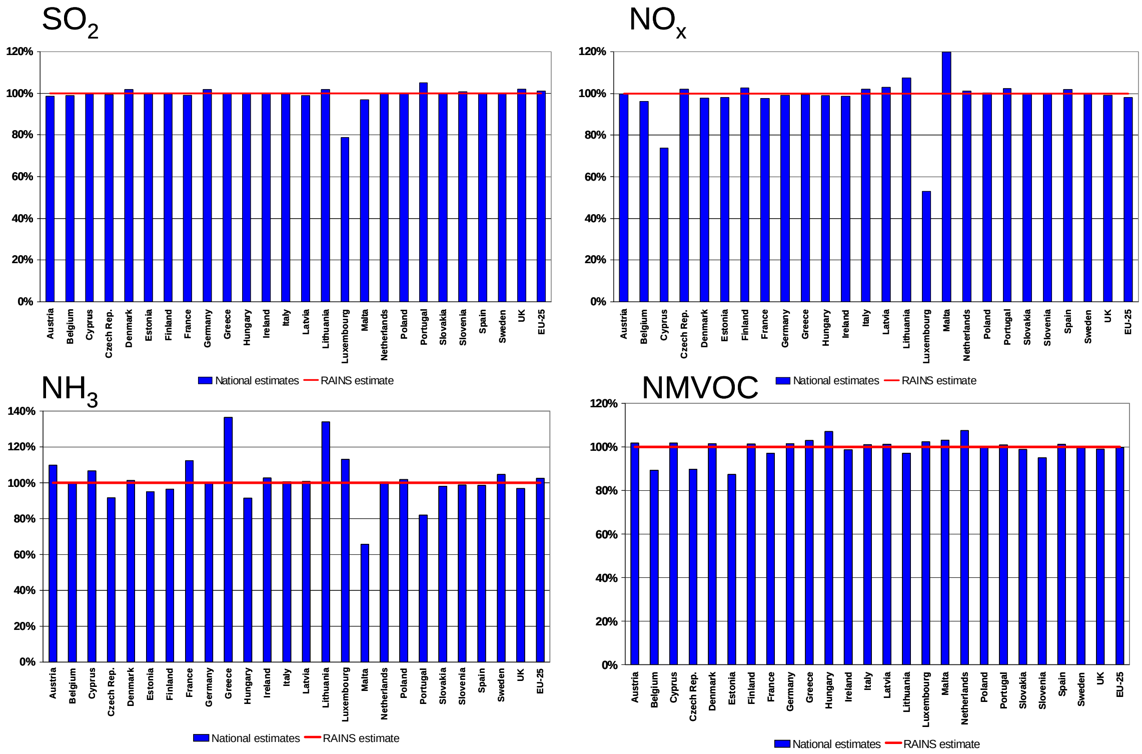


Figure 3.3: Comparison of the recent submissions of national emission inventories for SO_2, NO_x, NH_3 and VOC (blue bars) with the GAINS estimates (red line) for the year 2000.

In contrast, despite the significant improvements in the national inventories for particulate matter that occurred since the CAFE analysis, there are still major discrepancies in the estimates of PM emissions. As shown in Figure 3.4, only 13 out of the 25 EU Member States have submitted their inventories for PM2.5. Compared to the inventories that were available for the CAFE analysis, recent national estimates reach now substantially closer agreement with the GAINS estimates, with remaining differences typically in the range of ±10 to 15 percent. However, no national estimates are available for the other 12 EU Member States, and existing inventories for other size fractions of particulate matter (TSP or PM10) show sometimes large differences to the corresponding GAINS estimates. Discrepancies occur especially for non-combustion sources and for the coarser PM10-PM2.5 fraction.

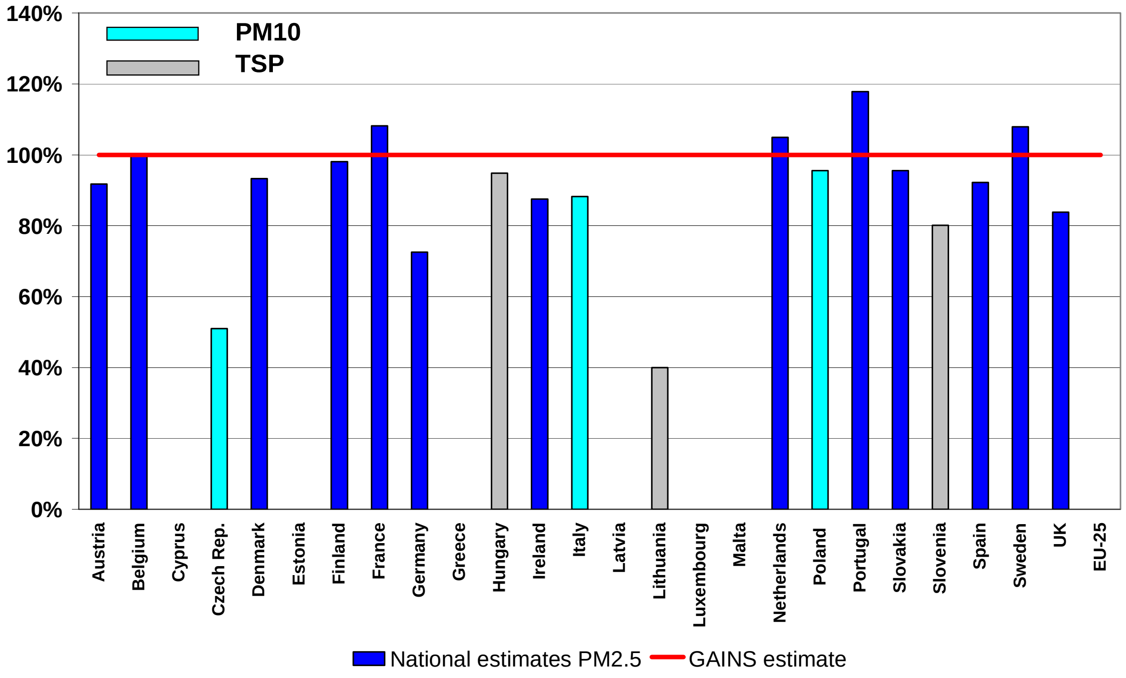


Figure 3.4: Comparison of the recent submissions of national PM inventories (blue/grey bars) with the RAINS/GAINS estimates (red line) for the year 2000.

3.3 *New baseline activity projections*

After the CAFE programme, a major effort was undertaken to update and expand the range of activity projections in order to provide a comprehensive basis for the NEC policy analysis. In particular, the following projections became available:

- National projections on energy, transport and agricultural activities, non-energy sources of VOC and industrial processes.
- New PRIMES energy and transport projection with updated assumptions on economic development, international oil prices and for several variants of climate policy targets.
- EU-wide livestock projections developed with a CAPRI model for the European Environment Agency study (EEA, 2004). These projections take into account the mid-term reform of the EU Common Agricultural Policy.
- New mineral nitrogen fertilizer projections for the EU-25 developed by the European Fertilizer Manufacturers Association (EFMA, 2005).
- For a number of sectors (e.g., vehicle refinishing, wood coating, marine coating) industrial associations provided information on expected developments for the EU-15 as a whole or for individual Member States. These projections were used when no national projections for a given sector are available.

3.4 Changes in the assumption on current legislation (CLE)

In general, the description of the temporal implementation rates of legislation in the various Member States has been greatly improved through country-specific information provided by national experts in the course of the bilateral consultations at IIASA. Furthermore, assumptions about application potentials of the various emission control measures were validated and updated by national experts.

3.4.1 Road transport

At the time of writing of this report, European institutions are finalising the agreement on the future standard on NO_x and possibly other pollutants. Therefore, the NEC baseline includes the new standards that are likely to be concluded by the time the Commission makes the new NEC proposal. To the extent the agreed new Euro-6 standard will be different from the proposed standard the baseline will be adjusted to ensure full consistency. However, the implication of this adjustment is likely to be small. The overall implications of the inclusion of Euro-5 and Euro-6 standards to the NEC baseline for light duty vehicles will be reported transparently in the final version of the baseline report for NEC. Implementation dates of 2009 for Euro-5 and 2014 for Euro-6 diesel passenger cars and light duty vehicles have been assumed

3.4.2 IPPC for pigs and poultry farms

In the course of the CAFE project it has not been possible to fully consider the implementation of the IPPC directive for pigs and poultry farms in a consistent way. For the purposes of the NEC assessment, improved information on the anticipated penetration of abatement measures has been provided by Member States. In addition, a specific EU service contract on integrated measures to reduce ammonia emissions (No. 070501/2005/422822/MAR/C) has delivered preliminary estimates of the percentage of animals (pigs and poultry) kept on farms that fall under IPPC legislation.

A comparison of these preliminary estimates with the perspectives provided by national experts to IIASA in the course of the bilateral consultations revealed for several countries significant discrepancies in the numbers of animals that are kept on IPPC farms. While for countries that have already advanced emission control programs in place (e.g., Denmark, Netherlands, Belgium) differences are small, for other countries where legislation is less advanced the European study finds much larger shares of animals kept on large farms than were reported by the national experts.

While the IPPC allows certain flexibility in the application of its provisions, it has been decided in the interest of maintaining international consistency and a fair starting point for the NEC analysis to assume for the NEC baseline a uniform application of agricultural IPPC for all Member States. In particular, it has been assumed that emission control measures reflected by the GAINS control options “low emission housing with covered storage and efficient application of manures” will be applied on all IPPC farms by 2010. Furthermore, in the absence of estimates of farm structure changes, the share of animals kept on IPPC farms has been kept constant after 2010. If national legislation resulted in stricter emission controls than IPPC, these interpretations have been used.

For cattle, the discussed possibility of introducing IPPC requirements has not been included in the NEC baseline, except for countries where this forms already part of existing legislation. Furthermore, for estimating the emission control potential, the NEC baseline assumes that all pigs on IPPC farms are kept on liquid manure systems.

The preliminary estimates of the EU service contract on integrated measures to reduce ammonia emissions as well as the assumptions taken for the NEC baseline projection have been provided to the IPPC steering committee for discussion in early December.

3.4.3 Solvent and product directives

For the CAFE analysis, the translation of the solvent and product directives into quantitative estimates of the penetration of emission control measures RAINS relied heavily on the results provided by the Expert Group on Technology (EGTEI). Since then, additional information was provided by industrial associations and national experts from Member States. In particular, industrial experts provided valuable information of different character on the use of decorative paints, wood coating, coil coating, protective and marine coating, printing, vehicle refinishing, automotive and can coating, adhesives use. This information has been used to the extent possible to refine the implementation rates of emission control measures in the Member States, although difficulties arose in aggregating detailed information into the broader categories considered by GAINS.

3.4.4 Residential combustion

Owing to the structural change in the GAINS model for this sector new data about current and future structures of this sector had to be collected, especially for biomass used in different types of stoves and boilers. Useful information was provided by national experts and in systematic studies conducted in several countries (Haakonson and Kvingedal, 2001; Karvosenoja *et al.*, 2006, Olsson *et al.*, 2003). For countries where such national studies are not available, experience from other countries with similar conditions has been extrapolated. In any case, the analysis considers typical replacement rates of stoves to describe the penetration of new equipment.

3.4.5 Other sources

Latest national information has been included for oil and gas production sector in Norway. Based on the information from representatives of the adhesive industry (Industrieverband Klebstoffe e.V., Germany) new descriptions of the “current legislation” control strategies for this sector were developed.

3.4.6 Other legislation (NEC 2010, air quality daughter directives

For methodological reasons and due to a lack of country-specific information, the NEC baseline and policy scenarios presented in this report do not embark on assumptions about additional measures beyond existing source-specific legislation that might be necessary to achieve compliance with the national emission ceilings in 2010 and/or with the air quality limit values laid down in the various daughter directives.

3.5 Update of data on emission control costs

3.5.1 Road transport measures

Cost data on Euro-5 and Euro-6 for diesel passenger cars and light-duty vehicles will be revised based on the assessments conducted by the European Commission (CEC, 2005b, CEC, 2006). As these measures are assumed to form part of the “current legislation” of the NEC baseline, their costs will be included into baseline costs of NEC baseline. However, when computing costs of proposed emission ceilings in comparison to the CAFE baseline, these costs must be added. Costs will be reported in a transparent way to facilitate this comparison.

3.5.2 Ammonia control costs

Costs for cleaning the exhaust air from poultry and pig stables as well as for covered manure storage have been updated based on information from UK (Ryan, 2004) and the Netherlands (Haan, 2006; personal communication).

The typical size of farms is a critical factor determining costs of ammonia abatement. Information about size distributions was collected from national experts in 2003 through the UNECE Expert Group on Ammonia Abatement questionnaire (Klimont *et al.*, 2005) and later supplemented by data from the EUROSTAT CRONOS database.

3.5.3 VOC control costs

The new cost data for coil coating, vehicle refinishing, and decorative painting, which were produced in the course of bilateral consultations with industry were implemented in GAINS. Costs for reducing emissions from domestic solvent applications were derived from BIPRO, 2002.

3.6 Revised atmospheric dispersion calculations

3.6.1 Regional scale calculations

For the NEC analysis an extended set of approximately 2000 scenario calculations with the EMEP Eulerian model has been compiled, based on the state of the EMEP model as of August 2006. These calculations include the recent gridded emission inventories for 2004, and have been performed for the meteorological conditions of five years (1996, 1997, 1998, 2000, 2003). However, for the first round of policy scenario analysis presented in this report, meteorological conditions for the year 1997 have been considered only, in order to maintain comparability with the computations and environmental targets analyzed in the CAFE programme for the Thematic Strategy on Air Pollution. The influence of the inter-annual meteorological variability on the robustness of emission ceilings could be subject of the subsequent round of model calculations in early 2007.

CAFE has explored a potentially large range of policy targets, which required at that time for the RAINS model transfer coefficients that cover the entire range. While such coefficients allow a universal application, they constitute an approximation of the responses of the EMEP model over a relatively large emission range, with a necessary lower overall quality of fit.

For the revision of the NEC directive, however, the Commission has indicated in its Thematic Strategy the environmental ambition level for which the emission ceilings should be determined. The new set of transfer coefficient has been tailored towards a narrow range of emission changes around the emission targets. Thus, it enables a much more precise representation of the response of the full EMEP model around this target emission level. In practice, the emission levels proposed in the Thematic Strategy have been adopted as the reference case, and sensitivity cases have been computed for deviations from these levels.

Computations of the ozone dispersion characteristics have applied a modified assumption on the development of hemispheric background concentrations over Europe. Following the advice received from the ACCENT FP6 European Network of Excellence on Atmospheric Composition Change on the "Urbino questions" posed by the Commission (Raes and Hjorth, 2006), the EMEP calculations for the NEC analysis assume for the year 2020 an increase in hemispheric background ozone by 4.5 ppb compared to the mid-1990s instead of a 2 ppb growth that had been implied for the CAFE analysis.

Furthermore, the source-receptor relationships have been analyzed with the assumptions that emissions in non-EU countries follow the baseline development as outlined for the year 2020 in Cofala *et al.*, 2006b. This is different to the CAFE analysis, for which for the non-EU countries the 2010 emission projections have been assumed as boundary conditions.

3.6.2 Assessment of urban air quality

As described in Sections 2.4.2 and 2.4.5, the methodologies for computing urban air quality at the European scale have been updated.

3.7 Update of critical loads of acidity and nutrient nitrogen

Since the CAFE analysis which was based on the 2004 data set of critical loads for acidity and nutrient nitrogen, the Coordination Centre for Effects (CCE) of the ICP on Modelling & Mapping under the LRTAP Convention has issued two 'Calls for Data' to its National Focal Centres (NFCs). These calls requested updates of the critical load and dynamic modelling data. In response to this call 26 NFCs (19 in the EU25) have updated their data on critical loads of acidity and nutrient nitrogen. To obtain a full European coverage, critical loads derived from the European background data base maintained by the CCE have been used for the remaining areas. Data on critical loads and related information is documented in CCE reports available at www.mnp.nl/cce/. In Figure 3.5 the 5th percentile of the acidity and nutrient nitrogen critical loads in each EMEP 50*50 km grid cell illustrates the spatial variation of ecosystem sensitivity over Europe. As can be seen, critical loads of nutrient nitrogen are in general lower than those of acidity.

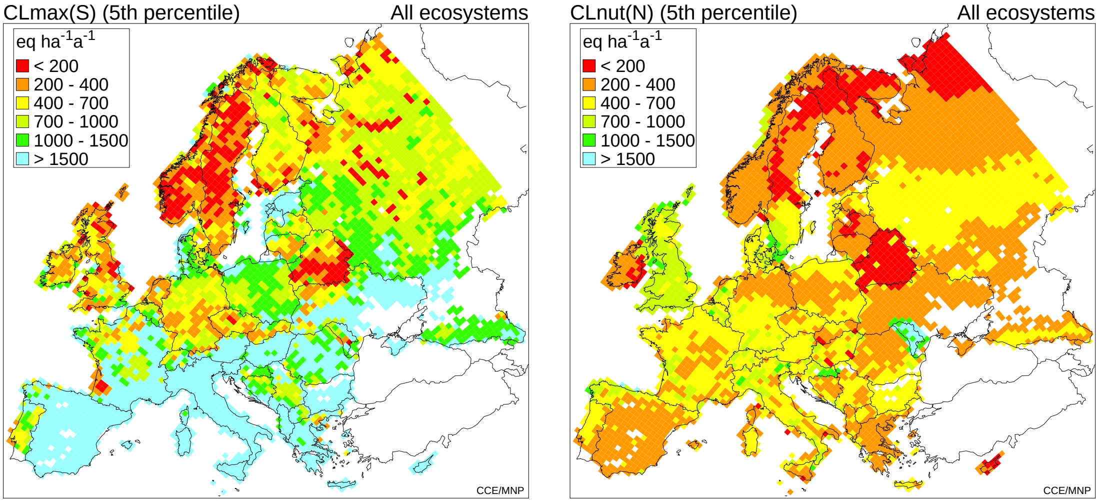


Figure 3.5: Critical loads (CLs) of acidity (left) and of nutrient nitrogen (right) for all ecosystems. Shown is the 5th percentile in every EMEP 50*50 km grid cell, thus indicating the deposition level which protects 95 percent of the ecosystem area.

Table 3.1: Availability of national estimates of critical loads data as of 2006 (Source: CCE)

Countries which submitted national estimates of critical loads to CCE	*Countries for which critical loads estimates from the European CCE database have been used*
Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Ireland, Italy, Latvia, Netherlands, Poland, Slovakia, Spain, Sweden, UK	Greece, Lithuania, Luxembourg, Malta, Portugal, Slovenia
Belarus, Bulgaria, Croatia, Moldova, Norway, Russian Federation, Switzerland	All other non-EU countries in the EMEP domain

The results of the data calls were presented to the Working Group on Effects (WGE) at their annual meetings (EB.AIR/WG.1/2005/10, ECE/EB.AIR/WG.1/2006/10) and approved for work under the Convention for Long-range Transboundary Air Pollution. In particular, the WGE approved the current data base of critical loads for use in the forthcoming review of the Gothenburg Protocol (ECE/EB.AIR/WG.1/2006/2; all ECE documents are available at www.unece.org/env/wge/).

The data base of critical loads, which contains information of about 1.25 million ecosystems/sites in Europe, has been made available to IIASA for use in integrated assessment. It should also be pointed out that exceedance calculations are now routinely carried out with ecosystem-specific depositions, thus removing an earlier identified bias.

3.8 New population data

For estimating health impacts, new population density data have been provided by JRC with a 100*100 m resolution. These data have been used to determine areas and diameters of 473 urban agglomerations in Europe and to distinguish in each EMEP grid cell the rural and urban population living in these agglomerations.

3.9 New assessment of ship emissions and their dispersion

The CAFE analysis has indicated that control of emissions from marine ships could constitute an important element of a cost-effective strategy to improve air quality in Europe. As a follow-up, the European Commission has initiated at study to explore this aspect in more detail and to provide quantitative information that could be incorporated into the GAINS model for a full cost-effectiveness analysis. To date this study has produced an interim report, exploring the potential for measures to control NO_x, SO_2, and primary PM2.5 emissions from international shipping in the European sea areas (Cofala *et al.*, 2006a). It estimated current emissions from different vessel categories in the various sea regions, it projected emissions into the future for a range of alternative assumptions about the implementation of emission control measures, and it assessed the environmental impacts of the different emission control scenarios.

The study covered five sea regions:

- the Baltic Sea,
- the North Sea (with the English Channel),
- the Mediterranean Sea,
- the Black sea and
- the North East Atlantic Ocean.

In each of these sea regions, potential measures will be studied in terms of their cost-efficiency for

- EU-flagged ships vs. non-EU flagged ships,
- vessel types (cargo, passenger ships (ferries)),
- shipping movements within the 12-mile limit zone from shore vs. shipping movements beyond the 12-mile limit zone.

However, the time schedule did not allow the full inclusion of the results of the report into the first round of model analysis for the revision of the NEC directive. Thus, the first round of the NEC analysis includes the revised emission estimates that have been developed for the different sea regions. The in-depth analysis of the cost-effectiveness of the available emission control measures in the various sea regions will be subject of the following report in the coming months.

3.10 Review of databases in the bilateral consultations with stakeholders

From March to November 2005, the databases of the GAINS model that describe the national situations in terms of driving forces, energy consumption, agricultural activities, emission source structures and emission control potentials have been reviewed by national experts. IIASA hosted a series of bilateral consultations with experts from Member States and industrial stakeholders to examine the draft GAINS databases and improve them to reflect to the maximum possible extent the country-specific conditions as seen by the various experts without compromising international consistency and comparability (Table 3.2).

This series of the bilateral consultations for the revision of the NEC Directive followed the earlier consultations that prepared the model input for the analyses of the CAFE programme (Amann *et al.*, 2004a). At these meetings, discussions addressed the input of national activity projections for energy, agriculture, non-energy sources of VOC and other industrial processes not related to energy consumption. They improved the representation of the national base year emission inventories in the GAINS model, and refined the descriptions of the temporal implementation patterns of national emission control legislation and the assessment of the potential for further emission reductions.

Table 3.2: Dates of bilateral consultations between experts from Member States and industrial associations and IIASA[1]

Country or industrial association	*Dates of bilateral consultations with IIASA*
Austria	26 September 2005
Belgium	15-16 September 2005
Czech Republic	20 June 2005
Denmark	6-7 September 2005
Estonia	2-3 November 2005
Finland	16-17 August 2005
France	18-19 October 2005
Germany	18-19 July 2005
Hungary	30-31 May 2005
Ireland	11-12 October 2005
Italy	27-28 June 2005
Latvia	8-9 November 2005
Malta	23 November 2005
Norway	10-11 November 2005
Poland	1-2 September 2005
Portugal	7-8 July 2005
Slovakia	12 July 2005
Slovenia	15-16 November 2005
Spain	15-16 June 2005
Sweden	21-22 September 2005
Netherlands	6-7 October 2005
UK	23-24 August 2005
Adhesives industry	22 March 2005
Printing industry	21 March 2005
EURELECTRIC	27 April 2005
ECCA (coil coating)	05 July 2005
CEPE (coatings)	23 September 2005

---

[1] Bilateral consultations were also held with Greece, but baseline data were not received in time to be included in this report.

This series of the bilateral consultations for the revision of the NEC Directive followed the earlier consultations that prepared the model input for the analyses of the CAFE programme (Amann *et al.*, 2004a). At these meetings, discussions addressed the input of national activity projections for energy, agriculture, non-energy sources of VOC and other industrial processes not related to energy consumption. They improved the representation of the national base year emission inventories in the GAINS model, and refined the descriptions of the temporal implementation patterns of national emission control legislation and the assessment of the potential for further emission reductions.

For agriculture, national projections and base year data were compared and discussed against statistical information available from international databases (FAO, EUROSTAT, IFA) and modelling results from CAPRI and the European Fertilizer Manufacturer Association (EFMA). For specific VOC sources related to solvent use, a number of meetings with several industrial associations were held. Industry provided sectoral information on activities, emission factors and their potential future developments.

The minutes of these consultations have been made available to the stakeholders to aid the understanding of the construction of the baseline scenario. The discussions at these bilateral meetings were followed up by intensive electronic data exchange until November 2006.

These consultations generated a wealth of well-documented new information, which helped to revise the GAINS databases so that national emission inventories can now be better reproduced while maintaining international consistency and comparability of the assessment. The GAINS estimates attempt to match the most recent estimates that have been communicated by national experts during the consultations, even if they have not yet been provided to EMEP through the official channels. However, a number of discrepancies between national data and the Europe-wide GAINS estimates could not be clarified to a satisfactory extent:

- While in most cases there is a good match between national inventories and GAINS estimates achieved for national total emissions, certain discrepancies occur between the estimates of sectoral emissions. Often this is caused by different sectoral groupings applied in national emission inventories, while the GAINS model applies a common sectoral structure for all countries. For instance, the GAINS model includes industrial power production and district heating plants in the power generation sector, while some national systems use the ownership of the plant as aggregation criterion. In addition, the definition of industrial process emissions is often a source of potential differences at least at the sectoral level (GAINS “process emissions” account only for the additional emissions that add to the fuel-related emissions).
- The UNECE nomenclature for reporting (NFR), while constituting an important step towards establishing consistency with the UNFCCC reporting format for greenhouse gases, bears certain ambiguity on details of air pollutants (e.g., on non-road mobile sources in industry and construction, emissions from industrial processes, emissions from soils).
- The new emission reporting system to the UNECE (NFR structure) does not allow for a detailed analysis of VOC inventories, since up to 70 percent of the emissions are grouped

into only four large categories. Some further detail, however, is vital for estimating the further potential for emission reductions.

- For many countries it was found difficult to establish consistency of data on fuel use, vehicle-km and vehicle numbers. In particular, projections of future mileage and registration data have only been received from a few countries. While this issue is of less concern for the emission calculation, it will become crucial for an accurate assessment of emission control costs.
- While the GAINS model consistently applies the "fuel sold" concept for computing emissions, some countries (e.g., Luxembourg) calculate their national emissions based on the "fuel used" concept.
- For a number of countries there still exist significant discrepancies between national and international statistics for animal numbers and fertilizer use.
- Only scarce information is available on animal housing types. The projection of their development is even more difficult, but of high relevance for estimating potential and costs of further emission reductions.
- The availability of information necessary to estimate accurately emissions of VOC from solvent use varies significantly among countries. This causes potential inconsistencies across countries and industrial sectors.

4 Input data

4.1 Energy projections

As a starting point for the further analysis, Table 4.1 summarizes the statistics on energy consumption by fuel for the year 2000 as implemented in the GAINS database. As these are historic data, both the national and PRIMES projections will be compared against the same basis.

Table 4.1: Primary energy consumption in 2000 [PJ]. Source: GAINS (based on EUROSTAT energy balances)

	Coal	*Biomass, waste*	*Heavy fuel oil*	*Diesel*	*Gasoline, LPG*	*Natural gas*	*Nuclear*	*Other renew.*	*Electr. import*1)	*Total*
Austria	119	128	114	253	114	324	0	153	-5	1200
Belgium	257	49	78	497	447	655	496	2	15	2496
Cyprus	1	0	47	22	25	1	0	1	0	99
Czech Rep.	823	28	58	147	112	385	147	6	-38	1668
Denmark	165	70	72	152	125	205	0	19	2	811
Estonia	102	21	10	16	14	31	0	0	-4	190
Finland	207	237	80	171	118	189	236	47	39	1325
France	494	448	452	1811	1351	1727	4538	259	-250	10830
Germany	3327	221	741	2469	2252	3334	1851	117	-46	14265
Greece	382	40	170	279	223	96	0	19	0	1208
Hungary	156	16	94	87	107	423	153	1	12	1049
Ireland	117	7	70	160	97	144	0	4	0	599
Italy	426	139	1262	1213	1335	2445	0	339	150	7309
Latvia	3	49	9	19	16	41	0	10	16	164
Lithuania	4	26	37	24	26	96	91	1	-5	301
Luxembourg	5	2	1	55	40	28	0	1	21	152
Malta	0	0	19	6	9	0	0	0	-1	34
Netherlands	269	60	112	504	569	1542	39	4	68	3167
Poland	2279	166	210	320	296	557	0	8	-23	3812
Portugal	155	133	247	220	175	97	0	46	3	1076
Slovakia	136	47	22	33	28	315	178	17	-10	766
Slovenia	57	17	6	51	39	35	52	15	-11	263
Spain	830	155	610	1027	853	800	672	125	16	5087
Sweden	95	294	131	237	263	57	619	286	-8	1975
UK	1771	58	176	1119	1735	3983	822	88	31	9782
EU-25	12179	2413	4827	10893	10370	17509	9894	1567	-26	69626
Bulgaria	270	23	52	59	63	136	196	10	-17	793
Croatia	30	22	99	56	42	121	24	16	11	421
Romania	279	116	171	137	98	635	59	53	-3	1545
Turkey	910	346	401	375	479	600	0	114	12	3236
Norway	56	49	9	151	147	245	0	515	-69	1104
Switzerland	6	23	36	264	247	110	289	137	-25	1087

1) Exports are indicated by negative numbers.

Table 4.2: Energy consumption of the EU-25 by fuel and sector in 2000 [PJ] Source: GAINS (based on PRIMES and EUROSTAT energy balances)

	Coal	*Biomass, waste*	*Heavy fuel oil*	*Diesel*	*Gasoline LPG*	*Natural gas*	*Nuclear*	*Other renew.*	*Electr.*[1)]	*Total*
Power sector	9248	437	1452	166	18	4425	9894	1531	-10214	16957
Industry	1535	789	1098	399	351	4855	0	4	3639	12670
Conversion	288	13	921	131	77	1208	0	0	1468	4107
Domestic	580	1173	113	2741	574	6391	0	33	4912	16517
Transport	0	0	70	7284	7535	17	0	0	169	15075
Non-energy	528	0	1173	173	1814	613	0	0	0	4300
Total	12179	2413	4827	10893	10370	17509	9894	1567	-26	69626

[1)] Power sector - gross power generation (reported with negative sign); the conversion sector includes own use of energy industries as well as transmission and distribution losses; Total - net electricity import. Exports are indicated by negative numbers.

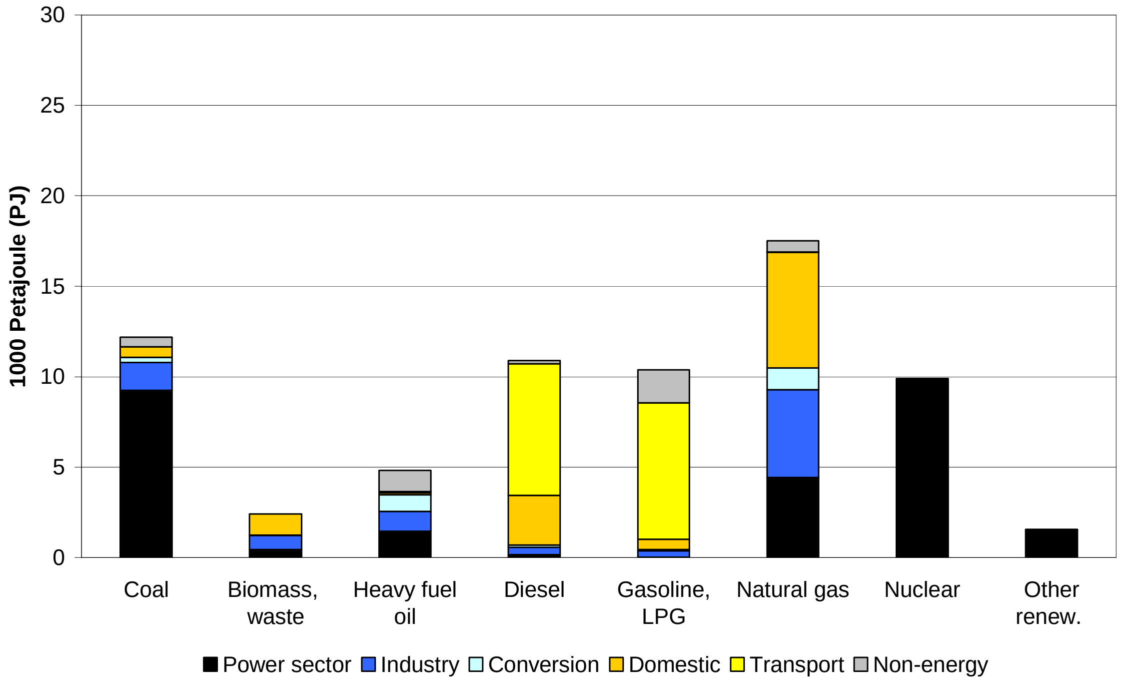


Figure 4.1: Energy consumption in 2000

4.1.1 National energy projections for 2020

For the revision of the NEC directive, DG-Environment of the European Commission has requested in 2005 all Member States to provide official national energy projections up to 2020 as a basis for the revision of the national emission ceilings directive. These projections must reflect national policies (as laid down, e.g., in governmental energy plans). Furthermore, these projections must include all necessary measures to comply with the Kyoto targets on greenhouse gas emissions and the burden sharing agreement for 2012. For 2020, it should be assumed as a minimum that the Kyoto emission caps remain unchanged. With these requirements, the national energy projections for the revision of the NEC Directive should be consistent with the energy projections presented by the Member States to UNFCCC in their Fourth National Communications in 2006.

In the course of the bilateral consultations in 2005-2006, 21 Member States have supplied national energy projections to IIASA for implementation into the GAINS model (Table 4.3)

Collectively, these national projections constitute the “National projections” baseline scenario for the revision of the NEC directive. For those Member States that have not provided their own energy projection, the “National projections” baseline case assumes by default the energy development as outlined by the “PRIMES €20” energy projection (see Section 4.1.2).

Table 4.3: Data sources for the “National projections” NEC baseline scenario[2]

	Data source	*Date of last information exchange*
Austria	National projection (2006)	12 June 2006
Belgium	National projection (2006)	31 August 2006
Cyprus	PRIMES €20 (2006)	No national inputs
Czech Rep.	National projection (2006)	01 August 2006
Denmark	National projection (2006)	06 April 2006
Estonia	National projection (2006)	30 October 2006
Finland	National projection (2006)	22 June 2006
France	National projection (2006)	30 June 2006
Germany	National projection (2006)	05 May 2006
Greece	PRIMES €20 (2006)	No national inputs
Hungary	National projection (2006)	11 August 2005
Ireland	National projection (2006)	11 September 2006
Italy	National projection (2006)	07 July 2006
Latvia	National projection (2006)	09 December 2005
Lithuania	PRIMES €20 (2006)	No national inputs
Luxembourg	PRIMES €20 (2006)	No national inputs
Malta	National projection (2006)	05 September 2006
Netherlands	National projection (2006)	14 September 2006
Poland	National projection (2006)	01 December 2005
Portugal	National projection (2006)	28 June 2006
Slovakia	National projection (2006)	30 October 2006
Slovenia	National projection (2006)	01 June 2006
Spain	National projection (2006)	22 September 2006
Sweden	National projection (2006)	08 September 2006
UK	National projection (2006)	28 February 2006
Bulgaria	PRIMES €20 (2006)	
Croatia	RAINS projection from 1996	
Romania	PRIMES €20 (2006)	
Turkey	PRIMES €20 (2006)	
Norway	National projection (2006)	02 February 2006
Switzerland	National projection (2006)	14 July 2006

---

[2] Data for Greece have been received after the start of the scenario calculations for this report.

The perceived evolution of fuel consumption in the various Member States is summarized for the year 2020 in Table 4.4. Overall, EU-25 Member States expect an increase in total primary energy use by 15 percent between 2000 and 2020. Coal consumption is projected to decrease by seven percent, while for natural gas a 44 percent increase is envisaged. Member States anticipate a seven percent drop in gasoline consumption and a 33 percent increase in diesel and light fuel oil. According to these projections, the EU-25 would turn from a net electricity exporter (26 PJ in 2000) into a net importer (31 PJ in 2020).

Table 4.4: Primary energy consumption of the national energy projections in 2020 [PJ] Source: GAINS, based on national submissions to IIASA.

	Coal	*Biomass, waste*	*Heavy fuel oil*	*Diesel*	*Gasoline LPG*	*Natural gas*	*Nuclear*	*Other renew.*	*Electr. import*1)	*Total*
Austria	129	179	53	389	86	463	0	201	0	1500
Belgium	160	82	53	567	449	933	338	15	17	2614
Cyprus	1	3	68	26	33	1	0	4	0	136
Czech Rep.	718	84	87	184	180	467	318	17	-25	2030
Denmark	114	122	54	174	146	315	0	45	-8	962
Estonia	173	27	13	30	16	45	0	2	-9	297
Finland	180	336	74	173	118	288	345	56	21	1591
France	484	711	540	2464	1113	2185	5093	360	-139	12811
Germany	3550	306	510	2616	1492	4041	693	363	-70	13501
Greece	293	30	166	422	303	277	0	67	9	1567
Hungary	119	99	0	182	128	615	161	1	21	1326
Ireland	63	35	35	277	173	326	0	18	6	933
Italy	657	406	507	1501	1314	3410	0	483	304	8582
Latvia	47	60	24	50	40	72	0	16	17	326
Lithuania	1	44	20	48	37	205	45	5	-14	391
Luxembourg	1	5	2	71	47	59	0	1	23	209
Malta	0	1	21	14	13	0	0	0	0	49
Netherlands	402	154	146	830	762	1555	39	96	12	3996
Poland	2046	305	297	566	387	1121	0	50	-19	4753
Portugal	96	149	224	349	172	358	0	100	-108	1340
Slovakia	259	55	28	65	49	399	89	28	-8	964
Slovenia	47	29	4	86	24	70	59	21	-23	317
Spain	516	335	417	1562	825	3381	626	394	0	8056
Sweden	84	430	122	242	247	196	448	275	-11	2033
UK	1170	160	100	1605	1465	4495	268	406	35	9704
EU-25	11310	4147	3565	14493	9619	25277	8522	3024	31	79988
Bulgaria	139	48	47	112	134	214	215	19	-20	909
Croatia	31	17	80	68	55	187	25	21	4	487
Romania	392	182	125	319	214	988	125	89	-3	2430
Turkey	935	325	483	662	1128	1790	0	367	-10	5681
Norway	68	58	13	187	182	358	0	455	7	1328
Switzerland	7	35	36	291	198	125	308	155	-23	1132

1) Exports are indicated by negative numbers.

Overall, this set of energy projection would lead to a two percent increase in CO_2 emissions compared to the base year level of the Kyoto protocol.

While these national projections are supposed to reflect the latest governmental views in the individual Member States on the future energy development, there is no guarantee for Europe-wide consistency in terms of assumptions on economic development trends, the prices of oil, gas, coal, etc., on electricity imports and exports, and on the availability of natural gas. Unfortunately, Member States did not supply sufficient detail to judge the EU-wide consistency of the underlying assumptions.

Table 4.5: Energy consumption of the EU-25 by fuel and sector for the national energy projections for 2020 [PJ]

	Coal	*Biomass, waste*	*Heavy fuel oil*	*Diesel*	*Gasoline LPG*	*Natural gas*	*Nuclear*	*Other renew.*	*Electr.1)*	*Total*
Power sector	8880	1545	510	131	12	8783	8522	2870	-13411	17843
Industry	1331	1284	954	509	311	6061	0	2	4652	15103
Conversion	235	137	870	347	118	1191	0	0	1603	4501
Domestic	375	1180	84	2576	447	7895	0	141	6975	19672
Transport	0	0	72	10765	7063	124	0	0	211	18235
Non-energy	488	0	1077	166	1666	1236	0	0	0	4633
Total	11309	4146	3566	14493	9616	25290	8522	3013	30	79987

Power sector - gross power generation (reported with negative sign); conversion sector includes own use of energy industries as well as transmission and distribution losses; Total - net electricity import

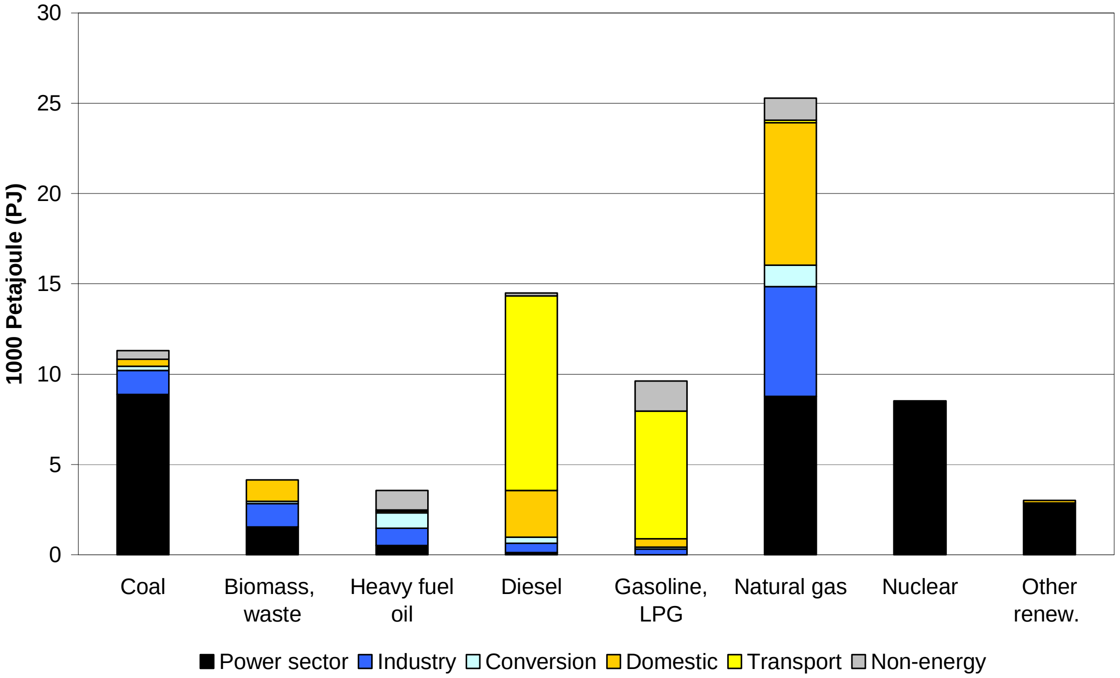


Figure 4.2: Energy consumption of the EU-25 as projected by the national scenarios for 2020

4.1.2 The PRIMES energy projection for a €20 carbon price

To explore the robustness of national emission estimates against alternative assumptions on the future development of the energy systems, an energy projection produced with the PRIMES model for all 25 EU Member States has been implemented into GAINS as a second baseline scenario. This projection follows the assumptions on macro-economic development adopted for the 2005 energy baseline projection of DG-TREN, with an increase of oil prices up to $50 by 2020.

Based on the guidance received from DG ENV’s Climate Change unit, without prejudging the actual implementation of the Kyoto agreement and of possible post-Kyoto regimes, this scenario assumes for 2010 for all energy consumers a revenue-neutral “shadow price” of €12 per tonne of CO_2. It is thus implicitly assumed that any measures having a compliance cost higher than this will not be undertaken by the EU’s energy system, but that other sectors (e.g., non-CO_2 greenhouse gases emitting sectors) would reduce their emissions, or that flexible instruments in the Kyoto Protocol would be used. In addition, the possibility of using carbon sinks would add to the flexibility. Concerning “post-Kyoto”, it was assumed that the “shadow price” of carbon dioxide would increase linearly to €20 per tonne of CO_2 in 2020. For 2020, this assumption would lead to seven percent decline in CO_2 emissions of the EU-25 Member States compared to the baseline emissions of the Kyoto treaty.

Table 4.6: Primary energy consumption of the PRIMES €20 carbon prices scenario in 2020 [PJ]. Source: GAINS, based on PRIMES energy balances

	Coal	*Biomass, waste*	*Heavy fuel oil*	*Diesel*	*Gasoline LPG*	*Natural gas*	*Nuclear*	*Other renew.*	*Electr. import*1)	*Total*
Austria	72	172	85	314	146	485	0	219	6	1500
Belgium	160	62	100	489	336	853	377	20	19	2415
Cyprus	1	3	68	26	33	1	0	4	0	135
Czech Rep.	469	86	76	188	195	572	342	11	-46	1892
Denmark	107	111	44	186	126	230	0	57	-12	848
Estonia	61	30	12	29	23	61	0	3	-1	217
Finland	114	380	85	217	142	264	375	68	14	1659
France	249	686	372	2160	1385	1872	5132	439	-178	12117
Germany	2022	768	411	2488	2296	4507	339	454	39	13324
Greece	293	30	166	422	303	277	0	67	9	1568
Hungary	90	85	58	132	148	636	150	7	10	1315
Ireland	25	26	46	217	166	249	0	27	4	760
Italy	705	250	1041	1274	1196	3348	0	446	135	8396
Latvia	4	75	16	31	26	111	0	14	8	286
Lithuania	1	44	20	48	37	205	45	5	-14	391
Luxembourg	1	5	2	71	47	59	0	1	23	209
Malta	0	1	23	8	13	0	0	0	0	46
Netherlands	277	143	126	351	606	1895	45	48	46	3539
Poland	1658	595	190	582	553	1162	173	66	-20	4961
Portugal	105	100	138	261	283	286	0	92	4	1269
Slovakia	124	57	54	49	72	435	205	26	-11	1011
Slovenia	40	23	11	56	55	76	58	18	6	342
Spain	183	432	572	1475	1171	1818	876	425	11	6963
Sweden	167	478	73	303	309	170	423	279	9	2211
UK	851	275	358	1099	1906	4119	1110	241	29	9987
EU-25	7780	4917	4148	12475	11573	23692	9649	3039	89	77363
Bulgaria	139	48	47	112	134	214	215	19	-20	909
Croatia	31	17	80	68	55	187	25	21	4	487
Romania	392	182	125	319	214	988	125	89	-3	2430
Turkey	935	325	483	662	1128	1790	0	367	-10	5681
Norway	16	71	30	186	144	223	0	556	-28	1199
Switzerland	7	131	29	234	248	210	299	167	-27	1297

1) Exports are indicated by negative numbers.

Larger fuel efficiency improvements than those assumed in the national energy projections would let total primary energy consumption grow between 2000 and 2020 by only 11 instead of 15 percent (Table 4.6). The larger degree of decarbonisation is reflected by a 36 percent reduction in coal consumption (compared to the seven percent decline in the national projections), while natural gas use would increase by only 35 percent compared to 44 percent as anticipated by Member States. Instead of a 33 percent increase in the consumption of middle distillates (diesel and light fuel oil, this scenario projects only a 15 percent increase. Gasoline use is suggested to grow by 12 percent (and not to shrink by seven percent). In total, the EU-25 would import even more electricity than in the national projections. Energy consumption by fuel and economic sector is shown in Table 4.7.

Table 4.7: Energy consumption by fuel and sector of the EU-25 for the PRIMES €20 energy projection for 2020 [PJ]. Data Source: GAINS, based on PRIMES energy balances

	Coal	*Biomass waste*	*Heavy fuel oil*	*Diesel*	*Gasoline LPG*	*Natural gas*	*Nuclear*	*Other renew.*	*Electr.* 1)	*Total*
PP	6150	2791	838	153	0	8388	9649	2897	-14261	16605
Industry	1328	378	1009	490	340	6156	0	0	4727	14428
Conversion	94	283	359	6	8	519	0	0	1766	3034
Domestic	147	1464	80	2743	447	7944	0	122	7594	20542
Transport	0	0	80	8893	8819	18	0	20	263	18094
Non-energy	61	0	1783	189	1958	667	0	0	0	4659
Total	7780	4917	4148	12475	11573	23692	9649	3039	89	77363

1) Power sector - gross power generation (reported with negative sign); conversion sector includes own use of energy industries as well as transmission and distribution losses; Total - net electricity import

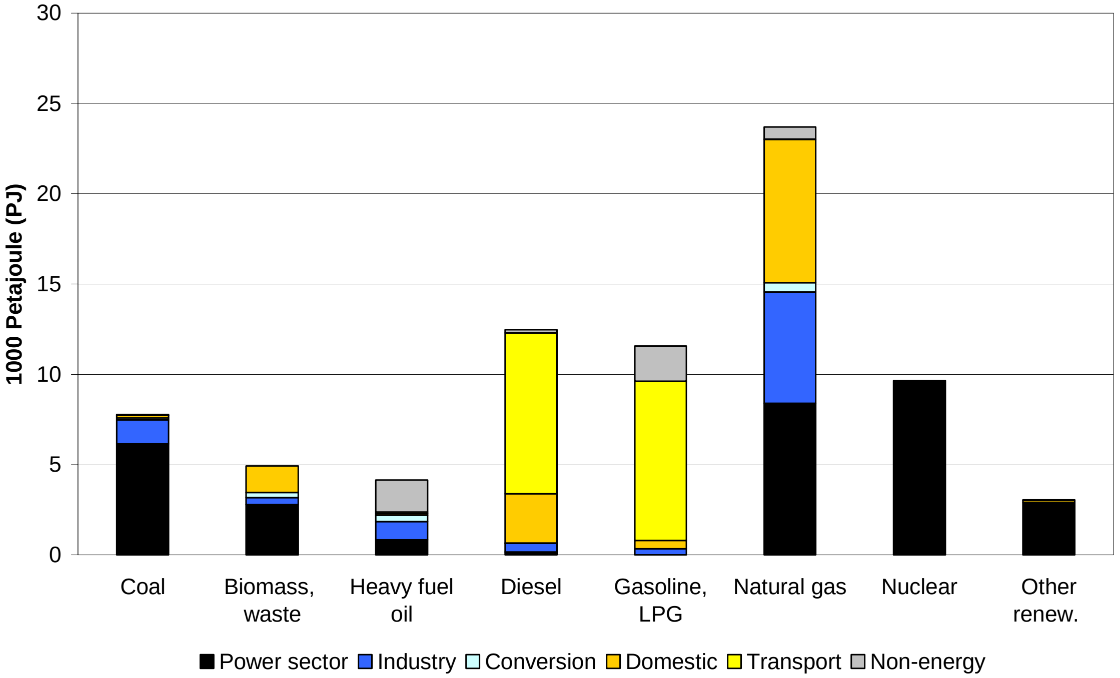


Figure 4.3: Energy consumption of the EU-25 in 2020 as projected in the PRIMES €20 scenario

4.1.3 The PRIMES energy projection for a €90 carbon price

As a third scenario, GAINS has implemented the PRIMES energy projection that assumes an increase of the carbon price by 2020 to 90 €/t CO_2. In this scenario CO_2 emissions decrease till 2020 by more than 22 percent relative to the baseline of the Kyoto treaty. In the €20 scenario that decrease was only seven percent. All other assumptions of the two projections (macroeconomic development, fuel prices in international markets) remain the same as in the 2005 energy baseline projection of DG-TREN.

Table 4.8: Primary energy consumption of the PRIMES €90 carbon price scenario in 2020 [PJ]. Source: GAINS, based on PRIMES energy balances

	Coal	*Biomass, waste*	*Heavy fuel oil*	*Diesel*	*Gasoline LPG*	*Natural gas*	*Nuclear*	*Other renew.*	*Electr. import*1)	*Total*
Austria	61	197	79	294	140	463	0	220	6	1458
Belgium	68	74	94	454	328	890	377	21	19	2325
Cyprus	1	3	68	26	33	1	0	4	0	135
Czech Rep.	314	108	75	185	190	591	368	14	-46	1798
Denmark	31	135	39	178	121	262	0	57	-12	812
Estonia	16	36	12	27	22	74	0	8	-1	194
Finland	73	391	82	200	139	231	430	72	14	1631
France	114	878	355	2045	1343	1647	5132	490	-178	11826
Germany	464	974	412	2313	2256	5044	339	514	39	12356
Greece	24	71	192	393	295	312	0	81	9	1377
Hungary	14	109	53	128	143	618	150	12	10	1237
Ireland	10	36	42	199	159	245	0	27	4	721
Italy	72	477	923	1226	1171	3186	0	548	135	7738
Latvia	3	84	13	29	25	99	0	14	8	276
Lithuania	1	51	19	45	36	176	72	5	-14	392
Luxembourg	1	5	2	67	44	58	0	1	23	202
Malta	0	1	23	8	13	0	0	0	0	46
Netherlands	99	158	137	356	588	1885	45	49	46	3363
Poland	722	843	190	559	539	1297	187	74	-20	4390
Portugal	1	124	110	248	275	283	0	120	4	1165
Slovakia	57	74	53	47	72	434	205	28	-11	959
Slovenia	0	32	11	52	53	87	67	18	6	325
Spain	31	544	553	1395	1132	1600	876	483	11	6626
Sweden	37	537	67	288	303	200	423	305	9	2168
UK	247	346	376	1066	1850	4246	1110	253	29	9524
EU-25	2461	6288	3983	11827	11269	23928	9782	3418	88	73044
Bulgaria	63	52	48	109	129	248	215	23	-20	868
Croatia	31	17	80	68	55	187	25	21	4	487
Romania	162	209	125	315	204	1054	126	95	-3	2288
Turkey	313	383	470	649	1124	1877	0	483	-10	5288
Norway	6	77	30	173	141	227	0	567	-28	1193
Switzerland	6	142	27	218	236	195	299	170	-27	1264

1) Exports are indicated by negative numbers.

Table 4.9: Energy consumption of the EU-25 by fuel and sector for the PRIMES €90 scenario for 2020 [PJ]. Data Source: GAINS, based on PRIMES energy balances

	Coal	*Biomass waste*	*Heavy fuel oil*	*Diesel*	*Gasoline LPG*	*Natural gas*	*Nuclear*	*Other renew.*	*Electr.*1)	Total
Power sector	1379	3859	834	151	0	9594	9782	3271	-14166	14704
Industry	839	570	872	512	357	5780	0	0	4815	13745
Conversion	65	275	341	6	8	525	0	0	1655	2875
Domestic	117	1583	71	2431	400	7322	0	147	7520	19592
Transport	0	0	80	8537	8538	38	0	0	264	17457
Non-energy	61	0	1784	190	1966	669	0	0	0	4670
Total	2461	6288	3983	11827	11269	23928	9782	3418	88	73044

1) Power sector - gross power generation (reported with negative sign); conversion sector includes own use of energy industries as well as transmission and distribution losses; Total - net electricity import

Table 4.8, Table 4.9 and Figure 4.4 present the energy consumption for this scenario. Compared with the PRIMES €20 scenario, in the €90 scenario total energy demand in the EU-25 decreases by six percent. Coal consumption is reduced to less than one third of the previous level. In turn, biomass consumption increases by 28 percent. This causes a decrease of the share of coal in total primary energy demand to three percent (from ten percent in the €20 scenario) and an increase in the share of biomass from six to nine percent. The share of natural gas increases by two percentage points and the shares of nuclear and other renewables increase by one percentage point each.

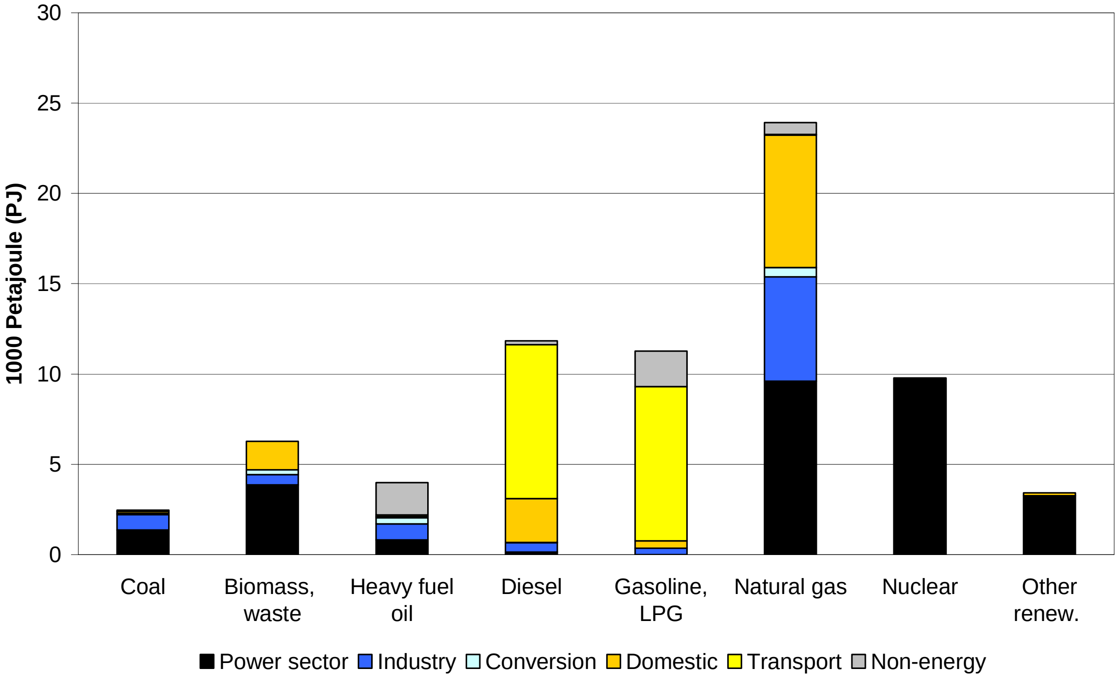


Figure 4.4: Energy consumption of the EU-25 in 2020 as projected in the PRIMES €90 scenario

4.2 Agricultural projections

As a starting point for the further analysis, Table 4.10 summarizes the statistics on agricultural activities for the year 2000 as implemented in the GAINS database.

Table 4.10: Agricultural activity date for the year 2000.

	Cattle	*Pigs*	*Chicken and poultry*	*Sheep and goats*	*Horses*	*Fertilizer consumption*	*Fertilizer production*
	1000 animal heads					kt N	
Austria	2155	3348	11787	395	82	121	185
Belgium	3001	7266	52230	176	73	145	1440
Cyprus	54	408	3310	625	7	8	0
Czech Rep.	1609	3315	32043	118	26	213	306
Denmark	1868	11922	21830	91	150	252	133
Estonia	253	300	2366	32	4	22	38
Finland	1057	1298	12570	107	57	167	245
France	20310	14930	270989	10788	444	2571	1494
Germany	14568	25767	118447	2305	520	1848	1308
Greece	566	936	28193	14449	140	285	216
Hungary	805	4834	31244	1219	79	320	290
Ireland	6558	1732	15338	7957	80	408	248
Italy	7245	8307	176722	12464	337	786	428
Latvia	367	394	3105	39	20	29	0
Lithuania	898	936	6373	39	75	98	530
Luxembourg	200	83	70	8	2	17	0
Malta	19	80	830	17	1	0	0
Netherlands	4070	13118	104972	1487	118	339	1300
Poland	5723	15447	111900	337	550	896	1497
Portugal	1172	2359	41195	4145	80	170	125
Slovakia	647	1488	12446	399	10	82	286
Slovenia	493	604	5107	118	14	34	0
Spain	6074	24367	169133	26892	499	1255	899
Sweden	1684	1918	16900	437	300	189	94
UK	11134	6482	168973	42340	291	1036	490
EU-25	92530	151639	1418072	126984	3959	11290	11551
Bulgaria	682	1512	14963	3595	364	144.9	403.6
Croatia	427	1233	11251	608	15	116	328.1
Romania	3051	5848	77993	8679	888	240	872.3
Turkey	11219	3	246477	38030	989	1276	479
Norway	987	609	12080	1841	48	103	618
Switzerland	1543	1498	6983	483	62	55	15

Data source: GAINS, based on EUROSTAT statistics, FAO, IFA, national statistical yearbooks, and bilateral consultations with national experts

4.2.1 National agricultural projections for 2020

In addition to the request for energy projections, DG-Environment of the European Commission has invited all Member States to provide official national projections of their agricultural activities up to 2020 as a basis for the revision of the NEC directive. These projections should reflect national agricultural policies (as laid down, e.g., in governmental plans). Furthermore, these projections must include all necessary measures to comply with the Kyoto targets on greenhouse gas emissions and the burden sharing agreement for 2012. For 2020, it should be assumed as a minimum that the Kyoto emission caps remain unchanged. With these requirements, the national agricultural projections for the revision of the NEC Directive should be consistent with the agricultural projections presented by the Member States to UNFCCC in their Fourth National Communications in 2006, however not taking into consideration areas outside of the modelling domain.

In the course of the bilateral consultations in 2006, 19 Member States as well as Norway and Switzerland have supplied national agricultural projections to IIASA for implementation into the GAINS model (Table 4.11). Collectively, these national projections constitute the “National Projections” baseline scenario for the revision of the NEC directive. For those Member States that have not provided their own agricultural projection, the “National Projections” baseline case assumes by default the agricultural development as outlined by the CAPRI (EEA, 2004) and EFMA (EFMA, 2005) agricultural and fertilizer projection (see Section 4.2.2). For Member States for which CAPRI and/or EFMA projections are unavailable, projections developed by the Food and Agricultural Organization (FAO) have been used (Bruinsma, 2003).

For the EU-25 as a whole, these national projections anticipate between 2000 and 2020 for cattle a 13 percent decline in livestock numbers (dairy cattle drops by about 18 percent and beef cattle by about 10 percent), for sheep a reduction by 10 percent and a four to five percent increase in the number of pigs and poultry. While these national projections reflect the latest governmental views of the individual Member States on the future agricultural development, there is no guarantee for Europe-wide consistency in terms of assumptions on economic development trends, and national as well EU-wide agricultural policies.

Table 4.11: Data sources for the “National Projections” NEC baseline scenario.

	Data source	*Date of last information exchange*	*Comments*
Austria	National (2006)	9 January 2006	
Belgium	National (2006)	14 September 2006	
Cyprus	FAO (2003), EFMA (2005)		
Czech Rep.	National (2005)	26 June 2006	
Denmark	National (2005)	10 November 2006	
Estonia	National (2006)	4 May 2006	
Finland	National (2005)	14 October 2005	
France	National (2004)	18 May 2004	
Germany	CAPRI (2004), EFMA (2005)		
Greece	CAPRI (2004), EFMA (2005)		
Hungary	National (2006)		Projection submitted to UNECE
Ireland	National (2006)	20 November 2006	
Italy	National (2006)	31 August 2006	
Latvia	National (2006)	7 February 2006	
Lithuania	CAPRI (2004), EFMA (2005)		
Luxembourg	CAPRI (2004), EFMA (2005)		
Malta	National (2006)	27 September 2006	Supplementary data from FAO and IFA used
Netherlands	National (2006)	14 September 2006	
Poland	National (2005)	19 October 2005	
Portugal	National (2006)	16 October 2006	
Slovakia	CAPRI (2004), EFMA (2005)		
Slovenia	National (2006)	6 September 2006	
Spain	National (2006)	22 September 2006	
Sweden	National (2006)	2 July 2006	
UK	National (2006)	27 July 2006	
Bulgaria	FAO (2003)		
Croatia	FAO (2003)		
Romania	FAO (2003)		
Turkey	FAO (2003)		
Norway	National (2005)	10 February 2005	
Switzerland	National (2006)	30 August 2006	

Table 4.12: National projections of agricultural activities for the year 2020. Source: GAINS, based on national submissions to IIASA.

	Cattle	*Pigs*	*Chicken and poultry*	*Sheep and goats*	*Horses*	*Fertilizer consumption*	*Fertilizer production*
	1000 animal heads					kt N	
Austria	1896	3228	13007	389	87	102	225
Belgium	2586	8073	54005	129	73	142	1440
Cyprus	48	457	4830	655	7	7	0
Czech Rep.	1400	3800	36234	260	28	230	310
Denmark	1371	14251	22326	98	165	180	0
Estonia	222	448	2640	87	4	21	38
Finland	491	1270	13113	116	65	145	210
France	19145	16327	226966	9971	458	2313	1374
Germany	12216	22490	89767	1592	770	1688	1000
Greece	520	994	23923	14819	140	202	200
Hungary	907	7000	43000	1600	82	398	250
Ireland	4937	1503	13200	4941	85	320	0
Italy	6418	9181	197983	11320	337	799	428
Latvia	350	508	5091	55	16	35	0
Lithuania	766	1208	12782	38	65	119	500
Luxembourg	189	94	86	7	2	16	0
Malta	19	82	1010	26	3	1	0
Netherlands	3506	11181	108629	1951	165	272	1000
Poland	4850	15598	171500	340	355	963	1450
Portugal	1256	2064	38699	3992	40	170	152
Slovakia	693	1901	11602	359	10	101	270
Slovenia	527	665	5552	142	17	33	0
Spain	5293	28449	194844	27208	497	1055	865
Sweden	1455	2490	20000	395	300	170	65
UK	8317	4835	175620	33813	291	976	500
EU-25	79378	158097	1486408	114303	4062	10459	10277
Bulgaria	677	931	20125	2411	365	151	350
Croatia	566	1273	12589	916	14	116	300
Romania	2855	6500	104000	8091	900	254	800
Turkey	14561	3	306826	43972	650	1200	600
Norway	907	633	14290	1416	55	90	630
Switzerland	1403	1348	7490	484	72	50	15

Data sources: GAINS, based on national submissions to IIASA

For the EU-25 as a whole, these national projections anticipate between 2000 and 2020 for cattle a 13 percent decline in livestock numbers (dairy cattle drops by about 18 percent while beef cattle by about 10 percent), for sheep a reduction by 10 percent and a four to five percent increase of pigs and poultry.

While these national projections reflect the latest governmental views of the individual Member States on the future agricultural development, there is no guarantee for Europe-wide consistency in terms of assumptions on economic development trends, and national as well EU-wide agricultural policies.

4.2.2 CAPRI agricultural projection including the CAP mid-term review

As an alternative to the national agricultural projections, EU-wide livestock projections developed for a CAPRI model study for the European Environment Agency study (EEA, 2004) and mineral fertilizer projections provided by the European fertilizer association EFMA have been implemented into GAINS (Table 4.13). The methodology used for CAPRI projections combines the standard structure of the agricultural sector model CAPSIM with amendments to systematically integrate external forecasts. CAPSIM is a partial equilibrium modelling tool with behavioural functions for activity levels, input demand, consumer demand and processing. It is designed for policy relevant analysis of the CAP and consequently covers the whole of agriculture of the EU Member States.

Table 4.13: CAPRI model projections of agricultural activities of fertilizer production and consumption for the year 2020. Source: GAINS, based on CAPRI results and EFMA projections.

	Cattle	*Pigs*	*Chicken and poultry*	*Sheep and goats*	*Horses*	*Fertilizer consumption*	*Fertilizer production*
			1000 animal heads			kt N	
Austria	1950	3532	11225	337	87	92	225
Belgium	2806	8241	67363	146	73	142	1440
Cyprus	48	457	4830	655	7	7	0
Czech Rep.	1435	3913	41035	171	28	333	310
Denmark	1343	13821	20533	91	165	190	0
Estonia	214	300	3052	36	4	30	38
Finland	886	1271	12152	79	65	156	210
France	18723	17408	317895	10986	458	2355	1374
Germany	12216	22490	89767	1592	770	1688	1000
Greece	520	994	23923	14819	140	202	200
Hungary	801	4695	31470	1446	82	392	250
Ireland	5306	1994	15621	7906	80	307	0
Italy	5794	9506	187656	9033	337	558	428
Latvia	270	409	3811	76	16	32	0
Lithuania	766	1208	12782	38	65	119	500
Luxembourg	189	94	86	7	2	16	0
Malta	17	74	980	25	3	1	0
Netherlands	3631	10892	124043	1570	165	231	1000
Poland	4887	19712	125282	476	355	1103	1450
Portugal	794	2692	32894	4148	40	87	152
Slovakia	693	1901	11602	359	10	101	270
Slovenia	528	773	5032	171	17	31	0
Spain	6614	29547	186444	27037	497	1007	865
Sweden	1747	1549	20160	422	300	159	65
UK	10732	5047	173346	33258	291	995	500
EU-25	82907	162520	1522983	114884	4057	10332	10277
Bulgaria	677	931	20125	2411	365	151	350
Croatia	566	1273	12589	916	14	116	300
Romania	2855	6500	104000	8091	900	254	800
Turkey	14561	3	306826	43972	650	1200	600
Norway	897	725	16325	1784	55	97	630
Switzerland	1422	1419	8477	501	72	47	15

The reference projection (EEA, 2004), referred further as the CAPRI projections, explores the long term impact of the Common Agricultural Policy (CAP) on the European Union agriculture. This scenario the is based on existing exogenous projections (e.g., FAPRI, FAO, DG AGRI) for cropping areas, production, consumption, feed use, supplemented by own trend projections.

For the EU-25 as a whole, these CAPRI model projections anticipate between 2000 and 2020 largely similar changes as the national projections. They foresee about 21 percent drop in dairy cattle numbers followed by about seven percent decline in beef. The development of the beef sector depends on the assumption of a continued milk quota regime with expected milk yield increases (approximately 30 percent on average) and on the long term demand shift from beef to pig and poultry meat. The latter (in terms of livestock numbers) are projected to increase by about 7.5 percent during the period. More details on the modelling approach and results of CAPRI reference run can be found in EEA (2004).

The mineral nitrogen fertilizer projection for EU-25 as well as Norway and Switzerland was developed by EFMA (2005). EFMA prepares such forecast annually using quantitative information from various sources (e.g. from USDA, FAPRI, DG AGRI) and combines this with qualitative analyses made by EFMA experts. The results are consulted with national experts. Overall for EU-25, EFMA projects a nine percent decline in N-fertilizer use between 2000 and 2015.

4.3 Emission control legislation

The NEC baseline projections estimate future emissions on the basis of the development of emission generating activities, country- and sector-specific emission factors and the progressing implementation rate of already decided emission control legislation. The analysis is based on a detailed inventory of national emission control legislation (including the transposition of EU-wide legislation) as of mid 2006. The baseline emission projections consider legislation listed in Table 4.14 to Table 4.18, and that they are fully implemented in all Member States according to the foreseen time schedule. They ignore, however, further measures that might be necessary to meet the national emission ceilings in 2010, if they are not already put into national legislation. Furthermore, the baseline projections neglect emission reduction measures that could be required for compliance with the EU air quality limit values, especially for NO_2 and PM10.

Table 4.14: Legislation considered in the baseline projections for SO_2 emissions

Large combustion plant directive
Directive on the sulphur content in liquid fuels
Directives on quality of petrol and diesel fuels
IPPC legislation on process sources
National legislation and national practices (if stricter)

Table 4.15: Legislation considered in the baseline projections for NO_x emissions

Large combustion plant directive
Euro-standards, including the Commission proposal on Euro-5 and Euro-6 for light duty vehicles
EU emission standards for motorcycles and mopeds
Legislation on non-road mobile machinery
Implementation failure of Euro-II and Euro-III for diesel (heavy duty and light duty) vehicles
IPPC legislation for industrial processes
National legislation and national practices (if stricter)

Table 4.16: Legislation considered in the baseline projections for VOC emissions

Stage I directive (liquid fuel storage and distribution)
Directive 91/441 (carbon canisters)
Euro-standards, including the Commission proposal on Euro-5 and Euro-6 for light duty vehicles
Fuel directive (RVP of fuels)
Solvents directive
Product directive (paints)
National legislation, e.g., Stage II (gasoline stations)

Table 4.17: Legislation considered in the baseline projections for NH_3 emissions

IPPC directive for pigs and poultry production
National legislation including elements of EU law, e.g., Nitrate or Water Framework directive as well as possible extension of IPPC directive to cattle
Current practice that includes implementation of *Code of Good Agricultural Practice* which is mandatory under the UNECE Gothenburg Protocol

Table 4.18: Legislation considered in the baseline projections for PM2.5 emissions

Large combustion plant directive
Euro-standards, including the Commission proposal on Euro-5 and Euro-6 for light duty vehicles
Emission standards for motorcycles and mopeds
Legislation on non-road mobile machinery
IPPC legislation on process sources
National legislation and national practices (if stricter)

5 Baseline emissions and scope for further emission reductions

The analysis presented in this report explores the scope for cost-effective emission controls that achieve in 2020 the environmental objectives of the Thematic Strategy on Air Pollution (TSAP) (see CEC, 2005a). In addition to the availability of further add-on emission control measures that are not yet adopted in the "current legislation", the scope for further measures depends critically on the structural composition of the emission sources. As pointed out in the NEC baseline analysis (Amann *et al.*, 2006), volumes of emission generative activities – and thus of baseline emissions – are direct consequences of economic development and of decisions in other policy areas. To illustrate the potential range of further emission controls in the year 2020, Table 5.1 to Table 5.5 compare emission estimates for the base year 2000 with the 2020 current legislation emission baselines and the lowest emission levels that can be achieved by maximum implementation of the measures contained in the RAINS database (MRR). These estimates are provided for the national activity projections (for energy and agriculture), for the PRIMES €20 scenario and the PRIMES €90 scenario. Depending on the pollutant, both the current legislation baseline emissions and the scope for further emission reductions are functions of the underlying activity projection, and thereby on the climate policy that is assumed in the projection. For the EU-25, in 2020 CO_2 emissions from these activity projections range from a three percent increase (compared to the Kyoto base year) for the national projections, over a seven percent decline for the PRIMES projection with an assumed carbon price of €20/t CO_2, to a 21 percent decline for the PRIMES scenario with the €90/t CO_2 carbon price (Table 5.6). While the above tables provide data for each Member State, Table 5.7 to Table 5.11 present the situation for various economic sectors following the SNAP categories of the CORINAIR inventory.

Table 5.1: SO_2 emissions by country, for the years 2000 and 2020, for the current legislation baseline (CLE) and the maximum reductions from the measures considered in the RAINS model (MRR), in kilotons

	2000	National activity projection 2020		PRIMES €20 and CAPRI MTR agricultural projection 2020		PRIMES €90 and CAPRI MTR agricultural projection 2020	
		CLE	MRR	CLE	MRR	CLE	MRR
Austria	34	20	18	23	21	22	20
Belgium	175	87	58	80	54	66	46
Cyprus1)	48	8	2	8	2	8	2
Czech Rep.	252	179	98	83	42	66	34
Denmark	28	21	14	19	14	17	13
Estonia	90	48	7	10	4	8	3
Finland	77	71	41	56	33	50	28
France	658	494	151	296	121	247	111
Germany	630	438	280	297	237	205	162
Greece1)	493	94	52	94	52	88	45
Hungary	484	60	32	110	23	47	13
Ireland	132	37	18	25	14	21	12
Italy	755	345	189	314	205	265	174
Latvia	14	19	9	9	6	8	6
Lithuania1)	48	15	4	15	4	15	4
Luxembourg1)	4	2	1	2	1	2	1
Malta	34	7	1	7	1	7	1
Netherlands	75	77	55	54	45	45	36
Poland	1509	857	321	778	281	418	172
Portugal	289	87	38	69	32	58	24
Slovakia	128	81	41	48	20	37	14
Slovenia	99	23	11	20	11	13	6
Spain	1458	447	184	338	164	307	154
Sweden	46	41	33	41	34	36	32
UK	1155	275	200	217	163	175	123
EU-25	8714	3833	1859	3013	1583	2231	1234
Bulgaria1)	847	116		116		91	
Croatia1)	108	65		65		65	
Romania1)	773	139		139		109	
Turkey1)	1646	911		911		437	
Norway	26	26		25		23	
Switzerland	17	14		16		15	

Note: 1) No national energy projection has been submitted. Data from the PRIMES €20 scenario are used instead.

Table 5.2: NO_x emissions by country, for the years 2000 and 2020, for the current legislation baseline (CLE) and the maximum reductions from the measures considered in the RAINS model (MRR), in kilotons

	2000	National activity projection 2020		PRIMES €20 and CAPRI MTR agricultural projection 2020		PRIMES €90 and CAPRI MTR agricultural projection 2020	
		CLE	MRR	CLE	MRR	CLE	MRR
Austria	202	129	109	112	91	107	88
Belgium	351	201	138	180	129	170	122
Cyprus[1)]	26	15	10	15	10	15	10
Czech Rep.	317	190	123	167	107	152	100
Denmark	213	126	86	114	94	111	90
Estonia	39	24	12	20	13	18	13
Finland	208	130	82	124	87	114	80
France	1475	864	557	771	560	724	544
Germany	1750	931	667	944	744	836	669
Greece[1)]	323	207	149	207	149	196	138
Hungary	186	105	65	98	60	91	56
Ireland	132	74	54	67	52	62	48
Italy	1353	769	591	730	567	661	503
Latvia	34	31	24	21	14	20	14
Lithuania[1)]	51	31	20	31	20	30	20
Luxembourg[1)]	33	17	14	17	14	16	13
Malta	8	9	7	8	6	8	6
Netherlands	410	233	209	239	207	229	196
Poland	840	431	320	459	348	398	299
Portugal	279	157	109	145	107	131	98
Slovakia	109	79	45	65	38	61	36
Slovenia	60	35	29	25	20	23	17
Spain	1345	854	557	840	528	739	493
Sweden	229	157	130	162	145	159	142
UK	1855	875	592	761	506	710	468
EU-25	11828	6676	4700	6324	4616	5784	4264
Bulgaria[1)]	163	110		110		100	
Croatia[1)]	87	104		104		104	
Romania[1)]	329	261		261		248	
Turkey[1)]	822	731		731		672	
Norway	222	172		164		162	
Switzerland	90	43		49		47	

Note: 1) No national energy projection has been submitted. Data from the PRIMES €20 scenario are used instead.

Table 5.3: PM2.5 emissions by country, for the years 2000 and 2020, for the current legislation baseline (CLE) and the maximum reductions from the measures considered in the RAINS model (MRR), in kilotons

	2000	National activity projection 2020		PRIMES €20 and CAPRI MTR agricultural projection 2020		PRIMES €90 and CAPRI MTR agricultural projection 2020	
		CLE	MRR	CLE	MRR	CLE	MRR
Austria	31	21	15	21	15	21	15
Belgium	36	26	18	22	16	20	15
Cyprus1)	2	2	1	2	1	2	1
Czech Rep.	63	38	16	33	15	29	12
Denmark	25	15	7	14	7	14	7
Estonia	23	16	5	9	3	8	2
Finland	28	23	7	24	7	27	6
France	293	129	64	161	71	164	71
Germany	157	99	81	103	81	95	73
Greece1)	47	31	18	31	18	23	13
Hungary	52	36	9	26	8	23	7
Ireland	16	9	5	7	5	7	5
Italy	158	112	63	94	56	89	54
Latvia	18	16	3	12	2	13	2
Lithuania1)	12	10	3	10	3	10	3
Luxembourg1)	3	2	2	2	2	2	2
Malta	1	0	0	0	0	0	0
Netherlands	27	18	15	18	15	18	15
Poland	197	144	42	139	45	128	37
Portugal	81	43	13	37	12	37	12
Slovakia	25	21	6	16	7	13	6
Slovenia	12	9	3	7	2	4	2
Spain	148	85	57	82	52	79	50
Sweden	23	17	11	16	11	15	11
UK	121	60	44	62	47	56	44
EU-25	1599	980	509	945	501	896	462
Bulgaria1)	61	42		42		35	
Croatia1)	21	16		16		16	
Romania1)	127	142		142		123	
Turkey1)	313	289		289		248	
Norway	56	43		43		43	
Switzerland	9	6		6		6	

Note: 1) No national energy projection has been submitted. Data from the PRIMES €20 scenario are used instead.

Table 5.4: NH_3 emissions by country, for the years 2000 and 2020, for the current legislation baseline (CLE) and the maximum reductions from the measures considered in the RAINS model (MRR), in kilotons

	2000	National activity projection 2020		PRIMES €20 and CAPRI MTR agricultural projection 2020		PRIMES €90 and CAPRI MTR agricultural projection 2020	
		CLE	MRR	CLE	MRR	CLE	MRR
Austria	60	59	37	59	37	59	37
Belgium	85	81	73	82	75	82	75
Cyprus1)	7	7	5	7	5	7	5
Czech Rep.	84	74	62	77	62	77	62
Denmark	90	74	43	73	43	73	43
Estonia	9	10	7	10	7	10	7
Finland	35	26	21	32	26	32	26
France	702	636	399	659	404	659	404
Germany1)	601	449	374	452	377	452	376
Greece1)	54	46	34	46	34	46	34
Hungary	77	83	54	69	45	69	45
Ireland	125	91	77	101	86	101	86
Italy	425	384	272	354	249	354	248
Latvia	13	14	9	12	8	12	8
Lithuania1)	37	39	25	39	25	39	25
Luxembourg1)	6	6	5	6	5	6	5
Malta	2	3	2	3	2	3	2
Netherlands	149	138	117	131	110	131	110
Poland	317	316	208	349	221	349	221
Portugal	76	68	43	56	34	56	34
Slovakia1)	31	30	18	30	18	30	18
Slovenia	20	20	14	19	13	19	13
Spain	390	364	219	368	222	368	222
Sweden	55	50	37	48	36	48	36
UK	328	265	210	279	223	279	223
EU-25	3777	3332	2364	3360	2366	3360	2364
Bulgaria1)	70	65		65		65	
Croatia1)	28	32		32		32	
Romania1)	151	145		145		145	
Turkey1)	423	493		493		493	
Norway	24	20		21		21	
Switzerland	53	43		48		48	

Note: 1) No national agricultural projection has been submitted. Data from the PRIMES €20 scenario are used instead.

Table 5.5: VOC emissions by country, for the years 2000 and 2020, for the current legislation baseline (CLE) and the maximum reductions from the measures considered in the RAINS model (MRR), in kilotons

	2000	National activity projection 2020		PRIMES €20 and CAPRI MTR agricultural projection 2020		PRIMES €90 and CAPRI MTR agricultural projection 2020	
		CLE	MRR	CLE	MRR	CLE	MRR
Austria	179	114	67	115	66	117	67
Belgium	225	129	100	126	98	126	97
Cyprus1)	14	5	4	5	4	5	4
Czech Rep.	246	159	69	148	65	146	65
Denmark	140	71	44	64	38	64	38
Estonia	39	22	13	22	11	22	11
Finland	158	90	52	85	49	85	48
France	1803	862	595	942	617	953	620
Germany	1461	858	535	922	583	923	582
Greece1)	291	127	73	127	73	125	71
Hungary	161	114	51	103	47	104	46
Ireland	87	60	30	52	28	51	28
Italy	1491	701	471	658	440	654	436
Latvia	69	43	21	40	13	40	13
Lithuania1)	73	44	19	44	19	44	18
Luxembourg1)	13	7	6	7	6	7	6
Malta	7	3	2	3	2	3	2
Netherlands	259	168	127	161	121	161	121
Poland	578	318	183	396	203	397	196
Portugal	270	157	105	151	101	150	99
Slovakia	88	61	34	57	30	56	30
Slovenia	53	30	13	26	13	26	12
Spain	1134	838	505	778	468	778	466
Sweden	240	123	89	131	98	131	99
UK	1380	837	603	820	587	816	583
EU-25	10459	5943	3810	5983	3784	5985	3757
Bulgaria1)	134	86		86		85	
Croatia1)	102	104		104		104	
Romania1)	406	288		288		294	
Turkey1)	784	474		474		477	
Norway	379	90		89		88	
Switzerland	161	90		90		90	

Note: 1) No national energy projection has been submitted. Data from the PRIMES €20 scenario are used instead.

Table 5.6: CO_2 emissions by country, for the UNFCCC base year, for 2000 and for 2020 for the national projections and the PRIMES €20 and PRIMES €90 projections, in million tons

	UNFCCC base year		National activity projection		PRIMES €20 and CAPRI MTR agricultural projection		PRIMES €90 and CAPRI MTR agricultural projection	
	(1990)	2000	2020		2020		2020	
	Mt	Mt	Mt	*Change to base year*	Mt	*Change to base year*	Mt	*Change to base year*
Austria	61	65	77	*26%*	72	*18%*	67	*10%*
Belgium	119	126	131	*10%*	122	*2%*	112	*-6%*
Cyprus$^{1)}$	5	7	9	*87%*	9	*87%*	9	*87%*
Czech Rep.	164	126	123	*-25%*	110	*-33%*	95	*-42%*
Denmark	53	53	54	*2%*	46	*-14%*	39	*-26%*
Estonia	38	19	27	*-29%*	15	*-60%*	11	*-71%*
Finland	56	58	59	*5%*	57	*1%*	50	*-12%*
France	397	405	452	*14%*	378	*-5%*	341	*-14%*
Germany	1015	860	854	*-16%*	773	*-24%*	637	*-37%*
Greece$^{1)}$	84	104	119	*42%*	119	*42%*	93	*11%*
Hungary	85	59	68	*-19%*	68	*-20%*	59	*-31%*
Ireland	32	45	59	*85%*	46	*46%*	43	*35%*
Italy	431	472	503	*17%*	504	*17%*	421	*-2%*
Latvia	19	7	17	*-7%*	11	*-39%*	10	*-45%*
Lithuania$^{1)}$	39	14	21	*-46%*	21	*-46%*	19	*-51%*
Luxembourg$^{1)}$	12	9	11	*-5%*	11	*-5%*	11	*-8%*
Malta	2	2	3	*56%*	3	*43%*	3	*43%*
Netherlands	158	169	206	*31%*	179	*13%*	162	*3%*
Poland	477	315	350	*-26%*	326	*-32%*	239	*-50%*
Portugal	44	66	80	*84%*	72	*65%*	58	*34%*
Slovakia	59	39	60	*1%*	54	*-8%*	48	*-20%*
Slovenia	16	15	17	*7%*	17	*7%*	13	*-16%*
Spain	228	306	451	*97%*	335	*47%*	299	*31%*
Sweden	56	53	58	*2%*	68	*21%*	55	*-2%*
UK	589	559	536	*-9%*	504	*-14%*	450	*-24%*
EU-25	4238	3954	4347	*3%*	3921	*-7%*	3346	*-21%*
Bulgaria$^{1)}$	98	46	48	*-51%*	48	*-51%*	42	*-57%*
Croatia$^{1)}$	23	23	27	*19%*	27	*19%*	27	*19%*
Romania$^{1)}$	184	92	143	*-22%*	143	*-22%*	123	*-33%*
Turkey$^{1)}$	126	223	389	*208%*	389	*208%*	330	*162%*
Norway	34	38	48	*40%*	39	*15%*	38	*9%*
Switzerland	45	42	40	*-10%*	44	*-1%*	41	*-7%*

Note: $^{1)}$ No national energy projection has been submitted. Data from the PRIMES €20 scenario are used instead.

Table 5.7: SO_2 emissions in the EU-25 by SNAP sector, for the years 2000 and 2020, for the current legislation baseline (CLE) and the maximum reductions from the measures considered in the RAINS model (MRR), (in kilotons)

		National activity projection		PRIMES €20 and CAPRI MTR agricultural projection		PRIMES €90 and CAPRI MTR agricultural projection	
	2000	2020		2020		2020	
SNAP sector		CLE	MRR	CLE	MRR	CLE	MRR
1: Energy industries	5624	1647	672	1088	531	521	275
2: Non-industrial combustion	719	475	303	313	192	276	174
3: Combustion in industry	1364	1029	466	889	396	736	330
4: Production processes	621	540	283	561	309	536	301
5: Extraction and distribution	0	0	0	0	0	0	0
6: Solvent use	0	0	0	0	0	0	0
7: Road transport	152	13	13	18	18	18	18
8: Other mobile sources	221	118	118	134	134	134	134
9: Waste treatment	8	6	4	3	1	3	1
10:Agriculture	6	5	0	6	0	6	0
Total EU-25	8714	3833	1859	3013	1583	2231	1234

Table 5.8: NO_x emissions in the EU-25 by SNAP sector, for the years 2000 and 2020, for the current legislation baseline (CLE) and the maximum reductions from the measures considered in the RAINS model (MRR), (in kilotons)

		National activity projection		PRIMES €20 and CAPRI MTR agricultural projection		PRIMES €90 and CAPRI MTR agricultural projection	
	2000	2020		2020		2020	
SNAP sector		CLE	MRR	CLE	MRR	CLE	MRR
1: Energy industries	2325	1400	683	1280	704	980	506
2: Non-industrial combustion	687	682	499	692	508	650	482
3: Combustion in industry	1372	1408	463	1257	426	1171	402
4: Production processes	191	209	92	196	98	187	96
5: Extraction and distribution	0	0	0	0	0	0	0
6: Solvent use	0	0	0	0	0	0	0
7: Road transport	5466	1776	1778	1733	1733	1659	1659
8: Other mobile sources	1763	1181	1181	1145	1145	1117	1117
9: Waste treatment	10	8	4	7	3	7	3
10:Agriculture	14	12	0	13	0	13	0
Total EU-25	11828	6676	4700	6324	4616	5784	4264

Table 5.9: PM2.5 emissions in the EU-25 by SNAP sector, for the years 2000 and 2020, for the current legislation baseline (CLE) and the maximum reductions from the measures considered in the RAINS model (MRR), (in kilotons)

		National activity projection		PRIMES €20 and CAPRI MTR agricultural projection		PRIMES €90 and CAPRI MTR agricultural projection	
	2000	2020		2020		2020	
SNAP sector		CLE	MRR	CLE	MRR	CLE	MRR
1: Energy industries	141	101	54	65	35	21	9
2: Non-industrial combustion	515	300	38	302	41	315	43
3: Combustion in industry	128	105	79	107	83	104	80
4: Production processes	203	165	87	161	91	152	86
5: Extraction and distribution	7	4	4	4	4	3	3
6: Solvent use	0	0	0	0	0	0	0
7: Road transport	301	94	94	94	94	90	90
8: Other mobile sources	152	62	62	61	61	60	60
9: Waste treatment	80	79	60	80	60	80	60
10:Agriculture	72	68	31	71	32	71	32
Total EU-25	1599	980	509	945	501	896	462

Table 5.10: NH_3 emissions in the EU-25 by SNAP sector, for the years 2000 and 2020, for the current legislation baseline (CLE) and the maximum reductions from the measures considered in the RAINS model (MRR), (in kilotons)

		National activity projection		PRIMES €20 and CAPRI MTR agricultural projection		PRIMES €90 and CAPRI MTR agricultural projection	
	2000	2020		2020		2020	
SNAP sector		CLE	MRR	CLE	MRR	CLE	MRR
1: Energy industries	5	12	22	16	23	15	21
2: Non-industrial combustion	17	16	15	17	16	17	16
3: Combustion in industry	3	5	10	3	9	4	9
4: Production processes	69	63	29	63	29	63	29
5: Extraction and distribution	0	0	0	0	0	0	0
6: Solvent use	0	0	0	0	0	0	0
7: Road transport	78	19	19	22	22	21	21
8: Other mobile sources	1	1	1	1	1	1	1
9: Waste treatment	149	145	145	143	143	143	143
10:Agriculture	3455	3072	2123	3096	2124	3096	2124
Total EU-25	3777	3332	2364	3360	2366	3360	2364

Table 5.11: VOC emissions in the EU-25 by SNAP sector, for the years 2000 and 2020, for the current legislation baseline (CLE) and the maximum reductions from the measures considered in the RAINS model (MRR), (in kilotons)

		National activity projection		PRIMES €20 and CAPRI MTR agricultural projection		PRIMES €90 and CAPRI MTR agricultural projection	
	2000	2020		2020		2020	
SNAP sector		CLE	MRR	CLE	MRR	CLE	MRR
1: Energy industries	100	96	96	121	121	118	118
2: Non-industrial combustion	989	460	90	541	96	574	98
3: Combustion in industry	51	75	75	47	47	48	48
4: Production processes	1076	1020	744	1038	763	1030	756
5: Extraction and distribution	679	563	427	613	459	609	456
6: Solvent use	3711	2605	1316	2548	1288	2548	1288
7: Road transport	2946	561	561	557	557	546	546
8: Other mobile sources	728	379	379	330	330	325	325
9: Waste treatment	111	123	114	123	114	123	114
10:Agriculture	69	60	7	65	8	65	8
Total EU-25	10459	5943	3810	5983	3784	5985	3757

6 The environmental targets of the Thematic Strategy on Air Pollution

In its Thematic Strategy on Air Pollution (CEC, 2005a), the European Commission has established environmental interim targets for the year 2020 to guide the ambition level of further measures to reduce the impacts of air pollution in Europe. The choice of the policy targets relied on the analyses conducted under the Clean Air For Europe (CAFE) programme, where costs, environmental improvements and economic benefits of a wide range of potential emission control strategies have been explored (see, e.g., Amann *et al.*, 2005a, Amann *et al.*, 2005b, Amann *et al.*, 2005c). Based on these quantitative assessments, the European Commission has agreed on a range of impact indicators as policy targets and established for the year 2020 quantitative objectives for each of the indicators. Acknowledging the preliminary nature of some of the input data that have been used for the CAFE analysis with the RAINS model, the European Commission has adopted a cautious approach in the Thematic Strategy on Air Pollution (TSAP) and expressed the environmental objectives in terms of relative improvements compared to the situation as it has been assessed for the year 2000 (Table 6.1).

Table 6.1: Environmental targets of the Thematic Strategy expressed as percentage improvements relative to the situation in the year 2000

	Unit of the indicator	Percentage improvement compared to the situation in 2000
Life years lost from particulate matter (YOLLs)	# of years of life lost	47 %
Area of forest ecosystems where acid deposition exceeds the critical loads for acidification	km^2	74 %
Area of freshwater ecosystems where acid deposition exceeds the critical loads for acidification	km^2	39 %
Ecosystems area where nitrogen deposition exceeds the critical loads for eutrophication	km^2	43 %
Premature mortality from ozone	# of cases	10 %
Area of forest ecosystems where ozone concentrations exceed the critical levels for ozone$^{1)}$	km^2	15 %

Note: 1) This effect has not been explicitly modelled in RAINS. The environmental improvements resulting from emission controls targeted at the other effect indicators have been determined in an ex-post analysis.

Note that the reduction percentages established as the TSAP policy targets by the Commission relate to the envisaged improvement compared to the environmental situation in the year 2000. In contrast, much of the CAFE scenario analyses have explored percentage targets in terms of the "gap closure" between the baseline situation in 2020 and the extreme case that could be achieved by full application of all measures that were contained in the RAINS databases at that time. The TSAP targets refer to the situation of the year 2000, and are not depending on estimates of baseline emissions nor on the modelled scope for further emission control measures. Indeed the analysis conducted for the NEC baseline scenario (Amann *et al.*, 2006) demonstrated a critical influence of the assumed developments of the energy and agricultural systems in Europe on baseline emissions. Obviously, the future developments of these sectors are strongly determined by policy decisions, which are to a large extent driven by concerns other than air pollution. As a consequence, baseline projections are connected with substantial uncertainties, which cannot be effectively lowered on a purely scientific basis. Further uncertainties are highlighted through the inclusion of structural changes (fuel substitution and energy efficiency improvements) into the GAINS analysis (in the "GAINS" mode as described in part 1 of this report), which affects the estimates of the "maximum technically feasible" emission reductions. The TSAP choice of relative targets referring to the situation in the year 2000 circumvented these uncertainties and anchored at a more robust reference point.

While the assessment of the environmental conditions in the historic year 2000 is certainly more robust than estimates of baseline emissions and control potentials for the year 2020, it is influenced by our understanding of emissions in that base year as well as by the accuracy of the quantification of the environmental impacts. As described in Section 3.2 of Part 1 of this report, since CAFE many countries have provided improved emission inventories for the year 2000 with sometimes significant changes compared to earlier submissions. In addition, the revised City-delta methodology (see Section 2.4 in Part 1 of this report) suggests larger impacts of local low-level emissions of primary PM2.5 than those that were applied for the CAFE analysis. For ecosystems impacts, national focal centres have supplied in 2005/2006 more precise estimates on critical loads, and the computation of eutrophication effects is now employing ecosystem-specific deposition values instead of grid-average deposition that was used for the CAFE estimates. All these changes have some influence on the quantitative estimates of the impact indicators for the year 2000. As shown in Table 6.2, the new methodology with the increased urban increments due to local PM emissions suggests approximately 10 percent more life years lost due the exposure to fine particles. Using more detailed ecosystem-specific deposition rates for the assessment of ecosystems receiving unsustainable amounts of nitrogen deposition increases the estimate of the unprotected area by 16 percent. With the latest critical loads data, forest area with excess acid deposition is seven percent lower than in CAFE, and the estimated number of premature deaths attributable to ozone declines by 11 percent.

For the analysis of emission control scenarios, this report applies the percentage improvements established by the Commission as environmental objectives (Table 6.1) to the updated estimates of the impact indicators for the year 2000 (Table 6.2). In other words, the optimization analysis of emission control scenarios searches for the least-cost combination of measures that achieve the relative targets established by the Thematic Strategy for EU-wide environmental improvements in relation to the year 2000.

Table 6.2: Indicators for the environmental impacts for the year 2000, TSAP estimates compared with the revised estimates for the NEC analysis

	YOLLs (million life years lost)		Eutrophication (km^2)		Acidification forests (km^2)		Acidification water (km^2)		Ozone mortality (# of cases of premature deaths)	
	TSAP	NEC	TSAP	NEC	TSAP	NEC	TSAP	NEC	TSAP	NEC
Austria	3.3	4.0	34137	35184	5241	373			422	361
Belgium	7.6	7.8	6134	6687	3618	4651			381	332
Cyprus	0.2	0.1	2296	3134	0	0			33	29
Czech Rep.	5.1	6.1	17481	11124	14815	8642			535	462
Denmark	1.7	2.2	1597	2972	956	1047			179	170
Estonia	0.3	0.3	2853	8385	62	0			21	18
Finland	0.7	0.8	59985	79671	3802	3378	229	26	58	48
France	26.1	30.5	171610	176645	20951	17026			2663	2641
Germany	43.3	47.1	102867	101569	74572	62263			4258	3702
Greece	4.0	5.5	10392	9326	82	941			627	566
Hungary	5.6	6.5	3302	10259	415	50			748	654
Ireland	0.8	0.9	1015	7931	1957	1927			74	67
Italy	30.2	29.9	74548	87867	2083	0	0	0	4507	4031
Latvia	0.6	0.9	16277	25842	174	371			65	58
Lithuania	1.2	1.1	11209	17651	357	12788			66	55
Luxembourg	0.2	0.3	901	821	328	272			31	27
Malta	0.1	0.1							22	21
Netherlands	10.6	10.9	2158	4070	3335	5106			416	359
Poland	19.2	22.6	78442	86412	52104	50184			1399	1196
Portugal	2.7	4.1	3280	20118	285	3886			450	402
Slovakia	2.6	2.9	16179	19225	4130	4428			239	202
Slovenia	0.9	1.0	4006	5264	116	647			112	95
Spain	12.0	12.2	54410	76050	876	900			2002	1823
Sweden	1.7	1.6	48176	36623	42912	37263	30427	27423	197	177
UK	22.3	24.7	9792	21401	9717	10200	625	661	1423	1223
EU-25	202.9	223.8	733048	854231	242887	226344	31280	28110	20927	18717
Bulgaria				45762		0				
Croatia				3470		640				
Romania				60763		3187				
Turkey										
Norway				9810		1648		57242		
Switzerland				16345		1706		118		

Figure 6.1 compares the impact indicators for the five different effects for the year 2020, for the different activity projections. The yellow bars indicate the improvements between 2000 and 2020 due reduced emissions following implementation of current legislation and structural changes in the energy and agricultural systems. The blue bars illustrate the range of emissions that can be reduced with the measures contained in the traditional RAINS model. Note that this range does not include additional emission reduction potentials from energy efficiency improvements and fuel substitutions that are included in the GAINS model. The black bars show the residual impacts that remained if all add-on emission control measures that are contained in the RAINS database were fully applied. The red dots and lines indicate the target level established by the TSAP, i.e., constant relations to the effect estimates for the year 2000. The revised methodology for

computing excess nitrogen deposition to ecosystems based on ecosystem-specific deposition rates causes in many cases systematically higher deposition to sensitive ecosystems (forests) due to the inclusion of the filtering effects of forest stands. While this has some impact on the baseline estimate for the year 2000, it diminishes the ecosystems area that could achieve sustainable conditions under the maximum technically feasible emission reductions.

Table 6.3: Environmental targets used for the cost-effectiveness analysis of this report

	Unit of the indicator	Target for relative improvement established by the TSAP (2020 relative to 2000)	Impact indicator for 2000	Target level of the impact indicator for 2020
Life years lost from particulate matter (YOLLs)	# of years of life lost	47 %	223.8	118.6
Ecosystems area where nitrogen deposition exceeds the critical loads for eutrophication	km^2	43 %	854,231	486,912
Area of forest ecosystems where acid deposition exceeds the critical loads for acidification	km^2	74 %	226,344	58,849
Area of freshwater ecosystems where acid deposition exceeds the critical loads for acidification	km^2	39 %	28,110	17,147
Acute mortality from ozone (premature deaths)	# of cases	10 %	18,717	16,845

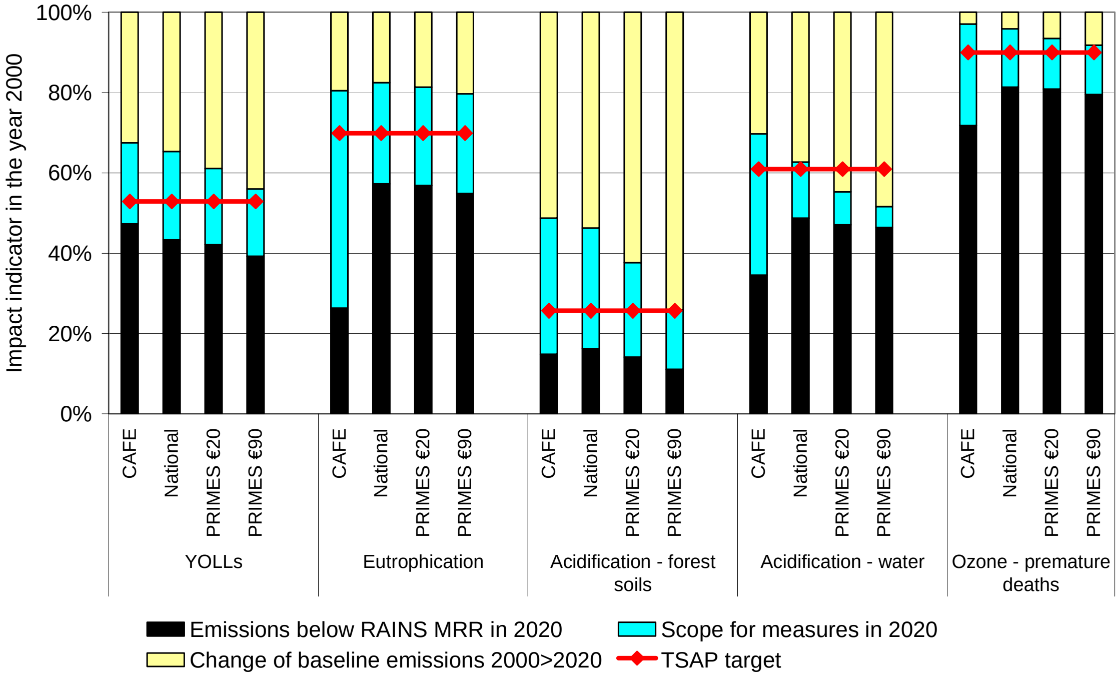


Figure 6.1: Changes in impact indicators for the year 2020

Next to cost-effectiveness, the analysis in CAFE addressed distributional aspects of emission controls across Member States and economic sectors. As a compromise between cost-effectiveness and equity, CAFE adopted the principle that improvements of health impacts from PM to the European population should not be constrained by concerns over spatial or national equity. Instead, measures should be applied wherever they yield the largest health benefits at least costs. In contrast, to protect the genetic pools of the various plant communities in the different regions of Europe, for ecosystem-related indicators the established targets demand equal relative improvements of the respective impact indicators in all Member States.

In order to maintain strict consistency between the CAFE approach and the NEC analysis, the Europe-wide environmental targets listed in Table 6.3 were formally translated into the target criteria that have been used for the CAFE analysis. In practice, the absolute quantities (e.g., km^2 of protected ecosystems) derived from the Europe-wide TSAP targets have been compared against the same quantities resulting from a series of optimization runs for different "gap closure" percentage targets as they have been applied by CAFE. Obviously, the numeric values of these "gap closure" targets differ from CAFE, since they are directly influenced by the revised estimates of baseline emissions and of the emission control potentials. In addition, this conversion also considers the impact indicators that have been used in CAFE for acidification and eutrophication, i.e., accumulated excess deposition over all ecosystems in a country, instead of the "protected area" indicator of TSAP.

For the range of baseline emissions spanned by the PRIMES €20 scenario it was found that the ecosystems area derived from the TSAP environmental targets relate to a 45 percent "CAFE" gap closure in terms of accumulated excess deposition for acidification, to a 60 percent gap closure for excess nitrogen deposition, and to a 32 percent gap closure target in terms of SOMO35 for ozone. This procedure was repeated for the other activity projections reported in this paper.

7 Optimized emission reductions to achieve the environmental targets of TSAP

Starting from the environmental targets that have been developed as described above, the GAINS optimization – in the "RAINS mode" – has been used to identify cost-effective sets of emission controls that would meet these objectives in 2020. To shed light into the relative stringencies implied by the targets for the different effects, four "single effect" optimizations have been carried out for the targets on PM health effects, eutrophication, acidification and ozone, respectively. As a fifth model run, a joint optimization has been conducted that simultaneously achieves the targets for all four effects at least costs. These optimizations search for combinations of emission control measures that are available but not applied in the "current legislation" baseline case. Consequently, the results are critically depending on the estimates of baseline emissions and of the potential for further measures. As pointed out earlier, assumptions on the future development of activity rates in the energy and agricultural systems have dominant impact on these projections, and consequently on the optimal allocation of further emission control measures. To explore this influence, the series of analysis (for the different environmental impacts) has been carried out for alternative energy and agricultural projections.

The resulting costs of these exploratory optimization runs are presented in Table 7.1. To meet only the health targets for fine particulate matter, emission control costs amount at 2.26 billion €/year for the national activity projections. If, however, a carbon price of €20/t CO_2 is assumed for the activity projections, emission control costs decline to 1.21 billion €/yr, and to 0.16 billion €/yr for the activity projection resulting in 20 percent lower CO_2 emissions. For the eutrophication target, for which agricultural emissions of NH_3 are critical, climate measures have less influence on air pollution control costs, which decline from 2.36 to 1.16 billion €/yr. The achievement of only the acidification targets under the national activity projections would require additional emission control costs of 2.6 billion €/yr. An ambitious climate policy, however, would achieve these targets as a side-effect without additional air pollution control costs. Costs for meeting the ozone targets range from 0.96 to 0.08 billion €/yr.

The joint optimization, which searches for emission control measures that meet all targets simultaneously at least costs, involves for the national activity projections costs of 4.07 billion €/yr. For a mild climate policy with a carbon price of €20/t CO_2, costs decline to 2.32 billion €/yr, and to 1.16 billion €/yr for an ambitious climate policy. In the latter case, costs relate mainly to the eutrophication target, for which agricultural emissions need to be reduced.

The cost figures listed above refer to the additional costs on top of the costs of the NEC baseline scenarios. As mentioned in Part 1 of this report, in comparison to the CAFE baseline, the NEC baseline includes the recent agreement on Euro-5 and Euro-6 for light duty vehicles. Thus, in order to compare total costs of the measures with the CAFE estimates the cost figures for stationary sources (as given above) and the costs for Euro-5 and Euro-6 need to be added. Information on emission control costs is provided in the impact assessment (CEC, 2005b, CEC, 2006) of the European Commission. However, a translation would be needed to make them consistent with the RAINS methodology, which requires additional information on the assumptions applied for the costs calculation in the impact assessment.

Because consensus on revised emission standards for heavy duty trucks is still outstanding and cost data for potential measures have not been made available for this report, the optimization analysis does not include a potential Euro-VI standard for heavy duty vehicles. The cost-effectiveness of such a measure will be explored in the following analysis cycle.

Table 7.1: Emission control costs of the optimized scenarios that meet the environmental objectives of the Thematic Strategy individually or jointly. (The cost figures presented in this table are additional on top of the costs of the NEC baseline cases.) To compare these figures with the cost estimates developed in CAFE for the TSAP, the costs of Euro-5 and Euro-6 measures that have now been included in the NEC baseline projection need to be added.

Environmental target	Target level		National activity projection	PRIMES €20 and CAPRI MTR agricultural projection	PRIMES €90 and CAPRI MTR agricultural projection
			Emission control costs (on top of baseline), million €/yr		
Life years lost from particulate matter (YOLLs)	118.6	million years of life lost	2265	1209	156
Ecosystems area where nitrogen deposition exceeds the critical loads for eutrophication	486.9	1000 km^2	2634	1851	1159
Area of forest ecosystems where acid deposition exceeds the critical loads for acidification	58.8	1000 km^2	2595	1007	0
Acute mortality from ozone (premature deaths)	16845	cases	956	460	83
All targets simultaneously			4074	2319	1160

While in the Thematic Strategy on Air Pollution the highest willingness to pay has been attributed to the improvement of health effects from fine particulate matter, the NEC analysis with its environmental targets derived from the TSAP as outlined above implies highest costs for meeting the eutrophication targets.

Leaving the confirmation of such a revised priority for policy judgement, the analysis presented in this report examines in more detail the three cases that meet all environmental objectives simultaneously.

The optimization analysis presented in this report addresses emission control measures in the EU-25. For the computations it applies the meteorological conditions of the year 1997, and it excludes the potential for further emission control measures for heavy duty vehicles, e.g., of a Euro-VI package.

The analysis of sensitivities and the influence of other important measures will be discussed in the next report to the NECPI group. Depending on the priorities established by the stakeholders in NECPI, such analyses could include, inter alia, the influence of the inter-annual meteorological variability (data for five meteorological years are available), inclusions of countries beyond the EU-25 into the optimization, the role of Europe-wide Euro-VI standards for heavy duty vehicles, and cost-effective reductions of ship emissions. Furthermore, input data for countries that have not yet supplied national activity projections could be included.

7.1 Resulting emission levels

Table 7.2 to Table 7.6 present for the five pollutants under consideration the emission levels that result from the European cost-effectiveness analysis on the basis of the three activity baselines. To meet the environmental objectives of the Thematic Strategy, a cost-effectiveness rationale would reduce SO_2 emissions between 69 and 74 percent compared to 2000, essentially depending on the amount of projected coal use.

Table 7.2: SO_2 emissions by country for the cost-optimized scenarios that meet in 2020 the environmental targets of the Thematic Strategies for Air Pollution, for the three activity projections, in kilotons

	2000	National activity projection 2020		PRIMES €20 and CAPRI MTR agricultural projection 2020		PRIMES €90 and CAPRI MTR agricultural projection 2020	
	kt	kt	*Change to 2000*	kt	*Change to 2000*	kt	*Change to 2000*
Austria	34	18	*-46%*	23	*-31%*	22	*-35%*
Belgium	175	66	*-62%*	66	*-62%*	66	*-62%*
Cyprus1)	48	8	*-84%*	8	*-84%*	8	*-84%*
Czech Rep.	252	115	*-54%*	71	*-72%*	65	*-74%*
Denmark	28	20	*-28%*	16	*-42%*	17	*-40%*
Estonia	90	15	*-84%*	6	*-93%*	8	*-91%*
Finland	77	47	*-38%*	47	*-39%*	50	*-34%*
France	658	304	*-54%*	204	*-69%*	247	*-62%*
Germany	630	350	*-44%*	292	*-54%*	205	*-67%*
Greece1)	493	71	*-86%*	93	*-81%*	88	*-82%*
Hungary	484	33	*-93%*	39	*-92%*	47	*-90%*
Ireland	132	24	*-82%*	24	*-82%*	21	*-84%*
Italy	755	296	*-61%*	303	*-60%*	262	*-65%*
Latvia	14	12	*-19%*	9	*-39%*	8	*-45%*
Lithuania1)	48	6	*-87%*	11	*-77%*	15	*-70%*
Luxembourg1)	4	1	*-65%*	2	*-61%*	2	*-62%*
Malta	34	4	*-88%*	7	*-79%*	7	*-79%*
Netherlands	75	61	*-18%*	52	*-30%*	45	*-39%*
Poland	1509	550	*-64%*	541	*-64%*	418	*-72%*
Portugal	289	51	*-82%*	58	*-80%*	58	*-80%*
Slovakia	128	46	*-64%*	37	*-71%*	36	*-72%*
Slovenia	99	11	*-89%*	15	*-85%*	13	*-87%*
Spain	1458	346	*-76%*	305	*-79%*	306	*-79%*
Sweden	46	41	*-10%*	41	*-11%*	36	*-23%*
UK	1155	241	*-79%*	193	*-83%*	175	*-85%*
EU-25	8714	2738	*-69%*	2464	*-72%*	2224	*-74%*
Bulgaria1)	847	116	*-86%*	116	*-86%*	91	*-89%*
Croatia1)	108	65	*-40%*	65	*-40%*	65	*-40%*
Romania1)	773	139	*-82%*	139	*-82%*	109	*-86%*
Turkey1)	1646	911	*-45%*	911	*-45%*	437	*-73%*
Norway	26	26	*-1%*	25	*-6%*	23	*-14%*
Switzerland	17	14	*-17%*	16	*-2%*	15	*-8%*

Note: 1) No national energy projection has been submitted. Data from the PRIMES €20 scenario are used instead.

For NO_x emissions, the optimization approach suggests reductions between 47 and 57 percent compared to the levels in 2000. Variations are related to differences between the national and PRIMES transport baseline projections.

Table 7.3: NO_x emissions by country for the cost-optimized scenarios that meet in 2020 the environmental targets of the Thematic Strategies for Air Pollution, for the three activity projections, in kilotons

		National activity projection		PRIMES €20 and CAPRI MTR agricultural projection		PRIMES €90 and CAPRI MTR agricultural projection	
	2000	2020		2020		2020	
	kt	kt	*Change to 2000*	kt	*Change to 2000*	kt	*Change to 2000*
Austria	202	122	*-39%*	107	*-47%*	106	*-48%*
Belgium	351	166	*-53%*	153	*-57%*	146	*-58%*
Cyprus1)	26	10	*-62%*	11	*-57%*	13	*-50%*
Czech Rep.	317	156	*-51%*	130	*-59%*	137	*-57%*
Denmark	213	100	*-53%*	101	*-52%*	99	*-53%*
Estonia	39	18	*-53%*	14	*-64%*	14	*-64%*
Finland	208	109	*-48%*	97	*-53%*	90	*-57%*
France	1475	656	*-56%*	654	*-56%*	632	*-57%*
Germany	1750	753	*-57%*	838	*-52%*	777	*-56%*
Greece1)	323	167	*-48%*	167	*-48%*	163	*-50%*
Hungary	186	87	*-53%*	82	*-56%*	78	*-58%*
Ireland	132	65	*-51%*	61	*-54%*	58	*-56%*
Italy	1353	722	*-47%*	681	*-50%*	639	*-53%*
Latvia	34	26	*-23%*	17	*-49%*	17	*-51%*
Lithuania1)	51	26	*-50%*	26	*-50%*	25	*-52%*
Luxembourg1)	33	15	*-55%*	15	*-54%*	15	*-55%*
Malta	8	7	*-18%*	6	*-26%*	8	*-10%*
Netherlands	410	223	*-46%*	236	*-42%*	226	*-45%*
Poland	840	366	*-56%*	398	*-53%*	353	*-58%*
Portugal	279	135	*-52%*	126	*-55%*	115	*-59%*
Slovakia	109	61	*-44%*	53	*-51%*	56	*-49%*
Slovenia	60	31	*-48%*	23	*-61%*	22	*-63%*
Spain	1345	676	*-50%*	612	*-55%*	571	*-58%*
Sweden	229	148	*-36%*	150	*-35%*	147	*-36%*
UK	1855	755	*-59%*	647	*-65%*	616	*-67%*
EU-25	11828	5599	*-53%*	5405	*-54%*	5122	*-57%*
Bulgaria1)	163	110	*-33%*	110	*-33%*	100	*-38%*
Croatia1)	87	104	*19%*	104	*19%*	104	*19%*
Romania1)	329	261	*-21%*	261	*-21%*	248	*-25%*
Turkey1)	822	731	*-11%*	731	*-11%*	672	*-18%*
Norway	222	172	*-23%*	164	*-26%*	162	*-27%*
Switzerland	90	43	*-52%*	49	*-46%*	47	*-47%*

Note: 1) No national energy projection has been submitted. Data from the PRIMES €20 scenario are used instead.

Following the cost-effectiveness concept, primary PM2.5 emissions should be reduced by 41 to 54 percent compared to 2000.

Table 7.4: PM2.5 emissions by country for the cost-optimized scenarios that meet in 2020 the environmental targets of the Thematic Strategies for Air Pollution, for the three activity projections, in kilotons

	2000	National activity projection 2020		PRIMES €20 and CAPRI MTR agricultural projection 2020		PRIMES €90 and CAPRI MTR agricultural projection 2020	
	kt	kt	*Change to 2000*	kt	*Change to 2000*	kt	*Change to 2000*
Austria	31	20	*-37%*	20	*-37%*	21	*-32%*
Belgium	36	20	*-44%*	17	*-51%*	19	*-46%*
Cyprus1)	2	2	*-26%*	2	*-26%*	2	*-26%*
Czech Rep.	63	28	*-56%*	23	*-64%*	22	*-65%*
Denmark	25	14	*-44%*	12	*-51%*	13	*-46%*
Estonia	23	15	*-38%*	8	*-66%*	7	*-69%*
Finland	28	20	*-28%*	18	*-35%*	26	*-5%*
France	293	110	*-62%*	149	*-49%*	161	*-45%*
Germany	157	89	*-43%*	94	*-40%*	93	*-41%*
Greece1)	47	21	*-55%*	21	*-56%*	18	*-62%*
Hungary	52	18	*-65%*	19	*-63%*	21	*-60%*
Ireland	16	8	*-48%*	6	*-64%*	7	*-58%*
Italy	158	83	*-47%*	71	*-55%*	74	*-53%*
Latvia	18	10	*-45%*	11	*-38%*	12	*-36%*
Lithuania1)	12	7	*-41%*	7	*-41%*	8	*-37%*
Luxembourg1)	3	2	*-41%*	2	*-41%*	2	*-42%*
Malta	1	0	*-54%*	0	*-56%*	0	*-56%*
Netherlands	27	16	*-42%*	17	*-39%*	18	*-36%*
Poland	197	75	*-62%*	104	*-47%*	124	*-37%*
Portugal	81	23	*-72%*	19	*-77%*	36	*-56%*
Slovakia	25	12	*-49%*	9	*-62%*	10	*-61%*
Slovenia	12	3	*-73%*	3	*-78%*	2	*-82%*
Spain	148	73	*-51%*	68	*-54%*	72	*-51%*
Sweden	23	16	*-30%*	16	*-32%*	15	*-35%*
UK	121	50	*-59%*	53	*-56%*	54	*-55%*
EU-25	1599	735	*-54%*	767	*-52%*	836	*-48%*
Bulgaria1)	61	42	*-32%*	42	*-32%*	35	*-42%*
Croatia1)	21	16	*-23%*	16	*-23%*	16	*-23%*
Romania1)	127	142	*11%*	142	*11%*	123	*-4%*
Turkey1)	313	289	*-8%*	289	*-8%*	248	*-21%*
Norway	56	43	*-22%*	43	*-22%*	43	*-23%*
Switzerland	9	6	*-30%*	6	*-34%*	6	*-34%*

Note: 1) No national energy projection has been submitted. Data from the PRIMES €20 scenario are used instead.

For emissions of ammonia, which make together with NO_x the largest contributions to eutrophication, reductions between 23 and 29m percent are computed. Larger reductions emerge for the high-CO_2 energy projections, while low carbon strategies, due to their lower air pollutant emissions, also release pressure on ammonia reductions.

Table 7.5: NH_3 emissions by country for the cost-optimized scenarios that meet in 2020 the environmental targets of the Thematic Strategies for Air Pollution, for the three activity projections, in kilotons

	2000	National activity projection 2020		PRIMES €20 and CAPRI MTR agricultural projection 2020		PRIMES €90 and CAPRI MTR agricultural projection 2020	
	kt	kt	*Change to 2000*	kt	*Change to 2000*	kt	*Change to 2000*
Austria	60	44	*-26%*	50	*-16%*	49	*-17%*
Belgium	85	76	*-10%*	78	*-8%*	79	*-7%*
Cyprus1)	7	6	*-23%*	6	*-22%*	6	*-23%*
Czech Rep.	84	64	*-23%*	66	*-21%*	69	*-18%*
Denmark	90	52	*-42%*	55	*-39%*	58	*-35%*
Estonia	9	9	*-3%*	7	*-23%*	7	*-23%*
Finland	35	24	*-31%*	30	*-14%*	31	*-10%*
France	702	474	*-32%*	510	*-27%*	537	*-23%*
Germany1)	601	391	*-35%*	399	*-34%*	405	*-33%*
Greece1)	54	36	*-34%*	38	*-29%*	39	*-27%*
Hungary	77	62	*-20%*	52	*-33%*	52	*-32%*
Ireland	125	79	*-37%*	90	*-28%*	92	*-26%*
Italy	425	327	*-23%*	304	*-28%*	307	*-28%*
Latvia	13	9	*-29%*	9	*-31%*	9	*-30%*
Lithuania1)	37	28	*-25%*	30	*-20%*	31	*-16%*
Luxembourg1)	6	5	*-24%*	5	*-22%*	5	*-16%*
Malta	2	3	*58%*	3	*57%*	3	*57%*
Netherlands	149	123	*-18%*	117	*-22%*	119	*-20%*
Poland	317	245	*-23%*	277	*-13%*	289	*-9%*
Portugal	76	52	*-31%*	46	*-39%*	48	*-36%*
Slovakia1)	31	27	*-11%*	28	*-9%*	28	*-8%*
Slovenia	20	14	*-32%*	14	*-33%*	14	*-28%*
Spain	390	270	*-31%*	304	*-22%*	318	*-19%*
Sweden	55	50	*-9%*	44	*-20%*	44	*-20%*
UK	328	225	*-31%*	252	*-23%*	259	*-21%*
EU-25	3777	2694	*-29%*	2813	*-26%*	2899	*-23%*
Bulgaria1)	70	65	*-6%*	65	*-6%*	65	*-6%*
Croatia1)	28	32	*12%*	32	*12%*	32	*12%*
Romania1)	151	145	*-4%*	145	*-4%*	145	*-4%*
Turkey1)	423	493	*16%*	493	*16%*	493	*16%*
Norway	24	20	*-17%*	21	*-14%*	21	*-14%*
Switzerland	53	43	*-19%*	48	*-9%*	48	*-9%*

Note: 1) No national agricultural projection has been submitted. Data from the PRIMES €20 scenario are used instead.

A similar response emerges for VOC emissions, for which reductions range between 45 and 49 percent compared to levels in the year 2000.

Table 7.6: VOC emissions by country for the cost-optimized scenarios that meet in 2020 the environmental targets of the Thematic Strategies for Air Pollution, for the three activity projections, in kilotons

		National activity projection		PRIMES €20 and CAPRI MTR agricultural projection		PRIMES €90 and CAPRI MTR agricultural projection	
	2000	2020		2020		2020	
	kt	kt	*Change to 2000*	kt	*Change to 2000*	kt	*Change to 2000*
Austria	179	110	*-39%*	111	*-38%*	115	*-36%*
Belgium	225	118	*-48%*	119	*-47%*	123	*-45%*
Cyprus1)	14	5	*-61%*	5	*-61%*	5	*-61%*
Czech Rep.	246	137	*-44%*	128	*-48%*	128	*-48%*
Denmark	140	67	*-52%*	61	*-56%*	62	*-56%*
Estonia	39	20	*-48%*	20	*-48%*	21	*-46%*
Finland	158	84	*-46%*	83	*-47%*	85	*-46%*
France	1803	818	*-55%*	916	*-49%*	945	*-48%*
Germany	1461	740	*-49%*	812	*-44%*	849	*-42%*
Greece1)	291	109	*-62%*	112	*-61%*	113	*-61%*
Hungary	161	85	*-48%*	93	*-42%*	102	*-37%*
Ireland	87	55	*-37%*	49	*-43%*	49	*-43%*
Italy	1491	596	*-60%*	609	*-59%*	627	*-58%*
Latvia	69	38	*-45%*	36	*-48%*	39	*-44%*
Lithuania1)	73	40	*-46%*	40	*-46%*	41	*-44%*
Luxembourg1)	13	7	*-48%*	7	*-48%*	7	*-46%*
Malta	7	2	*-75%*	2	*-77%*	2	*-68%*
Netherlands	259	164	*-37%*	159	*-39%*	160	*-38%*
Poland	578	294	*-49%*	379	*-34%*	396	*-31%*
Portugal	270	141	*-48%*	141	*-48%*	150	*-45%*
Slovakia	88	59	*-34%*	51	*-43%*	51	*-43%*
Slovenia	53	18	*-66%*	19	*-65%*	18	*-66%*
Spain	1134	722	*-36%*	677	*-40%*	757	*-33%*
Sweden	240	117	*-51%*	126	*-47%*	131	*-45%*
UK	1380	758	*-45%*	757	*-45%*	815	*-41%*
EU-25	10459	5304	*-49%*	5512	*-47%*	5790	*-45%*
Bulgaria1)	134	86	*-36%*	86	*-36%*	85	*-36%*
Croatia1)	102	104	*2%*	104	*2%*	104	*2%*
Romania1)	406	288	*-29%*	288	*-29%*	294	*-27%*
Turkey1)	784	474	*-39%*	474	*-39%*	477	*-39%*
Norway	379	90	*-76%*	89	*-76%*	88	*-77%*
Switzerland	161	90	*-44%*	90	*-44%*	90	*-44%*

Note: 1) No national energy projection has been submitted. Data from the PRIMES €20 scenario are used instead.

The resulting ranges in national emission reductions are illustrated in Figure 7.1 to Figure 7.5.

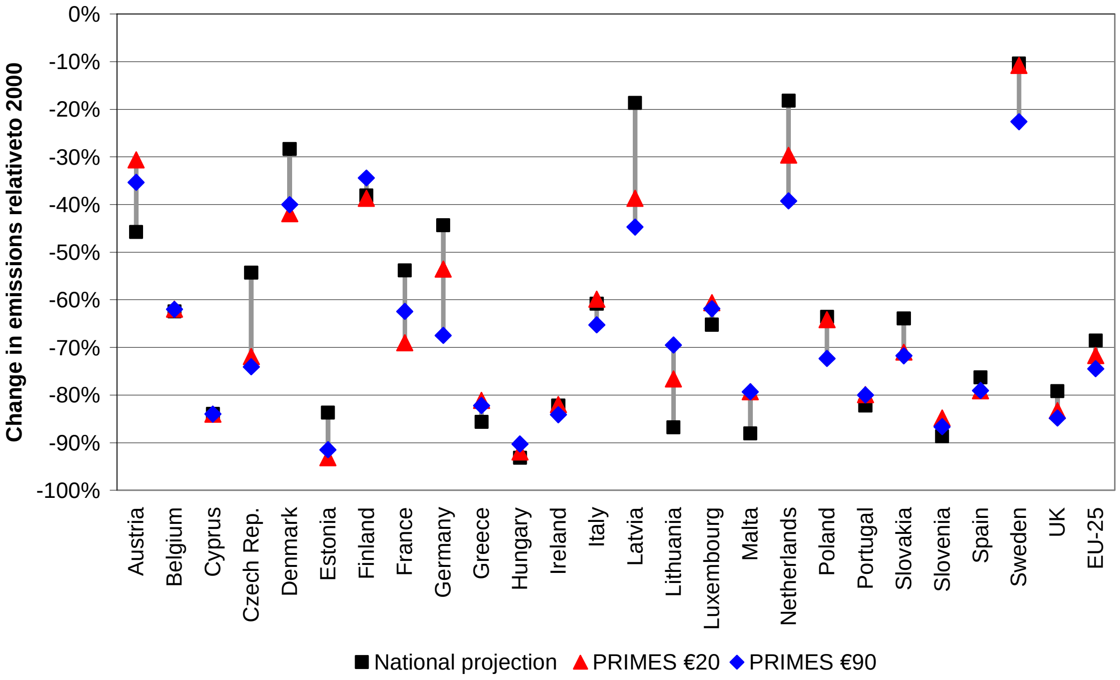


Figure 7.1: SO_2 emissions for the cost-optimized scenarios that meet in 2020 the environmental targets of the Thematic Strategies for Air Pollution, for the three activity projections, relative to the emissions in 2000

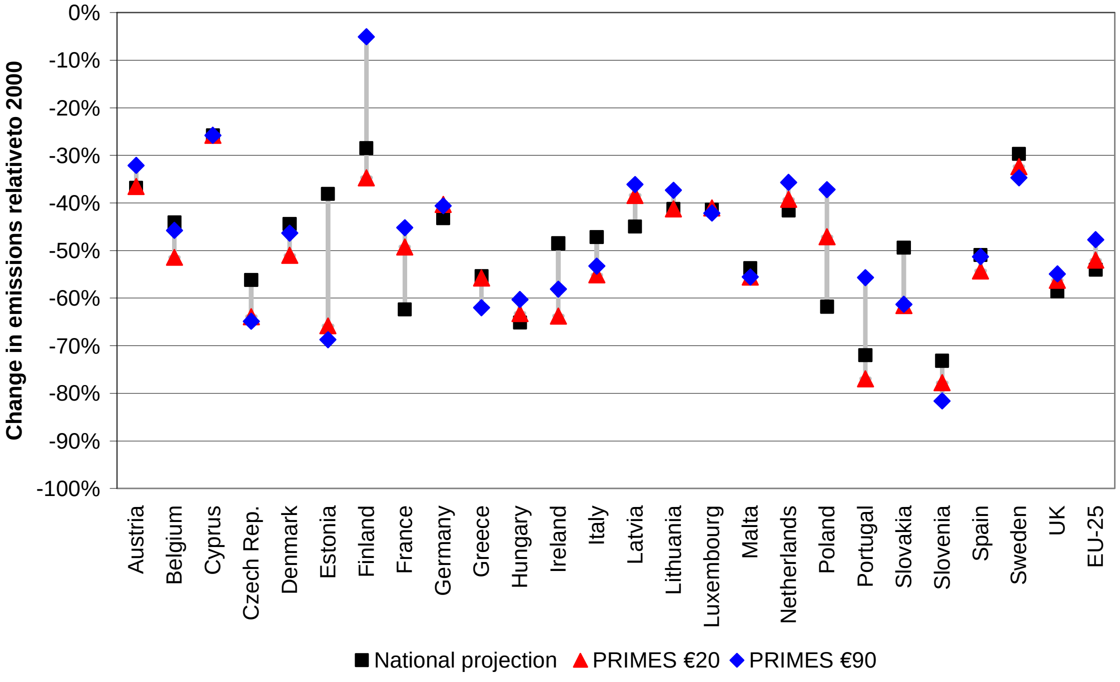


Figure 7.2: NO_x emissions for the cost-optimized scenarios that meet in 2020 the environmental targets of the Thematic Strategies for Air Pollution, for the three activity projections, relative to the emissions in 2000

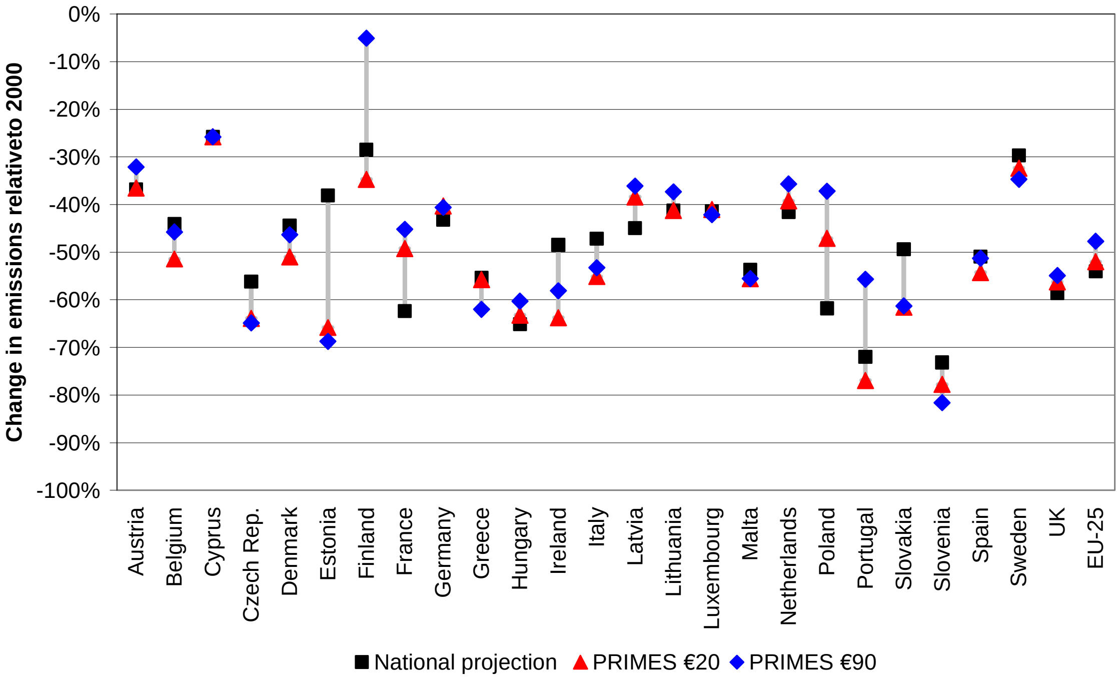


Figure 7.3: PM2.5 emissions for the cost-optimized scenarios that meet in 2020 the environmental targets of the Thematic Strategies for Air Pollution, for the three activity projections, relative to the emissions in 2000

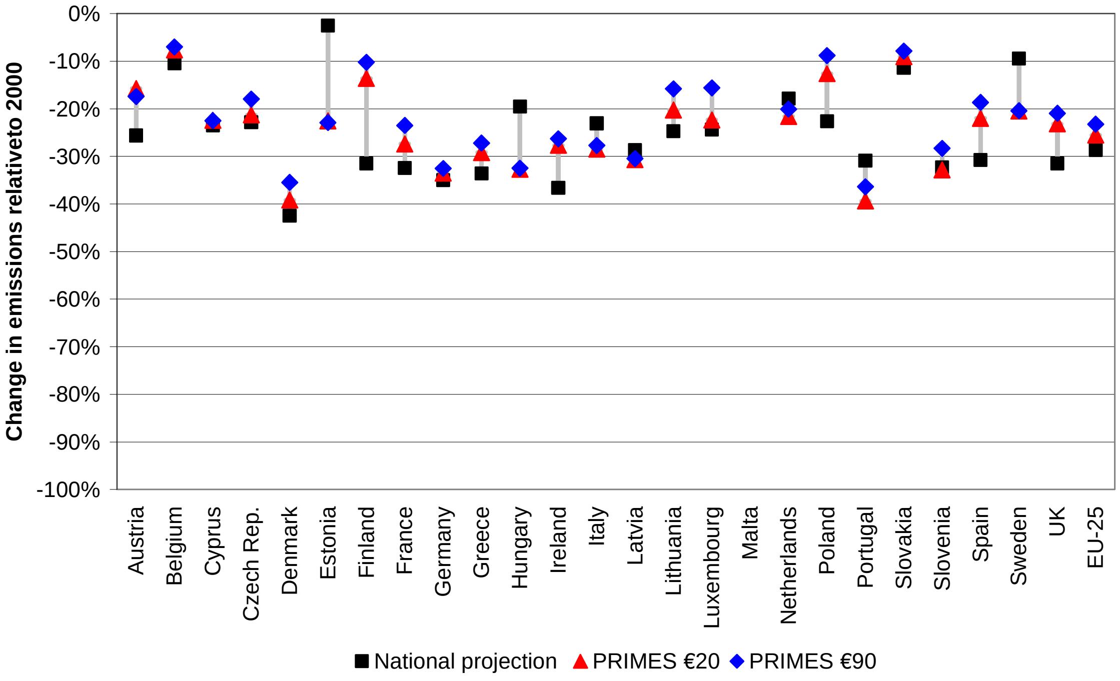


Figure 7.4: NH_3 emissions for the cost-optimized scenarios that meet in 2020 the environmental targets of the Thematic Strategies for Air Pollution, for the three activity projections, relative to the emissions in 2000

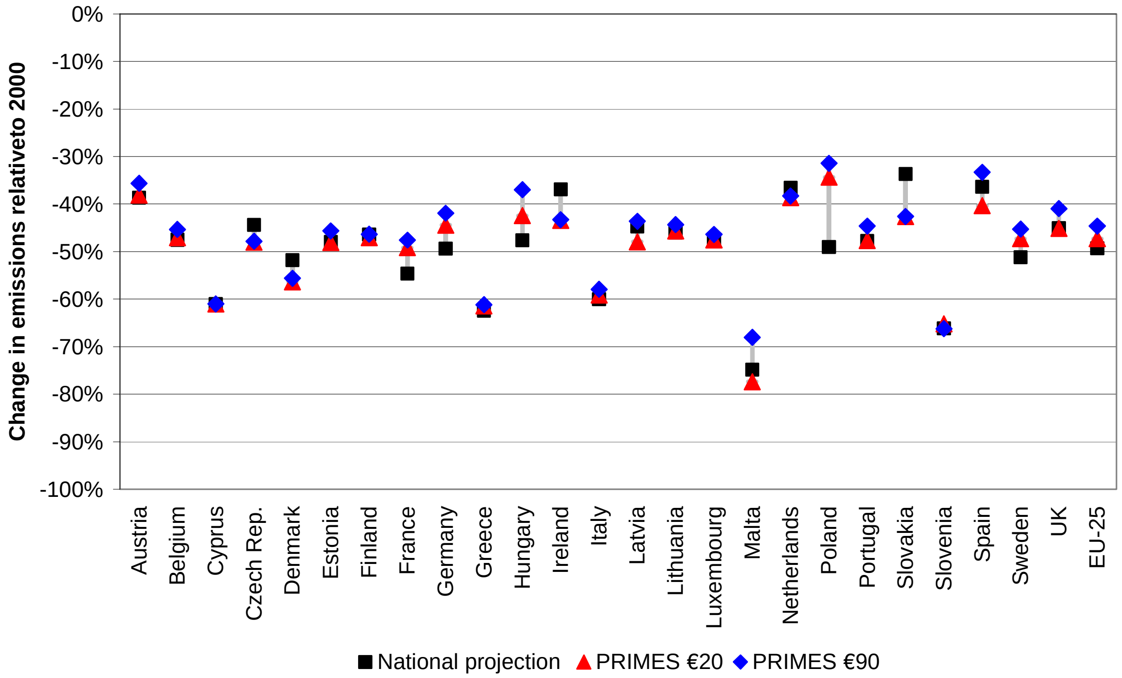


Figure 7.5: VOC emissions for the cost-optimized scenarios that meet in 2020 the environmental targets of the Thematic Strategies for Air Pollution, for the three activity projections, relative to the emissions in 2000

Table 7.7: SO_2 emissions in the EU-25 by SNAP sector, for the cost-optimized scenarios that meet in 2020 the environmental targets of the Thematic Strategies for Air Pollution, for the three activity projections, in kilotons

		National activity projection		PRIMES €20 and CAPRI MTR agricultural projection		PRIMES €90 and CAPRI MTR agricultural projection	
	2000	2020		2020		2020	
SNAP sector	kt	kt	*Change to 2000*	kt	*Change to 2000*	kt	*Change to 2000*
1: Energy industries	5624	1192	*-79%*	886	*-84%*	521	*-91%*
2: Non-industrial combustion	719	353	*-51%*	257	*-64%*	276	*-62%*
3: Combustion in industry	1364	715	*-48%*	715	*-48%*	736	*-46%*
4: Production processes	621	343	*-45%*	451	*-27%*	536	*-14%*
5: Extraction and distribution	0	0	*0%*	0	*0%*	0	*0%*
6: Solvent use	0	0	*0%*	0	*0%*	0	*0%*
7: Road transport	152	13	*-91%*	18	*-88%*	18	*-88%*
8: Other mobile sources	221	118	*-46%*	134	*-39%*	134	*-39%*
9: Waste treatment	8	4	*-42%*	2	*-78%*	2	*-76%*
10:Agriculture	6	0	*-100%*	0	*-100%*	0	*-100%*

Table 7.8: NO_x emissions in the EU-25 by SNAP sector, for the cost-optimized scenarios that meet in 2020 the environmental targets of the Thematic Strategies for Air Pollution, for the three activity projections, in kilotons

	2000	National activity projection 2020		PRIMES €20 and CAPRI MTR agricultural projection 2020		PRIMES €90 and CAPRI MTR agricultural projection 2020	
SNAP sector	kt	kt	*Change to 2000*	kt	*Change to 2000*	kt	*Change to 2000*
1: Energy industries	2325	1055	*-55%*	987	*-58%*	820	*-65%*
2: Non-industrial combustion	687	669	*-3%*	685	*0%*	646	*-6%*
3: Combustion in industry	1372	776	*-43%*	700	*-49%*	726	*-47%*
4: Production processes	191	144	*-24%*	152	*-20%*	151	*-21%*
5: Extraction and distribution	0	0	*0%*	0	*0%*	0	*0%*
6: Solvent use	0	0	*0%*	0	*0%*	0	*0%*
7: Road transport	5466	1769	*-68%*	1733	*-68%*	1659	*-70%*
8: Other mobile sources	1763	1181	*-33%*	1145	*-35%*	1117	*-37%*
9: Waste treatment	10	4	*-57%*	3	*-69%*	3	*-67%*
10:Agriculture	14	0	*-100%*	0	*-100%*	0	*-100%*

Table 7.9: PM2.5 emissions in the EU-25 by SNAP sector, for the cost-optimized scenarios that meet in 2020 the environmental targets of the Thematic Strategies for Air Pollution, for the three activity projections, in kilotons

	2000	National activity projection 2020		PRIMES €20 and CAPRI MTR agricultural projection 2020		PRIMES €90 and CAPRI MTR agricultural projection 2020	
SNAP sector	kt	kt	*Change to 2000*	kt	*Change to 2000*	kt	*Change to 2000*
1: Energy industries	141	79	*-44%*	48	*-66%*	21	*-85%*
2: Non-industrial combustion	515	198	*-62%*	260	*-49%*	313	*-39%*
3: Combustion in industry	128	94	*-26%*	95	*-26%*	104	*-18%*
4: Production processes	203	112	*-45%*	112	*-45%*	148	*-27%*
5: Extraction and distribution	7	4	*-38%*	4	*-36%*	3	*-62%*
6: Solvent use	0	0	*0%*	0	*0%*	0	*0%*
7: Road transport	301	94	*-69%*	94	*-69%*	90	*-70%*
8: Other mobile sources	152	62	*-59%*	61	*-60%*	60	*-61%*
9: Waste treatment	80	61	*-23%*	61	*-24%*	64	*-19%*
10:Agriculture	72	31	*-57%*	32	*-56%*	32	*-55%*

Table 7.10: NH_3 emissions in the EU-25 by SNAP sector, for the cost-optimized scenarios that meet in 2020 the environmental targets of the Thematic Strategies for Air Pollution, for the three activity projections, in kilotons

		National activity projection 2020		PRIMES €20 and CAPRI MTR agricultural projection 2020		PRIMES €90 and CAPRI MTR agricultural projection 2020	
SNAP sector	2000 kt	kt	*Change to 2000*	kt	*Change to 2000*	kt	*Change to 2000*
1: Energy industries	5	14	*163%*	16	*207%*	14	*175%*
2: Non-industrial combustion	17	16	*-5%*	17	*1%*	17	*3%*
3: Combustion in industry	3	4	*33%*	4	*45%*	3	*9%*
4: Production processes	69	43	*-37%*	57	*-18%*	60	*-13%*
5: Extraction and distribution	0	0	*0%*	0	*0%*	0	*0%*
6: Solvent use	0	0	*0%*	0	*0%*	0	*0%*
7: Road transport	78	19	*-75%*	22	*-72%*	21	*-73%*
8: Other mobile sources	1	1	*74%*	1	*84%*	1	*82%*
9: Waste treatment	149	145	*-3%*	143	*-4%*	143	*-4%*
10:Agriculture	3455	2452	*-29%*	2554	*-26%*	2640	*-24%*

Table 7.11: VOC emissions in the EU-25 by SNAP sector, for the cost-optimized scenarios that meet in 2020 the environmental targets of the Thematic Strategies for Air Pollution, for the three activity projections, in kilotons

		National activity projection 2020		PRIMES €20 and CAPRI MTR agricultural projection 2020		PRIMES €90 and CAPRI MTR agricultural projection 2020	
SNAP sector	2000 kt	kt	*Change to 2000*	kt	*Change to 2000*	kt	*Change to 2000*
1: Energy industries	100	96	*-4%*	121	*21%*	118	*18%*
2: Non-industrial combustion	989	378	*-62%*	519	*-48%*	567	*-43%*
3: Combustion in industry	51	72	*41%*	47	*-8%*	48	*-6%*
4: Production processes	1076	836	*-22%*	872	*-19%*	1012	*-6%*
5: Extraction and distribution	679	507	*-25%*	556	*-18%*	603	*-11%*
6: Solvent use	3711	2378	*-36%*	2381	*-36%*	2439	*-34%*
7: Road transport	2946	561	*-81%*	557	*-81%*	546	*-81%*
8: Other mobile sources	728	354	*-51%*	330	*-55%*	325	*-55%*
9: Waste treatment	111	115	*4%*	120	*8%*	123	*12%*
10:Agriculture	69	7	*-89%*	8	*-88%*	8	*-88%*

7.2 Emission control costs

Costs required to reduce emissions to the levels indicated in Table 7.2 to Table 7.6 vary over the analyzed baseline activity projections by more than a factor of three (Table 7.12 to Table 7.14), with the ambition of the GHG target as a determining factor. For instance, while costs for further SO_2 reduction for the national projections, which imply a three percent increase in CO_2 emissions, amount to 950 million €/yr, they diminish to nil for the -20 percent CO_2 energy projection. Similar effects can be seen for the other pollutants, although for ammonia to a lesser extent.

Note that Table 7.12 to Table 7.17 display the additional costs in addition to the current legislation baseline projections. Thus, they do not include baseline costs in general, and also not the costs for the recently agreed Euro-5 and Euro-6 standards. As mentioned in Part 1 of the report, costs for these transport measures are still under development. To compare the costs indicated in the Thematic Strategy (7.1 billion €/year) with these estimates, the Euro-5 and Euro-6 costs need to be added to the numbers displayed in Table 7.12 to Table 7.17.

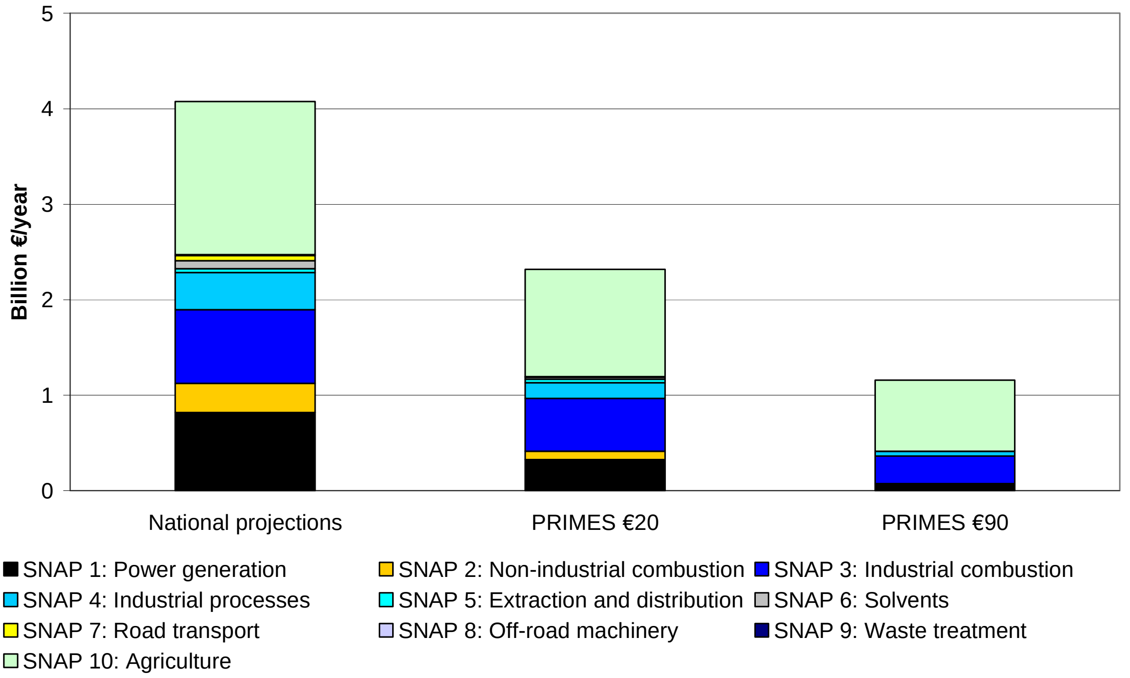


Figure 7.6: Emission control costs on top of the costs of the NEC current legislation projections for the optimized scenarios for the EU-25 by SNAP sector

Table 7.12: Total costs and costs for SO_2 emission control costs of the optimized scenarios for the EU-25 by SNAP sector, on top of the CLE baseline projections, in million €/year

SNAP sector	Total costs			SO_2		
	National projections	PRIMES €20	PRIMES €90	National projections	PRIMES €20	PRIMES €90
1: Energy industries	819	327	71	433	105	0
2: Non-industrial combustion	305	86	5	112	26	0
3: Combustion in industry	773	553	287	283	86	0
4: Production processes	389	165	50	122	41	0
5: Extraction and distribution	38	36	0	0	0	0
6: Solvent use	84	21	0	0	0	0
7: Road transport	54	0	0	0	0	0
8: Other mobile sources	0	0	0	0	0	0
9: Waste treatment	9	7	2	0	0	0
10:Agriculture	1603	1124	745	0	0	0
Total	4074	2319	1160	950	258	0

Table 7.13: NO_x and P2.5 emission control costs of the optimized scenarios for the EU-25 by SNAP sector, on top of the CLE baseline projections, in million €/year

SNAP sector	NO_x			PM2.5		
	National projections	PRIMES €20	PRIMES €90	National projections	PRIMES €20	PRIMES €90
1: Energy industries	370	207	71	16	14	0
2: Non-industrial combustion	23	11	5	170	49	0
3: Combustion in industry	476	451	287	15	17	0
4: Production processes	77	39	30	37	36	0
5: Extraction and distribution	0	0	0	0	0	0
6: Solvent use	0	0	0	0	0	0
7: Road transport	54	0	0	0	0	0
8: Other mobile sources	0	0	0	0	0	0
9: Waste treatment	2	2	2	3	3	0
10:Agriculture	3	3	3	0	0	0
Total	1005	713	397	241	120	0

Table 7.14: NH_3 and VOC emission control costs of the optimized scenarios for the EU-25 by SNAP sector, on top of the CLE baseline projections, in million €/year

SNAP sector	NH_3 National projections	NH_3 PRIMES €20	NH_3 PRIMES €90	VOC National projections	VOC PRIMES €20	VOC PRIMES €90
1: Energy industries	0	0	0	0	0	0
2: Non-industrial combustion	0	0	0	0	0	0
3: Combustion in industry	0	0	0	0	0	0
4: Production processes	135	41	21	17	8	0
5: Extraction and distribution	0	0	0	38	36	0
6: Solvent use	0	0	0	84	21	0
7: Road transport	0	0	0	0	0	0
8: Other mobile sources	0	0	0	0	0	0
9: Waste treatment	0	0	0	4	1	0
10:Agriculture	1600	1121	742	0	0	0
Total	1735	1162	762	143	66	0

Table 7.15: Total costs and costs for SO_2 emission control costs of the optimized scenarios by country, on top of the CLE baseline projections, in million €/year

	Total costs			SO_2		
	National projections	PRIMES €20	PRIMES €90	National projections	PRIMES €20	PRIMES €90
Austria	59	26	25	3	0	0
Belgium	73	49	22	15	6	0
Cyprus	14	11	7	0	0	0
Czech Rep.	123	62	15	64	6	0
Denmark	207	154	109	1	1	0
Estonia	29	19	12	26	2	0
Finland	66	46	24	48	8	0
France	649	369	209	128	43	0
Germany	636	258	98	233	2	0
Greece	100	60	32	13	0	0
Hungary	75	45	17	16	22	0
Ireland	133	96	74	19	0	0
Italy	248	151	86	35	4	0
Latvia	25	6	6	3	0	0
Lithuania	67	51	38	4	1	0
Luxembourg	7	6	2	0	0	0
Malta	11	8	0	1	0	0
Netherlands	221	78	41	49	1	0
Poland	400	282	55	167	130	0
Portugal	83	40	18	22	3	0
Slovakia	41	16	3	23	4	0
Slovenia	70	27	15	21	2	0
Spain	452	243	148	41	8	0
Sweden	11	38	36	0	0	0
UK	276	178	66	17	12	0
EU-25	4074	2319	1160	950	258	0
Bulgaria	0	0	0	0	0	0
Croatia	0	0	0	0	0	0
Romania	0	0	0	0	0	0
Turkey	0	0	0	0	0	0
Norway	0	0	0	0	0	0
Switzerland	0	0	0	0	0	0

Table 7.16: Control costs for NO_x and PM2.5 emissions of the optimized scenarios by country, on top of the CLE baseline projections, in million €/year

	NO_x			PM2.5		
	National projections	PRIMES €20	PRIMES €90	National projections	PRIMES €20	PRIMES €90
Austria	9	5	1	1	1	0
Belgium	24	23	15	11	8	0
Cyprus	7	5	2	0	0	0
Czech Rep.	32	35	6	4	3	0
Denmark	21	11	9	2	2	0
Estonia	2	10	6	0	0	0
Finland	10	30	23	1	2	0
France	187	80	49	33	11	0
Germany	231	149	51	13	6	0
Greece	27	26	17	8	8	0
Hungary	12	7	6	32	4	0
Ireland	14	6	2	1	1	0
Italy	33	35	6	54	19	0
Latvia	4	2	2	1	0	0
Lithuania	4	4	4	0	0	0
Luxembourg	2	2	1	0	0	0
Malta	0	1	0	0	0	0
Netherlands	62	5	2	2	2	0
Poland	65	51	30	39	25	0
Portugal	12	7	6	10	8	0
Slovakia	11	8	2	2	1	0
Slovenia	7	2	1	1	1	0
Spain	125	107	83	5	6	0
Sweden	10	21	20	0	0	0
UK	93	78	52	22	12	0
EU-25	1005	713	397	241	120	0
Bulgaria	0	0	0	0	0	0
Croatia	0	0	0	0	0	0
Romania	0	0	0	0	0	0
Turkey	0	0	0	0	0	0
Norway	0	0	0	0	0	0
Switzerland	0	0	0	0	0	0

Table 7.17: Control costs for NH_3 and VOC emissions of the optimized scenarios by country, on top of the CLE baseline projections, in million €/year

	NH_3			VOC		
	National projections	PRIMES €20	PRIMES €90	National projections	PRIMES €20	PRIMES €90
Austria	45	20	24	0	0	0
Belgium	18	10	6	5	1	0
Cyprus	7	5	5	0	0	0
Czech Rep.	21	18	9	1	0	0
Denmark	184	139	99	0	0	0
Estonia	1	7	7	0	0	0
Finland	6	5	1	0	0	0
France	291	230	160	9	5	0
Germany	148	95	47	12	6	0
Greece	51	27	15	1	0	0
Hungary	16	11	11	0	0	0
Ireland	98	89	72	1	0	0
Italy	104	90	80	22	3	0
Latvia	16	3	3	0	0	0
Lithuania	58	46	35	0	0	0
Luxembourg	4	3	1	0	0	0
Malta	0	0	0	10	8	0
Netherlands	96	69	39	13	0	0
Poland	126	76	25	2	0	0
Portugal	37	22	13	2	0	0
Slovakia	4	2	1	0	0	0
Slovenia	40	22	15	0	0	0
Spain	273	120	65	8	2	0
Sweden	0	16	16	0	0	0
UK	89	37	14	56	39	0
EU-25	1735	1162	762	143	66	0
Bulgaria	0	0	0	0	0	0
Croatia	0	0	0	0	0	0
Romania	0	0	0	0	0	0
Turkey	0	0	0	0	0	0
Norway	0	0	0	0	0	0
Switzerland	0	0	0	0	0	0

8 Summary

This report analyzes emission control scenarios that meet the environmental objectives established by the European Commission in its Thematic Strategy for Air Pollution. Compared to the assessment conducted in the context of the Clean Air For Europe (CAFE) programme, this analysis starts from a substantially revised databases on emission inventories, activity projections and impact indicators that result from the series of bilateral consultations between IIASA and experts from Member States and industry. Key factors that have changed since the CAFE analysis include the national projections of energy use and agricultural activities, emission inventories for the year 2000, an improved treatment of urban air quality, and more precise computations of nitrogen deposition to ecosystems. In addition, the optimization runs reflect the recent agreements on Euro-5 and Euro-6 standards for light duty vehicles by including these measures into the set of current legislation in the baseline scenario, and do not involve them in the cost-effectiveness analysis.

With these improved data sets, the analysis translates the environmental objectives that have been presented in the Thematic Strategy as relative improvements of certain impact indicators in relation to the situation in the year 2000, into new target levels of these impact indicators for 2020. The analysis considers targets for health impacts of fine particles, for excess nitrogen deposition, for acidification of forest soils and water ecosystems, and for health impacts of ground-level ozone.

Three series of optimization runs, for three different projections of energy use and agricultural activities, identified the least-cost sets of measures that meet the environmental objectives established by the Thematic Strategy. Compared to the current legislation baseline projections, these measures incur costs of 4.1, 2.3 and 1.2 billion €/year for the national activity projections, for the projections for a €20 carbon price per ton of CO_2 emissions and for a €90 carbon price, respectively.

Depending on the underlying activity projections, these cost-effective scenarios suggest for 2020 SO_2 emissions in the EU-25 to be reduced by 69 to 74 percent in comparison to 2000, NO_x emissions by 47 to 57 percent, primary emissions of PM2.5 by 44 to 54 percent, ammonia by 23 to 29 percent and VOC emissions by 45 to 49 percent. Obviously, there are significant differences across Member States, depending on the environmental conditions and the marginal costs of the remaining emission control measures.

As a striking feature, a strong connection between the CO_2 emissions implied by the underlying activity projections and air pollution emission control costs can be detected. For the national activity projections that imply a three percent increase in CO_2 emissions compared to the base year of the Kyoto treaty, air pollution control costs amount to 4.1 billion €/yr on top of the costs of current legislation. In contrast, emission control costs decline to 1.2 billion €/yr for the energy projection that would result in a 21 percent decline in the EU-25 CO_2 emissions. Not only total costs decline with increasing ambition levels of climate strategies, the distribution of air pollution control costs across economic sectors changes. For instance, the share of the power sector in total air pollution control expenditures declines from 20 to six percent, while that of agriculture increases from 39 to more than 60 percent for an ambitious climate target. However, even for the agricultural sector absolute costs decline by more than a factor of two for the low CO_2 case.

The results presented in this report provide a first quantitative perspective on how an emission reduction strategy that meets the environmental targets of the Thematic Strategy on Air Pollution could look like. Further work is necessary to establish the robustness of the quantitative outcomes and analyze important aspects that are closely connected to the development of national emission ceilings. These aspects will be dealt with in a further report, which will explore, inter alia, the involvement of countries beyond the EU-25, the impacts of the inter-annual meteorological variability on robust emission ceilings, the cost-effectiveness of Euro-VI standards for heavy duty vehicles, updates of input data for countries that have not yet submitted national information, etc.

References

Amann, M., Bertok, I., Cofala, J., Gyarfas, F., Heyes, C., Klimont, Z., Schöpp, W. and Winiwarter, W. (2004a). Baseline Scenarios for the Clean Air for Europe (CAFE) Programme. CAFE Report #1. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

Amann, M., Cofala, J., Heyes, C., Klimont, Z., Mechler, R., Posch, M. and Schöpp, W. (2004b). The RAINS model. Documentation of the model approach prepared for the RAINS review. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria, www.iiasa.ac.at/rains/review/index.html.

Amann, M., Bertok, I., Cabala, R., Cofala, J., Heyes, C., Gyarfas, F., Klimont, Z., Schöpp, W. and Wagner, F. (2005a). Exploratory CAFE scenarios for further improvements of European air quality. CAFE Report # 5. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria, www.iiasa.ac.at/rains/CAFE_files/CAFE-C-full-march16.pdf.

Amann, M., Bertok, I., Cabala, R., Cofala, J., Heyes, C., Gyarfas, F., Klimont, Z., Schöpp, W. and Wagner, F. (2005b). Analysis for the final CAFE scenario. CAFE Report # 6. International Institute for Applied Systems Analysis (IIASA), http://www.iiasa.ac.at/rains/CAFE_files/CAFE-D3.pdf.

Amann, M., Bertok, I., Cabala, R., Cofala, J., Heyes, C., Gyarfas, F., Klimont, Z., Schöpp, W. and Wagner, F. (2005c). A further emission control scenario for the Clean Air For Europe (CAFE) programme. CAFE Report # 7. International Institute for Applied Systems Analysis (IIASA), www.iiasa.ac.at/rains/CAFE_files/CAFE-D28.pdf.

Amann, M., Bertok, I., Cofala, J., Heyes, C., Klimont, Z., Posch, M., Schöpp, W. and Wagner, F. (2006). Baseline scenarios for the revision of the NEC Emission Ceilings Directive Part 1: Emission projections. NEC Scenario Analysis Report Nr. 1. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria, http://www.iiasa.ac.at/rains/CAFE_files/NEC-BL-p1-v21.pdf.

Anderson, H. R., Atkinson, R. W., Peacock, J. L., Marston, L. and Konstantinou, K. (2004). Meta-analysis of time-series studies and panel studies of Particulate Matter (PM) and Ozone (O3). World Health Organization, Bonn, http://www.euro.who.int/document/e82792.pdf.

BIPRO (2002). Screening study to identify reductions in VOC emissions due to the restrictions in the VOC content of products. Final Report. European Commission, Brussels, Belgium.

Broderick, D. R., Houck, J. E. and Crouch, J. (2005). Development of Fireplace Baseline Particulate Emisison Factor Database. OMNI and HBPA report,.

Bruinsma, J. (2003). World agriculture towards 2015/2030. An FAO Perspective. World Food and Agricultural Organization (Rome) and Earthscan (London).

CEC (2005a). Communication from the Commission to the Council and the European Parliament on a Thematic Strategy on Air Pollution. SEC(2005) 1132. Commission of the European Communities, Brussels, http://eur-lex.europa.eu/LexUriServ/site/en/com/2005/com2005_0446en01.pdf.

CEC (2005b). Commission Staff Working Document : Annex to the Proposal for a Regulation of the European Parliament and of the Council on type approval of motor vehicles with respect to emissions and on access to vehicle repair information, amending Directive 72/306/EEC and Directive. {COM(2005) 683 final}. Commission of the European Community, Brussels, Belgium.

CEC (2006). Impact Assessment for Euro 6 emission limits for light duty vehicles. Commission Staff Working Document. Commission of the European Communities, Brussels, Belgium, http://ec.europa.eu/enterprise/automotive/pagesbackground/pollutant_emission/impact_assessment_euro6.pdf.

Cofala, J. and Syri, S. (1998a). Sulfur emissions, abatement technologies and related costs for Europe in the RAINS model database. IR-98-035. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

Cofala, J. and Syri, S. (1998b). Nitrogen oxides emissions, abatement technologies and related costs for Europe in the RAINS model database. IR-98-88. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

Cofala, J., Amann, M., Heyes, C., Klimont, Z., Posch, M., Schöpp, W., Tarasson, L., Jonson, J. E., Whall, C. and Stavrakaki, A. (2006a). Analysis of Policy Measures to Reduce Ship Emissions in the Context of the Revision of the National Emissions Ceilings Directive. Service Contract No 070501/2005/419589/MAR/C1. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

Cofala, J., M., A., Klimont, Z., Bertok, I., Heyes, C., Schoepp, W. and Wagner, F. (2006b). Draft input data for projections of air pollutant emissions in the non-EU countries up to 2020. CIAM report 1/2006. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria, http://www.iiasa.ac.at/rains/reports/ciam1_2006.pdf.

EEA (2004). Outlooks on selected agriculture variables for the 2005 State of the Environment and the Outlook Report. EEA/RNC/03/016. European Environment Agency, Copenhagen.

EFMA (2005). Forecast of Food, Farming and Fertilizer Use in the European Union 2005-2015. European Fertilizer Mannufacturers Association, Brussels.

Fowler, D., Muller, J., Smith, R. I., Cape, J. N. and Erisman, J. W. (2005). Nonlinearities in Source Receptor Relationships for Sulfur and Nitrogen Compounds. Ambio 34(1), 41-46.

Haakonson, G. and Kvingedal, E. (2001). Emissions from wood combustion in Norway. Emission factors, inventory of wood combustion appliances and firing practices. 2001/36. Statistics Norway, Oslo, Norway.

Henriksen, E. (2005). Industrial validation. CleanairTask 4.2 EU CRAFT project report. Oslo, Norway.

Hettelingh, J.-P., Posch, M. and Slootweg, J. (2004). Critical loads and dynamic modelling results. RIVM Report 259101014. Coordination Center for Effects, Bilthoven, Netherlands, http://www.mnp.nl/cce/publ/PR2004.jsp.

Heyes, C., Schöpp, W., Amann, M. and Unger, S. (1996). A Reduced-Form Model to Predict Long-Term Ozone Concentrations in Europe. WP-96-12. International Institute for Applied Systems Analysis, Laxenburg, Austria.

Höglund-Isaksson, L. and Mechler, R. (2005). The GAINS Model for Greenhouse Gases - Version 1.0 :
Methane (CH_4). Interim Report IR-05-54. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria, http://www.iiasa.ac.at/rains/reports/IR54-GAINS-CH4.pdf.

Johansson, L., Leckner, B., Gustavsson, L., Cooper, D., Tullin, C., Potter, A. and Berntsen, M. (2005). Particle emissions from residential bio-fuel boilers and stoves - old and modern techniques. Graz, Austria.

Karlsson, G. P., Karlsson, P. E., Soja, G., Vandermeiren, K. and Pleijel, H. (2004). Test of the short-term critical levels for acute ozone injury on plants-- improvements by ozone uptake modelling and the use of an effect threshold. Atmospheric Environment 38(15), 2237-2245.

Karvosenoja, N., Klimont, Z., Tohka, A. and Johansson, M. (2006). Fine particle emissions, emission reduction potential and reduction costs in Finland in 2020. The Finnish Environment 46.

Klaassen, G., Amann, M., Berglund, C., Cofala, J., Höglund-Isaksson, L., Heyes, C., Mechler, R., Tohka, A., Schöpp, W. and Winiwarter, W. (2004). The Extension of the RAINS Model to Greenhouse Gases. IR-04-015. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

Klaassen, G., Berglund, C. and Wagner, F. (2005). The GAINS Model for Greenhouse Gases - Version 1.0: Carbon Dioxide (CO_2). IIASA Interim Report IR-05-53. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria, http://www.iiasa.ac.at/rains/reports/IR53-GAINS-CO2.pdf.

Klimont, Z., Amann, M. and Cofala, J. (2000). Estimating Costs for Controlling Emissions of Volatile Organic Compounds from Stationary Sources in Europe. IR-00-51. International Institute for Applied Systems Analysis, Laxenburg, Austria.

Klimont, Z., Cofala, J., Bertok, I., Amann, M., Heyes, C. and Gyarfas, F. (2002). Modelling Particulate Emissions in Europe: A Framework to Estimate Reduction Potential and Control Costs. IR-02-076. International Institute for Applied Systems Analysis (IIASA), Laxenburg.

Klimont, Z., Webb, J. and Dämmgen, U. (2005). Livestock husbandry systems in Europe: Evaluation of the 2003 UNECE ammonia expert group questionnaire. Emissions from European Agriculture,. K. e. al. Wageningen, the Netherlands, Wageningen Academic Publishers,**:** 71-96.

Klimont, Z. and Brink, C. (2006). Modelling of Emissions of Air Pollutants and Greenhouse Gases from Agricultural Sources in Europe. IR-04-048. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

Nilsson, J. and Grennfelt, P. (1988). Critical Loads for Sulphur and Nitrogen. Nord 1988:97. Nordic Council of Ministers, Copenhagen, Denmark.

Olsson, M., Kjällstrand, J. and Petersson, G. (2003). Specific chimney emissions and biofuel characteristics of softwood pellets for residential heating in Sweden. Biomass and Bioenergy 24, 51-57.

Olsson, M. (2004). Wood Pellets: Sustainable Heating for Residences. Vision - e-journal of the World Student Community for Sustainable Development.

Pope, C. A., Burnett, R., Thun, M. J., Calle, E. E., Krewski, D., Ito, K. and Thurston, G. D. (2002). Lung Cancer, Cardiopulmonary Mortality and Long-term Exposure to Fine Particulate Air Pollution. Journal of the American Medical Association 287(9), 1132-1141.

Posch, M., Hettelingh, J.-P. and Smet, P. A. M. D. (2001). Characterization of critical load exceedances in Europe. Water, Air and Soil Pollution 130, 1139-1144.

Posch, M., Slootweg J. and Hettelingh J.-P. (2005). European critical loads and dynamic modelling: CCE Status Report 2005. MNP Report 259101016. Coordination Center for Effects, Bilthoven, Netherlands, http://www.mnp.nl/cce/publ/SR2005.jsp.

Raes, F. and Hjorth, J. (2006). Answers to the Urbino Questions. ACCENT's firs policy-driven synthesis. ACCENT Secretariat, University di Urbino, Italy.

Ryan, M. (2004). Ammonia Emission Abatement Measures; Unit Cost of Measures for Agriculture. Technical Advice Unit Rural Development Service, UK.

Samaras, Z. (2006). RAINS Removal Efficiencies for Mobile Sources. Comparisons with Copert III and IV/Artemis. Aristotele University . Thessaloniki, Greece, http://forum.europa.eu.int/Public/irc/env/cafe_baseline/library?l=/necd_-_200181ec/revision_necd_2005/working_group_necpi/meetings/12-13_july_2006&vm=detailed&sb=Title.

Schöpp, W., Amann, M., Cofala, J., Heyes, C. and Klimont, Z. (1999). Integrated Assessment of European Air Pollution Emission Control Strategies. Environmental Modeling and Software 14(1), 1-9.

Seinfeld, J. and Pandis, S. (1998). Atmospheric Chemistry and Physics - From Air Pollution to Climate Change. New York, Wiley Interscience.

Simpson, D., Fagerli, H., Jonson, J. E., Tsyro, S., Wind, P. and Tuovinen, J.-P. (2003). Transboundary Acidification, Eutrophication and Ground Level Ozone in Europe. Part 1: Unified EMEP Model Description. EMEP Status Report 1/2003. EMEP Meteorological Synthesizing Centre - West, Norwegian Meteorological Institute, Oslo, http://www.emep.int/UniDoc/index.html.

Sternhufvud, C., Karvosenoja, N., Illerup, J., Kindbom, K., Lükewille, A., Johansson, M. and Jensen, D. (2004). Particulate matter emissions and abatement options in residential wood burning in the Nordic countries. ANP 2004:735. Nordic Council of Ministers, Copenhagen.

Strehler, A. (2000). Technologies of wood combustion. Ecological Engineering 16, 25-40.

Thunis, P., Rouïl, L., Cuvelier, C., Bessagnet, B., Builtjes, P., Douros, J., Kerschbaumer, A., Pirovano, G., Schaap, M., Stern, R. and Tarrason, L. (2006). Analysis of model responses to emission-reduction scenarios within the CityDelta project. Atmospheric Environment submitted.

Tohka, A. (2005). The GAINS Model for Greenhouse Gases –Version 1.0: HFC, PFC and SF6. Interim Report IR-05-56. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria, http://www.iiasa.ac.at/rains/reports/IR56-GAINS-F.pdf.

UBA (2004). Manual on methodologies and criteria for modelling and mapping of critical loads and levels and air pollution effects, risks and trends. Umweltbundesamt, Dessau, Germany, www.icpmapping.org.

UNECE/WHO (2004). Modelling and Assessment of the Health Impact of Particulate Matter and Ozone. EB.AIR/WG.1/2004/11. United Nations Economic Commission for Europe, Geneva, http://www.unece.org/env/documents/2004/eb/wg1/eb.air.wg1.2004.11.e.pdf.

Vaupel, J. W. and Yashin, A. I. (1985). Targetting Lifesaving: Demographic Linkages Between Population Structure and Life Expectancy. WP-85-78. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

Wagner, F., Schöpp, W. and Heyes, C. (2006). The RAINS optimization module for the Clean Air For Europe (CAFE) Programme. IR-06-29. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

WHO (2003). Health Aspects of Air Pollution with Particulate Matter, Ozone and Nitrogen Dioxide. World Health Organization, Bonn, www.euro.who.int/document/e79097.pdf.

Wierzbicka, A., Lillieblad, L., Pagels, J., Strand, M., Gudmundsson, A., Gharibi, A., Switlicki, E., Sanati, M. and Bohgard, M. (2005). Particle emissions from district heating units operating on three commonly used biofuels. Atmospheric Environment, 39(139-150).

Winiwarter, W. (2005). The GAINS Model for Greenhouse Gases - Version 1.0: Nitrous Oxide (N_2O). Interim Report IR-05-55. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria, http://www.iiasa.ac.at/rains/reports/IR55-GAINS-N2O.pdf.