NEC Scenario Analysis Report Nr. 3

Cost-optimized reductions of air pollutant emissions in the EU Member States to address the environmental objectives of the Thematic Strategy on Air Pollution

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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

Acknowledgements

The European Commission acknowledges that the GAINS control strategy format is the property of IIASA. IIASA acknowledges that the BAT control strategy values (based on the GAINS control strategy format) belong to the author, i.e., the European Commission (DG Environment) and that they are property of the European Community. Any use of the BAT control strategy values outside the range of Community level legislation has to take place in accordance with the consent of the European Commission. In case of any use, a clear reference should be made to the author.

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1 Introduction

In its Thematic Strategy on Air Pollution, the European Commission outlined the strategic approach towards cleaner air in Europe (CEC, 2005) and established environmental objectives 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.

The process to set national ceilings for the emissions of the relevant air pollutants 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.*, 2006b). In a further step, analysis explored sets of cost-effective measures that achieve the environmental ambition levels of the Thematic Strategy. This assessment has been presented to the meeting of the NECPI working group on December 18, 2006, and is documented in Amann *et al.*, 2006a. As follow-up, the present report analyzes potential emission ceilings that emerge from the environmental objectives established in the second round, and studies the robustness of the identified emission reduction requirements against a range of uncertainties.

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. The methodology of the GAINS model and the differences to the RAINS methodology has been summarized in Amann *et al.*, 2006a. The different optimization approaches are documented in Wagner *et al.*, 2006 and Wagner *et al.*, 2007. In January 2007, the GAINS model has been reviewed by a team of experts from Member States and stakeholders; the findings of the review are available on http://www.iiasa.ac.at/rains/reports/gains-review.pdf.

The remainder of the report is organized as follows: In the interest of a comprehensive but concise description of methodology, input data and results, Section 2 provides a brief outline of the methodology of the GAINS model. To some extent the text repeats the description given in the last report, but contains the revisions applied to the City-delta methodology. Section 3 summarizes the changes that have been implemented since the NEC report #2 of December 2006. Section 4 describes the baseline activity projections that have been used for the cost-optimized scenarios. Section 5 discusses how the environmental objectives of the Thematic Strategy on Air Pollution have been translated into environmental targets for the NEC analysis. Section 6 presents two series of optimized emission reductions that meet the environmental targets. It analyzes the impacts of alternative baseline projections, the role of an EU-wide introduction of EURO VI standards for heavy duty vehicles, and the influence of emission reductions from regions outside the EU-27. Section 7 provides some concluding remarks, noting that further sensitivity analyses will explore the robustness of the results presented in this report.

2 Methodology

2.1 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 2.1: 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 2.1, 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:

$$E_{i,p} = \sum_k \sum_m A_{i,k} ef_{i,k,m,p} x_{i,k,m,p} \qquad (1)$$

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 taking into account 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:

- *Behavioural 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 behavioural 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 important 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:

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

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 2.2 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.

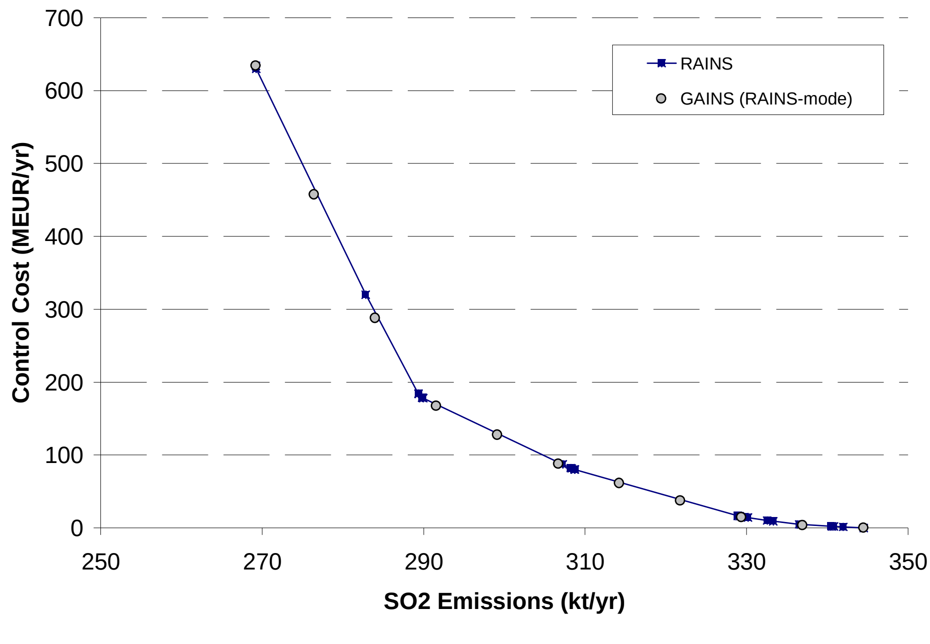

Figure 2.2: Validation of an original RAINS cost curve with the GAINS model operated in the “RAINS” mode

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 2.3, 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).

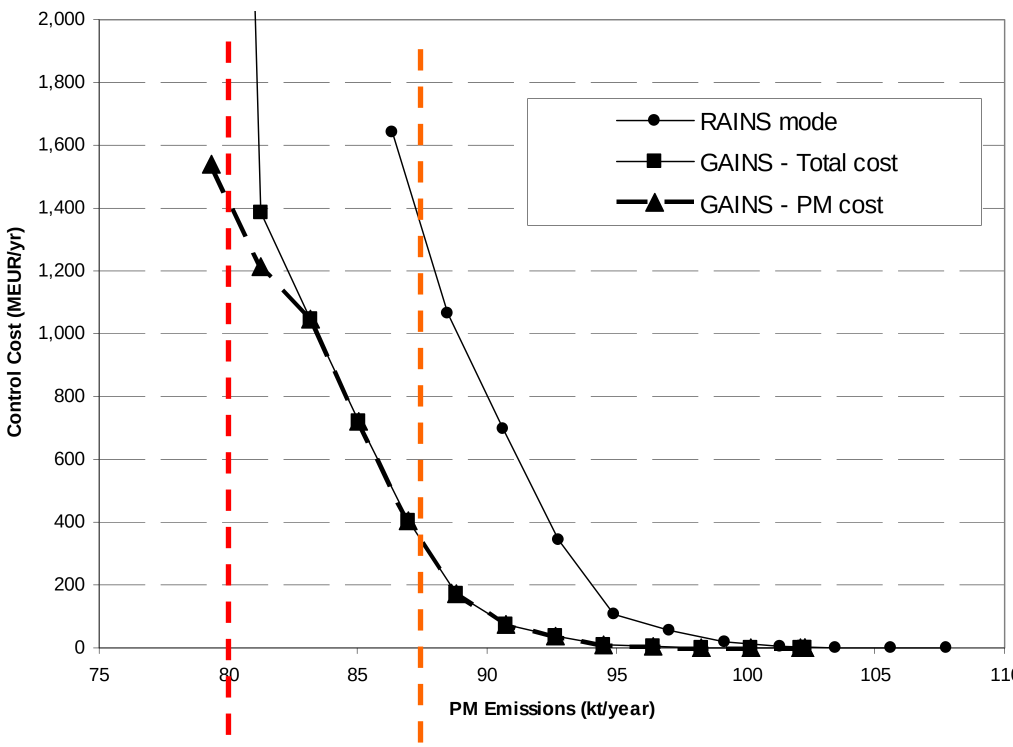

Figure 2.3: Single pollutant cost curves for PM2.5 in the year 2020. This illustrates the difference in maximum technically feasible reductions (MTFR) in the full GAINS model compared to the RAINS mode of GAINS. For details see text.

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 27 Member States of the EU, 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:

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

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:

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

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.

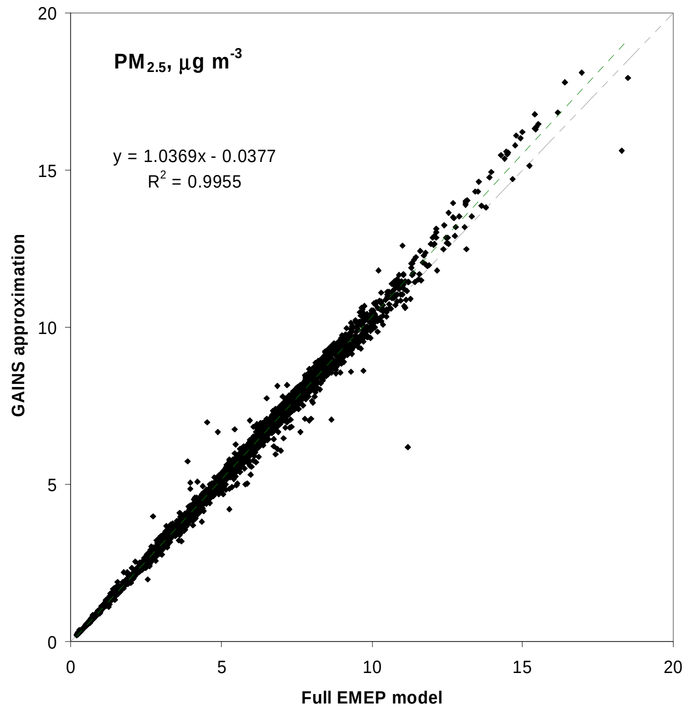

Figure 2.4: Validation of the GAINS approximations of the functional relationships against computations of the full EMEP model around the emission levels outlined in the Thematic Strategy for Air Pollution.

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 * 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 km * 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 km * 50 km grid element. In the City-delta approach the mass within the 50 km * 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.

As described in more detail in Amann *et al.*, 2006a, a methodology has been developed to quantify the contributions of urban emissions from low level sources to increased PM2.5 concentrations within cities. The "City-delta" methodology to compute urban increments of PM2.5 levels has been discussed at the workshop on "Cost-effective control of urban air pollution" at IIASA in late November 2006. Following recommendations from workshop participants, national experts and scientific peers, a number of changes have been applied to methodology, assumptions and input data.

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)

$$\Delta c = \frac{1}{2\sqrt{2}} \frac{1}{\sqrt{K_{zz}}} \frac{\sqrt{D}}{U} Q \quad . \tag{9}$$

The diffusivity K_{zz} as well as wind speeds and city diameters along the wind directions show variations over the year. In Equation 9 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 $(D^{0.5}/U)$ 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:

$$\Delta c = \frac{1}{2\sqrt{2}} \frac{1}{\sqrt{K}} \frac{\sqrt{D}}{U} Q = \alpha \cdot \frac{\sqrt{D}}{U} Q \tag{10}$$

Following advice from scientific peers, the wind speed has been introduced as a linear term into this equation.

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 – 1.0 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. 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)*:

$$\Delta c = \alpha \cdot \frac{\sqrt{D}}{U} \cdot Q + \beta \cdot \frac{\sqrt{D}}{U} \cdot Q \cdot \frac{d}{365} \qquad (11)$$

In a further step, a regression analysis estimated the regression coefficients α and β in Equation 10 from the data sample on *Δc* computed by three urban dispersion models (i.e., Chimere, CAMx, RCG) for the seven City-delta cities (Berlin, Krakow, Lisbon, London, Milan, Paris, Prague) , with city-specific data on diameters *D*, wind speeds *U*, low wind speed days *d*, and changes in emission fluxes *ΔQ*.

Results of the computations of the three fine-scale urban dispersion models indicate a strong influence of the chosen of the size target domain for which the average change in PM2.5 concentrations is computed. Following advice from experts, the analysis has been carried out for two target domains. For the purposes of health impact assessment, a population-weighted change in PM2.5 concentrations within the city domain has been computed based on concentration and population fields with a 5 km * 5 km resolution. To facilitate comparison of predicted increments with observed monitoring data, a second target domain encompassing the 5 km * 5 km grid cell with highest population density has been specified. Concentrations computed for this domain should be more closely comparable to observations of urban background stations in the city centres, but not to measurements at street canyons and industrial sites.

Table 2.1: Computed changes in annual mean PM2.5 concentrations (in µg/m^3) for the two target domains in response to eliminating all urban low-level emissions

	*5 km * 5 km*	*Population-weighted*
Berlin	3.9	2.5
Krakow	1.6	1.6
Lisbon	6.1	4.2
London	1.7	1.2
Milan	5.0	3.5
Paris	10.8	7.9
Prague	0.8	0.6

For the data sample obtained from the three fine-scale dispersion models for six cities, regression analyses determined the coefficients α and β in Equation 10. For the PM2.5 changes in the 5 km * 5 km grid cell with largest population density, values of 0.49 and 0.87 have been estimated for α and β, respectively (r^2=0.98). Changes of population-weighted PM2.5 concentrations can be best described with an α of 0.35 and β of 0.56 (r^2=0.97). Variations in computed concentration changes for different models, as well as the City-delta approximation, are displayed in Figure 2.5.

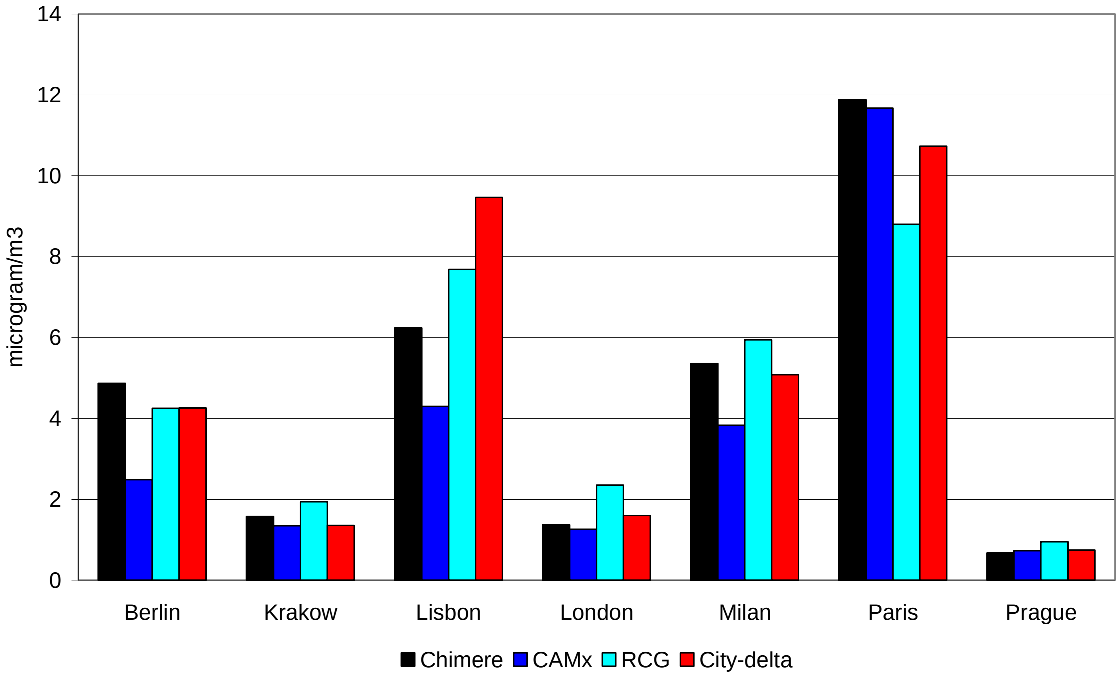

Figure 2.5: Urban increments of PM2.5 in a 5 km *5 km city centre grid cell computed by the three fine-scale dispersion models and the City-delta approximation for the emissions of the year 2020.

To estimate urban increments for all European cities based on the functional relationship identified in Equation 10, a database has been prepared with city-specific information on population densities, city area, city diameters, wind speeds, number of low wind days in winter for the 477 cities with more than 100,000 inhabitants. Since the last report, city domains with the most densely populated areas have been identified, Norwegian cities have been added, and wind speed data have been drawn from a multi-year meteorological data set. For each urban agglomeration, the database holds information on the shape, area and population densities (with a 1*1 km resolution) for the most densely populated areas which comprise about 66 percent of the total urban population (e.g., Figure 2.6). The database covers cities with 430 million people, and holds detailed data on population density distributions for 286 million people.

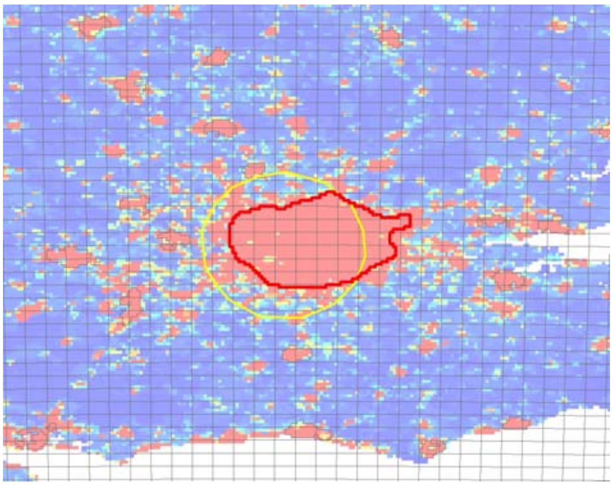

Figure 2.6: The city-domain (i.e., within the red line) for which the urban increment is computed for London

Special emphasis has been devoted to estimating urban emissions of low level sources. It has to be mentioned that in the course of the bilateral consultations with national experts the GAINS estimates of sectoral national 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. However, there is little information on emissions from urban areas.

In the absence of city-specific emission data 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. 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.

For each country, sectoral national emissions reported in the EMEP database have been scaled to the national 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 2.2 have been made. Essentially, it is assumed that all emissions of SNAP sector 2 (domestic and service sector), 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), SNAP sector 4 (non-combustion related emissions from industrial processes) and waste incineration plants (SNAP 9) are assumed to be released form high stacks, 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.

Table 2.2: 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.)	0 % 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

Furthermore, a cross-country comparison of the obtained sectoral emissions on a per-capita basis revealed significant differences across countries that are difficult to explain. Thus, urban emissions from SNAP sector 7 (road traffic) have been re-estimated based on the share of urban population in a country and information from the TREMOVE model that, on average, per-capita emissions from transport are 15 percent higher for the urban population than rural dwellers. While this generic approach has to be considered as extremely rough, it delivers a more uniform – and more plausible estimate on urban transport emissions than the default method described above.

In addition, an assumption has been made that, in the EU-15 countries, Norway and Switzerland, wood burning for heating purposes (SNAP sector 2) does not take place in the centers of cities with more than 1 million inhabitants. For all other cities (i.e., urban areas in the EU-15 with less than 1 million people, and in all cities of the new Member States) it has been assumed that per-capita emissions from solid fuels are in the city centres only half of the national average.

Despite these adjustments, there remain 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. 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 2.7). Most strikingly, however, are variations in per-capita emissions from the transport sector across European countries. As a consequence, there are significant differences also in the spatial emission densities across European cities (Figure 2.8).

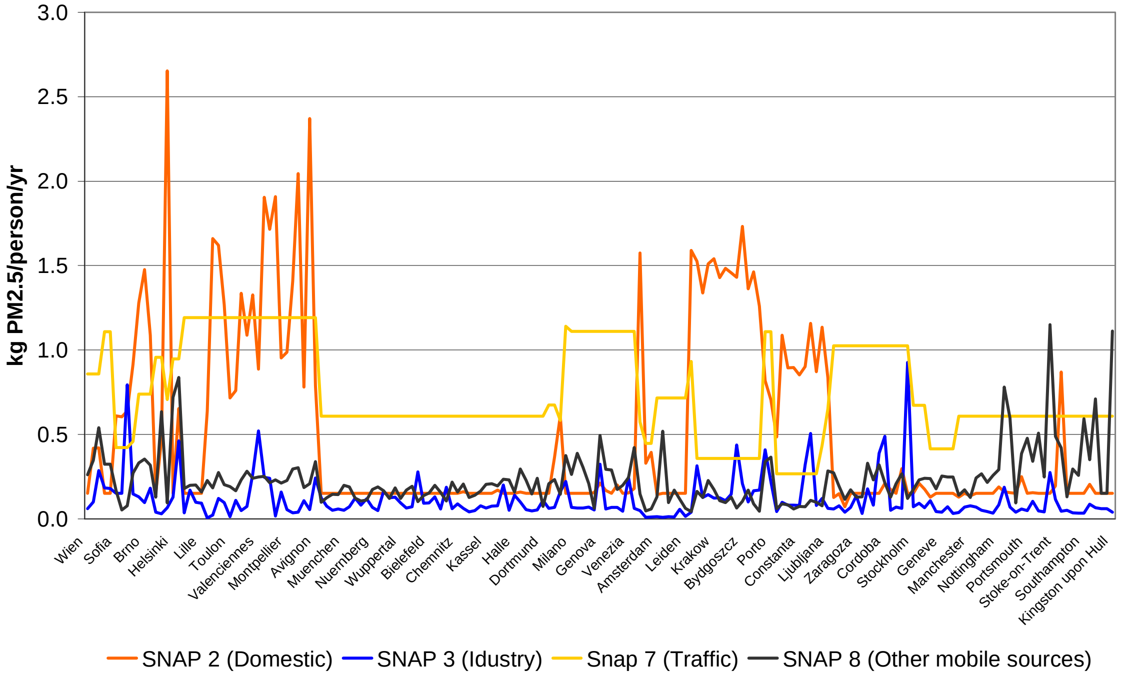

Figure 2.7: Urban per-capita emissions from low-level sources, for the European cities with more than 250.000 inhabitants

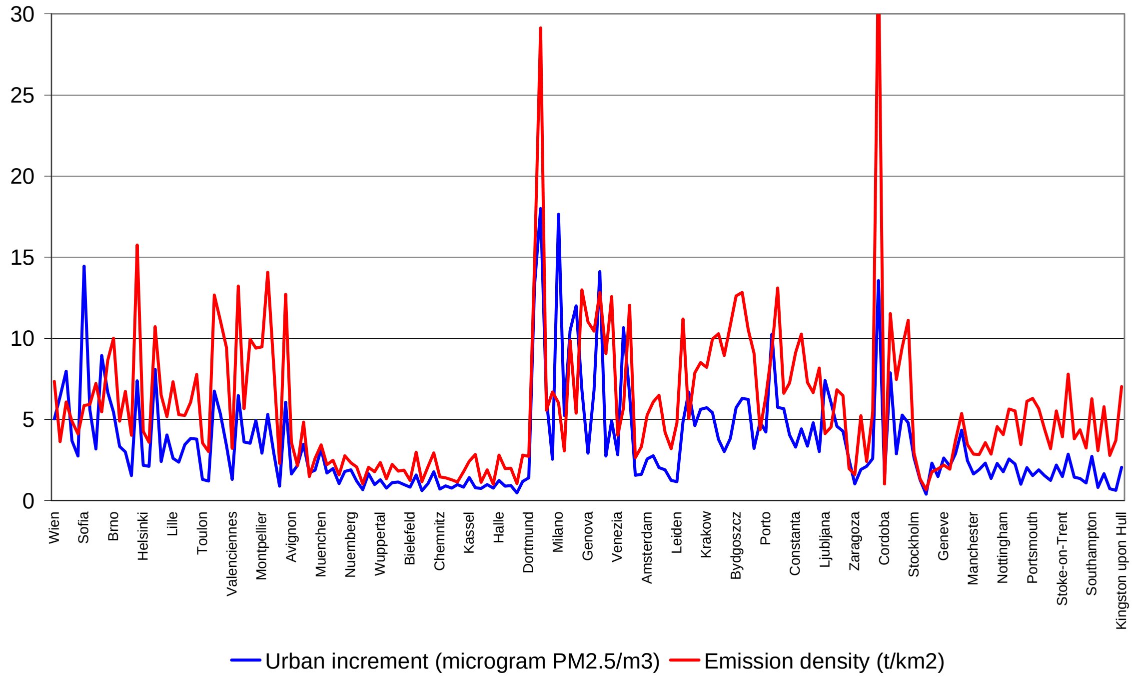

Figure 2.8: Emission densities and computed urban increments for the European cities with more than 250.000 inhabitants

The following graphs (Figure 2.9 to Figure 2.18) compare for the European cities with more than 200.000 inhabitants PM2.5 concentrations computed for the 5 km * 5 km city centre domain with 2004 monitoring data for urban background stations provided by the AIRBASE database. The bars indicate computed values of the urban increments, the contribution from long-range transport as computed by the EMEP model (corrected for the impact of urban emissions within the same grid cell) and assumptions on mineral dust and sea salt. PM2.5 from natural sources and secondary organic aerosols are excluded. AIRBASE data are plotted as given in the database due to insufficient information on monitoring techniques, applied correction factors, etc.

The second series of graphs display the computed contributions to the urban increment from low-level emissions by SNAP sector.

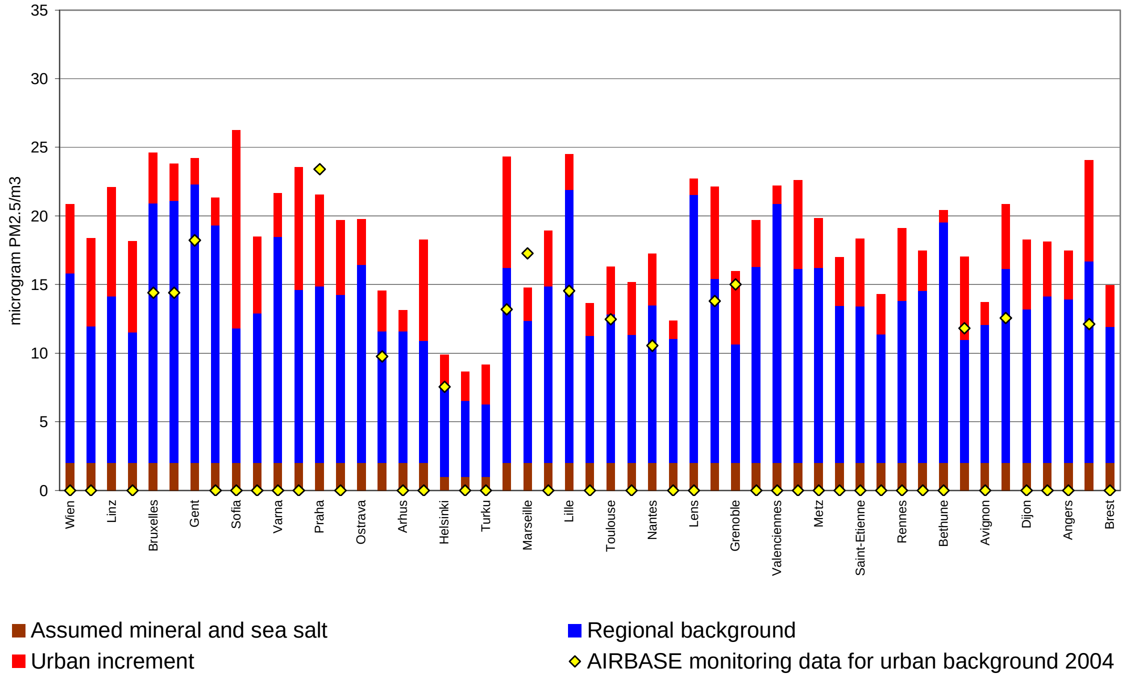

Figure 2.9: Comparison between computed PM2.5 concentrations representative for the 5 km * 5 km city centre area and measurements as reported in the AIRBASE database, for 2004

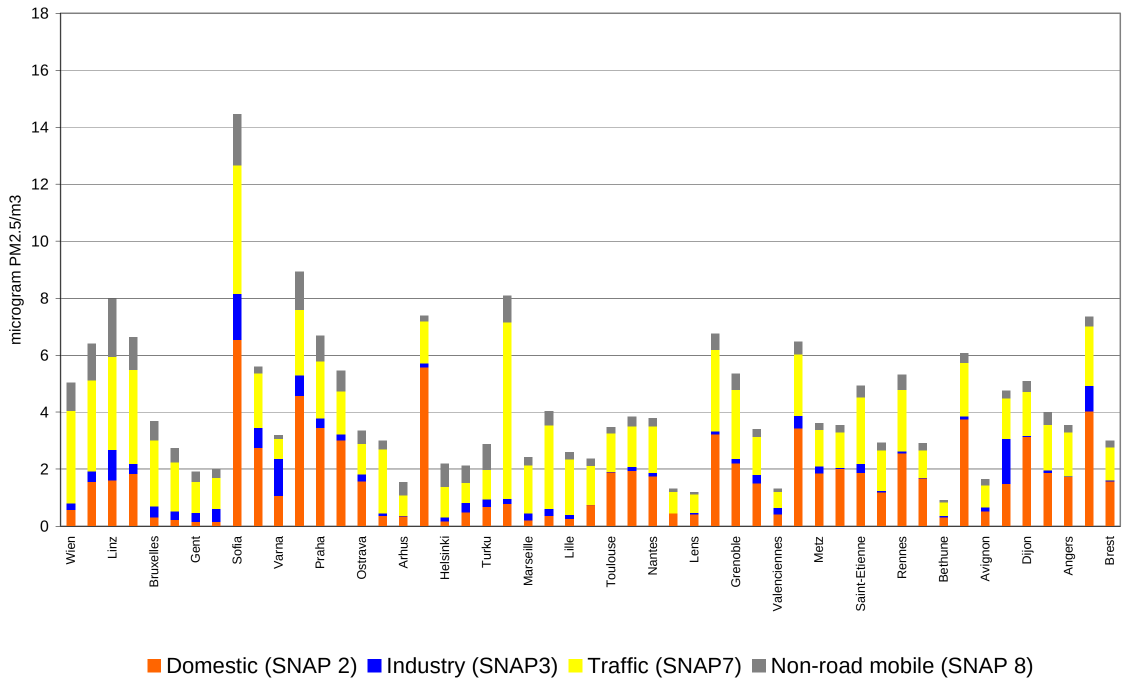

Figure 2.10: Contributions to the urban increments made by urban emissions of low level sources (for the emissions of 2000)

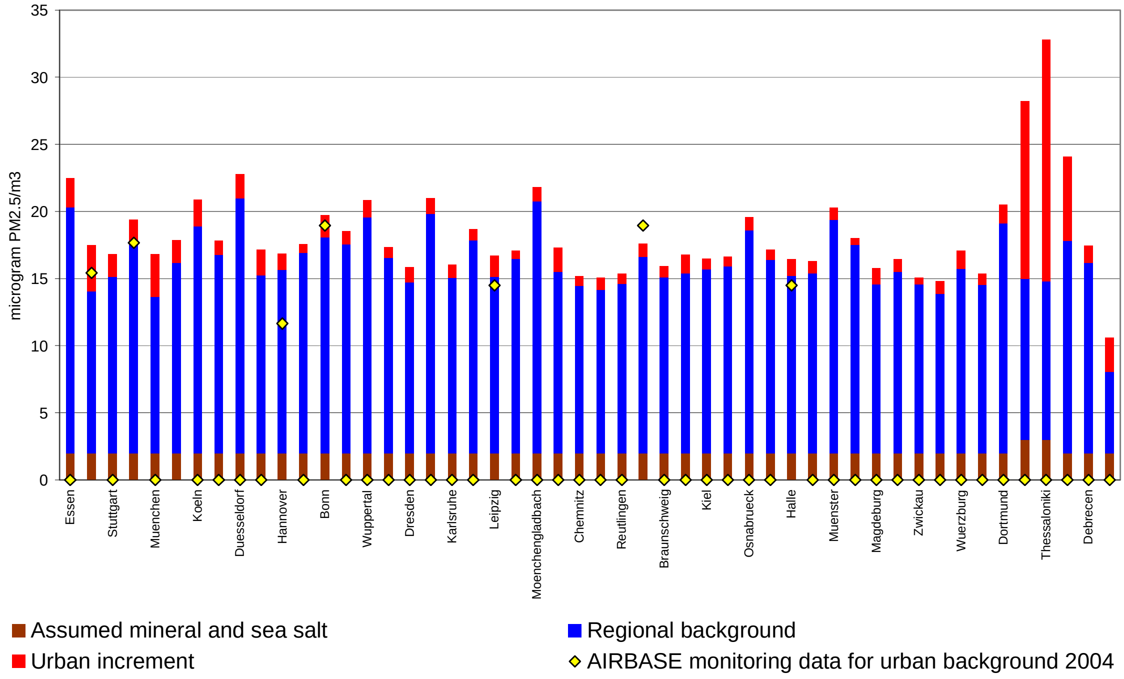

Figure 2.11: Comparison between computed PM2.5 concentrations representative for the 5 km * 5 km city centre area and measurements as reported in the AIRBASE database, for 2004

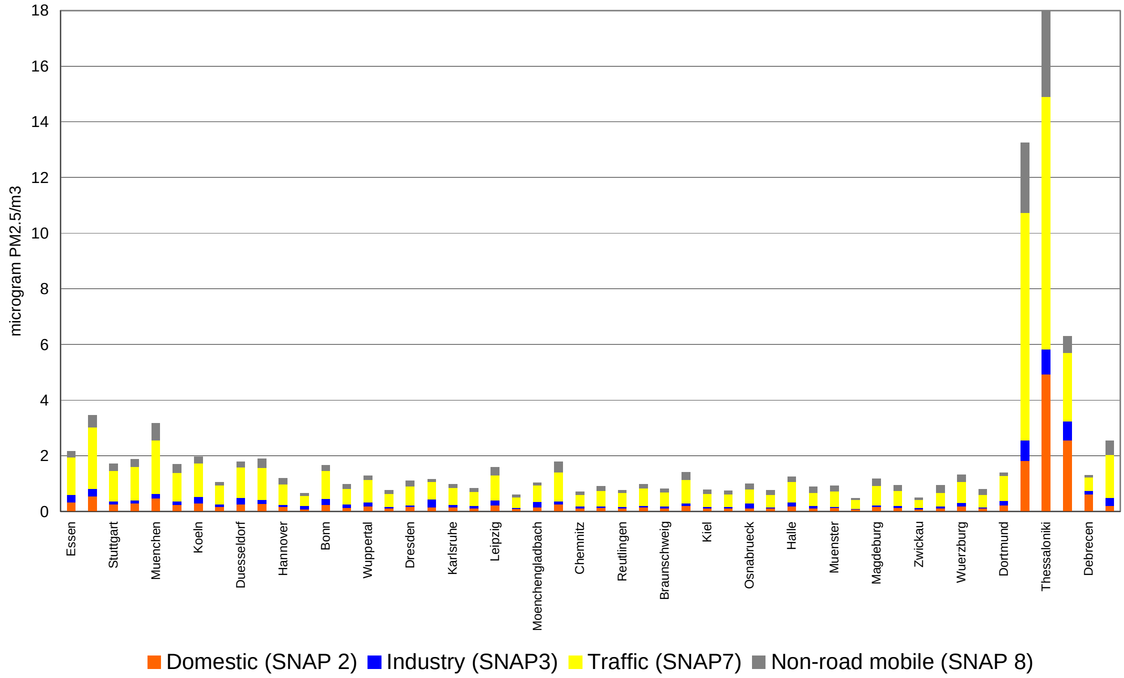

Figure 2.12: Contributions to the urban increments made by urban emissions of low level sources (for the emissions of 2000)

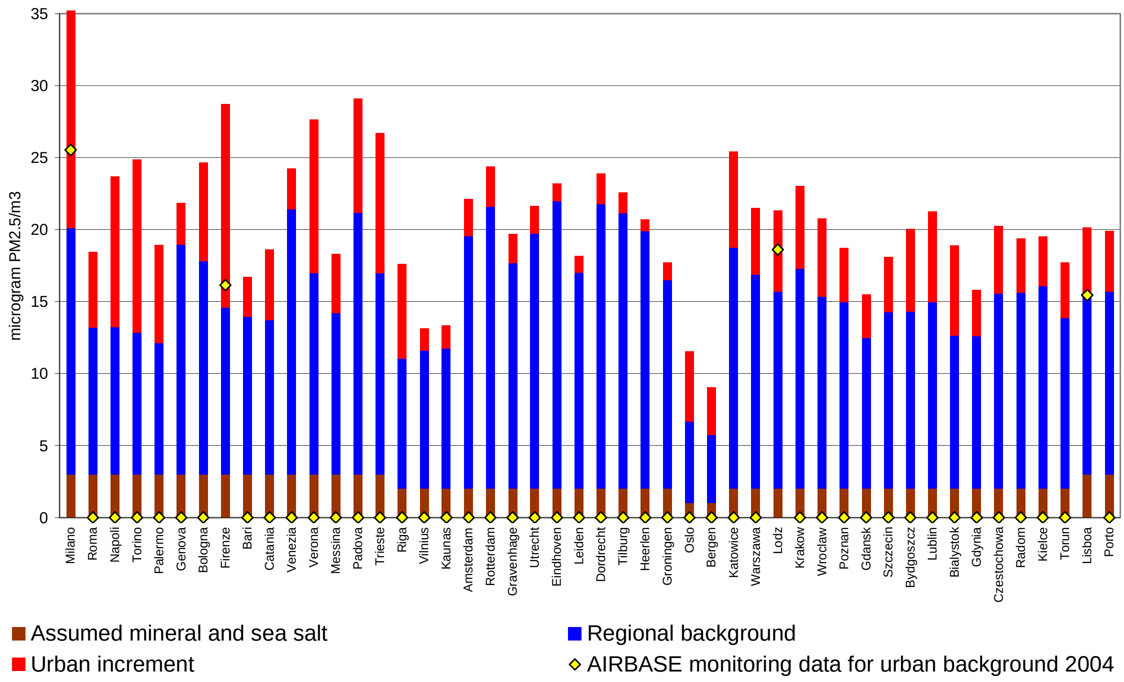

Figure 2.13: Comparison between computed PM2.5 concentrations representative for the 5 km * 5 km city centre area and measurements as reported in the AIRBASE database, for 2004

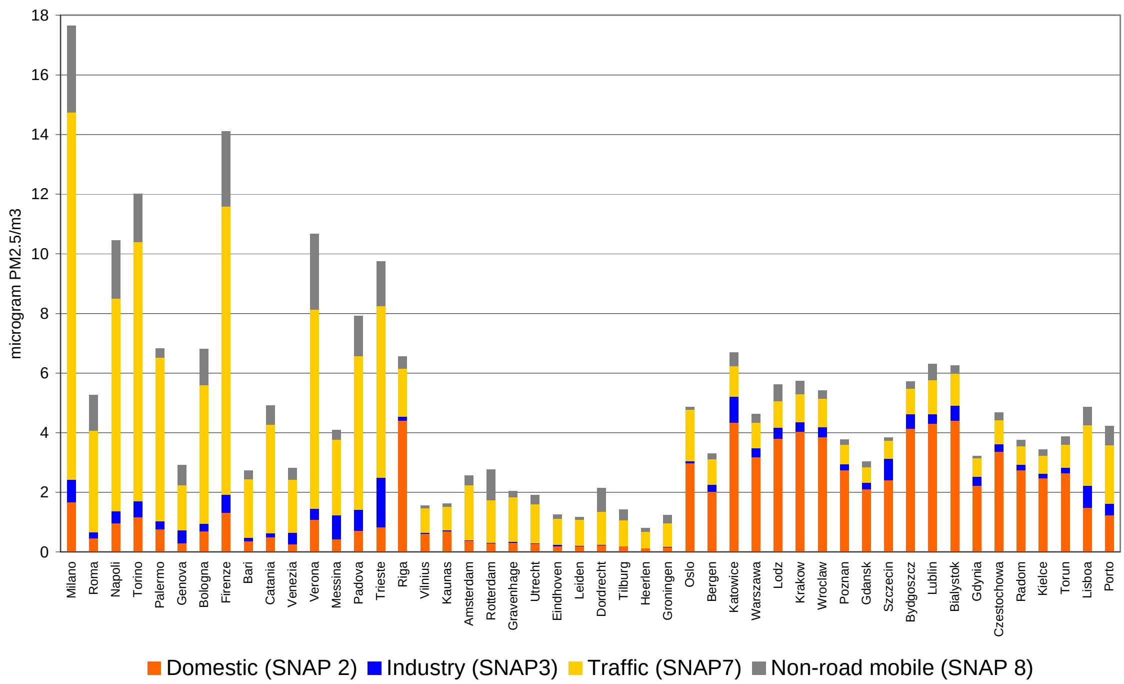

Figure 2.14: Contributions to the urban increments made by urban emissions of low level sources (for the emissions of 2000)

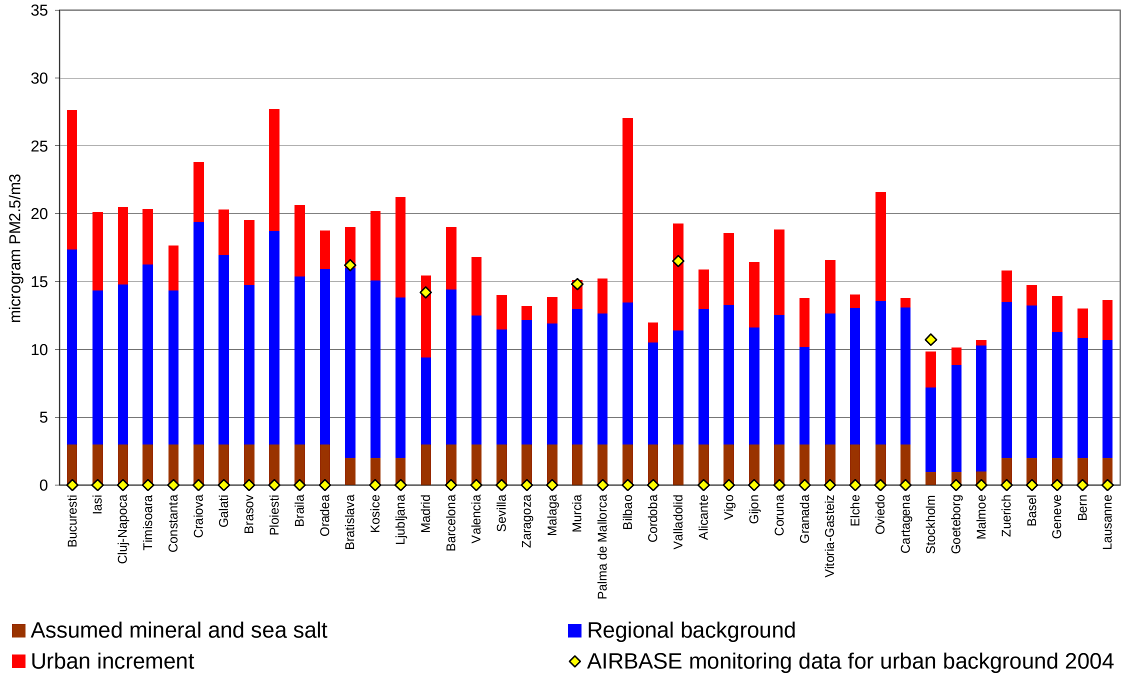

Figure 2.15: Comparison between computed PM2.5 concentrations representative for the 5 km * 5 km city centre area and measurements as reported in the AIRBASE database, for 2004

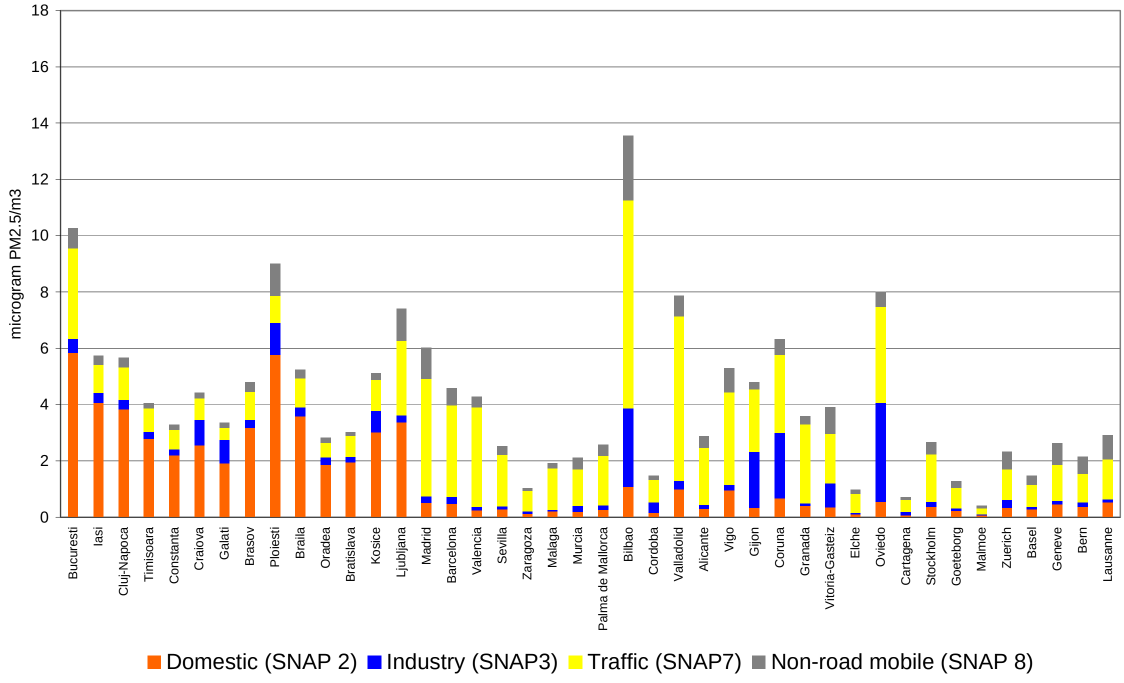

Figure 2.16: Contributions to the urban increments made by urban emissions of low level sources (for the emissions of 2000)

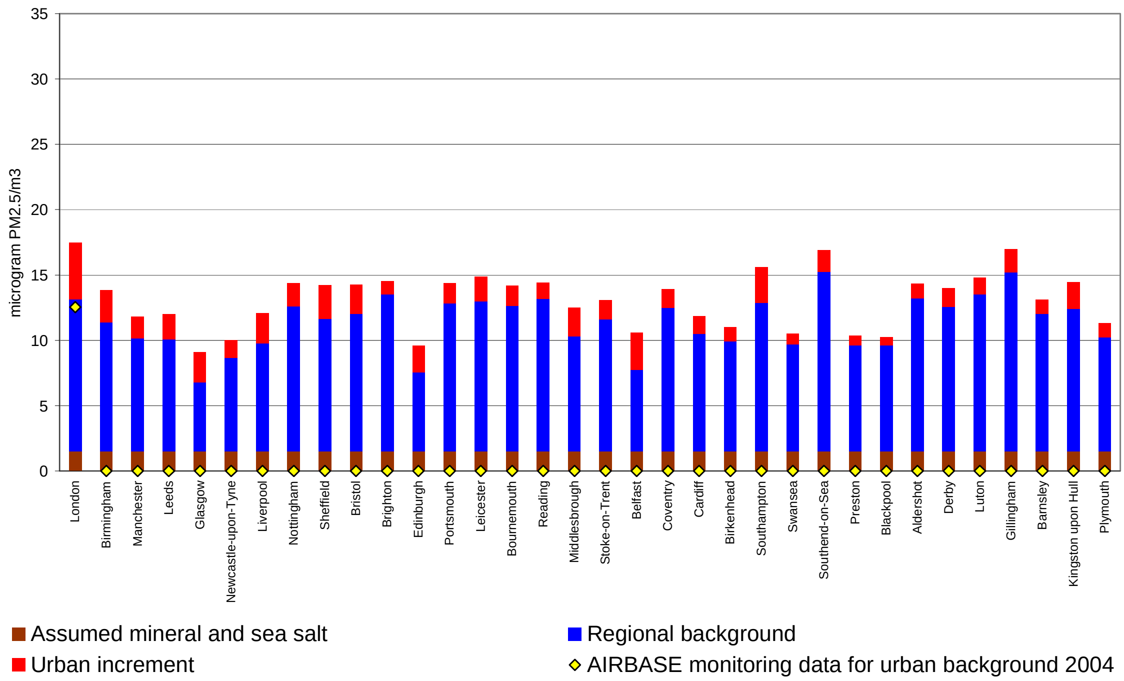

Figure 2.17: Comparison between computed PM2.5 concentrations representative for the 5 km * 5 km city centre area and measurements as reported in the AIRBASE database, for 2004

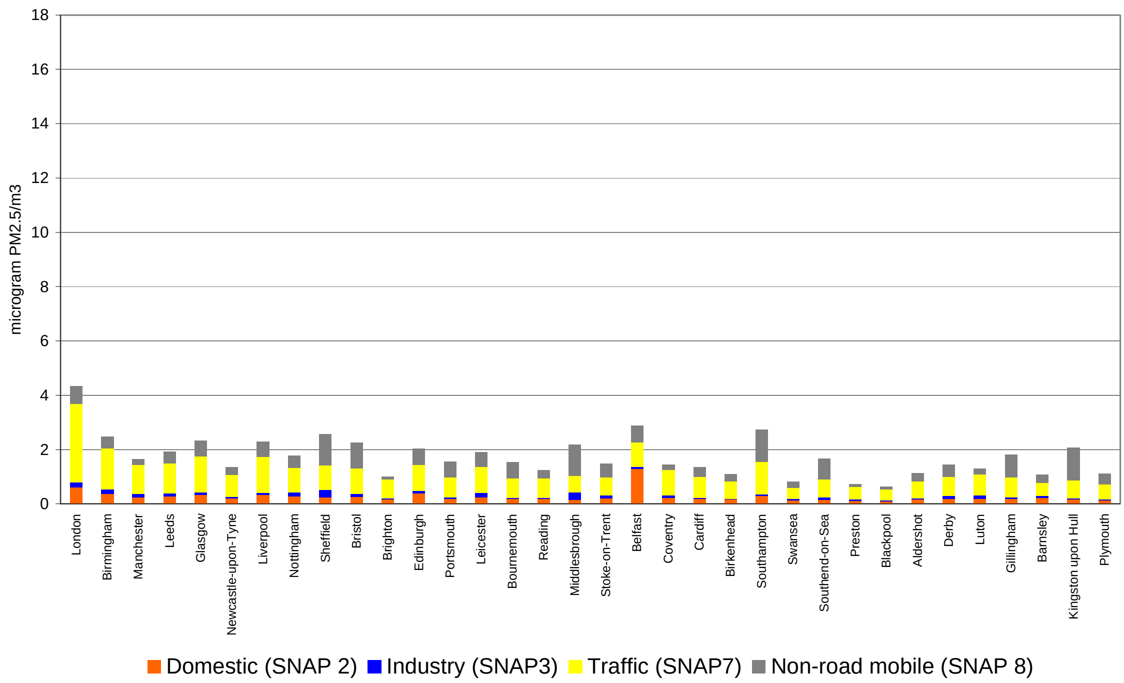

Figure 2.18: Contributions to the urban increments made by urban emissions of low level sources (for the emissions of 2000)

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, 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 analysis presented in Amann *et al.*, 2006a, the revised methodology and data that are used for the this assessment result in lower urban increments of PM2.5 and are similar to the results used for the CAFE analysis.

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, derived from 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.

While a final validation of the estimates of urban increments cannot be done without reliable and better documented observations for many more urban areas, the modifications applied to the City-delta methodology since the last report point to the critical influence of the input data on urban emissions. In general, making urban emission data more coherent across cities in Europe yields much more realistic estimates of the impact of urban emissions on urban air quality. The current lack of internationally comparable urban emission inventories with solid documentation has to be seen as the major obstacle for further improvements 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:

$$Dep_{p,j} = Dep_{p,j,0} - \sum_i P_{i,j,p,0}(E_{i,p,0} - E_{i,p}) \quad (12)$$

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*
$P_{i,j,p,0}$	Transfer matrix for pollutant *p* for emission changes around the reference emissions.

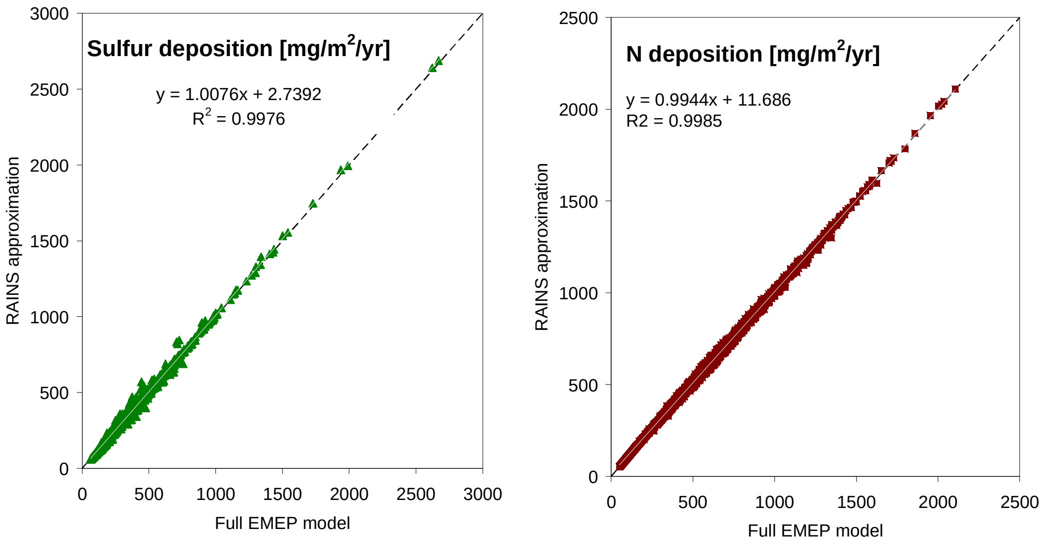

Figure 2.19: Comparison of the impact indicators calculated from the reduced-form approximations of the GAINS model with the results from the full EMEP Eulerian model, for the final CAFE scenario.

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:

$$O3_l = O3_{l,0} - \sum_i N_{i,l}(n_{i,0} - n_i) - \sum_i V_{i,l}(v_{i,0} - v_i) \qquad (13)$$

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*.

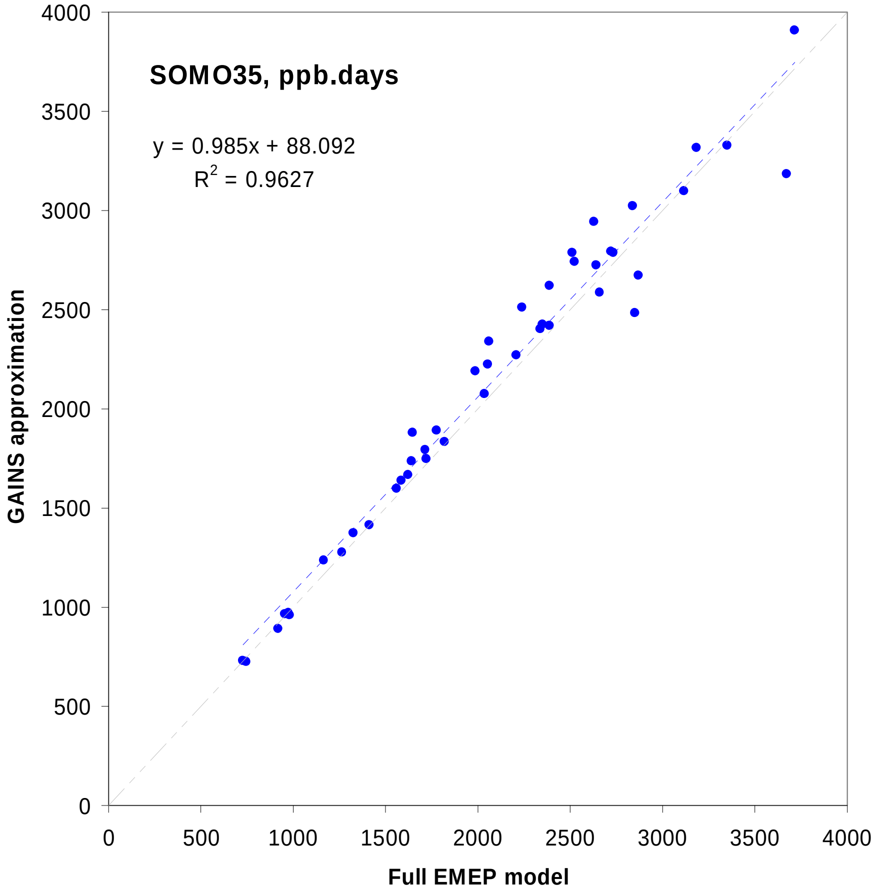

Figure 2.20: Comparison of the impact indicators calculated from the reduced-form approximations of the GAINS model with the results from the full EMEP Eulerian model, for the final CAFE scenario.

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 2.21). Within cities, these increases counteract reductions in ozone resulting from regional scale reductions of NO_x emissions.

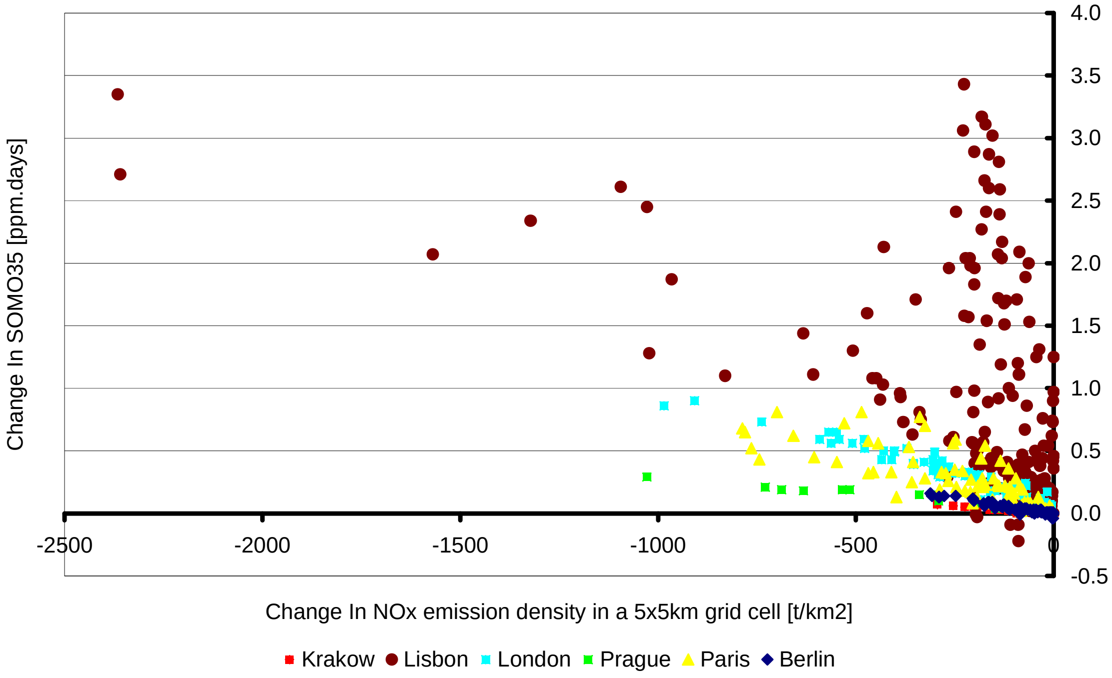

Figure 2.21: Change in the SOMO35 indicator in response to reductions of urban NO_x emissions as computed by the CAMx model for six European cities participating in the City-delta project.

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 2.21 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 13 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 13, 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:

$$l_c(t) = \exp\left(-\sum_{z=c}^{t} \mu_{z,z-c+w_0}\right). \quad (14)$$

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:

$$e_c = \int_c^{w_1} \bar{l}_c(t)\,dt = \int_c^{w_1} \exp\left(-RR_{PM} \sum_{z=c}^{t} \mu_{z,z-c+w_0}\right)dt \quad (15)$$

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:

$$\Delta e_c = \beta PM \int_c^{w_1} l_c(t) \log l_c(t)dt \quad (16)$$

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:

$$\Delta L_l = \sum_{c=w_0}^{w_1} \Delta L_{c,i} = \beta \sum_{j \in l} PM_j \frac{Pop_j}{Pop_l} \sum_{c=w_0}^{w_1} Pop_{c,l} \int_c^{w_1} l_c(t) \log l_c(t)dt \quad (17)$$

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:

$$AAE_{q,l} = AAE_{q,l,0} - \sum_{p} \sum_{i} a_{i,l,p,q} (E_{i,p,0} - E_{i,p}) \qquad (18)$$

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 18 and then AAE from the individual critical loads according to:

$$AAE_{q,l} = \sum_{j \in l} \sum_{u} A_{q,j,u} \cdot \max\{Dep_{p,j} - CL_{q,j,u}, 0\} \Big/ \sum_{j \in l} \sum_{u} A_{q,j,u} \qquad (19)$$

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 19 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

$$Mort_l = \tfrac{2}{365} Deaths_l \cdot RR_{O3} \cdot O3_l \qquad (20)$$

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 $\mu g/m^3$ 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

As one of its most policy-relevant features, the optimization approach of the GAINS 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 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

$$C = \sum_{i,k} \left(\sum_{m} c^{x}_{i,k,m} \cdot x_{i,k,m} + \sum_{k'} c^{y}_{i,k,k'} y_{i,k,k'} \right) \tag{21}$$

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:

$$x^{\min}_{i,k,m} \le x_{i,k,m} \le x^{\max}_{i,k,m}, \; x^{\min}_{i,k} \le x_{i,k} \le x^{\max}_{i,k}, \quad y^{\min}_{i,k,k'} \le y_{i,k,k'} \le y^{\max}_{i,k,k'} \tag{22}$$

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:

$$x_{i,k,m} \le appl^{\max}_{i,k,m} x_{i,k}, \quad appl^{CLE}_{i,k,m} \le appl^{\max}_{i,k,m} \tag{23}$$

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 $ef_{i,k,m,p}$:

$$E_{i,p} = \sum_{k} \sum_{m} ef_{i,k,m,p} \cdot x_{i,k,m} \tag{24}$$

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

$$\sum_{m} ef_{i,k,m,p} \cdot x_{i,k,m} \le IEF^{CLE}_{i,k,p} \cdot x_{i,k} \tag{25}$$

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

$$x_{i,k} + \sum_{k'} y_{i,k,k'} - \sum_{k'} \eta_{i,k,'k} \cdot y_{i,k,'k} = x_{i,k}^{CLE} \quad (26)$$

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. A detailed mathematical description of the GAINS optimization model is provided in Wagner *et al.*, 2007.

For the analyses in this report, the GAINS model was operated in the "RAINS mode", i.e., considering environmental constraints on air pollution only and disabling all features that allow modifications of the underlying energy projections. The features of the "RAINS mode" optimization of the GAINS model have been assessed during the GAINS review. The review report is available at http://www.iiasa.ac.at/rains/reports/gains-review.pdf.

3 Changes since the NEC report #2

Since the NEC report #2 that has been presented to the NECPI working group in December 2006 (Amann *et al.*, 2006a), a number of changes have been introduced to the GAINS model. Improvements relate to input data used for the calculations of emissions from energy use, agricultural activities, and solvents use. The dispersion calculations employ now meteorological conditions of five different years, and the methodology to compute urban pollution has been improved.

The following paragraphs provide a brief summary of the changes. Details can be extracted from a comparison of the 'NEC02' and 'NEC03' versions of the GAINS model that is accessible over the Internet (http://www.iiasa.ac.at/web-apps/apd/RainsWeb/).

3.1 Input data for energy-related emissions

Numerous changes were implemented for input data that are used for computing energy-related emissions:

- The national energy projections supplied by Greece and Lithuania have been implemented. However, the new energy projection from Norway have been obtained too late to be implemented for this round of analysis (following the advice of the NECPI working group).
- A wide range of comments and clarifications from national experts on the earlier interpretation of national energy projections, emission factors, penetration of control measures and applicabilities of control technologies has been implemented. These include in particular:
    - For Finland revised emission factors and control potentials for industrial processes for biomass waste fuels in industry.
    - For Malta, emission factors and the penetration of control technologies as well as their applicabilities in the power generation sector have been reassessed to reflect a higher share of internal combustion engines in fuel consumption
    - For Switzerland, emission factors and the penetration of control technologies have been revised according to the recent studies, so that are now consistent with the new submission of the Swiss emission inventory to EMEP.
    - For Belgium, emissions from biomass use in the domestic sector have been reassessed.
    - For Ireland, data on the structure of biomass and renewable energy use have been corrected.
    - For Greece and Lithuania, new information on emission factors and the "current legislation" penetration of control measures have been implemented.
    - For Germany, small adjustments to the distribution of PM emissions from road transport in the year 2000 have been applied so that the current GAINS estimates are fully consistent with the results from the German national transport model.

- For the Czech Republic and Malta, emission ceilings for 2010 have been corrected, and emission ceilings have been introduced for Bulgaria and Romania.
- For the UK the penetration of emission control legislation for light duty vehicles has been corrected.
- Emission factors for Euro 5 and 6 have been adjusted to reflect the values that have been finally agreed by the Council and the European Parliament.
- Costs of measures in the transport sector have been calculated taking into account information on Euro 5 and Euro 6 costs provided by DG-ENV. It should be mentioned that, compared to the CAFE analysis, Euro 5 and Euro 6 has been included in the NEC baseline, with estimated costs of €5.1 billion per year when using national activity projections in GAINS and of €3.0 billion per year when assuming that Member States embark on climate change policies. The latter was estimated by using the Long Range Energy Modelling projections (made with the PRIMES model) and assuming that the cost of climate policies would be €20 per tonne of CO_2 in 2020.
- Emission control strategies for national shipping have been adjusted to establish consistency with the baseline scenario from the Study on 'Policy measures to Reduce Ship Emissions in the Context of the Revision of the NEC Directive' (Cofala *et al.*, 2007).
- Information about the macroeconomic assumptions made by Member States for their national energy projections (i.e., population, GDP, value added by economic sectors) has been uploaded to the GAINS Internet version to the extent this information has been provided by the countries.

3.2 Input data for agricultural emissions

A variety of improvements has been introduced to the input data for the agricultural sector:

- New national projections of agricultural activities for Denmark were incorporated. They rely on the most recent Danish projections and were provided to IIASA in November 2006
- Based on the communication with Finnish experts in March 2007, cattle projections for 2020 have been corrected for Finland
- Modifications to existing agricultural projections for Bulgaria, Malta and Turkey were introduced following comments from national experts (Malta – January 2007) and resulting from more recent statistical information.
- New national projections for VOC sources for Romania were developed on the basis of data provided in January 2007.

3.2.1 IPPC for pigs and poultry farms

The implementation of the IPPC directive for pigs and poultry has been reviewed on the basis of information that was made available in January and February 2007 within the work under the

European Commission service contract on integrated measures to reduce ammonia emissions (No. 070501/2005/422822/MAR/C1). The new data on pig and poultry IPPC farms were developed by the consortium led by Alterra (Netherlands). They have been consulted with the IPPC review Advisory Group (group of representatives from Member States and other stakeholders set up by the Commission as part of the IPPC review process) and reviewed by national experts associated with this group. The data is available for EU-25.

Furthermore, the interpretation of IPPC legislation for farms has been extensively discussed under the integrated measures contract mentioned above and compared to the GAINS implementation that has been presented in December 2006. Drawing on feedback from Member States and the IPPC review Advisory Group, the definition of representative IPPC-BAT technology in RAINS has been revised, specifically for countries where no detailed information about national transposition of this legislation has been provided. The previous interpretation assumed efficient application of manures as part of IPPC-BAT, while in the current interpretation (noting that land spreading is in general not part of the IPPC definition of installation) this is not the case. The extent to which efficient manure spreading is included follows assumptions provided by Member States during the CAFE, NEC and IPPC consultations. Compared to the December 2006 baseline, the less optimistic implementation perspectives of low ammonia application techniques lead to higher ammonia emissions in several countries. This is partly compensated by revised assumptions about low nitrogen feeding, i.e., extending its application to IPPC farms if this was not the case so far.

Table 3.1: Summary of actions that have been taken to modify the NEC baseline projection for NH_3 presented in the NEC report #2 in December 2006. These changes resulted from discussions with the Commission and IPPC Implementation Committee within the Integrated Measures on Ammonia contracts (Alterra and IIASA)

Issue	Action	Impact on NH_3 emissions
IPPC installation (exclude manure spreading)	Modify penetration	+
Update of numbers of farms under IPPC	Modify penetration	+/-
Structural changes (more larger farms, higher IPPC penetration)	Modify penetration	-
Low nitrogen feed (higher penetration and lower costs)	Modify penetration	-

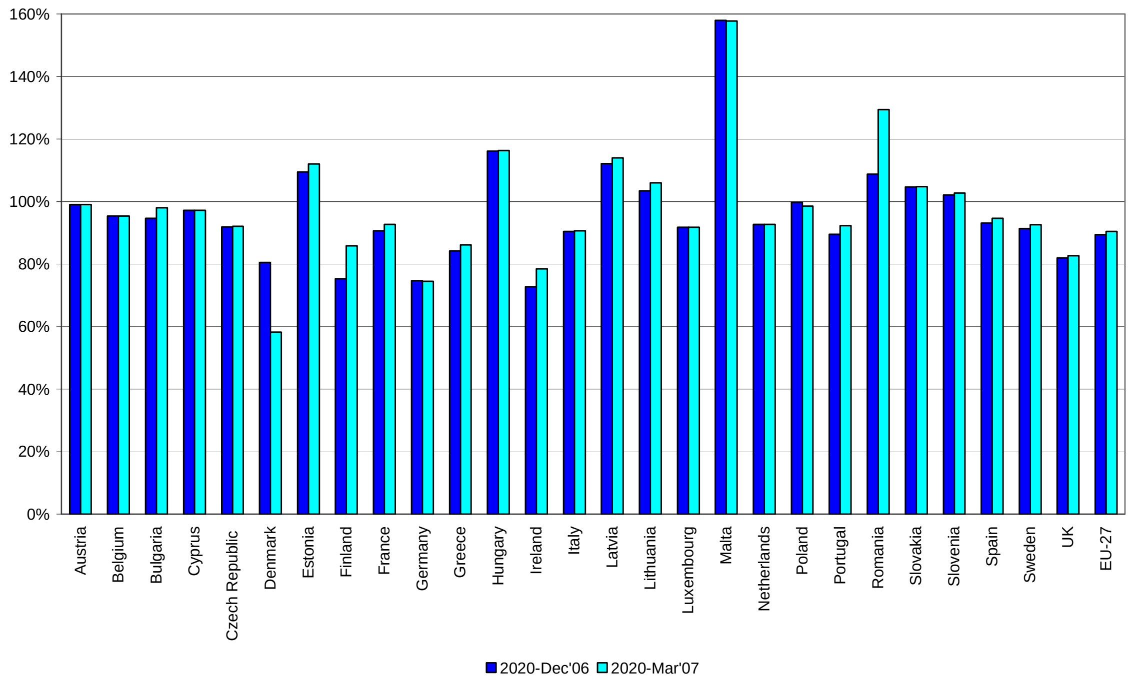

Figure 3.1: Comparison of 2020 projections of ammonia emissions presented in the NEC report # 2 (2020-Dec'06) and the estimates of this report (2020-March'07). The graph shows NH_3 emissions relative to the levels in 2000.

3.2.2 Solvent and product directives

Based on the comments received from ESIG (January 2007), the constraints on the maximum penetration of abatement options for domestic use of solvents that have originally been drawn from BIPRO (2002) study have been revised. With the less optimistic position of ESIG, the application of stage 2 and 3 is now strongly limited within the time horizon under study, i.e., by 2020 stage 2 has half of its potential and for stage 3 the maximum implementation is set to only 20 percent

3.2.3 Residential combustion

Stricter constraints on the maximum penetration of advanced combustion technology and small scale ESP within the time horizon under analysis were implemented. While this has minor implications for CLE emission projections, it implies lower emission reduction potentials for PM and VOC from this sector.

3.2.4 Country assumptions

- Denmark provided a new projection of ammonia emissions reflecting the implementation of recent policies. This leads to significant further reductions of ammonia in the baseline projection, i.e., from 73.5 kt to about 53 kt NH_3 in 2020. This is in accordance with the Danish communication.

- After consultation with national experts from Belgium, the VOC control strategy and applicability rates for a number of technologies were modified. The changes concern mainly residential combustion of wood and the food and drink industry and lead to slightly higher CLE and MTFR levels.

3.2.5 Ammonia control costs

A review of the costs of low nitrogen feed[1] (LNF in the GAINS model) within the European Commission service contract on integrated measures to reduce ammonia emissions (No. 070501/2005/422822/MAR/C1) suggested revised costs for that option. Latest data available to the consortium and estimates in recent European and American studies show a sharp decline in costs for such measures. Several strategies are being explored in a large number of studies and pilot projects, and optimising feeding strategies seems to be a very promising option in the near future. Achieving reductions of few percent in nitrogen excretion might even come at no net costs at all, especially for pigs. The measures included in GAINS achieve emission reductions of 10-20 percent and require a combination of both cheaper and more expensive/advanced strategies. In the current implementation of GAINS the unit costs of these measures were nearly halved mainly through modified assumptions on additional costs of optimized feed.

3.3 City-delta

Following feedbacks from scientific peers and national experts, a wide range of changes has been implemented for the City-delta methodology and databases compared to the December report. A comprehensive summary of the revised methodology is provided in Section 2.

3.4 Multi-year meteorology

While CAFE and the NEC report #2 employed atmospheric dispersion characteristics that have been estimated on the meteorological conditions of 1997, the analysis presented in this report relies on the mean meteorological conditions of five years, i.e., 1996, 1997, 1998, 2000 and 2003. This approach follows the recommendations of the NECPI group, and foresees sensitivity analyses for the meteorological conditions of 2003 to test the robustness against extreme meteorological conditions as they might emerge from climate change.

3.5 Emissions from non-EU countries

The analysis in CAFE relied on source-receptor relationships which were derived for permutations of emissions around the levels computed for 2010. Thereby, also for non-EU countries, emissions for 2010 have been implicitly assumed as boundary conditions.

The improved source-receptor relationships used for the NEC analysis allow for flexible assumptions on the emissions for non-EU countries. Inter alia, the analysis could include

[1] e.g., phase feeding, low protein feed, addition of synthetic amino acids, etc.

additional information on the development of emissions outside the EU-27 after the year 2010, and could assess the implications on emission ceilings for the EU-27 Member States.

Since CAFE, IIASA revised emission inventories and projections of anthropogenic activities for the non-EU countries, inter alia, in preparation for the review of the Gothenburg Protocol of the Convention on Long-range Transboundary Air Pollution. Bilateral consultations were held with national experts from Russia, the Ukraine and Belarus, which resulted in significantly modified baseline emission projections. In general, the new emission projections for 2020 are substantially lower than the former estimates for 2010, partly due to lower expectations on future coal use, and partly to due an optimistic interpretation of emission control legislation that has been recently passed in some countries.

Compared to the CAFE analysis, emissions projections have also been updated for Bulgaria, Romania, Croatia and Turkey. Current projections for 2020 are substantially lower than the earlier 2010 estimates, mainly due to the recent adoptions of emission control legislation in these countries, which counteracts the anticipated growth in population and economic development. For Norway and Switzerland, national activity projections have been incorporated.

Emission projections for sea regions have been updated to reflect the recent estimates produced by Cofala *et al.*, 2007.

Table 3.2: Emissions within the modelling domain outside the EU-27 as estimated by GAINS with current data, and as used for the CAFE analysis.

	Recent estimates of emissions in 2020					Emissions used for CAFE				
	SO_2	NO_x	NH_3	VOC	PM2.5	SO_2	NO_x	NH_3	VOC	PM2.5
	Land-based sources									
Albania	31	36	27	43	7	31	36	27	43	7
Belarus	146	155	131	150	42	182	239	131	252	47
Bosnia-H.	380	58	18	51	16	380	58	18	51	16
TFYROM	72	43	15	36	8	72	43	15	36	8
R. Moldova	102	63	45	41	13	102	63	45	41	13
Russia	966	2030	527	1738	542	3125	3297	524	3363	634
Serbia-M.	168	173	73	155	42	168	173	73	155	42
Ukraine	755	926	254	564	296	1866	1363	253	1196	315
Sum	3594	4267	1613	3294	1268	6899	6055	1610	5653	1384
	Sea regions									
NE Atlantic	804	1048	0	35	91	632	834	0	19	56
Baltic Sea	171	404	0	22	29	225	517	0	17	29
Black Sea	91	118	0	7	10	133	174	0	6	12
Med. Sea	1714	2311	2	114	198	2003	2711	0	88	179
North Sea	406	946	1	41	68	423	971	0	32	54
Sea regions	3186	4827	3	219	396	3416	5207	0	162	330

4 Baseline projections

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 national and 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
Bulgaria	268	23	52	60	63	136	196	10	-17	792
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	120	21	10	16	14	31	0	0	-3	208
Finland	207	237	80	171	117	189	236	47	39	1324
France	494	448	452	1811	1351	1727	4538	259	-250	10830
Germany	3327	221	741	2469	2252	3334	1851	117	11	14322
Greece	382	40	170	279	223	96	0	19	0	1208
Hungary	156	16	94	87	107	423	153	1	12	1049
Ireland	117	8	70	160	97	144	0	5	0	600
Italy	426	139	1262	1213	1335	2445	0	339	150	7309
Latvia	3	49	9	19	16	41	0	10	16	164
Lithuania	3	23	43	26	24	86	93	1	-14	286
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
Romania	271	119	171	138	98	636	59	54	-3	1542
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	14	1997
UK	1771	58	176	1119	1735	3983	822	88	51	9802
EU-27	12734	2552	5057	11093	10528	18272	10151	1632	45	72064
Croatia	30	22	99	56	42	121	24	16	11	421
Turkey	881	274	404	375	485	601	0	173	12	3206
Norway	56	49	9	151	147	245	0	515	-69	1104
Switzerland	8	72	25	270	237	101	289	133	-25	1108

[1)] Exports are indicated by negative numbers.

It should be noted that there are discrepancies between energy balances provided by national statistics and by EUROSTAT. For the EU-27 as a whole differences are below 0.5 percent, but larger discrepancies exist for a few countries.

Table 4.2: Energy consumption of the EU-27 by fuel and sector in 2000 [PJ] Source: GAINS (based on national and EUROSTAT energy balances)

	Coal	*Biomass, waste*	*Heavy fuel oil*	*Diesel*	*Gasoline LPG*	*Natural gas*	*Nuclear*	*Other renew.*	*Electr.*[1)]	*Total*
Power sector	9695	437	1533	172	18	4675	10151	1595	-10549	17728
Industry	1588	802	1180	414	354	5149	0	4	3741	13232
Conversion	319	15	957	134	77	1260	0	0	1607	4369
Domestic	594	1298	117	2757	590	6497	0	33	5011	16896
Transport	0	0	72	7443	7635	19	0	0	234	15403
Non-energy	539	0	1197	173	1854	673	0	0	0	4435
Total	12734	2552	5057	11093	10528	18272	10151	1632	45	72064

[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.

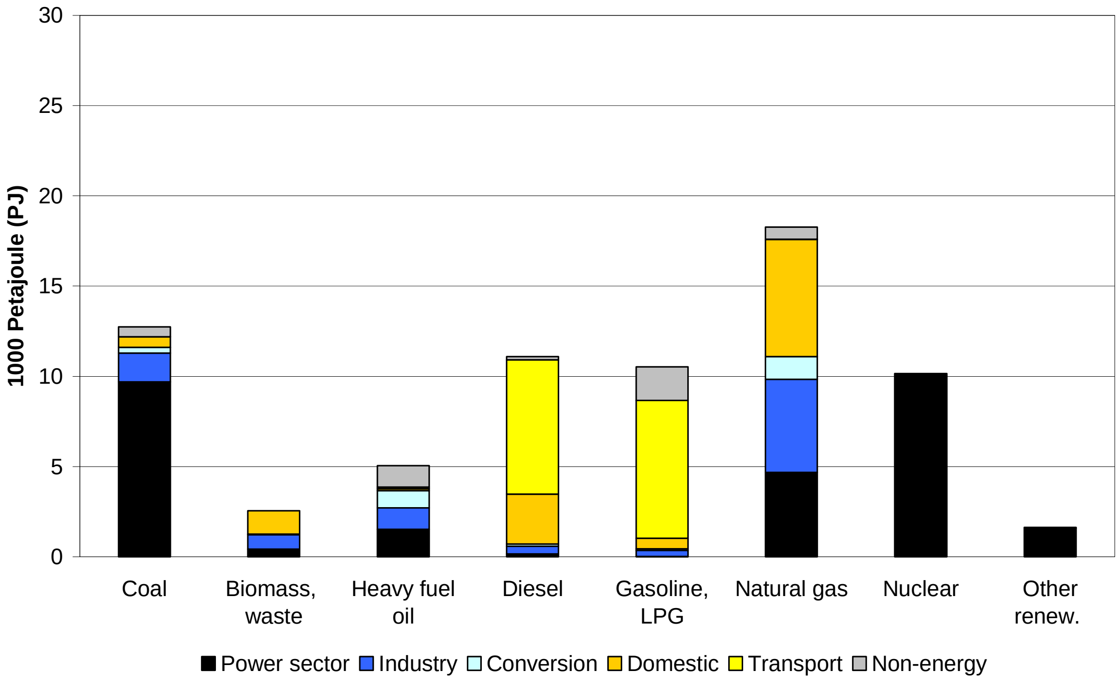

Figure 4.1: Energy consumption in 2000

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, in principle, 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, 23 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

	Data source	*Date of last information exchange*
Austria	National projection (2006)	04 July 2006
Belgium	National projection (2006)	31 August 2006
Bulgaria	PRIMES €20 (2006)	No national inputs
Cyprus	PRIMES €20 (2006)	No national inputs
Czech Rep.	National projection (2006)	01 August 2006
Denmark	National projection (2006)	11 November 2006
Estonia	National projection (2006)	30 October 2006
Finland	National projection (2006)	23 February 2007
France	National projection (2006)	30 June 2006
Germany	National projection (2006)	05 May 2006
Greece	National projection (2006)	04 December 2006
Hungary	National projection (2006)	11 August 2005
Ireland	National projection (2006)	05 December 2006
Italy	National projection (2006)	07 July 2006
Latvia	National projection (2006)	09 December 2005
Lithuania	National projection (2006)	20 January 2007
Luxembourg	PRIMES €20 (2006)	No national inputs
Malta	National projection (2006)	24 January 2007
Netherlands	National projection (2006)	14 September 2006
Poland	National projection (2006)	01 December 2005
Portugal	National projection (2006)	31 August 2006
Romania	PRIMES €20 (2006)	No national inputs
Slovakia	National projection (2006)	16 November 2006
Slovenia	National projection (2006)	06 October 2006
Spain	National projection (2006)	22 September 2006
Sweden	National projection (2006)	08 September 2006
UK	National projection (2006)	20 September 2006
Croatia	RAINS projection from 1996	No national inputs
Turkey	PRIMES €20 (2006)	No national inputs
Norway	National projection (2006)	02 February 2006
Switzerland	National projection (2006)	23 January 2007

The perceived evolution of fuel consumption in the various Member States is summarized for the year 2020 in Table 4.4. Overall, EU-27 Member States expect an increase in total primary energy use by 16 percent between 2000 and 2020. Coal consumption is projected to decrease by six percent, while for natural gas a 46 percent increase is envisaged. Member States anticipate a five percent drop in gasoline consumption and a 33 percent increase in diesel and light fuel oil. According to these projections, the EU-27 net electricity imports would increase by about 80 percent until 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
Bulgaria	139	48	47	112	134	214	215	19	-20	909
Cyprus	1	3	68	26	33	1	0	4	0	135
Czech Rep.	718	84	87	184	180	467	318	17	-25	2031
Denmark	114	122	54	174	146	315	0	45	-8	962
Estonia	173	27	13	30	16	45	0	3	-9	298
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	8	13579
Greece	393	46	140	274	343	423	0	65	6	1690
Hungary	119	99	0	182	128	615	161	1	21	1325
Ireland	63	26	35	277	172	326	0	34	6	940
Italy	657	406	507	1501	1314	3410	0	483	304	8580
Latvia	47	60	24	50	40	72	0	16	17	324
Lithuania	4	51	62	54	38	258	45	4	-14	503
Luxembourg	1	5	2	71	47	59	0	1	23	209
Malta	0	1	21	14	13	0	0	0	0	50
Netherlands	402	154	146	830	762	1555	39	96	12	3997
Poland	2046	305	297	566	387	1121	0	50	-19	4753
Portugal	96	149	224	349	172	358	0	100	-108	1339
Romania	392	182	125	319	214	988	125	94	-3	2435
Slovakia	259	55	28	65	49	399	89	28	-8	966
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-27	11943	4391	3755	14782	10005	26677	8862	3153	82	83649
Croatia	31	17	80	68	55	187	25	21	4	487
Turkey	935	325	483	662	1128	1790	0	417	-10	5731
Norway	68	58	13	187	182	358	0	455	7	1328
Switzerland	9	91	23	291	197	115	308	151	-23	1161

1) Exports are indicated by negative numbers.

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-27 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	9387	1577	599	136	12	9236	8862	2987	-14033	18763
Industry	1419	1321	963	522	306	6663	0	3	4884	16081
Conversion	248	134	947	348	118	1242	0	0	1705	4742
Domestic	383	1354	84	2538	472	8138	0	151	7226	20345
Transport	0	0	71	11073	7418	119	0	12	301	18993
Non-energy	507	4	1091	166	1678	1279	0	0	0	4726
Total	11943	4391	3755	14782	10005	26677	8862	3153	82	83649

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

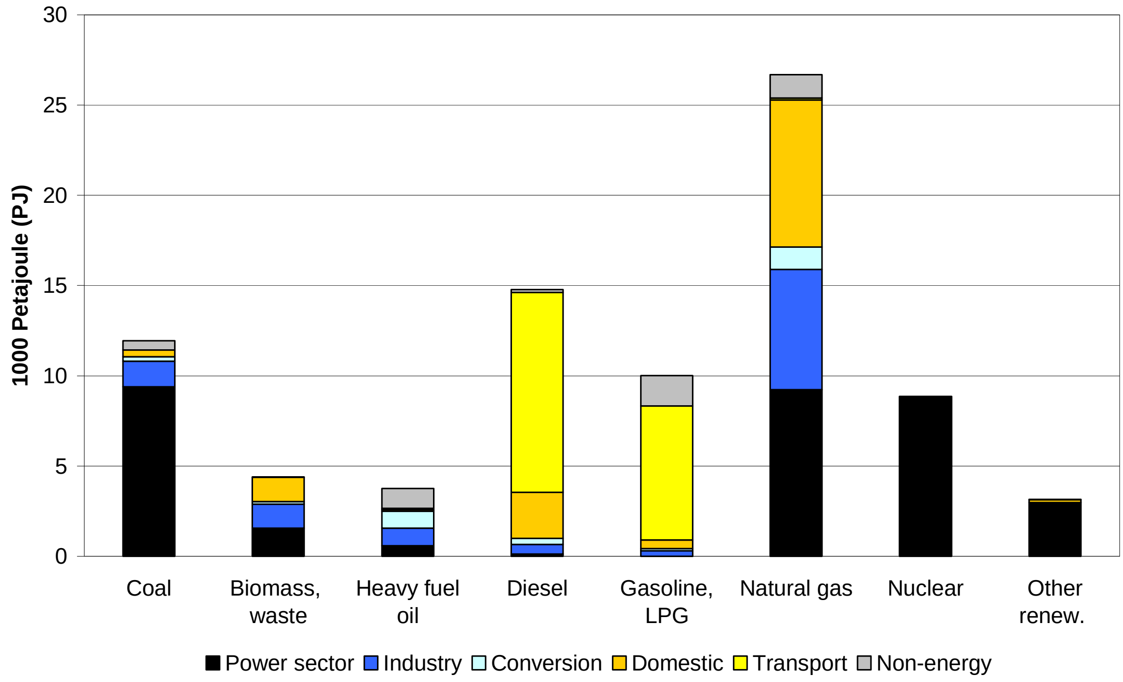

Figure 4.2: Energy consumption of the EU-27 as projected by the national scenarios for 2020

Overall for the EU-27, this set of energy projection would lead to a tone percent increase in CO_2 emissions compared to the base year level of the Kyoto protocol (Table 4.8).

4.1.2 The Long Range Energy Modelling energy projection for a carbon price of €20/t CO_2

To explore the robustness of national emission estimates against alternative assumptions on the future development of the energy systems, an energy projection produced in the context of the Long Range Energy Modelling with the PRIMES model for all 27 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 Transport and Energy, 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 to determine the amounts and types of energy used per sector and Member State. 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, unless such measures were already part of existing legislation. These include energy efficiency measures in Member States or energy policies that aim at promoting renewable energy and co-generation. The scenarios builds on the baseline scenario for Long Range Energy Modelling from 2006 (Mantzos and Capros, 2006). Concerning the "post-Kyoto" regime 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 a nine percent decline in CO_2 emissions of the 27 EU Member States compared to the base year emissions of the Kyoto Protocol.

Table 4.6: Primary energy consumption of the Long Range Energy Modelling results with €20/tCO_2 in 2020 [PJ]. Source: GAINS, based on projected energy balances of the PRIMES model

	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	220	6	1500
Belgium	160	62	100	489	336	853	377	20	19	2415
Bulgaria	139	48	47	112	134	214	215	19	-20	909
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	445	-178	12122
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	459	135	8408
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	67	-20	4961
Portugal	105	100	138	261	283	286	0	92	4	1269
Romania	392	182	125	319	214	988	125	94	-3	2435
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	426	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-27	8311	5147	4320	12906	11921	24894	9989	3173	66	80727
Croatia	31	17	80	68	55	187	25	21	4	487
Turkey	935	325	483	662	1128	1790	0	417	-10	5731
Norway	16	71	30	186	144	223	0	556	-28	1199
Switzerland	7	131	29	234	248	210	299	171	-27	1301

[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 12 instead of 16 percent (Table 4.6). The larger degree of decarbonisation is reflected by a 36 percent reduction in coal consumption (compared to the six percent decline in the national projections), while natural gas use would increase by only 36 percent compared to 46 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 16percent increase. Gasoline use is suggested to grow by 13 percent (and not to shrink by five percent). In total, the EU-27 net imports of electricity are 20 percent lower 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-27 for the Long Range Energy Modelling results with €20/tCO_2 for 2020 [PJ]. Data Source: GAINS, projected energy balances of the PRIMES model

	Coal	*Biomass waste*	*Heavy fuel oil*	*Diesel*	*Gasoline LPG*	*Natural gas*	*Nuclear*	*Other renew.*	*Electr.* [1)]	*Total*
PP	6574	2824	875	154	0	8706	9989	2995	-14805	17313
Industry	1397	408	1066	514	343	6715	0	0	4959	15403
Conversion	107	286	388	7	8	572	0	0	1858	3225
Domestic	152	1629	81	2793	479	8164	0	158	7781	21238
Transport	0	0	88	9249	9115	21	0	20	273	18766
Non-energy	80	0	1822	189	1975	717	0	0	0	4783
Total	8311	5147	4320	12906	11921	24894	9989	3173	66	80727

[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

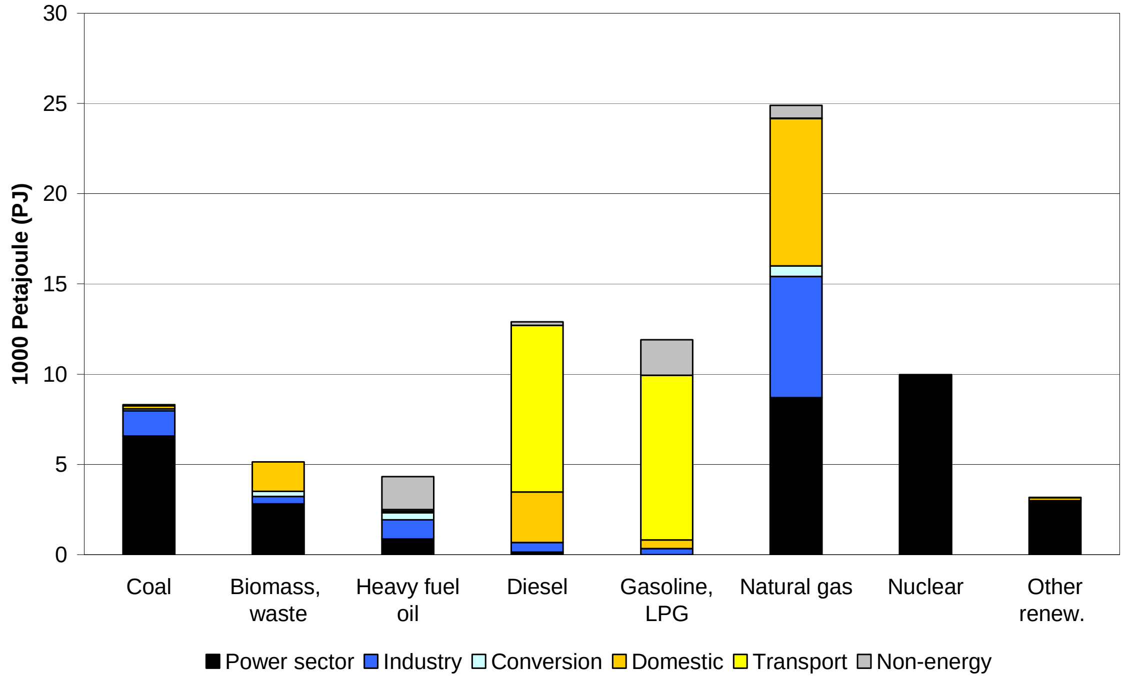

Figure 4.3: Energy consumption of the EU-27 in 2020 as projected in the PRIMES €20 scenario

Table 4.8: CO_2 emissions by country, for the UNFCCC base year, for 2000 and for 2020 for the national projections, the Long Range Energy Modelling projections with €20/tCO_2 and the baseline projection used in CAFE for TSAP

	UNFCCC base year (1990) Mt	2000 Mt	National activity projection 2020 Mt	*Change to base year*	"PRIMES €20/t CO_2" and CAPRI MTR agricultural projection 2020 Mt	*Change to base year*	Baseline projection used in CAFE for TSAP 2020 Mt	*Change to base year*
Austria	61	65	77	*27%*	72	*18%*	69	*13%*
Belgium	119	126	131	*10%*	122	*2%*	121	*2%*
Bulgaria	98	46	48	*-51%*	48	*-51%*	42	*-57%*
Cyprus[1)]	5	7	9	*73%*	9	*73%*	9	*78%*
Czech Rep.	164	126	123	*-25%*	110	*-33%*	90	*-45%*
Denmark	53	53	54	*2%*	46	*-14%*	46	*-13%*
Estonia	38	19	27	*-29%*	15	*-60%*	12	*-69%*
Finland	56	58	59	*5%*	57	*2%*	61	*8%*
France	397	414	462	*16%*	387	*-3%*	431	*9%*
Germany	1015	860	854	*-16%*	773	*-24%*	734	*-28%*
Greece	84	104	127	*51%*	119	*42%*	106	*27%*
Hungary	85	59	68	*-20%*	68	*-20%*	59	*-30%*
Ireland	32	45	59	*84%*	46	*45%*	47	*47%*
Italy	431	472	503	*17%*	504	*17%*	439	*2%*
Latvia	19	7	17	*-8%*	11	*-40%*	9	*-55%*
Lithuania	39	14	28	*-27%*	21	*-46%*	19	*-51%*
Luxembourg[1)]	12	9	11	*-5%*	11	*-5%*	12	*0%*
Malta	2	2	3	*48%*	3	*35%*	3	*40%*
Netherlands	158	169	206	*31%*	179	*13%*	180	*14%*
Poland	477	315	350	*-27%*	326	*-32%*	305	*-36%*
Portugal	44	66	80	*83%*	72	*64%*	80	*82%*
Romania	184	92	143	*-22%*	143	*-22%*	97	*-47%*
Slovakia	59	39	60	*2%*	54	*-8%*	49	*-17%*
Slovenia	16	15	17	*7%*	17	*7%*	15	*-4%*
Spain	228	306	451	*98%*	335	*47%*	324	*42%*
Sweden	56	53	58	*3%*	68	*21%*	63	*13%*
UK	589	559	536	*-9%*	504	*-14%*	515	*-12%*
EU-27	4521	4100	4564	*1%*	4122	*-9%*	3938	*-13%*
Croatia[1)]	23	23	27	*19%*	27	*19%*	26	*13%*
Turkey[1)]	126	223	389	*208%*	389	*208%*	353	*180%*
Norway	34	38	48	*42%*	39	*16%*	42	*24%*
Switzerland	45	43	42	*-7%*	44	*-2%*	46	*1%*

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

4.2 Agricultural projections

As a starting point for the further analysis, Table 4.9 summarizes the statistics on agricultural activities for the year 2000 as implemented in the GAINS database.

Table 4.9: Agricultural activity data 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
Bulgaria	652	1512	14963	3595	374	145	404
Cyprus	54	408	3310	625	7	8	0
Czech Rep.	1609	3315	32043	118	26	213	306
Denmark	1868	11922	21831	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
Romania	2532	4797	70076	8195	865	239	872
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-27	95714	157948	1503112	138774	5198	11674	12827
Croatia	427	1233	11251	608	15	116	328
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 4.10). 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-27 as a whole (Table 4.11), these national projections anticipate between 2000 and 2020 for cattle a 13 percent decline in livestock numbers (dairy cows drop by about 16 percent and beef cattle by about 11 percent), for sheep a reduction by 10 percent and about six percent increase in the number of pigs and poultry. Use of nitrogen fertilizers is estimated to decline in the EU-27 by about six percent.

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 4.10: 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	
Bulgaria	FAO (2003)		Update using CRONOS database
Cyprus	FAO (2003), EFMA (2005)		
Czech Rep.	National (2005)	26 June 2006	
Denmark	National (2006)	10 November 2006	
Estonia	National (2006)	4 May 2006	
Finland	National (2006)	1 March 2007	
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 January 2007	For some categories discrepancies for historical years, supplementary data from FAO, IFA , and CRONOS database used
Netherlands	National (2006)	14 September 2006	
Poland	National (2005)	19 October 2005	
Portugal	National (2006)	16 October 2006	
Romania	FAO (2003), National (2007)	26 January 2007	For some categories discrepancies for historical years, supplementary data from FAO and IFA used
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	
Croatia	FAO (2003)		
Turkey	FAO (2003)		Update using CRONOS database
Norway	National (2005)	10 February 2005	
Switzerland	National (2006)	10 January 2007	

Table 4.11: 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
Bulgaria	677	1100	22958	2411	373	151	350
Cyprus	48	457	4830	655	7	7	0
Czech Rep.	1400	3800	36234	260	28	230	310
Denmark	1310	14728	18146	95	168	176	0
Estonia	222	448	2640	87	4	21	38
Finland	791	1270	13113	97	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
Romania	2630	7300	90000	8297	800	391	800
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-27	82924	166974	1595185	124988	5238	10996	11427
Croatia	566	1273	12589	916	14	116	300
Turkey	14561	4	344710	32000	664	1200	600
Norway	907	633	14290	1416	55	90	630
Switzerland	1403	1357	7490	485	72	50	15

Data sources: GAINS, based on national submissions to IIASA

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 4.12). 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 4.12: 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
Bulgaria	677	1100	22958	2411	373	151	350
Cyprus	48	457	4830	655	7	7	0
Czech Rep.	1435	3913	41035	171	28	333	310
Denmark	1343	13821	18441	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	14	74	1010	26	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
Romania	2740	7300	90000	8295	800	391	800
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-27	86322	170920	1633880	125590	5230	10873	11427
Croatia	566	1273	12589	916	14	116	300
Turkey	14561	4	344710	32000	664	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-27 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 cow 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 eight 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); projections for Bulgaria and Romania originate from FAO sudy Bruinsma, 2003. 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 4.13 to Table 4.17, 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 4.13: 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 4.14: Legislation considered in the baseline projections for NO_x emissions

Large combustion plant directive
Euro-standards, including adopted Euro-5 and Euro-6 for light duty vehicles
EU emission standards for motorcycles and mopeds
Legislation on non-road mobile machinery
Higher real life emissions of Euro-II and Euro-III for diesel heavy duty and light duty vehicles compared with the test cycle
IPPC legislation for industrial processes
National legislation and national practices (if stricter)

Table 4.15: 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 adopted 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 4.16: Legislation considered in the baseline projections for NH_3 emissions

IPPC directive for pigs and poultry production
National legislation including elements of EU law, i.e., Nitrate and Water Framework directives
Current practice that includes implementation of *Code of Good Agricultural Practice* which is mandatory under the UNECE Gothenburg Protocol

Table 4.17: Legislation considered in the baseline projections for PM2.5 emissions

Large combustion plant directive
Euro-standards, including the adopted Euro-5 and Euro-6 standards 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)

4.4 Baseline emission projections

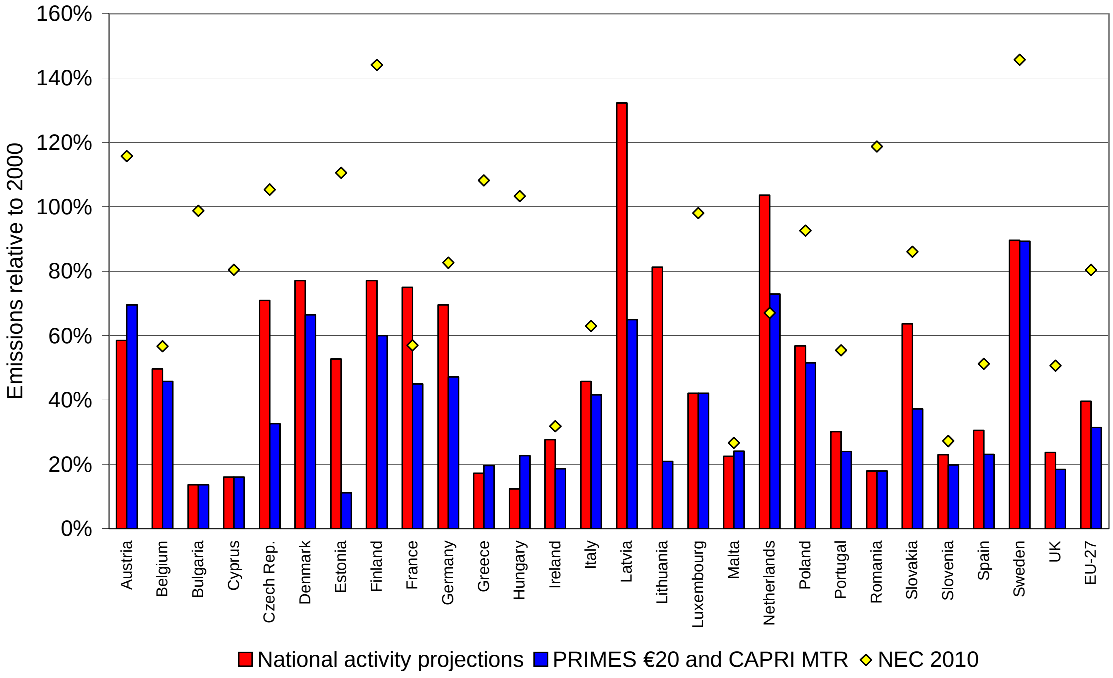

Figure 4.4: Current legislation emission projections for SO_2 for 2020, compared with the national emission ceilings for 2010

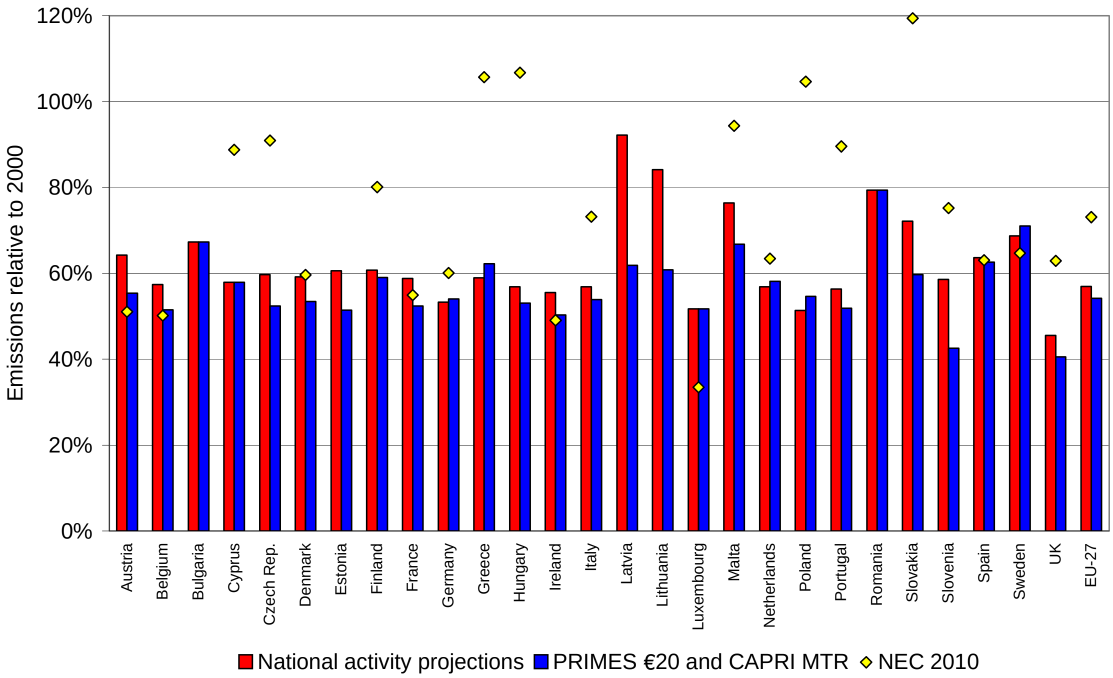

Figure 4.5: Current legislation emission projections for NO_x for 2020, compared with the national emission ceilings for 2010

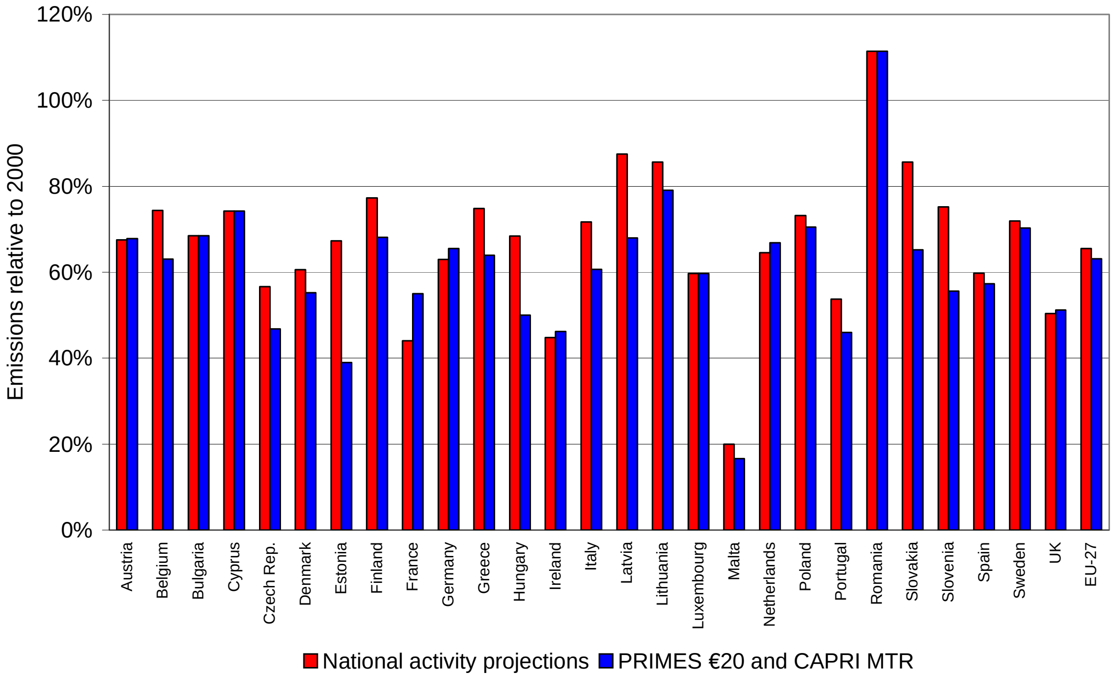

Figure 4.6: Current legislation emission projections for PM2.5 for 2020

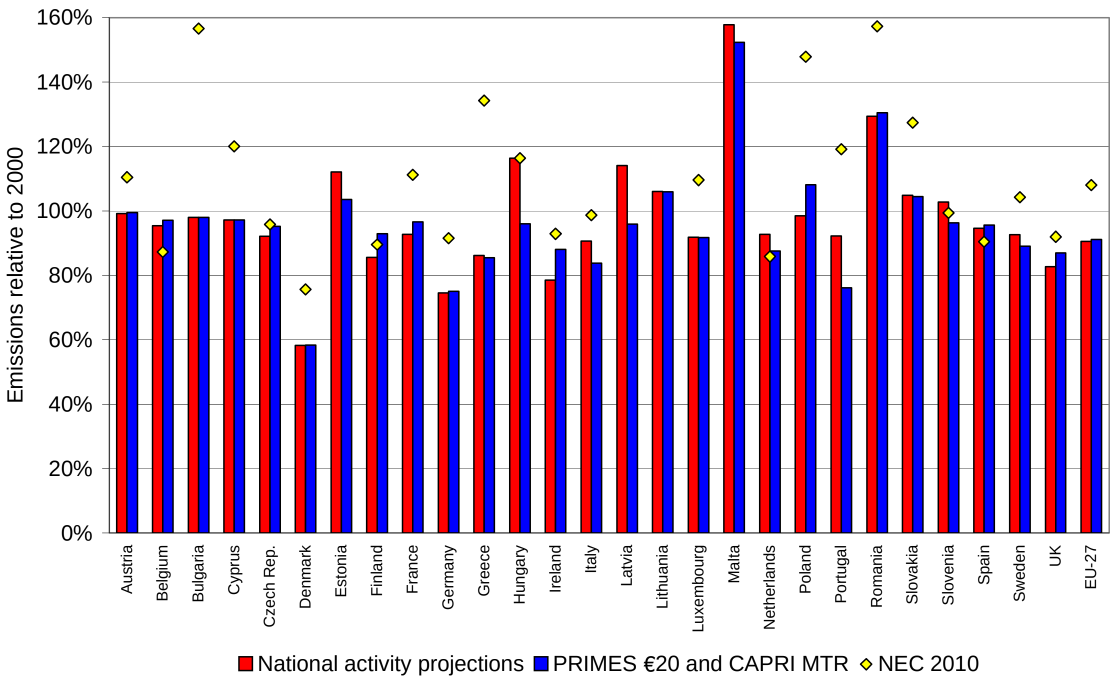

Figure 4.7: Current legislation emission projections for NH_3 for 2020, compared with the national emission ceilings for 2010

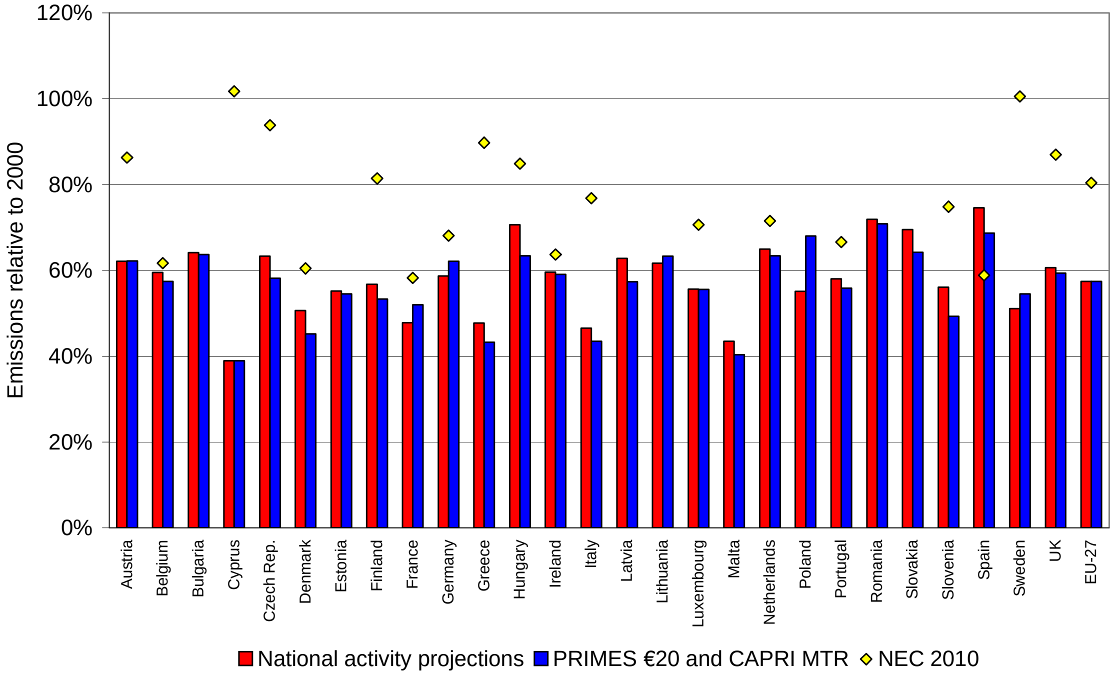

Figure 4.8: Current legislation emission projections for VOC for 2020, compared with the national emission ceilings for 2010

5 Health and environmental objectives of the Thematic Strategy

In its Thematic Strategy on Air Pollution (CEC, 2005), the European Commission has established health and environmental objectives 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 objectives 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.*, 2005c, Amann *et al.*, 2005b, Amann *et al.*, 2005a). 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 5.1).

Table 5.1: Environmental objectives 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)	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	Number 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 in the area of forest ecosystems exceeding ozone levels resulting from emission controls that are 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.*, 2006b) 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), 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. Since CAFE many Member States have provided improved emission inventories for the year 2000 with sometimes significant changes compared to earlier submissions. In addition, the City-delta methodology has been revised since 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. Most notably, the analysis presented in this report employs atmospheric source-receptor relationships that reflect the meteorological conditions of five years (1996, 1997, 1998, 2000, 2003), in contrast to the CAFE assessment, which relied on 1997 meteorology only.

All these changes have some influence on the quantitative estimates of the impact indicators for the year 2000. As shown in Table 5.2 and Figure 5.1, the revised city-delta methodology together with the five-years mean meteorology delivers for the EU-25 now urban increments that are comparable to those used in CAFE, but somewhat lower than the increments applied for the December 2006 report. 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 (between the TSAP and the NEC report #2 – see Amann *et al.*, 2006a). The five-years mean meteorology applied in this report suggests even six percent larger area of ecosystems with nitrogen deposition above their critical loads than the calculations for 1997 meteorology. Using long-term meteorology suggest five percent more forest area with excess acid deposition than the CAFE analysis, and a 20 percent higher number of premature deaths attributable to ozone exposure (Table 5.3).

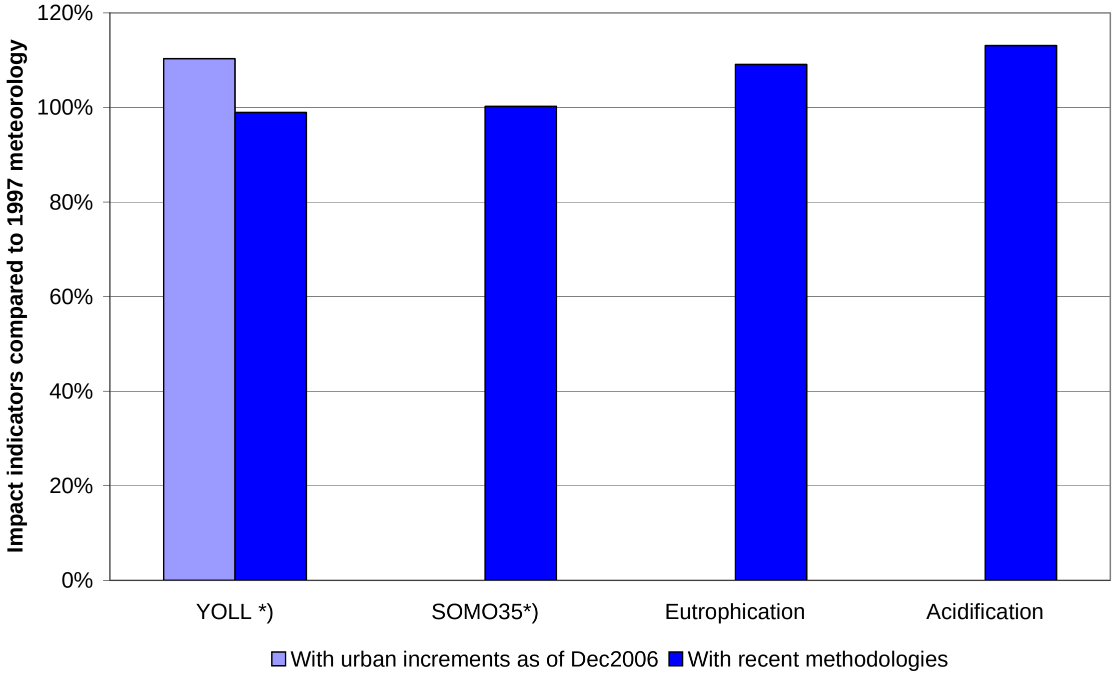

Figure 5.1: Impact indicators for the year 2000 computed with 5-years meteorology compared to indicators based on 1997 meteorology

For all effects except eutrophication, the analysis of emission control scenarios in this report applies the percentage improvements established by the Commission as environmental objectives (Table 5.1) to the updated estimates of the impact indicators for the year 2000 (Table 5.2, Table 5.3). 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 5.2: Indicators for the environmental impacts for the year 2000, TSAP estimates compared with the estimates presented in the NEC scenario report #2 of December 2006 with 1997 meteorology (Amann *et al.*, 2006a) and the estimates based on five-years mean meteorology and revised city-delta methodology (NEC3)

	Lost life years attributable to anthropogenic PM2.5 (million life years lost)			Ozone mortality (# of cases of premature deaths)		
	TSAP	*NEC2*	*NEC3*	*TSAP*	*NEC2*	*NEC3*
Austria	3.3	4.0	3.5	422	361	397
Belgium	7.6	7.8	7.0	381	332	320
Cyprus	0.2	0.1	0.1	33	29	29
Czech Rep.	5.1	6.1	5.5	535	462	514
Denmark	1.7	2.2	2.0	179	170	159
Estonia	0.3	0.3	0.3	21	18	18
Finland	0.7	0.8	0.8	58	48	41
France	26.1	30.5	24.6	2663	2641	2397
Germany	43.3	47.1	44.1	4258	3702	3743
Greece	4	5.5	4.7	627	566	567
Hungary	5.6	6.5	5.8	748	654	735
Ireland	0.8	0.9	0.8	74	67	57
Italy	30.2	29.9	27.2	4507	4031	4179
Latvia	0.6	0.9	0.7	65	58	46
Lithuania	1.2	1.1	1.1	66	55	74
Luxembourg	0.2	0.3	0.2	31	27	27
Malta	0.1	0.1	0.1	22	21	23
Netherlands	10.6	10.9	10.3	416	359	342
Poland	19.2	22.6	19.9	1399	1196	1347
Portugal	2.7	4.1	3.2	450	402	396
Slovakia	2.6	2.9	2.7	239	202	234
Slovenia	0.9	1.0	0.9	112	95	105
Spain	12	12.2	11.1	2002	1823	1755
Sweden	1.7	1.6	1.7	197	177	164
UK	22.3	24.7	21.8	1423	1223	1083
EU-25	202.9	223.8	200.3	20927	18717	18752
Bulgaria			3.3			482
Romania			10.2			1061
EU-27			213.8			20295
Norway			0.6			64
EU-27 + Norway			214.4			20359
Croatia						303
Turkey						1544
Switzerland						355

Table 5.3: Indicators for the environmental impacts for the year 2000, TSAP estimates compared with the estimates presented in the NEC scenario report #2 of December 2006 with 1997 meteorology (Amann *et al.*, 2006a) and the estimates based on five-years mean meteorology (NEC3)

	Eutrophication (km^2)			Acidification forests (km^2)			Acidification water (km^2)		
	TSAP	*NEC2*	*NEC3*	*TSAP*	*NEC2*	*NEC3*	*TSAP*	*NEC2*	*NEC3*
Austria	34137	35184	35618	5241	373	373			
Belgium	6134	6687	6730	3618	4651	4591			
Cyprus	2296	3134	3049	0	0	0			
Czech Rep.	17481	11124	11162	14815	8642	9158			
Denmark	1597	2972	3039	956	1047	1200			
Estonia	2853	8385	12316	62	0	0			
Finland	59985	79671	112220	3802	3378	6115	229	26	91
France	171610	176645	176710	20951	17026	19649			
Germany	102867	101569	101804	74572	62263	62491			
Greece	10392	9326	9326	82	941	943			
Hungary	3302	10259	10278	415	50	50			
Ireland	1015	7931	7403	1957	1927	1695			
Italy	74548	87867	87696	2083	0	0	0	0	0
Latvia	16277	25842	26781	174	371	538			
Lithuania	11209	17651	17651	357	12788	13219			
Luxembourg	901	821	821	328	272	272			
Malta									
Netherlands	2158	4070	4124	3335	5106	5106			
Poland	78442	86412	86408	52104	50184	53034			
Portugal	3280	20118	20107	285	3886	3345			
Slovakia	16179	19225	19236	4130	4428	4707			
Slovenia	4006	5264	5264	116	647	647			
Spain	54410	76050	75050	876	900	900			
Sweden	48176	36623	60026	42912	37263	58438	30427	27423	36812
UK	9792	21401	20972	9717	10200	9424	625	661	650
EU-25	733048	854231	913791	242887	226344	255896	31280	28110	37553
Bulgaria		45762	45600		0	0			
Romania		60763	60560		3187	3516			
EU-27		960756	1019951		229531	259412		28110	37553
Norway		9810	13086		1648	2789		57242	67597
EU-27+Norway		970566	1033037		213179	262201		85352	105150
Croatia		3470	3081		640	351			
Turkey									
Switzerland		16345	18866		1706	1899		118	131

For eutrophication, a strict application of the percentage reduction target of the TSAP (-43 percent between 2000 and 2020) delivers with ecosystem-specific deposition figures reduction targets that are beyond the range of feasibility even if all technical emission control measures contained in the GAINS model were applied. Thus, the methodological change of using ecosystem-specific instead of grid-average deposition leads – for constant reduction percentage targets – to substantially modified environmental ambition levels and distorts the relative emphases that have been put in the Thematic Strategy on eutrophication versus the other impacts. To maintain comparable ambition levels across the effects, the TSAP reduction figure for eutrophication has been recomputed with ecosystem-specific deposition for the TSAP emissions, and the resulting number of unprotected ecosystems area has been compared with the area computed with ecosystem-specific deposition for the emissions of the year 2000. On this basis, the reanalysis yields for the EU-27 a 31 percent improvement in the area of unprotected ecosystems compared to the year 2000, instead of the 43 percent of the TSAP that was based on calculations with grid average deposition. The 31 percent reduction target is then further on used to represent the environmental ambition of the TSAP with the modified calculation methodology.

Table 5.4: Impact indicators for the year 2000 and the target levels for 2020 derived from the environmental objectives of the Thematic Strategy on Air Pollution

	Unit	TSAP target for 2020	*EU25* Impact indicator for 2000	*EU25* Target level 2020	*EU27* Impact indicator for 2000	*EU27* Target level 2020	*EU-27 + Norway* Impact indicator for 2000	*EU-27 + Norway* Target level 2020
Lost life years attributable to anthropogenic PM2.5	YOLL	47%	200.3	106.2	213.8	113.3	214.4	113.6
Eutrophication computed with ecosystem specific deposition	km^2	31%	913,791	681,673	1,019,951	703,766	1,033,037	705,577
Acidification – forests	km^2	74%	255,896	66,533	259,412	67,447	262,201	68,172
Acidification – freshwater	km^2	39%	37,553	22,907	37,553	22,907	105150	64,142
Premature mortality attributable to ozone	# of cases	10%	18,752	16,877	20,295	18,266	20,359	18,323

The analysis in this report, which covers an extended model area including Bulgaria, Romania and Norway, applies the TSAP percentage reduction targets as they are described above to the entire domain.

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 PM2.5 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 5.1 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 national activity projections it was found that the ecosystems area derived from the TSAP environmental targets relate to a 55 percent "CAFE gap closure" in terms of accumulated excess deposition for acidification, to a 70 percent gap closure for excess nitrogen deposition, while the SOMO35 target for ozone is already achieved in the baseline case. This procedure was repeated for the other activity projections reported in this paper.

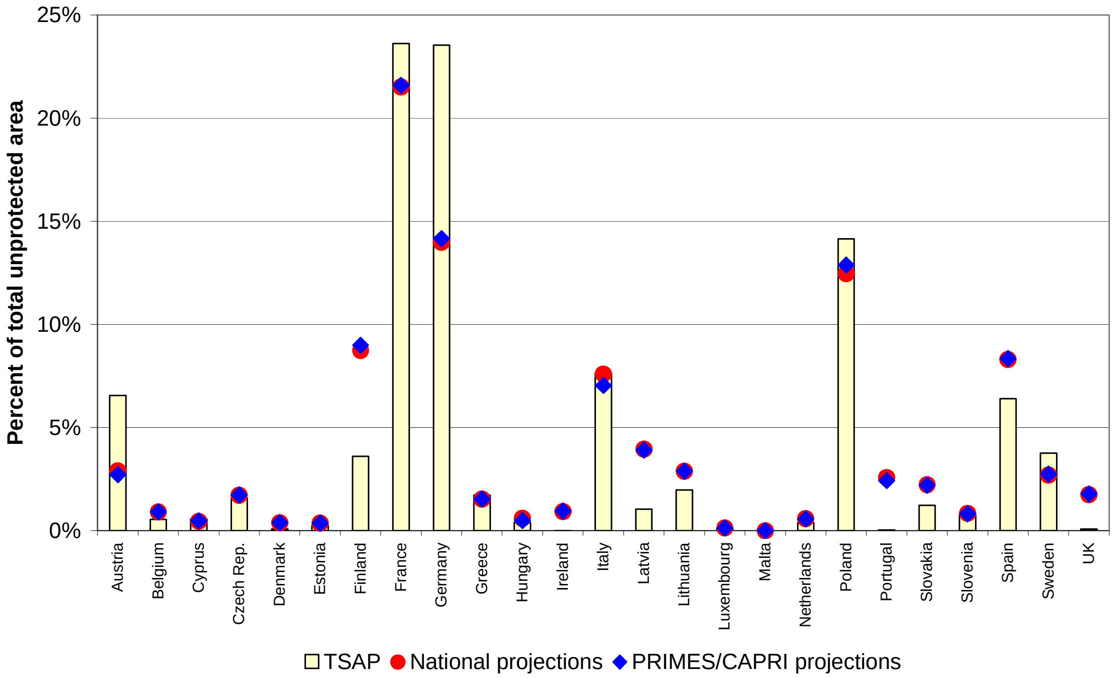

Figure 5.2: Distribution of ecosystems area with nitrogen deposition above critical loads TSAP calculations vs. NEC optimizations with EURO VI

6 Least-cost emission reductions that address the environmental objectives of the Thematic Strategy

The "RAINS mode" of GAINS optimization model has been used to identify least-cost combinations of emission reductions that address the environmental objectives of the Thematic Strategy on Air Pollution.

To explore the range on important policy determinants, the central analysis was carried out for variants in the three dimensions:

- national activity projections versus the "PRIMES €20" energy and CAPRI agricultural projections,
- with and without introduction of the proposed EURO VI standards for heavy duty vehicles in all Member States,
- assuming 2010 and 2020 emission projections for countries and sea regions outside the EU-27.

With the extended model domain including Bulgaria, Romania and Norway, this analysis applies the environmental objectives also to these countries. It also considers the scope for emission reduction measures in these countries in a way fully compatible to the treatment of the EU-25 countries.

6.1 Summary

With the environmental targets presented in the preceding section (see Table 5.4) and assuming for 2020 the development of emissions in the non-EU countries and sea regions as outlined in Table 3.2, optimized emission reductions in the EU-27 involve emission control costs between €6.5 and €9.5 billion per year in addition to the costs of the TSAP baseline. These figures include costs for Euro 5/6 measures. Compared to the NEC baseline, costs range between €3.8 and €4.8 billion per year, depending on the assumed activity projection and the role of EURO VI measures for heavy duty vehicles (Table 6.1 to Table 6.4). It turns out that EU-wide introduction of EURO VI is a cost-effective measure for the case of national activity projections, saving approximately 80 million €/yr in 2020. Vice versa, if a more climate-friendly energy policy were pursued, the same environmental impacts that result from the proposed Euro VI measures could be achieved by additional measures at stationary sources at slightly lower costs (-35 million €/yr for the PRIMES €20 projection). The introduction of EURO VI, however, has substantial implications on the distribution of costs across economic sectors, and would especially relieve the pressure on further measures in the agricultural sector.

As shown in Figure 6.1, single-objective optimizations for each of the environmental targets separately show that, with the chosen interpretations of the TSAP environmental targets, the achievement of the eutrophication objective is most costly, involving costs of approximately 3 billion €/yr. Measures to meet the objectives for health impacts from PM require control costs of approximately 1.6 billion €/yr, while those for acidification only 0.5 billion €/yr. The translated objectives for ozone would be met already by the baseline projection without further measures.

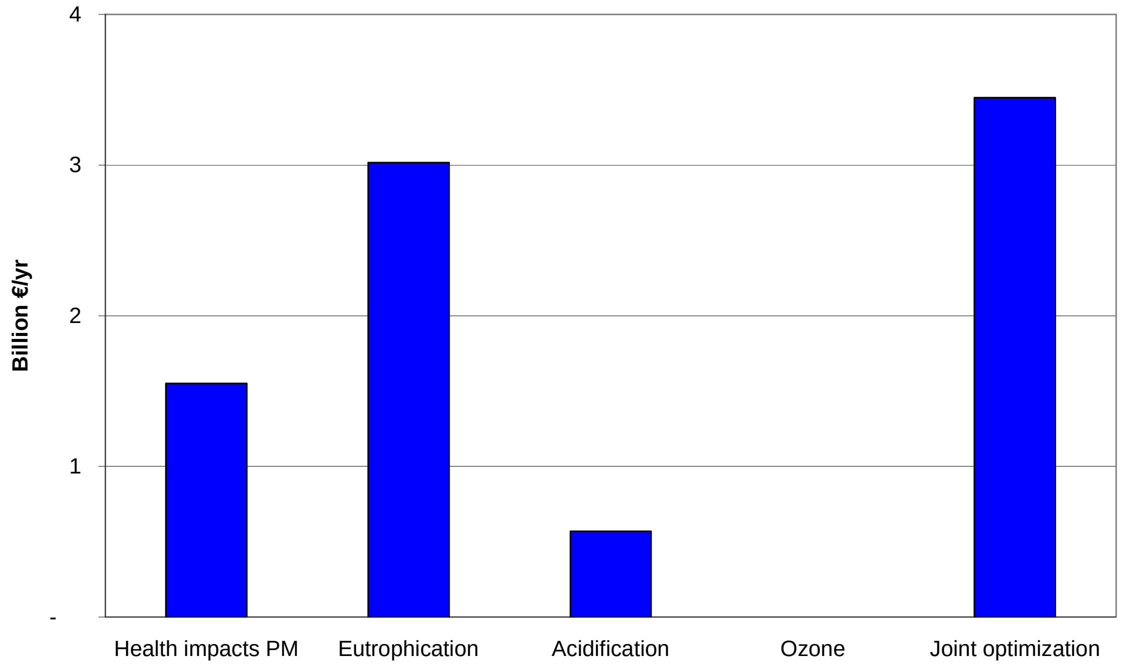

Figure 6.1: Costs for achieving the four environmental objectives separately and jointly. These figures exclude costs for Euro5/6 measures.

It is important to mention that this priority ranking is different from the relative emphases attributed to the four endpoints in the Thematic Strategy, where health impacts from PM has received highest priority.

Confirming the findings of earlier analysis, costs for achieving the environmental targets of the Thematic Strategy depend crucially on the underlying volumes and structures of anthropogenic activities in general and in particular on the implied evolution of CO_2 emissions. As illustrated in Figure 6.2, emission control costs (on top or the costs for the Thematic Strategy baseline) for the national projections, which result in a +1 percent increase in CO_2 emissions of the EU-27, are more than three billion €/yr more expensive than the measures that would be necessary if the €20 carbon price projection would materialize. Additional costs do not only occur in the transport sector, but also for stationary sources. Even the agricultural sector, which is not a major source of CO_2 emissions, would have to bear 20 percent higher air pollution control costs to compensate for higher emissions in other sector in a high CO_2 projection.

As shown in Table 6.2, the analysis with the 2020 emissions from the non-EU countries achieves the environmental objectives of the Thematic Strategy with significantly less reductions of SO_2, NO_x, PM and VOC emissions within the EU than estimated in CAFE for the Thematic Strategy. The main reason for this reduced pressure lies in the fact that the CAFE analysis, in absence of more information, has assumed constant 2010 emissions for the non-EU countries also for 2010. Bilateral consultations with non-EU countries that have been carried out with national experts from Russia, Ukraine and Belarus revealed existing legislation in these countries that require certain emission reduction requirements especially for large sources. While the actual compliance with such legislation is burdened with uncertainties, assuming factual implementation as it is done for legislation in EU Member States would result in significant cuts in emission. On this basis, SO_2 emissions in the non-EU countries would be in 2020 approximately 3000 kt lower than assumed in CAFE for 2010, NO_x emissions by 1300 kt, PM2.5 emissions by 0.2 million tons and VOC emissions by 1300 kt. Obviously, assuming such emission reductions outside the EU territory relieves pressure for measures within the EU.

In general, most stringent demand for further emission reductions originates from the environmental objectives on health impacts from PM and on eutrophication. With the five-years mean meteorology, the Europe-wide objectives for ozone will be achieved already by the baseline projection and do not require additional emission reductions, most notably for VOC. However, the low pressure on VOC emissions in the European-wide analysis does not mean that further measures to reduce VOC emissions would not be cost-effective at the local scale, especially to meet the air quality limit values within urban areas. It is also noteworthy that the environmental targets for acidification would not be automatically met in the current legislation baseline case. However, meeting the health targets for PM will at the same time also achieve the targets for acidification without any further measures.

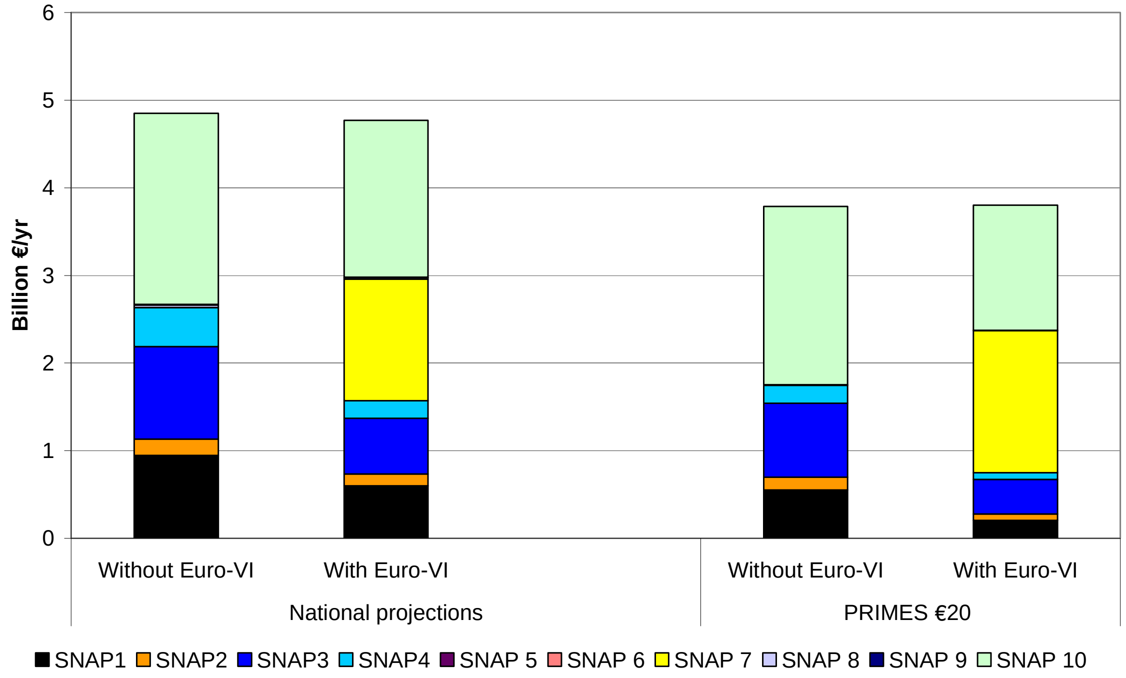

Figure 6.2: Air pollution emission control costs for the optimized scenarios with the 2020 projections for regions outside the EU-27. These costs are in addition to the NEC baseline and do not include costs for Euro5/6.

Table 6.1: Summary of emissions and emission control costs for the EU-27 for the 2020 boundary conditions

	2000	*National projections*				*PRIMES €20*			
		Without EURO VI		With EURO VI		Without EURO VI		With EURO VI	
		Emissions (kt) with 2020 boundary conditions							
SO_2	10322	3300	-68%	3429	-67%	3200	-69%	3221	-69%
NO_x	12322	5633	-54%	5444	-56%	5472	-56%	5250	-57%
PM2.5	1782	881	-51%	894	-50%	948	-47%	1006	-44%
NH_3	3975	2750	-31%	2813	-29%	2816	-29%	2910	-27%
VOC	11007	6207	-44%	6153	-44%	6237	-43%	6171	-44%
CO_2	4521	4564	1%	4564	1%	4122	-9%	4122	-9%
		Emission control costs (mio €/yr) with 2020 boundary conditions (in addition to the costs of the CAFE baseline)							
SO_2		390		315		7		2	
NO_x *)		1952		2502		1639		2336	
PM2.5		139		105		32		9	
NH_3		2369		1845		2090		1455	
VOC		0		0		0		0	
Total		4850		4768		3768		3803	
Euro5/6		5136		5136		3000		3000	
Total		9986		9904		6768		6803	

*) includes costs for EURO VI

Table 6.2: Summary of emissions and emission control costs for the EU-25 for the 2020 boundary conditions

	2000	*National projections*				*PRIMES €20*				*TSAP*	
		Without EURO VI		With EURO VI		Without EURO VI		With EURO VI			
		Emissions (kt) with 2020 boundary conditions									
SO_2	8702	3066	-65%	3190	-63%	2948	-66%	2968	-66%	1566	-82%
NO_x	11829	5360	-55%	5183	-56%	5195	-56%	4966	-58%	4657	-61%
PM2.5	1594	789	-50%	803	-50%	830	-48%	857	-46%	714	-55%
NH_3	3773	2579	-32%	2638	-30%	2637	-30%	2731	-28%	2779	-26%
VOC	10460	5855	-44%	5803	-45%	5885	-44%	5822	-44%	5252	-50%
CO_2	4239	4372	3%	4372	3%	3930	-7%	3930	-7%	3938	-7%
		Costs (bn €/yr) with 2020 boundary conditions (in addition to CAFE baseline)									
SO_2		384		312		7		2			
NO_x		1861		2304		1555		2178			
PM2.5		108		75		22		8			
NH_3		2229		1735		2000		1363			
VOC		0		0		0		0			
Total		4582		4426		3584		3551			
Euro5/6		5050		5050		2920		2920			
Total		9632		9476		6504		6471		7100	

*) includes costs for EURO VI

Table 6.3: Summary of emissions and emission control costs for the EU-27 for the 2010 boundary conditions

	2000	*National projections* Without EURO VI	With EURO VI		*PRIMES €20* Without EURO VI	With EURO VI	
		Emissions (kt) with 2020 boundary conditions					
SO_2	10322		2965	-71%		2998	-71%
NO_x	12322		5275	-57%		5090	-59%
PM2.5	1782		863	-52%		913	-49%
NH_3	3975		2698	-32%		2733	-31%
VOC	11007		6149	-44%		6171	-44%
CO_2	4521		4564	1%		4122	-9%
		Emission control costs (mio €/yr) with 2020 boundary conditions (in addition to the costs of the CAFE baseline)					
SO_2			660		-13830	81	
NO_x *)			3058		-44887	2755	
PM2.5			172		-9097	56	
NH_3			2712		-3267	2556	
VOC			0		-2400	-12	
Total			6602		-73481	5436	
Euro5/6			5136		3000	3000	
Total			11738		-70481	8436	

*) includes costs for EURO VI

Table 6.4: Summary of emissions and emission control costs for the EU-25 for the 2010 boundary conditions as they have been assumed in CAFE

	2000	*National projections* Without EURO VI	With EURO VI		*PRIMES €20* Without EURO VI	With EURO VI		*TSAP*	
		Emissions (kt) with 2010 boundary conditions							
SO_2	8702		2779	-68%		2745	-68%	1566	-82%
NO_x	11829		5020	-58%		4832	-59%	4657	-61%
PM2.5	1594		773	-51%		814	-49%	714	-55%
NH_3	3773		2535	-33%		2568	-32%	2779	-26%
VOC	10460		5800	-45%		5822	-44%	5252	-50%
CO_2	4239		4372	3%		3930	-7%	3938	-7%
		Costs (bn €/yr) with 2010 boundary conditions (in addition to CAFE baseline)							
SO_2			629			81			
NO_x			2845			2552			
PM2.5			138			33			
NH_3			2517			2372			
VOC			0			-12			
Total			6129			5027			
Euro5/6			5050			2920			
Total			11179			7947		7100	

*) includes costs for EURO VI

6.2 Emission reductions

6.2.1 Emissions by country

Table 6.5: SO_2 emissions (kt) for 2000 and for the optimized scenarios for 2020, assuming the 2020 projections of emissions outside the EU-27

	2000	National activity projections				PRIMES €20 energy and CAPRI agricultural projections			
		Baseline CLE	Without EURO VI	With EURO VI	MRR[2)]	Baseline CLE	Without EURO VI	With EURO VI	MRR[2)]
Austria	34	20	20	20	19	23	23	23	22
Belgium	175	87	72	72	61	80	77	78	56
Bulgaria	847	116	111	111	35	116	115	115	35
Cyprus[1)]	48	8	8	8	3	8	8	8	3
Czech Rep.	252	178	142	142	101	82	82	82	42
Denmark	28	21	20	21	13	19	18	18	13
Estonia	90	48	48	48	8	10	10	10	4
Finland	76	59	59	59	47	46	46	46	37
France	658	493	342	346	226	296	272	281	137
Germany	630	438	420	420	292	297	297	297	242
Greece[1)]	483	83	83	83	50	95	94	94	57
Hungary	484	60	39	45	32	110	106	110	24
Ireland	132	36	36	36	18	25	25	25	13
Italy	755	345	266	304	145	314	312	312	159
Latvia	14	19	15	19	9	9	9	9	6
Lithuania[1)]	48	39	39	39	11	10	10	10	5
Luxembourg[1]	4	2	2	2	1	2	2	2	1
Malta	34	8	8	8	2	8	8	8	2
Netherlands	75	77	73	73	55	54	54	54	45
Poland	1509	857	551	586	327	778	775	777	285
Portugal	289	87	75	81	39	69	69	69	33
Romania	773	139	123	128	54	139	138	138	54
Slovakia	128	81	58	62	42	48	47	47	20
Slovenia	99	23	17	18	11	20	19	20	11
Spain	1457	446	396	419	209	336	335	335	162
Sweden	46	41	41	41	33	41	41	41	33
UK	1155	274	239	239	201	213	207	213	152
EU-27	10322	4085	3300	3429	2043	3246	3200	3221	1651
Croatia[1)]	108	62	62	62		62	62	62	
Turkey[1)]	1646	911	911	911		911	911	911	
Norway	26	26	26	26	22	25	25	25	23
Switzerland	20	18	18	18		16	16	16	
EU-25	8702	3831	3066	3190	1953	2992	2948	2968	1561

1) No national projections have been supplied. The PRIMES €20 projection and/or the CAPRI agricultural projections have been used instead for the national scenario.

2) Maximum application of all technical measures considered in the RAINS model

Table 6.6: SO_2 emissions (kt) for 2000 and for the optimized scenarios for 2020, assuming the 2010 projections of emissions outside the EU-27

	2000	National activity projections				PRIMES €20 energy and CAPRI agricultural projections			
		Baseline CLE	Without EURO VI	With EURO VI	MRR[2)]	Baseline CLE	Without EURO VI	With EURO VI	MRR[2)]
Austria	34	20		20	19	23		23	22
Belgium	175	87		68	61	80		67	56
Bulgaria	847	116		111	35	116		115	35
Cyprus[1)]	48	8		8	3	8		8	3
Czech Rep.	252	178		130	101	82		76	42
Denmark	28	21		19	13	19		18	13
Estonia	90	48		48	8	10		10	4
Finland	76	59		59	47	46		46	37
France	658	493		326	226	296		253	137
Germany	630	438		410	292	297		292	242
Greece[1)]	483	83		83	50	95		94	57
Hungary	484	60		36	32	110		57	24
Ireland	132	36		28	18	25		25	13
Italy	755	345		265	145	314		311	159
Latvia	14	19		14	9	9		9	6
Lithuania[1)]	48	39		20	11	10		10	5
Luxembourg[1]	4	2		1	1	2		2	1
Malta	34	8		4	2	8		8	2
Netherlands	75	77		68	55	54		52	45
Poland	1509	857		469	327	778		703	285
Portugal	289	87		63	39	69		63	33
Romania	773	139		76	54	139		138	54
Slovakia	128	81		51	42	48		44	20
Slovenia	99	23		17	11	20		17	11
Spain	1457	446		293	209	336		311	162
Sweden	46	41		41	33	41		41	33
UK	1155	274		238	201	213		203	152
EU-27	10322	4085		2965	2043	3246		2998	1651
Croatia[1)]	108	62		62		62		62	
Turkey[1)]	1646	911		911		911		911	
Norway	26	26		26	22	25		25	23
Switzerland	20	18		18		16		16	
EU-25	8702	3831		2779	1953	2992		2745	1561

1) No national projections have been supplied. The PRIMES €20 projection and/or the CAPRI agricultural projections have been used instead for the national scenario.

2) Maximum application of all technical measures considered in the RAINS model

Table 6.7: NO_x emissions (kt) for 2000 and for the optimized scenarios for 2020, assuming the 2020 projections of emissions outside the EU-27

	2000	National activity projections				PRIMES €20 energy and CAPRI agricultural projections			
		Baseline CLE	Without EURO VI	With EURO VI	MRR[2)]	Baseline CLE	Without EURO VI	With EURO VI	MRR[2)]
Austria	202	130	119	105	91	112	103	92	76
Belgium	351	201	168	155	140	181	149	141	125
Bulgaria	163	110	74	71	61	110	76	74	61
Cyprus[1)]	26	15	10	12	9	15	13	13	9
Czech Rep.	315	188	145	151	120	165	121	125	101
Denmark	213	126	92	91	85	114	96	95	90
Estonia	39	24	14	14	11	20	13	13	12
Finland	212	129	99	106	93	125	90	99	86
France	1475	867	658	635	530	773	631	597	500
Germany	1750	933	711	666	593	945	799	736	626
Greece[1)]	326	192	167	164	146	203	181	175	160
Hungary	186	106	79	75	57	98	74	75	52
Ireland	132	74	64	62	49	67	60	54	45
Italy	1353	769	721	692	562	729	680	648	534
Latvia	34	31	24	25	23	21	15	16	13
Lithuania[1)]	50	42	27	29	21	30	22	23	18
Luxembourg[1]	33	17	15	11	10	17	15	11	10
Malta	8	6	5	5	5	6	5	5	5
Netherlands	410	233	206	202	181	238	218	208	180
Poland	840	431	351	346	302	459	374	379	330
Portugal	279	157	129	125	104	145	126	121	101
Romania	329	261	200	189	157	261	201	210	157
Slovakia	109	79	56	57	41	65	48	51	36
Slovenia	60	35	33	33	31	25	24	23	21
Spain	1343	855	677	641	527	841	612	571	490
Sweden	229	157	132	133	122	163	145	140	135
UK	1855	845	660	647	513	752	579	555	443
EU-27	12322	7014	5633	5444	4583	6680	5472	5250	4415
Croatia[1)]	87	53	53	53		53	53	53	
Turkey[1)]	822	704	731	704		731	731	731	
Norway	222	172	149	152	140	164	140	143	133
Switzerland	91	49	49	49		49	49	49	
EU-25	11829	6643	5360	5183	4366	6309	5195	4966	4198

1) No national projections have been supplied. The PRIMES €20 projection and/or the CAPRI agricultural projections have been used instead for the national scenario.

2) Maximum application of all technical measures considered in the RAINS model

Table 6.8: NOx emissions (kt) for 2000 and for the optimized scenarios for 2020, assuming the 2010 projections of emissions outside the EU-27

	2000	National activity projections				PRIMES €20 energy and CAPRI agricultural projections			
		Baseline CLE	Without EURO VI	With EURO VI	MRR[2)]	Baseline CLE	Without EURO VI	With EURO VI	MRR[2)]
Austria	202	130		100	91	112		87	76
Belgium	351	201		151	140	181		136	125
Bulgaria	163	110		67	61	110		69	61
Cyprus[1)]	26	15		10	9	15		10	9
Czech Rep.	315	188		140	120	165		117	101
Denmark	213	126		90	85	114		93	90
Estonia	39	24		14	11	20		13	12
Finland	212	129		108	93	125		99	86
France	1475	867		606	530	773		569	500
Germany	1750	933		643	593	945		710	626
Greece[1)]	326	192		161	146	203		174	160
Hungary	186	106		69	57	98		69	52
Ireland	132	74		59	49	67		54	45
Italy	1353	769		684	562	729		647	534
Latvia	34	31		25	23	21		16	13
Lithuania[1)]	50	42		29	21	30		23	18
Luxembourg[1]	33	17		11	10	17		11	10
Malta	8	6		5	5	6		5	5
Netherlands	410	233		186	181	238		195	180
Poland	840	431		339	302	459		370	330
Portugal	279	157		123	104	145		120	101
Romania	329	261		188	157	261		189	157
Slovakia	109	79		52	41	65		48	36
Slovenia	60	35		32	31	25		23	21
Spain	1343	855		623	527	841		569	490
Sweden	229	157		133	122	163		139	135
UK	1855	845		627	513	752		534	443
EU-27	12322	7014		5275	4583	6680		5090	4415
Croatia[1)]	87	53		53		53		53	
Turkey[1)]	822	704		704		731		731	
Norway	222	172		152	140	164		143	133
Switzerland	91	49		49		49		49	
EU-25	11829	6643		5020	4366	6309		4832	4198

1) No national projections have been supplied. The PRIMES €20 projection and/or the CAPRI agricultural projections have been used instead for the national scenario.

2) Maximum application of all technical measures considered in the RAINS model

Table 6.9: PM2.5 emissions (kt) for 2000 and for the optimized scenarios for 2020, assuming the 2020 projections of emissions outside the EU-27

	2000	National activity projections				PRIMES €20 energy and CAPRI agricultural projections			
		Baseline CLE	Without EURO VI	With EURO VI	MRR[2)]	Baseline CLE	Without EURO VI	With EURO VI	MRR[2)]
Austria	31	21	20	20	16	21	20	20	15
Belgium	36	26	21	21	18	22	21	21	16
Bulgaria	61	42	21	21	9	42	34	34	9
Cyprus[1)]	2	2	2	2	1	2	2	2	1
Czech Rep.	57	32	28	28	17	27	25	25	15
Denmark	25	15	14	14	7	14	13	13	7
Estonia	23	16	11	15	5	9	8	8	3
Finland	31	24	22	22	11	21	21	21	7
France	293	129	115	117	66	161	154	157	71
Germany	158	100	91	91	82	104	97	97	84
Greece[1)]	48	36	28	28	18	31	26	26	19
Hungary	52	36	26	26	12	26	21	21	9
Ireland	16	7	7	7	5	7	7	7	5
Italy	158	113	90	94	66	96	78	79	58
Latvia	18	16	10	11	4	12	11	11	3
Lithuania[1)]	13	11	8	8	4	10	7	7	3
Luxembourg[1]	3	2	2	2	2	2	2	2	2
Malta	1	0	0	0	0	0	0	0	0
Netherlands	27	18	16	16	15	18	18	17	15
Poland	197	144	99	99	66	139	118	123	57
Portugal	81	43	23	25	13	37	21	36	12
Romania	127	142	70	70	28	142	84	116	28
Slovakia	25	21	14	15	9	16	10	12	7
Slovenia	12	9	4	4	3	7	3	5	3
Spain	143	85	71	72	57	82	73	73	53
Sweden	23	17	16	16	12	16	16	16	11
UK	121	61	52	53	45	62	58	59	47
EU-27	1782	1167	881	894	592	1125	948	1006	561
Croatia[1)]	21	13	13	13		13	13	13	
Turkey[1)]	313	289	290	289		290	290	290	
Norway	56	43	42	42	14	43	43	43	14
Switzerland	12	7	7	7		6	6	6	
EU-25	1594	984	789	803	555	942	830	857	523

1) No national projections have been supplied. The PRIMES €20 projection and/or the CAPRI agricultural projections have been used instead for the national scenario.

2) Maximum application of all technical measures considered in the RAINS model

Table 6.10: PM2.5 emissions (kt) for 2000 and for the optimized scenarios for 2020, assuming the 2010 projections of emissions outside the EU-27

	2000	National activity projections				PRIMES €20 energy and CAPRI agricultural projections			
		Baseline CLE	Without EURO VI	With EURO VI	MRR[2)]	Baseline CLE	Without EURO VI	With EURO VI	MRR[2)]
Austria	31	21		19	16	21		20	15
Belgium	36	26		21	18	22		20	16
Bulgaria	61	42		21	9	42		26	9
Cyprus[1)]	2	2		2	1	2		2	1
Czech Rep.	57	32		28	17	27		24	15
Denmark	25	15		14	7	14		13	7
Estonia	23	16		10	5	9		8	3
Finland	31	24		22	11	21		20	7
France	293	129		113	66	161		152	71
Germany	158	100		90	82	104		96	84
Greece[1)]	48	36		27	18	31		24	19
Hungary	52	36		25	12	26		20	9
Ireland	16	7		6	5	7		7	5
Italy	158	113		89	66	96		77	58
Latvia	18	16		10	4	12		11	3
Lithuania[1)]	13	11		8	4	10		7	3
Luxembourg[1]	3	2		2	2	2		2	2
Malta	1	0		0	0	0		0	0
Netherlands	27	18		16	15	18		17	15
Poland	197	144		96	66	139		117	57
Portugal	81	43		23	13	37		21	12
Romania	127	142		69	28	142		73	28
Slovakia	25	21		14	9	16		10	7
Slovenia	12	9		4	3	7		3	3
Spain	143	85		70	57	82		72	53
Sweden	23	17		16	12	16		16	11
UK	121	61		50	45	62		56	47
EU-27	1782	1167		863	592	1125		913	561
Croatia[1)]	21	13		13		13		13	
Turkey[1)]	313	289		289		290		290	
Norway	56	43		42	14	43		42	14
Switzerland	12	7		7		6		6	
EU-25	1594	984		773	555	942		814	523

1) No national projections have been supplied. The PRIMES €20 projection and/or the CAPRI agricultural projections have been used instead for the national scenario.

2) Maximum application of all technical measures considered in the RAINS model

Table 6.11: NH_3 emissions (kt) for 2000 and for the optimized scenarios for 2020, assuming the 2020 projections of emissions outside the EU-27

	2000	National activity projections				PRIMES €20 energy and CAPRI agricultural projections			
		Baseline CLE	Without EURO VI	With EURO VI	MRR[2)]	Baseline CLE	Without EURO VI	With EURO VI	MRR[2)]
Austria	60	59	41	43	37	59	42	44	37
Belgium	85	81	74	76	73	82	76	77	75
Bulgaria	69	68	57	59	54	68	59	59	54
Cyprus[1)]	7	7	5	5	5	7	6	6	5
Czech Rep.	84	77	62	63	59	79	63	65	58
Denmark	91	53	47	49	47	53	47	49	47
Estonia	9	11	7	7	7	10	7	7	7
Finland	35	30	27	26	24	32	29	28	26
France	702	651	462	472	393	678	479	501	397
Germany	601	448	384	395	371	451	383	395	373
Greece[1)]	54	47	36	37	34	46	37	38	34
Hungary	77	90	61	61	49	74	51	51	42
Ireland	125	98	86	87	83	110	98	99	92
Italy	425	385	287	294	264	355	270	277	240
Latvia	13	15	9	10	9	12	8	8	8
Lithuania[1)]	37	40	28	30	25	40	26	30	25
Luxembourg[1]	6	6	5	5	5	6	5	5	5
Malta	2	3	3	3	2	3	3	3	2
Netherlands	149	138	123	123	117	131	116	118	111
Poland	317	312	239	241	211	342	262	274	233
Portugal	76	70	50	52	42	57	49	51	34
Romania	133	173	113	116	91	174	121	120	92
Slovakia	31	32	26	26	18	32	27	27	18
Slovenia	20	21	14	15	14	19	14	15	12
Spain	390	369	250	261	217	373	274	286	220
Sweden	55	51	38	40	37	49	36	40	36
UK	323	267	214	218	205	281	230	240	219
EU-27	3975	3598	2750	2813	2493	3625	2816	2910	2502
Croatia[1)]	28	32	32	32		32	32	32	
Turkey[1)]	422	491	491	491		491	491	491	
Norway	24	21	13	14	13	21	13	15	12
Switzerland	52	41	41	41		45	45	45	
EU-25	3773	3358	2579	2638	2348	3383	2637	2731	2356

1) No national projections have been supplied. The PRIMES €20 projection and/or the CAPRI agricultural projections have been used instead for the national scenario.

2) Maximum application of all technical measures considered in the RAINS model

Table 6.12: NH_3 emissions (kt) for 2000 and for the optimized scenarios for 2020, assuming the 2010 projections of emissions outside the EU-27

	2000	National activity projections				PRIMES €20 energy and CAPRI agricultural projections			
		Baseline CLE	Without EURO VI	With EURO VI	MRR[2)]	Baseline CLE	Without EURO VI	With EURO VI	MRR[2)]
Austria	60	59		42	37	59		41	37
Belgium	85	81		75	73	82		76	75
Bulgaria	69	68		57	54	68		57	54
Cyprus[1)]	7	7		5	5	7		5	5
Czech Rep.	84	77		61	59	79		62	58
Denmark	91	53		47	47	53		47	47
Estonia	9	11		8	7	10		7	7
Finland	35	30		25	24	32		27	26
France	702	651		445	393	678		459	397
Germany	601	448		387	371	451		384	373
Greece[1)]	54	47		35	34	46		35	34
Hungary	77	90		59	49	74		50	42
Ireland	125	98		85	83	110		96	92
Italy	425	385		282	264	355		257	240
Latvia	13	15		10	9	12		8	8
Lithuania[1)]	37	40		28	25	40		28	25
Luxembourg[1]	6	6		5	5	6		5	5
Malta	2	3		3	2	3		3	2
Netherlands	149	138		122	117	131		115	111
Poland	317	312		232	211	342		258	233
Portugal	76	70		48	42	57		47	34
Romania	133	173		106	91	174		109	92
Slovakia	31	32		24	18	32		23	18
Slovenia	20	21		14	14	19		13	12
Spain	390	369		242	217	373		253	220
Sweden	55	51		37	37	49		37	36
UK	323	267		211	205	281		229	219
EU-27	3975	3598		2698	2493	3625		2733	2502
Croatia[1)]	28	32		32		32		32	
Turkey[1)]	422	491		491		491		491	
Norway	24	21		13	13	21		13	12
Switzerland	52	41		41		45		45	
EU-25	3773	3358		2535	2348	3383		2568	2356

1) No national projections have been supplied. The PRIMES €20 projection and/or the CAPRI agricultural projections have been used instead for the national scenario.

2) Maximum application of all technical measures considered in the RAINS model

Table 6.13: VOC emissions (kt) for 2000 and for the optimized scenarios for 2020, assuming the 2020 projections of emissions outside the EU-27

	2000	National activity projections				PRIMES €20 energy and CAPRI agricultural projections			
		Baseline CLE	Without EURO VI	With EURO VI	MRR[2)]	Baseline CLE	Without EURO VI	With EURO VI	MRR[2)]
Austria	184	114	114	112	74	115	114	113	73
Belgium	225	134	133	130	105	130	128	125	103
Bulgaria	134	86	83	82	43	86	83	82	43
Cyprus[1)]	14	5	5	5	4	5	5	5	4
Czech Rep.	234	148	148	147	74	137	136	136	69
Denmark	141	71	71	70	46	64	63	63	40
Estonia	39	22	21	20	13	22	20	20	11
Finland	160	91	91	90	54	85	85	85	51
France	1803	862	858	850	620	942	937	927	641
Germany	1461	858	843	835	572	922	906	895	616
Greece[1)]	291	139	130	130	77	126	118	117	76
Hungary	161	114	111	110	53	103	100	99	50
Ireland	86	51	51	50	31	52	51	50	29
Italy	1509	702	688	685	509	658	646	641	471
Latvia	69	43	42	42	22	40	38	38	14
Lithuania[1)]	69	42	39	39	20	44	40	40	20
Luxembourg[1]	13	7	7	6	5	7	7	6	5
Malta	7	3	3	3	2	3	3	3	2
Netherlands	259	168	167	166	134	161	160	158	129
Poland	578	319	316	313	191	396	392	389	212
Portugal	270	157	156	155	109	151	151	149	106
Romania	414	298	269	267	124	298	269	267	124
Slovakia	88	61	61	60	36	57	51	51	32
Slovenia	53	30	19	19	14	26	19	19	14
Spain	1125	838	825	819	523	778	762	755	486
Sweden	240	123	122	121	96	131	131	129	105
UK	1380	837	835	825	631	821	819	808	614
EU-27	11007	6325	6207	6153	4182	6358	6237	6171	4140
Croatia[1)]	102	42	42	42		42	42	42	
Turkey[1)]	784	474	474	470		474	474	474	
Norway	379	90	89	88	65	89	88	87	65
Switzerland	160	88	88	88		88	88	88	
EU-25	10460	5942	5855	5803	4016	5974	5885	5822	3973

1) No national projections have been supplied. The PRIMES €20 projection and/or the CAPRI agricultural projections have been used instead for the national scenario.

2) Maximum application of all technical measures considered in the RAINS model

Table 6.14: VOC emissions (kt) for 2000 and for the optimized scenarios for 2020, assuming the 2010 projections of emissions outside the EU-27

	2000	National activity projections				PRIMES €20 energy and CAPRI agricultural projections			
		Baseline CLE	Without EURO VI	With EURO VI	MRR[2)]	Baseline CLE	Without EURO VI	With EURO VI	MRR[2)]
Austria	184	114		112	74	115		113	73
Belgium	225	134		130	105	130		125	103
Bulgaria	134	86		82	43	86		82	43
Cyprus[1)]	14	5		5	4	5		5	4
Czech Rep.	234	148		147	74	137		136	69
Denmark	141	71		70	46	64		63	40
Estonia	39	22		20	13	22		20	11
Finland	160	91		90	54	85		85	51
France	1803	862		850	620	942		927	641
Germany	1461	858		835	572	922		895	616
Greece[1)]	291	139		130	77	126		117	76
Hungary	161	114		110	53	103		99	50
Ireland	86	51		50	31	52		50	29
Italy	1509	702		684	509	658		641	471
Latvia	69	43		42	22	40		38	14
Lithuania[1)]	69	42		39	20	44		40	20
Luxembourg[1]	13	7		6	5	7		6	5
Malta	7	3		3	2	3		3	2
Netherlands	259	168		166	134	161		158	129
Poland	578	319		312	191	396		389	212
Portugal	270	157		155	109	151		149	106
Romania	414	298		266	124	298		267	124
Slovakia	88	61		60	36	57		51	32
Slovenia	53	30		19	14	26		19	14
Spain	1125	838		819	523	778		755	486
Sweden	240	123		121	96	131		129	105
UK	1380	837		825	631	821		808	614
EU-27	11007	6325		6149	4182	6358		6171	4140
Croatia[1)]	102	42		42		42		42	
Turkey[1)]	784	474		470		474		474	
Norway	379	90		88	65	89		87	65
Switzerland	160	88		88		88		88	
EU-25	10460	5942		5800	4016	5974		5822	3973

1) No national projections have been supplied. The PRIMES €20 projection and/or the CAPRI agricultural projections have been used instead for the national scenario.

2) Maximum application of all technical measures considered in the RAINS model

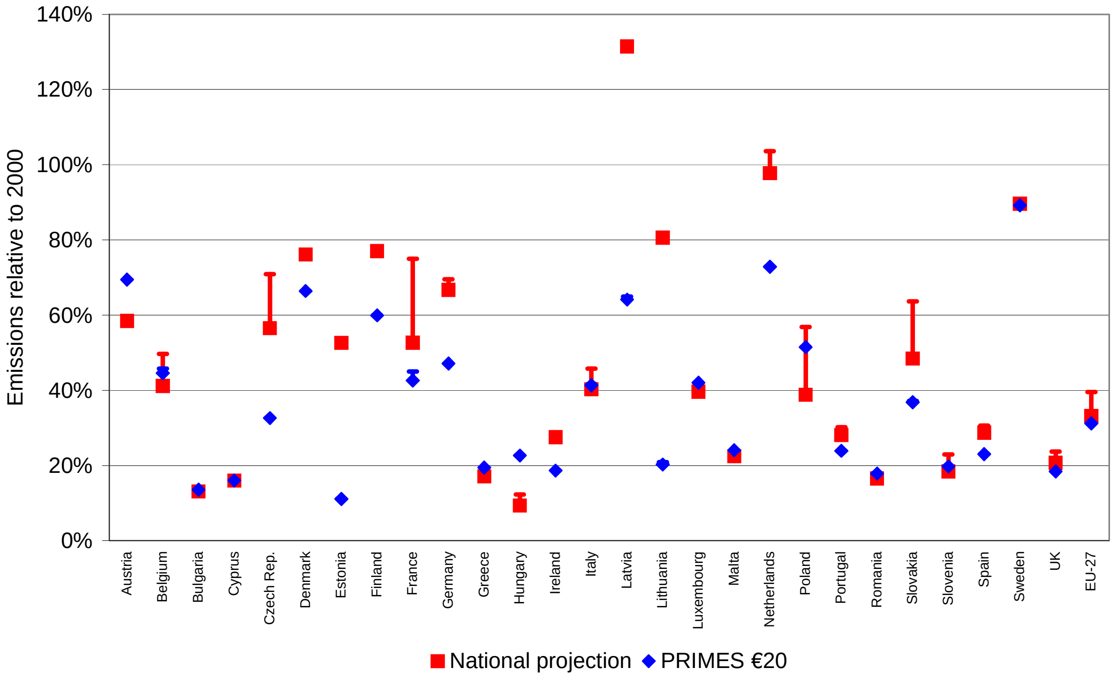

Figure 6.3: Optimized SO_2 emission levels and additional emission reductions beyond CLE baseline, for the calculation with EU-wide introduction of EURO VI measures

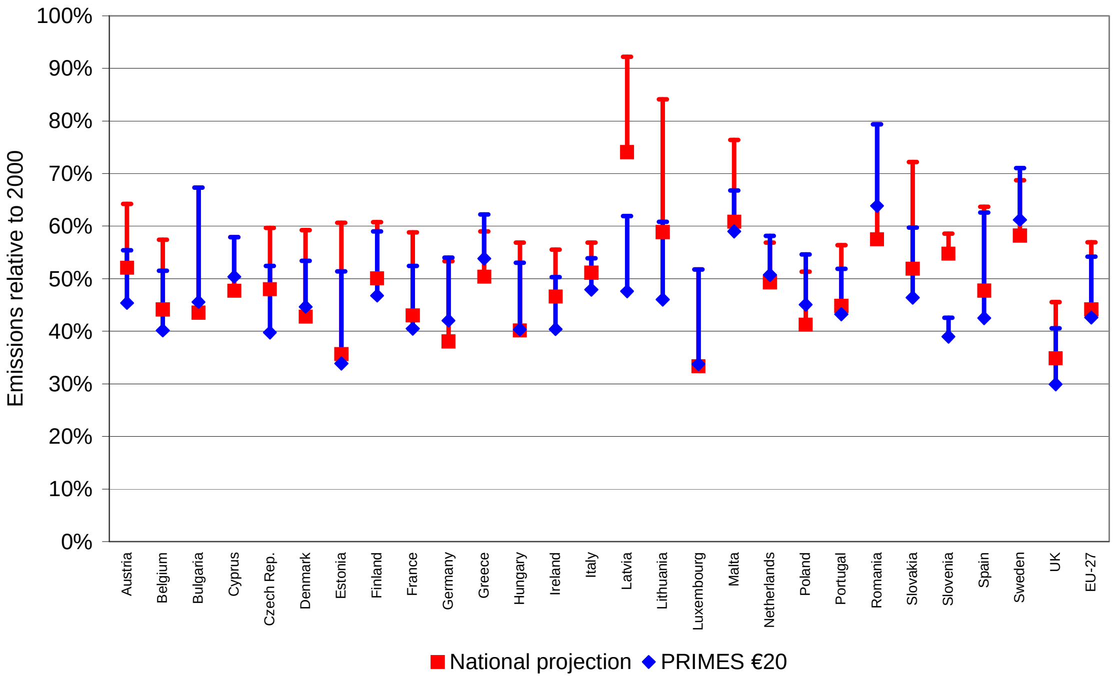

Figure 6.4: Optimized NO_x emission levels and additional emission reductions beyond CLE baseline, for the calculation with EU-wide introduction of EURO VI measures

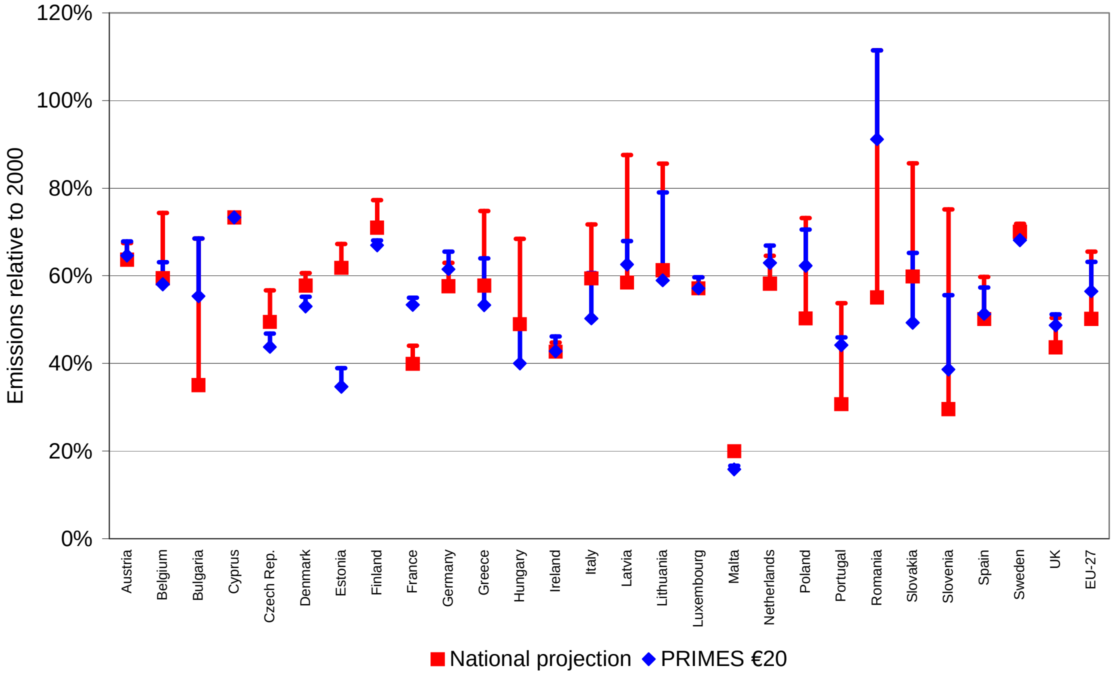

Figure 6.5: Optimized PM2.5 emission levels and additional emission reductions beyond CLE baseline, for the calculation with EU-wide introduction of EURO VI measures

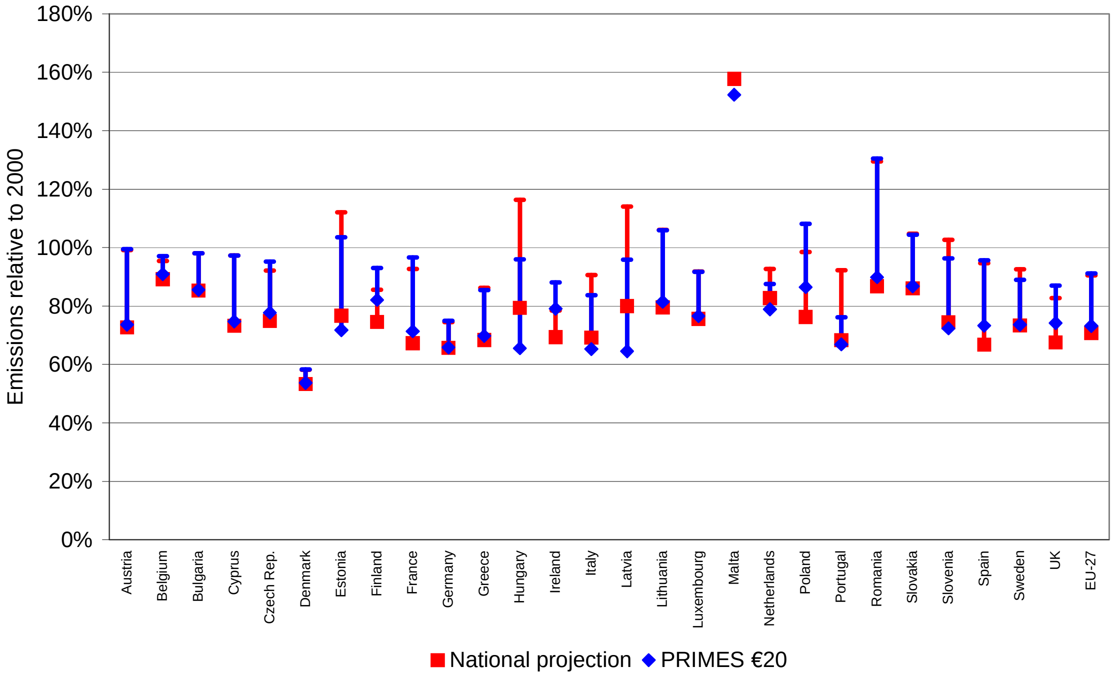

Figure 6.6: Optimized NH_3 emission levels and additional emission reductions beyond CLE baseline, for the calculation with EU-wide introduction of EURO VI measures

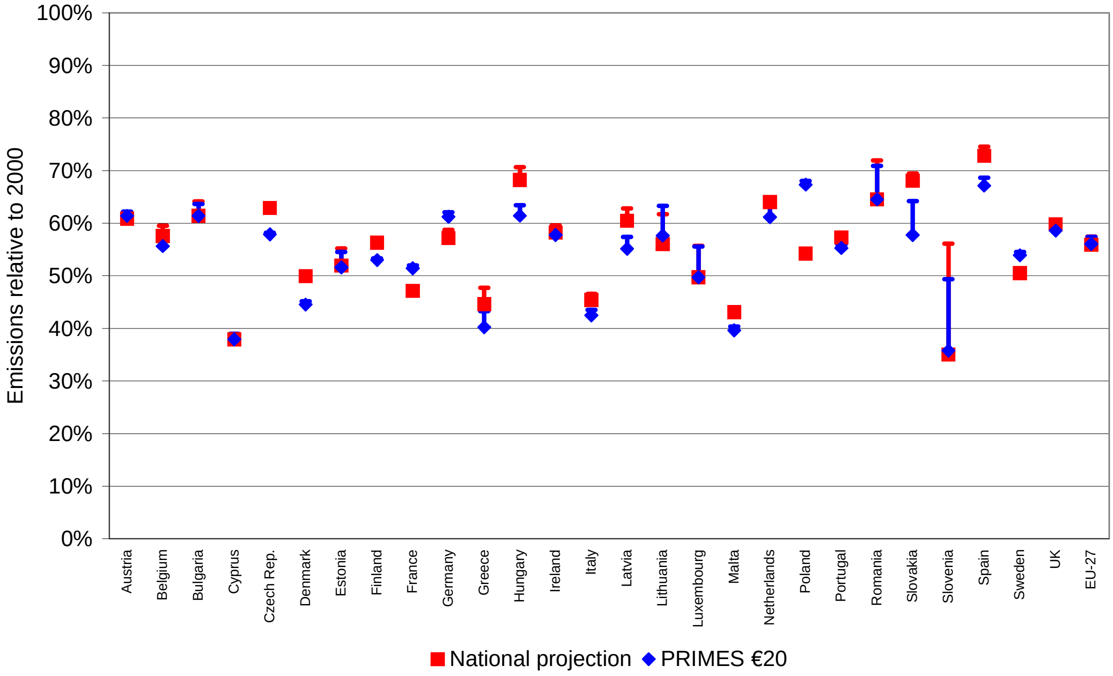

Figure 6.7: Optimized VOC emission levels and additional emission reductions beyond CLE baseline, for the calculation with EU-wide introduction of EURO VI measures

6.2.2 Emissions by SNAP sector

Table 6.15: SO_2 emissions (kt) for the EU-27 by SNAP sector for 2000 and for the optimized scenarios for 2020, assuming the 2020 projections of emissions outside the EU-27

	2000	National activity projections				PRIMES €20 energy and CAPRI agricultural projections			
		Baseline CLE	Without EURO VI	With EURO VI	MRR[1)]	Baseline CLE	Without EURO VI	With EURO VI	MRR[1)]
1: Power generation	7009	1782	1503	1521	876	1185	1184	1184	630
2: Domestic	741	488	384	384	312	327	327	327	202
3: Industrial combustion	1516	1109	907	966	504	980	966	978	435
4: Industrial processes	650	572	425	460	295	592	569	577	320
5: Extraction and distrib.	0	0	0	0	0	0	0	0	0
6: Solvents	0	0	0	0	0	0	0	0	0
7: Road transport	156	14	14	14	14	20	20	20	20
8: Other mob. sources	236	109	62	79	37	134	134	134	43
9: Waste	8	6	4	4	4	3	1	2	1
10: Agri-culture	5	5	0	0	0	6	0	0	0
EU-27	10322	4085	3300	3429	2043	3246	3200	3221	1651

1) Maximum application of all technical measures considered in the RAINS model

Table 6.16: SO_2 emissions (kt) for the EU-27 by SNAP sector for 2000 and for the optimized scenarios for 2020, assuming the 2010 projections of emissions outside the EU-27

	2000	National activity projections				PRIMES €20 energy and CAPRI agricultural projections			
		Baseline CLE	Without EURO VI	With EURO VI	MRR[1)]	Baseline CLE	Without EURO VI	With EURO VI	MRR[1)]
1: Power generation	7009	1782		1303	876	1185		1130	630
2: Domestic	741	488		373	312	327		289	202
3: Industrial combustion	1516	1109		836	504	980		903	435
4: Industrial processes	650	572		385	295	592		521	320
5: Extraction and distrib.	0	0		0	0	0		0	0
6: Solvents	0	0		0	0	0		0	0
7: Road transport	156	14		14	14	20		20	20
8: Other mob. sources	236	109		50	37	134		133	43
9: Waste	8	6		4	4	3		1	1
10: Agri-culture	5	5		0	0	6		0	0
EU-27	10322	4085		2965	2043	3246		2998	1651

1) Maximum application of all technical measures considered in the RAINS model

Table 6.17: NO_x emissions (kt) for the EU-27 by SNAP sector for 2000 and for the optimized scenarios for 2020, assuming the 2020 projections of emissions outside the EU-27

	2000	National activity projections				PRIMES €20 energy and CAPRI agricultural projections			
		Baseline CLE	Without EURO VI	With EURO VI	MRR[1)]	Baseline CLE	Without EURO VI	With EURO VI	MRR[1)]
1: Power generation	2495	1485	1029	1110	754	1345	977	1054	748
2: Domestic	702	702	658	670	516	717	668	685	527
3: Industrial combustion	1416	1488	723	818	531	1337	647	785	480
4: Industrial processes	237	259	159	183	119	244	158	188	124
5: Extraction and distrib.	0	0	0	0	0	0	0	0	0
6: Solvents	0	0	0	0	0	0	0	0	0
7: Road transport	5599	1807	1807	1405	1405	1790	1790	1306	1306
8: Other mob. sources	1851	1254	1254	1254	1254	1229	1229	1229	1229
9: Waste	10	8	4	4	4	7	3	3	3
10: Agri-culture	11	11	0	0	0	12	0	0	0
EU-27	12322	7014	5633	5444	4583	6680	5472	5250	4415

1) Maximum application of all technical measures considered in the RAINS model

Table 6.18: NO_x emissions (kt) for the EU-27 by SNAP sector for 2000 and for the optimized scenarios for 2020, assuming the 2010 projections of emissions outside the EU-27

	2000	National activity projections				PRIMES €20 energy and CAPRI agricultural projections			
		Baseline CLE	Without EURO VI	With EURO VI	MRR[1)]	Baseline CLE	Without EURO VI	With EURO VI	MRR[1)]
1: Power generation	2495	1485		1040	754	1345		1023	748
2: Domestic	702	702		654	516	717		676	527
3: Industrial combustion	1416	1488		761	531	1337		692	480
4: Industrial processes	237	259		157	119	244		163	124
5: Extraction and distrib.	0	0		0	0	0		0	0
6: Solvents	0	0		0	0	0		0	0
7: Road transport	5599	1807		1405	1405	1790		1306	1306
8: Other mob. sources	1851	1254		1254	1254	1229		1229	1229
9: Waste	10	8		4	4	7		3	3
10: Agri-culture	11	11		0	0	12		0	0
EU-27	12322	7014		5275	4583	6680		5090	4415

1) Maximum application of all technical measures considered in the RAINS model

Table 6.19: PM2.5 emissions (kt) for the EU-27 by SNAP sector for 2000 and for the optimized scenarios for 2020, assuming the 2020 projections of emissions outside the EU-27

	2000	National activity projections				PRIMES €20 energy and CAPRI agricultural projections			
		Baseline CLE	Without EURO VI	With EURO VI	MRR[1)]	Baseline CLE	Without EURO VI	With EURO VI	MRR[1)]
1: Power generation	199	140	82	89	64	103	78	101	44
2: Domestic	567	356	303	305	86	353	333	338	70
3: Industrial combustion	143	132	106	107	88	130	125	128	88
4: Industrial processes	236	205	121	128	91	201	141	172	95
5: Extraction and distrib.	7	5	5	5	5	5	5	5	5
6: Solvents	0	0	0	0	0	0	0	0	0
7: Road transport	310	99	99	94	94	98	98	92	92
8: Other mob. sources	157	69	69	69	69	69	69	69	69
9: Waste	85	85	64	65	64	85	66	67	63
10: Agri-culture	77	78	33	33	33	81	34	34	34
EU-27	1782	1167	881	894	592	1125	948	1006	561

1) Maximum application of all technical measures considered in the RAINS model

Table 6.20: PM2.5 emissions (kt) for the EU-27 by SNAP sector for 2000 and for the optimized scenarios for 2020, assuming the 2010 projections of emissions outside the EU-27

	2000	National activity projections				PRIMES €20 energy and CAPRI agricultural projections			
		Baseline CLE	Without EURO VI	With EURO VI	MRR[1)]	Baseline CLE	Without EURO VI	With EURO VI	MRR[1)]
1: Power generation	199	140		79	64	103		67	44
2: Domestic	567	356		298	86	353		333	70
3: Industrial combustion	143	132		103	88	130		115	88
4: Industrial processes	236	205		120	91	201		135	95
5: Extraction and distrib.	7	5		5	5	5		5	5
6: Solvents	0	0		0	0	0		0	0
7: Road transport	310	99		94	94	98		92	92
8: Other mob. sources	157	69		69	69	69		69	69
9: Waste	85	85		64	64	85		64	63
10: Agri-culture	77	77		33	33	81		34	34
EU-27	1782	1166		863	592	1125		913	561

1) Maximum application of all technical measures considered in the RAINS model

Table 6.21: NH_3 emissions (kt) for the EU-27 by SNAP sector for 2000 and for the optimized scenarios for 2020, assuming the 2020 projections of emissions outside the EU-27

	2000	National activity projections				PRIMES €20 energy and CAPRI agricultural projections			
		Baseline CLE	Without EURO VI	With EURO VI	MRR[1)]	Baseline CLE	Without EURO VI	With EURO VI	MRR[1)]
1: Power generation	6	12	18	15	23	16	18	16	24
2: Domestic	18	18	18	18	16	18	18	18	17
3: Industrial combustion	3	5	11	5	13	4	9	3	11
4: Industrial processes	75	68	41	59	30	68	60	64	30
5: Extraction and distrib.	0	0	0	0	0	0	0	0	0
6: Solvents	0	0	0	0	0	0	0	0	0
7: Road transport	78	20	20	20	20	22	22	22	22
8: Other mob. sources	1	1	1	1	1	1	1	1	1
9: Waste	180	175	175	175	175	173	173	173	173
10: Agri-culture	3615	3299	2467	2519	2214	3322	2513	2611	2224
EU-27	3975	3598	2750	2813	2493	3625	2816	2910	2502

1) Maximum application of all technical measures considered in the RAINS model

Table 6.22: NH_3 emissions (kt) for the EU-27 by SNAP sector for 2000 and for the optimized scenarios for 2020, assuming the 2010 projections of emissions outside the EU-27

	2000	National activity projections				PRIMES €20 energy and CAPRI agricultural projections			
		Baseline CLE	Without EURO VI	With EURO VI	MRR[1)]	Baseline CLE	Without EURO VI	With EURO VI	MRR[1)]
1: Power generation	6	12		18	23	16		17	24
2: Domestic	18	18		18	16	18		18	17
3: Industrial combustion	3	5		8	13	4		7	11
4: Industrial processes	75	68		35	30	68		38	30
5: Extraction and distrib.	0	0		0	0	0		0	0
6: Solvents	0	0		0	0	0		0	0
7: Road transport	78	20		20	20	22		22	22
8: Other mob. sources	1	1		1	1	1		1	1
9: Waste	180	175		175	175	173		173	173
10: Agri-culture	3615	3299		2423	2214	3322		2456	2224
EU-27	3975	3598		2698	2493	3625		2733	2502

1) Maximum application of all technical measures considered in the RAINS model

Table 6.23: VOC emissions (kt) for the EU-27 by SNAP sector for 2000 and for the optimized scenarios for 2020, assuming the 2020 projections of emissions outside the EU-27

	2000	National activity projections				PRIMES €20 energy and CAPRI agricultural projections			
		Baseline CLE	Without EURO VI	With EURO VI	MRR[1)]	Baseline CLE	Without EURO VI	With EURO VI	MRR[1)]
1: Power generation	108	101	101	101	101	124	124	124	124
2: Domestic	1094	562	540	541	113	638	621	621	121
3: Industrial combustion	56	79	79	79	79	51	51	51	51
4: Industrial processes	1157	1114	1114	1114	799	1131	1130	1130	817
5: Extraction and distrib.	704	587	584	584	441	635	630	630	473
6: Solvents	3865	2709	2683	2683	1608	2651	2626	2626	1574
7: Road transport	3070	584	584	528	528	581	581	514	514
8: Other mob. sources	766	388	388	388	388	340	340	340	340
9: Waste	111	124	124	124	115	124	124	124	115
10: Agri-culture	77	77	10	10	10	83	11	11	11
EU-27	11007	6325	6207	6153	4182	6358	6237	6171	4140

1) Maximum application of all technical measures considered in the RAINS model

Table 6.24: VOC emissions (kt) for the EU-27 by SNAP sector for 2000 and for the optimized scenarios for 2020, assuming the 2010 projections of emissions outside the EU-27

	2000	National activity projections				PRIMES €20 energy and CAPRI agricultural projections			
		Baseline CLE	Without EURO VI	With EURO VI	MRR[1)]	Baseline CLE	Without EURO VI	With EURO VI	MRR[1)]
1: Power generation	108	101		101	101	124		124	124
2: Domestic	1094	562		537	113	638		621	121
3: Industrial combustion	56	79		79	79	51		51	51
4: Industrial processes	1157	1114		1114	799	1131		1130	817
5: Extraction and distrib.	704	587		584	441	635		630	473
6: Solvents	3865	2709		2683	1608	2651		2626	1574
7: Road transport	3070	584		528	528	581		514	514
8: Other mob. sources	766	388		388	388	340		340	340
9: Waste	111	124		124	115	124		124	115
10: Agri-culture	77	77		10	10	83		11	11
EU-27	11007	6325		6149	4182	6358		6171	4140

1) Maximum application of all technical measures considered in the RAINS model

6.3 Emission control costs

The following tables provide emission control costs by Member States and SNAP sector. In presenting the cost estimates, (arbitrary) assumptions have been made on the allocation of costs of multi-pollutant measures to a single pollutant to avoid double-counting of costs. In essence, costs have been allocated to the “main” pollutant, or the pollutant for which the largest emission reduction percentage is achieved. In particular, costs of Euro-packages in the transport sector have been fully accounted under NO_x, even if they also reduce PM and VOC emissions. For the domestic sector, costs of measures for cleaner heating devices for solid fuels have been accounted under PM, although they also reduce VOC and sometimes NO_x emissions. It is important to mention that these (arbitrary) rules have been only applied for presenting the costs in the following tables. The GAINS optimization avoids such allocation and considers reductions of multiple pollutants at one single cost figure as described in Section 2.3.

6.3.1 Emission control costs by country

Table 6.25: Emission control costs for SO_2 on top of the CAFE baseline scenario (million €/yr) for the optimized scenarios based on 2020 emission projections for non-EU countries

	National activity projections			PRIMES €20 energy and CAPRI agricultural projections		
	Without EURO VI	With EURO VI	MRR[2)]	Without EURO VI	With EURO VI	MRR[2)]
Austria	0	0	19	0	0	13
Belgium	6	6	53	1	0	79
Bulgaria	1	1	68	0	0	68
Cyprus[1)]	0	0	22	0	0	22
Czech Rep.	17	17	151	0	0	134
Denmark	1	0	73	0	0	26
Estonia	0	0	73	0	0	21
Finland	0	0	81	0	0	42
France	74	70	585	4	2	269
Germany	10	10	1254	0	0	514
Greece[1)]	0	0	130	0	0	94
Hungary	10	5	27	1	0	54
Ireland	0	0	56	0	0	22
Italy	45	21	548	0	0	301
Latvia	1	0	17	0	0	4
Lithuania[1)]	0	0	23	0	0	6
Luxembourg[1]	0	0	4	0	0	4
Malta	0	0	3	0	0	2
Netherlands	3	3	109	0	0	51
Poland	166	143	647	0	0	552
Portugal	3	1	121	0	0	59
Romania	5	3	103	0	0	103
Slovakia	12	9	51	0	0	34
Slovenia	3	2	23	0	0	19
Spain	15	6	302	0	0	267
Sweden	0	0	55	0	0	65
UK	17	17	155	2	0	215
EU-27	390	315	4752	7	2	3039
Croatia[1)]	0	0		0	0	
Turkey[1)]	0	0		0	0	
Norway	0	0	22	0	0	18
Switzerland	0	0		0	0	
EU-25	384	312	4581	7	2	2868

1) No national projections have been supplied. The PRIMES €20 projection and/or the CAPRI agricultural projections have been used instead for the national scenario.
2) Maximum application of all technical measures considered in the RAINS model

Table 6.26: Emission control costs for NO_x on top of the NEC baseline scenario (million €/yr) for the optimized scenarios based on 2020 emission projections for non-EU countries. These numbers include costs for EURO VI measures that have also impacts on PM emissions.

	National activity projections			PRIMES €20 energy and CAPRI agricultural projections		
	Without EURO VI	With EURO VI	MRR[2)]	Without EURO VI	With EURO VI	MRR[2)]
Austria	19	44	140	18	45	150
Belgium	42	64	186	69	54	183
Bulgaria	31	60	118	26	54	118
Cyprus[1)]	7	6	14	1	5	14
Czech Rep.	66	53	243	58	58	200
Denmark	55	46	132	44	34	88
Estonia	18	17	52	19	17	27
Finland	70	37	121	85	23	105
France	212	268	1168	157	265	1021
Germany	428	468	1016	329	439	1169
Greece[1)]	27	60	187	20	76	203
Hungary	32	52	173	26	36	174
Ireland	15	18	116	9	25	106
Italy	36	153	838	35	160	1080
Latvia	15	12	25	19	11	37
Lithuania[1)]	25	19	87	27	22	67
Luxembourg[1]	3	16	31	3	15	31
Malta	0	6	6	0	5	6
Netherlands	88	59	200	81	95	359
Poland	113	204	499	133	192	489
Portugal	23	47	153	7	33	120
Romania	60	138	377	57	105	377
Slovakia	24	28	140	19	21	127
Slovenia	3	4	18	2	3	17
Spain	125	314	1085	107	283	924
Sweden	92	64	164	53	21	56
UK	323	245	1276	253	240	1170
EU-27	1952	2502	8565	1639	2336	8416
Croatia[1)]	0	0		0	0	
Turkey[1)]	0	0		0	0	
Norway	34	35	93	56	55	103
Switzerland	0	0		0	0	
EU-25	1861	2304	8070	1555	2178	7921

1) No national projections have been supplied. The PRIMES €20 projection and/or the CAPRI agricultural projections have been used instead for the national scenario.

2) Maximum application of all technical measures considered in the RAINS model

Table 6.27: Emission control costs for PM2.5 on top of the NEC baseline scenario (million €/yr) for the optimized scenarios based on 2020 emission projections for non-EU countries.

	National activity projections			PRIMES €20 energy and CAPRI agricultural projections		
	Without EURO VI	With EURO VI	MRR[2]	Without EURO VI	With EURO VI	MRR[2]
Austria	0	0	348	0	0	381
Belgium	9	8	181	0	0	142
Bulgaria	8	7	539	1	0	539
Cyprus[1]	0	0	7	0	0	7
Czech Rep.	3	3	420	0	0	309
Denmark	0	0	262	0	0	215
Estonia	1	0	162	0	0	196
Finland	1	1	744	0	0	691
France	13	6	3078	2	0	5334
Germany	8	5	772	2	1	1114
Greece[1]	2	2	381	0	0	168
Hungary	3	3	499	1	1	412
Ireland	0	0	47	0	0	74
Italy	12	2	1423	1	0	696
Latvia	1	1	340	0	0	477
Lithuania[1]	0	0	265	0	0	315
Luxembourg[1]	0	0	4	0	0	4
Malta	0	0	1	0	0	1
Netherlands	1	1	131	0	0	130
Poland	22	21	1650	8	5	2884
Portugal	10	7	369	5	0	262
Romania	23	23	2107	10	1	2107
Slovakia	3	2	297	1	0	122
Slovenia	1	1	29	1	0	22
Spain	6	5	634	0	0	811
Sweden	0	0	126	0	0	86
UK	11	7	340	1	0	304
EU-27	139	105	15157	32	9	17803
	0					
Croatia[1]	0	0		0	0	
Turkey[1]	0	0		0	0	
Norway	0	0	518	0	0	515
Switzerland	0	0		0	0	
EU-25	108	75	12511	22	8	15156

1) No national projections have been supplied. The PRIMES €20 projection and/or the CAPRI agricultural projections have been used instead for the national scenario.

2) Maximum application of all technical measures considered in the RAINS model

Table 6.28: Emission control costs for NH_3 on top of the NEC baseline scenario (million €/yr) for the optimized scenarios based on 2020 emission projections for non-EU countries.

	National activity projections			PRIMES €20 energy and CAPRI agricultural projections		
	Without EURO VI	With EURO VI	MRR[2)]	Without EURO VI	With EURO VI	MRR[2)]
Austria	74	52	195	68	52	203
Belgium	56	22	97	41	20	105
Bulgaria	24	15	69	15	14	69
Cyprus[1)]	11	9	21	8	7	21
Czech Rep.	36	28	77	30	21	79
Denmark	63	43	73	66	36	71
Estonia	17	15	17	14	13	14
Finland	18	23	67	15	15	68
France	369	319	1293	353	283	1423
Germany	168	84	445	202	85	445
Greece[1)]	59	38	116	43	27	116
Hungary	23	22	181	17	17	128
Ireland	91	86	199	90	83	219
Italy	253	225	605	213	185	587
Latvia	17	6	19	15	6	16
Lithuania[1)]	59	47	99	82	41	99
Luxembourg[1)]	6	4	9	4	4	9
Malta	0	0	4	0	0	4
Netherlands	62	55	193	58	44	203
Poland	97	83	528	115	61	567
Portugal	52	45	171	15	11	168
Romania	115	95	409	74	78	411
Slovakia	12	8	82	8	7	82
Slovenia	23	18	42	16	12	42
Spain	394	321	1065	270	209	1083
Sweden	95	67	134	99	42	110
UK	175	117	343	158	82	347
EU-27	2369	1845	6555	2090	1455	6689
Croatia[1)]	0	0		0	0	
Turkey[1)]	0	0		0	0	
Norway	104	58	104	104	51	104
Switzerland	53	98		0	0	
EU-25	2229	1735	6077	2000	1363	6209

1) No national projections have been supplied. The PRIMES €20 projection and/or the CAPRI agricultural projections have been used instead for the national scenario.

2) Maximum application of all technical measures considered in the RAINS model

Table 6.29: Emission control costs for VOC on top of the NEC baseline scenario (million €/yr) for the optimized scenarios based on 2020 emission projections for non-EU countries.

	National activity projections			PRIMES €20 energy and CAPRI agricultural projections		
	Without EURO VI	With EURO VI	MRR[2]	Without EURO VI	With EURO VI	MRR[2]
Austria	0	0	209	0	0	222
Belgium	0	0	247	0	0	241
Bulgaria	0	0	120	0	0	120
Cyprus[1]	0	0	10	0	0	10
Czech Rep.	0	0	647	0	0	648
Denmark	0	0	301	0	0	301
Estonia	0	0	21	0	0	22
Finland	0	0	205	0	0	207
France	0	0	1407	0	0	1424
Germany	0	0	2410	0	0	2476
Greece[1]	0	0	252	0	0	247
Hungary	0	0	156	0	0	155
Ireland	0	0	122	0	0	118
Italy	0	0	1286	0	0	1452
Latvia	0	0	129	0	0	127
Lithuania[1]	0	0	156	0	0	157
Luxembourg[1]	0	0	7	0	0	7
Malta	0	0	9	0	0	9
Netherlands	0	0	417	0	0	426
Poland	0	0	751	0	0	767
Portugal	0	0	190	0	0	193
Romania	0	0	1018	0	0	1018
Slovakia	0	0	246	0	0	245
Slovenia	0	0	34	0	0	38
Spain	0	0	2171	0	0	1726
Sweden	0	0	237	0	0	238
UK	0	0	2065	0	0	2079
EU-27	0	0	14825	0	0	14674
Croatia[1]	0	0		0	0	
Turkey[1]	0	0		0	0	
Norway	0	0	353	0	0	353
Switzerland	0	0		0	0	
EU-25	0	0	13686	0	0	13536

1) No national projections have been supplied. The PRIMES €20 projection and/or the CAPRI agricultural projections have been used instead for the national scenario.

2) Maximum application of all technical measures considered in the RAINS model

Table 6.30: Total emission control costs for all pollutants on top of the NEC baseline scenario (million €/yr) for the optimized scenarios based on 2020 emission projections for non-EU countries.

	National activity projections			PRIMES €20 energy and CAPRI agricultural projections		
	Without EURO VI	With EURO VI	MRR[2)]	Without EURO VI	With EURO VI	MRR[2)]
Austria	94	96	912	86	97	968
Belgium	113	101	764	111	75	749
Bulgaria	64	83	914	42	68	914
Cyprus[1)]	19	15	74	10	12	74
Czech Rep.	122	100	1539	88	79	1369
Denmark	119	89	841	111	70	701
Estonia	37	33	326	33	29	281
Finland	89	61	1219	99	38	1113
France	667	662	7530	516	550	9471
Germany	614	568	5896	532	524	5717
Greece[1)]	87	100	1067	63	103	827
Hungary	68	82	1034	45	54	924
Ireland	105	104	540	99	108	540
Italy	346	401	4700	249	345	4117
Latvia	35	19	530	33	18	661
Lithuania[1)]	85	66	630	110	63	644
Luxembourg[1)]	9	20	54	7	19	54
Malta	0	6	24	0	5	22
Netherlands	154	118	1050	140	138	1170
Poland	398	451	4075	256	259	5258
Portugal	89	99	1004	26	44	802
Romania	205	260	4016	141	183	4017
Slovakia	50	47	817	28	28	611
Slovenia	29	25	146	18	15	139
Spain	541	646	5257	377	491	4811
Sweden	187	131	717	152	63	556
UK	526	386	4179	413	322	4113
EU-27	4850	4768	49853	3768	3803	50621
Croatia[1)]	0	0		0	0	
Turkey[1)]	0	0		0	0	
Norway	139	93	1091	159	106	1093
Switzerland	87	132		0	0	
EU-25	4582	4426	44924	3584	3551	45690

1) No national projections have been supplied. The PRIMES €20 projection and/or the CAPRI agricultural projections have been used instead for the national scenario.

2) Maximum application of all technical measures considered in the RAINS model

Table 6.31: Total emission control costs for all pollutants on top of the NEC baseline scenario (million €/yr) for the optimized scenarios based on 2010 emission projections for non-EU countries.

	National activity projections			PRIMES €20 energy and CAPRI agricultural projections		
	Without EURO VI	With EURO VI	MRR[2)]	Without EURO VI	With EURO VI	MRR[2)]
Austria		126	912		144	968
Belgium		141	764		120	749
Bulgaria		107	914		95	914
Cyprus[1)]		20	74		19	74
Czech Rep.		165	1539		121	1369
Denmark		113	841		108	701
Estonia		26	326		26	281
Finland		72	1219		56	1113
France		928	7530		802	9471
Germany		738	5896		695	5717
Greece[1)]		131	1067		139	827
Hungary		119	1034		79	924
Ireland		131	540		132	540
Italy		511	4700		435	4117
Latvia		23	530		18	661
Lithuania[1)]		89	630		80	644
Luxembourg[1)]		21	54		21	54
Malta		7	24		5	22
Netherlands		214	1050		210	1170
Poland		648	4075		393	5258
Portugal		137	1004		59	802
Romania		366	4016		315	4017
Slovakia		78	817		50	611
Slovenia		38	146		28	139
Spain		926	5257		708	4811
Sweden		177	717		110	556
UK		548	4179		466	4113
EU-27		6602	49853		5436	50621
Croatia[1)]		0			0	
Turkey[1)]		178			0	
Norway		119	1091		145	1093
Switzerland		1			0	
EU-25		6129	44924		5027	45690

1) No national projections have been supplied. The PRIMES €20 projection and/or the CAPRI agricultural projections have been used instead for the national scenario.

2) Maximum application of all technical measures considered in the RAINS model

6.3.2 Emission control costs by SNAP sector

Table 6.32: SO_2 emission control costs on top of the NEC baseline scenario (million €/yr) for the EU-27 by SNAP sector for 2000 and for the optimized scenarios for 2020, assuming the 2020 projections of emissions outside the EU-27

	National activity projections			PRIMES €20 energy and CAPRI agricultural projections		
	Without EURO VI	With EURO VI	MRR[1)]	Without EURO VI	With EURO VI	MRR[1)]
1: Power generation	154	146	2908	0	0	1490
2: Domestic	48	47	342	0	0	336
3: Ind. combustion	102	66	1180	3	0	877
4: Ind. processes	59	39	232	3	2	226
5: Extraction & distr.	0	0	0	0	0	0
6: Solvents	0	0	0	0	0	0
7: Road transport	0	0	0	0	0	0
8: Other mobile	27	18	90	0	0	109
9: Waste	0	0	0	0	0	0
10: Agriculture	0	0	0	0	0	0
EU-27	390	315	4752	7	2	3039

1) Maximum application of all technical measures considered in the RAINS model

Table 6.33: SO_2 emission control costs on top of the NEC baseline scenario (million €/yr) for the EU-27 by SNAP sector for 2000 and for the optimized scenarios for 2020, assuming the 2010 projections of emissions outside the EU-27

	National activity projections			PRIMES €20 energy and CAPRI agricultural projections		
	Without EURO VI	With EURO VI	MRR[1)]	Without EURO VI	With EURO VI	MRR[1)]
1: Power generation		321	2908		17	1490
2: Domestic		54	342		17	336
3: Ind. combustion		155	1180		30	877
4: Ind. processes		96	232		17	226
5: Extraction & distr.		0	0		0	0
6: Solvents		0	0		0	0
7: Road transport		0	0		0	0
8: Other mobile		34	90		1	109
9: Waste		0	0		0	0
10: Agriculture		0	0		0	0
EU-27		660	4752		81	3039

1) Maximum application of all technical measures considered in the RAINS model

Table 6.34: NO_x emission control costs on top of the NEC baseline scenario (million €/yr) for the EU-27 by SNAP sector for 2000 and for the optimized scenarios for 2020, assuming the 2020 projections of emissions outside the EU-27. These figures include total costs for the EURO VI measures.

	National activity projections			PRIMES €20 energy and CAPRI agricultural projections		
	Without EURO VI	With EURO VI	MRR[1)]	Without EURO VI	With EURO VI	MRR[1)]
1: Power generation	755	423	2574	544	204	2682
2: Domestic	107	64	1749	135	65	1762
3: Ind. combustion	921	544	2462	840	395	2027
4: Ind. processes	160	77	385	131	44	314
5: Extraction & distr.	0	0	0	0	0	0
6: Solvents	0	0	0	0	0	0
7: Road transport	0	1387	1388	0	1622	1622
8: Other mobile	0	0	0	0	0	0
9: Waste	4	4	4	4	2	4
10: Agriculture	3	3	3	4	4	4
EU-27	1952	2502	8566	1639	2336	8416

1) Maximum application of all technical measures considered in the RAINS model

Table 6.35: NO_x mission control costs on top of the NEC baseline scenario (million €/yr) for the EU-27 by SNAP sector for 2000 and for the optimized scenarios for 2020, assuming the 2010 projections of emissions outside the EU-27. These figures include total costs for the EURO VI measures.

	National activity projections			PRIMES €20 energy and CAPRI agricultural projections		
	Without EURO VI	With EURO VI	MRR[1)]	Without EURO VI	With EURO VI	MRR[1)]
1: Power generation		651	2574		289	2682
2: Domestic		115	1749		93	1762
3: Ind. combustion		732	2462		635	2027
4: Ind. processes		165	385		109	314
5: Extraction & distr.		0	0		0	0
6: Solvents		0	0		0	0
7: Road transport		1387	1388		1622	1622
8: Other mobile		0	0		0	0
9: Waste		4	4		4	4
10: Agriculture		3	3		4	4
EU-27		3058	8566		2755	8416

1) Maximum application of all technical measures considered in the RAINS model

Table 6.36: PM2.5 emission control costs on top of the NEC baseline scenario (million €/yr) for the EU-27 by SNAP sector for 2000 and for the optimized scenarios for 2020, assuming the 2020 projections of emissions outside the EU-27

	National activity projections			PRIMES €20 energy and CAPRI agricultural projections		
	Without EURO VI	With EURO VI	MRR[1)]	Without EURO VI	With EURO VI	MRR[1)]
1: Power generation	36	28	235	8	1	157

2: Domestic	31	24	12565	8	6	15526
3: Ind. combustion	32	27	210	2	0	186
4: Ind. processes	37	24	2140	13	2	1927
5: Extraction & distr.	0	0	1	0	0	1
6: Solvents	0	0	0	0	0	0
7: Road transport	0	0	0	0	0	0
8: Other mobile	0	0	0	0	0	0
9: Waste	4	3	4	1	0	4
10: Agriculture	0	0	2	0	0	2
EU-27	139	105	15157	32	9	17803

1) Maximum application of all technical measures considered in the RAINS model

Table 6.37: PM2.5 emission control costs on top of the NEC baseline scenario (million €/yr) for the EU-27 by SNAP sector for 2000 and for the optimized scenarios for 2020, assuming the 2010 projections of emissions outside the EU-27

	National activity projections			PRIMES €20 energy and CAPRI agricultural projections		
	Without EURO VI	With EURO VI	MRR[1)]	Without EURO VI	With EURO VI	MRR[1)]
1: Power generation		41	235		14	157
2: Domestic		44	12565		9	15526
3: Ind. combustion		41	210		13	186
4: Ind. processes		41	2140		17	1927
5: Extraction & distr.		0	1		0	1
6: Solvents		0	0		0	0
7: Road transport		0	0		0	0
8: Other mobile		0	0		0	0
9: Waste		4	4		3	4
10: Agriculture		0	2		0	2
EU-27		172	15157		56	17803

1) Maximum application of all technical measures considered in the RAINS model

Table 6.38: NH_3 emission control costs on top of the NEC baseline scenario (million €/yr) for the EU-27 by SNAP sector for 2000 and for the optimized scenarios for 2020, assuming the 2020 projections of emissions outside the EU-27

	National activity projections			PRIMES €20 energy and CAPRI agricultural projections		
	Without EURO VI	With EURO VI	MRR[1)]	Without EURO VI	With EURO VI	MRR[1)]
1: Power generation	0	0	0	0	0	0
2: Domestic	0	0	0	0	0	0
3: Ind. combustion	0	0	0	0	0	0
4: Ind. processes	191	62	267	58	27	267
5: Extraction & distr.	0	0	0	0	0	0
6: Solvents	0	0	0	0	0	0
7: Road transport	0	0	0	0	0	0
8: Other mobile	0	0	0	0	0	0
9: Waste	0	0	0	0	0	0
10: Agriculture	2178	1784	6288	2032	1428	6422
EU-27	2369	1845	6555	2090	1455	6689

1) Maximum application of all technical measures considered in the RAINS model

Table 6.39: NH_3 emission control costs on top of the NEC baseline scenario (million €/yr) for the EU-27 by SNAP sector for 2000 and for the optimized scenarios for 2020, assuming the 2010 projections of emissions outside the EU-27

	National activity projections			PRIMES €20 energy and CAPRI agricultural projections		
	Without EURO VI	With EURO VI	MRR[1)]	Without EURO VI	With EURO VI	MRR[1)]
1: Power generation		0	0		0	0
2: Domestic		0	0		0	0
3: Ind. combustion		0	0		0	0
4: Ind. processes		232	267		214	267
5: Extraction & distr.		0	0		0	0
6: Solvents		0	0		0	0
7: Road transport		0	0		0	0
8: Other mobile		0	0		0	0
9: Waste		0	0		0	0
10: Agriculture		2480	6288		2342	6422
EU-27		2712	6555		2556	6689

1) Maximum application of all technical measures considered in the RAINS model

Table 6.40: VOC SO_2 emission control costs on top of the NEC baseline scenario (million €/yr) for the EU-27 by SNAP sector for 2000 and for the optimized scenarios for 2020, assuming the 2020 projections of emissions outside the EU-27

	National activity projections			PRIMES €20 energy and CAPRI agricultural projections		
	Without EURO VI	With EURO VI	MRR[1)]	Without EURO VI	With EURO VI	MRR[1)]
1: Power generation	0	0	0	0	0	0
2: Domestic	0	0	0	0	0	0
3: Ind. combustion	0	0	0	0	0	0
4: Ind. processes	0	0	1077	0	0	1076
5: Extraction & distr.	0	0	1449	0	0	1538
6: Solvents	0	0	12295	0	0	12057
7: Road transport	0	0	0	0	0	0
8: Other mobile	0	0	0	0	0	0
9: Waste	0	0	4	0	0	4
10: Agriculture	0	0	0	0	0	0
EU-27	0	0	14825	0	0	14674

1) Maximum application of all technical measures considered in the RAINS model

Table 6.41: VOC emission control costs on top of the NEC baseline scenario (million €/yr) for the EU-27 by SNAP sector for 2000 and for the optimized scenarios for 2010, assuming the 2010 projections of emissions outside the EU-27

	National activity projections			PRIMES €20 energy and CAPRI agricultural projections		
	Without EURO VI	With EURO VI	MRR[1)]	Without EURO VI	With EURO VI	MRR[1)]
1: Power generation		0	0		0	0
2: Domestic		0	0		0	0
3: Ind. combustion		0	0		0	0
4: Ind. processes		0	1077		0	1076
5: Extraction & distr.		0	1449		0	1538
6: Solvents		0	12295		-12	12057
7: Road transport		0	0		0	0
8: Other mobile		0	0		0	0
9: Waste		0	4		0	4
10: Agriculture		0	0		0	0
EU-27		0	14825		-12	14674

1) Maximum application of all technical measures considered in the RAINS model

Table 6.42: Total emission control costs on top of the NEC baseline scenario (million €/yr) for the EU-27 by SNAP sector for 2000 and for the optimized scenarios for 2020, assuming the 2020 projections of emissions outside the EU-27

	National activity projections			PRIMES €20 energy and CAPRI agricultural projections		
	Without EURO VI	With EURO VI	MRR[1)]	Without EURO VI	With EURO VI	MRR[1)]
1: Power generation	945	597	5716	552	204	4329
2: Domestic	186	135	14656	144	71	17624
3: Ind. combustion	1055	637	3853	846	396	3090
4: Ind. processes	447	201	4101	205	75	3811
5: Extraction & distr.	0	0	1450	0	0	1539
6: Solvents	0	0	12295	0	0	12057
7: Road transport	0	1387	1388	0	1622	1622
8: Other mobile	27	18	90	0	0	109
9: Waste	8	7	12	5	2	12
10: Agriculture	2182	1787	6293	2035	1431	6428
EU-27	4850	4768	49854	3768	3803	50621

1) Maximum application of all technical measures considered in the RAINS model

Table 6.43: Total emission control costs on top of the NEC baseline scenario (million €/yr) for the EU-27 by SNAP sector for 2000 and for the optimized scenarios for 2020, assuming the 2010 projections of emissions outside the EU-27

	National activity projections			PRIMES €20 energy and CAPRI agricultural projections		
	Without EURO VI	With EURO VI	MRR[1)]	Without EURO VI	With EURO VI	MRR[1)]
1: Power generation		1013	5716		320	4329
2: Domestic		213	14656		118	17624
3: Ind. combustion		929	3853		678	3090
4: Ind. processes		535	4101		356	3811
5: Extraction & distr.		0	1450		0	1539
6: Solvents		0	12295		-12	12057
7: Road transport		1387	1388		1622	1622
8: Other mobile		34	90		1	109
9: Waste		8	12		7	12
10: Agriculture		2483	6293		2345	6428
EU-27		6602	49854		5436	50621

1) Maximum application of all technical measures considered in the RAINS model

In order to compare these costs to the costs of the CAFE baseline, cost of the Euro5/6 measures that are included in the NEC baseline, but were not included in the CAFE baseline, need to be added. For the EU-27, these costs amount in 2020 for the national activity projections to €5125 million/yr and for the PRIMES €20 projection at €3000 million /yr.

7 Sensitivity analyses

A number of sensitivity analyses have been conducted to explore the robustness of the GAINS optimization results against uncertainties in key assumptions and input parameters. This report addresses (i) impacts of uncertainties in the quantification of the urban increments of PM concentrations that originate from local emissions, (ii) the role of emission control measures for ships outside the EU-27 territory in a cost-effective solution, and (iii) the potential implications of a further harmonization of emission limit values for large combustion plants.

7.1 Modified City-delta estimates

A first sensitivity analysis explored the robustness of the cost-optimal allocation of emission reductions against different quantifications of the urban increment that has been computed with the City-delta approach for fine particulate matter based on the methodology as outlined in Section 2.4.2 of this report. Two test cases explored, for the national activity projections with EURO VI measures, the changes in optimized emission ceilings if the default urban increments that have been computed as described before in this report were doubled or entirely ignored, respectively. This means that the optimization analysis has been repeated for two cases with significantly different quantifications of the impacts of urban low level emissions on urban air quality. Since the different assumptions on the urban increments implies different health impacts (in terms of Years of Life Lost – YOLLs) also for the base year, the baseline and the MRR scenarios, the target level of YOLLs that serves as a constraint in the GAINS optimization had to be recalculated accordingly from the modified base year value.

The resulting changes in the levels of optimized emissions of the various pollutants are illustrated in Figure 7.1 to Figure 7.4. It turns out that, for the given set of environmental targets, different assumptions on the urban increment have in general a rather small impact on the allocation of cost-optimal emission reductions at the national scale. For SO_2, significant variations (±10 percent) occur only for four out of the 27 EU Member States. Differences in optimized NO_x and NH_3 emissions are marginal in all cases, and also for primary PM2.5 emissions differences range within a few percentage points.

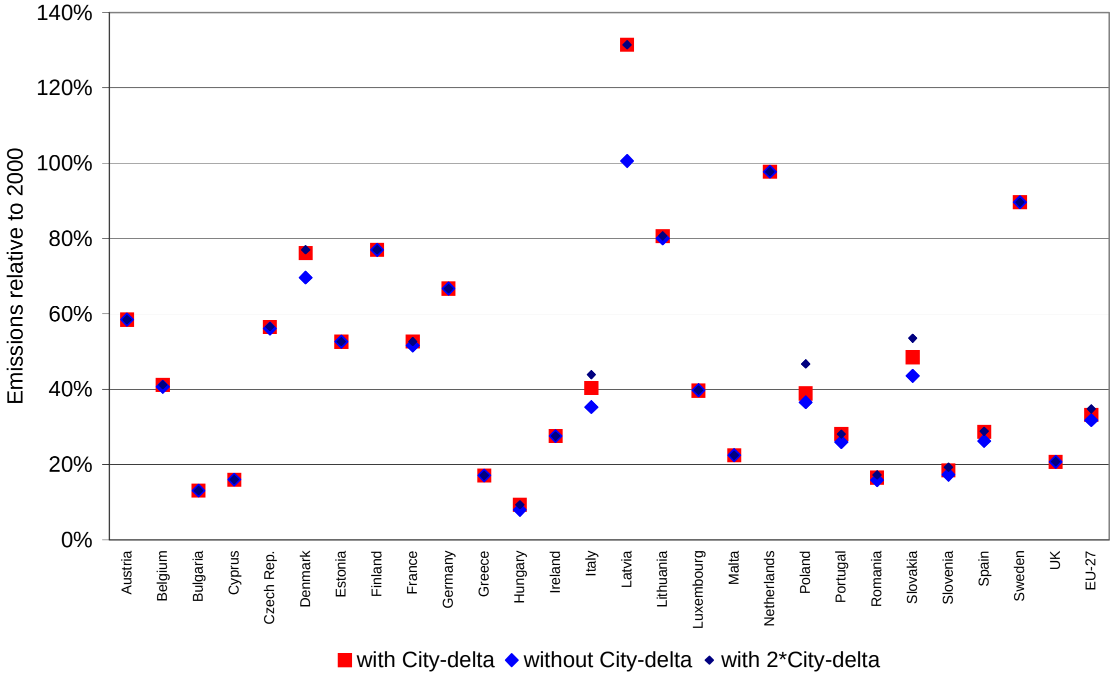

Figure 7.1: Optimized SO_2 emissions (relative to the year 2000) for the national activity projections with EURO VI measures assumed in all countries, for three different assumptions on the computed city-deltas

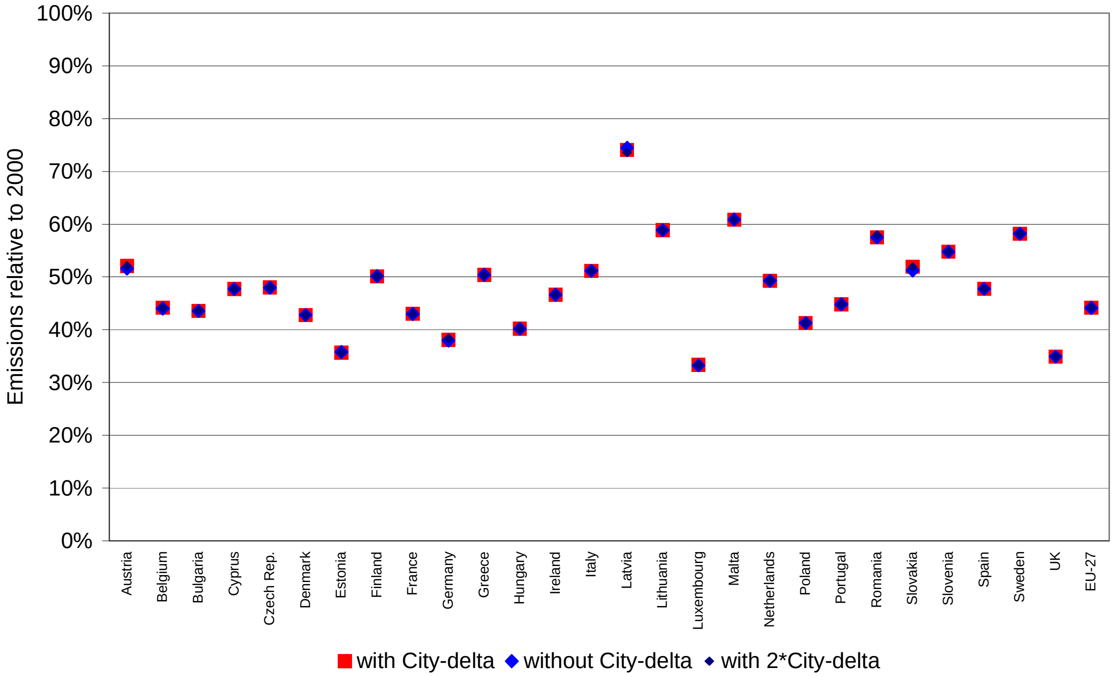

Figure 7.2: Optimized NO_x emissions (relative to the year 2000) for the national activity projections with EURO VI measures assumed in all countries, for three different assumptions on the computed city-deltas

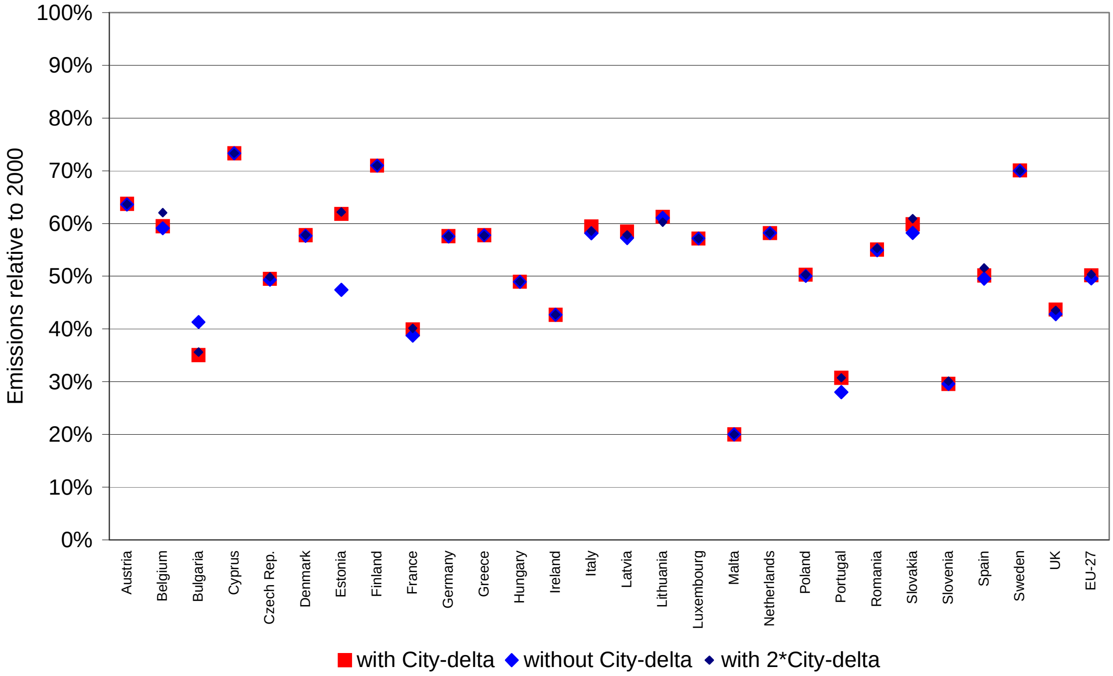

Figure 7.3: Optimized PM2.5 emissions (relative to the year 2000) for the national activity projections with EURO VI measures assumed in all countries, for three different assumptions on the computed city-deltas

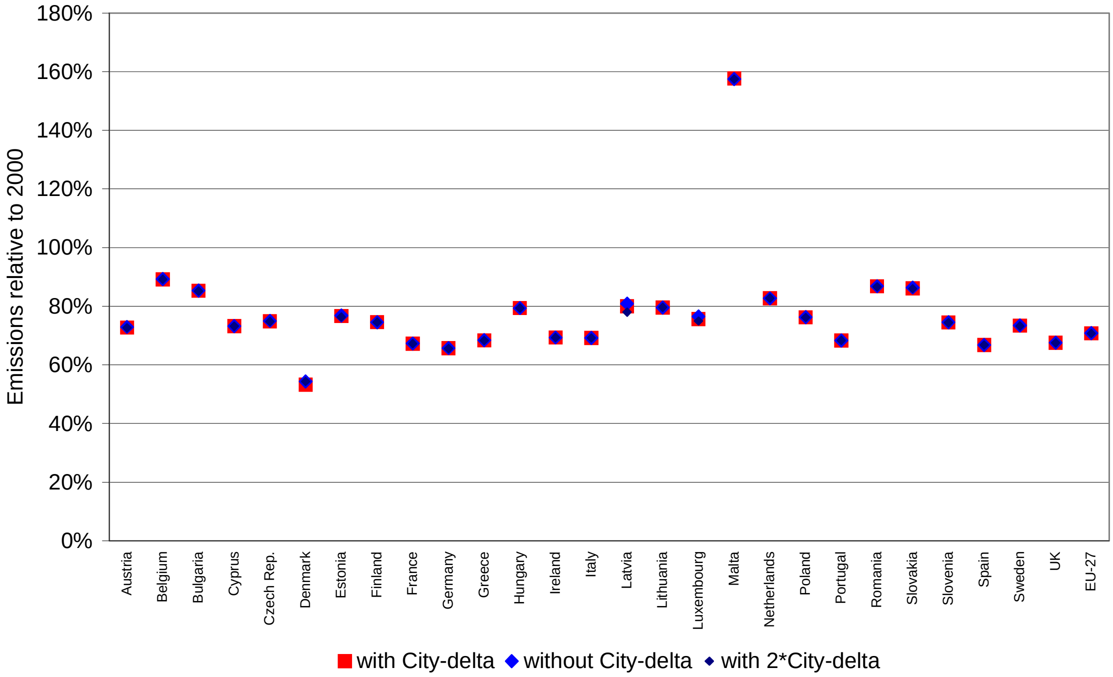

Figure 7.4: Optimized NH_3 emissions (relative to the year 2000) for the national activity projections with EURO VI measures assumed in all countries, for three different assumptions on the computed city-deltas

This perhaps surprising result is explained by two major factors.

First, in the GAINS optimization the city-delta assigns different weights to the control of urban low level emission sources of PM2.5 compared to all other sources. Thus, with the City-delta emission controls at urban low level sources are more cost-effective than controls of other sources. The optimization will therefore give higher priority to such measures, i.e., in the transport sector and for domestic heating. However, in practice, the particular assumptions for the analysis do not consider additional mitigation potential for transport emissions, since the implementation of EURO VI measures is exogenously assumed as given in the definition of the scenario. Thus, the optimization has no freedom to apply further measures in the transport sector. For the domestic sector, there exists a potential for further PM control mainly for wood burning, but as wood burning occurs only in a few countries and even there hardly in cities, there is in practice very little scope for such measures.

The second reason is related to the choice of the environmental objectives for the optimization analysis, which attributes overriding priority to improvements in the eutrophication indicators. Most other environmental targets are met almost automatically as a side impact of the measures that are necessary to satisfy the eutrophication constraints. Therefore, a different quantification of the urban increment in PM2.5 concentrations that influences the calculation of health impacts of fine particles does not affect the achievement of the eutrophication target, and has therefore only very little impact on the optimized results.

7.2 Cost-effectiveness of emission reductions at ships

The main cost-effectiveness analysis presented in this report focuses on emission control measures for land-based sources within the EU-27 and assumes the emission projections for sources outside this region as given. However, it is perceivable that certain measures that are technically available to reduce emissions at these other sources could form cost-effective elements in a strategy to achieve the environmental targets within the EU. Thus, a second sensitivity analysis addressed the cost-effectiveness of technical measures to reduce SO_2 and NO_x emissions from seagoing vessels.

The analysis explored four discrete packages of emission control measures that could be taken at ships in different sea regions (Table 7.1). It has been assumed that national shipping will be subject to the same type of legislation as vessels on international trips.

The study quantified their impact on ship emissions and the consequences on background pollution levels in the EU, and explored the remaining need for measures at the land-based sources within the European Union in order to meet the environmental objectives.

In a cost-effective solution the reduction of emissions from international shipping affects the need to control land-based emission sources. Aggregated results are presented in Table 7.2. The base case presents the cost-efficient national emissions for land-based sources in Europe computed for the ‘Current legislation’ case with baseline emissions from international shipping as described earlier in this report. This scenario determines additional reductions from stationary sources necessary for achieving the objectives of the Thematic Strategy. All scenarios include the effects of implementation of Euro 5 and 6 emission standards on cars and light-duty trucks but do not take into account Euro VI standards for heavy-duty trucks and buses, which are currently under consideration.

Table 7.1: Packages of emission reduction measures assumed for ships

	Baseline
SO_2	Sulphur content as in the EU Marine Fuel Directive (OJ L 191/59, 2005): 1.5% S in residual oil for all ships in "Sulphur Emissions Control Area" (SECA, i.e., North Sea and Baltic Sea); 1.5% S fuel all passenger ships in other sea regions surrounding the European Union; 0.1% S fuel at berth in ports
NO_x	MARPOL NO_x standards for ships built since 2000
	Ambition level 1 - all ships
SO_2	As in the baseline
NO_x	Slide valve retrofit on all slow-speed engines pre-2000
	Internal engine modifications for all new engines post-2010
	Ambition level 2 - all ships
SO_2	0.5% S in residual oil or scrubbing equivalent (2g SO_2/kWh) in SECA, and for passenger vessels everywhere. Cargo vessels as in the baseline
NO_x	Slide valve retrofit on all slow-speed engines pre-2000
	Humid air motors for all new engines post-2010
	Ambition level 3 - all ships
SO_2	Passenger and cargo ships: SECA - 1.0% S in residual oil from 2010, 0.5% or scrubbing equivalent from 2015. Other sea regions - as in the baseline but 0.5% or scrubbing equivalent from 2020
NO_x	Pre-2010 vessels: 15% reduction above baseline level through available retrofit measures. Post-2010 vessels: 50% reduction above baseline level.
	Ambition level 4 - all ships
SO_2	As ambition level 3
NO_x	Pre-2010 vessels: 15% reduction above baseline level through available retrofit measures. Post-2010 vessels: Selective catalytic reduction (SCR) technology

Reduction of emissions from shipping allows higher emissions from land-based sources. Aggregated national emissions of SO_2 for EU27 plus Norway are six to 20 percent higher than in the base case (compare scenarios with "Ambition level 2" and "Ambition level 3"). Emissions of NO_x can increase by four to five percent compared with the scenario with only baseline measures on shipping. Cost-optimal emissions of primary PM2.5 can increase by two to seven percent. Although shipping does not emit meaningful amounts of ammonia (NH_3), land-based ceilings for that pollutant are affected by shipping control strategies. That linkage operates, first of all, via the eutrophication target. Lower deposition of oxidized nitrogen due to control of NO_x emissions from ships allow higher levels of reduced N from ammonia emissions. Thus in our scenarios ammonia emissions can be five to eight percent higher.

Inclusion of measures on shipping importantly influences emission control costs. The costs for national sources are 24 percent (Ambition level 1) to 59 percent (Ambition level 4) lower than for the base case. About 30 to 40 percent of that cost reduction is due to lower costs of controlling ammonia emissions from agriculture. Even after including higher costs for the shipping sector, important net cost savings are possible (1.2 and 1.5 billion €/year for "Ambition level 1" and

“Ambition level 2”, respectively). In spite of quite high costs of reducing emissions from shipping (3.2 billion €/year) for the “Ambition level 4” scenario, the net costs of that scenario are only five percent higher than the baseline costs.

Table 7.3 to Table 7.6 present emissions by country for the scenarios. Differences in national costs are shown in Table 7.7. Countries with a high proportion of their area located close to the sea coast benefit most from stricter controls on shipping emissions. For the “Ambition level 2” scenario Cyprus, Denmark, Estonia, Finland, Greece, Latvia, Sweden and Norway reduce their national control costs by more than 85 percent. Costs for Bulgaria, Italy, Lithuania, Netherlands, Portugal, and UK are 40 to 70 percent lower.

Emission reductions from shipping are much higher than the corresponding increase in the emissions from land-based sources. For SO_2, the ratio is two to four depending on the scenario. For NO_x this ratio is six to seven. This is because a smaller fraction of emissions from shipping is transported to sensitive receptor areas, than it is a case with the emissions from land-based stationary sources. Nevertheless, since costs of reducing (weekly controlled or uncontrolled) emissions from shipping are low compared with the costs of further cutting emissions from already heavily controlled stationary sources, reducing emissions from shipping is cost-efficient.

Table 7.2: Emissions of air pollutants in 2020 and emission control costs for optimized scenarios with different ambition levels of controlling emissions from international shipping

	Ambition level for shipping				
	Base case	Level 1 all ships	Level 2 all ships	Level 3 all ships	Level 4 all ships
Emissions, kilotons:					
National sources (EU27 plus Norway)					
SO2	3327	3238	3525	3978	3978
NOx	5782	5946	6022	6054	6091
PM 2.5	923	920	942	986	987
NH3	2763	2794	2902	2933	2977
International shipping					
SO2	3186	3186	2767	758	758
NOx	4828	4383	3511	3212	2732
PM 2.5	396	396	394	338	338
Cost on top of ‘Current legislation’ baseline, million Euro/year					
National sources (land-based)	5025	3810	2713	2264	2041
Shipping(1)	0	47	828	2523	3232
Total	5025	3856	3541	4786	5273
Difference from base case		-1169	-1484	-238	249

[1] Includes control costs for international and national shipping

Table 7.3: Optimized SO_2 emissions from national sources for shipping scenarios with different ambition levels

		Ambition level for shipping			
	Base case	Level 1 all ships	Level 2 all ships	Level 3 all ships	Level 4 all ships
Austria	20	20	20	20	20
Belgium	72	71	72	74	74
Bulgaria	111	111	111	115	115
Cyprus	8	8	8	8	8
Czech Rep.	142	141	142	157	157
Denmark	20	19	21	21	21
Estonia	48	48	48	48	48
Finland	59	59	59	59	59
France	342	339	346	435	435
Germany	420	411	420	426	426
Greece	83	83	83	83	83
Hungary	39	39	45	55	55
Ireland	36	36	36	36	36
Italy	266	266	326	339	339
Latvia	15	15	19	19	19
Lithuania	39	38	39	39	39
Luxembourg	2	2	2	2	2
Malta	8	4	8	8	8
Netherlands	73	73	73	77	77
Poland	551	551	621	855	855
Portugal	75	75	81	86	86
Romania	123	104	133	137	137
Slovakia	58	56	68	81	81
Slovenia	17	17	19	22	22
Spain	398	346	420	446	446
Sweden	41	41	41	41	41
UK	239	239	239	264	264
EU-27	3301	3212	3499	3952	3952
Croatia	62	62	62	62	62
Turkey	911	911	910	910	910
Norway	26	26	26	26	26
Switzerland	18	18	18	18	18

Table 7.4: Optimized NO_x emissions from national sources for shipping scenarios with different ambition levels

		Ambition level for shipping			
	Base case	Level 1 all ships	Level 2 all ships	Level 3 all ships	Level 4 all ships
Austria	119	120	119	119	122
Belgium	168	170	173	174	174
Bulgaria	74	73	79	81	82
Cyprus	10	14	15	15	15
Czech Rep.	145	149	156	156	158
Denmark	92	96	102	102	102
Estonia	14	18	21	23	23
Finland	99	113	123	125	125
France	658	672	691	691	691
Germany	711	746	761	765	765
Greece	167	171	169	171	172
Hungary	79	83	87	87	87
Ireland	64	66	69	69	69
Italy	721	721	713	713	713
Latvia	24	26	29	30	30
Lithuania	27	31	33	33	33
Luxembourg	15	15	15	15	15
Malta	5	5	5	5	5
Netherlands	206	222	220	220	220
Poland	351	366	366	378	393
Portugal	129	133	136	136	138
Romania	200	195	189	189	197
Slovakia	56	60	61	61	61
Slovenia	33	33	33	33	33
Spain	677	671	664	665	666
Sweden	132	138	135	135	135
UK	660	696	727	728	732
EU-27	5633	5803	5892	5921	5958
Croatia	53	53	53	53	53
Turkey	731	730	728	728	728
Norway	149	143	130	133	133
Switzerland	49	49	49	49	49

Table 7.5: Optimized emissions of fine particles (PM2.5) from national sources for shipping scenarios with different ambition levels

		Ambition level for shipping			
	Base case	Level 1 all ships	Level 2 all ships	Level 3 all ships	Level 4 all ships
Austria	20	20	20	20	20
Belgium	21	21	21	24	24
Bulgaria	21	21	22	31	31
Cyprus	2	2	2	2	2
Czech Rep.	28	28	28	29	29
Denmark	14	14	14	14	14
Estonia	11	11	15	15	15
Finland	22	22	22	24	24
France	115	114	118	119	119
Germany	91	91	92	92	93
Greece	28	28	28	31	31
Hungary	26	25	26	26	26
Ireland	7	7	7	7	7
Italy	90	90	94	94	94
Latvia	10	10	11	11	11
Lithuania	8	8	8	8	8
Luxembourg	2	2	2	2	2
Malta	0	0	0	0	0
Netherlands	16	16	16	17	17
Poland	99	99	99	101	101
Portugal	23	23	25	27	27
Romania	70	70	70	82	82
Slovakia	14	14	15	16	16
Slovenia	4	4	4	4	4
Spain	71	71	72	78	78
Sweden	16	16	16	16	16
UK	52	51	53	56	56
EU-27	881	879	900	944	945
Croatia	13	13	13	13	13
Turkey	290	290	290	290	290
Norway	42	42	42	42	42
Switzerland	7	7	7	7	7

Table 7.6: Optimized emissions of ammonia (NH_3) from national sources for shipping scenarios with different ambition levels

		Ambition level for shipping			
	Base case	Level 1 all ships	Level 2 all ships	Level 3 all ships	Level 4 all ships
Austria	41	41	40	40	39
Belgium	74	74	74	75	75
Bulgaria	57	58	59	59	60
Cyprus	5	6	7	7	7
Czech Rep.	62	60	60	60	60
Denmark	47	51	53	53	53
Estonia	7	8	10	11	11
Finland	27	26	29	30	30
France	462	464	474	479	487
Germany	384	379	383	385	387
Greece	36	39	45	46	46
Hungary	61	61	61	61	61
Ireland	86	87	88	89	90
Italy	287	294	311	316	325
Latvia	9	11	12	12	12
Lithuania	28	30	31	31	32
Luxembourg	5	5	5	5	5
Malta	3	3	3	3	3
Netherlands	123	122	124	125	126
Poland	239	237	243	243	244
Portugal	50	52	57	58	61
Romania	113	113	115	116	115
Slovakia	26	25	25	24	24
Slovenia	14	14	15	15	15
Spain	250	260	279	285	296
Sweden	38	44	50	50	50
UK	214	216	229	235	243
EU-27	2750	2779	2881	2912	2956
Croatia	32	32	32	32	32
Turkey	491	491	491	491	491
Norway	13	15	21	21	21
Switzerland	41	41	41	41	41

Table 7.7: Emission control costs by country for optimized scenarios meeting Thematic Strategy objectives for shipping scenarios with different ambition levels

		Ambition level for shipping			
	Base case	Level 1 all ships	Level 2 all ships	Level 3 all ships	Level 4 all ships
Austria	94	101	115	121	125
Belgium	113	102	69	56	48
Bulgaria	64	55	35	25	21
Cyprus	19	6	0	0	0
Czech Rep.	122	120	102	93	90
Denmark	119	36	11	11	11
Estonia	37	10	1	0	0
Finland	89	41	3	1	1
France	667	597	481	411	387
Germany	614	494	394	362	342
Greece	87	34	11	8	8
Hungary	68	56	43	38	38
Ireland	105	94	74	68	58
Italy	346	316	203	177	145
Latvia	35	11	3	2	2
Lithuania	85	55	42	38	33
Luxembourg	9	8	10	10	10
Malta	0	1	0	0	0
Netherlands	190	76	66	53	49
Poland	398	357	285	138	115
Portugal	89	71	41	33	25
Romania	205	209	182	167	160
Slovakia	50	44	34	30	31
Slovenia	29	28	24	22	21
Spain	541	500	354	311	262
Sweden	187	40	9	8	8
UK	526	315	163	124	97
EU-27	4886	3778	2757	2309	2087
Croatia					
Turkey	0	4	8	8	8
Norway	139	48	2	1	1
Switzerland	0	0	0	0	0

The analysis reveals a clear role for emission controls at ships in a cost-effective strategy. As shown in Figure 7.5, lower SO_2, NO_x and PM2.5 emissions from ships relieves some pressure for reductions at land-based sources. Furthermore, as demonstrated in Figure 7.6, total emission control costs (i.e., for land-based sources and for ships) with increasing stringency of controls of ship emissions up to the Package 2. For stricter measures for ship emissions, costs increase again, but only for Package 4 total costs are higher than the costs of land-based sources in the reference case, in which no measures for ship emissions are assumed. Changes national emissions are displayed in Figure 7.7 to Figure 7.10.

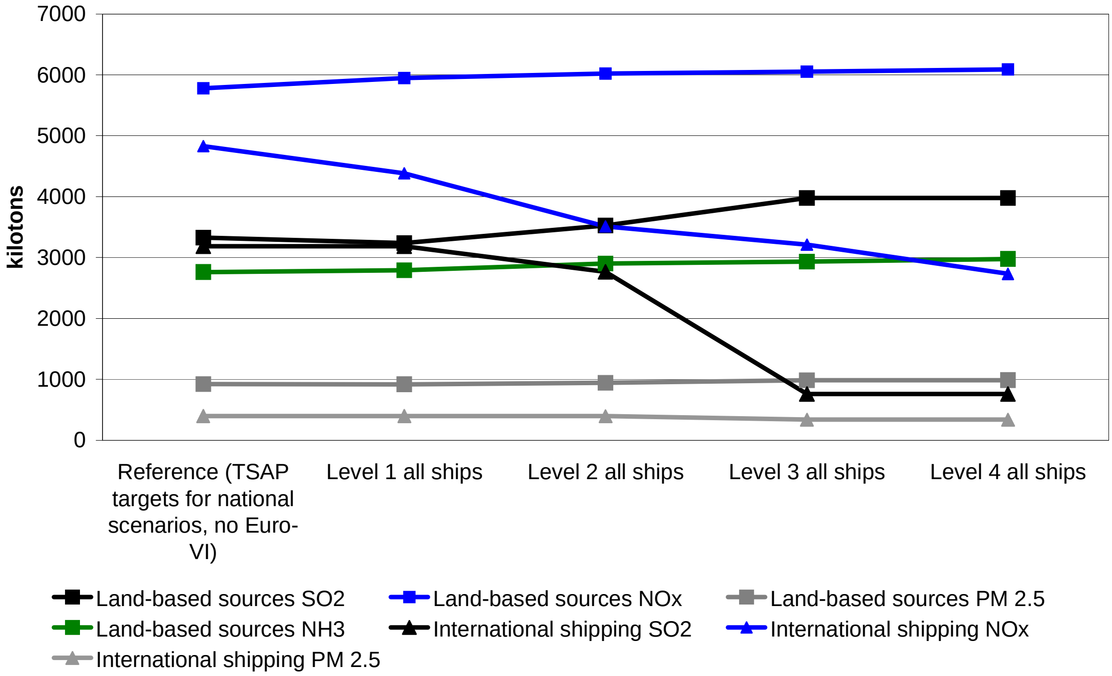

Figure 7.5: Emissions from land-based sources and ships for meeting the TSAP targets

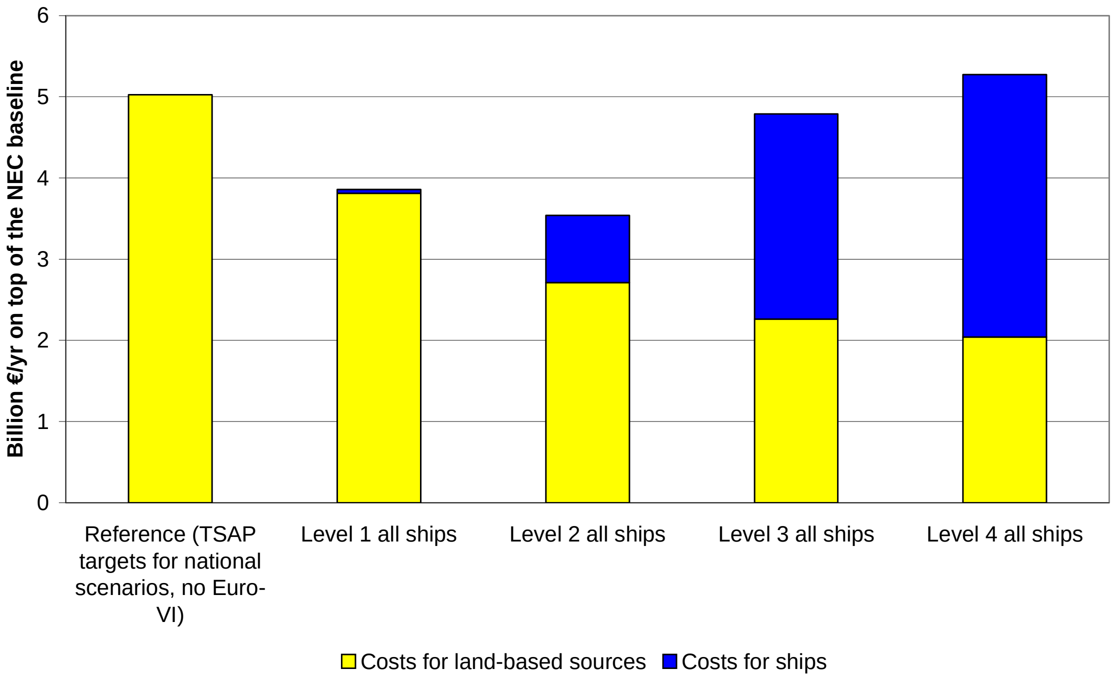

Figure 7.6: Costs for achieving the TSAP targets for the national activity projections without EURO VI, for the four sensitivity cases with different measures for ship emission reductions assumed.

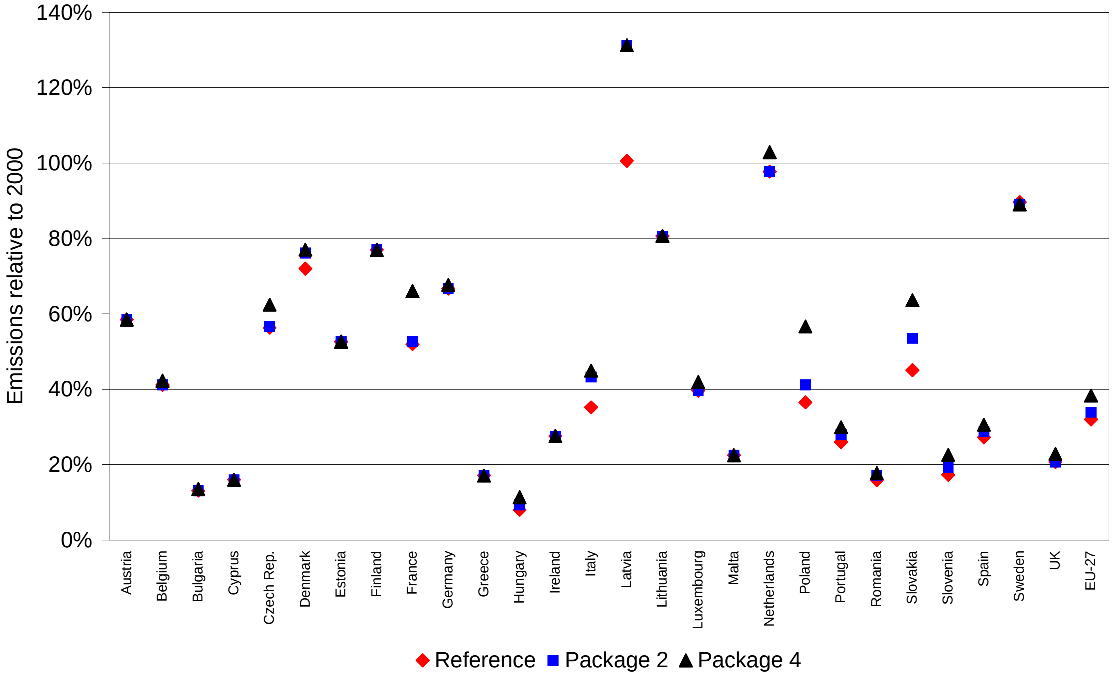

Figure 7.7: Optimized levels of SO_2 emissions for the ship control scenarios, for the national activity projections, without EURO VI measures. The reference case refers to measures taken at land-based sources only.

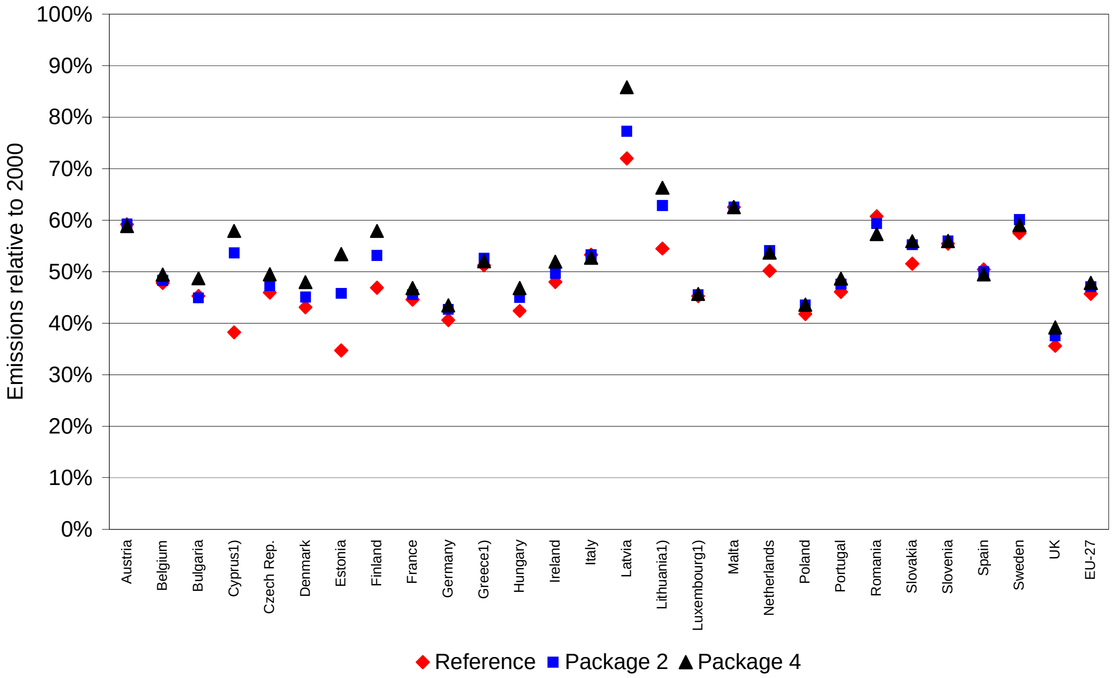

Figure 7.8: Optimized levels of NO_x emissions for the ship control scenarios, for the national activity projections, without EURO VI measures. The reference case refers to measures taken at land-based sources only.

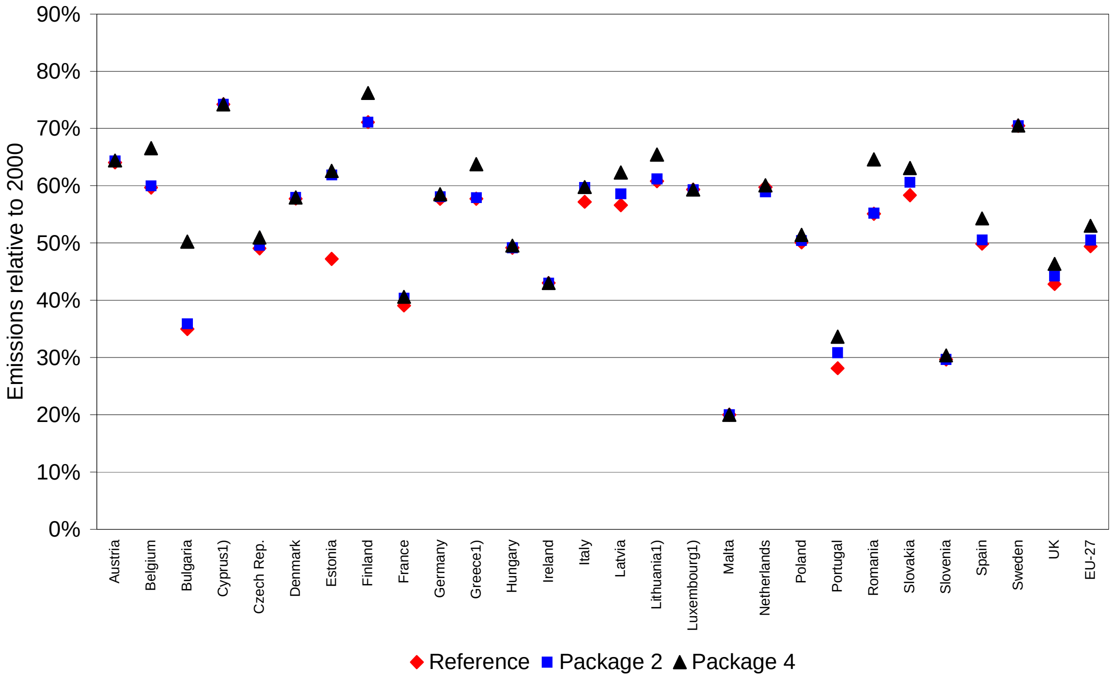

Figure 7.9: Optimized levels of PM2.5 emissions for the ship control scenarios, for the national activity projections, without EURO VI measures. The reference case refers to measures taken at land-based sources only.

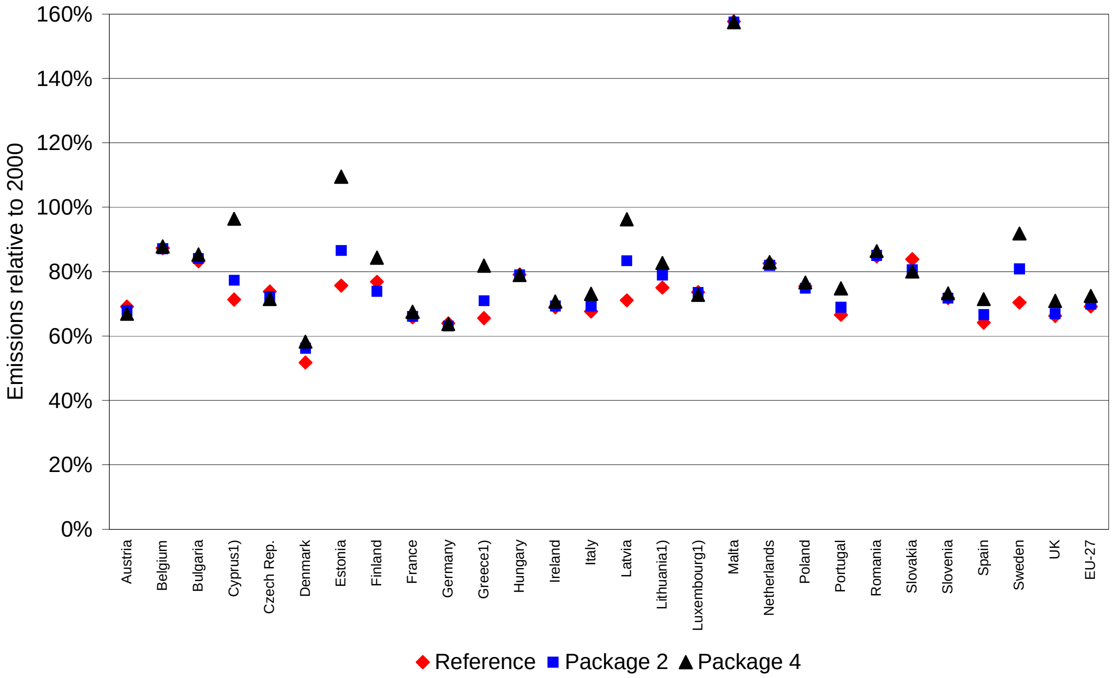

Figure 7.10: Optimized levels of NH_3 emissions for the ship control scenarios, for the national activity projections, without EURO VI measures. The reference case refers to measures taken at land-based sources only.

7.3 Impacts of Europe-wide measures at large combustion plants

A third sensitivity analysis explored the potential impacts from more harmonized emission limit values for large combustion plants. The BREF documents developed under the IPPC Directive provide a range of emission levels associated with the application of the best available techniques (BAT). For computing national emissions, the GAINS baseline projection adopts the national interpretations on the applicability of the emission limit values as they have been provided to IIASA in the course of the bilateral consultations on the GAINS input data. The sensitivity analysis explores the impacts on national emissions if the emissions of all large combustion plants would be at the upper (less stringent) or lower (more stringent) end of the range of emissions levels associated with the application of the BAT as given in the BREF note for large combustion plants. The analysis has been carried out for SO_2, NO_x and PM2.5 emissions, and for the national activity projections for 2010 and 2020. The resulting emissions have then been compared to the baseline emissions that rely on the national interpretations of the IPPC directive. These estimates provide useful input for an analysis of the implications of optimized emission control strategies, for which they indicate how much of the additional emission controls could be achieved through an EU-wide harmonization of emission limit values for large combustion plants set at the BAT BREFs levels.

While the national interpretations of the implications of the IPPC directive have been supplied by Member States to IIASA, the quantifications of possible harmonized emission limit values and their applicability in the individual Member States for the source categories considered in the GAINS model has been provided by the European Commission, DG-ENV.

Table 7.8: National total SO_2 emissions from the baseline projection compared with the cases with emissions for large combustion plants corresponding to the BAT ranges given in the IPPC LCP BREF documents (kilotons)

	2010			*2020*		
	Baseline – national interpretation	Upper end of the BAT range (least stringent)	Lower end of the BAT range (most stringent)	Baseline – national interpretation	Upper end of the BAT range (least stringent)	Lower end of the BAT range (most stringent)
Austria	21	24	21	20	24	19
Belgium	99	95	92	87	88	85
Bulgaria	441	117	116	116	97	94
Cyprus	18	8	6	8	8	6
Czech Rep.	236	133	109	178	120	96
Denmark	20	31	21	21	29	22
Estonia	76	21	14	48	22	15
Finland	66	61	50	59	63	52
France	494	407	394	493	393	371
Germany	470	492	338	438	506	321
Greece	178	110	71	83	105	64
Hungary	144	51	50	60	48	47
Ireland	35	32	27	36	30	26
Italy	340	353	320	345	361	326
Latvia	23	11	10	19	15	13
Lithuania	39	27	26	39	30	29
Luxembourg	2	2	2	2	2	2
Malta	9	5	4	8	5	4
Netherlands	67	76	59	77	86	66
Poland	1165	528	475	857	511	450
Portugal	134	89	81	87	86	80
Romania	331	119	112	139	127	118
Slovakia	68	69	68	81	81	80
Slovenia	27	19	18	23	17	16
Spain	501	396	373	446	413	396
Sweden	43	58	48	41	59	49
UK	458	260	243	274	227	214
EU-27	5504	3595	3147	4085	3554	3062

Table 7.9: NO_x emissions from the baseline projection compared with the cases with emissions for large combustion plants corresponding to the BAT ranges given in the IPPC LCP BREF note (kilotons)

	2010			*2020*		
	Baseline – national interpretation	Upper end of the BAT range (least stringent)	Lower end of the BAT range (most stringent)	Baseline – national interpretation	Upper end of the BAT range (least stringent)	Lower end of the BAT range (most stringent)
Austria	172	172	168	130	130	125
Belgium	259	246	240	201	193	182
Bulgaria	156	142	135	110	103	98
Cyprus	18	16	14	15	13	12
Czech Rep.	297	233	222	188	162	147
Denmark	168	146	143	126	112	107
Estonia	37	31	25	24	21	16
Finland	169	155	142	129	122	109
France	1187	1093	1075	867	779	755
Germany	1212	1151	1052	933	868	746
Greece	233	227	209	192	199	182
Hungary	140	126	122	106	106	98
Ireland	100	98	92	74	72	62
Italy	1074	1095	1057	769	782	738
Latvia	42	37	36	31	30	28
Lithuania	51	49	45	42	39	33
Luxembourg	25	25	25	17	17	17
Malta	8	5	4	6	5	5
Netherlands	293	291	276	233	236	217
Poland	683	485	460	431	415	375
Portugal	211	184	178	157	145	136
Romania	334	295	281	261	250	230
Slovakia	95	81	78	79	71	67
Slovenia	52	43	42	35	33	32
Spain	1161	1001	968	855	781	733
Sweden	182	182	173	157	156	148
UK	1204	1009	974	845	763	711
EU-27	9562	8619	8237	7014	6603	6107

Table 7.10: Total national PM2.5 emissions from the baseline projection compared with the cases with emissions for large combustion plants corresponding to the BAT ranges given in the IPPC LCP BREF note (kilotons)

	2010			2020		
	Baseline – national interpretation	Upper end of the BAT range (least stringent)	Lower end of the BAT range (most stringent)	Baseline – national interpretation	Upper end of the BAT range (least stringent)	Lower end of the BAT range (most stringent)
Austria	25	25	25	21	21	21
Belgium	29	29	29	26	26	26
Bulgaria	63	43	43	42	37	37
Cyprus	2	1	1	2	1	1
Czech Rep.	49	46	45	32	30	30
Denmark	20	20	20	15	15	15
Estonia	16	15	15	16	15	15
Finland	26	24	23	24	22	21
France	168	168	164	129	129	125
Germany	115	117	113	100	102	98
Greece	41	37	37	36	34	34
Hungary	33	31	31	36	31	31
Ireland	10	10	9	7	7	7
Italy	135	135	133	113	114	113
Latvia	17	17	17	16	15	15
Lithuania	12	11	11	11	11	11
Luxembourg	2	2	2	2	2	2
Malta	0	0	0	0	0	0
Netherlands	21	22	21	18	19	18
Poland	173	168	167	144	141	139
Portugal	52	48	47	43	41	40
Romania	142	119	119	142	118	117
Slovakia	20	17	17	21	17	17
Slovenia	10	7	7	9	6	6
Spain	106	103	102	85	83	82
Sweden	19	20	18	17	18	16
UK	80	76	74	61	58	57
EU-27	1386	1312	1291	1167	1115	1093

8 Conclusions

This report presents an initial cost-effectiveness analysis for the revision of the emission ceilings based on the updated GAINS model framework and input data. Changes include, inter alia, the consideration of the inter-annual meteorological variability, a refined representation of urban concentration levels of PM2.5 and deposition fields of nitrogen compounds, feedbacks from national experts on emission inventories and projections, improved estimates of emissions from the countries outside the EU and a more detailed representation of emission control measures in the agricultural sector. A first attempt has been made to convert the environmental objectives established by the Thematic Strategy on Air Pollution (TSAP) into quantitative targets taking into account the changes in modelling methodologies and input data.

The strict application of the quantitative targets of the TSAP for the protection of human health, ozone and acid deposition remains achievable with the new environment of model methodology, input data and assumptions. In fact, with the five years meteorological conditions the achievement of these targets requires less emission controls than suggested by the TSAP based on the assessment with the 1997 meteorology. Especially for ozone, the environmental objectives would not employ any further emission controls beyond the current legislation baseline.

In contrast, even the full application of all available emission control measures would not meet the quantitative objective given in the TSAP for eutrophication, essentially due to the improved spatial resolution of the estimates of nitrogen deposition. To enable a meaningful cost-effectiveness analysis also for eutrophication, an adjusted target has been developed. The adjusted target corresponds to the improvement of the eutrophication impact indicator[2] as calculated with the revised methodology between the year 2000 and the indicative emission levels for 2020 that is outlined in the Thematic Strategy.

Despite the large number of substantial changes to modelling methodology and input data that have been implemented since the second NEC report presented in December 2006, surprisingly small changes emerge from the introduction of five years meteorological conditions and the revision of the City-delta approach. However, the emphasis given to the individual environmental objectives is considerable changed in comparison to the priorities in the Thematic Strategy. The analytical work for the Thematic Strategy assumed largest priority (e.g., in terms of willingness to pay for emission control measures) to health impacts from fine particles, followed by eutrophication and ozone, and gave least priority to ground-level ozone. The new targets that have been derived as described above put highest priority to eutrophication (at a similar level than the Thematic Strategy), and suggests significantly less efforts for acidification and health impacts from PM. For ground-level ozone, the new target does not imply any further emission control measures beyond the current legislation. Whether this change in environmental priorities maintains the political objectives of the Thematic Strategy requires further discussion among the stakeholders.

A series of sensitivity analyses has been conducted to explore the impact of alternative exogenous assumptions and methodologies on the optimization results. It has been shown that, for the chosen

[2] The area of ecosystems with nitrogen deposition exceeding the critical loads for eutrophication has been used as in impact indicator.

set of environmental targets, the actual quantification of the impact of local low level emissions of PM on urban concentrations of PM2.5 have very little impact on the cost-optimal allocation of emission control measures. However, it must be kept in mind that this result is to a large extent caused by the low priority given in the set of environmental objectives to health impacts of PM compared to eutrophication. Since in this analysis the achievement of the health target emerges as a side-effect of the eutrophication goal, alternative quantifications of the impact of PM emission on health effects (within reasonable limits) do not cause changes to the emission reductions that are geared towards the eutrophication target.

In contrast, the assumptions on control measures that would be taken for marine vessels have significant impact on the cost-optimal allocation of measures at the land-based sources within the EU. It is shown that implementation of certain packages of emission controls could significantly reduce emission control costs at land-based sources. Three out of the four analyzed packages turn out as overall cost-effective, i.e., total emission control costs of land-based and marine measures are lower than costs of the reference case which does not consider further measures for ships.

Finally, an analysis explored the implications of harmonized emission limit values for large combustion plants on total national emissions. For 2020, an EU-wide application of emission limit values that correspond to the lower range of the BAT emission ranges given in the IPPC BAT BREF documents would decrease in the EU-27 total SO_2 emissions by 25 percent, NO_x emissions by 13 percent and PM2.5 emissions by six percent below what is estimated with the current national interpretations of the requirements of the IPPC directive.

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