CAFE Scenario Analysis Report Nr. 5

Exploratory CAFE scenarios for further improvements of European air quality

Background paper for the meeting of the
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Table of contents

1 Introduction

The Clean Air For Europe (CAFE) programme of the European Commission aims at a comprehensive assessment of the available measures for further improving European air quality beyond the achievements expected from the full implementation of all present air quality legislation. For this purpose, CAFE has compiled a set of baseline projections outlining the consequences of present legislation on the future development of emissions, of air quality and of health and environmental impacts up to the year 2020.

In its integrated assessment, CAFE will explore the cost-effectiveness of further measures, using the optimization approach of the RAINS model. This optimization will identify the cost-effective set of measures beyond current legislation that achieve exogenously determined environmental policy targets at least cost. For this purpose, the RAINS model will explore in an iterative way the costs and environmental impacts implied by gradually tightened environmental quality objectives, starting from the baseline (current legislation - CLE) case up to the maximum that can be achieved through full application of all presently available technical emission control measures (the maximum technically feasible reduction case - MTFR).

The results from the CAFE baseline assessment have been described in Amann *et al.* (2004a) (http://www.iiasa.ac.at/rains/CAFE_files/Cafe-Lot1_FINAL(Oct).pdf). The estimate of the maximum range for emission reductions that is offered from full application of presently available emission control technology is documented in Amann *et al.* (2004b) (http://www.iiasa.ac.at/rains/CAFE_files/baseline3v2.pdf). Detailed results on sectoral and country-specific emission and cost estimates can be extracted from the Internet version of the RAINS model (www.iiasa.ac.at/rains).

In its previous report, IIASA has explored cost-effective emission reductions for meeting environmental targets for human health (from PM and ozone) and for ecosystems.

Against this background information, this paper informs the CAFE Working Group on Target Setting and Policy Advice about recent modeling results on cost-effective emission control strategies for reducing health impacts from PM.

The first version of the RAINS optimization model for particulate matter has been used to identify cost-minimal sets of emission control measures that lead to environmental improvements at least cost. For this report, optimization analyses addressed health impacts attributable to the exposure of fine particulate matter (PM2.5) and explores alternative ways of target setting.

2 Input data

The analysis presented in this report relies on:

- The CAFE baseline projections of anthropogenic activities for the year 2020 as described in the CAFE baseline report (http://www.iiasa.ac.at/rains/CAFE_files/Cafe-Lot1_FINAL(Oct).pdf), in particular the energy projections of the revised "with climate measures" projection of the PRIMES model. Cost data and resulting cost curves used for the optimization analysis are available from the RAINS Internet version (www.iiasa.ac.at/rains) – Version November 2004.

- Source-receptor relationships that reflect the response of air quality towards changes in the various precursor emissions as modelled by the recent version (October 2004) of the EMEP Eulerian dispersion model. This initial optimization analysis relies on calculations for the meteorological conditions of the year 1997, while final calculations need to consider the full range of inter-annual meteorological variability.

- National population projections of the UN (median projection)

2.1 Emission control measures for mobile sources

After the last report the Commission has provided assumptions on removal efficiencies and costs for mobile sources for the RAINS scenario analysis. Two scenarios have been prepared. A "with measures" scenario comes close to the possible future emission performance as estimated by RICARDO PLC (*RICARDO, 2004: Final report to CITEPA for supporting information for the RAINS model. October 2003 (revised April 2004*). It should be noted that stakeholders have provided further information on removal efficiencies and costs for light and heavy duty vehicles. Once this information has been validated, it can also be used in the RAINS model. For heavy duty vehicles, a "maximum technically feasible reduction" scenario, which in addition simulates the effects of an implementation of the US 2007 NO_x emission standard for heavy-duty trucks.

Emission standards presented in Table 11.1 of the Annex have been incorporated into the RAINS model by modifying data on removal efficiencies. For light-duty vehicles it has been assumed that the relative improvement in removal efficiency will be the same as for diesel cars. Table 11.2 in the Annex presents the assumptions about the costs of individual EURO stages for diesel vehicles, based on the RICARDO study.

Table 2.1 provides the emission reductions that are computed for 2020 for the additional measures. Calculations are based on the assumption that the new standards will be enforced in the beginning of 2010 for light-duty vehicles and in 2015 for heavy-duty vehicles. The "with measures" scenario reduces the NO_x emissions in the EU-25 by seven percent compared to the "current legislation" baseline case, and PM2.5 emissions by about 3 percent. For 2020, the additional costs of these measures are estimated at about 1.9 billion €/year. An implementation of stricter standards for heavy-duty vehicles (the MTFR scenario) would reduce NO_x emissions additionally by about 240 kilotons, or by four percentage points, on top of the reductions of the "with measures" scenario.

Table 2.1: Emission reductions and costs of additional measures on road diesel vehicles. All values are for the year 2020.

	"With measures" scenario					MTFR scenario	
	NO_x reduction		PM2.5 reduction		Additional	NO_x reduction	
	kt	% of national total	kt	% of national total	cost Mio €/year	kt	% of national total
Austria	11.2	9%	0.8	3%	50	17.1	13%
Belgium	14.9	8%	1.2	5%	82	21.4	11%
Cyprus	0.9	5%	0.1	4%	3	1.4	7%
Czech Rep.	4.0	4%	0.2	1%	20	8.1	7%
Denmark	4.6	4%	0.3	2%	20	7.3	7%
Estonia	0.5	3%	0.0	0%	4	1.1	8%
Finland	4.9	4%	0.3	1%	21	8.1	7%
France	69.1	8%	6.4	4%	259	104.3	13%
Germany	57.2	7%	3.8	3%	360	103.0	13%
Greece	4.7	2%	0.2	0%	26	9.8	5%
Hungary	5.3	6%	0.3	1%	26	9.8	12%
Ireland	5.1	8%	0.4	4%	33	8.1	13%
Italy	42.6	6%	2.7	3%	185	65.6	10%
Latvia	1.0	7%	0.1	2%	7	1.9	12%
Lithuania	1.6	6%	0.1	1%	11	3.2	12%
Luxembourg	2.3	13%	0.1	5%	11	4.4	25%
Malta	0.2	7%	0.0	4%	1	0.5	13%
Netherlands	17.9	7%	1.1	4%	82	29.1	12%
Poland	11.9	3%	0.6	1%	60	22.2	6%
Portugal	13.8	9%	0.9	2%	68	19.0	12%
Slovakia	4.1	7%	0.3	2%	22	7.0	12%
Slovenia	1.2	5%	0.1	1%	6	1.9	8%
Spain	53.9	8%	3.3	4%	267	79.8	12%
Sweden	4.9	3%	0.3	1%	24	10.0	7%
UK	50.3	6%	2.7	4%	221	88.4	11%
Total	388.1	7%	26.2	3%	1868	632.3	11%

Table 2.2: Costs of the “with further road measures” scenario in the EU-25 calculated for 2020 (million €/year)

	Costs of emission control measures for road vehicles		
	Baseline CLE	With further measures	Difference
Diesel heavy duty trucks	17808	18584	+776
Diesel cars and light duty vehicles	5304	6396	+1092
Total costs for vehicles	40198	42066	+1868

2.2 Emissions from ships

The calculations presented in this report include revised assumptions on the possibility for controlling emissions from sea regions (international shipping). These revisions are based on new material presented in the recent the study by ENTEC (ENTEC, 2005: Service Contract on Ship Emissions: Assignment, Abatement and Market-based Instruments. Report for the European Commission Directorate General Environment . February 2005, ENTEC UK Limited.). This report identifies several emission control options for seagoing vessels and estimates their efficiency and costs. The most important options are listed in Table 2.3.

Table 2.3: Measures available to control emissions from ships. The reduction efficiency of each measure is given in parenthesis, compared with the "unabated" case. Source: ENTEC, 2005

SO_2
Low sulfur heavy fuel oil (original S content - 2.7%)
- Desulfurization down to 1.5 %
- Desulfurization down to 0.5 %
Sea water scrubbing (85 % removal efficiency)
Low sulfur marine gas oil (0.2%, 0.1 % from 2008)
NO_x:
MARPOL emission standards (9 %)
Slide valve retrofit on slow speed engines (20 %)
Internal engine modifications (30 %)
Humid air motors (70 %)
SCR (90 %)

Note: The use of low sulphur fuels simultaneously reduces the emissions of PM by 15 - 20 %

Following the recommendations of the responsible unit in DG ENV, three emission scenarios from international shipping were developed. The assumptions on emission controls for these three scenarios are shown in Table 2.4. The "current legislation" scenario represents "business as usual" with the measures already decided as well as measures that are state of the art technology for new ships (e.g., slide valve modification for slow speed engines). The "medium ambition" scenario includes – in addition to the current legislation measures - implementation of relatively cheap measures, with costs per ton of NO_x avoided below 50 €/t). In this scenario it is assumed that measures are implemented at ships of all flags. Finally, the "maximum technically feasible scenario" assumes full implementation of the best available emission control technology on all existing and new ships.

Resulting emissions for these three scenarios as well as the corresponding emission control costs are presented in Table 2.5to Table 2.8.

Table 2.4: Assumptions taken on emission controls for sea regions

Current legislation (CLE)	
SO_2	EU sulphur proposal as per Common Position, i.e:, 1.5% S marine fuel oil for all ships in the North Sea and the Baltic Sea; 1.5% S fuel for all passenger ships in the other EU seas; low sulfur marine gas oil; 0.1% S fuel at berth in ports.
NO_x	MARPOL NO_x standards for all ships built since 2000
Medium ambition	
SO_2	As in the BAU scenario
NO_x:	Slide valve retrofit on all slow-speed engines pre-2000 (later engines already have these) Internal engine modifications for all new engines post-2010
Maximum Technically Feasible Reduction (MTFR)	
SO_2	0.5% S fuel for all ships in all EU seas. 0.1% at berth.
NO_x	SCR on all ships (retrofit & new built)

Table 2.5: NO_x emissions from international shipping by sea region, kilotons

	2000	Current legislation 2020	Medium ambition 2020	Max. feasible reduction 2020
Atlantic Ocean	566	834	757	95
Baltic Sea	349	517	470	59
Black Sea	118	174	158	20
Mediterranean Sea	1808	2711	2461	310
North Sea	659	971	882	111
Total sea regions	3501	5207	4728	595

Table 2.6: SO_2 emissions from international shipping by sea region, kilotons

	2000	Current legislation 2020	Medium ambition 2020	Max. feasible reduction 2020
Atlantic Ocean	396	632	632	122
Baltic Sea	242	225	225	75
Black Sea	83	133	133	26
Mediterranean Sea	1237	2003	2003	388
North Sea	460	423	423	141
Total sea regions	2418	3415	3415	752

Table 2.7: Primary emissions of PM2.5 from international shipping by sea region, kilotons

	2000	Current legislation	Medium ambition	Max. feasible reduction
Atlantic Ocean	34	56	56	46
Baltic Sea	21	29	29	28
Black Sea	7	12	12	10
Mediterranean Sea	108	179	179	146
North Sea	40	54	54	53
Total sea regions	210	330	330	282

Table 2.8: Costs for controlling emissions from international shipping by sea region, million €/year

	2000	Current legislation	Medium ambition	Max. feasible reduction
Atlantic Ocean	6	63	67	1287
Baltic Sea	4	376	379	720
Black Sea	1	13	14	270
Mediterranean Sea	29	220	234	4122
North Sea	7	707	712	1353
Total sea regions	47	1378	1406	7752

3 Assumptions and caveats

The optimization results presented in this report reflect work in progress, employing a number of assumptions that have influence on the quantitative outcome. Thus it is essential to review the optimization results in the light of the assumptions taken.

3.1 Main assumptions

- **"With climate measures" CAFE baseline scenario.** With the exception of the C9 scenario, the analysis presented in this paper is based on the "with climate measures" baseline projection developed by the PRIMES model (http://www.iiasa.ac.at/rains/CAFE_files/Cafe-Lot1_FINAL(Oct).pdf) (version August 2004), which provides one EU-wide consistent projection of future development. In some cases national perspectives envisage different assumptions on important driving forces such as economic development and energy policy. The implications of alternative energy projections, e.g., those performed by national governments, are explored with the C9 scenario. in

- **Maximum Technically Feasible Emission Reductions for stationary sources as presented to the Working Group at the Session in November** (http://www.iiasa.ac.at/rains/CAFE_files/baseline3v2.pdf)**.** Unavoidably, the choice of what is considered as technically feasible in 2020 is to some extent arbitrary. Voices were raised that suggested the assumptions made by RAINS to be very conservative (e.g., excluding certain retrofit options, e.g., of large point sources of marine vessels as well as assuming only the traditional replacement rate of small sources), while other stakeholders might claim certain assumptions to be too optimistic. Eventually, for developing solid policy advice, the target setting approach will need to prove robust with respect to uncertainties in the assumptions on what is technically feasible to implement.

- **City-Delta results have been implemented in the optimisation, but are not in their final shape.** City-Delta results have been incorporated into the RAINS optimization. The preliminary approach for quantifying the incremental pollution within urban areas originating from low-level sources as presented at the last meeting of the Working Group has been improved along various lines, most recently by improved wind speed data. As explained earlier, the City-Delta approach with its focus on the health impact quantification addresses PM concentrations in urban background air, consistent with the recommendations of the joint WHO-UN/ECE Task Force on Health. Obviously, this approach does not address small-scale concentration differences within cities, e.g., in street canyons. Thus, the concentration results presented in this report cannot be readily related to potential air quality limit values, as they apply at all locations.

- **1997 meteorology.** All source-receptor relationships have been developed for the meteorology of 1997. As discussed in earlier meetings of the Working Group on Target Setting, the inter-annual meteorological variability is substantial and needs to be taken into account when producing final policy advice. Due to lack of time, it was not yet possible to incorporate additional meteorological years into the RAINS optimization.

- **All assumptions made for quantifying health impacts from PM** in the RAINS model (see Amann, 2004c). The RAINS methodology for calculating losses of life expectancy attributable to the exposure to fine particulate matter involves a number of assumptions, which have been discussed at and approved by the joint WHO-UN/ECE Task Force on Health (http://www.euro.who.int/eprise/main/WHO/Progs/AIQ/Activities/20031204_1). Important assumptions include
    - the association of mortality with the long-term exposure to PM2.5,
    - that effects occur only for people older than 30 years, i.e., that infant mortality is excluded,
    - that the coefficients for relative risk found in US studies (Pope et al., 2002) are applicable to Europe,
    - that the linear relative risk function is applicable to particles smaller than 2.5 µm originating from primary anthropogenic PM emissions and from secondary inorganic aerosols, but that PM2.5 from natural sources do not cause health effects. Also, due to the inability to accurately model the fate of secondary organic aerosols, their contribution to health impacts is ignored,
    - that potential differences of particles according to their chemical composition, size distribution and number counts of particles are ignored.

3.2 Caveats

As discussed in the introduction, this report presents work in progress. Thus, all quantitative results presented in this report must be considered provisional due to a number of factors:

- For all environmental problems considered, new functional relationships have been developed from the data set of EMEP model runs produced in October 2004. Due to limited time it was not yet possible to fully evaluate the performance of these new functional relationships with the scientific scrutiny that is usually applied for RAINS analyses. While the present formulation produces approximations that are considered acceptable by the model developers given the present scope of the RAINS analysis, further refinements might lead to more accurate formulations. The full documentation of the source-receptor relationships has not yet been completed.
- Lack of time and priority given by the Working Group to the exploration of other aspects did not permit performing full uncertainty analysis. This report, however, presents a first assessment of the sensitivity of model results towards changes in input assumptions, in particular on alternative energy and agricultural scenarios.

4 Scenarios for further improvements of European air quality

It has been shown in earlier RAINS analyses that within the next few decades environmental 'no-effect' levels will not be achievable with currently available emission control measures given the projected levels of anthropogenic activities, such as energy consumption and agricultural production. To design emission control strategies that lead to cost-effective environmental improvements on the way towards a full achievement of such no-effect levels, the formulation of environmental interim targets might be a useful concept. The choice of a particular interim target will not only determine the cost-effectiveness of a next policy step, but has also critical impact on the distribution of costs and benefits across Member States.

The RAINS optimization identifies the least-cost combination of measures that achieve specified environmental objectives of alternative interim targets. Thus the RAINS optimization tool can provide valuable insight into the cost-effectiveness of alternative target setting concepts and their implications on the distributions of costs and benefits.

The last reports to the CAFE Working Group on Target setting explored the implications of three target setting principles:

- A "limit value" concept, which requests certain levels of PM2.5 concentrations to be achieved everywhere in the EU.
- A "gap closure" approach, which for equal *relative* improvements in (population-weighted) PM2.5 exposure or in terms of loss in life expectancy in each grid square. A number of ambition levels have been defined using a common scale of what is achievable in terms of impacts through dedicated emission control measures between the "current legislation" of the baseline scenario and the maximum technically feasible emission reductions including further road measures.
- A "Europe-wide" objective, exploring the least-cost allocation of emission control measures across Member States and sectors to achieve an overall reduction of health impacts (or population-weighted PM exposure) in the EU-25 irrespective of the location of the improvement.

Based on illustrative calculations for these three these target setting principles, discussions in the Working Group on Target Setting and Policy Advice addressed potential conflicts between economic efficiency and perceived equity among the actors. It was found that the "Europe-wide" objective achieves maximum economic effectiveness, while the other two principles score higher in equity terms, depending on the underlying concept of equity. A variety of alternative equity concepts were formulated, such as

- minimizing differences between absolute exposure levels of individuals to pollution, or
- minimizing differences between the relative improvements of environmental impacts across countries from the emission control strategy, or
- minimizing differences in emission control costs
    - on a per capita-basis or
    - related to various notions of economic wealth, such as
        - GDP measured in Market Exchange Rates, or
        - GDP measured in Purchasing Power Standards, or
- minimizing differences in costs for a life month gained.

Each of these concepts renders other target setting principles as favourable.

To further explore the features of these target setting principles, a third set of CAFE scenarios has been developed. These calculations address for health impacts attributable to PM2.5 variants for each of the three target setting principles for a range of environmental ambition levels. They also explore the cost-effectiveness of Europe-wide measures for further reductions of road transport emissions for the different target setting principles and environmental ambition levels. For the other environmental endpoints considered by CAFE, calculations explore the set of emission control measures that achieve all these targets jointly at least costs. As a first step of an uncertainty analysis, calculations explore the sensitivity of these joint optimization scenarios towards changes in the underlying energy and agricultural projections, especially in view of alternative projections reported by some Member States. Finally, the report explores costs of achieving PM2.5 limit values in 2015.

In summary, the following calculations have been carried out:

Uniform limit values for PM2.5

C1 Uniform limit values on PM2.5 in urban background air, assuming further road measures

C2 Uniform limit values on PM2.5 in urban background air, without further road measures

Gap closure on PM2.5 concentrations/health impacts from PM2.5

C3 Uniform "gap closure" in terms of health-relevant PM2.5 exposure, assuming further road measures

C4 Uniform "gap closure" in terms of health-relevant PM2.5 exposure, without further road measures

C5 Uniform "gap closure" in terms of health-relevant PM2.5 exposure, assuming further road measures, sensitivity case with an assumed cut-off threshold of the concentration-response function at 7 µg/m3.

Europe-wide targets on the overall improvement of health impacts from PM2.5

C6 Europe-wide improvement of PM2.5 health impacts irrespective of their locations, assuming further road measures

C7 Europe-wide improvement of PM2.5 health impacts irrespective of their locations, without further road measures

Joint optimization for targets on PM, acidification, eutrophication and ozone

C8 Joint optimizations

Sensitivity analysis with national energy projections

C9 As C8, but with national energy projections

Exploration of potential limit values for 2015

C10 Europe-wide limit values on PM2.5 in urban background air to be attained in 2015

For each of these scenario families, a series of calculations has been performed ranging a wide span of environmental ambition levels.

Part 1 of this report introduces results for the scenario families C1 to C7. The joint optimization (C8), the sensitivity analyses with national energy projections (C9) and limit values for 2015 (C10) will be reported in Part 2.

The following chapters describe for each target setting principle the rationale of the target and describe the technicalities how these targets have been represented in the RAINS model. They provide the relation between environmental ambition levels and emission control costs at the aggregated European level, and show costs and implied emission control measures for each Member State. A further graph illustrates the environmental achievements of the scenarios (for PM2.5 in terms of increased life expectancy). The overall cost-effectiveness of the scenario variants is analysed with a graph showing emission control costs versus remaining life years lost (YOLL), while equity aspects are illustrated showing for all Member States the costs for a life month gained for the various scenarios.

It should be noted that the RAINS model quantifies impacts on mortality through changes in life expectancy and through the number of life years lost (YOLL). These life years lost are a stock variable and are computed as the impact of increased life expectancy for the entire population older than 30 years. On the other hand, the RAINS model quantifies emission control costs on an annual basis, i.e., as a flow variable. Thus, these variables cannot be directly compared with each other, and care must be taken when interpreting this numbers.

5 Uniform limit values for air quality

As a first approach, cost-effective emission reductions have been explored that bring PM2.5 concentrations in urban background air sheds everywhere in the EU-25 below a certain limit.

The RAINS model, with its inclusion of City-Delta, allows addressing concentrations at PM2.5 at urban background, but not at hot spots in street canyons or around industrial locations. Furthermore, the EMEP model, on which the RAINS model rests its calculations of PM dispersion, does not quantify contributions from natural sources, i.e., mineral dust, sea salt and biogenic material and of secondary organic aerosols.

While a quantification of the organic material from biogenic sources and of secondary organic aerosols is difficult, indications on the magnitude of the mineral fraction can be derived from chemical analyses of PM2.5 samples. A literature review, inter alia taking into account the information presented in the PM position paper of CAFE, quotes Spanish measurements with approximately 3 $\mu g/m^3$ mineral contributions, Scandinavian studies with roughly 1 $\mu g/m^3$, and measurements in Austria and the UK lying in between. Thus, in absence of more information, an assumption is made that the mineral contribution amounts in Mediterranean countries at 3 $\mu g/m^3$, in Scandinavia at 1 $\mu g/m^3$, and all other countries at 2 $\mu g/m^3$.

With the consolidated model set up, a set of scenarios has been developed aiming at reducing annual mean PM2.5 concentrations below a uniform limit value in all urban areas in the EU. As outlined above, the RAINS model does not include street canyon scale, and thus is not applicable for the present definition of the EU air quality limit value. The results presented here apply to urban background air.

Obviously, to be feasible a generally applicable limit value must be achievable everywhere. Thus, based on the calculations with the present data set some cities cannot reduce PM2.5 in 2020 much below 17 $\mu g/m^3$, even with full application of all available control measures at the European scale. On the other hand, there are very few spots where a level of 20 $\mu g/m^3$ is computed to remain exceeded. To compare with hypothetical air quality limit values, contributions from natural organic sources and from secondary organic aerosols must be added, and provisions need to be made to reflect street canyon situations. While an estimate of the biogenic fraction is difficult to derive, literature data suggest for the additional PM2.5 burden in street canyons compared to urban background air to reach typically up to 5 $\mu g/m^3$. There are indications, however, that in some cases this street canyon add-on could reach significantly higher values than 5 $\mu g/m^3$.

With the present implementation of the EMEP model and the data used for quantifying the urban increments in PM2.5 according to the City-Delta approach, bringing annual mean PM2.5 concentrations below 17 $\mu g/m^3$ appears to be most difficult in Thessaloniki and Genova. In both cases a high urban increment is computed due to high local emission densities (inter alia, due to PM emissions from ships in harbours) and the low wind speeds given in the available data set. Furthermore, for both cities there is less scope for further reducing emissions from local stationary low-level emission sources than in more northern regions where the contribution from home heating is more pronounced. Thus, the major scope for reducing the urban increment is through changes in traffic emissions for which, however, only a limited potential is assumed in the road measure package considered in this analysis.

Thus, within the given modelling system a strict Europe-wide interpretation of the limit value approach could not achieve limit values below 17 µg/m^3 in the year 2020, even if further road measures were implemented according to the assumptions described above.

An exception for Thessaloniki would enable for other cities the limit value to be reduced to approximately 16 µg/m^3, where it would approach the limit of feasibility computed for Genova. If an exception were granted to Genova too, the limit value could be further lowered to 15 µg/m^3, at which level implementation in the Benelux cities would become difficult. Obviously, this sequence of exceptions could be continued arbitrarily. As illustrated, e.g., in Figure 5.2, each exception has dramatic impact on the distribution of emission control efforts across the Member States.

While there are obvious uncertainties in the present modelling approach that caution the calculation results for individual cities, the general features of such a limit value approach and of potential exceptions will hold also for a practical implementation in the real world.

Table 5.1: Costs for stationary sources (million €/year) and years of life lost (YOLL) of the limit value scenarios. The additional costs of the road measures package are estimated at 1868 million €/year.

Ambition level	*With further road measures*				*Without further road measures*	
	Without exceptions		With exceptions for Thessaloniki and Genova		With exceptions for Thessaloniki and Genova	
Limit value	Costs (Million €/yr)	YOLL (million years)	Costs (Million €/yr)	YOLL (million years)	Costs (Million €/yr)	YOLL (million years)
Baseline	0	135.4			0	137.3
19 µg/m^3	0	133.2				
18 µg/m^3	152	129.1				
17 µg/m^3	937	128.0				
16 µg/m^3			697	126.3	1302	125.6
15.5 µg/m^3			1438	122.3	2393	121.6
15 µg/m^3			2677	116.6	5245	114.1
14.5 µg/m^3			6858	107.9		
MTFR	37838	96.1	37838	96.1	37838	97.9

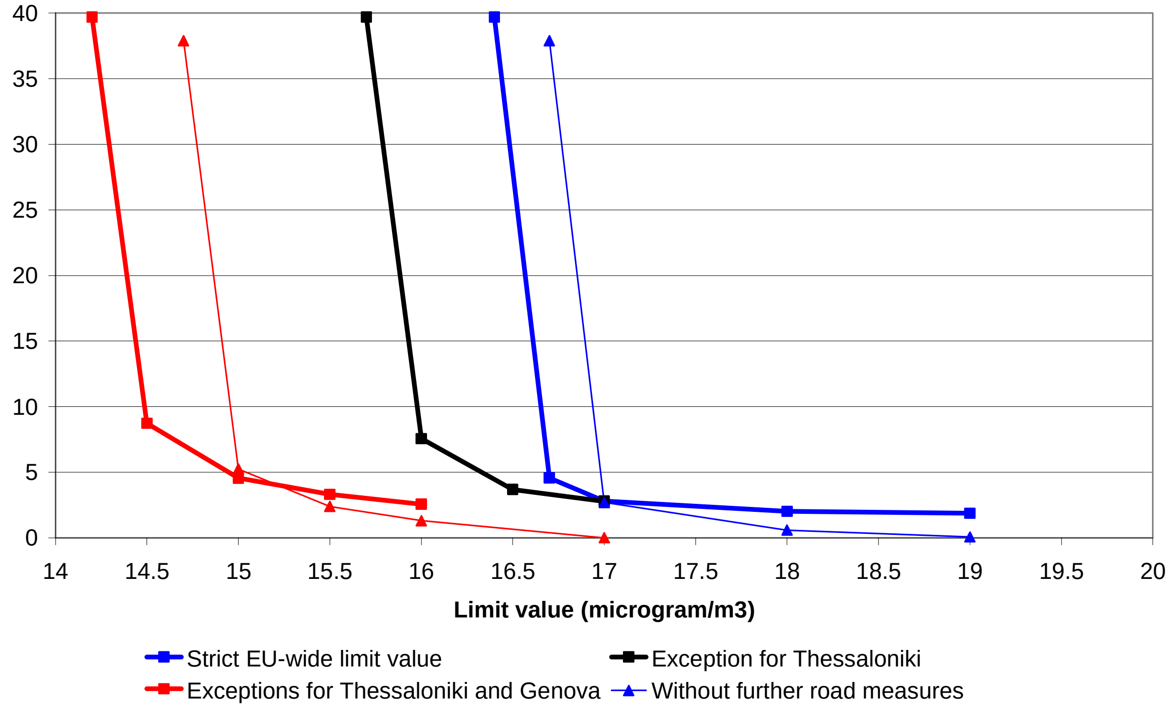


Figure 5.1: Costs of the limit value scenarios (billion €/year), costs for stationary and mobile sources

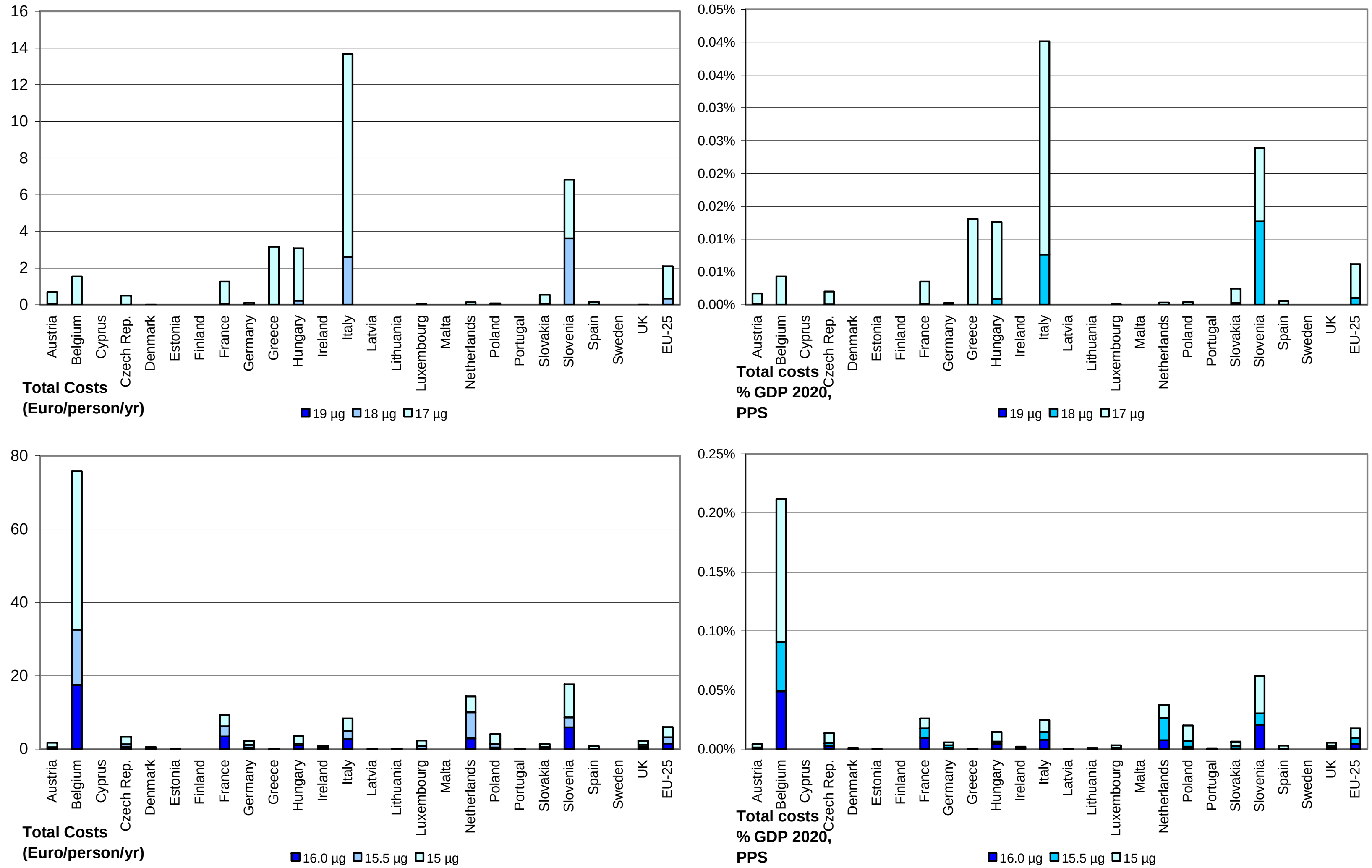


Figure 5.2: Emission control costs for stationary sources on a per-capita basis (left) and per GDP expressed in purchasing power standards (right) for the strict EU-wide limit value scenarios (top panel) and for the scenarios with exceptions for Thessaloniki and Genova (bottom panel)

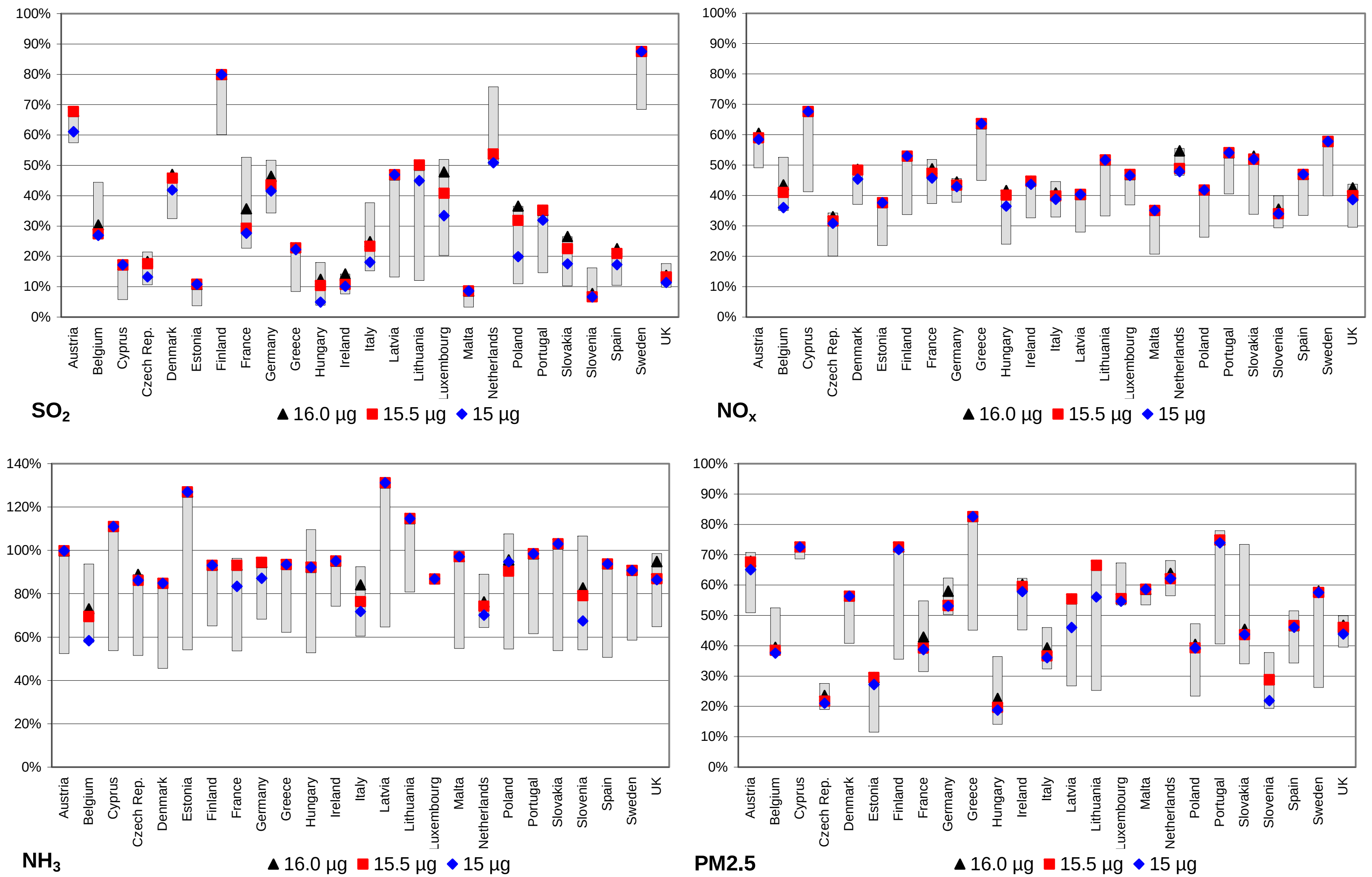


Figure 5.3: Cost-minimal emission reductions at stationary sources for bringing PM2.5 in urban background air everywhere below 16, 15.5 and 15 µg/m^3, assuming implementation of further road measures. Exceptions are assumed for Thessaloniki and Genova. The 100 percent line refers to the emission level in the year 2000. The grey range indicates the scope for emission reductions considered in the RAINS optimization.

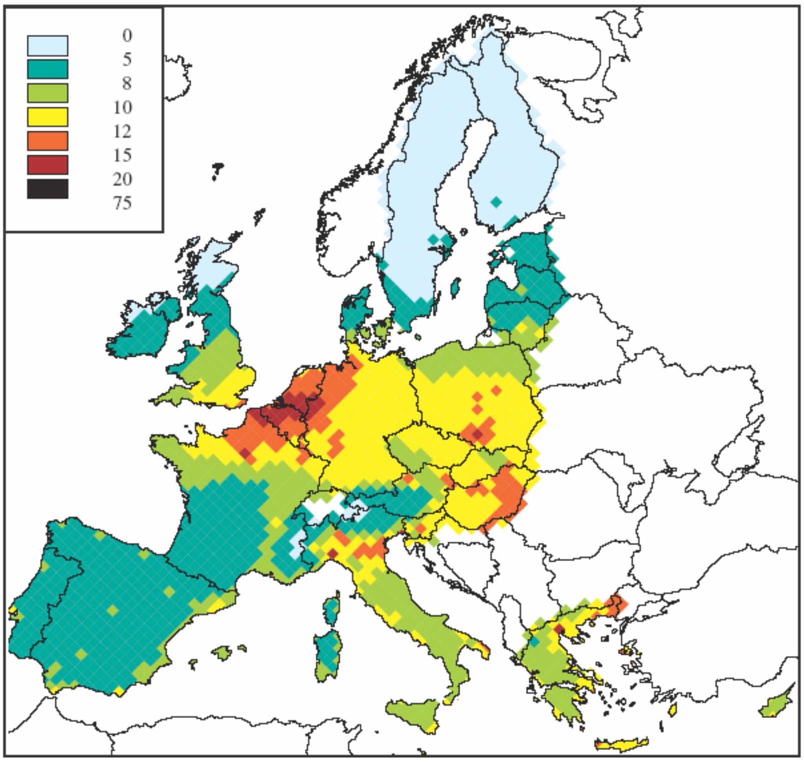


Figure 5.4: Computed PM2.5 concentrations (in urban areas, if applicable) for the 17 μg/m^3 limit value scenario without exceptions. Mineral contribution is included.

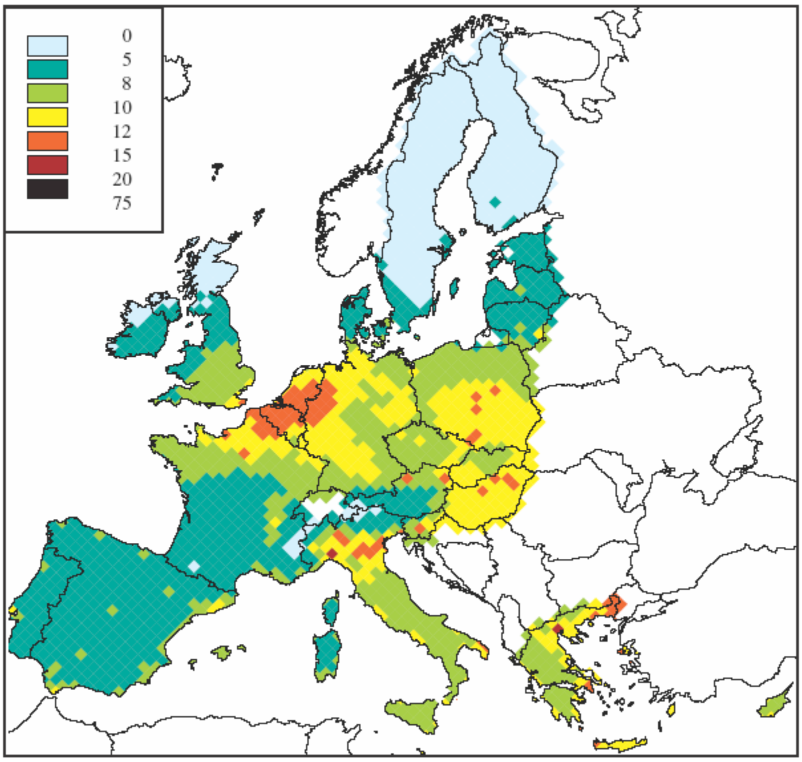


Figure 5.5: Computed PM2.5 concentrations (in urban areas, if applicable) for the 15 μg/m^3 limit value scenario with exceptions for Thessaloniki and Genova. Mineral contribution is included.

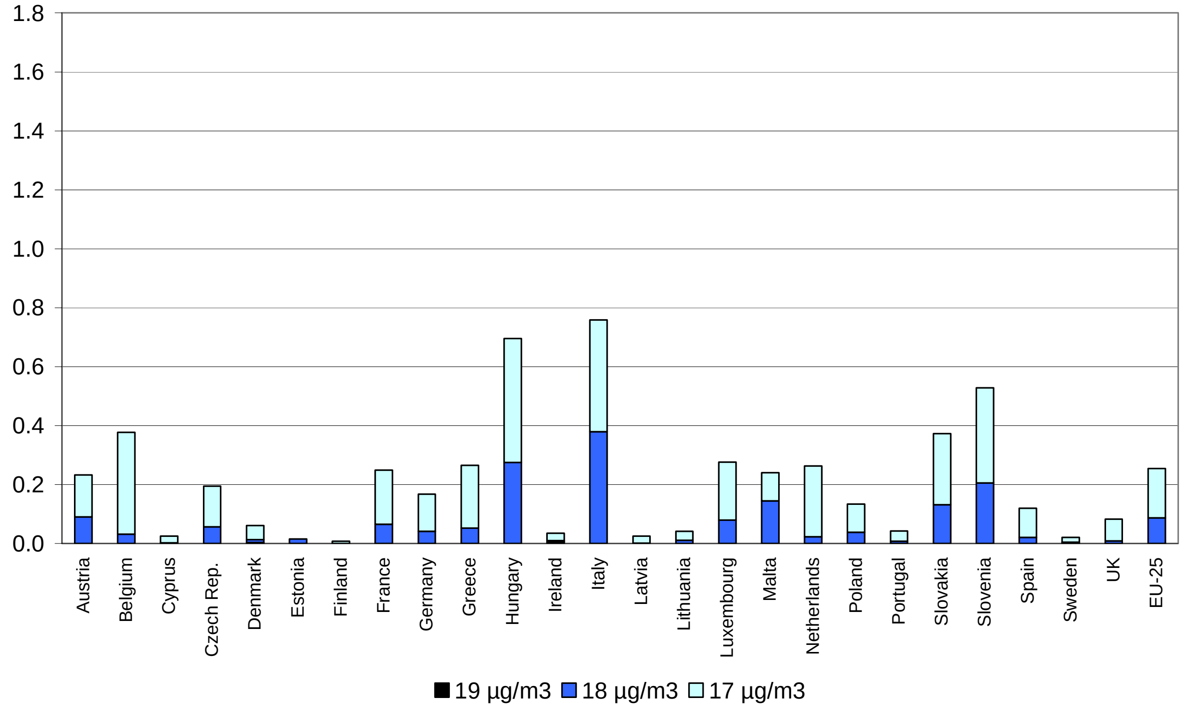


Figure 5.6: Gains in statistical life expectancy (in months) for the strict limit value scenarios without exceptions

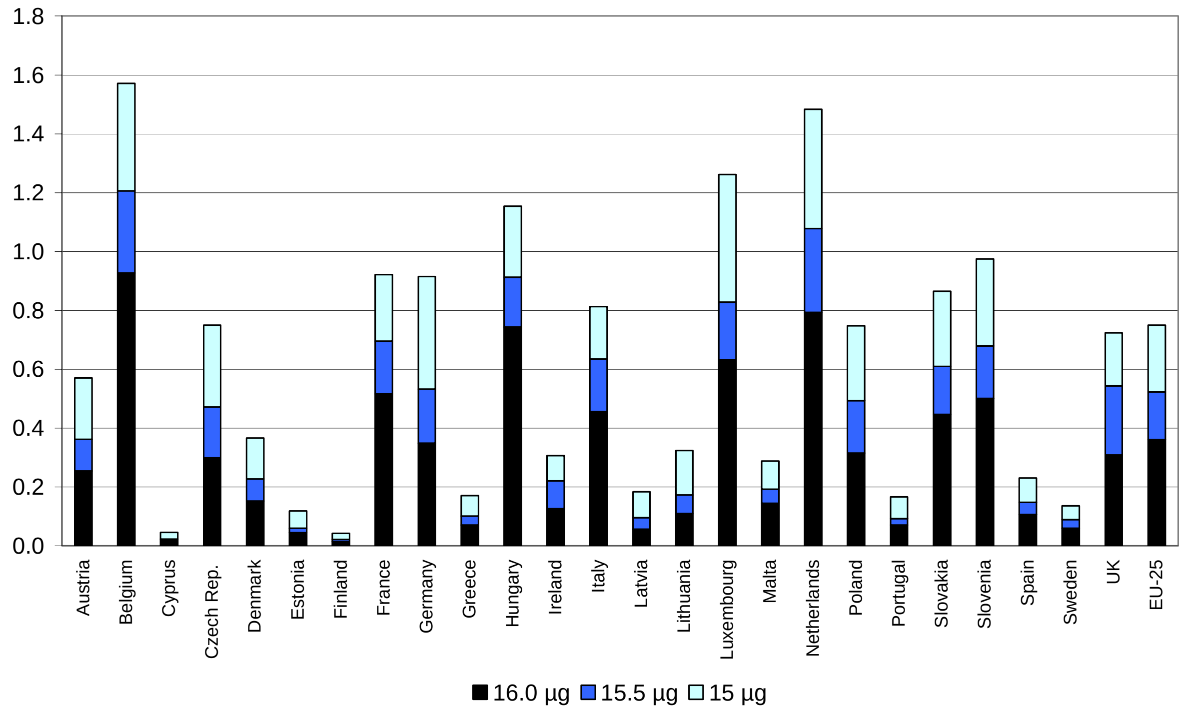


Figure 5.7: Gains in statistical life expectancy (in months) for selected limit value scenarios with exceptions for Thessaloniki and Genova

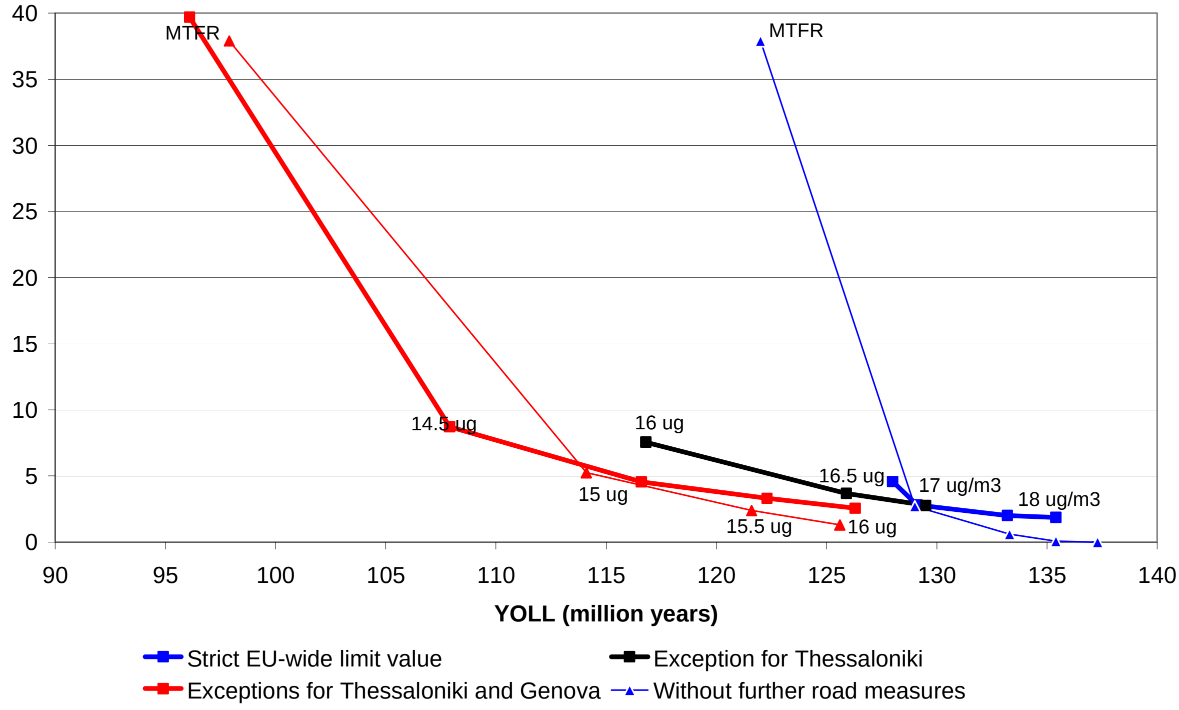


Figure 5.8: Cost-effectiveness of the different limit value scenarios: Costs for stationary and mobile sources (in billion €/year) versus life years lost (million of years)

Figure 5.8 analyzes the cost-effectiveness of the various limit value scenarios. For the scenarios assuming further road measures, the curve starts with a limit value 18 µg/m^3 at the costs of these road measures (on top of the costs of legislation). The strict limit value scenario (thick dark blue curve) reaches its limit below 17 µg/m^3 . If an exception is granted for Thessaloniki, the reductions continue along the heavy black line down to a feasible limit value of 16 µg/m^3 affecting Genova. If Genova received an exception too, the cost-effectiveness would follow the heavy red line, with no costs involved (on top of the costs of road measures) for achieving 16 g/m^3 and reach the limit of feasibility below 14.5 µg/m^3. Without Europe-wide road measures (thin line), the 16 µg/m^3 limit value could be achieved through measures for selected stationary sources at lower costs (except in Genova and Thessaloniki).

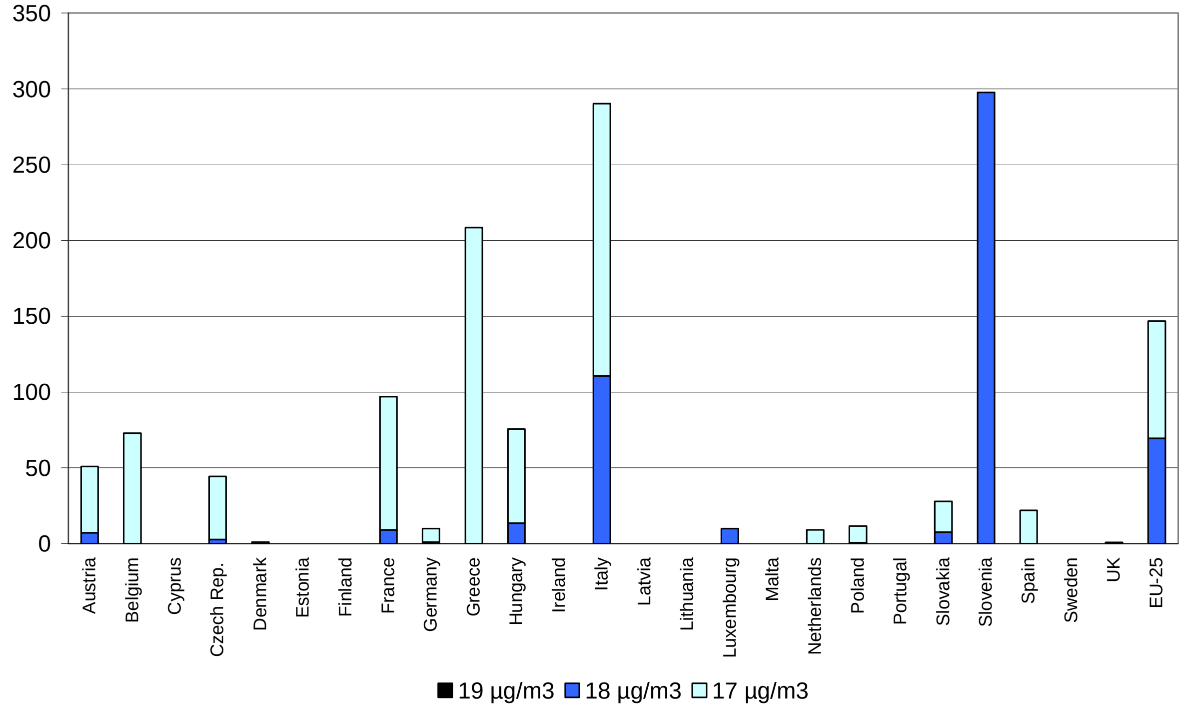


Figure 5.9: Costs per life year saved for the strict limit value scenarios (in €/year)

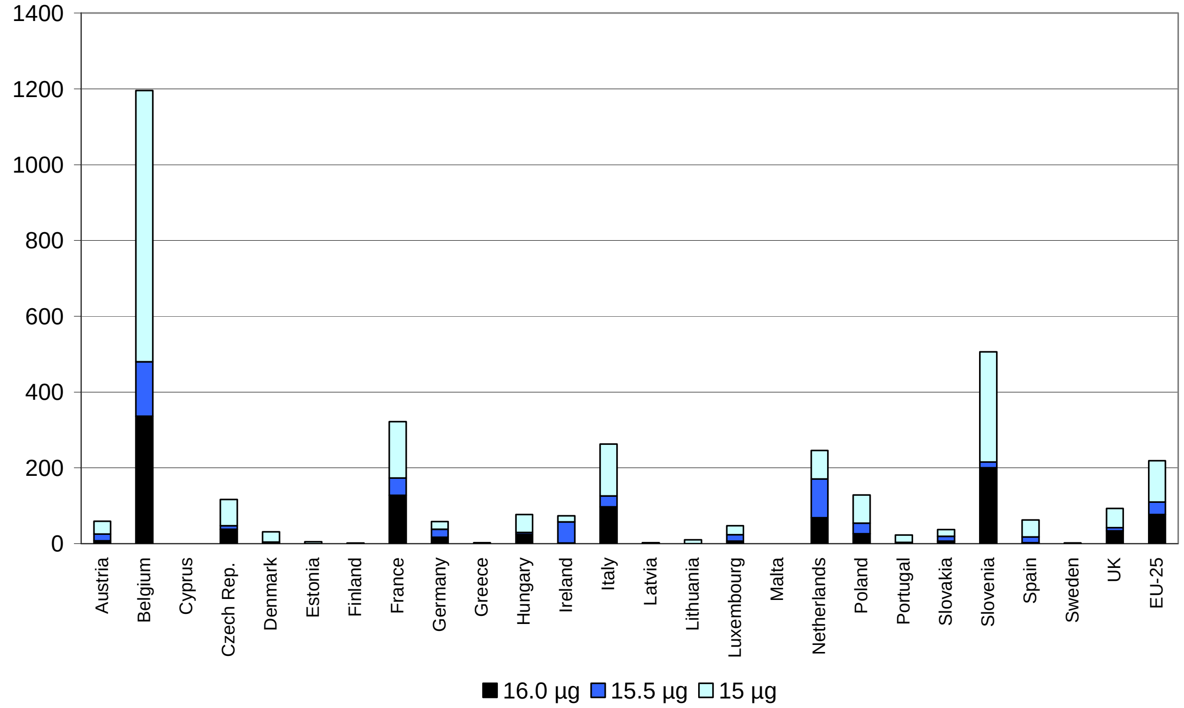


Figure 5.10: Costs for a life year saved (€/year) for selected limit value scenarios with exceptions for Thessaloniki and Genova

Table 5.2: Population-weighted PM2.5 exposure of the limit value scenarios relative to the baseline 2020

		Strict limit value scenarios Limit value [μg/m³]			Limit value scenarios with exceptions for Thessaloniki and Genova Limit value [μg/m³]				
	CLE	19.0	18.0	17.0	16.0	15.5	15.0	14.5	MTFR
Austria	100%	100%	98%	96%	95%	93%	89%	83%	71%
Belgium	100%	100%	100%	96%	89%	86%	82%	77%	74%
Cyprus	100%	100%	100%	99%	100%	99%	99%	99%	96%
Czech Rep.	100%	100%	99%	97%	95%	92%	87%	81%	65%
Denmark	100%	100%	100%	99%	97%	95%	92%	87%	72%
Estonia	100%	100%	100%	99%	99%	98%	96%	94%	80%
Finland	100%	100%	100%	100%	99%	99%	98%	97%	86%
France	100%	100%	99%	95%	91%	87%	83%	75%	69%
Germany	100%	100%	99%	97%	95%	92%	86%	78%	69%
Greece	100%	100%	99%	95%	99%	98%	97%	95%	89%
Hungary	100%	100%	96%	91%	90%	88%	85%	76%	65%
Ireland	100%	100%	100%	99%	95%	91%	88%	79%	69%
Italy	100%	100%	93%	85%	91%	88%	84%	81%	75%
Latvia	100%	100%	100%	99%	98%	97%	95%	93%	81%
Lithuania	100%	100%	100%	99%	98%	97%	94%	91%	79%
Luxembourg	100%	100%	99%	96%	91%	88%	81%	72%	64%
Malta	100%	100%	97%	95%	96%	95%	94%	92%	89%
Netherlands	100%	100%	100%	97%	90%	87%	82%	75%	69%
Poland	100%	100%	99%	98%	95%	92%	88%	85%	72%
Portugal	100%	100%	100%	99%	98%	97%	95%	91%	70%
Slovakia	100%	100%	98%	94%	93%	90%	86%	80%	66%
Slovenia	100%	100%	97%	91%	92%	88%	84%	78%	70%
Spain	100%	100%	99%	96%	97%	95%	93%	89%	78%
Sweden	100%	100%	100%	99%	98%	97%	95%	92%	75%
UK	100%	100%	100%	98%	93%	88%	84%	73%	65%
Total	100%	100%	98%	95%	93%	90%	86%	80%	71%

6 Uniform relative improvements (gap closure)

To reap health benefits that are not associated with peak exposure (e.g., those occurring below limit values) and to achieve a more equitable distribution of costs and benefits across Member States, the gap closure concept has been proposed and practically used, e.g., for the cost-effectiveness analyses of the NEC Directive.

As discussed in an earlier report, the recent constellation of emission control potentials, atmospheric dispersion characteristics, contributions from non-EU sources and environmental sensitivity, a uniform relative improvement of the gap between current situation and the ultimate environmental objective of reaching the “no-effect” level is limited by little scope for improvements at a few locations with often untypical situations. Thus, the first report to the Working Group on Target Setting explored source-related “gap closure” concepts, dividing the scope for improvements between the projected “current legislation” case of the baseline scenario and the full application of all presently available control measures for stationary sources, however excluding further road measures (Figure 6.1).

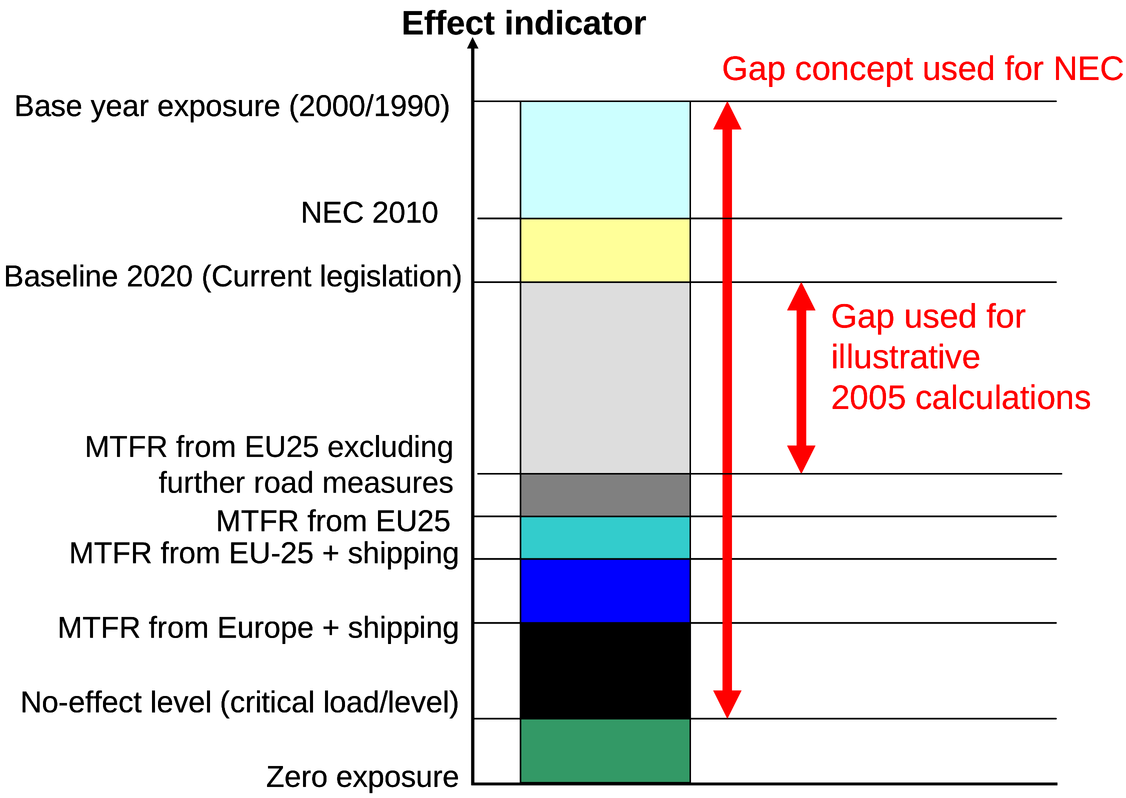


Figure 6.1: Concept of gap closure applied for the first set of exploratory RAINS calculations (Scenarios A)

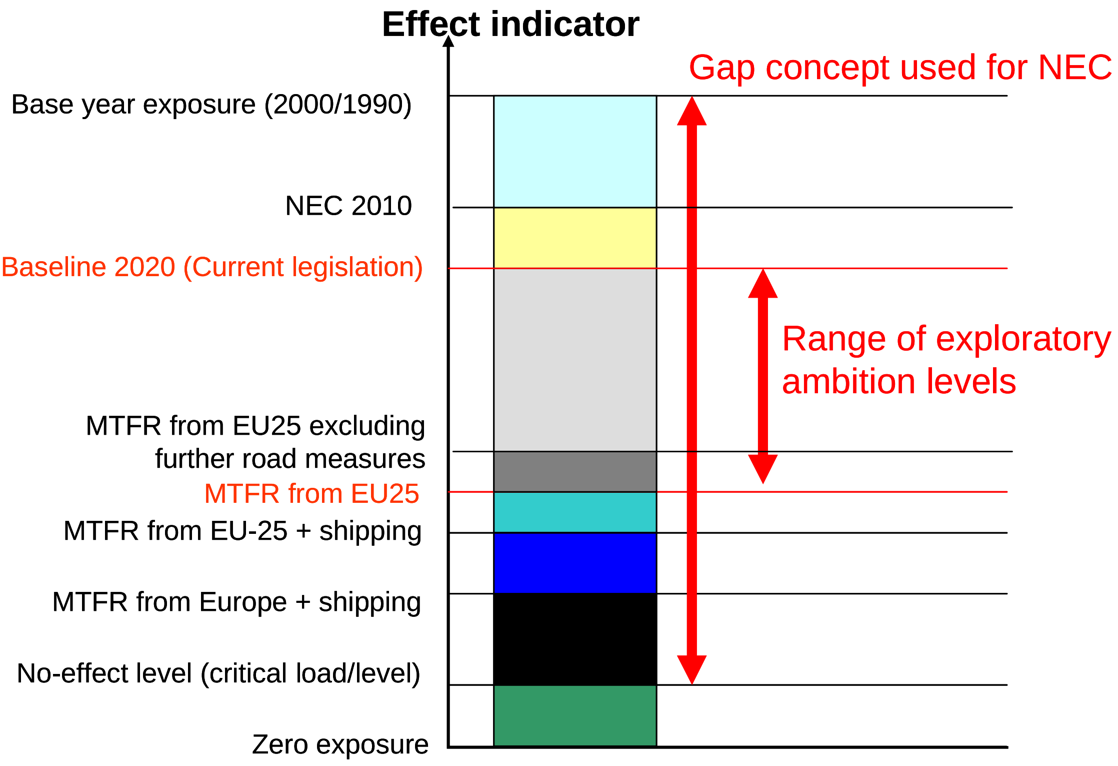


Figure 6.2: Concept of gap closure applied for the RAINS calculations presented in this report (Scenarios C)

This report follows this source-based definition of the gap, but includes the scope for measures at mobile sources (further road measures) in the analysis. Thus, a number of ambition levels dividing the range between

- the situation calculated for the baseline emissions in 2020, and the
- maximum technically feasible emission reductions that could be achieved within the EU-25 including the potential offered by further road measures and excluding the scope for emission reductions from marine ships and from non-EU countries

have been explored for in this analysis.

As stated in the earlier report, it is understood that this provisional definition of a gap closure is entirely different from the "effect-based" gap closure concept that was used in the preparations for the NEC directive, since it does not establish any relationship with the environmental long-term target of the European Union. At the same time, both quantifications of the "baseline" emission levels for 2020 and the "maximum technically feasible reduction" (MTFR) case are loaded with serious uncertainties and potentially strategically motivated disagreements, which make this definition prone for political dispute.

A number of calculations have been performed that explore the response in terms of emission reductions towards gradually tightened gap closure targets (Table 6.1).

It has been shown in earlier analyses that gap closure concepts yields better overall cost-effectiveness than, e.g., the limit value approach, because it employs cost-effective potential for environmental improvements at concentrations below the limit value. At the same time, a crude application of the gap closure approach calling for equal relative improvements at all sites might imply higher economic burdens at comparably clean sites where a larger relative contribution to pollution is made from non-controllable (natural or anthropogenic) background sources, without yielding corresponding environmental improvements. Earlier applications of the gap closure principles, e.g., for the cost-effectiveness analysis of the NEC Directive, have refined the definition of the gap, and thereby have substantially improved the cost-effectiveness. As an initial step, this report explores a modified gap closure approach, which introduces in the target setting a cut-off threshold for PM2.5.

In a first step, this sensitivity approach computes for each grid cell the gap as the difference in PM2.5 concentrations between the baseline situation (current legislation in 2020) and the maximum technically feasible reduction case including road measures. In a second step, this gap is reduced by the given gap closure percentage, and the resulting target concentration (from the computed anthropogenic sources of PM2.5) is computed. In a third step, a lower threshold is introduced, i.e., target levels below the threshold are increased to the threshold level. For this illustrative calculation a value of 7 $\mu g/m^3$ has been assumed for the cut-off, inspired by the range of PM2.5 concentrations for which health impacts have been observed in the underlying study of the American Cancer Society (Pope et al., 2002). Since these observations include for obvious reasons all PM2.5 including the natural and mineral fraction which is not modelled by RAINS, as a conservative estimate the mineral fraction estimated as described above has been subtracted for each grid cell. As a result the gap closure target aims at reducing the modelled fraction of anthropogenic PM2.5 in each grid cell by a given percentage in relation to the concentration computed for the baseline scenario, but not below a level of 7 $\mu g/m^3$ including the mineral fraction.

Table 6.1: Costs for stationary sources (million €/year) and years of life lost (YOLL) of the gap closure scenarios. Costs of the package for mobile sources amount to 1868 million €/year.

Ambition level	*With further road measures*				*Without further road measures*	
	Without threshold		With cut-off of 7 $\mu g/m^3$		Without threshold	
(Gap closure %)	Costs (Million €/yr)	YOLL (million years)	Costs (Million €/yr)	YOLL (million years)	Costs (Million €/yr)	YOLL (million years)
Baseline	0	135.4			0	137.3
40 %	1296	119.9			1705	119.4
50 %	2127	115.5			2832	114.9
60 %	3392	111.3	3160	111.6	4589	111.0
70 %	5222	107.6	4822	107.8	7409	107.2
80 %	8756	103.5	7932	103.2	15263	103.0
90 %	16319	99.6			infeasible	
MTFR	37838	96.1				

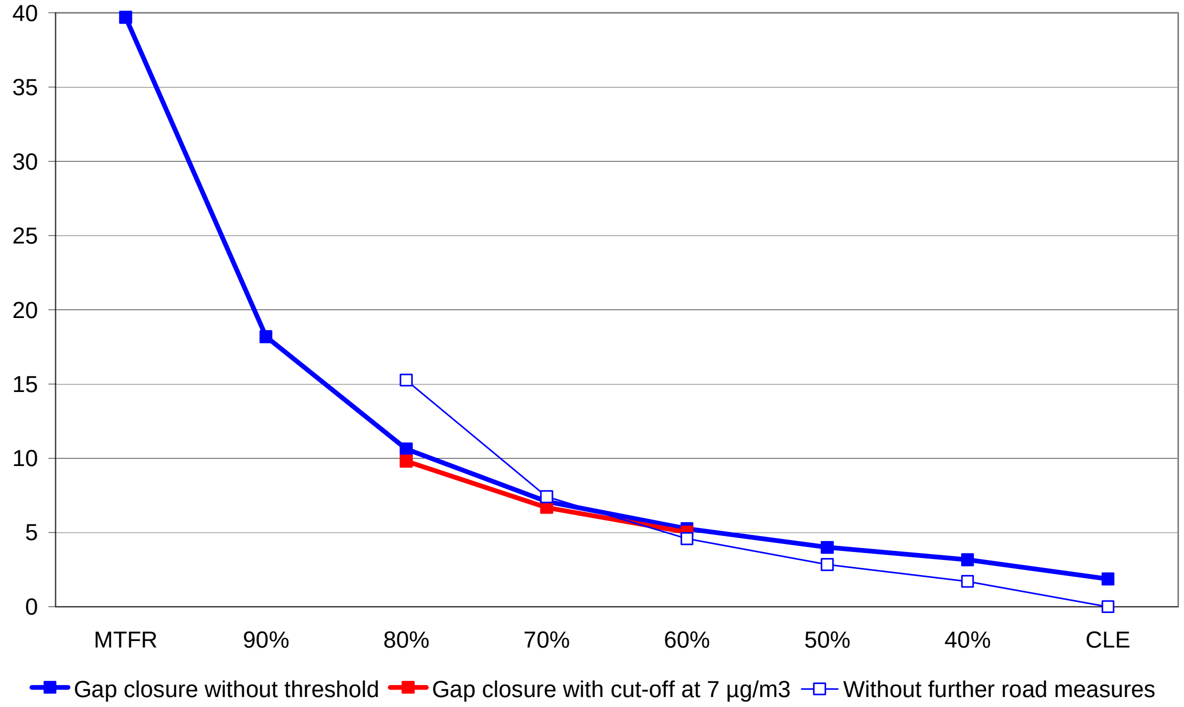


Figure 6.3: Costs of the gap closure scenarios (€/year)

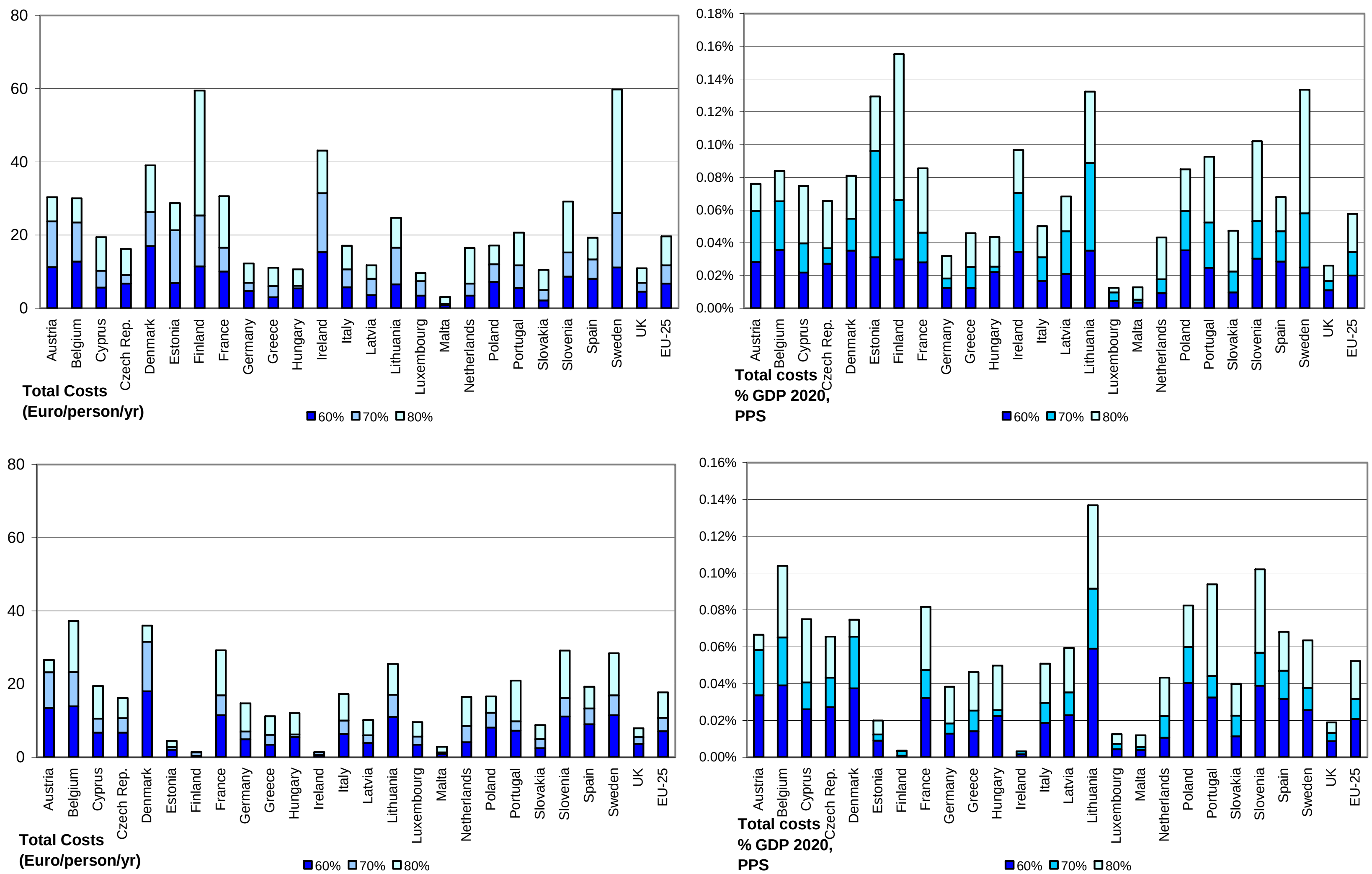


Figure 6.4: Emission control costs for stationary sources on a per-capita basis (left) and per GDP expressed in purchasing power standards (right) for the gap closure scenarios, for the scenarios without threshold (top row) and with a cut-off threshold of 7 μg/m^3 (bottom row).

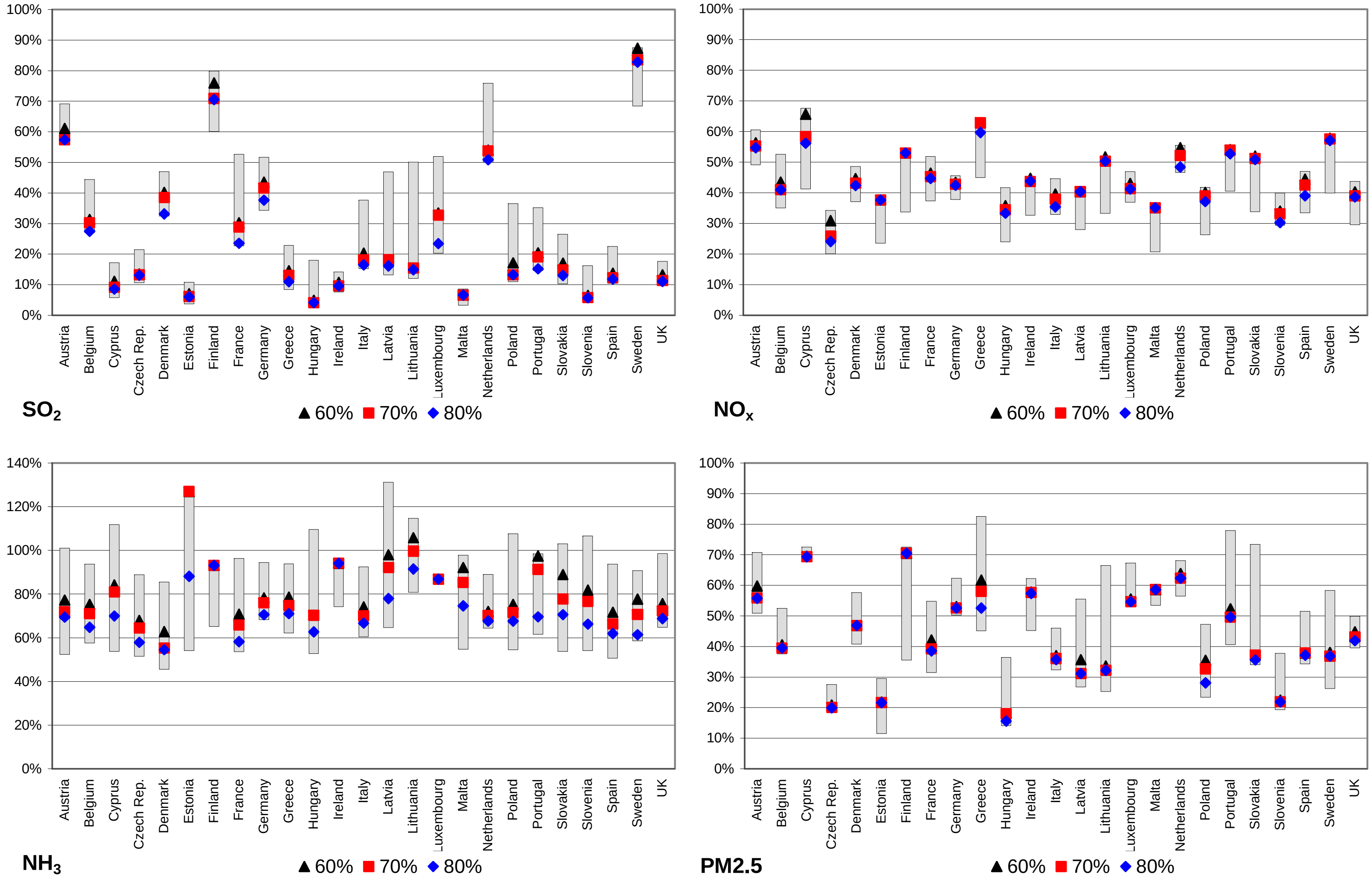


Figure 6.5: Cost-minimal emission reductions for three selected gap closure scenarios with a cut-off of 7 µg/m^3 PM2.5. The 100 percent line refers to the emission level in the year 2000. The grey range indicates the scope for emission reductions considered in the RAINS optimization.

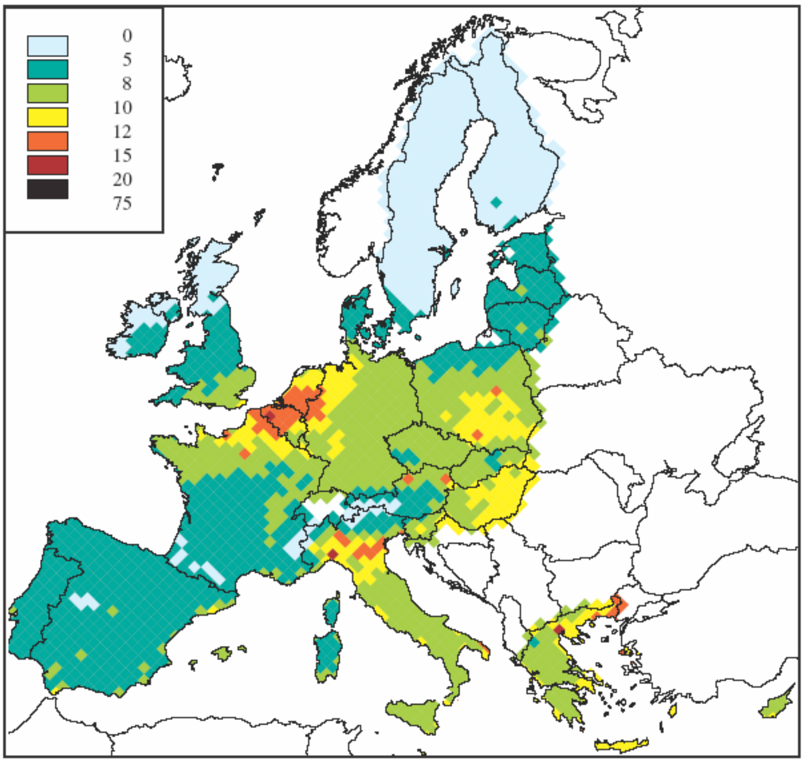


Figure 6.6: Computed PM2.5 concentrations (in urban areas, if applicable) for the 70% gap closure scenario with a cut-off of 7 µg/m^3. Mineral contribution is included.

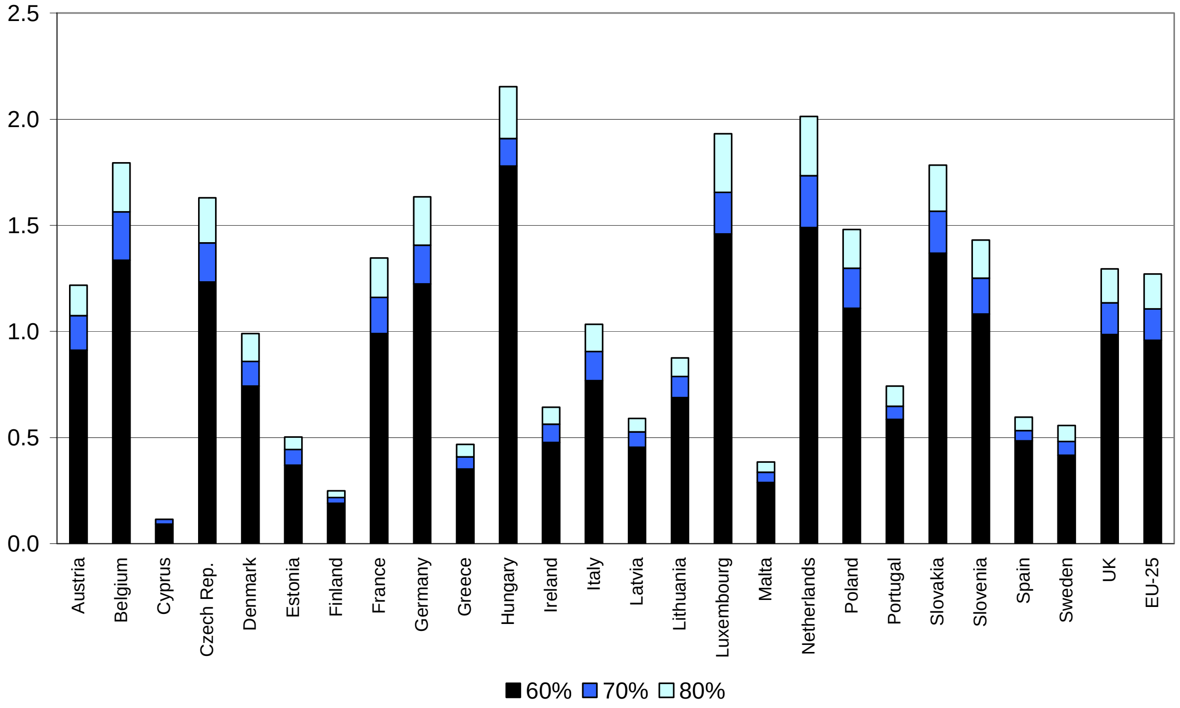


Figure 6.7: Gains in statistical life expectancy (in months) for selected gap closure scenarios without a threshold

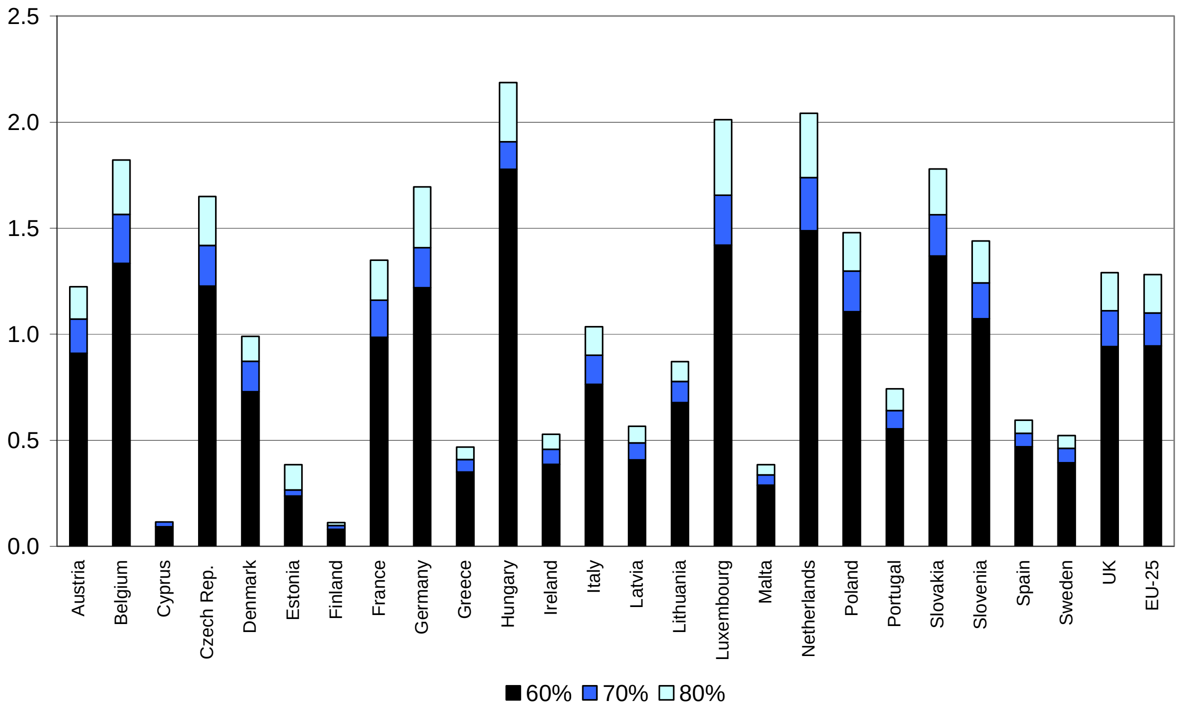


Figure 6.8: Gains in statistical life expectancy (in months) for selected gap closure scenarios with a cut-off of 7 µg/m^3

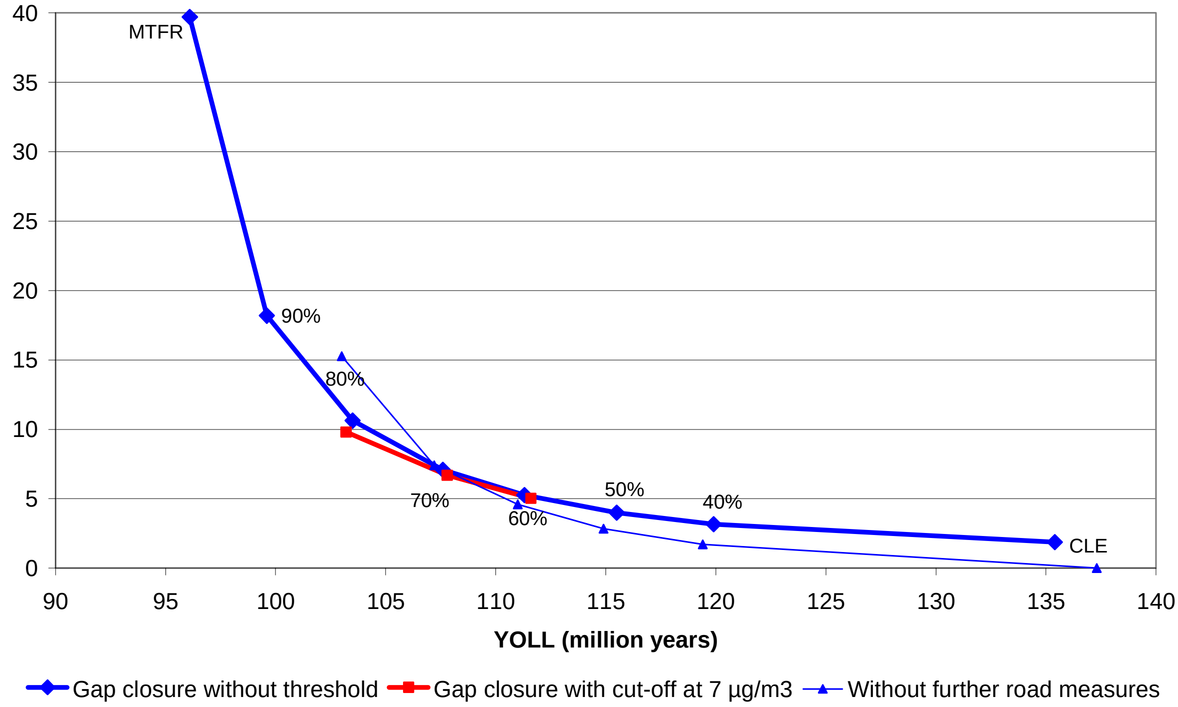


Figure 6.9: Costs of the gap closure scenarios (including the costs of road measures) without threshold and the gap closures with a cut-off at 7 g/m^3 (in billion €/year) versus life years lost attributable to the exposure of PM2.5

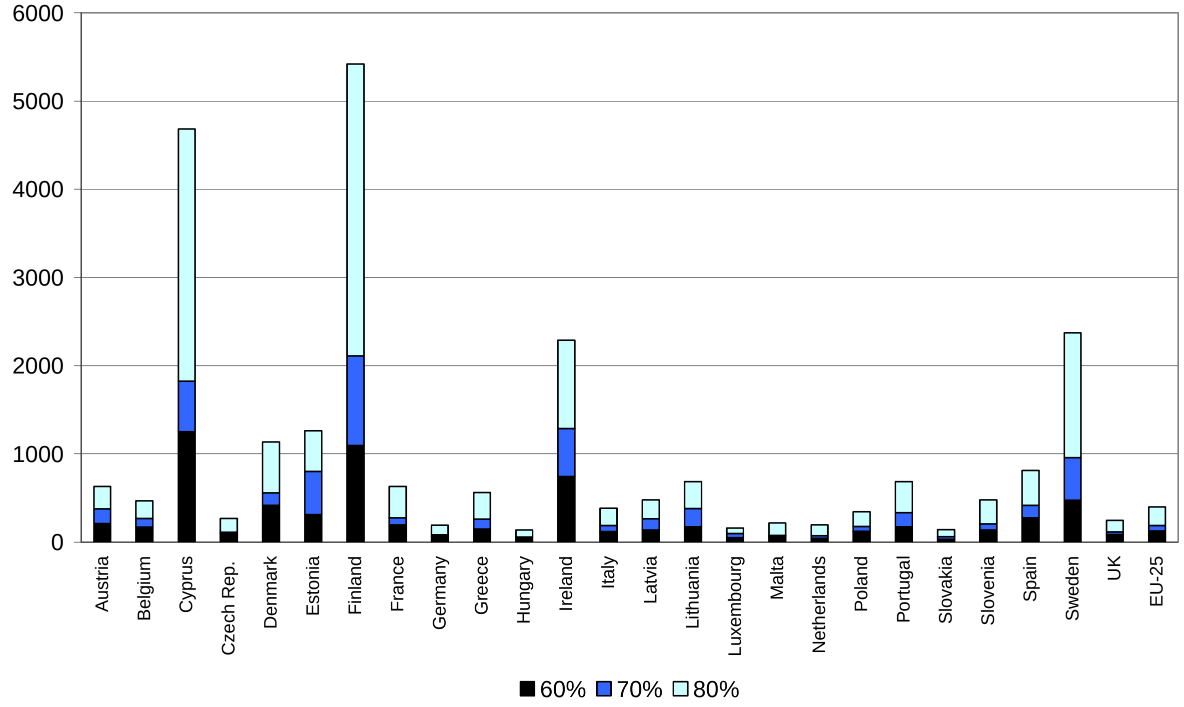


Figure 6.10: Costs per life year saved for three selected gap closure scenarios without threshold (in €/year)

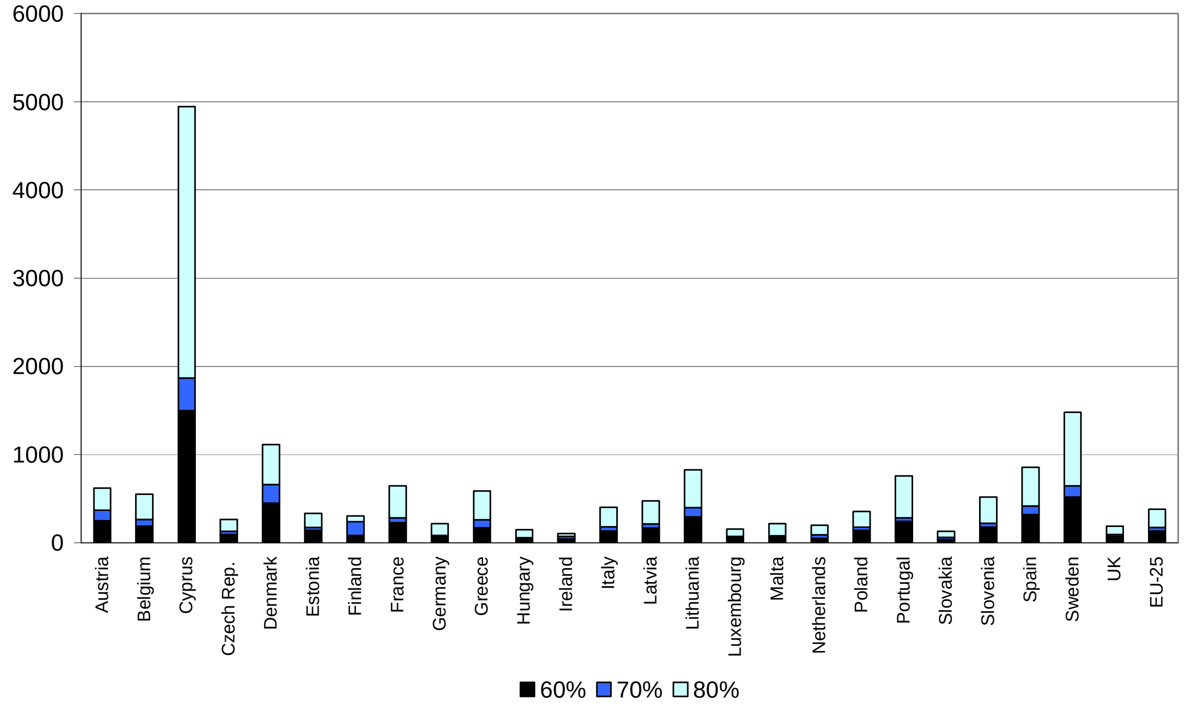


Figure 6.11: Costs per life year saved for three selected gap closure scenarios with a cut-off of 7 µg/m^3 (in €/year)

Table 6.2: Population-weighted PM2.5 exposure of the gap closure scenarios relative to the baseline 2020

		Strict gap closure scenarios			Gap closure scenarios with cut-off at 7 µg/m³				
		Gap closure target			Gap closure target				
	CLE	60%	70%	80%	60%	70%	80%	60%	MTFR
Austria	100%	83%	80%	77%	83%	80%	77%	83%	71%
Belgium	100%	85%	82%	79%	85%	82%	79%	85%	74%
Cyprus	100%	98%	97%	97%	98%	97%	97%	98%	96%
Czech Rep.	100%	79%	75%	72%	79%	75%	71%	79%	65%
Denmark	100%	83%	81%	78%	84%	80%	78%	84%	72%
Estonia	100%	88%	85%	83%	92%	91%	87%	92%	80%
Finland	100%	91%	90%	89%	96%	95%	95%	96%	86%
France	100%	82%	79%	75%	82%	79%	75%	82%	69%
Germany	100%	81%	78%	75%	81%	78%	74%	81%	69%
Greece	100%	93%	92%	91%	93%	92%	91%	93%	89%
Hungary	100%	76%	75%	71%	76%	75%	71%	76%	65%
Ireland	100%	82%	78%	75%	85%	82%	80%	85%	69%
Italy	100%	85%	82%	80%	85%	83%	80%	85%	75%
Latvia	100%	88%	86%	84%	89%	87%	85%	89%	81%
Lithuania	100%	86%	84%	83%	87%	85%	83%	87%	79%
Luxembourg	100%	79%	75%	71%	79%	75%	70%	79%	64%
Malta	100%	93%	92%	91%	93%	92%	91%	93%	89%
Netherlands	100%	82%	79%	75%	82%	79%	75%	82%	69%
Poland	100%	83%	80%	77%	83%	80%	77%	83%	72%
Portugal	100%	81%	79%	76%	82%	79%	76%	82%	70%
Slovakia	100%	78%	75%	72%	78%	75%	72%	78%	66%
Slovenia	100%	82%	79%	76%	82%	79%	76%	82%	70%
Spain	100%	85%	83%	81%	85%	83%	81%	85%	78%
Sweden	100%	84%	82%	79%	85%	83%	81%	85%	75%
UK	100%	78%	75%	72%	79%	76%	72%	79%	65%
Total	100%	82%	79%	76%	82%	80%	76%	82%	71%

7 A Europe-wide target

As a third alternative, the environmental target could be established Europe-wide, for instance in terms of increased life expectancy or, if population-weighted, in terms of years of life lost (YOLL). The optimization would then identify those measures in the EU-25 that would achieve a given improvement of YOLL at least costs. The location where the health benefit occurs is thus not taken into account, and the optimization will allocate measures to those regions where benefits are largest over all of Europe. While this approach maximizes the use of resources, it might compromise on (perceived) equity aspects, because not all Member States do receive equitable environmental improvements.

An attempt has been made to explore with the RAINS optimization the features of such a target setting concept for reducing health impacts from PM.

This approach is based on the assumption of no threshold above which PM2.5 from anthropogenic sources is harmful to human health, but rather that any reduction in PM2.5 concentration from anthropogenic origin will lead to health benefits. The actual benefit of a unit of reduced PM2.5 concentration, however, depends on the population density in the affected area. The more people live in an area, the more effective will be a reduction of PM concentration in the area.

The RAINS framework with its routine for life expectancy calculations and population databases has all information to implement such an approach. It can calculate YOLL for each individual grid cell with a 50*50 km resolution distinguishing urban and rural population, and the results can be aggregated for the entire EU-25.

For the current legislation baseline case, accumulated life shortening is calculated at 140 million years. With maximum technically feasible emission reductions for stationary sources (including further road measures), this number would reduce to 96 million years, i.e., by approximately 30 percent.

A series of repeated optimization runs with stepwise reduced years of life lost YOLLs (starting with no additional costs on top of current legislation up to the costs of the maximum technically feasible reductions of 38 billion €/year has been conducted to explore the range between these two extreme cases. As to be expected, there is a potential for large reductions at low costs, while the maximum achievable improvement would be rather costly to reach (Figure 7.1).

Because in reality further road measures can only be taken in Europe for all Member States simultaneously, two analyses were carried with and without further road measures. Thus, for each of these two cases the actual optimization in RAINS includes only emission controls at stationary sources. Because of the non-existence of a threshold for health effects of PM, the results presented below are independent from the absolute emission level, i.e., they are not influenced by the level of emissions from mobile sources.

As indicated above, while this approach aims for the most effective use of resources, it compromises on equity issues. To explore this important aspect further, the distributions of costs and health benefits have been further examined.

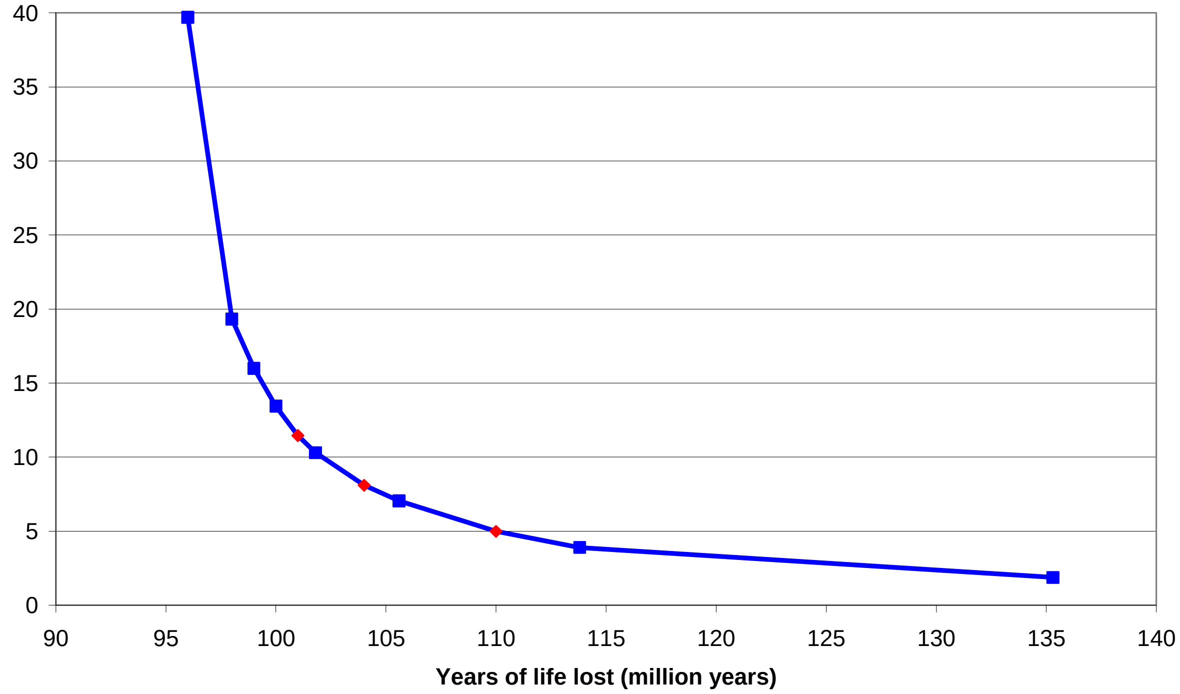


Figure 7.1: Years of life lost (YOLL, million years) attributable to the exposure to anthropogenic PM2.5 against annual emission control costs (in billion €/year), assuming further road measures. The red marks indicate the three illustrative cases C6/1 to C6/3 that are analyzed in more detail.

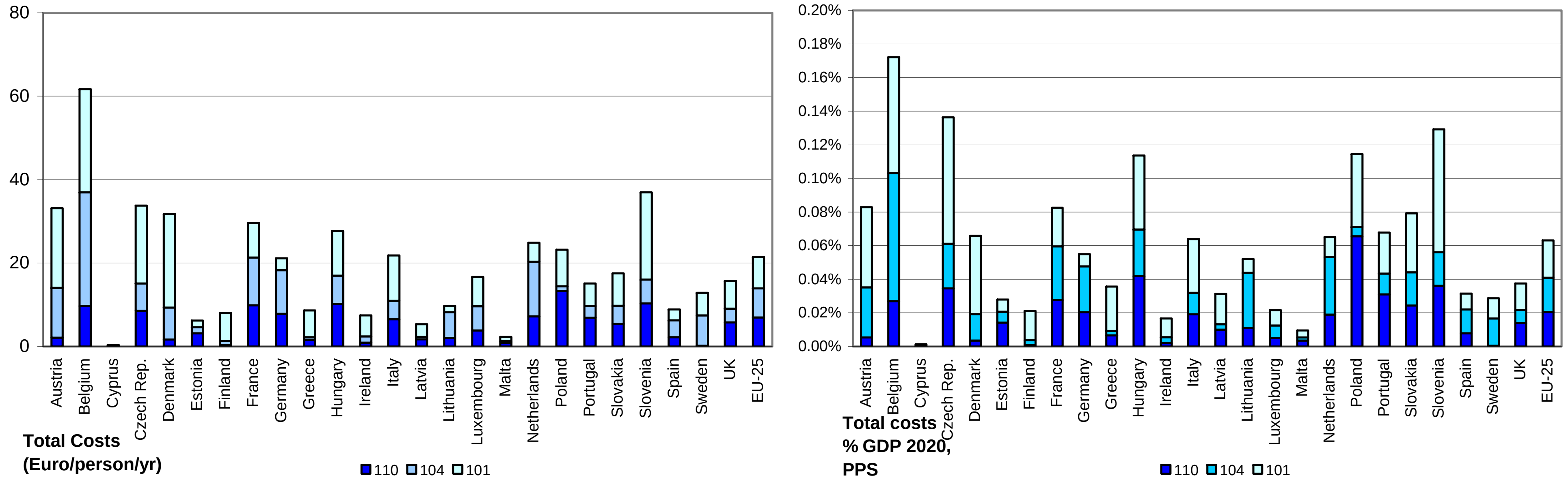


Figure 7.2: Emission control costs for stationary sources on a per-capita basis (left) and per GDP expressed in purchasing power standards (right)

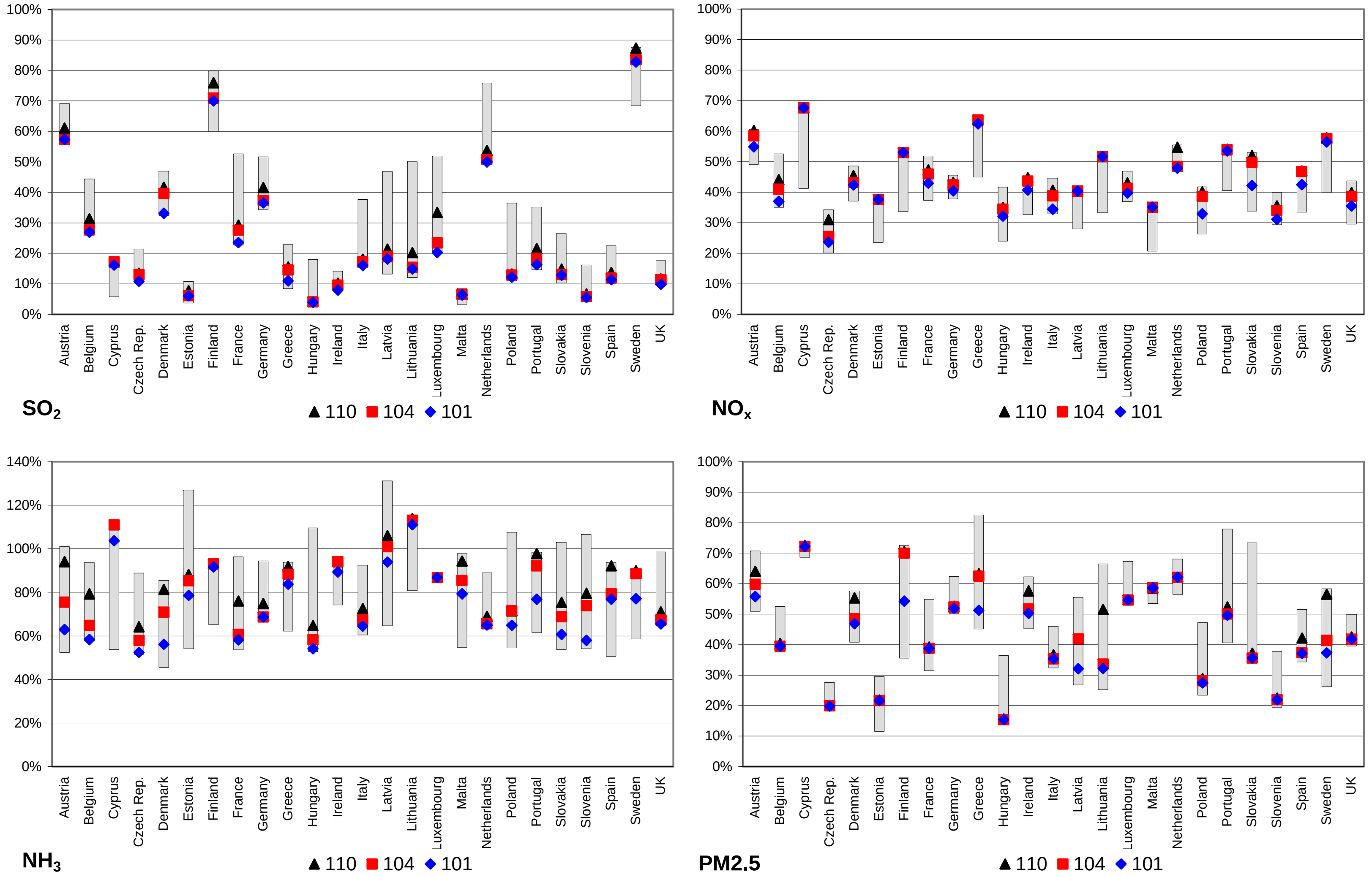


Figure 7.3: Cost-minimal emission reductions of three selected Europe-wide optimized PM2.5 reductions. The 100 percent line refers to the emission level in the year 2000. The grey range indicates the scope for emission reductions considered in the RAINS optimization.

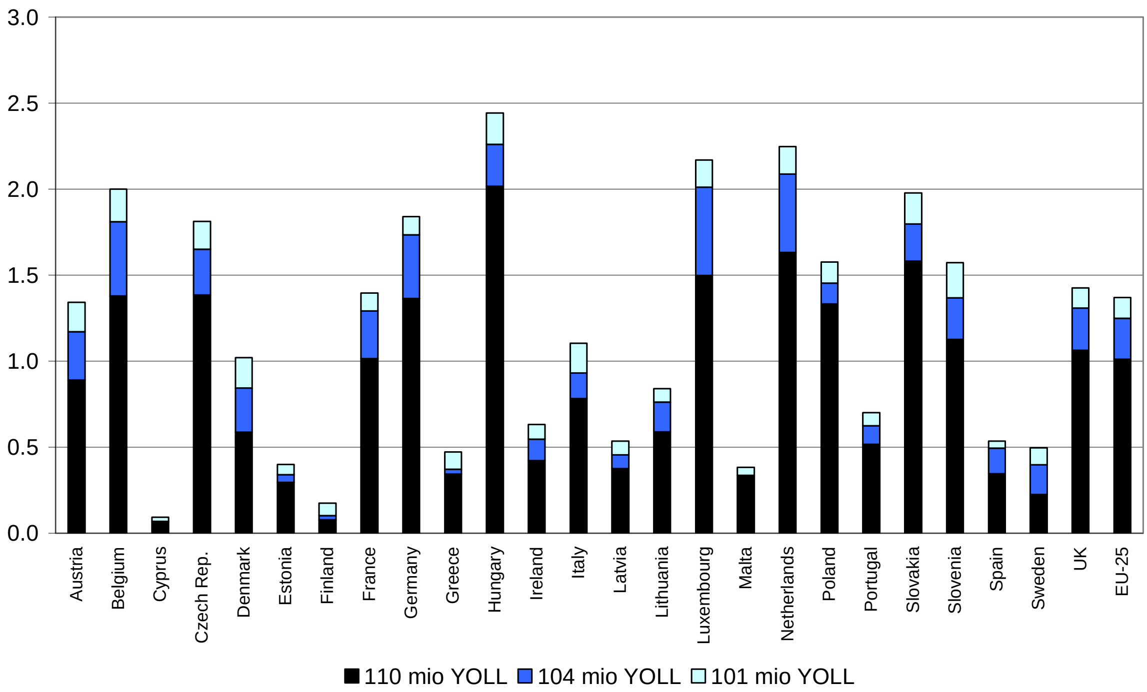


Figure 7.4: Gains in statistical life expectancy (in months) for the three selected YOLL levels

As a consequence, there are also variations in the costs per gained month of life expectancy in Europe (Figure 7.5).

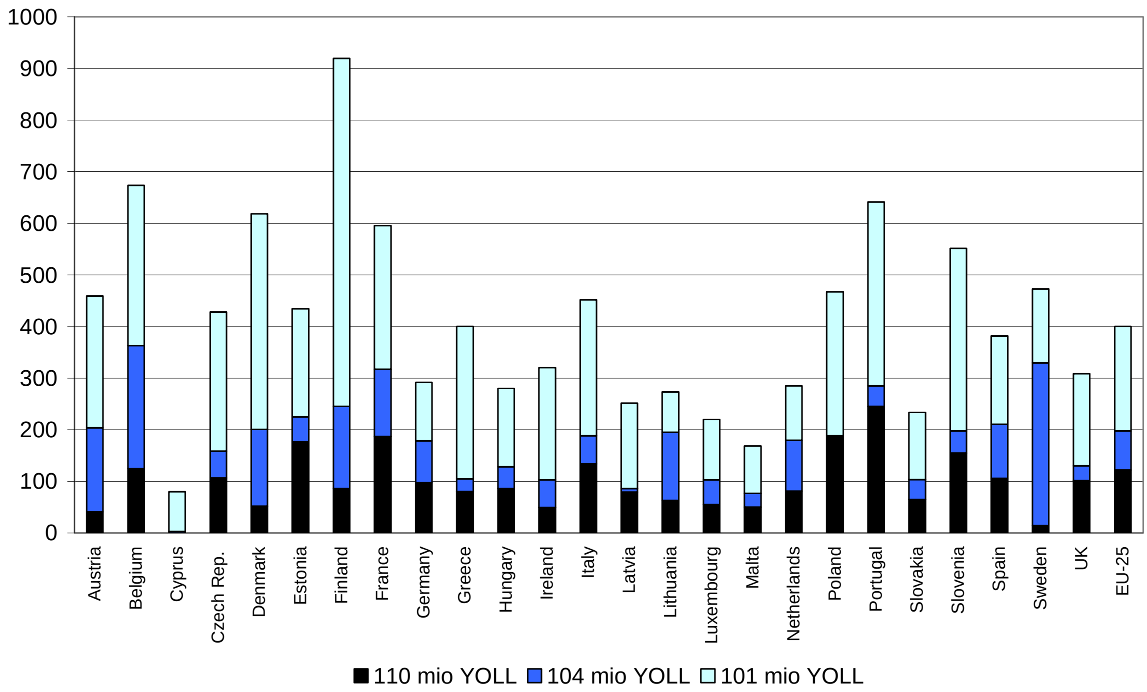


Figure 7.5: Costs for a gained month in statistical life expectancy (€/year) for three selected YOLL levels, with further road measures assumed.

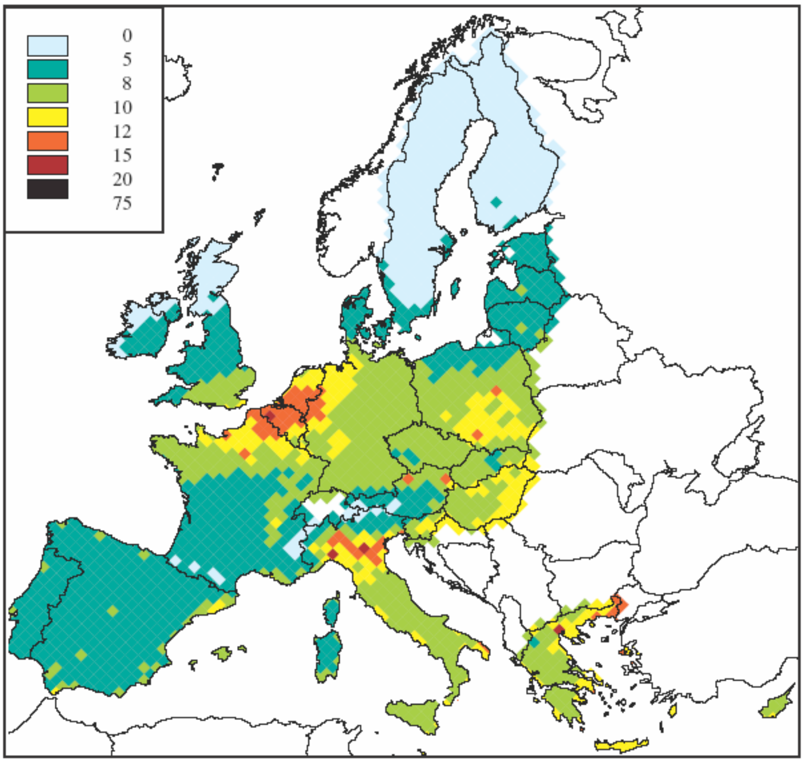


Figure 7.6: Computed PM2.5 concentrations (for urban areas, where applicable) for the C6/2 104 mio YOLL medium ambition scenario (in µg/m^3), including the mineral contribution

Table 7.1: Population-weighted PM2.5 exposure of the Europe-wide target scenarios relative to the baseline 2020

		YOLL target (million years)							
	CLE	113.8	110	104	101	100	99	98	MTFR
Austria	100%	86%	83%	78%	75%	74%	73%	73%	71%
Belgium	100%	86%	84%	79%	77%	76%	76%	75%	74%
Cyprus	100%	99%	98%	98%	98%	98%	97%	97%	96%
Czech Rep.	100%	80%	76%	71%	68%	68%	67%	66%	65%
Denmark	100%	89%	87%	81%	77%	76%	76%	75%	72%
Estonia	100%	92%	91%	89%	87%	85%	84%	83%	80%
Finland	100%	97%	96%	95%	92%	91%	90%	90%	86%
France	100%	85%	81%	76%	74%	74%	73%	72%	69%
Germany	100%	81%	79%	73%	71%	71%	70%	69%	69%
Greece	100%	95%	93%	93%	91%	91%	90%	90%	89%
Hungary	100%	77%	73%	70%	68%	67%	66%	66%	65%
Ireland	100%	85%	84%	79%	76%	75%	75%	73%	69%
Italy	100%	87%	85%	82%	79%	78%	77%	76%	75%
Latvia	100%	93%	90%	88%	86%	85%	84%	83%	81%
Lithuania	100%	91%	88%	85%	83%	83%	82%	81%	79%
Luxembourg	100%	80%	77%	70%	68%	67%	66%	65%	64%
Malta	100%	94%	93%	92%	91%	91%	90%	90%	89%
Netherlands	100%	82%	80%	74%	73%	72%	71%	70%	69%
Poland	100%	84%	79%	78%	76%	75%	74%	74%	72%
Portugal	100%	92%	83%	80%	77%	76%	76%	76%	70%
Slovakia	100%	79%	75%	72%	69%	68%	67%	67%	66%
Slovenia	100%	84%	81%	77%	73%	73%	72%	72%	70%
Spain	100%	91%	89%	85%	83%	81%	81%	81%	78%
Sweden	100%	93%	92%	85%	82%	81%	80%	79%	75%
UK	100%	79%	77%	71%	69%	68%	68%	66%	65%
Total	100%	84%	81%	77%	75%	74%	73%	72%	71%

8 Comparison of the three target setting approaches

8.1 Cost-effectiveness

The three target setting approaches can be compared against their costs and environmental achievements. Figure 8.1 plots the costs (for stationary sources) of the optimized scenarios presented in this paper against the years of life lost for the case with further road measures.

As to be expected on theoretical ground, the Europe-wide approach (blue line) yields best cost-effectiveness and reduces life years lost at least costs. In contrast, the limit value approach (black lines) shows a clear deviation from the cost-effectiveness frontier, especially if limit values approach the technical limits of feasibility in isolated urban areas. For a strict application of Europe-wide gap limit values, the thick black line highlights three to four times higher costs for bringing down years of life lost at 128 million years. The flexibility introduced by the exception for Thessaloniki opens up further cost-effective measures, until the limit of feasibility is reached in Genova. Allowing for a violation of the limit value in Genova creates additional scope for higher cost-effectiveness.

The cost-effectiveness of the gap closure approach lies between that of the two other principles, and is rather sensitive towards the formulation of the gap. As indicated by the medium red line, additional flexibility, e.g., by relaxing demands for low polluted sites through a cut-off value, brings the cost-effectiveness closer towards the theoretical optimum.

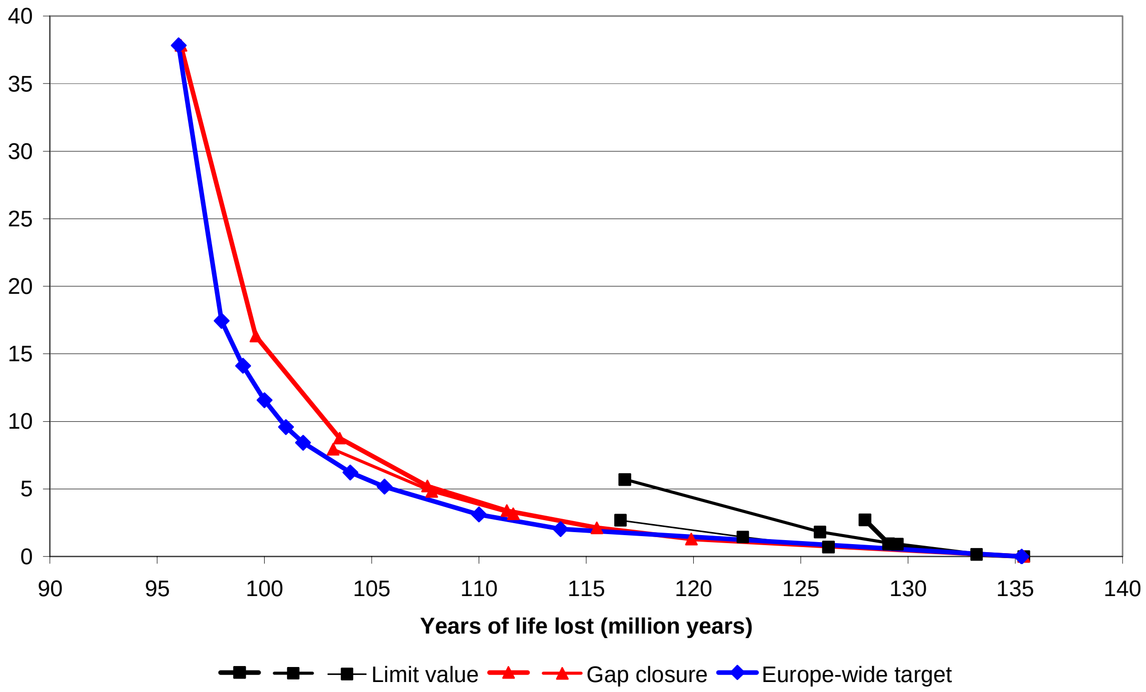


Figure 8.1: Emission control costs for stationary sources (in billion €/year) vs. Years of Life Lost (YOLL, million years) of the optimized scenarios for the three target setting approaches. This graph shows the scenarios with further road measures.

8.2 Equity

There are clear differences in the distributions of costs and environmental benefits between the different target setting principles. While the existence of a notion of equity seems important for establishing acceptability for a proposed interim target, the exact meaning of equity is less clear. It is also not entirely clear among which groups equity is aimed for: among Member States, between different economic sectors, between companies of the same sector in different Member States, between different social groups in the community or in individual Member States, etc.?

A large number of criteria could be developed against which equity between different actors could be established. For instance, equity criteria could relate to

- differences between absolute exposure levels of individuals to pollution, or
- differences between the relative improvements of environmental impacts across countries from the emission control strategy, or
- differences in emission control costs
    - on a per capita-basis or
    - related to various notions of economic wealth, such as
        - GDP measured in Market Exchange Rates, or
        - GDP measured in Purchasing Power Standards, or
- differences in costs for a life month gained.

While there is a variety of statistical measures and economic indicators to quantify disparities within a given population, for simplicity this report uses the coefficient of variation. The coefficient of variation (CV) is a statistical measure of the standard deviation (σ) of a variable from its mean:

$$CV = \frac{s\tan dard\ deviation}{mean} * 100\%$$

The standard deviation is usually the best measure of spread. However, for large variations in the mean (like in this case), CV is a better statistics describing the spread of Member State data from the EU mean. The smaller the CV, the closer (i.e., more equal) are the Member States to the EU mean.

Figure 8.2 presents the coefficients of variations over the Member States for four different criteria (costs per capita, costs per GDP in Purchasing Power Standards, gains in life expectancies relative to the baseline projection for 2020, costs for a life year gained). The graph clearly demonstrates that different criteria lead to different conclusions about equity. In general, the limit value principle shows largest differences between Member States for all four criteria. The gap closure approach performs obviously best in terms of the relative improvement in life expectancy compared to the baseline projection for 2020 – which is in fact exactly the definition of the gap closure used for the target setting. In terms of costs, the strict gap closure principle results in large disparities, while the modified gap closure scenario with the cut-off threshold is among the leading approaches. The Europe-wide targets, while they a priori ignore any distributional aspects, rank high for all four criteria and perform best for the 'equity of effectiveness' criterion in terms of costs per life year saved.

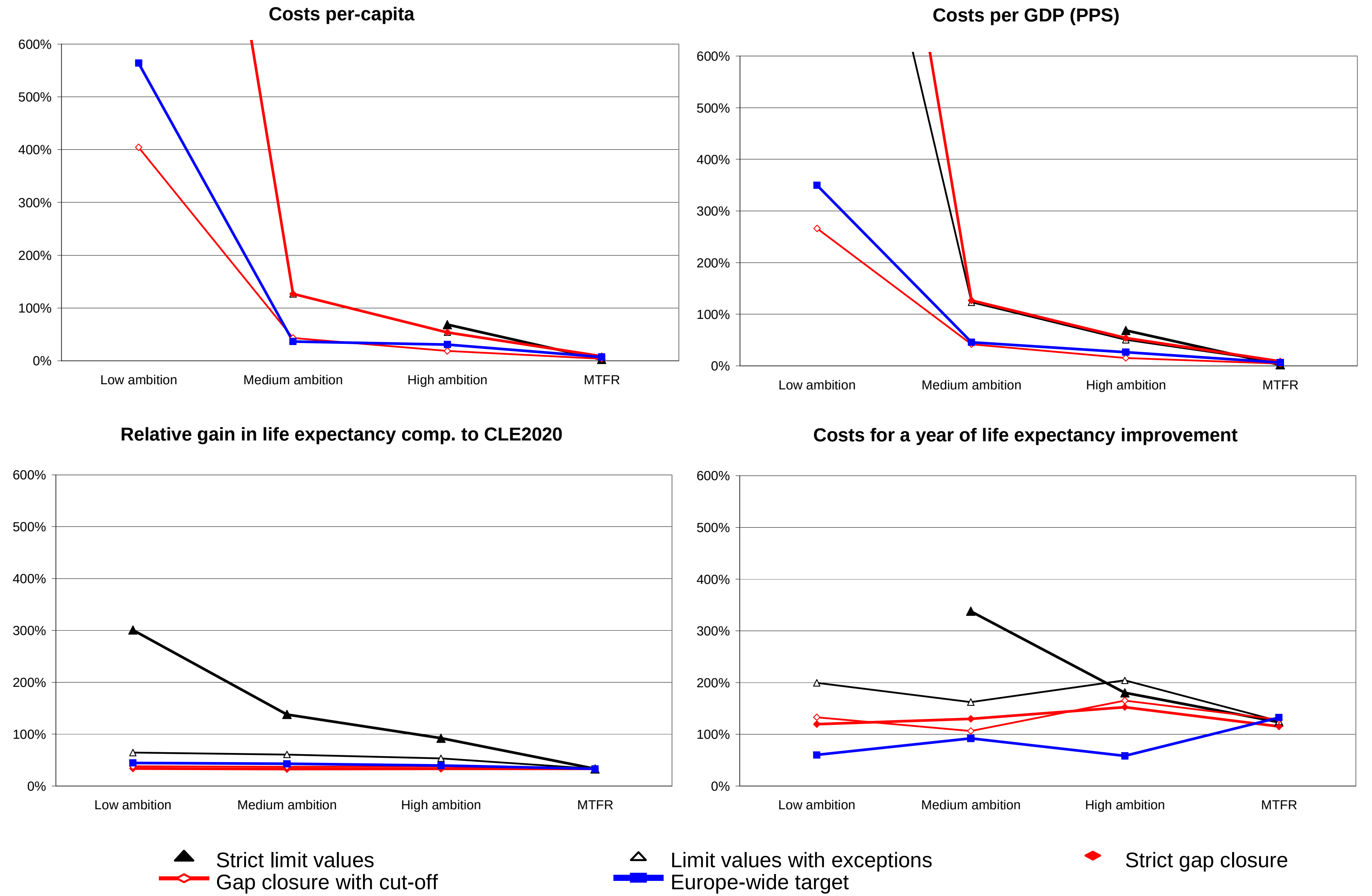


Figure 8.2: Coefficients of variations quantifying the range of selected equity criteria over Member States

9 Joint optimization for PM2.5, ozone, acidification and eutrophication

A set of scenarios has been developed that, individually or jointly, address the environmental endpoints considered in the CAFE programme (PM2.5, ozone, acidification and eutrophication). The following sets of effect indicators, target setting principles and ambition levels have been explored:

For PM2.5:

> Europe-wide improvements in statistical life expectancy attributable to reduced exposure to PM2.5. Target levels: 110, 104 and 101 million years of life lost, equivalent to Scenarios C6/1 to C6/3.

For ozone:

> For health impacts attributable to ozone RAINS calculates the number of premature deaths attributable to ozone (SOMO35) on a grid basis and sums them up to a country balance. Formally, this is equivalent to a gap closure calculated on the basis of population-weighted SOMO35 grid data. Target levels: Gap closure of 70, 80 and 90 percent – comparable to the CAFE A2 scenarios. No separate targets have been considered in this first optimization study for vegetation effects from ozone. However, the critical level for forest trees (AOT40) parallels the SOMO35 to the large extent, so that an optimization targeted at AOT40 would yield similar results as the SOMO35 optimization.

For acidification:

> A "gap closure" between CLE and MTFR in terms of the total deposition of acidifying compounds in excess of the critical loads for acidification, accumulated over all ecosystem types (forests, semi-natural, water) and ecosystems area in a country. Target levels: Gap closure of 70, 80 and 90 percent – comparable to the CAFE A3 scenarios.

For eutrophication:

> A "gap closure" between CLE and MTFR in terms of the total deposition of nitrogen compounds in excess of the critical loads for eutrophicatoin, accumulated over all ecosystem types (forests, semi-natural, water) and ecosystems area in a country. Target levels: Gap closure of 70, 80 and 90 percent – comparable to the CAFE A4 scenarios.

As a first step, the RAINS optimization model has been used to identify the cost-minimal combination of emission reduction measures that meet each of these targets individually. In a further step, an illustrative joint optimization has been carried out that arbitrarily combines targets of equal ambition level (low/medium/high) of all four problems considered. It should be noted that such a combination of ambition levels implies a value judgment on the relative importance of the individual air quality problems. Such a judgement is beyond the remit – and the abilities – of a formal scientific cost-effectiveness analysis.

Table 9.1 presents for the optimized scenarios the aggregated effect indicators and the total emission control costs.

Table 9.1: Aggregated effect indicators for the four environmental endpoints and emission control costs from the individually and jointly optimized scenarios

PM indicator (million YOLLs)	CLE	110	104	101	MTFR
PM optimized	135.4	110.0	104.0	101.0	96.1
O_3 optimized	135.4	133.4	132.9	132.4	96.1
Acidification optimized	135.4	115.9	113.7	109.6	96.1
Eutrophication optimized	135.4	119.1	116.7	114.2	96.1
Joint optimization	135.4	110.0	104.0	101.0	96.1
Ozone indicator (SOMO35)	CLE	70%	80%	90%	MTFR
PM optimized	50486	48969	48214	46449	41051
O_3 optimized	50486	44346	43291	42157	41051
Acidification optimized	50486	48236	47091	45480	41051
Eutrophication optimized	50486	46655	45557	44565	41051
Joint optimization	50486	44263	43239	42146	41051
Acidification indicator (accumulated excess deposition)	CLE	70%	80%	90%	MTFR
PM optimized	1404	558	418	365	301
O_3 optimized	1404	1289	1271	1252	301
Acidification optimized	1404	533	454	378	301
Eutrophication optimized	1404	731	651	570	301
Joint optimization	1404	514	426	357	301
Eutrophication indicator (accumulated excess deposition)	CLE	70%	80%	90%	MTFR
PM optimized	6931	4771	3922	3281	2329
O_3 optimized	6931	6286	6161	6034	2329
Acidification optimized	6931	4759	4187	3425	2329
Eutrophication optimized	6931	3677	3211	2758	2329
Joint optimization	6931	3663	3149	2706	2329
Costs (million €/year)	CLE	Low	Medium	High	MTFR
PM optimized	0	3108	6221	9586	37838
O_3 optimized	0	1882	3228	5076	37840
Acidification optimized	0	3302	4675	8337	37840
Eutrophication optimized	0	3974	6243	10260	37840
Joint optimization	0	5579	9310	14020	37840

To illustrate the linkages between the environmental endpoints, a “gap closure” indicator has been developed that scales the range between CLE and the MTFR from zero to 100%. The composite gap closure indicator, which sums up the achieved gap closure percentages for each of the four environmental endpoints, allows highlighting the extent to which emission reductions targeted at one particular endpoint lead to improvements of other effects as a side impact.

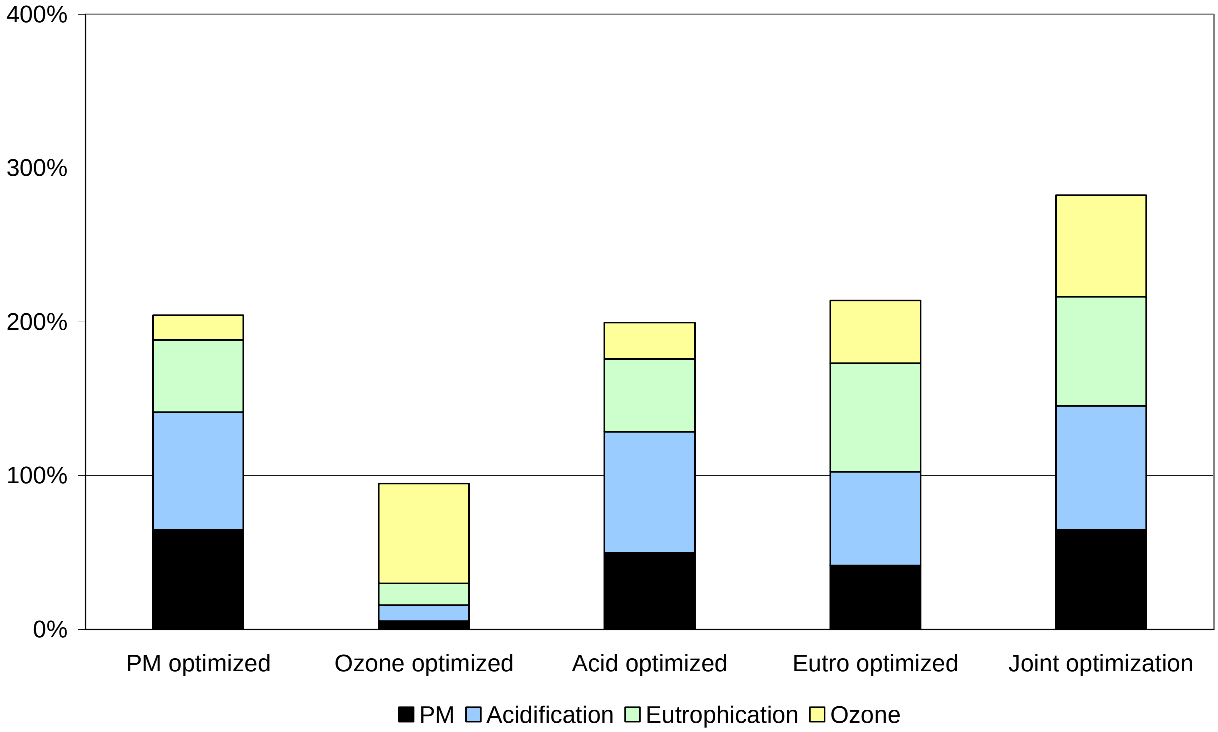


Figure 9.1: Composite gap closure index (adding up the achieved gap closure percentage points for each air quality problem between zero percent (CLE) and 100 percent (MTFR)) for the single effect and the joint optimization, for the low ambition levels.

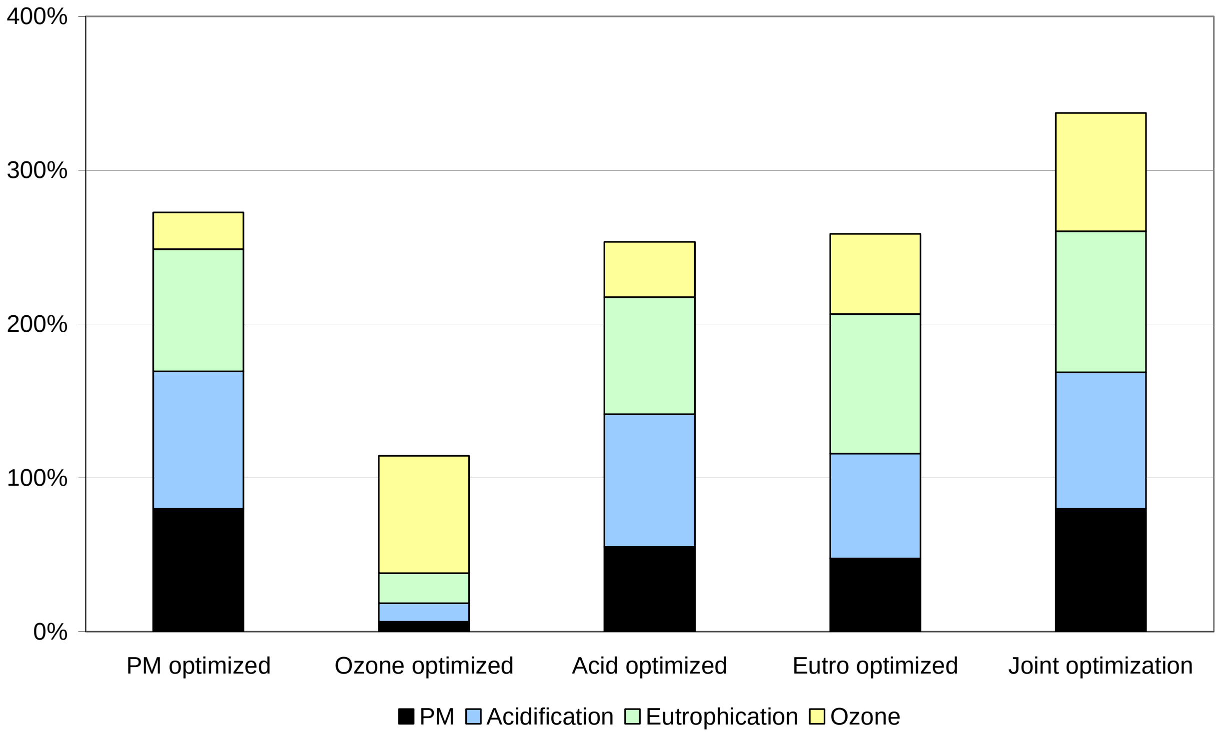


Figure 9.2: Composite gap closure index (adding up the achieved gap closure percentage points for each air quality problem between zero percent (CLE) and 100 percent (MTFR)) for the single effect and the joint optimization, for the medium ambition levels.

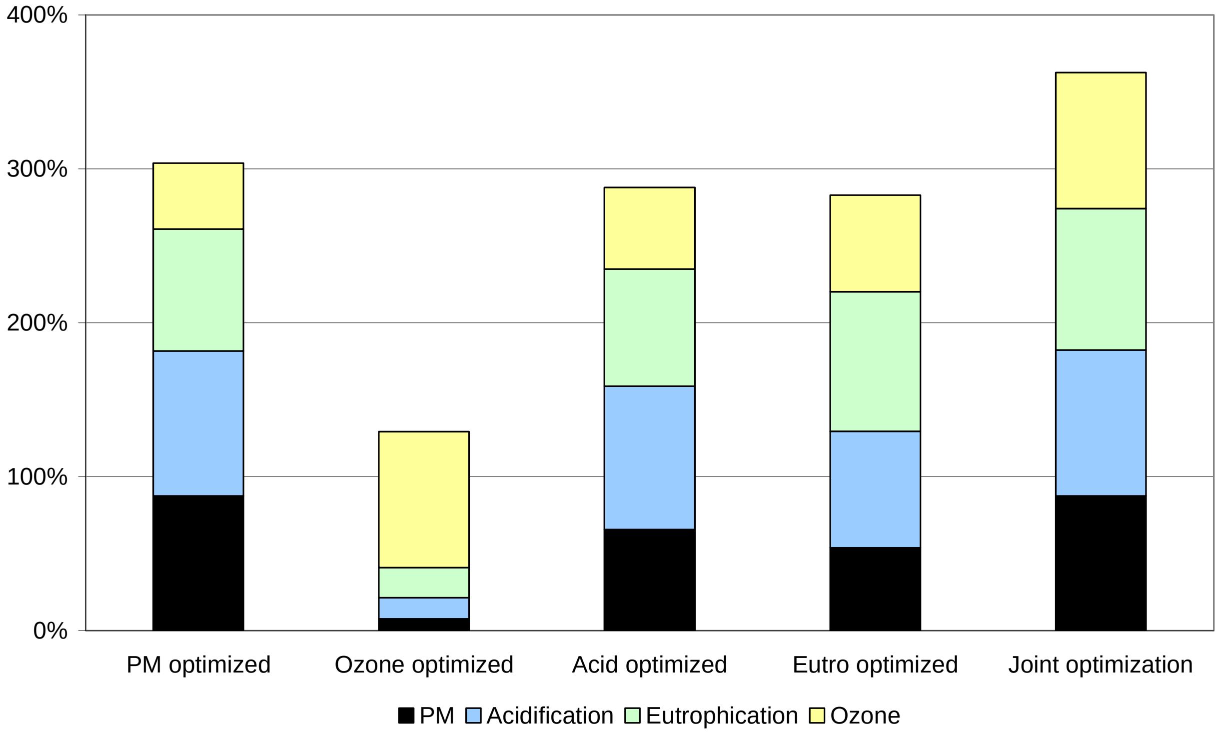
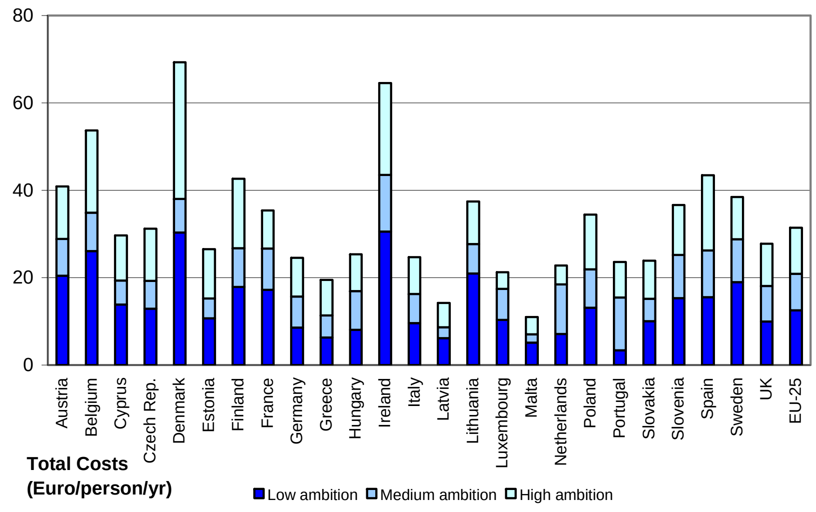


Figure 9.3: Composite gap closure index (adding up the achieved gap closure percentage points for each air quality problem between zero percent (CLE) and 100 percent (MTFR)) for the single effect and the joint optimization, for the high ambition levels.

As illustrated in Figure 9.1 to Figure 9.3, there are strong synergies between emission controls aimed at PM exposure, acidification and eutrophication. Each of these approaches yields substantial co-benefits for the other problems. It is interesting to note, however, that a PM-only approach yields a higher composite gap closure for these three problems than strategies aimed at acidification or eutrophication. On the other hand, there are only very small co-benefits from an ozone strategy for the other air quality problems. As to be expected on theoretical grounds, the joint optimization achieves largest improvements for each individual endpoint.



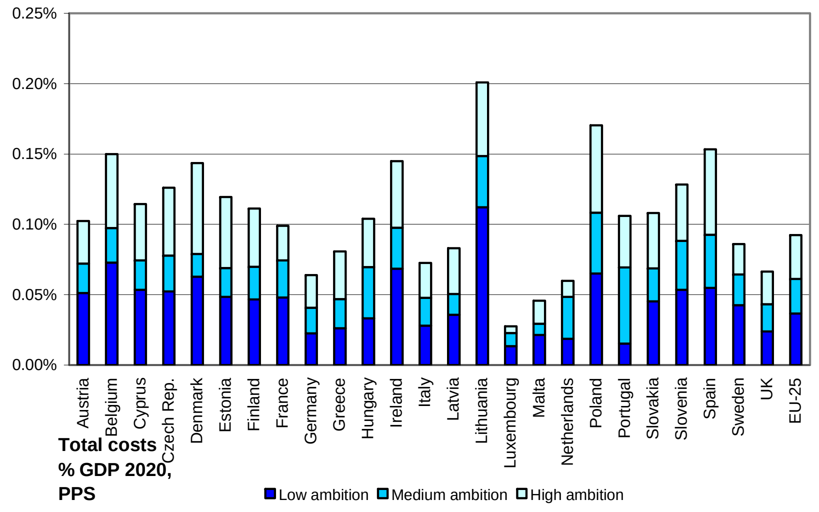


Figure 9.4: Emission control costs for stationary sources on a per-capita basis (left) and per GDP expressed in purchasing power standards (right) for the joint optimization scenarios

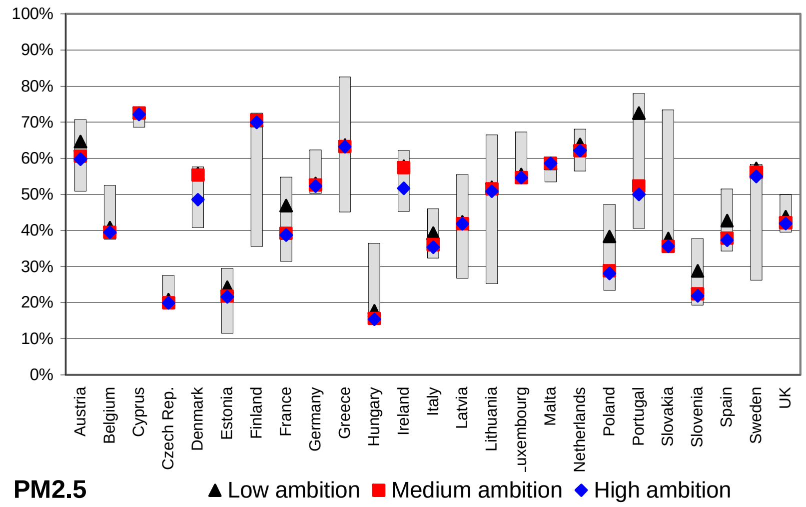


Figure 9.5: Cost-minimal emission reductions at stationary sources for the joint optimization scenarios assuming implementation of further road measures. The 100 percent line refers to the emission level in the year 2000. The grey range indicates the scope for emission reductions considered in the RAINS optimization.

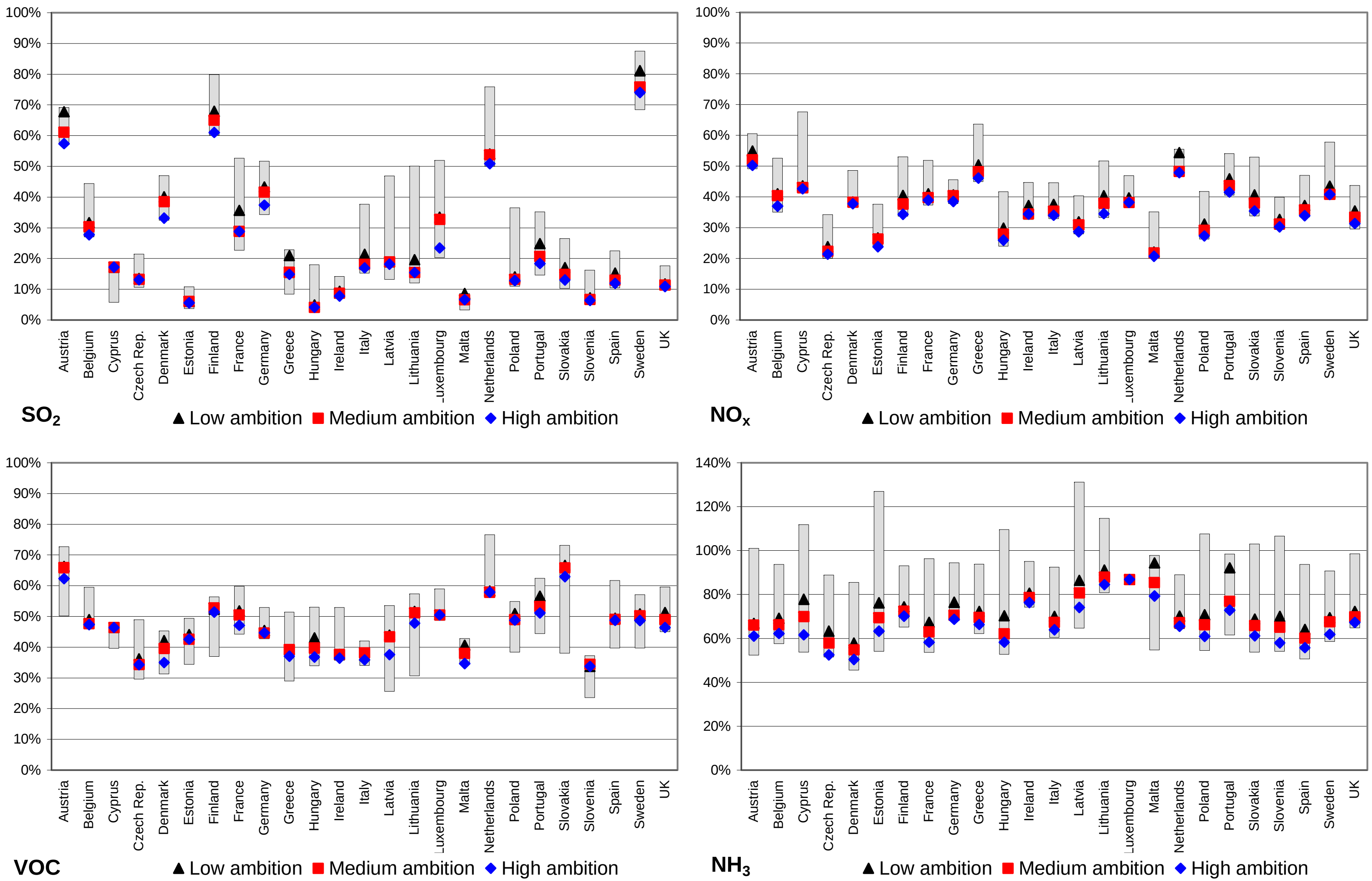


Figure 9.6: Cost-minimal emission reductions at stationary sources for the joint optimization scenarios assuming implementation of further road measures. The 100 percent line refers to the emission level in the year 2000. The grey range indicates the scope for emission reductions considered in the RAINS optimization.

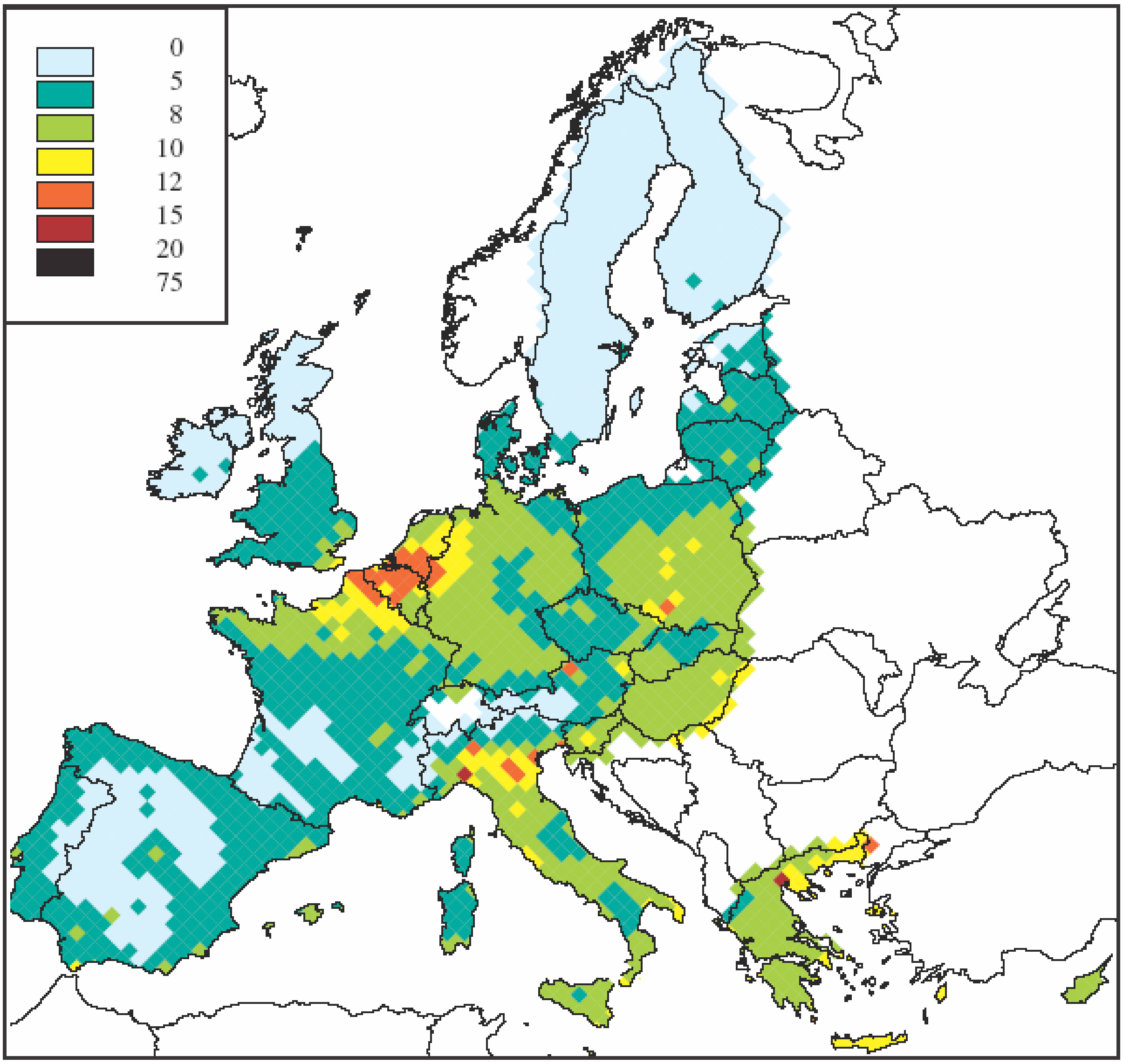


Figure 9.7: Computed PM2.5 concentrations (in urban areas, if applicable) for the medium ambition joint optimization scenario. Mineral contribution is included.

10 Sensitivity analyses

10.1 Sensitivity analysis with medium ambition measures for seagoing ships

As a sensitivity analysis, Scenario C8 was repeated with the same environmental targets but assuming implementation of the "medium ambition" package for sea-going ships as described in Section 2.

Table 10.1: Costs for the joint optimization scenarios with and without medium ambition level measures for ships (million €/year)

	Scenario C8 without ship measures	Scenario C9 with "medium ambition" measures for ships			
	Costs for land-based sources	Costs for land-based sources	Costs for ships	Total costs	Cost difference to C8
Low ambition	5579	5251	28	5279	-300
Medium ambition	9310	8896	28	8924	-386
High ambition	14020	13180	28	13208	-812

10.2 Sensitivity analysis with national energy and agricultural projections

As a further sensitivity analysis, the joint multi-effect scenario C8 has been repeated with the national projections on energy consumption and agricultural activities. In the course of the preparation of the CAFE baseline scenario, Member States were invited to submit their national perspectives on future energy and agricultural development. Such national projections have been received from 10 countries for energy and agriculture, respectively (see also Amann *et al.*, Baseline Scenarios for the Clean Air for Europe (CAFE) Programme, International Institute for Applied Systems Analysis, 2004; http://www.iiasa.ac.at/rains/CAFE_files/Cafe-Lot1_FINAL(Oct).pdf).

In general, for most countries national projections foresee a somewhat higher energy use than assumed in the CAFE Baseline scenario "with climate measures" as developed with the PRIMES model. Although Member States were invited to submit projections that are compliant with the obligations of the Kyoto protocol for greenhouse gases, for all countries CO_2 emissions of the submitted national energy projections exceed those of the "with climate measures" CAFE baseline scenario, which meets at the EU level the Kyoto obligations. For eight of the ten countries, i.e., all countries except Sweden and the UK, the national projection even surpass the CO_2 emissions of the "without climate measures" scenario of the PRIMES model, which reflects business-as-usual without any constraint on greenhouse gas emissions (Figure 10.1).

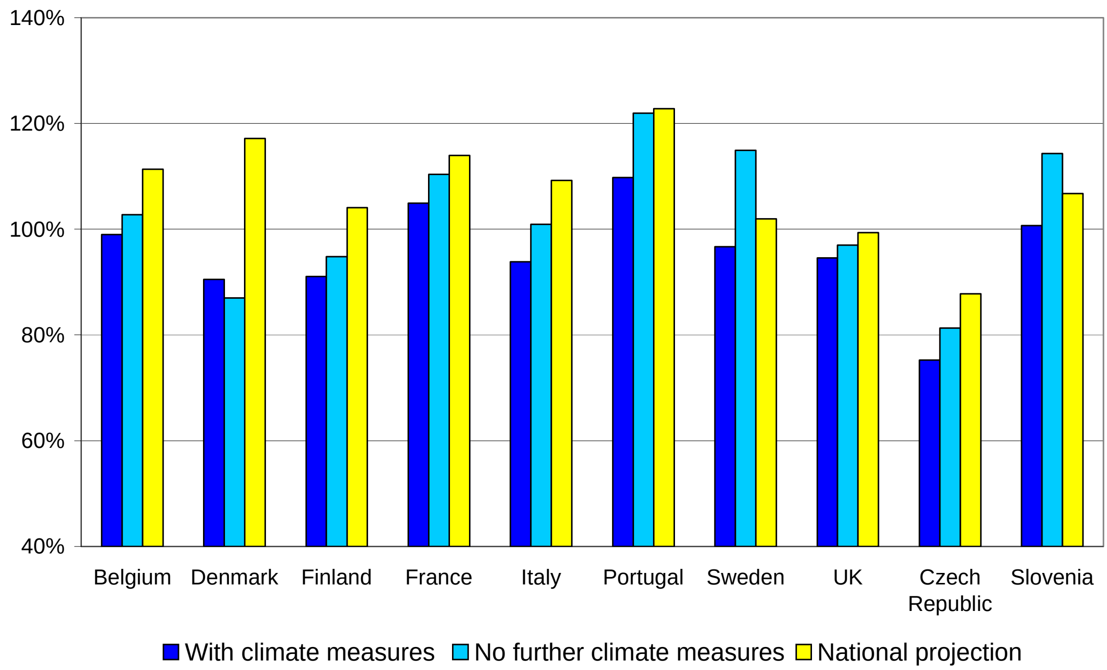


Figure 10.1: CO_2 emissions of the national energy projections (yellow bars) compared to the PRIMES projections with and without further climate measures, relative to the year 2000

These differences in the structures and volumes of energy consumption lead to different levels of emissions of air pollutants, which are in general higher than those of the CAFE baseline "with further climate measures. Figure 10.2 to Figure 10.5 display the differences in "current legislation" baseline emissions for the year 2010 (note, however, that the optimization analysis is carried out for 2020).

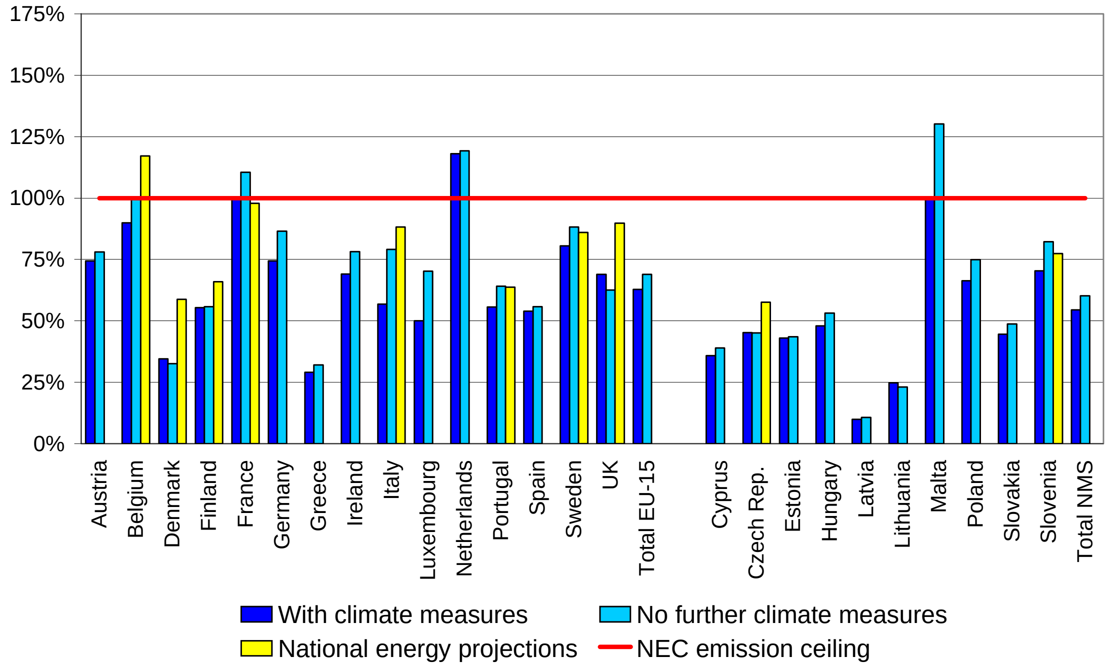


Figure 10.2: Estimated SO_2 emissions for 2010 compared with the emission ceilings for SO_2

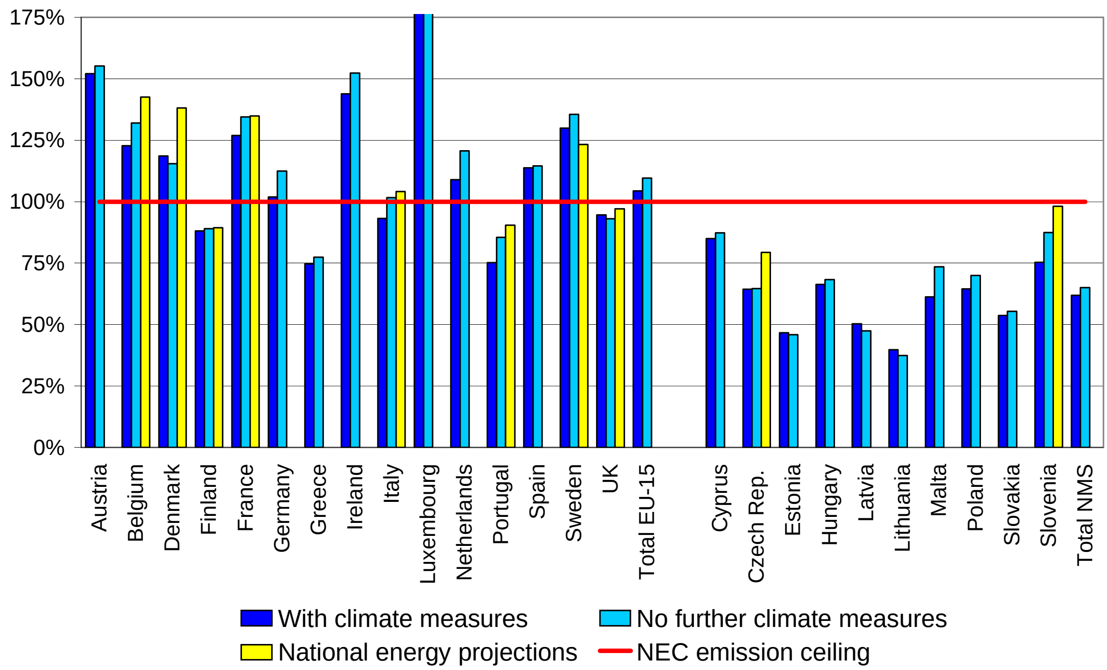


Figure 10.3: Projected NO_x emissions for the year 2010 compared with the national emission ceilings

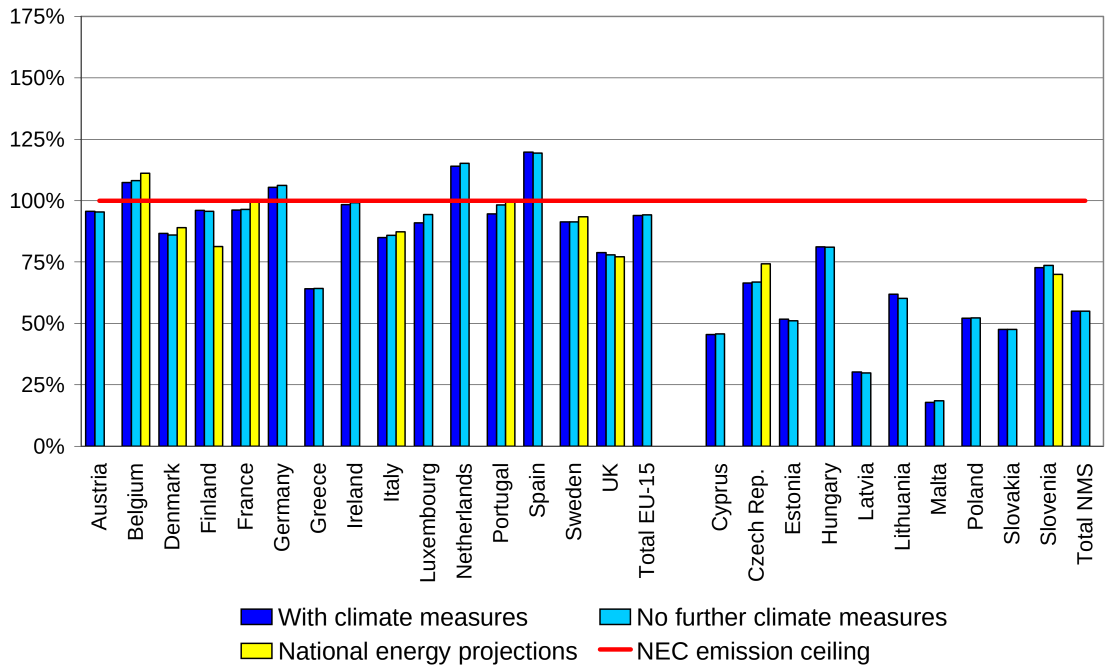


Figure 10.4: Projected VOC emissions for the year 2010 compared with the national emission ceilings

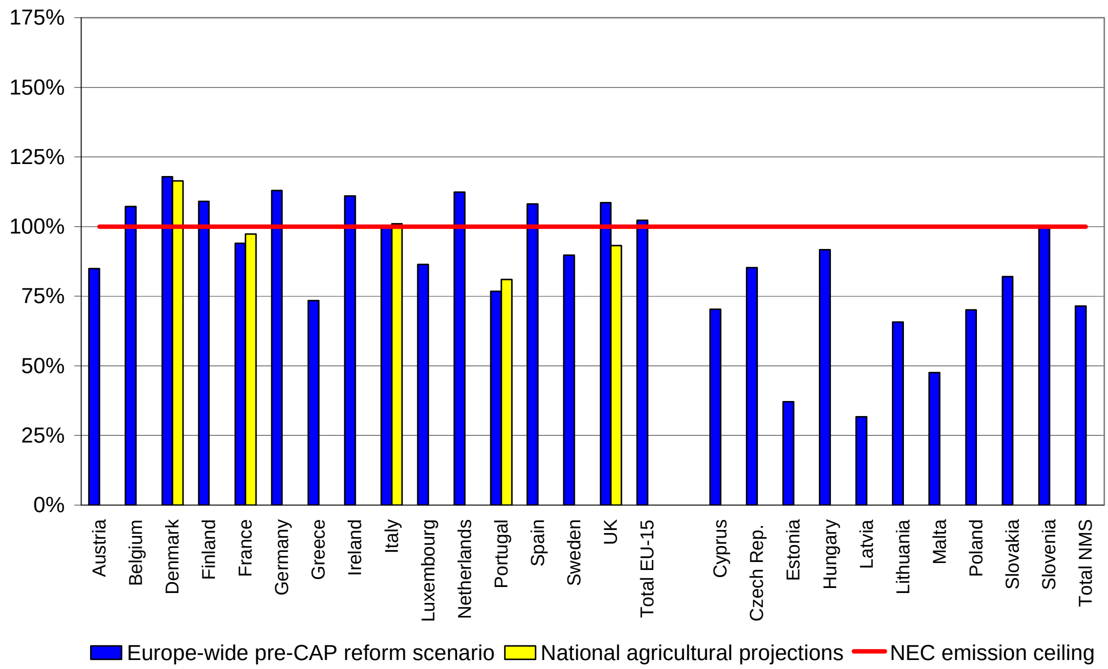


Figure 10.5: Projected NH_3 emissions for the year 2010 compared with the national emission ceilings, for the EU-15

Without further analysis of the plausibility of these national projections, they have been employed to test the robustness of the optimization analysis against different assumptions on one of the most important exogenous input data. As an initial sensitivity analysis, the C8 calculation has been repeated with the cost curves resulting from the national energy and agricultural projections for those countries where they were available. For all other countries the “with further climate measures” baseline scenario has been applied. The optimization analysis identified then the cost-minimal allocation of emission control measures for the recomputed environmental targets of the C8 analysis. In practice, the same gap closure concepts have been employed based on the “current legislation” and “maximum technically feasible reduction” cases of the national energy and agricultural projections. For PM2.5, the same absolute improvements of YOLLs as in the C8 scenario – starting from the baseline projection - have been established as targets.

A comparison with the costs of the “with climate measures” scenario (Table 10.3) reveals that for this particular sensitivity analysis the environmental targets can be achieved at lower costs (Table 10.2). The higher emissions of the baseline projection and the increased room for emission reductions through technical measures resulting from the higher use of fossil fuels make the achievement of the same relative environmental improvements less costly. If the environmental targets were specified in absolute terms, however, e.g., in form of an air quality limit value, costs would be most likely higher.

Table 10.2: Costs of the single-effect and joint optimization runs for the national scenarios (million €/year)

	Ambition level			
	low	medium	high	MTFR
Acidification optimized	3160	4416	7553	40220
Eutrophication optimized	3432	5478	9195	40220
Ozone optimized	1796	3131	5078	40220
PM optimized	2139	3749	5079	40220
Joint optimization	4895	7711	12080	40220

Table 10.3: Costs of the single-effect and joint optimization runs for the “with climate measures” baseline scenario (million €/year)

	Ambition level			
	low	medium	high	MTFR
PM optimized	3302	4675	8337	37840
Acidification optimized	3974	6243	10260	37840
Eutrophication optimized	1882	3228	5076	37840
Ozone optimized	3108	6221	9586	37840
Joint optimization	5579	9310	14020	37840

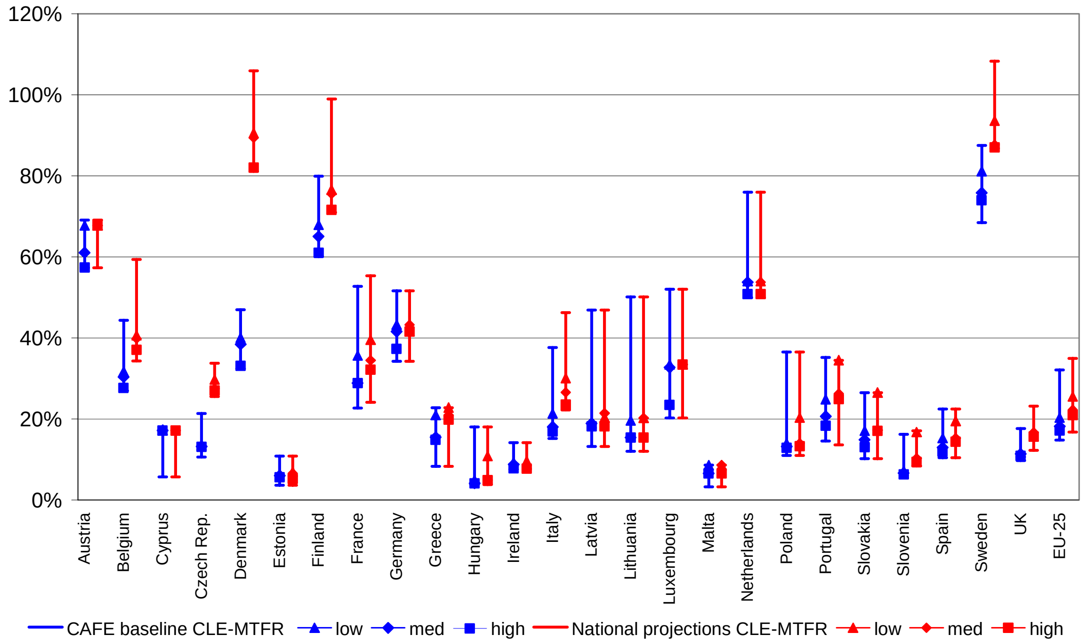


Figure 10.6: SO_2 emissions for the optimized multi-effect scenario, for the CAFE baseline with climate measures (C8) and the national energy and agricultural projections (C9), relative to the emissions of the year 2000 (=100%).

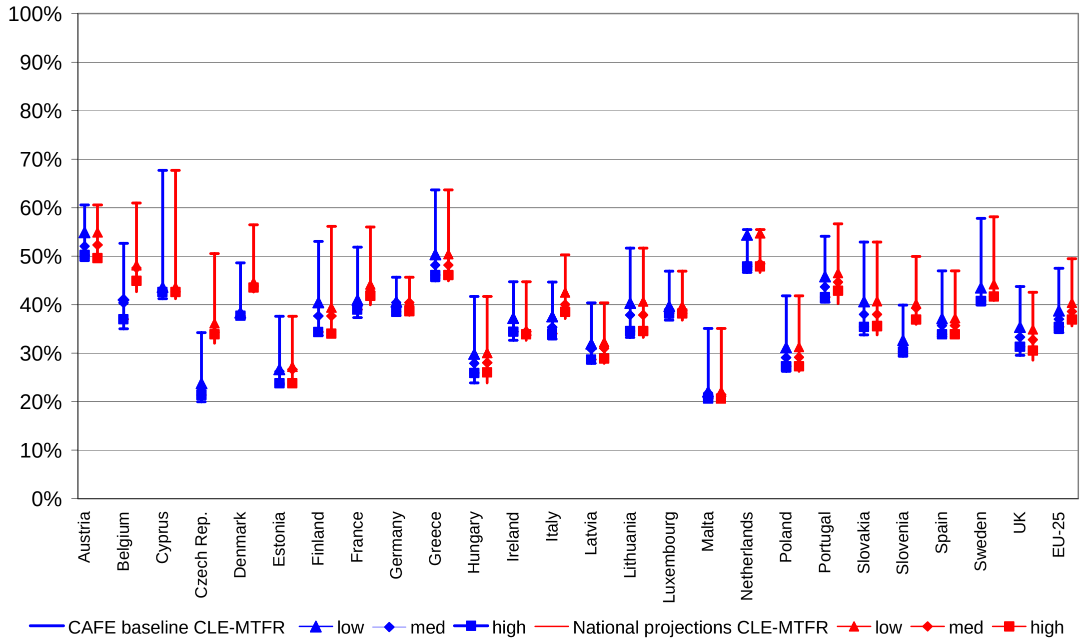


Figure 10.7: NO_x emissions for the optimized multi-effect scenario, for the CAFE baseline with climate measures (C8) and the national energy and agricultural projections (C9), relative to the emissions of the year 2000 (=100%).

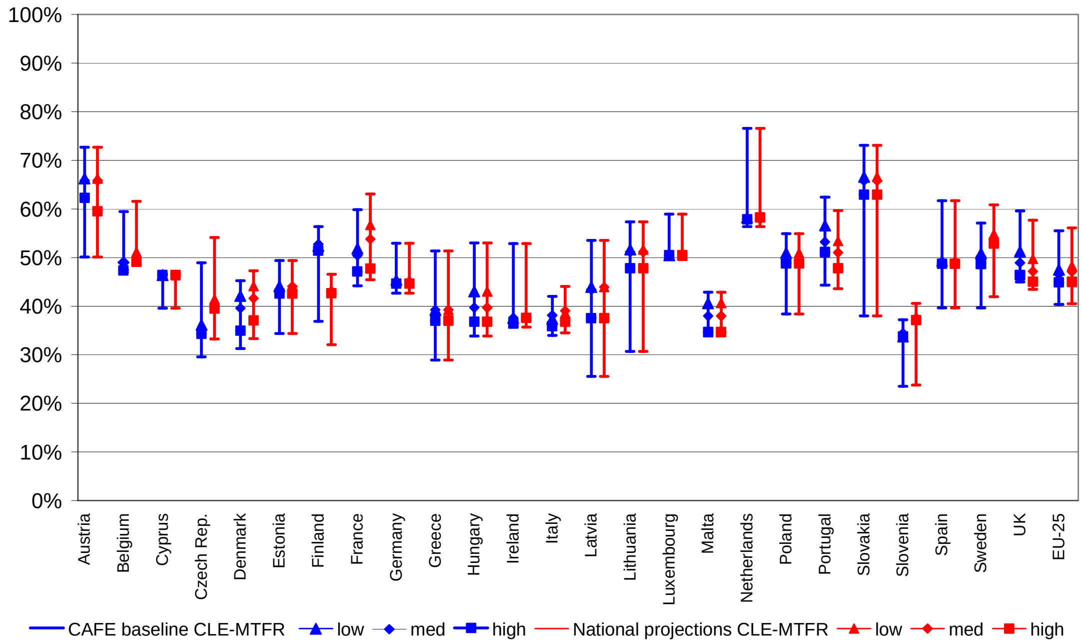


Figure 10.8: VOC emissions for the optimized multi-effect scenario, for the CAFE baseline with climate measures (C8) and the national energy and agricultural projections (C9), relative to the emissions of the year 2000 (=100%).

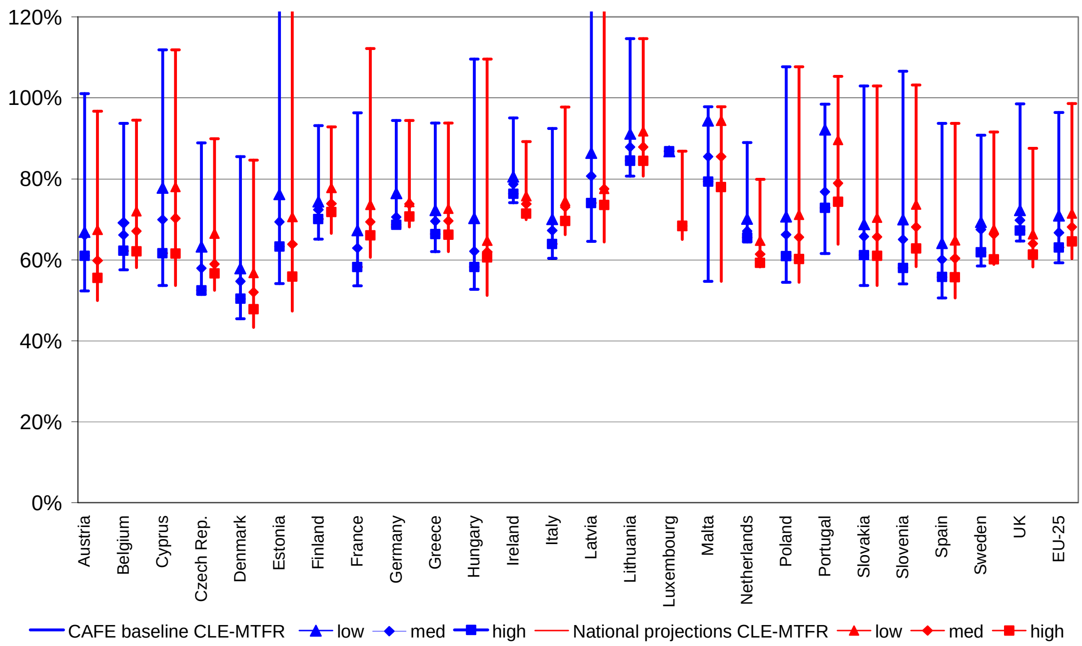


Figure 10.9: NH_3 emissions for the optimized multi-effect scenario, for the CAFE baseline with climate measures (C8) and the national energy and agricultural projections (C9), relative to the emissions of the year 2000 (=100%).

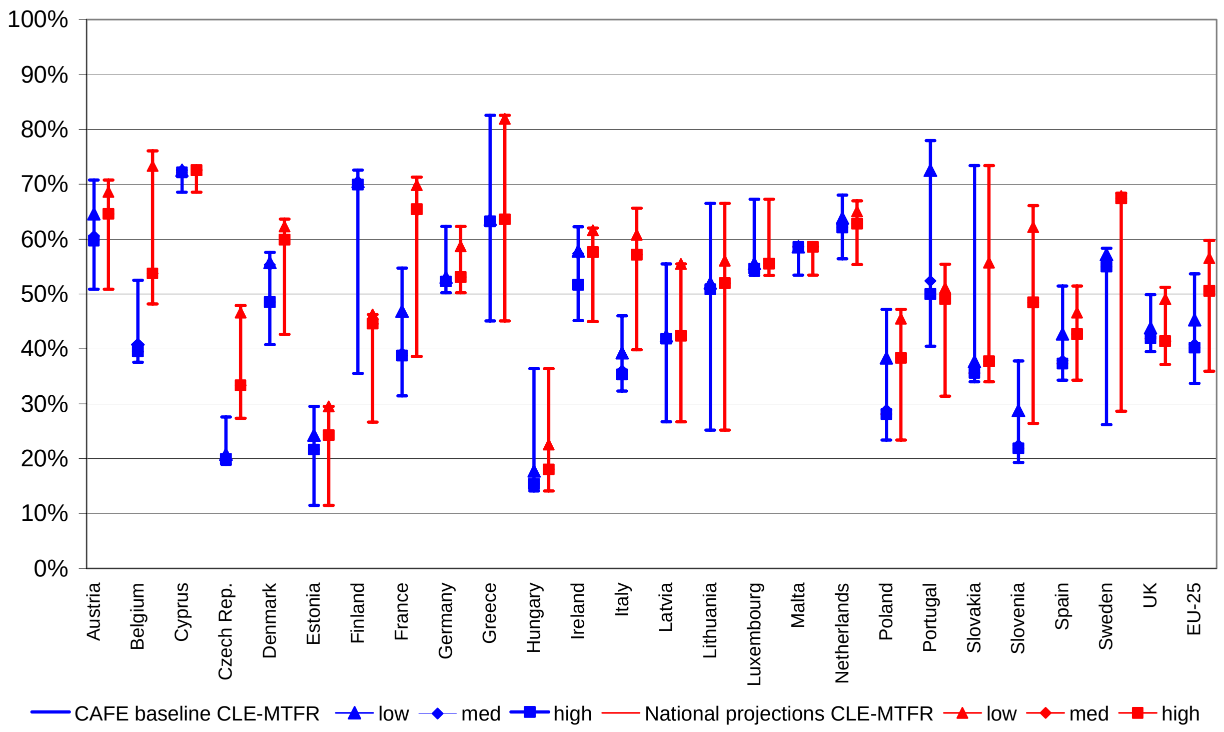


Figure 10.10: PM2.5 emissions for the optimized multi-effect scenario, for the CAFE baseline with climate measures (C8) and the national energy and agricultural projections (C9), relative to the emissions of the year 2000 (=100%).

10.3 Sensitivity analysis with alternative health impact hypothesis

The standard approach for quantifying health impacts in the RAINS model follows the advice given in the systematic review of the World Health Organization to CAFE, stating that mortality effects of fine particulate matter can be best associated with population exposure to total PM2.5 mass. The review did not find current evidence strong enough to recommend a differentiated treatment of the various chemical components of PM.

However, uncertainty remains about the relative potency of various PM components. Inter alia, some hypothesis associate less health impacts with secondary inorganic aerosols and suggest primary PM2.5 emissions, especially from combustion sources, as a major cause of health damage.

While this cost-effectiveness analysis does not aim to entertain speculations on the pros and cons of the various hypotheses, a sensitivity analysis was carried out to explore the impacts on optimized emission control strategies under the assumptions that only primary PM2.5 emissions from anthropogenic sources contributed to mortality effects. For this purpose, the RAINS optimization considered only the source-receptor relationships for primary PM2.5 emissions, but ignored all contributions from secondary inorganic aerosols for the mortality assessment. In absence of a validated concentration-response function that quantifies the relationships between mortality and ambient concentrations of PM2.5 from primary emissions only, the RAINS calculation applied the same relative improvements in YOLLs that were calculated for the C8 scenario to the hypothetical YOLLs that would result from primary PM2.5 particles only. Thus, the optimization aims for the same relative improvements in health impacts as the joint optimization scenario C8, but associates all mortality effects to primary PM2.5 emissions only.

If no other environmental endpoints were considered (e.g., as it is the case in the C6 scenario), such an optimization would obviously only call for measures on primary PM2.5 emissions, and thus would suggest dramatically different allocations of emission reductions than those resulting from an optimization based on total PM2.5 mass. Obviously, since no measures for the precursor emissions of secondary aerosols, costs will be significantly lower (Table 10.4).

Table 10.4: Emission control costs for strategies aimed at reducing health impacts from PM2.5 (million €/year), for the hypothesis that health impacts are associated with total PM2.5 concentrations and for an alternative hypothesis that secondary aerosols are not associated with health impacts.

	Hypothesis for health impacts caused by total PM2.5 mass (C6)	Hypothesis for health impacts caused by primary PM2.5 emissions only (C10)
Low ambition	3108	449
Medium ambition	6227	1415
High ambition	9586	3288

However, one of the fundamental objectives of the CAFE programme is to develop a comprehensive strategy for reaching clean air in Europe, bringing together and balancing against each other the requirements for the most important air quality problems. Thus, emission reductions are considered in a multi-pollutant/multi-effect context, and the optimal use of resources is sought for that maximizes synergies between different environmental problems.

Thus, an optimization has been carried out that explores the cost-effective emission reductions for achieving the health targets (based on the "primary PM2.5" only hypothesis) together with the targets for the other environmental problems (acidification, eutrophication, ozone) as used in the C8 joint optimization case.

In contrast to a health-only optimization, in a multi-effect context the control of precursor emissions of secondary aerosols becomes necessary for reducing acidification, eutrophication and ozone, in addition to the measures for primary PM emissions, which are linked to health impacts. Thus, in such a joint optimization there is a much smaller difference in emission control costs between these two health impact hypotheses. In addition, this difference depends on the ambition level. As shown in Table 10.5, the "primary PM2.5" approach is somewhat cheaper than the "total PM2.5 mass" strategy at low to medium ambition levels, but is more expensive for the high ambition case.

Table 10.5: Emission control costs for the joint multi-effect optimization, for the conventional approach associating health impacts with total PM2.5 mass and for a "primary PM2.5 emissions only" hypothesis (million €/year)

	Hypothesis for health impacts caused by total PM2.5 mass (C6)	Hypothesis for health impacts caused by primary PM2.5 emissions only (C10)
Low ambition	5579	4166
Medium ambition	9310	8293
High ambition	14024	14509

For many countries there are only very small differences in the reduction requirements for the various pollutants resulting from these two different health impact hypotheses (Figure 10.11 to Figure 10.14). Most notably, for a "PM2.5 only" hypothesis, SO_2 measures are relaxed in Spain, Portugal and Greece, where acidification is not a major problem. At the same time, more stringent control measures are computed for primary PM2.5 in these countries. There are no significant differences in required NO_x and NH_3 controls.

Overall, it can be stated that the multi-effect approach adopted for the CAFE analysis maximizes the robustness of emission control strategies against one of the major uncertainties in the understanding of health impacts from air pollution.

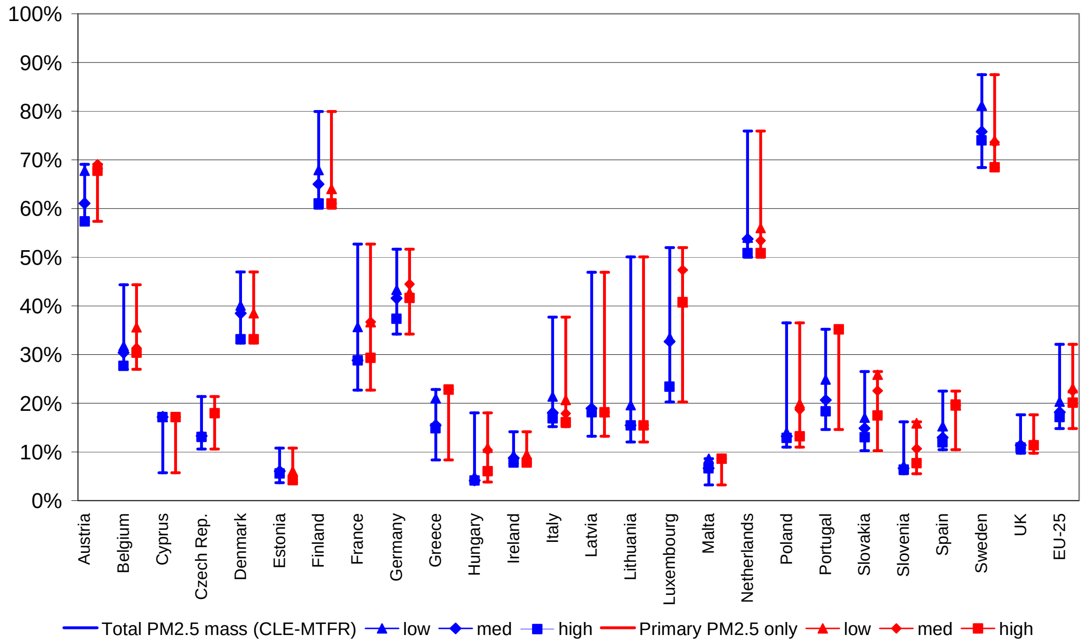


Figure 10.11: SO_2 emissions of the joint optimization runs for the two health impact hypotheses, relative to the emissions of the year 2000 (=100%).

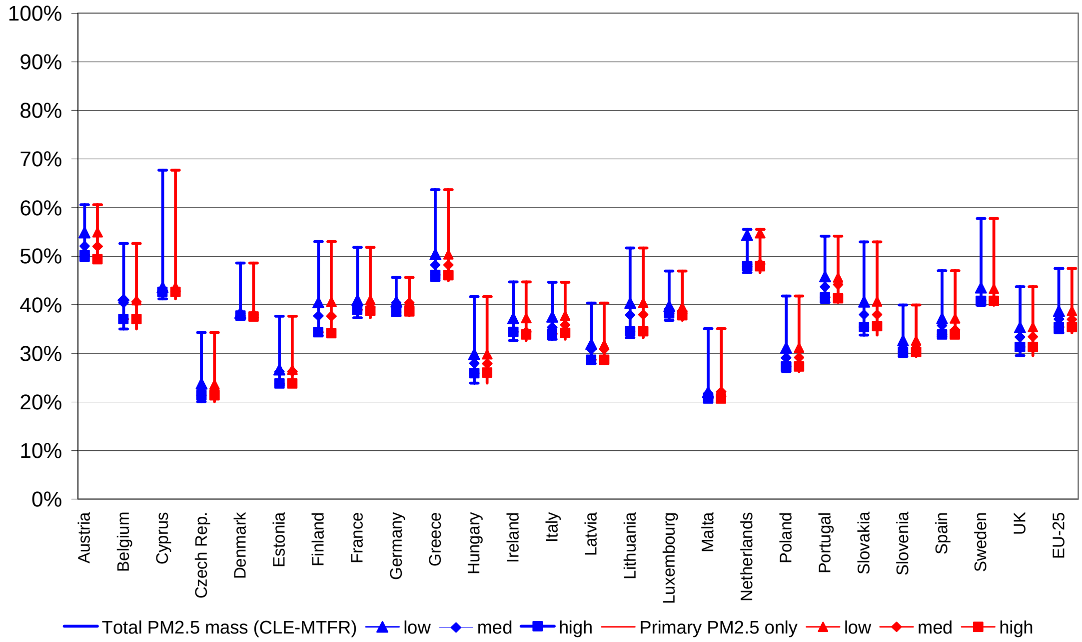


Figure 10.12: NO_x emissions of the joint optimization runs for the two health impact hypotheses, relative to the emissions of the year 2000 (=100%).

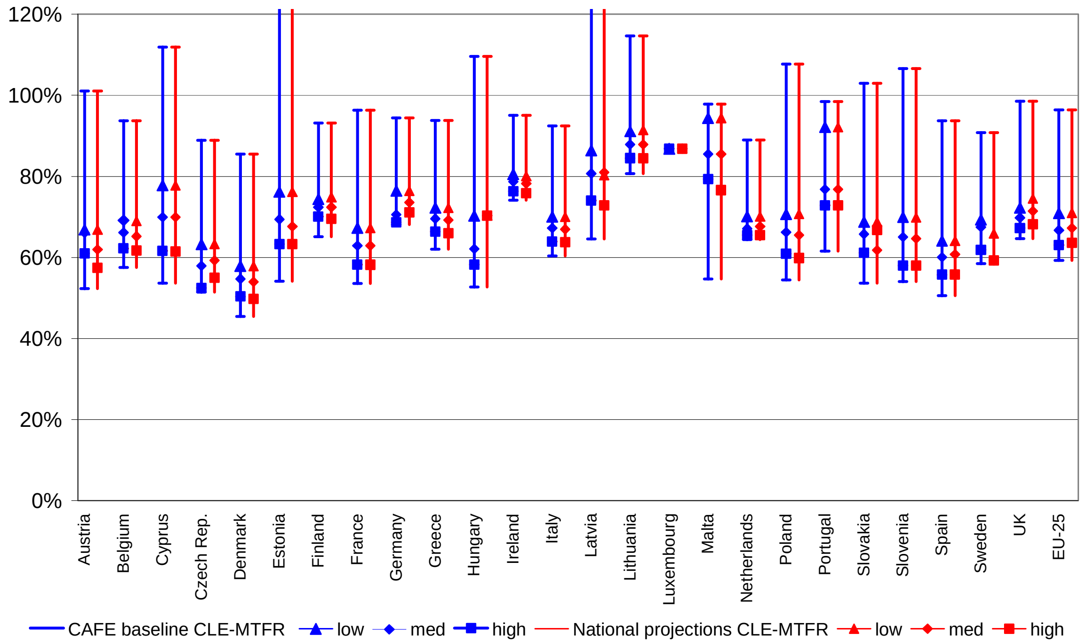


Figure 10.13: NH_3 emissions of the joint optimization runs for the two health impact hypotheses, relative to the emissions of the year 2000 (=100%).

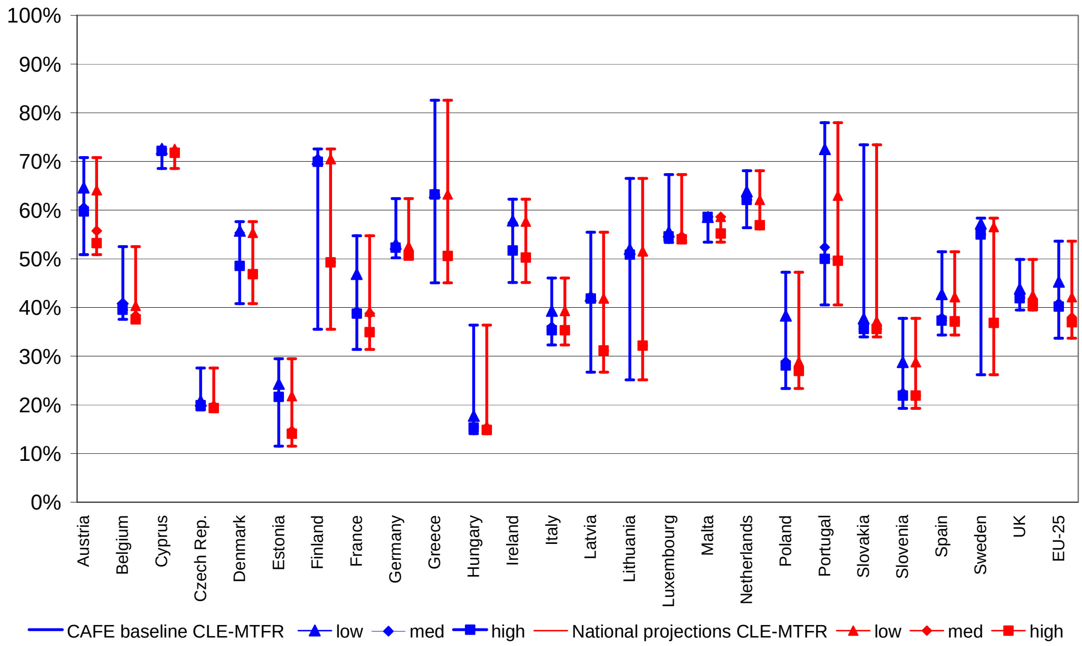


Figure 10.14: PM2.5 emissions of the joint optimization runs for the two health impact hypotheses, relative to the emissions of the year 2000 (=100%).

11 Air quality limit values for 2015

All the calculations presented above have been carried out for the year 2020. To inform the discussion about a possible air quality limit for PM2.5, the Working Group on Target Setting requested analysis of the feasibility of limit values for the year 2015. With the energy and agricultural projections for 2015, the RAINS model has been applied to repeat the C1 (limit value) optimization analyses.

Figure 11.1 presents resulting costs of these optimization runs. For the 2015 calculations, no further road measures are assumed.

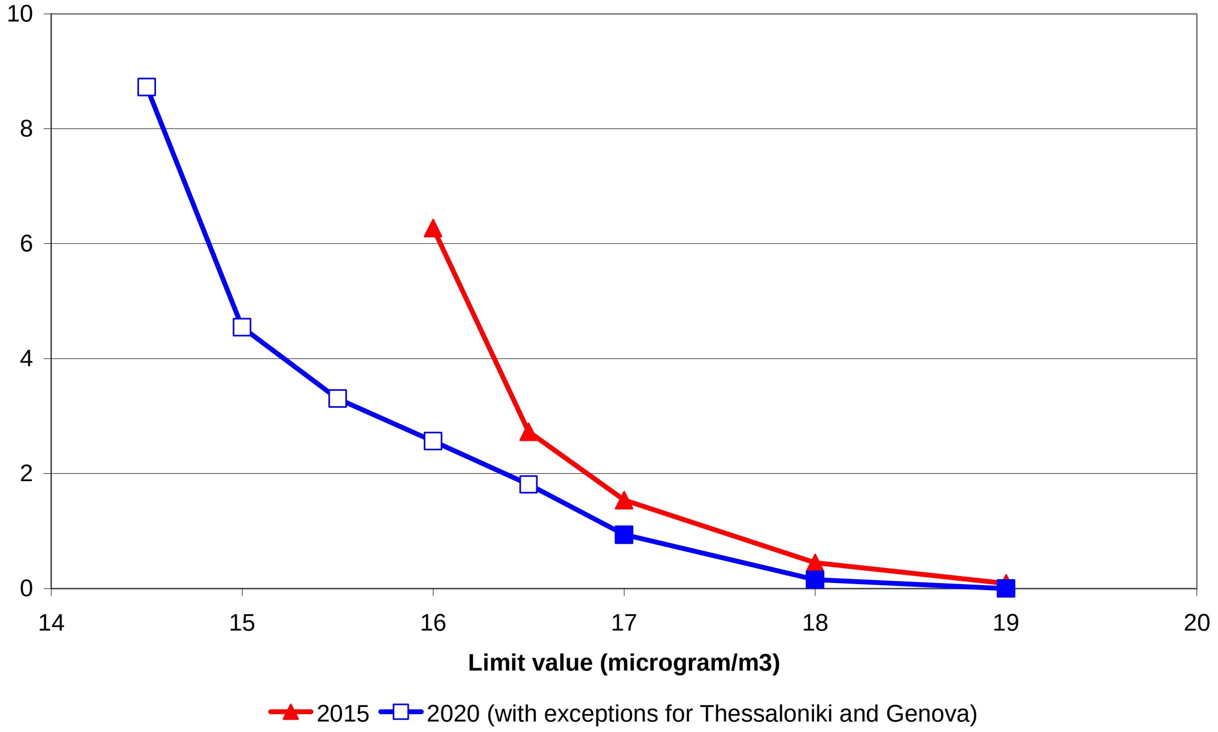


Figure 11.1: Annual costs of reaching different levels of air quality limit values in 2020 (Scenario C1) and 2015 (Scenario C12), in billion €/year. Both cases assume exceptions for Thessaloniki and Genova.

Annex

Table 11.1: Emission standards for the scenarios with additional measures for diesel road vehicles. PM values for heavy-duty vehicles for ESC/ETC cycle respectively.

Vehicle category/standard	*NOx*	*PM*
Diesel cars	g/km	mg/km
Euro IV	0.25	25
"with measures"	0.065	2
Diesel heavy-duty vehicles	g/kWh	mg/kWh
Euro V	2.00	20/30
"with measures"	1.4	10/15
MTFR (US2007 equivalent)	0.4	10/15

Source: Ricardo, 2004

Table 11.2: Assumptions about emission control costs for individual Euro stages

Measure	*Investment cost, €/vehicle*	*Fixed O+M, % invest. cost/year*	*Other,% of fuel cost*
Light-duty cars and trucks			
Euro I	59	21.2	0.0
Euro II	183	6.5	0.0
Euro III	355	3.4	0.0
Euro IV	536	2.5	0.0
"with measures"	738	2.0	0.0
Heavy-duty diesel trucks			
Euro I	1484	1.6	0.0
Euro II	2795	5.3	2.0
Euro III	4126	5.4	5.7
Euro IV	7590	5.8	6.0
Euro V	8341	4.9	6.3
"with measures"	9500	4.1	7.2
MTFR	n.a.	n.a.	n.a.

Source: Ricardo, 2004