CAFE Scenario Analysis Report Nr. 6

A final set of scenarios for the Clean Air For Europe (CAFE) programme

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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 further steps, the CAFE integrated assessment has explored the costs and environmental benefits associated with 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 CAFE assessment is based on recent scientific knowledge, taking into account

- advice received from the World Health Organization on the health impacts of air pollution (http://www.euro.who.int/document/e79097.pdf),
- information on vegetation impacts of air pollution compiled by the UNECE Working Group on Effects (http://www.unece.org/env/wge/welcome.html),
- syntheses of the understanding and modelling of the dispersion of air pollutants in the atmosphere at the regional scale developed by the European Monitoring and Evaluation Programme (EMEP) (http://www.unece.org/env/emep/welcome.html) under the Convention on Long-range Transboundary Air Pollution including the review of the EMEP Eulerian model (http://www.unece.org/env/documents/2004/eb/ge1/eb.air.ge.1.2004.6.e.pdf), and the modelling of urban pollution developed within the City-Delta project (http://rea.ei.jrc.it/netshare/thunis/citydelta/),
- projections of future economic activities and their implications on the evolution of energy systems (www.europa.eu.int/comm/dgs/energy_transport/figures/trends_2030/index_en.htm) and agricultural activities.

For integrating this variety of information to allow policy-relevant conclusions, CAFE has employed the Regional Air Pollution Information and Simulation (RAINS) model (www.iiasa.ac.at/rains). The model is freely available on the Internet (http://www.iiasa.ac.at/web-apps/tap/RainsWeb/) and has been subject to extensive peer review (http://europa.eu.int/comm/environment/air/cafe/pdf/rains_report_review.pdf). Its databases have been reviewed in detail during more than 20 bilateral consultations involving more than 100 experts from Member States and industry.

All databases used for the analysis (http://www.iiasa.ac.at/web-apps/tap/RainsWeb) and all interim reports (http://www.iiasa.ac.at/rains/cafe.html) developed for the iterative discussions conducted in the CAFE Working Group on Target Setting and Policy Advice as well as in the CAFE Steering Group are available on the Internet. A series of five CAFE scenario reports has been produced for these discussions:

- CAFE Report #1: *Baseline Scenarios for the Clean Air for Europe (CAFE) Programme* (http://www.iiasa.ac.at/rains/CAFE_files/Cafe-Lot1_FINAL(Oct).pdf).

- CAFE Report #2: *The "Current Legislation" and the "Maximum Technically Feasible Reduction" cases for the CAFE baseline emission projections*. (http://www.iiasa.ac.at/rains/CAFE_files/baseline3v2.pdf).
- CAFE Report #3: *First Results from the RAINS Multi-Pollutant/Multi-Effect Optimization including Fine Particulate Matter* (http://www.iiasa.ac.at/rains/CAFE_files/CAFE-A-full-jan12.pdf).
- CAFE Report #4: *Target Setting Approaches for Cost-effective Reductions of Population Exposure to Fine Particulate Matter in Europe*. (http://www.iiasa.ac.at/rains/CAFE_files/CAFE-B-full-feb3.pdf).
- CAFE Report #5: *Exploratory CAFE Scenarios for Further Improvements of European Air Quality*. (http://www.iiasa.ac.at/rains/CAFE_files/CAFE-C-full-march16.pdf).

This paper (*A final set of scenarios for the Clean Air For Europe (CAFE) programme*) constitutes the sixth CAFE report and introduces the set of policy scenarios that will be used by the European Commission as a basis for outlining its strategy towards cleaner air in Europe.

Section 2 of this report summarizes the most important data sources and assumptions on which the analysis is based and recalls the caveats for drawing policy-relevant conclusions from this model assessment. Section 3 introduces the final set of scenarios that is used by the European Commission as a basis for the Thematic Strategy on Air Pollution, distinguishing three cases with different levels of environmental ambition. Section 4 presents a range of sensitivity analysis to explore the robustness and potential biases of the final CAFE scenarios. Conclusions are drawn in Section 5.

The main body of this report presents scenario results at a level that is of interest from a Community-wide perspective. More detailed information on sectoral implications is presented in the Annex to this report. All details for individual countries and sectors are available on the Internet (http://www.iiasa.ac.at/rains/cafe.html).

2 Input data and main assumptions

The input data and main assumptions for the CAFE integrated assessment process have been developed over the last three years involving a wide range of experts from national and industrial stakeholders. These data have been presented in a series of stakeholder workshops (http://forum.europa.eu.int/Public/irc/env /cafe_baseline/library) and are described in detail in the various documents and Internet databases. In summary, the analysis of the final CAFE scenarios 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 and agricultural projections compiled from a variety of sources. 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. The CAFE analysis employs national population projections published by the UN (median projection).

- While energy projections reflect latest thinking including the implications of climate agreements, projections of agricultural activities do not yet include potential changes in livestock numbers resulting from the CAP reform. However, potential biases resulting from this omission are discussed in Section 4.6.1.

- For non-EU countries, emissions have been assumed to follow the "current legislation" projection presented in Amann *et al.* (2004c). This means that no additional emission control measures have been assumed for these countries in any of the scenarios presented in this report.

- The assumptions on the "Maximum Technically Feasible Emission Reductions" employed for stationary sources have been presented to the Working Group on Target Setting at their Session in November 2004 (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 were 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.

- For road transport, all scenarios with the exception of the sensitivity analysis in Section 4.4 assume Europe-wide implementation of a package with further measures to control NO_x and PM emissions from diesel light and heavy duty vehicles. The assumptions on removal efficiencies and costs adopted for these calculations have been derived from the possible future emission performance as estimated by RICARDO (2004). They are provided in Annex 1 and described in detail in Amann *et al*. (2005). Apart from the work by RICARDO (2004), the Commission had independently started preparations for new emission standards for light-duty vehicles and heavy-duty vehicles by sending out questionnaires to the stakeholders. A questionnaire on light-duty vehicles was sent in February 2004 and another one on heavy-duty vehicles in May 2004. These questionnaires requested cost and technology data on a number of emission reduction scenarios for light and heavy duty vehicles. All responses were received by the beginning of June 2004 for light-duty vehicles and somewhat later for heavy-duty vehicles. The light duty vehicle emission and cost data has been validated by a panel of independent experts and will be used in the impact assessment of the new Euro-5 standard for light-duty vehicles. That work took considerably more time than expected because of the need to interpret the rather diverse responses received, to fill data gaps and to further consult with the stakeholders. The final element of industry input was only received in February 2005. Because of the work on light-duty vehicle data, the validation of heavy-duty vehicle emission reduction and cost data could not yet be started and will be undertaken later in 2005. Based on the review of the light-duty vehicle emission data, it appears that the reduction potential for NO_x is overestimated in the RICARDO (2004) data given the incremental cost. However, it seems that RICARDO (2004) may have underestimated the potential for NO_x reduction from heavy-duty vehicles. Overall, the reduction potential for NO_x from transport measures has thus uncertainties and the same is the case for the estimated costs, which need to be considered approximate at this stage. The impact assessment of further road measures will use the updated emission reduction and cost data and will thus give a more accurate picture of the reduction potential from light- and heavy-duty vehicles.

- For international shipping, the emission projection follows the assumptions made for the CAFE baseline scenario assuming implementation of emission control measures that are already decided. These include for SO_2 the EU sulphur proposal as per Common Position, i.e., 1.5% sulphur marine fuel oil for all ships in the North Sea and the Baltic Sea; 1.5% sulphur fuel for all passenger ships in the other EU seas; low sulphur marine gas oil and 0.1% sulphur fuel at berth in ports. For NO_x, new standards for all ships built since 2000 have been considered. In addition, measures that are state-of-the-art technology for new ships (e.g., slide valve modification for slow speed engines) are incorporated in the emission projections. As a sensitivity analysis, Section 4.1 analyzes the implications of additional measures to control emissions from ships.
- Source-receptor relationships 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.
- For all environmental problems considered, new functional relationships have been developed from the data set of EMEP and City-Delta model runs. 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 initial analysis suggests the present approximations are acceptable in the policy-relevant range of emissions for the purposes of CAFE, further refinements might lead to more accurate formulations. The full documentation of the source-receptor relationships has not yet been completed.

While extensive efforts have been made to establish consensus on the input data among the stakeholders, insufficient time prevented validating the databases in full detail for each pollutant, country and economic sector. Thus, while this process ensures the robustness of the overall results at the European level, care should be taken in drawing detailed conclusions on specific control measures in individual countries. Thus, all results for individual countries must be considered as indicative and further validation with national experts needs to be carried out before solid results can be derived at the national and sectoral level.

3 Three central multi-effect scenarios

A set of scenarios has been developed that, individually or jointly, address the four environmental endpoints considered in the CAFE programme (health impacts from PM2.5, ozone, acidification and eutrophication). It has been shown in the earlier CAFE reports that even the maximum application of all presently available control measures (with the assumptions taken by RAINS) will not entirely eliminate all risk from air pollution to human health and ecosystems everywhere in Europe. For developing practical strategies to reduce health and vegetation damage from air pollution, the CAFE Working Group on Target Setting and Policy Advice has developed the concept of environmental interim targets that would guide the next step of cost-effective emission control measures in Europe. Following the discussions in the Working Group, the following sets of effect indicators and target setting principles have been applied as metrics for the interim environmental targets for the final set of CAFE scenarios:

For PM2.5:

> The target is to reduce the (population-weighted) loss in statistical life expectancy (i.e., of life years lost – “YOLL”) attributable to exposure to PM2.5 in Europe at least costs. The optimization identifies those measures that would achieve in the EU-25 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, maximizing the cost-effectiveness of resources spent. While in theory such an approach might compromise on (perceived) equity aspects, because not all Member States receive equitable environmental improvements, earlier analysis has revealed that in practice with the current data set most equity indicators are comparable to other target setting principles.

For eutrophication:

> For eutrophication, the scenarios aim at reducing excess nitrogen deposition accumulated over all ecosystems in a country by an equal percentage for all Member States. The relative improvement (“gap closure”) is scaled between the baseline current legislation case (CLE) and the maximum technically feasible reductions (MTFR) that have been computed for 2020. It needs to be emphasized that this 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 could make this definition prone to political dispute.

For acidification:

> Also for acidification a country-wide “gap closure” has been applied. This scales the envisioned improvement between the baseline current legislation (CLE) and the maximum technical MTFR in terms of total deposition of acidifying compounds in excess of the critical loads for acidification, accumulated over all ecosystem types (forests, semi-natural, water) in a country. The optimization has been carried out for this ‘accumulated excess deposition’, while results are displayed separately for different types of ecosystems.

For ozone:

> For health impacts attributable to ozone, RAINS calculates the number of premature deaths attributable to ozone (based on the SOMO35 concept) 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. As an interim target for 2020, the "country-wide gap closure concept" is applied asking for the same relative improvement (scaled between CLE and MTFR) for all countries.
>
> 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 a large extent, so that an optimization targeted at AOT40 is likely to yield similar results as the SOMO35 optimization.

As a first step, the RAINS optimization model has been used to identify, for each environmental endpoint separately, the increase in costs for successively tightened environmental ambition levels in terms of the selected effect indicators. This analysis has been carried out over the range between the "current legislation" (CLE) case of the CAFE baseline scenario (i.e., without any further emission control measures) and the improvements from the maximum technically feasible emission reductions (MTFR). The resulting relations between environmental ambition levels and emission control costs are presented in Figure 3.1. It shows that, between the CLE and MTFR cases, costs increase most rapidly for the protection of human health from fine particles, followed by improvements in eutrophication and acidification. Over large domains, improvements in ground-level ozone are attainable at the lowest costs.

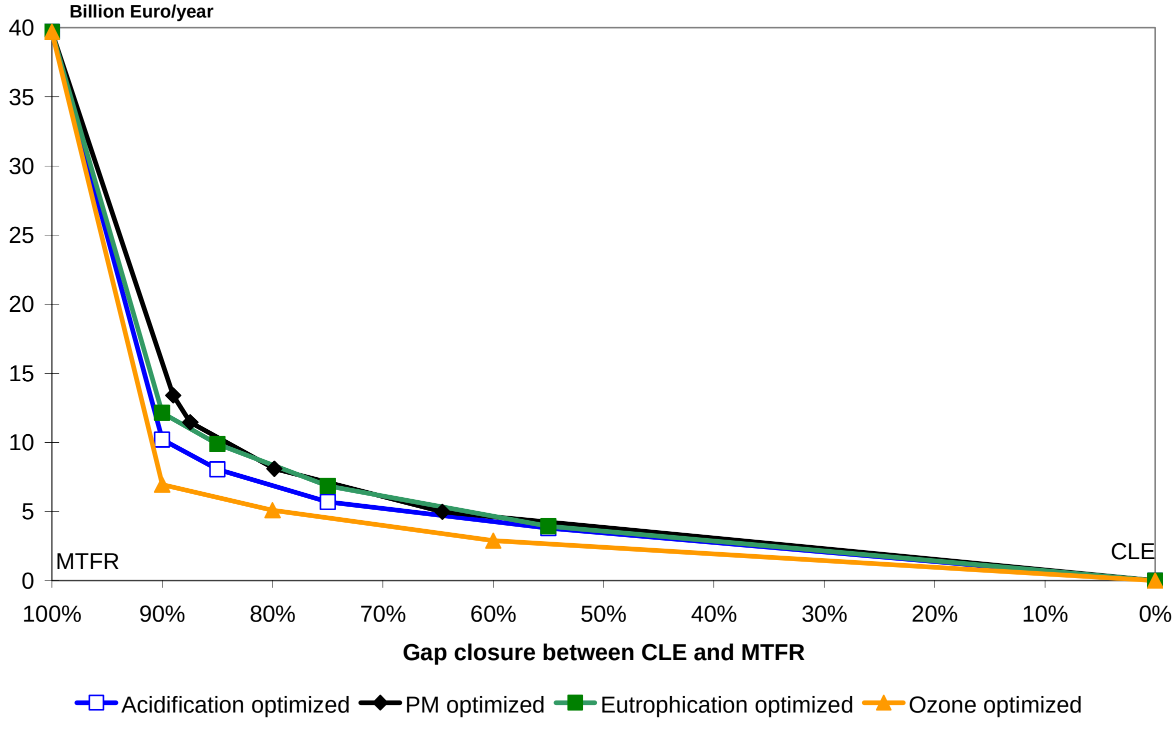

Figure 3.1: Costs for improving the indicators of the four selected environmental end points between the CAFE baseline current legislation projection (CLE) and the maximum technically feasible emission reductions (MTFR), in billion €/year

In a further step, for each of the environmental endpoints three target levels have been chosen in the range of environmental ambition where costs begin to rise sharply. The following targets have been selected:

- For health impacts from PM: 110, 104 and 101 million years of life lost, equivalent to CAFE scenarios C6/1 to C6/3.
- For eutrophication: Country-wise “gap closures” in accumulated excess deposition of 55, 75 and 85 percent between CLE and MTFR. Note that this definition of gap closure is fundamentally different from the gap closure concepts applied for the emission ceilings directive. For CAFE, the gap relates strictly to the range between “Current legislation” and “Maximum technically feasible reductions”, i.e., it is defined solely on source-related criteria. In contrast, for the emission ceilings directive and for the Gothenburg protocol, the gap referred to the exposure in the base year in excess of the sustainable environmental long-term targets (no-effect levels, such as critical loads). In no case can numerical gap closure targets of these analyses be compared.
- For acidification: Country-wise “gap closures” in accumulated excess deposition of 55, 75 and 85 percent between CLE and MTFR. The same note on the gap closure definition as for eutrophication applies.
- For ozone: Country-wise gap closures” of the population-weighted health-relevant SOMO35 metric by 60, 80 and 90 percent.

Table 3.1 presents for the optimized scenarios the aggregated effect indicators and total emission control costs.

In a further step, a series of three joint optimizations has been carried out that combines targets for all four environmental end points. While with the selected set of targets there are 81 permutations possible, three cases (A, B, C) have been arbitrarily chosen that combine with each other the lowest, medium and highest ambition levels of each environmental endpoint.

It needs to be emphasized that such a combination of targets carries an implicit value judgement. As shown in Figure 3.2, for each of the three analysed cases the choice made allocates highest resources to the improvement of human health related to fine particulate matter. This is followed by measures to combat eutrophication, driven by the motivation to foster timely action against eutrophication, as this problem is still increasing without indications of a trend reversal. Additional efforts to further reduce acidification rank third, while least resources are allocated for strengthened ozone controls because effective improvements are cheapest to implement compared to the other problems analysed in CAFE. The environmental ambition levels employed for the final scenario analysis are presented in Table 3.2.

Table 3.1: 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	137.3	110.0	104.0	101.0	96.0
Eutrophication optimized	137.3	122.7	117.9	115.4	96.0
Acidification optimized	137.3	120.0	115.0	112.1	96.0
O_3 optimized	137.3	133.7	132.9	132.4	96.0
Joint optimization	137.3	110.0	104.0	101.0	96.0
Ozone indicator (SOMO35)	CLE	60%	80%	90%	MTFR
PM optimized	52427	48972	48214	46477	41051
Eutrophication optimized	52427	47597	46137	45015	41051
Acidification optimized	52427	48918	47903	46446	41051
O_3 optimized	52427	45494	43291	42157	41051
Joint optimization	52427	45469	43254	42150	41051
Acidification indicator (accumulated excess deposition)	CLE	55%	75%	85%	MTFR
PM optimized	1464	558	418	365	300
Eutrophication optimized	1464	842	692	610	300
Acidification optimized	1464	661	492	416	300
O_3 optimized	1464	1307	1271	1252	300
Joint optimization	1464	543	414	353	300
Eutrophication indicator (accumulated excess deposition)	CLE	55%	75%	85%	MTFR
PM optimized	7200	4768	3925	3291	2320
Eutrophication optimized	7200	4351	3435	2968	2320
Acidification optimized	7200	5210	4550	3807	2320
O_3 optimized	7200	6399	6161	6034	2320
Joint optimization	7200	4167	3288	2837	2320
Costs (million €/year)	CLE	Case “A”	Case “B”	Case “C”	MTFR
PM optimized	0	4976	8079	11424	39720
Eutrophication optimized	0	3937	6840	9892	39720
Acidification optimized	0	3792	5696	8057	39720
O_3 optimized	0	2903	5096	6944	39720
Joint optimization	0	5923	10679	14852	39720

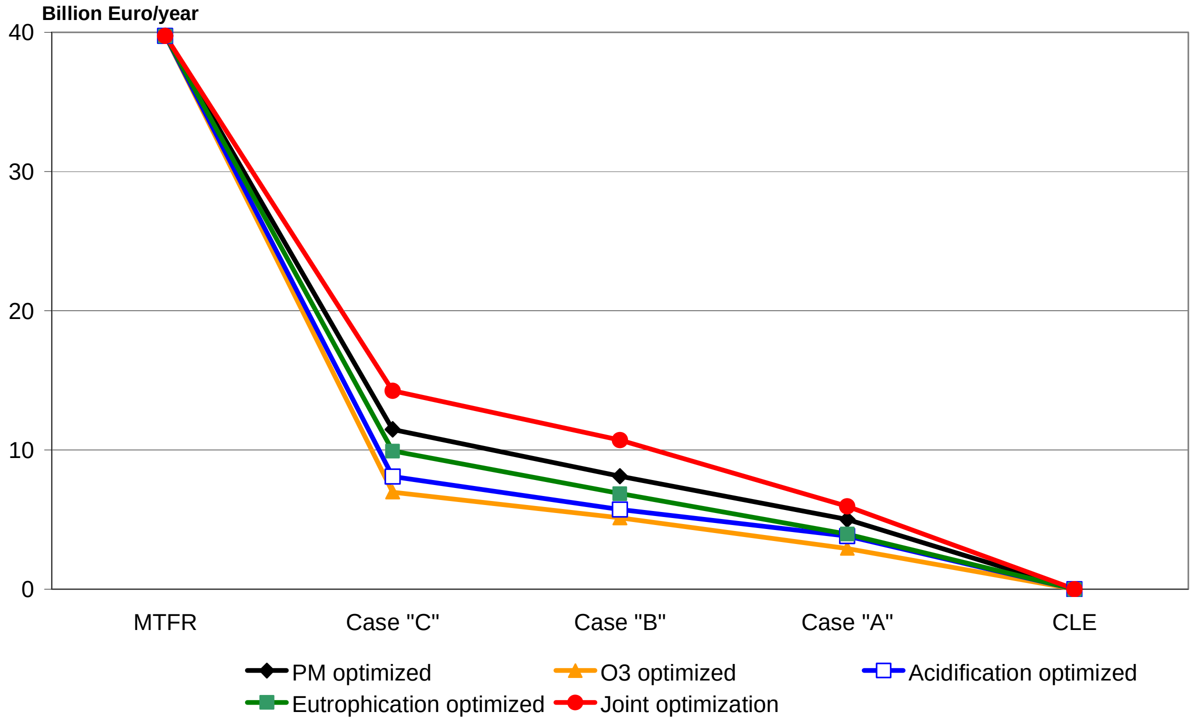

Figure 3.2: Emission control costs to reach the targets for the three ambition levels for the individual targets and for the joint optimization

Table 3.2: Selected numerical values of the effect indicators for the final CAFE scenarios

	Current legislation	*Case "A"*	*Case "B"*	*Case "C"*	*Maximum technically feasible reductions*
Years of life lost due to PM2.5 (EU-wide, million YOLLs)	137	110	104	101	96
Acidification (country-wise gap closure on cumulative excess deposition)	0%	55%	75%	85%	100%
Eutrophication (country-wise gap closure on cumulative excess deposition)	0%	55%	75%	85%	100%
Ozone (country-wise gap closure on SOMO35)	0%	60%	80%	90%	100%

3.1 Emission reductions

A series of optimization analyses have been conducted for the three sets of environmental targets. The following tables and graphs present resulting emission reductions for the five pollutants under consideration (Table 3.3 to Table 3.7), the sectoral reductions for each pollutants (Table 3.8 to Table 3.12), and emission control costs (Table 3.13 to Table 3.16).

Table 3.3: SO_2 emissions for the year 2000, the emission ceiling for 2010, the current legislation baseline in 2020 and the optimized scenarios for the three environmental ambition levels (kt SO_2)

	2000	*2010*	*2020*	*Optimized scenarios for 2020*			*2020*
		National emission ceiling	Baseline Current legislation	Case “A”	Case “B”	Case “C”	Maximum technically feasible reductions
Austria	38	39	26	23	23	22	22
Belgium	187	99	83	59	57	51	50
Cyprus	46	39	8	8	8	8	3
Czech Rep.	250	265	53	34	33	32	26
Denmark	28	55	13	12	11	9	9
Estonia	91	100	10	7	6	6	3
Finland	77	110	62	59	52	49	46
France	654	375	345	191	188	165	148
Germany	643	520	332	267	263	240	220
Greece	481	523	110	89	71	64	40
Hungary	487	500	88	23	20	19	19
Ireland	132	42	19	14	12	11	10
Italy	747	475	281	153	133	122	113
Latvia	16	101	8	6	3	3	2
Lithuania	43	145	22	9	7	7	5
Luxembourg	4	4	2	1	1	1	1
Malta	26	9	2	2	2	2	1
Netherlands	84	50	64	45	43	43	42
Poland	1515	1397	554	201	201	195	167
Portugal	230	160	81	53	44	39	34
Slovakia	124	110	33	20	18	16	13
Slovenia	97	27	16	6	6	6	5
Spain	1489	746	335	214	183	176	155
Sweden	58	67	50	50	47	46	39
UK	1186	585	209	157	135	130	115
EU-25	**8735**	**6543**	**2805**	**1704**	**1567**	**1462**	**1290**

Table 3.4: NO_x emissions for the year 2000, the emission ceiling for 2010, the current legislation baseline in 2020 and the optimized scenarios for the three environmental ambition levels (kt NO_x)

	2000	*2010* National emission ceiling	*2020* Baseline Current legislation	*Optimized scenarios for 2020* Case "A"	Case "B"	Case "C"	*2020* Maximum technically feasible reductions
Austria	192	103	127	107	100	96	94
Belgium	333	176	190	142	135	123	117
Cyprus	26	23	18	14	11	11	11
Czech Rep.	318	286	113	81	71	68	64
Denmark	207	127	105	84	79	78	77
Estonia	37	60	15	10	10	9	9
Finland	212	170	117	89	80	73	71
France	1447	810	819	622	575	567	540
Germany	1645	1051	808	698	665	634	622
Greece	322	344	209	169	156	148	145
Hungary	188	198	83	61	52	49	45
Ireland	129	65	63	50	45	45	42
Italy	1389	990	663	538	491	472	457
Latvia	35	61	15	11	11	10	10
Lithuania	49	110	27	21	19	17	16
Luxembourg	33	11	18	13	13	13	12
Malta	9	8	4	2	2	2	2
Netherlands	399	260	240	219	193	191	186
Poland	843	879	364	275	246	230	221
Portugal	263	250	156	127	115	109	106
Slovakia	106	130	60	45	40	38	36
Slovenia	58	45	24	20	18	17	17
Spain	1335	847	681	515	483	455	447
Sweden	251	148	150	119	104	103	100
UK	1753	1167	817	648	584	549	518
EU-25	**11581**	**8319**	**5888**	**4678**	**4297**	**4107**	**3965**

Table 3.5: VOC emissions for the year 2000, the emission ceiling for 2010, the current legislation baseline in 2020 and the optimized scenarios for the three environmental ambition levels (kt VOC)

	2000	*2010* National emission ceiling	*2020* Baseline Current legislation	*Optimized scenarios for 2020* Case "A"	Case "B"	Case "C"	*2020* Maximum technically feasible reductions
Austria	190	159	138	130	120	113	95
Belgium	242	139	144	118	115	114	114
Cyprus	13	14	6	6	6	6	5
Czech Rep.	242	220	119	97	83	83	72
Denmark	128	85	58	52	45	45	40
Estonia	34	49	17	15	15	15	12
Finland	171	130	97	90	90	88	63
France	1542	1050	923	846	778	720	682
Germany	1528	995	809	739	682	682	652
Greece	280	261	144	110	104	104	81
Hungary	169	137	90	73	67	62	57
Ireland	88	55	46	35	33	31	31
Italy	1738	1159	731	676	663	624	591
Latvia	52	136	28	23	23	20	13
Lithuania	75	92	43	39	38	36	23
Luxembourg	13	9	8	7	7	7	6
Malta	5	12	2	2	2	2	2
Netherlands	265	185	203	161	153	153	149
Poland	582	800	320	296	284	284	223
Portugal	260	180	162	147	133	132	115
Slovakia	88	140	64	59	56	56	33
Slovenia	54	40	20	19	18	18	13
Spain	1121	662	692	571	550	547	445
Sweden	305	241	174	153	153	149	121
UK	1474	1200	878	766	720	683	663
EU-25	**10661**	**8150**	**5916**	**5230**	**4937**	**4771**	**4303**

Table 3.6: NH_3 emissions for the year 2000, the emission ceiling for 2010, the current legislation baseline in 2020 and the optimized scenarios for the three environmental ambition levels (kt NH_3)

	2000	*2010*	*2020*	*Optimized scenarios for 2020*			*2020*
		National emission ceiling	Baseline Current legislation	Case "A"	Case "B"	Case "C"	Maximum technically feasible reductions
Austria	54	66	54	45	39	36	28
Belgium	81	74	76	63	58	47	47
Cyprus	6	9	6	5	4	4	3
Czech Rep.	74	80	65	48	43	43	38
Denmark	91	69	78	60	53	49	41
Estonia	10	29	12	8	7	7	5
Finland	35	31	32	28	26	25	23
France	728	780	702	545	455	442	390
Germany	638	550	603	490	451	438	435
Greece	55	73	52	44	40	38	34
Hungary	78	90	85	53	48	44	41
Ireland	127	116	121	108	102	99	94
Italy	432	419	399	314	293	281	261
Latvia	12	44	16	12	11	10	8
Lithuania	50	84	57	50	45	43	40
Luxembourg	7	7	6	5	5	4	4
Malta	1	3	1	1	1	1	1
Netherlands	157	128	140	110	104	103	101
Poland	309	468	333	221	217	200	169
Portugal	68	90	67	62	59	52	42
Slovakia	32	39	33	24	23	19	17
Slovenia	18	20	20	14	13	12	10
Spain	394	353	370	284	247	231	199
Sweden	53	57	49	43	39	36	31
UK	315	297	310	223	216	212	204
EU-25	**3824**	**3976**	**3686**	**2860**	**2598**	**2477**	**2266**

Table 3.7: Primary emissions of PM2.5 for the year 2000, the current legislation baseline in 2020 and the optimized scenarios for the three environmental ambition levels (kt PM2.5)

	2000	*2010*	*2020*	*Optimized scenarios for 2020*			*2020*
		National emission ceiling	Baseline Current legislation	Case "A"	Case "B"	Case "C"	Maximum technically feasible reductions
Austria	37		27	24	22	22	19
Belgium	43		24	17	17	17	16
Cyprus	2		2	2	2	2	2
Czech Rep.	66		18	13	13	13	13
Denmark	22		13	12	11	11	9
Estonia	22		6	5	5	5	3
Finland	36		27	26	26	26	13
France	290		165	122	113	112	91
Germany	171		111	90	90	90	86
Greece	49		41	31	31	28	22
Hungary	60		22	11	9	9	8
Ireland	14		9	8	8	7	6
Italy	209		99	77	75	74	67
Latvia	7		4	3	3	3	2
Lithuania	17		12	9	9	6	4
Luxembourg	3		2	2	2	2	2
Malta	1		0	0	0	0	0
Netherlands	36		26	23	22	22	20
Poland	215		102	62	60	59	50
Portugal	46		37	33	24	23	19
Slovakia	18		14	7	7	7	6
Slovenia	15		6	4	3	3	3
Spain	169		90	72	64	63	58
Sweden	67		39	38	38	25	18
UK	129		67	55	54	54	51
EU-25	**1749**		**964**	**746**	**709**	**683**	**589**

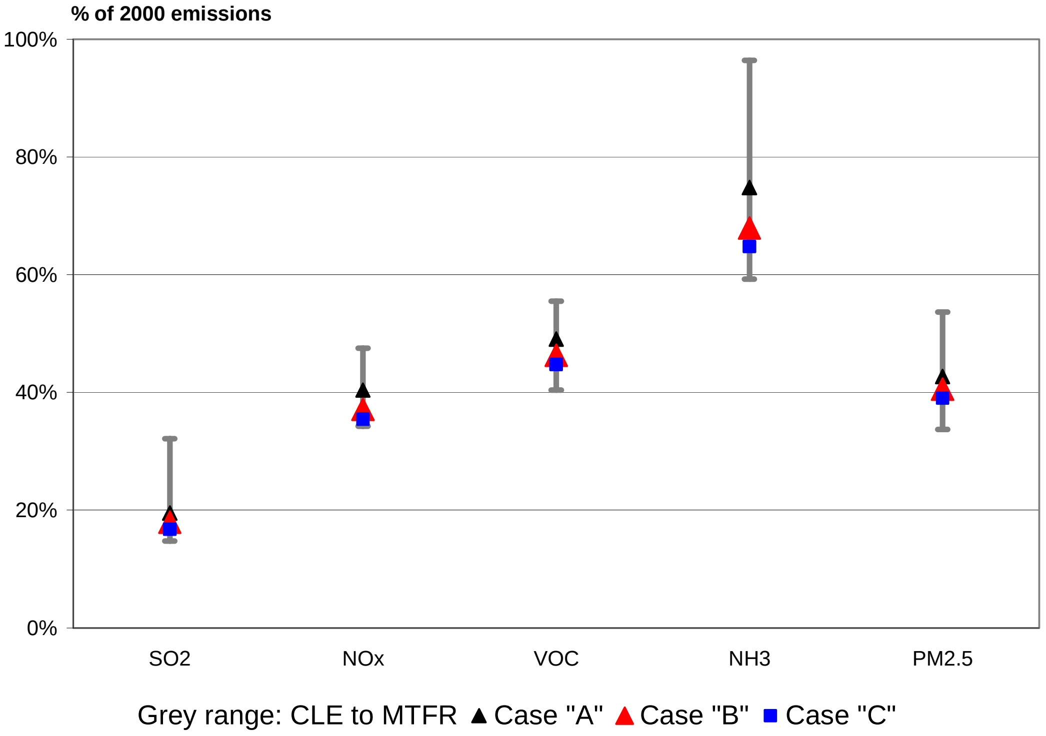

Figure 3.3: Emission reductions for the five pollutants for EU-25 in relation to the levels in the year 2000 (100% line). The grey range indicates the scope of further reductions beyond the current legislation baseline case (top end of the grey range) up to the maximum technically feasible reductions (bottom end).

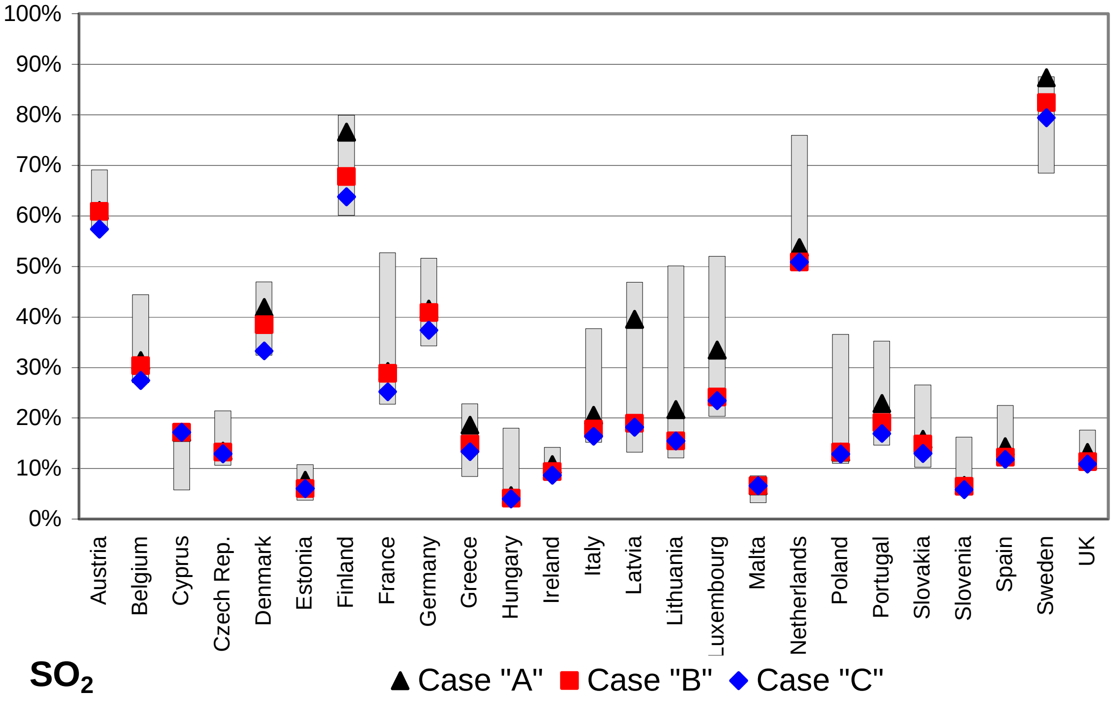

Figure 3.4: Emission reductions for SO_2 in relation to the levels in the year 2000 (100% line). The grey range indicates the scope of further reductions beyond the current legislation baseline case (top end of the grey range) up to the maximum technically feasible reductions (bottom end)

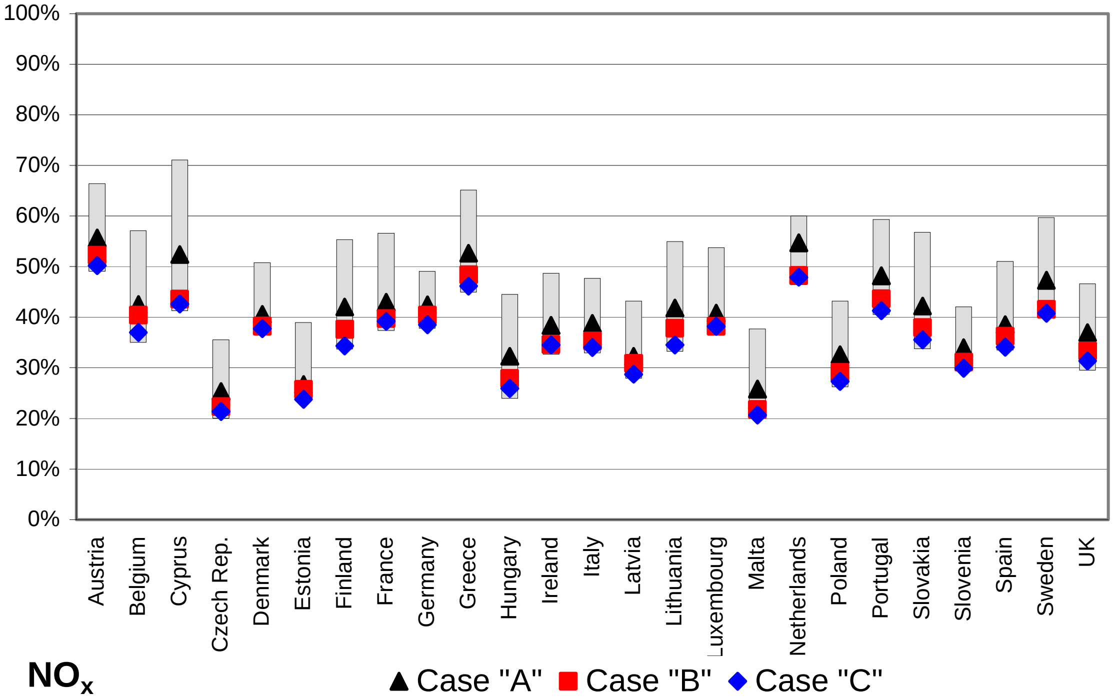

Figure 3.5: Emission reductions for NO_x in relation to the levels in the year 2000 (100% line). The grey range indicates the scope of further reductions beyond the current legislation baseline case (top end of the grey range) up to the maximum technically feasible reductions (bottom end)

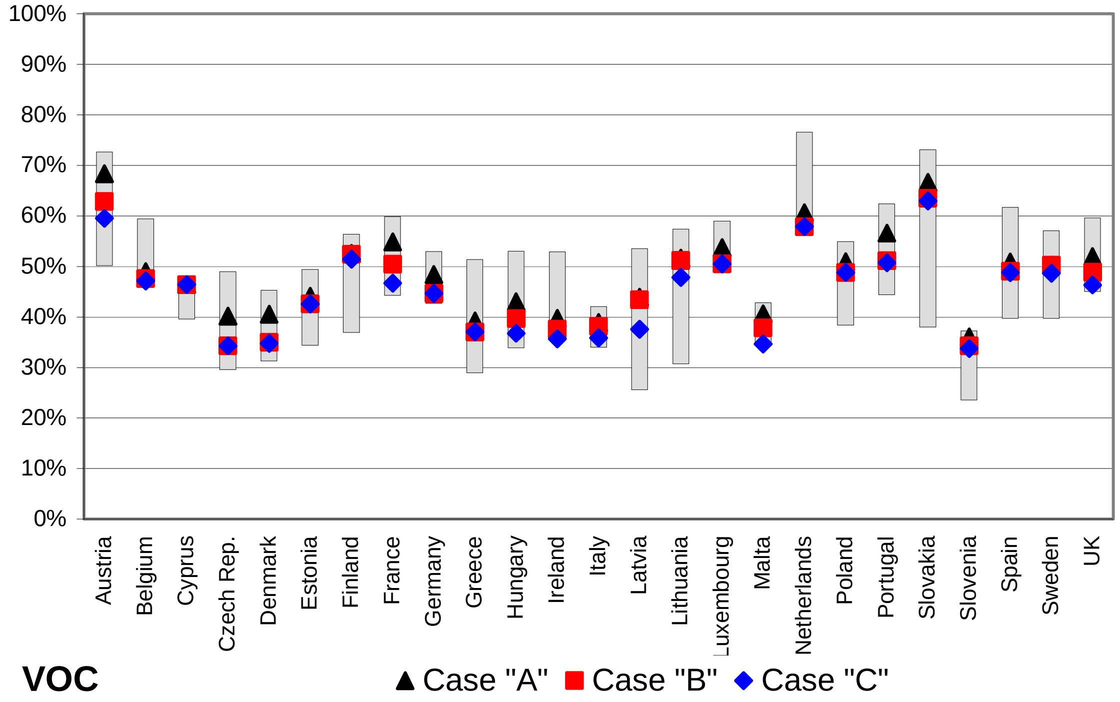

Figure 3.6: Emission reductions for VOC in relation to the levels in the year 2000 (100% line). The grey range indicates the scope of further reductions beyond the current legislation baseline case (top end of the grey range) up to the maximum technically feasible reductions (bottom end)

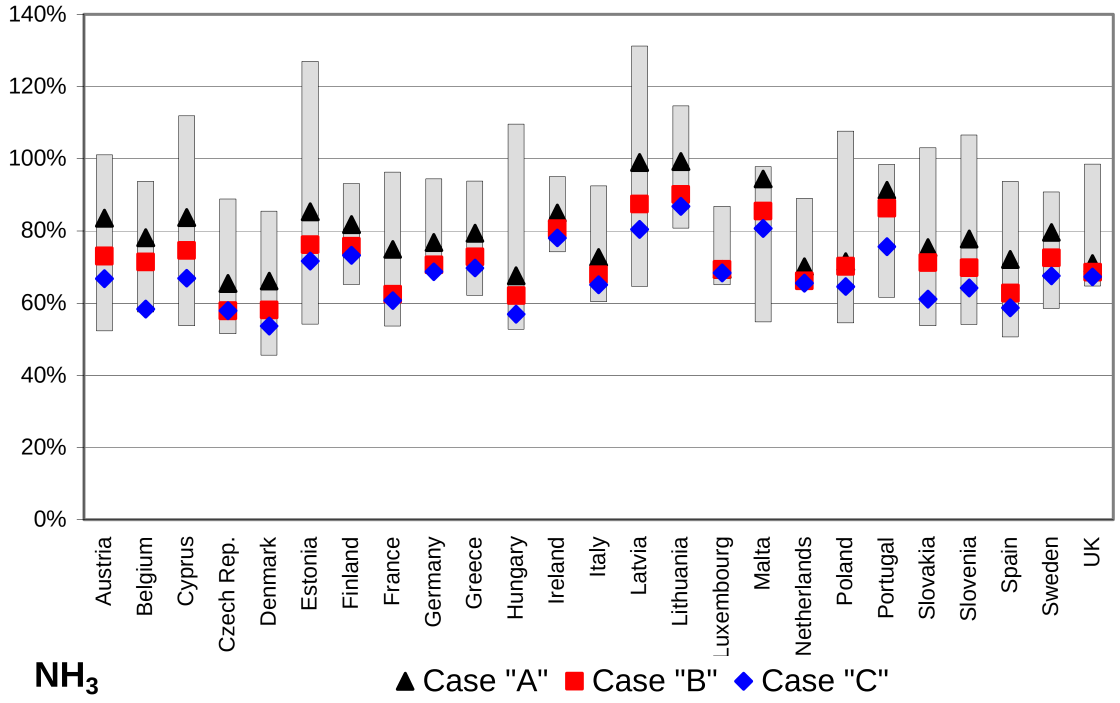

Figure 3.7: Emission reductions for NH_3 in relation to the levels in the year 2000 (100% line). The grey range indicates the scope of further reductions beyond the current legislation baseline case (top end of the grey range) up to the maximum technically feasible reductions (bottom end)

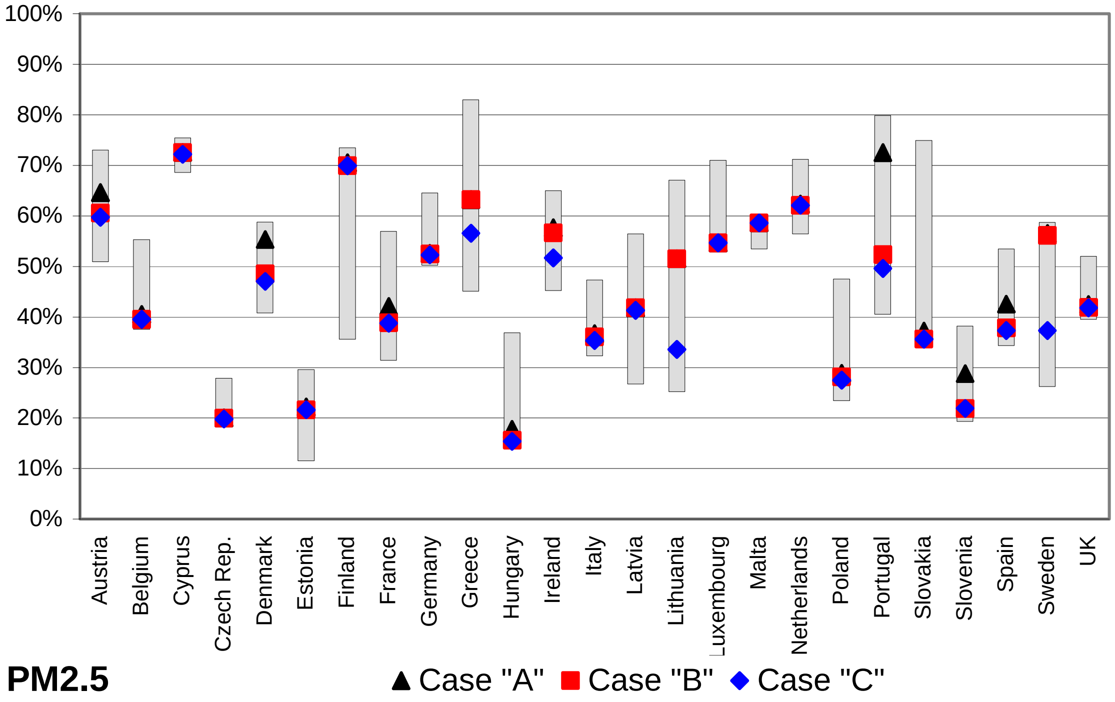

Figure 3.8: Emission reductions for PM2.5 in relation to the levels in the year 2000 (100% line). The grey range indicates the scope of further reductions beyond the current legislation baseline case (top end of the grey range) up to the maximum technically feasible reductions (bottom end)

Table 3.8: Sectoral shares in SO_2 emission reductions in 2020

		Case "A"		*Case "B"*		*Case "C"*	
	Baseline emissions in 2020 (kt)	Reduction from baseline (kt)	Share of total reduction in EU-25	Reduction from baseline (kt)	Share of total reduction in EU-25	Reduction from baseline (kt)	Share of total reduction in EU-25
Conversion	645	325	*30%*	356	*29%*	364	*27%*
Domestic	202	23	*2%*	24	*2%*	63	*5%*
Industry	435	191	*17%*	221	*18%*	229	*17%*
Power plants	606	199	*18%*	208	*17%*	240	*18%*
Industrial processes	693	261	*24%*	294	*24%*	304	*23%*
Waste	7	4	*0%*	5	*0%*	5	*0%*
Transport	217	98	*9%*	130	*11%*	138	*10%*
Total	**2805**	**1101**	***100%***	**1238**	***100%***	**1343**	***100%***

Table 3.9: Sectoral shares in NO_x emission reductions in 2020

		Case "A"		*Case "B"*		*Case "C"*	
	Baseline emissions in 2020 (kt)	Reduction from baseline (kt)	Share of total reduction in EU-25	Reduction from baseline (kt)	Share of total reduction in EU-25	Reduction from baseline (kt)	Share of total reduction in EU-25
Conversion	264	118	*10%*	160	*10%*	174	*10%*
Domestic	596	10	*1%*	63	*4%*	71	*4%*
Industry	660	284	*23%*	375	*24%*	404	*23%*
Power plants	801	112	*9%*	271	*17%*	403	*23%*
Industrial processes	538	286	*24%*	322	*20%*	327	*18%*
Waste	15	12	*1%*	13	*1%*	13	*1%*
Transport	3013	388	*32%*	388	*24%*	388	*22%*
Total	**5888**	**1210**	***100%***	**1592**	***100%***	**1780**	***100%***

Table 3.10: Sectoral shares in PM2.5 emission reductions in 2020

		Case "A"		*Case "B"*		*Case "C"*	
	Baseline emissions in 2020 (kt)	Reduction from baseline (kt)	Share of total reduction in EU-25	Reduction from baseline (kt)	Share of total reduction in EU-25	Reduction from baseline (kt)	Share of total reduction in EU-25
Conversion	15	3	*1%*	3	*1%*	4	*1%*
Domestic	319	70	*32%*	104	*41%*	127	*45%*
Industry	12	4	*2%*	4	*2%*	5	*2%*
Power plants	55	22	*10%*	22	*9%*	22	*8%*
Industrial processes	213	49	*22%*	51	*20%*	52	*18%*
Waste	46	42	*19%*	42	*16%*	42	*15%*
Other	112	3	*2%*	3	*1%*	3	*1%*
Transport	194	26	*12%*	26	*10%*	26	*9%*
Total	**964**	**218**	**100%**	**255**	**100%**	**282**	**100%**

Table 3.11: Sectoral shares in NH_3 emission reductions in 2020

		Case "A"		*Case "B"*		*Case "C"*	
	Baseline emissions in 2020 (kt)	Reduction from baseline (kt)	Share of total reduction in EU-25	Reduction from baseline (kt)	Share of total reduction in EU-25	Reduction from baseline (kt)	Share of total reduction in EU-25
Poultry	470	267	*32%*	272	*25%*	274	*23%*
Fertilizer use	660	275	*33%*	275	*25%*	275	*23%*
Pigs	800	110	*13%*	183	*17%*	250	*21%*
Dairy cows	644	122	*15%*	174	*16%*	199	*16%*
Other cattle	676	44	*5%*	150	*14%*	161	*13%*
Industrial processes	54	5	*1%*	26	*2%*	38	*3%*
Other animals	166	2	*0%*	7	*1%*	12	*1%*
Other	215	0	*0%*	0	*0%*	0	*0%*
Total	**3686**	**826**	***100%***	**1088**	***100%***	**1209**	***100%***

Table 3.12: Sectoral shares in VOC emission reductions in 2020

		Case "A"		*Case "B"*		*Case "C"*	
	Baseline emissions in 2020 (kt)	Reduction from baseline (kt)	Share of total reduction in EU-25	Reduction from baseline (kt)	Share of total reduction in EU-25	Reduction from baseline (kt)	Share of total reduction in EU-25
Coatings	1008	183	*27%*	300	*31%*	335	*29%*
Solvents	1402	156	*23%*	246	*25%*	269	*24%*
Industrial processes	880	219	*32%*	239	*24%*	244	*21%*
Conversion	763	80	*12%*	125	*13%*	167	*15%*
Waste	182	42	*6%*	51	*5%*	55	*5%*
Domestic	531	5	*1%*	16	*2%*	73	*6%*
Transport	1036	0	*0%*	0	*0%*	0	*0%*
Other	114	0	*0%*	0	*0%*	0	*0%*
Total	**5916**	**685**	***100%***	**977**	***100%***	**1143**	***100%***

3.1.1 Summary of reduction measures

The RAINS model determines the cost-optimal emission reductions for meeting the environmental improvements based on a detailed assessment of the emission control potentials and costs that are available in each country and economic sector beyond implementation of the "current legislation". A full description of the measures taken in each optimization case for each of the more than 300 emission source categories in the 25 Member States is beyond the scope of this report but can be extracted from the Internet implementation of the RAINS model (www.iiasa.ac.at/rains).

This section provides a summary description of the measures that are typically taken in the majority of Member States and that make substantial contributions to the overall emission reductions. Tables with quantitative information about the role of the various measures are provided in the Annex.

Although extensive consultations have been carried out with Member States and industrial stakeholders for the development of the CAFE baseline, some issues on the precise applicability of certain control measures in particular countries could not be completely resolved. While these uncertainties will most likely not change the overall conclusions, they need to be kept in mind when interpreting individual country results at a detailed level. While the RAINS methodology can provide indications of measures that could make cost-effective contributions to Europe-wide emission reduction strategies, it does not allow drawing conclusions on specific measures for a particular plant in a given country.

Measures to reduce SO_2 emissions

Conversion sector (refineries):

- Low sulphur heavy fuel oil (below 1 % S)
- Control of industrial process emissions in refineries
- In scenarios with higher ambition levels also flue gas desulphurization for boilers and furnaces

Domestic sector:

- Low sulphur heavy fuel oil (below 1 % S)
- Low sulphur coal
- In scenarios with higher ambition levels also low sulphur gas oil (below 0.1 % S)

Industry:

- Low sulphur heavy fuel oil (below 1 % S)
- Low sulphur coal
- In-furnace sulphur control measures
- In scenarios with higher ambition levels also flue gas desulphurization on boilers and furnaces

Power plants:

- Flue gas desulphurization on all existing plants
- High efficiency FGD on new plants using high sulphur fuels

Industrial processes:

- Controls on process emissions beyond current legislation (stringency depends on the ambition level)

Waste:

- Good practice
- Ban on open burning of agricultural and municipal waste

Transport:

- Further reduction of S content of fuels (beyond current national legislation) used in national sea traffic and national fishing

The use of low sulphur heavy fuel oil (below 1 % S) is selected for the majority of countries even for the low ambition levels. The degree of implementation of FGD technology depends on country-specific conditions and the selected ambition level.

Measures to reduce NO_x emissions:

Conversion:

- Combustion modifications and selective non-catalytic reduction (SNCR) for lower ambition levels (all countries)
- SCR for higher ambition levels in countries where NO_x reduction is required
- Controls on process sources in oil refineries

Domestic:

- Primary measures on heavy fuel oil and gas boilers in the commercial sector (all countries)
- For higher ambition levels also controls on light fuel oil commercial boilers

Industry:

- Combustion modification measures and SNCR for scenarios with lower ambition levels (all countries)
- SCR for higher ambition levels in countries where NO_x reduction is required

Power plants:

- Combustion modification on all existing plants for which SCR is not yet required
- SCR on all coal and oil new plants

Industrial processes:

- Further controls on process emissions beyond current legislation (stringency depends on ambition level)

Waste:

- Good practice
- Ban of open burning of agricultural and municipal waste

Transport:

- Additional measures on light duty diesel vehicles for all countries
- Additional measures on heavy duty diesel vehicles for all countries

Measures to reduce PM emissions:

Conversion:

- High efficiency dedusters (electrostatic precipitators, fabric filters) for process sources in refineries and coking plants
- Good housekeeping on oil fired furnaces

Domestic:

- Dedusters (cyclones, fabric filters) on boilers in the commercial sector
- Accelerated introduction of new boilers in the residential sector (mainly for biomass)
- In the scenarios with higher ambition levels non-catalytic inserts for fireplaces and stoves

Industry:

- High efficiency dedusters for all countries and all ambition levels
- Good housekeeping measures on oil boilers

Power plants:

- High efficiency dedusters for all existing and new boilers using solid fuels
- Good housekeeping measures on oil boilers (for all countries and all ambition levels)

Industrial processes:

- High efficiency dedusters to control stack emissions
- Good practice to control fugitive emissions (for all countries and all ambition levels)

Transport:

- Additional measures for light duty diesel vehicles for all countries
- Additional measures for heavy duty diesel vehicles for all countries
- Low sulphur fuels for national sea traffic and national fishing, which also reduces the PM emissions

Waste:

- Good practice
- Ban on open burning of agricultural and household waste

Measures to reduce ammonia emissions:

Livestock:

- Low ammonia applications for poultry, dairy cows and pigs (all ambition levels)
- Low emission housing with integrated closed storage for poultry (limited in the low ambition level)
- Low ammonia application of other cattle manures (not in the low ambition case)
- Change of feeding strategies for pigs (in the high ambition case)
- Low emission housing for dairy cows (in the high ambition case)
- Low ammonia application of manure for sheep (in the high ambition case)

Fertilizer application:

- Substitution of urea fertilizer with an alternative mineral fertilizer characterized by low ammonia loss, e.g., ammonium nitrate, to the maximum possible extent for all ambition levels

Fertilizer production

- End-of-pipe emission controls (not in the low ambition case)

Measures to reduce NMVOC emissions

Industrial processes

- Reduction of fugitive losses in organic chemical industry (all ambition levels)
- Switch from cutback to emulsion bitumen (road paving with asphalt) (all ambition levels)

Paint applications

- Further reduction of solvent content of coatings in industrial applications (all ambition levels)
- Further reduction of solvent content for decorative paints (mainly for the higher ambition levels)

Solvent use:

- Relatively small reductions in a large number of sectors; further penetration of combination of substitution and end-of-pipe measures (e.g., carbon adsorption, thermal incineration) (all ambition levels)
- More stringent measures for the printing sector including substitution of adhesives and inks for low or solvent free inputs, reduction of solvent content of cleaning and dampening agents and wider use of carbon adsorption (for medium and high ambition levels)

Controls of emission from the production and distribution of liquid fuels:

- Improved flaring efficiency, at installations that are not yet state-of-the-art (all ambition levels)
- Reduction of fugitive losses from processes and storage (all ambition levels)
- Stage II for gasoline distribution, if not yet implemented

Domestic (linked to PM measures):

- Accelerated introduction of new boilers in the residential sector for biomass
- In the scenarios with higher ambition levels inserts for fireplaces and stoves

Waste:

- Ban on open burning of agricultural and household waste (all ambition levels)

3.2 Emission control costs

Table 3.13: Emission control costs for the current legislation and for the optimized scenarios (million €/year)

	Current legislation	*Mobile sources*	*Additional costs for stationary sources*			
	Costs for stationary and mobile sources	Additional costs for further measures on road emissions	Case “A”	Case “B”	Case “C”	Maximum technically feasible reductions
Austria	1401	50	64	170	266	1353
Belgium	1959	82	136	262	645	899
Cyprus	128	3	6	14	20	77
Czech Rep.	1324	20	103	191	219	594
Denmark	1015	20	78	184	270	780
Estonia	188	4	9	15	23	155
Finland	1092	21	44	117	187	1067
France	7796	259	739	1704	2095	7528
Germany	13937	360	541	1277	1960	3980
Greece	1941	26	40	102	193	974
Hungary	1015	26	74	153	254	541
Ireland	1035	33	70	165	227	674
Italy	7466	185	404	867	1264	3226
Latvia	217	7	6	15	26	131
Lithuania	384	11	41	87	134	422
Luxembourg	304	11	8	16	17	39
Malta	40	1	2	3	5	19
Netherlands	3340	82	106	345	376	897
Poland	3966	60	579	739	1047	3727
Portugal	1630	68	28	139	239	1388
Slovakia	710	22	40	68	127	344
Slovenia	270	6	17	43	61	181
Spain	5725	267	353	790	1317	4183
Sweden	1657	24	62	174	314	1543
UK	7321	221	507	1170	1699	3129
EU-25	**65862**	**1868**	**4055**	**8811**	**12984**	**37852**

Table 3.14: Emission control costs for stationary sources by pollutant for the low ambition Case “A”, on top of the costs of the current legislation (million €/year)

	SO_2	NO_x	NH_3	VOC	PM2.5	Total
Austria	5	19	35	1	4	64
Belgium	22	31	58	11	13	136
Cyprus	0	3	3	0	0	6
Czech Rep.	23	28	44	1	7	103
Denmark	1	18	56	2	0	78
Estonia	1	5	2	0	1	9
Finland	2	25	16	1	0	44
France	141	179	270	14	134	739
Germany	75	60	365	12	29	541
Greece	5	21	10	1	3	40
Hungary	26	13	31	1	3	74
Ireland	2	10	48	8	0	70
Italy	91	120	138	11	44	404
Latvia	0	2	3	0	0	6
Lithuania	6	4	30	0	1	41
Luxembourg	1	2	5	0	0	8
Malta	0	1	0	0	0	2
Netherlands	20	5	62	11	7	106
Poland	263	80	104	2	131	579
Portugal	12	6	8	0	2	28
Slovakia	9	13	15	0	3	40
Slovenia	5	4	8	0	0	17
Spain	60	83	199	3	8	353
Sweden	0	39	20	2	1	62
UK	27	130	252	77	21	507
EU-25	**800**	**903**	**1785**	**157**	**411**	**4055**

Table 3.15: Emission control costs for stationary sources by pollutant for the medium ambition Case “B”, on top of the costs of the current legislation (million €/year)

	SO_2	NO_x	NH_3	VOC	PM2.5	Total
Austria	6	60	79	7	18	170
Belgium	28	61	133	20	20	262
Cyprus	0	7	7	0	0	14
Czech Rep.	24	62	89	8	7	191
Denmark	4	39	121	12	9	184
Estonia	3	7	5	0	1	15
Finland	15	68	33	1	0	117
France	148	468	771	84	234	1704
Germany	97	194	883	71	32	1277
Greece	16	55	25	3	3	102
Hungary	30	46	64	3	10	153
Ireland	6	42	102	13	1	165
Italy	129	434	229	19	56	867
Latvia	2	4	7	0	0	15
Lithuania	9	14	63	0	1	87
Luxembourg	3	8	5	1	0	16
Malta	0	2	0	0	0	3
Netherlands	33	123	154	26	8	345
Poland	263	191	131	7	146	739
Portugal	22	33	19	10	54	139
Slovakia	11	29	22	1	4	68
Slovenia	6	15	15	0	7	43
Spain	104	200	428	7	52	790
Sweden	6	119	46	2	2	174
UK	56	468	340	278	29	1170
EU-25	**1021**	**2752**	**3770**	**573**	**695**	**8811**

Table 3.16: Emission control costs for stationary sources by pollutant for the high ambition Case “C”, on top of the costs of the current legislation (million €/year)

	SO_2	NO_x	NH_3	VOC	PM2.5	Total
Austria	13	89	128	14	23	266
Belgium	58	142	402	24	20	645
Cyprus	0	7	13	0	0	20
Czech Rep.	29	84	89	8	9	219
Denmark	12	48	186	13	12	270
Estonia	3	12	7	0	1	23
Finland	28	113	43	2	0	187
France	270	546	858	185	236	2095
Germany	217	487	1147	71	38	1960
Greece	26	102	41	3	21	193
Hungary	33	74	128	7	12	254
Ireland	11	43	144	24	5	227
Italy	176	620	325	63	80	1264
Latvia	3	10	12	1	0	26
Lithuania	9	26	79	1	19	134
Luxembourg	3	8	6	1	0	17
Malta	0	3	0	1	0	5
Netherlands	33	133	176	26	8	376
Poland	283	301	283	7	172	1047
Portugal	32	76	50	13	68	239
Slovakia	19	48	54	2	4	127
Slovenia	9	21	23	1	7	61
Spain	120	405	721	9	61	1317
Sweden	16	132	82	6	78	314
UK	73	726	414	455	32	1699
EU-25	**1477**	**4255**	**5410**	**935**	**908**	**12984**

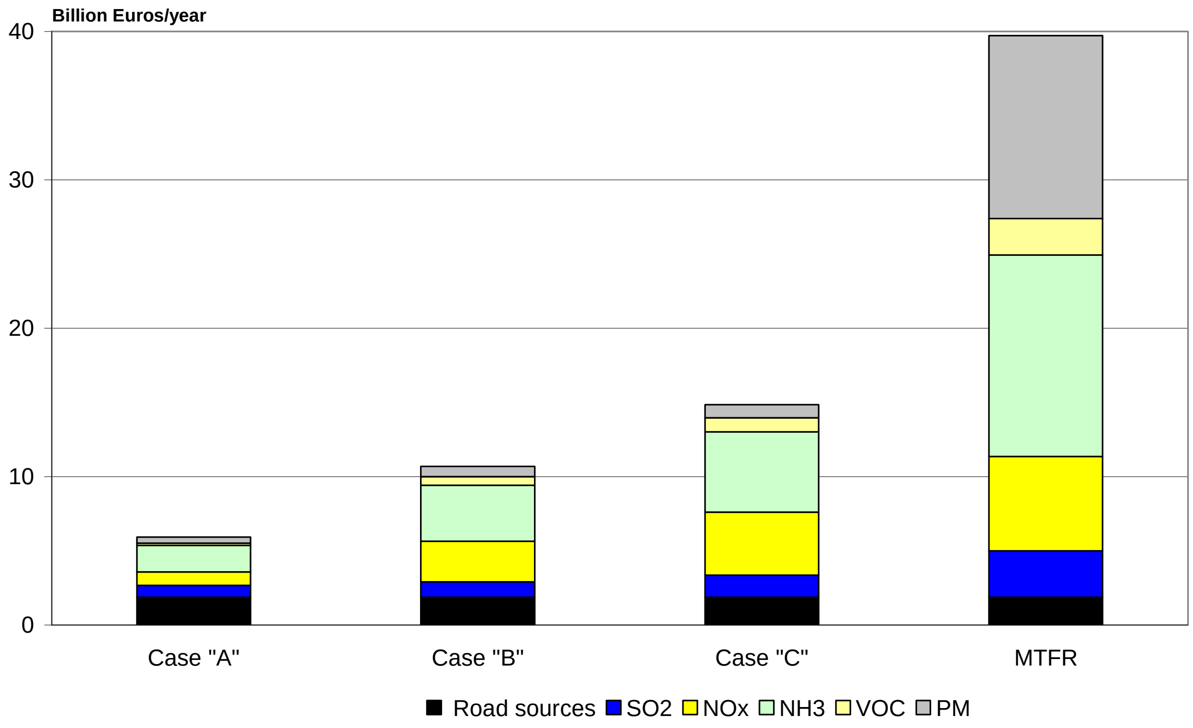

Figure 3.9: Emission control costs on top of the costs of the current legislation baseline, by pollutant (in billion €/year)

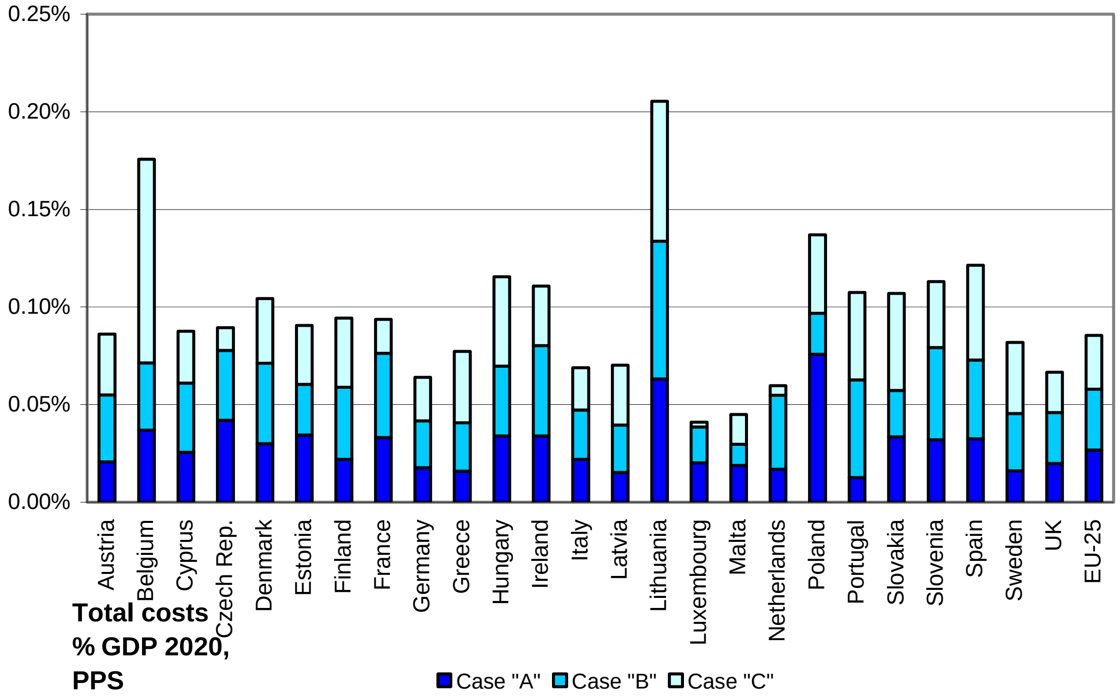

Figure 3.10: Emission control costs for stationary sources expressed as a percentage of GDP using Purchasing Power Parities (PPS) for the scenarios optimized for the three environmental ambition levels

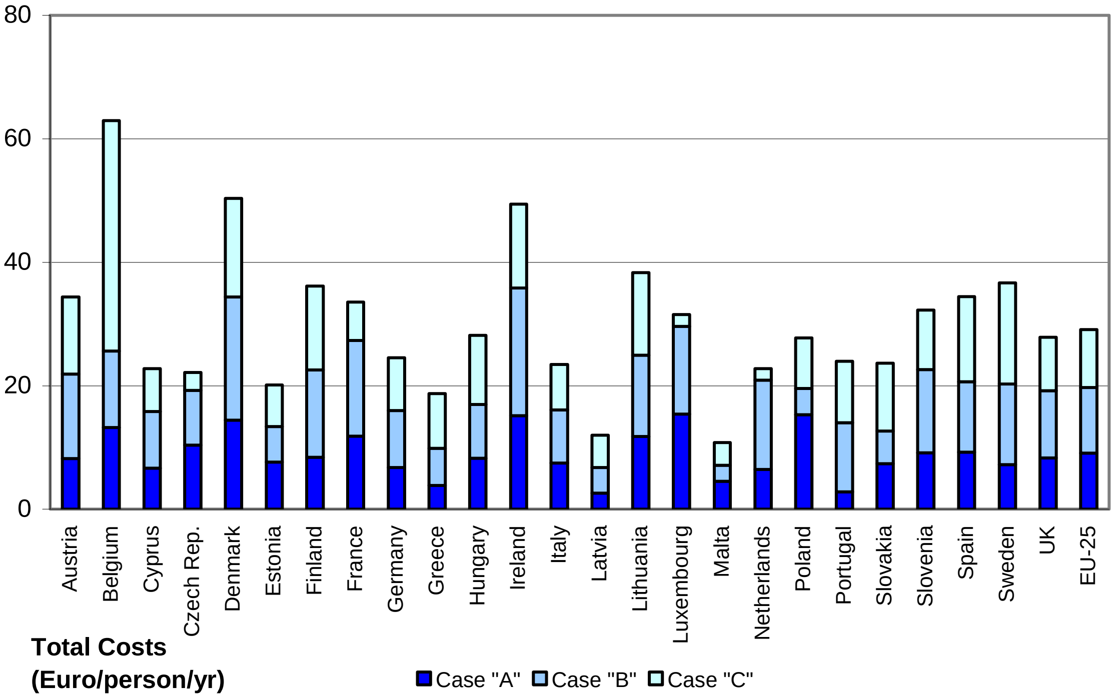

Figure 3.11: Per capita emission control costs for stationary sources (on top of the current legislation baseline) for the three optimized scenarios (€/year)

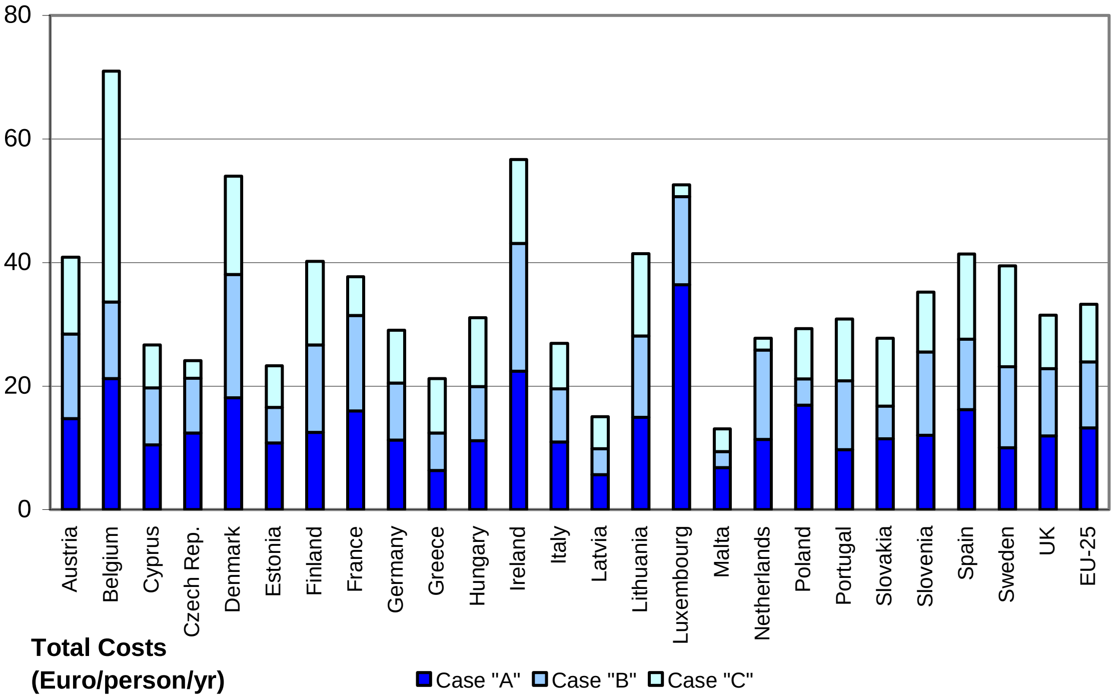

Figure 3.12: Per capita emission control costs for stationary and mobile sources (on top of the current legislation baseline) for the three optimized scenarios (€/year)

3.3 Physical benefits

While it is beyond the scope of the cost-effectiveness analysis conducted by the RAINS model to quantify physical benefits of emission control measures in great detail, the RAINS model contains modules to assess the impacts of reduced emissions on selected impact indicators. More detail on the methods applied for quantifying these impact indicators can be found in the model documentation prepared for the peer review of the RAINS model (www.iiasa.ac.at/rains/review/review-full.pdf).

3.3.1 Loss in life expectancy attributable to exposure to fine particulate matter

With the methodology described in Amann *et al.* (2004), the RAINS model estimates changes in the loss in statistical life expectancy that can be attributed to changes in anthropogenic emissions (ignoring the role of secondary organic aerosols). This calculation is based on the assumption that health impacts can be associated with changes in PM2.5 concentrations. Following the advice of the joint World Health Organization/UNECE Task Force on Health (http://www.unece.org/env/documents/2004/eb/wg1/eb.air.wg1.2004.11.e.pdf), RAINS applies a linear concentration-response function and associates all changes in the identified anthropogenic fraction of PM2.5 with health impacts. Thereby, no health impacts are calculated for PM from natural sources and for secondary organic aerosols. It transfers the rate of relative risk for PM2.5 identified by Pope *et al.* (2002) for 500,000 individuals in the United States to the European situation and calculates mortality for the population older than 30 years. Thus, the assessment in RAINS does not quantify infant mortality and thus underestimates overall effects. The calculations include estimates of increased PM2.5 concentrations in urban background air based on the City-Delta methodology.

For the CAFE calculation, RAINS estimates suggest the statistical life expectancy of a European citizen to be shortened by 8.1 months as a consequence of the exposure to anthropogenic PM2.5. Within the EU-25, largest losses in statistical life expectancy are calculated for Belgium (13.2 months) and lowest for Finland (2.6 months), see Table 3.17. Emission control measures included in the current legislation are expected to increase statistical life expectancy in 2020 on average by 2.6 months, so that even in Belgium life expectancy loss should decrease to 8.9 months. Taking this expected average loss of life expectancy of 5.5 months as a starting point, the CAFE scenarios explore measures to reduce this loss to 4.4, 4.1 and 4.0 months, respectively. These targets correspond to 110, 104 and 101 million life years lost for the EU-25 (Table 3.18). Spatial distributions of these gains in life expectancy are provided in Figure 3.13 and Figure 3.14.

Table 3.17: Losses in statistical life expectancy attributable to the exposure to anthropogenic PM2.5 for the year 2000, the emission ceilings for 2010, the current legislation baseline in 2020 and the optimized scenarios for the three environmental ambition levels (in months)

	2000	*2010*	*2020*	*Optimized scenarios for 2020*			*2020*
		National emission ceilings	Baseline, Current legislation	Case “A”	Case “B”	Case “C”	Maximum technically feasible reductions
Austria	7.2	5.7	5.4	4.4	4.2	4.0	3.8
Belgium	13.2	9.5	8.9	7.3	7.0	6.7	6.5
Cyprus	4.8	4.3	4.2	4.1	4.1	4.1	4.0
Czech Rep.	8.8	6.5	5.8	4.4	4.1	4.0	3.8
Denmark	5.9	4.7	4.5	3.8	3.6	3.4	3.2
Estonia	3.8	3.2	3.0	2.7	2.6	2.6	2.4
Finland	2.6	2.3	2.2	2.1	2.1	2.1	1.9
France	8.0	6.0	5.5	4.5	4.2	4.1	3.8
Germany	9.2	6.8	6.5	5.1	4.7	4.6	4.4
Greece	6.7	5.5	5.2	4.9	4.8	4.7	4.6
Hungary	10.6	8.3	7.6	5.6	5.3	5.2	4.9
Ireland	4.0	2.9	2.6	2.1	2.0	1.9	1.8
Italy	9.0	6.1	5.3	4.3	4.1	4.0	3.9
Latvia	4.5	4.0	3.8	3.4	3.3	3.2	3.0
Lithuania	6.1	5.4	5.0	4.4	4.3	4.1	3.9
Luxembourg	9.6	7.0	6.8	5.1	4.7	4.4	4.2
Malta	5.6	4.3	4.1	3.8	3.8	3.7	3.6
Netherlands	11.8	8.6	8.3	6.6	6.1	5.9	5.7
Poland	9.6	7.5	6.5	5.2	5.0	4.9	4.7
Portugal	5.1	3.2	3.2	2.8	2.5	2.4	2.2
Slovakia	9.1	7.2	6.4	4.8	4.6	4.4	4.2
Slovenia	8.2	6.5	6.0	4.8	4.6	4.4	4.1
Spain	5.2	3.5	3.2	2.8	2.7	2.6	2.5
Sweden	3.5	2.9	2.7	2.4	2.4	2.2	2.0
UK	6.9	5.0	4.6	3.5	3.2	3.1	3.0
EU-25	8.1	5.9	5.5	4.4	4.1	4.0	3.8

Table 3.18: Life years lost due to the exposure to anthropogenic PM2.5 for the year 2000, the emission ceilings for 2010, the current legislation baseline in 2020 and the optimized scenarios for the three environmental ambition levels (million years)

	2000	*2010* National emission ceilings	*2020* Baseline, Current legislation	*Optimized scenarios for 2020* Case "A"	Case "B"	Case "C"	*2020* Maximum technically feasible reductions
Austria	3.28	2.62	2.45	2.00	1.90	1.83	1.72
Belgium	7.61	5.46	5.13	4.23	4.02	3.87	3.72
Cyprus	0.21	0.19	0.18	0.18	0.18	0.18	0.18
Czech Rep.	5.05	3.74	3.32	2.51	2.37	2.30	2.16
Denmark	1.74	1.37	1.32	1.12	1.06	1.02	0.95
Estonia	0.26	0.22	0.20	0.18	0.18	0.17	0.16
Finland	0.74	0.66	0.63	0.60	0.59	0.59	0.53
France	26.09	19.39	17.95	14.47	13.50	13.17	12.25
Germany	43.30	32.05	30.70	24.00	22.36	21.64	20.76
Greece	3.96	3.26	3.07	2.88	2.84	2.80	2.73
Hungary	5.61	4.39	3.99	2.95	2.82	2.72	2.59
Ireland	0.80	0.57	0.53	0.42	0.39	0.38	0.36
Italy	30.16	20.54	17.70	14.51	13.85	13.50	12.98
Latvia	0.56	0.50	0.47	0.42	0.41	0.40	0.38
Lithuania	1.18	1.04	0.97	0.84	0.83	0.79	0.76
Luxembourg	0.24	0.18	0.17	0.13	0.12	0.11	0.11
Malta	0.12	0.09	0.09	0.08	0.08	0.08	0.08
Netherlands	10.55	7.69	7.48	5.89	5.50	5.33	5.09
Poland	19.17	15.02	13.00	10.27	10.05	9.83	9.35
Portugal	2.74	1.76	1.72	1.52	1.35	1.30	1.20
Slovakia	2.57	2.02	1.80	1.35	1.29	1.25	1.17
Slovenia	0.92	0.72	0.67	0.54	0.51	0.49	0.46
Spain	12.04	8.02	7.49	6.44	6.12	6.02	5.74
Sweden	1.70	1.39	1.31	1.19	1.15	1.06	0.97
UK	22.29	16.13	15.03	11.28	10.54	10.19	9.65
EU-25	**202.88**	**149.00**	**137.35**	**110.00**	**104.00**	**101.00**	**96.03**

Table 3.19: PM2.5 population exposure indices (population weighted PM2.5 concentrations in urban background air of the cities in each country) relative to the levels anticipated for the implementation of the emission ceilings directive in 2010 (=100%)

	2000	*2010*	*2020*	*Optimized scenarios for 2020*			*2020*
		National emission ceilings	Baseline, Current legislation	Case “A”	Case “B”	Case “C”	Maximum technically feasible reductions
Austria	119%	100%	93%	81%	77%	76%	71%
Belgium	136%	100%	92%	81%	79%	77%	75%
Cyprus	108%	100%	98%	97%	97%	97%	96%
Czech Rep.	130%	100%	90%	72%	69%	67%	64%
Denmark	123%	100%	96%	83%	79%	75%	71%
Estonia	113%	100%	93%	87%	85%	84%	79%
Finland	111%	100%	95%	91%	90%	89%	81%
France	131%	100%	91%	76%	71%	70%	65%
Germany	132%	100%	95%	78%	74%	72%	69%
Greece	120%	100%	95%	89%	88%	87%	84%
Hungary	128%	100%	91%	69%	66%	64%	61%
Ireland	128%	100%	92%	80%	77%	75%	72%
Italy	138%	100%	87%	77%	74%	73%	71%
Latvia	108%	100%	96%	89%	87%	86%	83%
Lithuania	110%	100%	94%	85%	83%	81%	78%
Luxembourg	132%	100%	95%	76%	71%	69%	65%
Malta	122%	100%	96%	91%	90%	90%	88%
Netherlands	133%	100%	96%	80%	75%	74%	71%
Poland	125%	100%	86%	69%	68%	67%	64%
Portugal	133%	100%	99%	92%	84%	82%	78%
Slovakia	122%	100%	91%	73%	70%	68%	66%
Slovenia	121%	100%	94%	81%	78%	76%	73%
Spain	132%	100%	94%	86%	83%	82%	80%
Sweden	120%	100%	94%	87%	85%	78%	73%
UK	132%	100%	93%	75%	72%	70%	67%
EU-25	131%	100%	93%	79%	75%	74%	71%

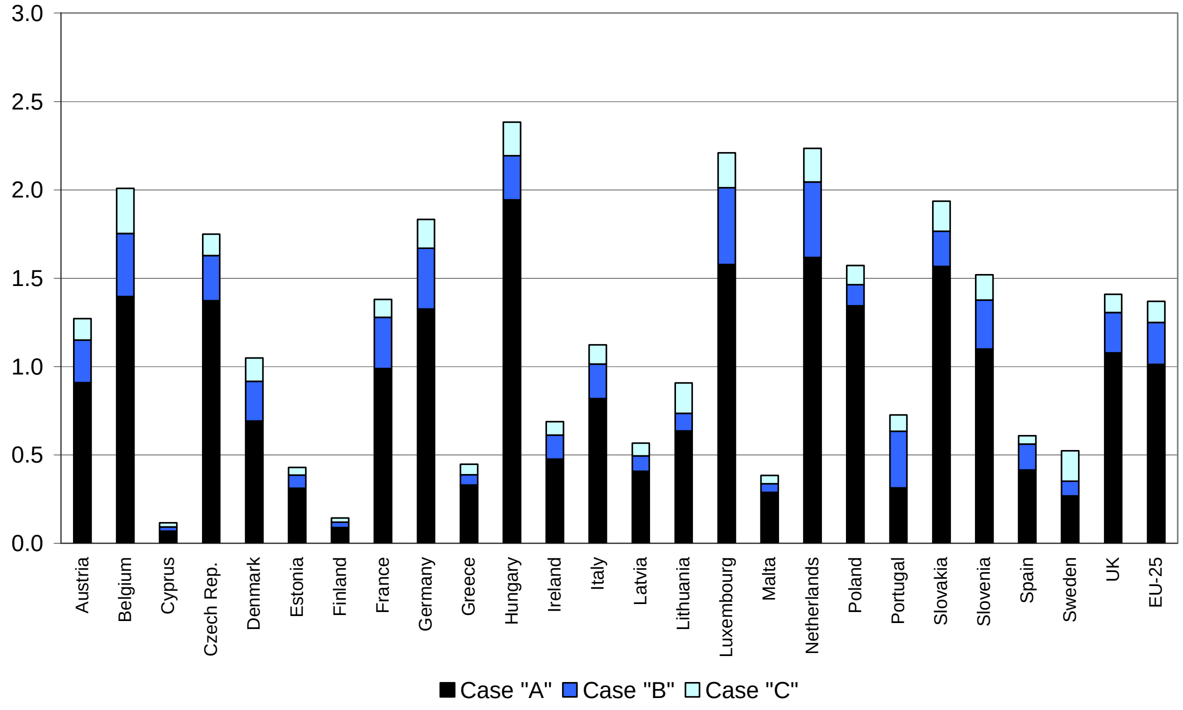

Figure 3.13: Gains in statistical life expectancy (in months) of the optimized scenarios compared to the CAFE current legislation baseline for 2020.

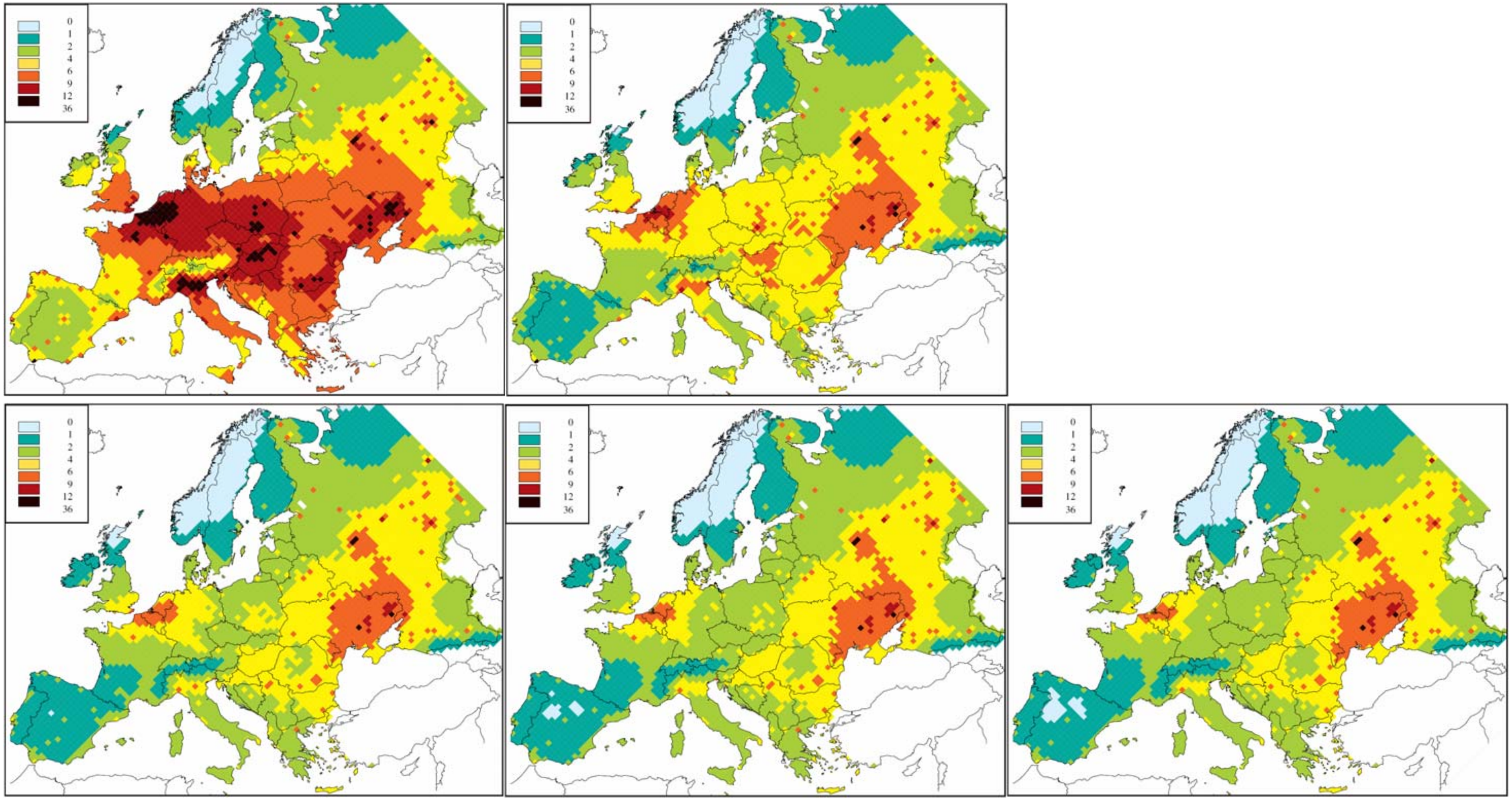

Figure 3.14: Loss in statistical life expectancy that can be attributed to the identified anthropogenic contribution to PM2.5 (months), for the year 2000 (top left graph), the baseline current legislation in 2020 (top right graph), Case “A” (bottom left), Case “B” (bottom centre) and Case “C” (bottom right). Calculation results for the meteorological conditions of 1997.

3.3.2 Excess nitrogen deposition

Excess nitrogen deposition poses a threat to a wide range of ecosystems, endangering their bio-diversities through changes in the plant communities. Critical loads indicating the maximum level of nitrogen deposition that can be absorbed by ecosystems without eutrophication have been estimated throughout Europe.

While many of the precursor emissions are declining over time in the baseline emission projection, the protection of ecosystems from eutrophication is expected to only gradually improve, mainly caused by the maintained level of ammonia emissions.

Table 3.20: Ecosystems area (km^2) with nitrogen deposition above the critical loads for eutrophication. Results calculated for 1997 meteorology, using grid-average deposition. Critical loads data base of 2004.

	Ecosystems area [1]	*2000*	*2020* Current legislation	Case "A"	Case "B"	Case "C"	MTFR[2]
Austria	35563	34137	30730	27465	25388	24421	18795
Belgium	6615	6134	4023	2473	2140	1838	1544
Cyprus	4806	2296	3056	2363	2337	2327	635
Czech Rep.	18364	17481	14072	7178	5665	4637	2193
Denmark	3031	1597	1126	337	95	62	25
Estonia	24326	2853	1409	1044	1036	1034	0
Finland	238698	59985	34468	15110	12699	10909	0
France	179227	171610	141840	102177	79631	72533	36132
Germany	106908	102867	100868	98463	97329	96496	91449
Greece	13714	10392	9993	7086	6363	6182	269
Hungary	10763	3302	2630	1716	1455	1253	498
Ireland	8791	1015	294	33	18	3	0
Italy	119679	74548	57135	34300	30231	28232	15319
Latvia	29982	16277	11399	4473	3763	3202	138
Lithuania	13182	11209	10647	8201	7178	6420	575
Luxembourg	935	901	767	527	445	403	371
Malta[3]							
Netherlands	3244	2158	1970	1661	1410	1320	867
Poland	91265	78442	71871	59669	56530	52359	16209
Portugal	11053	3280	1323	159	107	52	0
Slovakia	18213	16179	10962	5475	4431	3349	794
Slovenia	4249	4006	3739	3203	3087	2118	884
Spain	84278	54410	42207	26615	20749	17648	5638
Sweden	184369	48176	29702	15634	12224	10085	1051
UK	73791	9792	4029	458	229	177	0
EU25	1285046	733048	590261	425819	374540	347059	193385

[1]) Ecosystems area for which critical loads data have been supplied

[2]) Maximum technically feasible emission reductions assumed for all European countries (including non-EU countries)

[3]) Data for Malta are not available

Table 3.21: Percent of ecosystems area with nitrogen deposition above the critical loads for eutrophication. Results calculated for 1997 meteorology, using grid-average deposition. Critical loads data base of 2004.

		2000	*2020*				
	Ecosystems area (km^2) 1)		Current legislation	Case "A"	Case "B"	Case "C"	MTFR 2)
Austria	35563	96%	86%	77%	71%	69%	53%
Belgium	6615	93%	61%	37%	32%	28%	23%
Cyprus	4806	48%	64%	49%	49%	48%	13%
Czech Rep.	18364	95%	77%	39%	31%	25%	12%
Denmark	3031	53%	37%	11%	3%	2%	1%
Estonia	24326	12%	6%	4%	4%	4%	0%
Finland	238698	25%	14%	6%	5%	5%	0%
France	179227	96%	79%	57%	44%	40%	20%
Germany	106908	96%	94%	92%	91%	90%	86%
Greece	13714	76%	73%	52%	46%	45%	2%
Hungary	10763	31%	24%	16%	14%	12%	5%
Ireland	8791	12%	3%	0%	0%	0%	0%
Italy	119679	62%	48%	29%	25%	24%	13%
Latvia	29982	54%	38%	15%	13%	11%	0%
Lithuania	13182	85%	81%	62%	54%	49%	4%
Luxembourg	935	96%	82%	56%	48%	43%	40%
Malta 3)							
Netherlands	3244	67%	61%	51%	43%	41%	27%
Poland	91265	86%	79%	65%	62%	57%	18%
Portugal	11053	30%	12%	1%	1%	0%	0%
Slovakia	18213	89%	60%	30%	24%	18%	4%
Slovenia	4249	94%	88%	75%	73%	50%	21%
Spain	84278	65%	50%	32%	25%	21%	7%
Sweden	184369	26%	16%	8%	7%	5%	1%
UK	73791	13%	5%	1%	0%	0%	0%
EU25	1285046	57%	46%	33%	29%	27%	15%

1) Ecosystems area for which critical loads data have been supplied

2) Maximum technically feasible emission reductions assumed for all European countries (including non-EU countries)

3) Data for Malta are not available

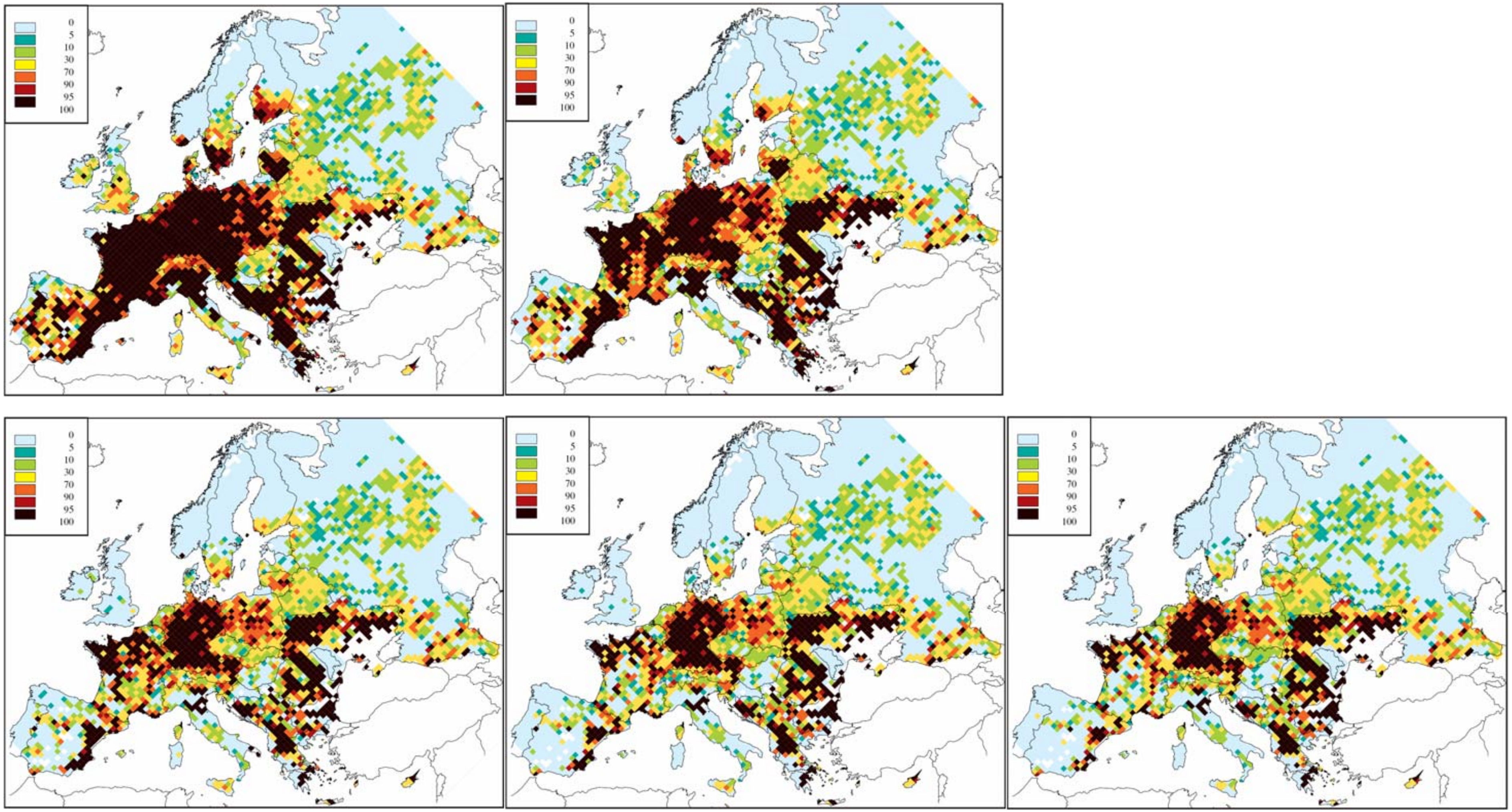

Figure 3.15: Percentage of total ecosystems area receiving nitrogen deposition above the critical loads for eutrophication for the year 2000 (top left graph), the baseline current legislation in 2020 (top right graph), Case “A” (bottom left), Case “B” (bottom centre) and Case “C” (bottom right). Calculation results for the meteorological conditions of 1997 using grid-average deposition.

3.3.3 Acid deposition to forest ecosystems

RAINS uses the concept of critical loads as a quantitative indicator for sustainable levels of sulphur and nitrogen deposition. Its analysis is based on the critical loads databases compiled by the Coordination Centre on Effects under the UNECE Working Group on Effects. This database combines quality-controlled critical loads estimates of the national focal centres for more than 1.6 million ecosystems (Posch *et al.*, 2004). National focal centres have selected a variety of ecosystem types as receptors for calculating and mapping critical loads. For most ecosystem types (e.g., forests), critical loads are calculated for both acidity and eutrophication. Other receptor types, such as streams and lakes, have only critical loads for acidity, on the assumption that eutrophication does not occur in these ecosystems. The RAINS analysis groups ecosystems into three classes (forests, semi-natural vegetation such as nature protection areas and freshwater bodies) and performs separate analyses for each class. The RAINS analysis compares for a given emission scenario the resulting deposition to these ecosystems with the critical loads and thus provides an indication to what extent the various types of ecosystems are still at risk of acidification. This indicator cannot be directly interpreted as the actual damage occurring at such ecosystems. To derive damage estimates, the historic rate of acid deposition as well as dynamic chemical processes in soils and lakes need to be considered, which can lead to substantial delays in the occurrence of acidification as well as in the recovery from acidification.

With its current data, the RAINS model estimates that in the year 2000 more than 20 percent of European forests or almost 250,000 km^2 received acid deposition above their sustainable critical loads. The emission reductions that are already agreed in the ‘current legislation’ should reduce this number in the year 2020 to approximately 120,000 km^2. With its environmental objectives, the CAFE scenarios explore the measures necessary to bring this number below 67,000, 60,000 and 55,000 km^2, respectively (Table 3.29, Table 3.30, Figure 3.16).

Table 3.22: Forest area (km²) with acid deposition above the critical loads for acidification. Results calculated for 1997 meteorology, using ecosystem-specific deposition. Critical loads data base of 2004.

	Ecosystems area [1]	*2000*	*2020* Current legislation	Case "A"	Case "B"	Case "C"	MTFR [2]
Austria	34573	5241	1625	864	685	546	162
Belgium	6526	3618	1643	1064	983	946	868
Cyprus	1854	0	0	0	0	0	0
Czech Rep.	18344	14815	5485	1864	1246	1060	334
Denmark	3009	956	172	44	37	35	9
Estonia	21252	62	0	0	0	0	0
Finland	236139	3802	2220	1771	1582	1559	874
France	168823	20951	7091	4356	3309	3056	1131
Germany	103113	74572	44339	26046	22211	19942	13281
Greece	13714	82	0	0	0	0	0
Hungary	10763	415	117	38	31	28	4
Ireland	4166	1957	959	736	685	643	380
Italy	92577	2083	657	241	241	241	241
Latvia	28941	174	130	3	3	0	0
Lithuania	12438	357	118	49	14	14	1
Luxembourg	934	328	128	17	10	2	0
Malta[3]							
Netherlands	3778	3335	3045	2685	2582	2492	1975
Poland	88281	52104	17356	998	777	583	177
Portugal	11053	285	53	18	4	0	0
Slovakia	18211	4130	1247	565	484	410	64
Slovenia	4190	116	0	0	0	0	0
Spain	84269	876	34	0	0	0	0
Sweden	180911	42912	27734	23084	22144	21727	15197
UK	19822	9717	4632	2464	2226	2115	1193
EU25	1167682	242887	118785	66905	59252	55397	35890

[1]) Ecosystems area for which critical loads data have been supplied

[2]) Maximum technically feasible emission reductions assumed for all European countries (including non-EU countries)

[3]) Data for Malta are not available

Table 3.23: Percent of forest area with acid deposition above the critical loads for acidification. Results calculated for 1997 meteorology, using ecosystem-specific deposition. Critical loads data base of 2004.

	Ecosystems area (km^2) [1]	*2000*	*2020* Current legislation	Case "A"	Case "B"	Case "C"	MTFR [2]
Austria	34573	15.2%	4.7%	2.5%	2.0%	1.6%	0.5%
Belgium	6526	55.4%	25.2%	16.3%	15.1%	14.5%	13.3%
Cyprus	1854	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Czech Rep.	18344	80.8%	29.9%	10.2%	6.8%	5.8%	1.8%
Denmark	3009	31.8%	5.7%	1.5%	1.2%	1.2%	0.3%
Estonia	21252	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%
Finland	236139	1.6%	0.9%	0.8%	0.7%	0.7%	0.4%
France	168823	12.4%	4.2%	2.6%	2.0%	1.8%	0.7%
Germany	103113	72.3%	43.0%	25.3%	21.5%	19.3%	12.9%
Greece	13714	0.6%	0.0%	0.0%	0.0%	0.0%	0.0%
Hungary	10763	3.9%	1.1%	0.4%	0.3%	0.3%	0.0%
Ireland	4166	47.0%	23.0%	17.7%	16.5%	15.4%	9.1%
Italy	92577	2.3%	0.7%	0.3%	0.3%	0.3%	0.3%
Latvia	28941	0.6%	0.5%	0.0%	0.0%	0.0%	0.0%
Lithuania	12438	2.9%	1.0%	0.4%	0.1%	0.1%	0.0%
Luxembourg	934	35.1%	13.7%	1.8%	1.0%	0.3%	0.0%
Malta [3]							
Netherlands	3778	88.3%	80.6%	71.1%	68.4%	66.0%	52.3%
Poland	88281	59.0%	19.7%	1.1%	0.9%	0.7%	0.2%
Portugal	11053	2.6%	0.5%	0.2%	0.0%	0.0%	0.0%
Slovakia	18211	22.7%	6.9%	3.1%	2.7%	2.3%	0.4%
Slovenia	4190	2.8%	0.0%	0.0%	0.0%	0.0%	0.0%
Spain	84269	1.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Sweden	180911	23.7%	15.3%	12.8%	12.2%	12.0%	8.4%
UK	19822	49.0%	23.4%	12.4%	11.2%	10.7%	6.0%
EU25	1167682	20.8%	10.2%	5.7%	5.1%	4.7%	3.1%

[1]) Ecosystems area for which critical loads data have been supplied

[2]) Maximum technically feasible emission reductions assumed for all European countries (including non-EU countries)

[3]) Data for Malta are not available

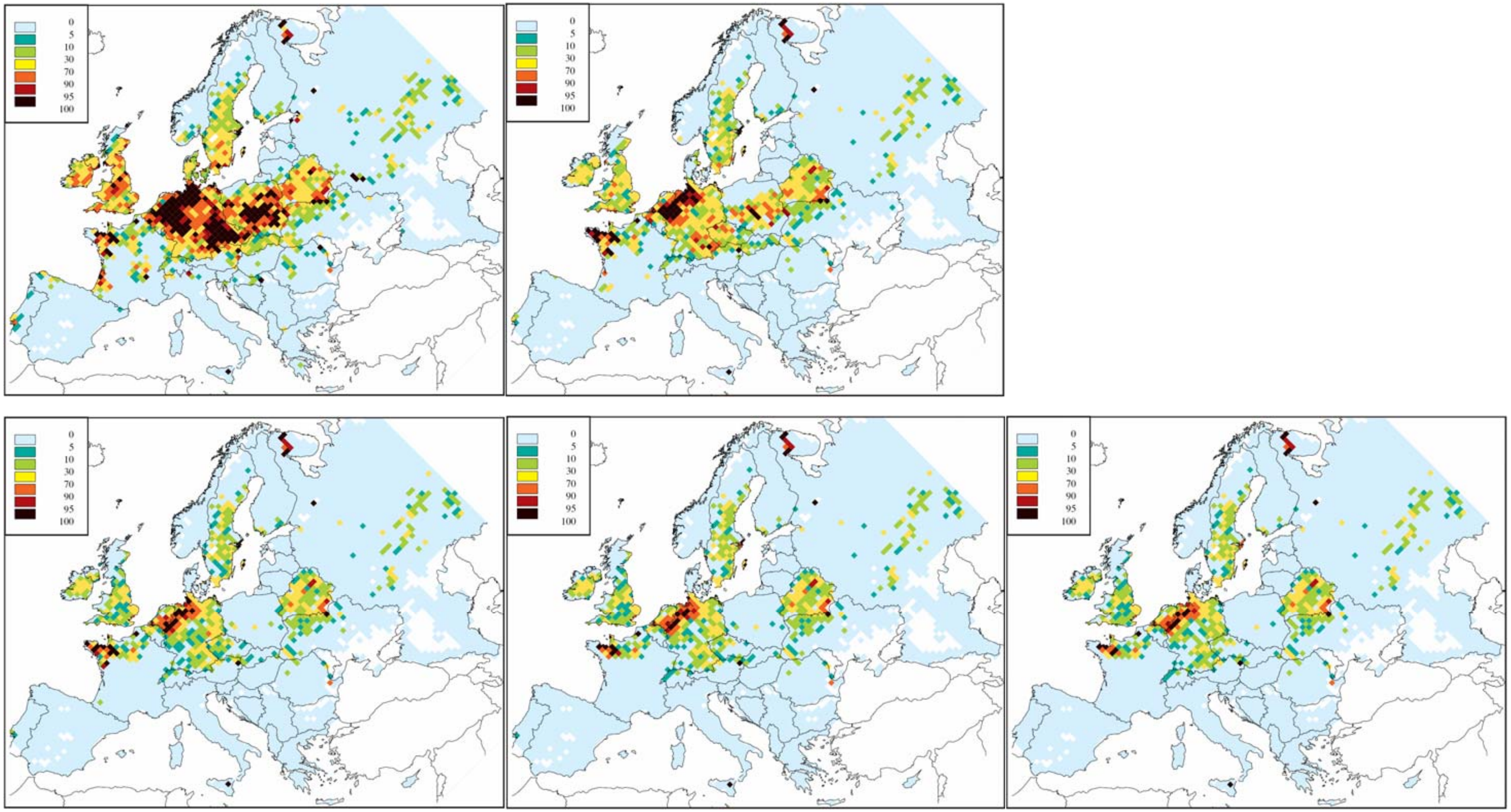

Figure 3.16: Percentage of forest area receiving acid deposition above the critical loads for the year 2000 (top left graph), the baseline current legislation in 2020 (top right graph), Case “A” (bottom left), Case “B” (bottom centre) and Case “C” (bottom right). Calculation results for the meteorological conditions of 1997, using ecosystem-specific deposition to forests.

3.3.4 Acid deposition to semi-natural ecosystems

A number of countries have provided estimates of critical loads for so-called "semi-natural" ecosystems. This group typically contains nature and landscape protection areas, many of them designated as "Natura2000" areas of the EU Habitat directive.

Table 3.24: Area of semi-natural ecosystems (km^2) with acid deposition above the critical loads for acidification. Results calculated for 1997 meteorology, using ecosystem-specific deposition. Critical loads data base of 2004.

	Ecosystems area [1]	*2000*	*2020* Current legislation	Case "A"	Case "B"	Case "C"	MTFR [2]
France	10014	3760	903	253	241	231	60
Germany	3946	2687	1615	991	829	693	448
Ireland	4609	474	108	47	39	35	20
Italy	26085	3	0	0	0	0	0
Netherlands	1296	817	620	346	304	298	231
UK	49700	15288	4597	1963	1670	1516	651
EU25	95651	23029	7843	3601	3083	2773	1410

[1]) Ecosystems area for which critical loads data have been supplied

[2]) Maximum technically feasible emission reductions assumed for all European countries (including non-EU countries)

Table 3.25: Percent of the area of semi-natural ecosystems with acid deposition above the critical loads for acidification. Results calculated for 1997 meteorology, using ecosystem-specific deposition. Critical loads data base of 2004.

	Ecosystems area (km^2) [1]	*2000*	*2020* Current legislation	Case "A"	Case "B"	Case "C"	MTFR [2]
France	10014	37.6%	9.0%	2.5%	2.4%	2.3%	0.6%
Germany	3946	68.1%	40.9%	25.1%	21.0%	17.6%	11.3%
Ireland	4609	10.3%	2.3%	1.0%	0.9%	0.8%	0.4%
Italy	26085	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Netherlands	1296	63.0%	47.8%	26.7%	23.4%	23.0%	17.8%
UK	49700	30.8%	9.3%	4.0%	3.4%	3.1%	1.3%
EU25	95651	24.1%	8.2%	3.8%	3.2%	2.9%	1.5%

[1]) Ecosystems area for which critical loads data have been supplied

2) Maximum technically feasible emission reductions assumed for all European countries (including non-EU countries)

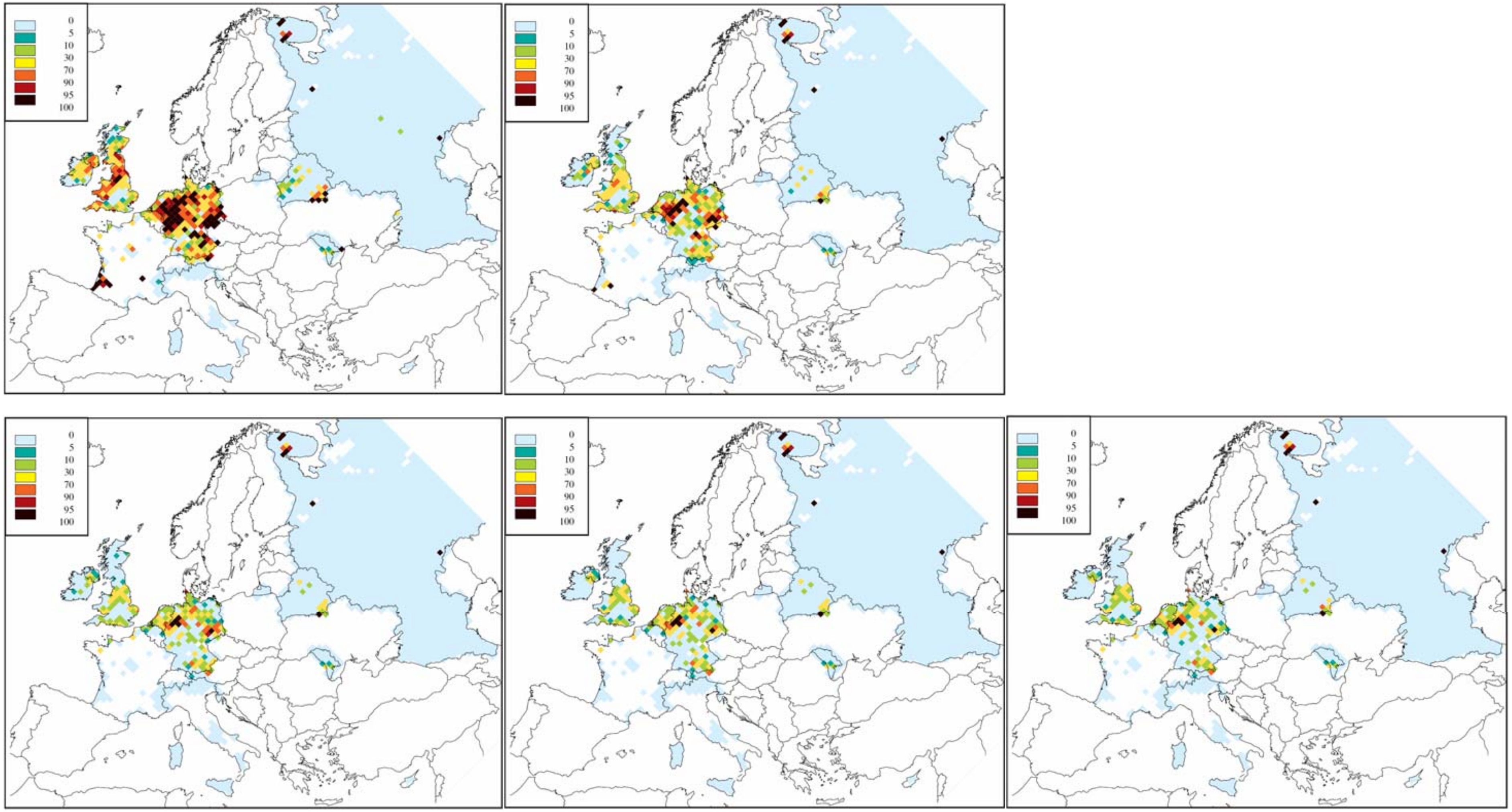

Figure 3.17: Percentage of the area of semi-natural ecosystems receiving acid deposition above the critical loads for the year 2000 (top left graph), the baseline current legislation in 2020 (top right graph), Case “A” (bottom left), Case “B” (bottom centre) and Case “C” (bottom right). Calculation results for the meteorological conditions of 1997, using ecosystem-specific deposition.

3.3.5 Acid deposition to freshwater bodies

In a number of countries critical loads have been estimated for the catchment areas of freshwater bodies (lakes and streams), which in the past experienced significant acidification. The baseline emission projections suggest a significant decline of acid deposition at many of these catchment areas, in many cases even below their critical loads. As indicated above, recovery from acidification requires acid deposition to stay some time below the critical loads.

Table 3.26: Catchments area (km^2) with acid deposition above the critical loads for acidification. Results calculated for 1997 meteorology, using grid-average deposition. Critical loads data base of 2004.

	Ecosystems area [1]	*2000*	*2020* Current legislation	Case "A"	Case "B"	Case "C"	MTFR [2]
Finland	30886	229	201	195	195	195	71
Sweden	204069	30427	21386	18305	17223	16591	10673
UK	7757	625	287	178	151	137	101
EU25	242712	31280	21874	18678	17569	16923	10845

[1] Ecosystems area for which critical loads data have been supplied

[2] Maximum technically feasible emission reductions assumed for all European countries (including non-EU countries)

Table 3.27: Percent of catchments area with acid deposition above the critical loads for acidification. Results calculated for 1997 meteorology, using grid-average deposition. Critical loads data base of 2004.

	Ecosystems area (km^2) [1]	*2000*	*2020* Current legislation	Case "A"	Case "B"	Case "C"	MTFR [2]
Finland	30886	0.7%	0.7%	0.6%	0.6%	0.6%	0.2%
Sweden	204069	14.9%	10.5%	9.0%	8.4%	8.1%	5.2%
UK	7757	8.1%	3.7%	2.3%	2.0%	1.8%	1.3%
EU25	242712	12.9%	9.0%	7.7%	7.2%	7.0%	4.5%

[1] Ecosystems area for which critical loads data have been supplied

[2] Maximum technically feasible emission reductions assumed for all European countries (including non-EU countries)

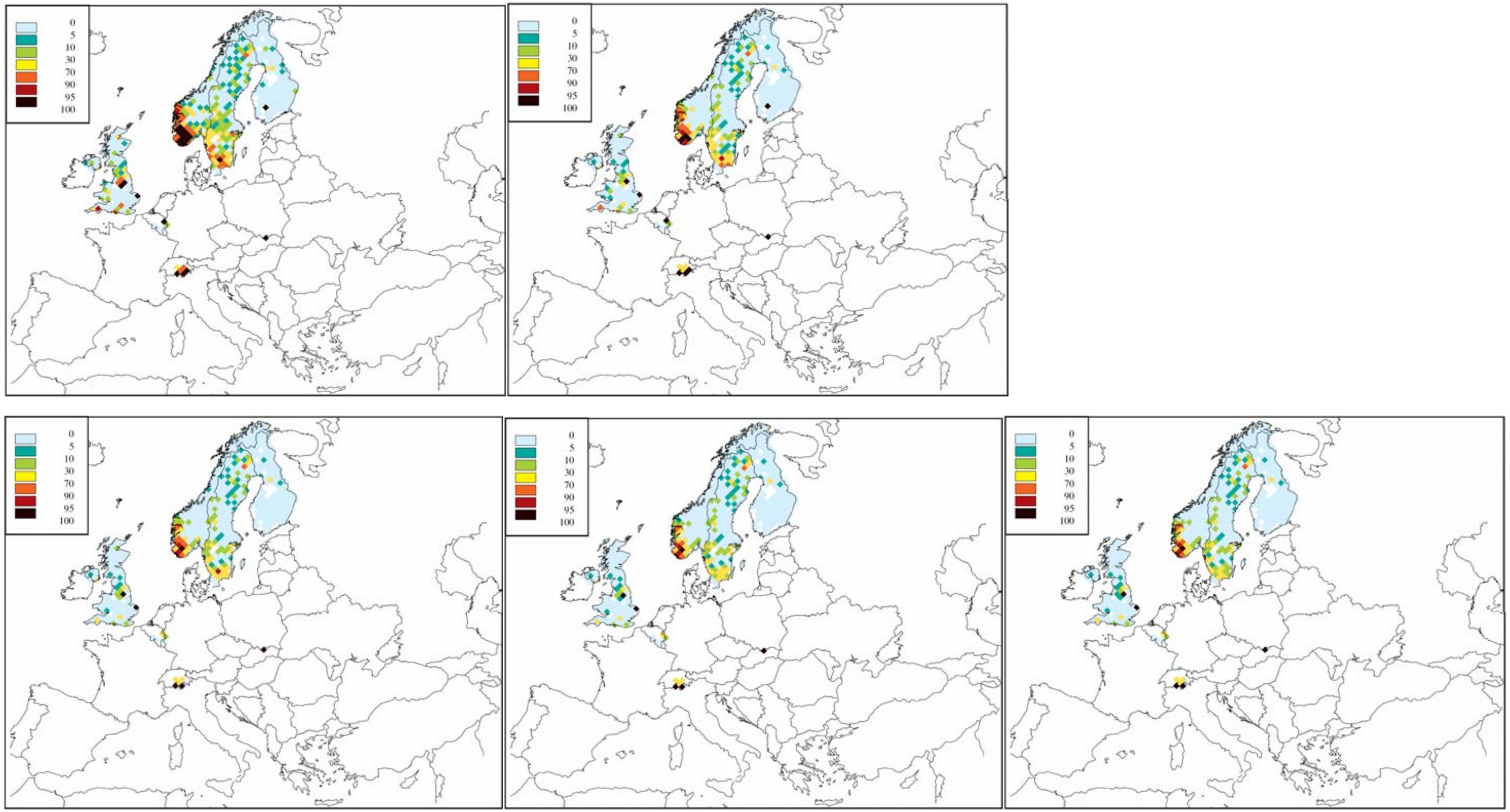

Figure 3.18: Percentage of freshwater ecosystems area receiving acid deposition above the critical loads for the year 2000 (top left graph), the baseline current legislation in 2020 (top right graph). Case "A" (bottom left), Case "B" (bottom centre) and Case "C" (bottom right). Calculation results for the meteorological conditions of 1997, using grid-average deposition.

3.3.6 Health effects attributable to exposure to ground-level ozone

In 2003, the WHO systematic review of health aspects of air quality in Europe confirmed the health relevance of exposure to ozone. The review found that recent epidemiological studies have strengthened the evidence that effects of ozone observed in short-term studies on pulmonary function, lung inflammation, respiratory symptoms, morbidity and mortality are independent of those from other pollutants, in particular in the summer season. It is also stated that controlled human exposure studies confirmed the potential of ozone to cause adverse effects. Some studies also suggest that long-term exposure to ozone reduces lung function growth in children. However, there is little evidence for an independent long-term O_3 effect on lung cancer or total mortality. The review provided convincing evidence that the level of 120 µg/m^3 does not provide protection against a number of severe health outcomes (WHO, 2003). This review concluded that '*there is little evidence from short-term effect epidemiological studies to suggest a threshold at the population level. It should be noted that many studies have not investigated this issue. Long-term studies on lung function do not indicate a threshold either. However, there may well be different concentration-response curves for individuals in the population, since in controlled human exposure and panel studies there is considerable individual variation in response to* O_3 *exposure.*' This question was re-assessed when WHO reviewed additional questions from CAFE and the results were basically confirmed (WHO, 2004). The uncertainties were investigated in greater detail, and it was concluded: '*… in some studies associations with outcomes ranging from mortality to respiratory symptoms have been reported from locations where ozone never exceeds 120 to 160 µg/m*^{3} *as 8-hour average values. Some panel studies suggest small effects on lung function above around 60 to 80 µg/m*^{3} *1-hour average. Our confidence in the existence of associations with health outcomes decreases at concentrations well below these levels as problems with negative correlations with other pollutants and lack of correlation with personal exposure increase but we do not have the evidence to rule them out*.'

The review also concluded that '*… time-series studies find linear or near-linear relationships between day-to-day variations in peak ozone levels and health endpoints down to low levels of exposure. As there are usually many more days with mildly elevated concentrations than days with very high concentrations, the largest burden on public health may be expected with the many days with mildly elevated concentrations, and not with the few days with very high concentrations*.'

Based on these findings from WHO, the UNECE-WHO Task Force on Health "*noted that the AOT60 concept used previously within the RAINS model might no longer be appropriate to account for the effects of ozone on human health in the light of the findings of the review published by the WHO/ECEH Bonn Office. In particular, the WHO review had concluded that effects might occur at levels below 60 ppb, which was the threshold level used to calculate AOT60, and a possible threshold, if any, might be close to background levels and not determinable. This review had also indicated that the effects of ozone on mortality and some morbidity outcomes were independent of those of PM*" (TFH, 2003).

Based on these considerations, the joint WHO/UNECE Task Force at its 7th Meeting developed specific recommendations concerning the inclusion of ozone-related mortality into RAINS. Key points of these recommendations are summarised below:

- The relevant health endpoint is mortality, even though several effects of ozone on morbidity are also well documented and causality established; however, available input data (e.g., on base rates) to calculate the latter on a European scale are often either lacking or not comparable.

- The relative risk for all-cause mortality is taken from the recent meta-analysis of European time-series studies, which was commissioned by WHO and performed by a group of experts from St. George’s Hospital in London, UK (WHO, 2004). The relative risk taken from this study is 1.003 for a 10 µg/m^3 increase in the daily maximum 8-hour mean (CI 1.001 and 1.004).
- In agreement with the recent findings of the WHO Systematic Review, a linear concentration-response function is applied.
- The effects of ozone on mortality are calculated from the daily maximum 8-hour mean. This is in line with the health studies used to derive the summary estimate used for the meta-analysis mentioned above.
- Even though current evidence was insufficient to derive a level below which ozone has no effect on mortality, a cut-off at 35 ppb, considered as a daily maximum 8-hour mean ozone concentration, is used. This means that for days with ozone concentration above 35 ppb as maximum 8-hour mean, only the increment exceeding 35 ppb is used to calculate effects. No effects of ozone on health are calculated on days below 35 ppb as maximum 8-hour mean. This exposure parameter is called SOMO35 (sum of means over 35) and is the sum of excess of daily maximum 8-h means over the cut-off of 35 ppb calculated for all days in a year.

This indicator is based on the application of a very conservative approach to integrated assessment modelling and takes account of the uncertainties in the shape of concentration-response function at very low ozone concentrations. It also reflects the seasonal cycle and geographical distribution of background ozone concentrations, as well as the range of concentrations for which models provided reliable estimates. However, the Task Force noted that it was highly likely that the overall effects of ozone on mortality are underestimated by this approach. Morbidity is not included at this stage.

For assessing ozone exposure in urban areas, urban background concentrations are used in most of the evidential health studies. Therefore, it is regarded as sufficient to use one average ozone concentration per city.

Following this approach, the RAINS model estimates for the year 2000 approximately 21,000 cases of premature death brought forward through exposure to ozone. For 2020, this number is calculated to decline to 17,500, and the CAFE scenarios explore measures to further reduce these numbers below 16,000, 15,700 and 15,500 (Figure 3.19, Table 3.28). While there is uncertainty about the estimated total number due to the critical influence of the assumption made on the cut-off level in the health impact assessment, the changes between these estimates (i.e., 3,500 cases per year less) between 2000 and 2020, and the corresponding changes thereafter for the various CAFE scenarios, are much more robust.

Table 3.28: Estimates of premature deaths attributable to the exposure to ozone (cases per year). These calculations are based on regional scale ozone calculations (50*50 km) and for the meteorological conditions of 1997. A cut-off value of 35 ppb has been applied to the impact assessment.

	2000			*2020*		
		Current legislation	Case "A"	Case "B"	Case "C"	MTFR [1)]
Austria	422	316	287	276	271	220
Belgium	381	345	334	327	322	309
Cyprus	33	32	31	31	30	19
Czech Rep.	535	390	348	333	325	257
Denmark	179	161	153	149	147	126
Estonia	21	22	21	20	20	13
Finland	58	60	56	55	54	39
France	2663	2171	1968	1911	1879	1655
Germany	4258	3316	3053	2951	2892	2535
Greece	627	568	541	531	527	334
Hungary	748	573	510	489	476	300
Ireland	74	79	76	74	74	68
Italy	4507	3556	3324	3240	3193	2583
Latvia	65	65	61	59	58	35
Lithuania	66	64	59	58	57	29
Luxembourg	31	26	24	23	22	20
Malta	22	20	19	18	18	15
Netherlands	416	369	353	345	340	336
Poland	1399	1112	1003	965	942	609
Portugal	450	437	411	399	392	350
Slovakia	239	177	157	150	146	99
Slovenia	112	82	75	72	71	52
Spain	2002	1687	1513	1474	1448	1271
Sweden	197	189	177	173	171	135
UK	1423	1705	1662	1644	1623	1554
EU25	20927	17522	16215	15767	15499	12962

1) Maximum technically feasible emission reductions assumed for all European countries (including non-EU countries)

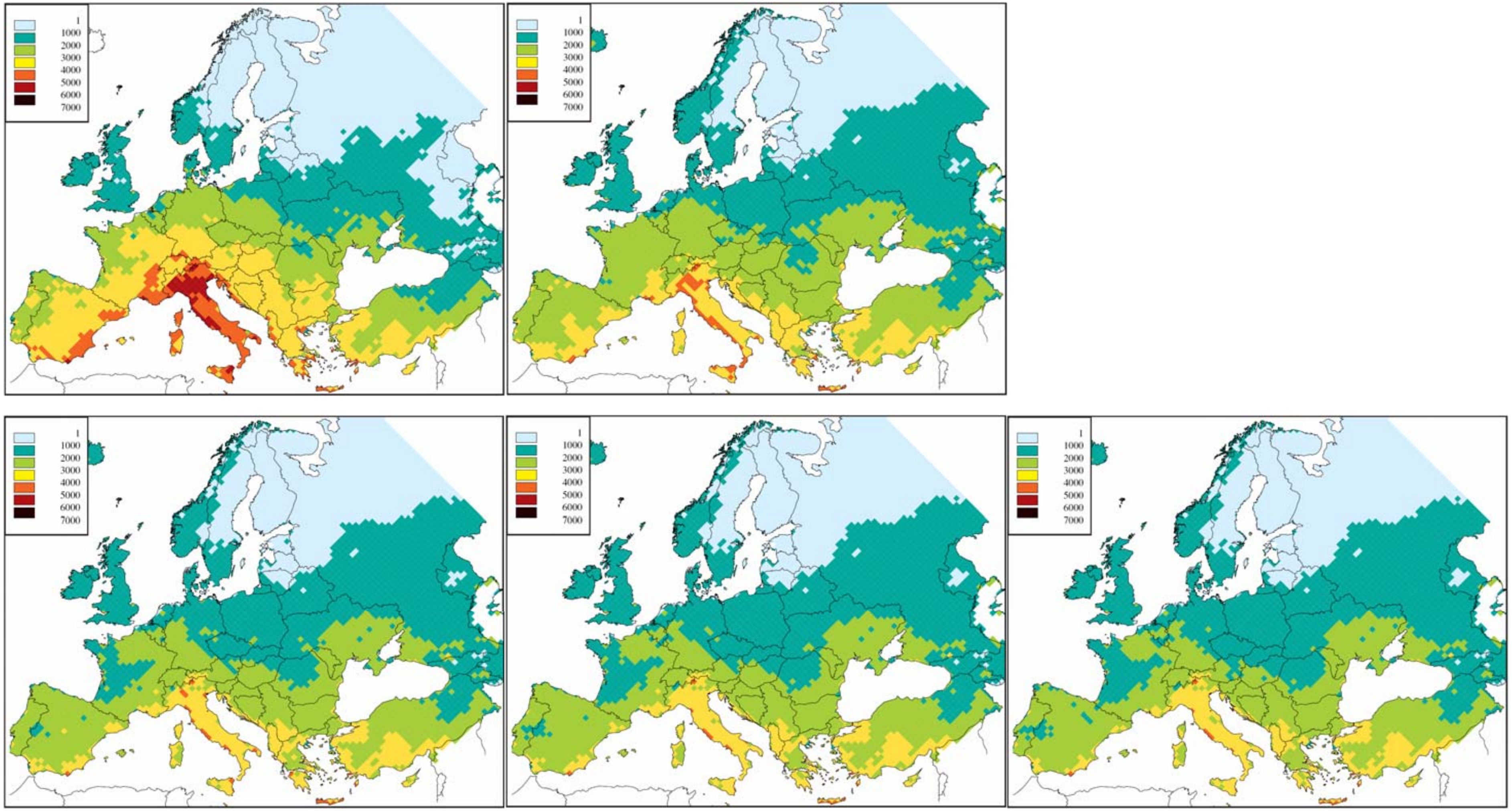

Figure 3.19 Health-relevant ozone exposure expressed as SOMO35 (ppb.days), for the year 2000 (top left graph), the baseline current legislation in 2020 (top right graph). Case “A” (bottom left), Case “B” (bottom centre) and Case “C” (bottom right). Calculation results for the meteorological conditions of 1997.

3.3.7 Vegetation impacts from ground-level ozone

The RAINS model applies the concept of critical levels to quantify progress towards the environmental long-term target of full protection of vegetation from ozone damage. At the UNECE workshop in Gothenburg in November 2002 (Karlsson *et al.*, 2003) it was concluded that the effective ozone dose, based on the flux of ozone into the leaves through the stomatal pores, represents the most appropriate approach for setting future ozone critical levels for forest trees. However, uncertainties in the development and application of flux-based approaches to setting critical levels for forest trees are at present too large to justify their application as a standard risk assessment method at a European scale.

Consequently, the UNECE Working Group on Effects retains in its Mapping Manual the AOT40 (accumulated ozone over a threshold of 40 ppb) approach as the recommended method for integrated risk assessment for forest trees, until the ozone flux approach will be sufficiently refined. However, such AOT40 measures are not considered suitable for quantifying vegetation damage, but can only be used as indicators for quantifying progress towards the environmental long-term targets.

The Mapping Manual defines critical levels for crops, forests and semi-natural vegetation in terms of different levels of AOT40, measured over different time spans. From earlier analyses of ozone time series for various parts of Europe, the critical level for forest trees (5 ppm.hours over the full vegetation period, April 1- September 30 is recommended as default) appears as the most stringent constraint. For most parts of Europe, the critical levels for other types of vegetation (i.e., semi-natural ecosystems and crops) will be automatically achieved if the 5 ppm.hours over six months condition is satisfied. Thus, if used for setting environmental targets for emission reduction strategies, the critical levels for forest trees would imply protection of the other receptors.

For the CAFE baseline projection, the forest area where critical levels are exceeded is computed to decline from 61 percent of the European forests in 2000 to 56 percent in the year 2020. CAFE scenarios explore reaching protection for 48, 50 and 52 percent of the European forest area, respectively (Table 3.29, Table 3.30).

Table 3.29: Forest area (km^2) where the critical levels for ozone are exceeded. Results calculated for 1997 meteorology.

	Ecosystems area [1]	2000	2020 Current legislation	Case "A"	Case "B"	Case "C"	MTFR [2]
Austria	37211	37211	37211	37211	37211	37211	15220
Belgium	5964	5964	5964	5961	5961	5961	5961
Cyprus	1116	1116	1116	1116	1116	1116	124
Czech Rep.	25255	25255	25255	25255	25255	25255	3631
Denmark	2807	2792	2511	2495	2495	2426	517
Estonia	18420	74	0	0	0	0	0
Finland	207003	113	0	0	0	0	0
France	137329	137316	136916	127317	123352	119375	83581
Germany	104559	104559	104411	104403	104372	104372	84169
Greece	21854	21854	21854	21640	21640	21640	5085
Hungary	16451	16451	16451	16451	16451	16451	0
Ireland	2464	2428	458	146	83	65	8
Italy	79743	79743	79743	79743	79743	79743	79049
Latvia	25101	1388	9	9	9	8	0
Lithuania	18901	7116	615	385	30	30	0
Luxembourg	1054	1054	1054	1054	1054	1054	1054
Malta	3	3	3	3	3	3	3
Netherlands	2912	2912	2912	2890	2869	2869	2866
Poland	89100	89100	84715	57734	45827	40147	0
Portugal	27336	27335	27266	25526	23882	20901	8751
Slovakia	20144	20144	20144	13906	11831	9199	8
Slovenia	10724	10724	10724	10724	10724	10724	1779
Spain	104595	104595	104595	104169	100018	97682	57930
Sweden	273144	49808	10134	3564	1686	1686	82
UK	14557	12316	7231	6305	5894	5246	3671
EU25	1247749	761372	701293	648006	621507	603162	353488

1) Ecosystems area for which critical loads data have been supplied

2) Maximum technically feasible emission reductions assumed for all European countries (including non-EU countries)

Table 3.30: Percent of forest area where the critical levels for ozone are exceeded. Results calculated for 1997 meteorology.

	Ecosystems area (km^2) 1)	*2000*	*2020*				
			Current legislation	Case “A”	Case “B”	Case “C”	MTFR 2)
Austria	37211	100%	100%	100%	100%	100%	41%
Belgium	5964	100%	100%	100%	100%	100%	100%
Cyprus	1116	100%	100%	100%	100%	100%	11%
Czech Rep.	25255	100%	100%	100%	100%	100%	14%
Denmark	2807	99%	89%	89%	89%	86%	18%
Estonia	18420	0%	0%	0%	0%	0%	0%
Finland	207003	0%	0%	0%	0%	0%	0%
France	137329	100%	100%	93%	90%	87%	61%
Germany	104559	100%	100%	100%	100%	100%	80%
Greece	21854	100%	100%	99%	99%	99%	23%
Hungary	16451	100%	100%	100%	100%	100%	0%
Ireland	2464	99%	19%	6%	3%	3%	0%
Italy	79743	100%	100%	100%	100%	100%	99%
Latvia	25101	6%	0%	0%	0%	0%	0%
Lithuania	18901	38%	3%	2%	0%	0%	0%
Luxembourg	1054	100%	100%	100%	100%	100%	100%
Malta	3	100%	100%	100%	100%	100%	100%
Netherlands	2912	100%	100%	99%	99%	99%	98%
Poland	89100	100%	95%	65%	51%	45%	0%
Portugal	27336	100%	100%	93%	87%	76%	32%
Slovakia	20144	100%	100%	69%	59%	46%	0%
Slovenia	10724	100%	100%	100%	100%	100%	17%
Spain	104595	100%	100%	100%	96%	93%	55%
Sweden	273144	18%	4%	1%	1%	1%	0%
UK	14557	85%	50%	43%	40%	36%	25%
EU25	1247749	61%	56%	52%	50%	48%	28%

1) Ecosystems area for which critical loads data have been supplied

2) Maximum technically feasible emission reductions assumed for all European countries (including non-EU countries)

3.3.8 Summary on physical benefits

The preceding description highlights the spatial diversity of air pollution damage. Health damage attributable to human exposure to fine particulate matter is highest in the Benelux region and in northern Italy. Largest violations of the ozone health and vegetation criteria are computed for the Mediterranean region, while acidification of lakes remains a problem mainly in Scandinavia and the UK. Acidification of forest soils is wide-spread in central Europe, and excess nitrogen input to terrestrial ecosystems occurs throughout most of the EU-25.

Discussions in the CAFE Working Group on Target Setting and Policy Advice focused on the balance of environmental improvements of further emission control measures across all

Member States. Indeed, the target setting principles adopted for the final CAFE scenario analysis safeguards environmental improvements in all Member States. As an illustration, Figure 3.20 presents for the CAFE Case "B" for each country its share in the overall European improvements of the four impact indicators. For instance, Germany would reap approximately 25 percent of all life years gained in Europe through the emission control measures of this scenario. In addition, it earns approximately eight percent of the European improvement of the eutrophication index (accumulated excess nitrogen deposition), 17 percent of the acidification index and approximately five percent of the avoided cases of premature deaths attributable to ozone. In summary, the graph demonstrates that all Member States receive benefits from the scenario, although different countries for different effects.

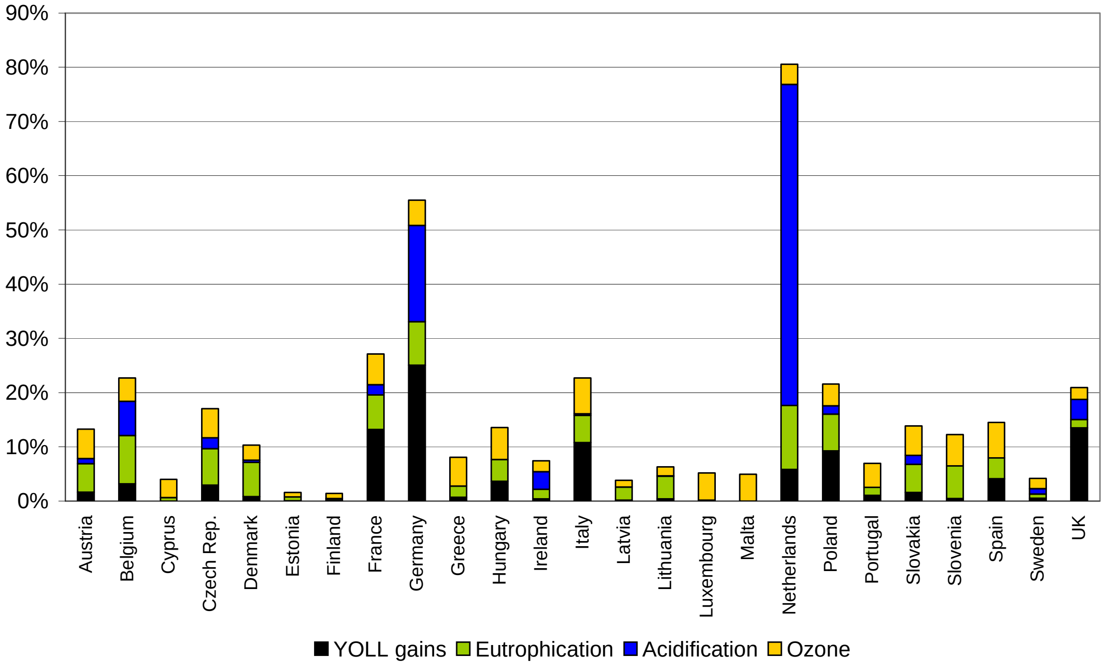

Figure 3.20: Environmental improvements in each Member State (expressed for each country as its share in the total European environmental improvement) achieved by the medium ambition Case "B", added up for the four environmental endpoints.

4 Sensitivity analyses

Insufficient time prevented a full uncertainty assessment of the central CAFE scenarios. However, a number of sensitivity analyses have been carried out to explore the robustness of the model results against variations in some of the most important input assumptions.

4.1 Further emission controls for seagoing ships

As described in Section 2, the central CAFE scenarios assume implementation of the currently decided control measures to reduce emissions from seagoing ships. These include for SO_2 the EU sulphur proposal as per Common Position, i.e., 1.5% sulphur marine fuel oil for all ships in the North Sea and the Baltic Sea; 1.5% sulphur fuel for all passenger ships in the other EU seas; low sulphur marine gas oil; and 0.1% sulphur fuel at berth in ports. For NO_x, implementation of the MARPOL NO_x standards for all ships built since 2000 have been assumed.

A sensitivity case has been analysed to explore the cost-effectiveness of further emission reduction measures for sea-going ships in the context of tightened ambition levels for land-based sources. Optimizations for the three cases of the CAFE scenario analyses have been repeated with the additional assumption that ships would reduce their NO_x emissions further through slide valve retrofits for slow speed engines. For 2020, costs of this measures are estimated at 28 million €/year.

The analysis reveals this option as highly cost-effective for all the three analysed cases. Maintaining the environmental interim targets of Case A, B and C, respectively, implementation of this NO_x control measure would relax costly emission control measures at land-based sources and thereby lead to substantial cost savings (Table 4.1).

Table 4.1: Costs for the sensitivity case with measures for ships compared to the central CAFE scenarios (million €/year)

	CAFE scenario without ship measures	Sensitivity case with "medium ambition" measures for ships			
	Costs for land-based sources	Costs for land-based sources	Costs for ships	Total costs	Cost difference to the central CAFE cases
Case "A"	5923	5783	28	5811	-112
Case "B"	10679	10492	28	10520	-159
Case "C"	14852	14499	28	14527	-325

Table 4.2: Emissions (kt) and control costs (million €/yr) for the central CAFE scenarios and the sensitivity cases with further reductions of ship emissions

			Central CAFE scenario			*Sensitivity case with ships*			
	2000	CLE	“A”	“B”	“C”	“A”	“B”	“C”	MTFR
Emissions									
SO_2	8735	2805	1704	1567	1462	1675	1563	1463	1290
NO_x	11581	5888	4678	4297	4107	4685	4300	4113	3965
VOC	10661	5916	5230	4937	4771	5222	4930	4757	4303
NH_3	3824	3686	2860	2598	2477	2899	2638	2510	2266
PM2.5	1749	964	746	709	683	746	708	679	589
Costs									
SO_2	0	0	800	1021	1477	836	1034	1473	3124
NO_x	0	0	903	2752	4255	887	2736	4215	6352
VOC	0	0	157	573	935	164	583	964	2457
NH_3	0	0	1785	3770	5410	1613	3563	5017	13584
PM2.5	0	0	411	695	908	416	708	962	12335
Mobile sources	0	0	1868	1868	1868	1868	1868	1868	1868
Ships	0	0	0	0	0	28	28	28	28
Total incl. ships	0	0	5923	10679	14852	5811	10520	14527	39748

4.2 The influence of the chosen environmental endpoints on the optimization results

The CAFE scenarios identify sets of emission control measures that simultaneously achieve the environmental targets for the four endpoints of concern (human health effects from PM, acidification, eutrophication and ground-level ozone). Thereby, in a cost-optimized solution each measure is justified by concrete environmental achievements for at least one of these endpoints.

A fundamental question relates to the balance between different target levels for the four endpoints in the joint optimization case. The authors of this report are not aware of an objective procedure for allocating weights to the different environmental endpoints on a purely scientific basis, and a subjective value judgment from decision makers seems unavoidable.

Following the advice from the CAFE Working Group on Target Setting, a four-step procedure was adopted. In a first step, the increase in emission control costs for gradually tightened environmental ambition levels has been identified for each problem individually (see also Figure 3.1). Second, a decision has been taken to give highest priority to improvement of health impacts attributable to the exposure to PM2.5, followed by eutrophication, acidification and ozone. In the third step, based on this principle, three levels of health improvements were identified that could be achieved at costs of approximately 5, 8 and 11 billion €/year, respectively, including the costs for further road transport emission controls (Table 4.3). These levels were chosen (a) to cover the range where emission control costs start to increase sharply, and (b) to span a sufficiently large range of environmental improvement that is feasible within the limits of the model analysis. Step #4 determined for each of the three CAFE cases by how much each of the other environmental impact indicators could be improved. This procedure followed the priority ranking established in the second step, and thus allowed less resources spent for eutrophication than for PM, less for acidification than for eutrophication, and less for ozone than for acidification. Finally, these targets have then been adopted for the central CAFE analysis.

Table 4.3: Emission control costs for the single-effect and multi-effect optimization cases (million €/yr)

	CLE	*Case "A"*	*Case "B"*	*Case "C"*	*MTFR*
PM optimized	0	4976	8079	11424	39720
Eutrophication optimized	0	3937	6840	9892	39720
Acidification optimized	0	3792	5696	8057	39720
O_3 optimized	0	2903	5096	6944	39720
Joint optimization	0	5923	10679	14852	39720

While this procedure follows the priority ranking proposed by the CAFE Working Group on Target Setting and Policy Advice, it does not guarantee that results in a given joint scenario are not driven solely by one single environmental objective. In such a case, further improvements would be possible for the other environmental endpoints at low costs. Furthermore, in such a case the optimal solution would critically depend on the quality of modelling of one environmental problem, while more balanced solutions could deliver more robust results that are driven by joint features of several problems.

To shed light into this question, a further sensitivity analysis explored the environmental drivers that determine the marginal emission reductions in the central CAFE scenarios. For this purpose, two optimizations have been carried out for targets on (i) health impacts attributable to PM only, and (ii) for the other environmental problems (i.e., acidification, eutrophication and health- and vegetation impacts from ozone).

As shown in Figure 4.1, overall emission control costs for the three ambition levels are similar for both cases, with slightly higher costs for the scenario with the ecosystems targets only. It also shows that in both cases additional costs for achieving the targets for the other environmental endpoints would typically range between 15 and 25 percent.

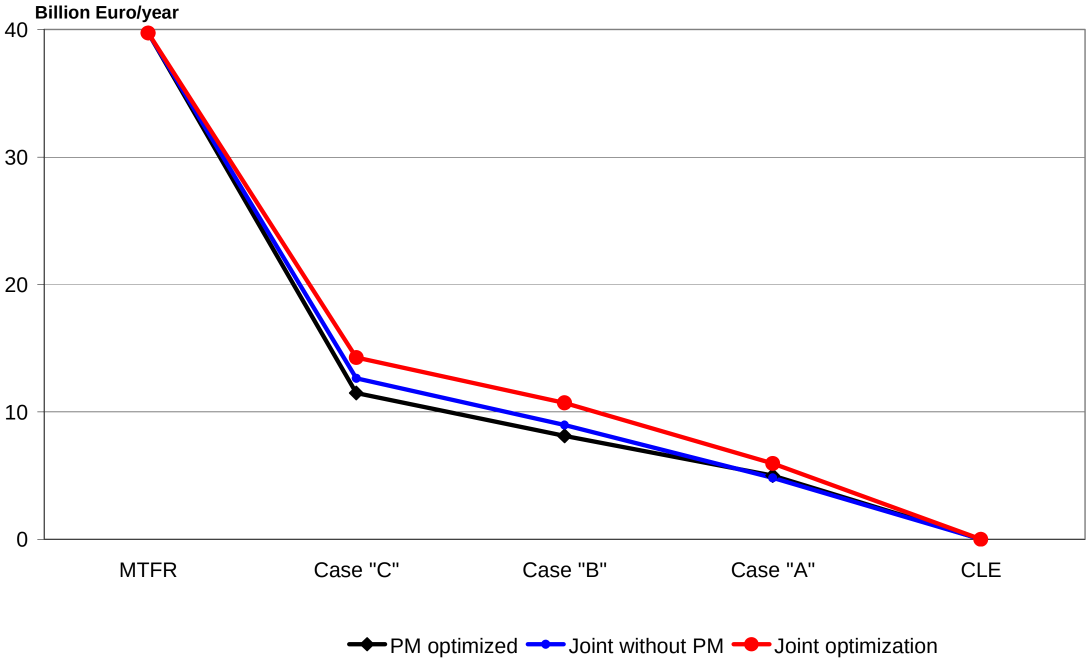

Figure 4.1: Emission control costs for sensitivity cases addressing (i) health impacts from PM only, (ii) the three other environmental endpoints considered in CAFE (i.e., acidification, eutrophication and ground-level ozone) and (iii) the joint optimization for all four endpoints, i.e., the central CAFE scenarios (billion €/year)

While overall emission reduction costs are similar, differences emerge in terms of reduction requirements for individual pollutants. As shown in Figure 4.2, with the chosen target levels a purely health- and PM-driven optimization suggests more emphasis on the reduction of SO_2 emissions - and obviously on PM2.5 emissions - than an ecosystems driven case. In contrast, an ecosystem driven strategy (including ground-level ozone) asks for larger NO_x and VOC reductions. The pressure on NH_3 emissions, however, is very similar in a health and an ecosystems driven case. In summary, it can be stated that in the central CAFE scenarios the stringency of SO_2 and PM2.5 reductions are determined at the margin by the selected health objectives, while ecosystems-related targets (including ozone) control the resulting NO_x and VOC reductions. The required levels of cuts in ammonia emissions are determined by both health and ecosystems targets.

It is interesting to not that the joint optimization asks for more ammonia reductions in the EU-25 as a whole than any of the single-objective optimizations. This is caused by the spatial differences of health and ecosystems impacts. Cost-effective achievement of the health targets require more ammonia reductions in central Europe (Germany, Czech Republic, Poland), the UK and in Italy, while the ecosystems targets imply more stringent ammonia measures in Austria, Denmark, France, Ireland, Spain, Greece, Sweden, Finland. To meet the combined targets in each country requires therefore a wider Europe-wide spread of ammonia reductions than any optimization for a single effect alone.

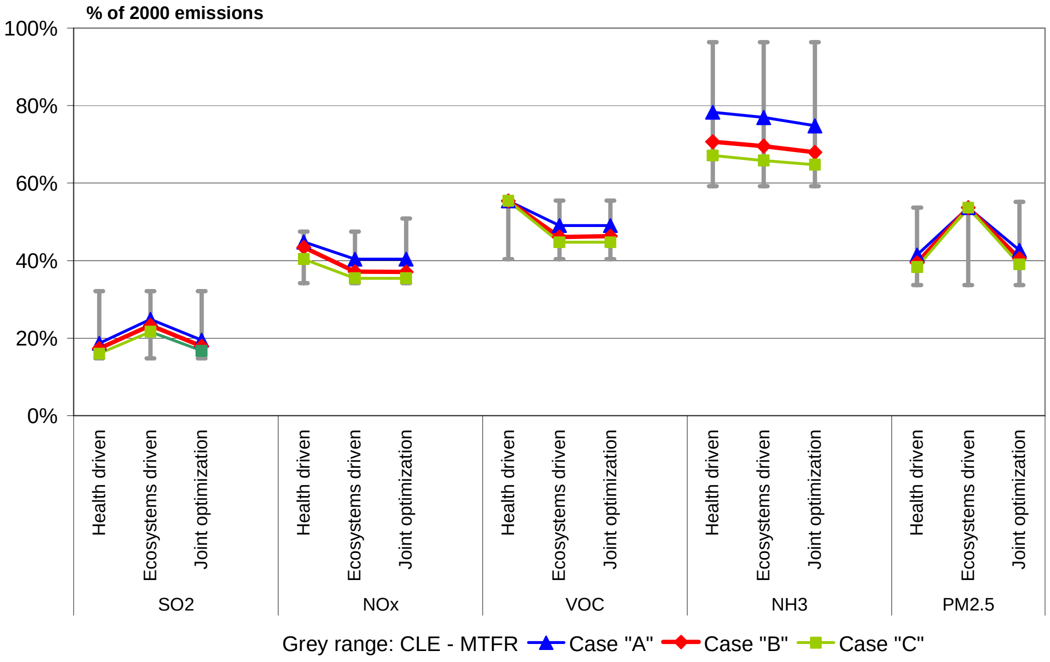

Figure 4.2: Emission reductions (relative to the levels in the year 2000) for the health driven case, the ecosystems driven case and the joint optimization for health and ecosystems targets of the central CAFE scenarios. The grey range indicates the scope for emission reductions between the current legislation baseline case for 2020 and the maximum technically feasible reductions.

4.3 Robustness against alternative health impact theories

One of the key uncertainties in the design of cost-effective strategies for improving health impacts from air pollution is the still imperfect understanding of the exact mechanism that causes damage to human health. The Systematic Review on Health Impacts of Air Pollution conducted by the World Health Organization for the CAFE programme concluded that "the present information shows that fine particles (commonly measured as PM2.5) are strongly associated with mortality and other endpoints such as hospitalization for cardio-pulmonary disease" (http://www.euro.who.int/document/e79097.pdf). There is uncertainty on the specific impacts of different PM components, and numerous hypotheses have been established for a wide range of different components or particle features (e.g., carbonaceous particles, heavy metals, ultra-fine particles, traffic-related particles, etc.). However, as reaffirmed by the joint WHO/UNECE Task Force on Health, "due to the absence of compelling toxicological data about different PM components acting in the complex ambient PM mixture, it was not possible to precisely quantify the relative importance of the main PM components for effects on human health at this stage" (http://www.unece.org/env/documents/2004/eb/wg1/eb.air.wg1.2004.11.e.pdf). Thus, the default approach taken by the RAINS model for quantifying health impacts from PM associates health impacts with the exposure to total PM2.5 mass concentrations, not distinguishing differential potencies of individual components. As a consequence, the RAINS model calculations balance controls for primary and secondary precursor emissions of PM2.5 using their contribution to total PM2.5 mass and their costs as criteria.

To explore the robustness of the optimization results conducted for CAFE, a sensitivity run was carried out based on the hypothesis that only anthropogenic primary particles contribute to health impacts, while secondary inorganic aerosols resulting from SO_2, NO_x and NH_3 emissions would not cause health impacts (Figure 4.3). It should be noted that this hypothesis is not supported by the WHO advice to the CAFE programme and is solely carried out to test the robustness of RAINS optimization results against one important uncertainty.

Because relative risk factors applicable to the exposure to primary PM only are not available, it is impossible to quantify health impacts based on such a hypothesis. Therefore the sensitivity analysis adopted the assumption that a linear concentration-response function would be applicable for the alternative theory in the same way as for the central "total PM2.5 mass" hypothesis. Thereby, the environmental target of improving health impacts (in terms of life years lost) by a certain percentage related to the baseline situation can be converted into a target of reducing ambient PM2.5 concentrations by a given percentage – either including all computed PM components or only those originating from primary particles from anthropogenic sources.

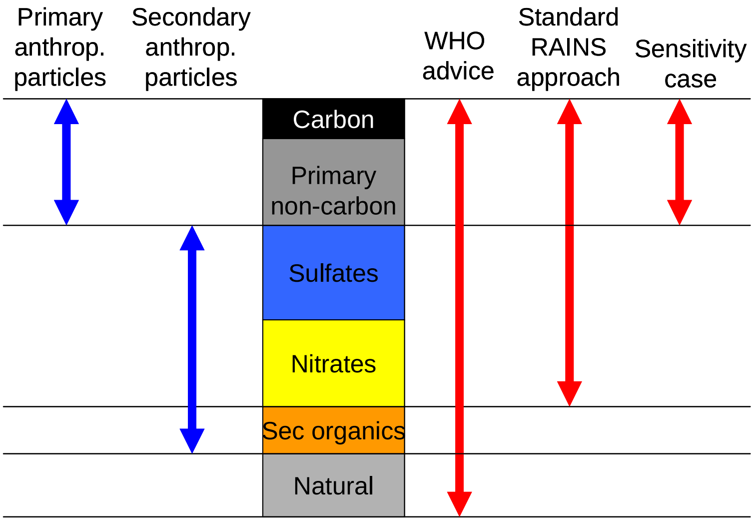

Figure 4.3: Components of PM and how they are associated with health impacts according to the advice from the WHO Systematic Review, the standard approach used by RAINS for the CAFE calculations and the sensitivity case.

With this concept, a single-effect sensitivity analysis has been carried out with the RAINS model aiming at *health impacts only*. In such a case the assumption that only primary PM emissions from anthropogenic sources are associated with health impacts relieves all needs for taking measures to reduce the precursor emissions of secondary inorganic aerosols, i.e., of SO_2, NO_x and NH_3. Consequently, emission control costs would drop sharply, between 25 and 45 percent depending on the level of environmental ambition (Table 4.4, Figure 4.4 left columns, Figure 4.5).

Table 4.4: Emission control costs in the EU-25 for scenarios optimized for health impacts, sensitivity case assuming health impacts from anthropogenic primary emissions of PM only compared with the standard approach (million €/year)

	Sensitivity case: Health impacts from primary PM only			*Standard approach*		
	CASE "A"	Case "B"	Case "C"	CASE "A"	Case "B"	Case "C"
SO_2	0	0	0	885	1265	1911
NO_x	0	0	0	168	511	1597
NH3	0	0	0	1489	3598	5005
VOC	0	0	0	0	0	0
PM2.5	492	1398	3632	565	837	1045
Mobile sources	1868	1868	1868	1868	1868	1868
Total	2360	3266	5500	4974	8079	11425

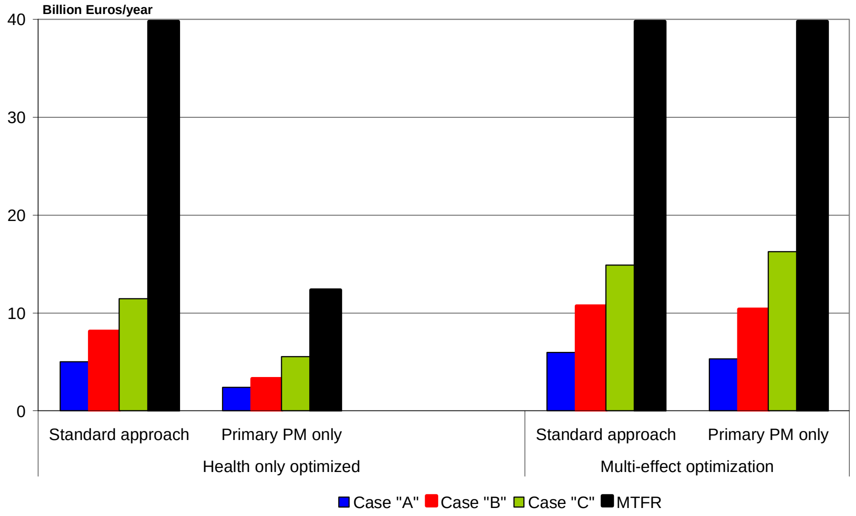

Figure 4.4: Emission control costs in the EU-25 for the health optimized (left columns) and the multi-effect (right columns) scenarios, sensitivity case assuming health impacts from anthropogenic primary emissions of PM only compared with the standard approach (billion €/year)

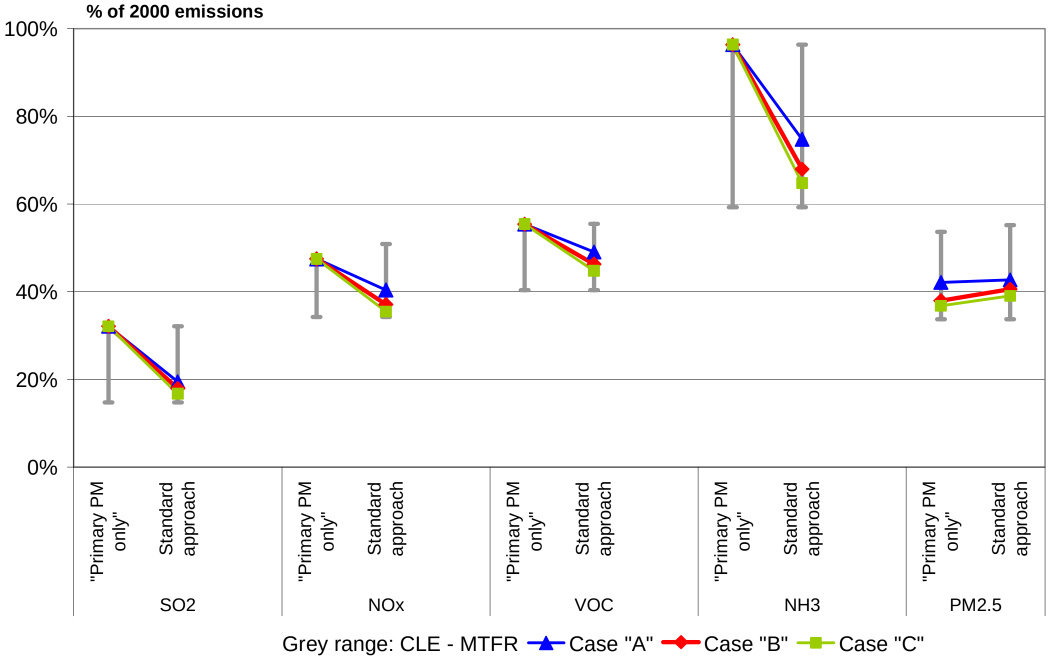

Figure 4.5: Emission levels in the EU-25 relative to the levels in the year 2000 optimized for the "health only" environmental targets. The grey range indicates the scope of emissions in the year 2020 between the baseline projection and the maximum technically feasible reductions. The left bars indicate the reductions resulting from the hypothesis that only primary emissions of PM2.5 contribute to health impacts, while the right columns provide for comparison the results from the standard approach assuming that inorganic aerosols also contribute to health impacts.

In reality, the CAFE assessment explores emission control strategies that contribute to a wider range of air pollution effects, considering acidification, eutrophication and ozone in addition to the health impacts from PM. If emission reductions were optimized for these multiple environmental effects jointly, the modified assumption on the impact mechanism of fine particles would only slightly change the balance of emission controls across pollutants compared to the standard approach (Figure 4.4 right column, Table 4.5). For most countries, to reach the multiple environmental targets, measures for reducing precursor emissions of secondary inorganic aerosols need to be taken to control acidification, eutrophication and ozone, while cuts in primary emissions of PM2.5 are required to improve human health impacts. Differences occur only in some Mediterranean countries, where no further SO_2 reductions are required to control acidification. To compensate for the associated increase in ambient PM2.5 concentrations, tighter measures on primary emissions of PM2.5 are necessary (Figure 4.6).

Table 4.5: Emission control costs in the EU-25 for the multi-effect scenarios, sensitivity case assuming health impacts from anthropogenic primary emissions of PM only compared with the standard approach (million €/year)

	Sensitivity case: Health impacts from primary PM only			*Standard approach*		
	CASE "A"	Case "B"	Case "C"	CASE "A"	Case "B"	Case "C"
SO_2	383	533	740	800	1021	1477
NO_x	907	2725	4240	903	2752	4255
NH3	1477	3226	4815	1785	3770	5410
VOC	152	585	940	157	573	935
PM2.5	492	1398	3632	411	695	908
Mobile sources	1868	1868	1868	1868	1868	1868
Total	5280	10335	16236	5923	10679	14852

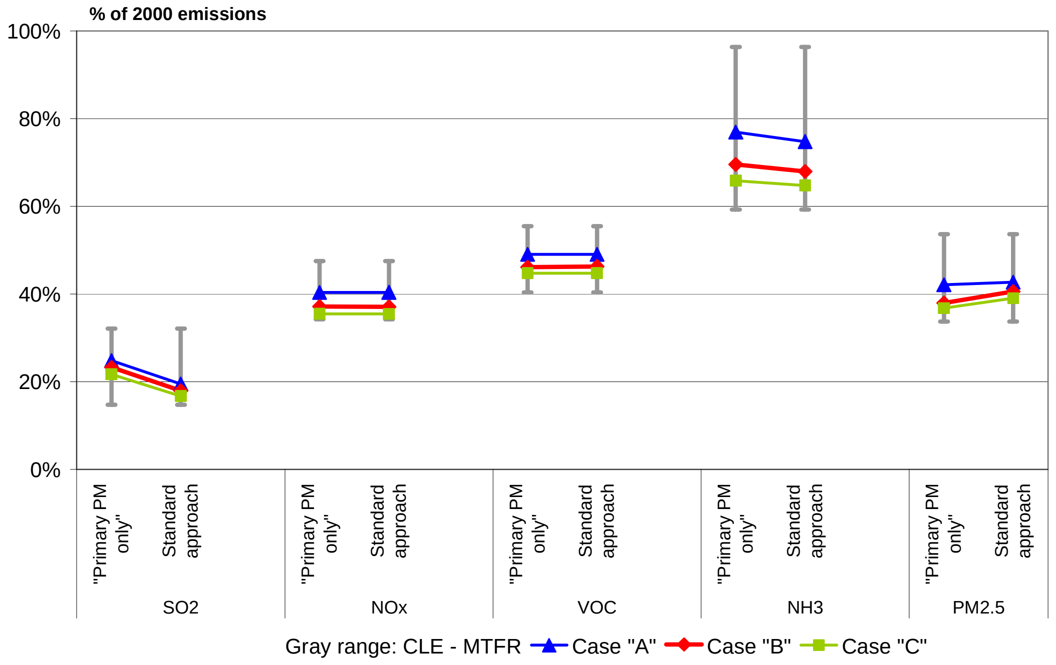

Figure 4.6: Emission levels in the EU-25 relative to the levels in the year 2000 optimized for the multi-effect environmental targets. The gray range indicates the scope of emissions in the year 2020 between the baseline projection and the maximum technically feasible reductions. The left bars indicate the reductions resulting from the hypothesis that only primary emissions of PM2.5 contribute to health impacts, while the right columns provide for comparison the results from the standard approach assuming that inorganic aerosols also contribute to health impacts.

4.4 Excluding further emission reductions from road vehicles

As advised by the CAFE Group on Target Setting and Policy Advice, the central CAFE policy scenarios assume for all Member States the implementation of a package with further measures to cut road transport emissions, especially from diesel light duty and diesel heavy duty vehicles. Detailed assumptions on emission removal efficiencies, costs and implementation dates are provided in Amann *et al*., 2005 (http://www.iiasa.ac.at/rains/CAFE_files/CAFE-C-full-march16.pdf).

To explore the cost-effectiveness of the assumed road measures package, a sensitivity analysis has been conduced for the same environmental targets of the central CAFE scenarios under the assumption that no further measures for road sources were implemented. To compensate for the missing reductions from mobile sources, stationary sources would have to reduce emissions further.

The optimization analysis reveals that, given the assumptions on technical feasibility of further emission controls, stationary sources could only compensate the missing emission reductions from road sources in the least ambitious Case "A". In such a case, overall emission control costs would increase from 5.9 to 6.1 billion €/year. For mobile sources, costs decline from 1.9 billion €/year to nil, while costs for stationary sources would increase by 2.1 billion €/year from 4.0 to 6.1 billion €/year (Table 4.6). It should be noted that, while the assumed package of road measures affects emissions of NO_x and PM, measures for all five pollutants released by stationary sources are required to compensate for the shortfall. Largest increases in costs emerge for the control of NO_x emissions. Furthermore, in many cases the missing reductions from mobile sources need to be compensated by even larger cuts from stationary sources, owing to the fact that road emissions have a more direct impact on PM2.5 concentrations in cities than emissions from stationary sources with high stacks.

For the environmental ambition level chosen for Case "A", the exclusion of further emission reductions for diesel road vehicles implies highest additional costs for the power sector (approximately 750 million €/year, which is more than tripling the costs of the central case) and for industrial sources (+660 million €/year), see Table 4.8 and Table 4.7. Figure 4.7 and Figure 4.8 compare emission reduction requirements for the Member States.

Achievement of the environmental objectives established for the Cases "B" and "C" does not appear to be feasible without the measures for diesel vehicles, even if all stationary sources adopt all technically available emission control measures as assumed in the MTFR scenario at a cost of 40 billion €/year.

Table 4.6: Emissions (kt) and control costs (million €/yr) for the central CAFE scenarios and the sensitivity cases without the package on further road measures

			Central CAFE scenario			*Sensitivity case without the package with further road measures*			
	2000	CLE	"A"	"B"	"C"	"A"	"B"	"C"	MTFR
Emissions									
SO_2	8735	2805	1704	1567	1462	1650	1290	1290	1290
NO_x	11581	5888	4678	4297	4107	4763	4353	4353	4353
VOC	10661	5916	5230	4937	4771	4978	4303	4303	4303
NH_3	3824	3686	2860	2598	2477	2826	2266	2266	2266
PM2.5	1749	964	746	709	683	765	616	616	616
Costs									
SO_2	0	0	800	1021	1477	872			3124
NO_x	0	0	903	2752	4255	2402			6352
VOC	0	0	157	573	935	386			2457
NH_3	0	0	1785	3770	5410	2025			13584
PM2.5	0	0	411	695	908	472			12335
Mobile sources	0	0	1868	1868	1868	0			1868
Total	0	0	5923	10679	14852	6158			39720

Table 4.7: Sectoral emission control costs for the Case "A" central CAFE scenarios assuming the implementation of further road measures and the sensitivity case without further road measures (million €/year)

	Central CAFE scenario, assuming implementation of further road measures	*Sensitivity case without the package of further road measures*
Conversion and waste treatment	393	592
Domestic	373	615
Industry	1167	1825
Power plants	307	1053
Agriculture	1752	1983
Transport (road and inland shipping)	1932	90
Total	***5923***	**6158**

Table 4.8: Sectoral emission reductions and control costs for the Case “A” central CAFE scenarios assuming the implementation of further road measures and the sensitivity case without further road measures

	Central CAFE scenario, assuming implementation of further road measures		*Sensitivity case without the package of further road measures*	
	Emissions removed (kt)	Emission control costs (million €/year)	Emissions removed (kt)	Emission control costs (million €/year)
SO_2				
Conversion	325	203	352	233
Domestic	23	12	23	12
Industry	191	177	200	188
Power plants	199	138	199	138
Industrial processes	261	204	264	209
Transport	4	3	4	3
Waste	98	64	113	90
Sum	*1102*	*800*	*1156*	*872*
NOx				
Conversion	118	155	154	322
Domestic	10	23	56	189
Industry	284	311	364	625
Power plants	112	149	225	895
Industrial processes	286	261	314	366
Transport	12	4	13	6
Waste	388	1868	0	0
Sum	*822*	*2771*	*1125*	*2402*
PM2.5				
Conversion	3	6	3	7
Domestic	70	316	77	373
Industry	4	8	4	9
Other	3	4	3	4
Power plants	22	20	22	20
Industrial processes	49	52	49	55
Transport	26	0	0	0
Waste	42	4	42	4
Sum	*218*	*411*	*200*	*472*
NH_3				
Other cattle	44	213	57	349
Dairy cows	122	544	133	591
Fertilizer use	275	240	275	239
Other animals	2	12	2	12
Pigs	110	328	117	375
Poultry	267	414	268	417
Industrial processes	5	33	6	41
Sum	*826*	*1784*	*859*	*2025*
VOC				
Coatings	183	76	306	198
Conversion	80	29	87	31
Domestic	5	6	10	23
Industrial processes	219	7	242	10
Solvents	156	34	240	119
Waste	42	4	53	6
Sum	*685*	*157*	*938*	*386*

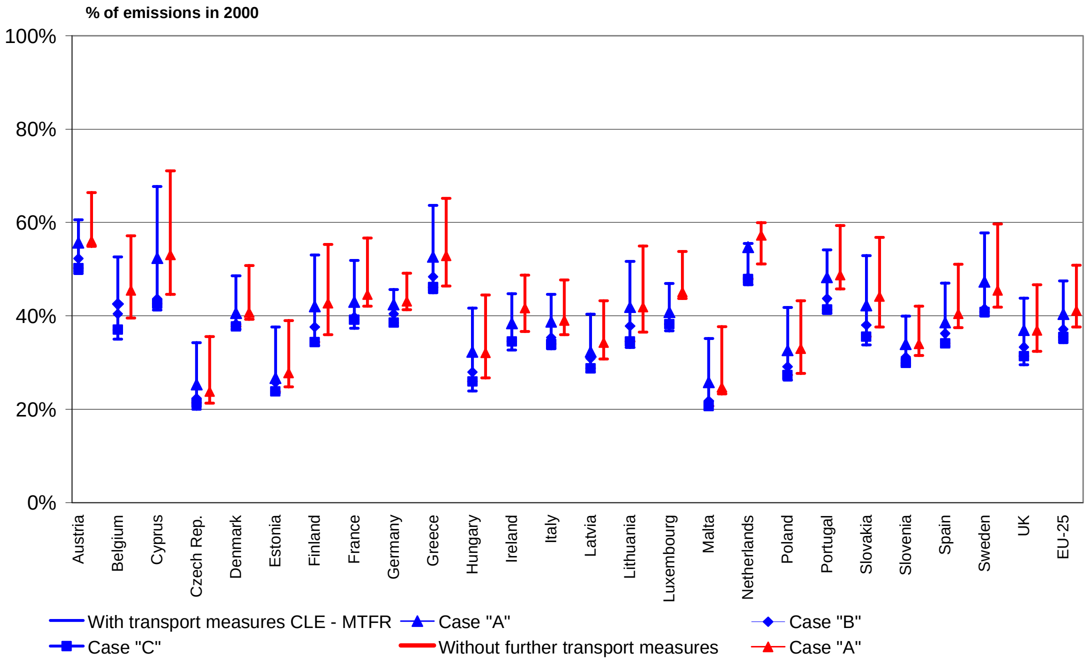

Figure 4.7: NO_x emissions for the CAFE environmental objectives, optimized with the package of further road measures (blue bars) and without the road measures package (red lines), relative to the emissions of the year 2000 (=100%)

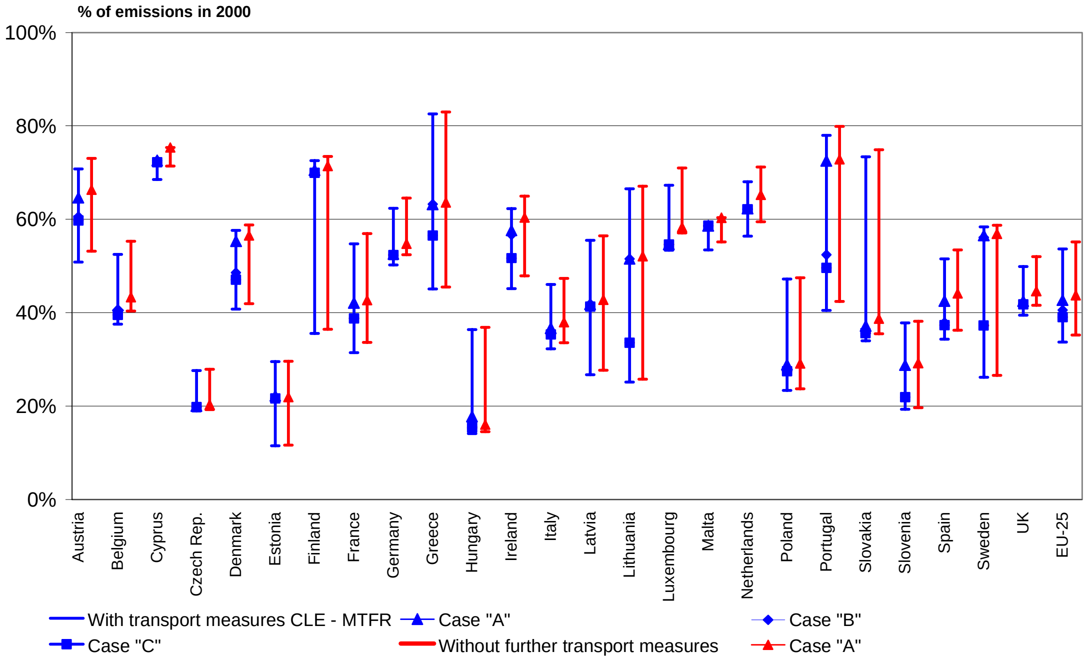

Figure 4.8: PM2.5 emissions for the CAFE environmental objectives, optimized with the package of further road measures (blue bars) and without the road measures package (red lines), relative to the emissions of the year 2000 (=100%)

4.5 Alternative energy and agricultural projections

The central CAFE scenarios are based on projections of future energy demand developed by the PRIMES energy model and of agricultural activities compiled from a variety of databases. These projections reflect a Europe-wide consistent perspective on future economic development and trades between Member States. Individual Member States or industrial sectors might have different perspectives.

A sensitivity analysis was carried out to explore to what extent the emission reductions derived from the RAINS optimization on the basis of the default projections are robust against alternative perspectives on future economic development. 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 (see also Amann *et al.*, Baseline Scenarios for the Clean Air for Europe (CAFE) Programme, 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 Slovenia, the national projections even surpass the CO_2 emissions of the “without climate measures” scenario of the PRIMES model, which reflects business-as-usual as outlined in the Energy and Transport Outlook 2030 of the Directorate General for Energy and Transport, where no constraints on greenhouse gas emissions have been assumed (Figure 4.9).

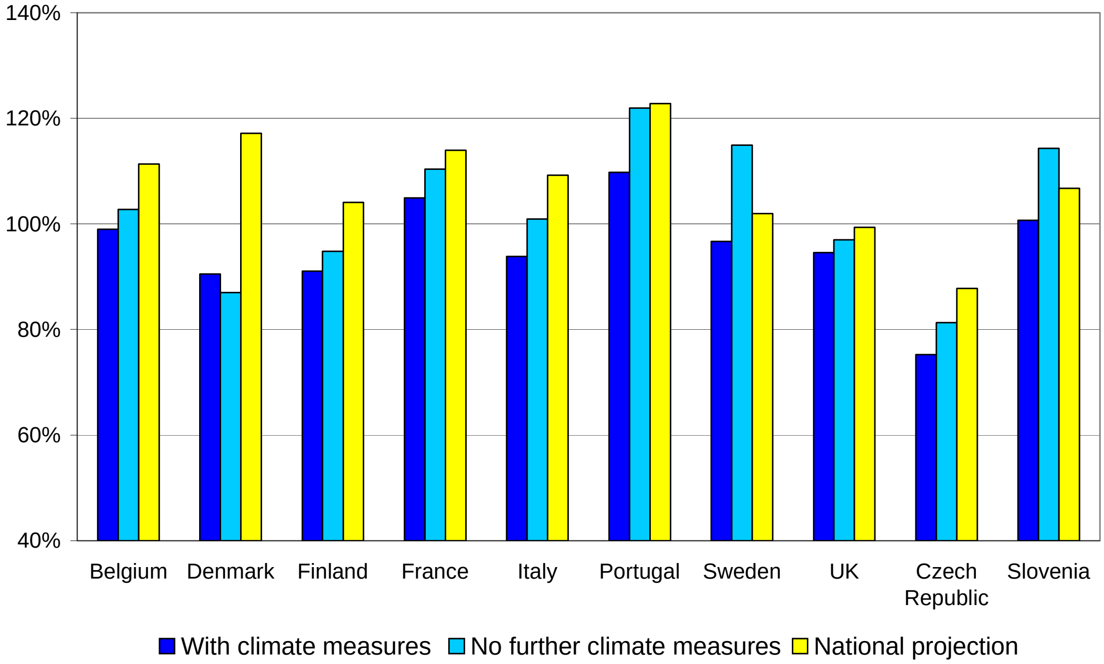

Figure 4.9: CO_2 emissions of the national energy projections (yellow bars) compared to the PRIMES projections with and without further climate measures, relative to the year 2000

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 4.10 to Figure 4.13 display the differences for the “current legislation” baseline emissions for the year 2010 (note, however, that the optimization analysis is carried out for 2020).

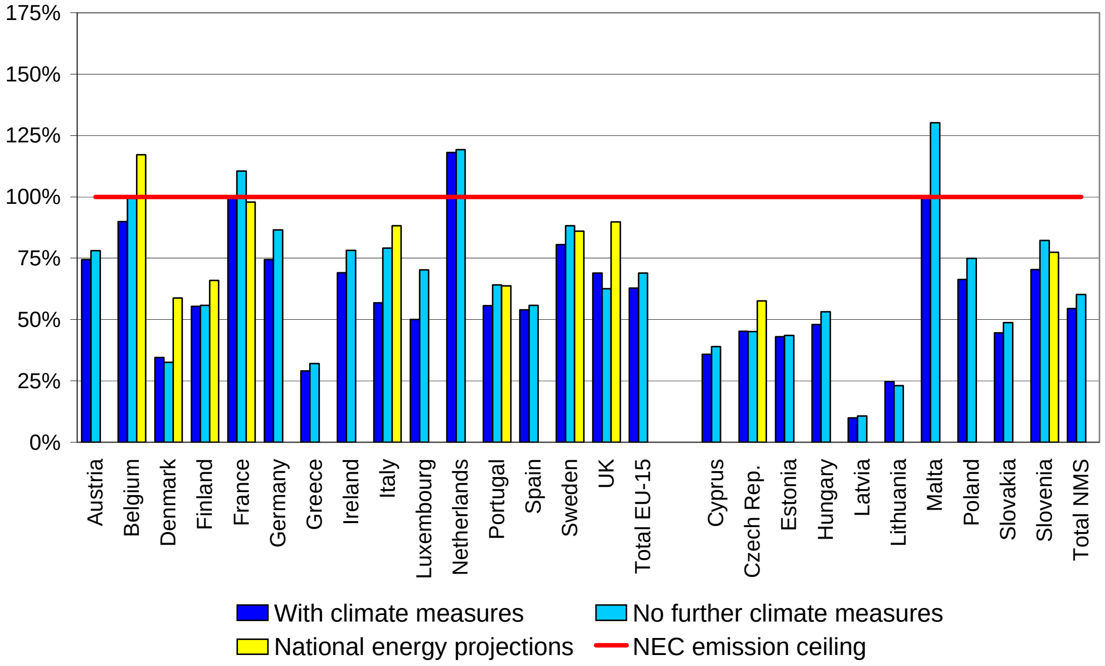

Figure 4.10: Estimated SO_2 emissions for 2010 compared with the emission ceilings for SO_2

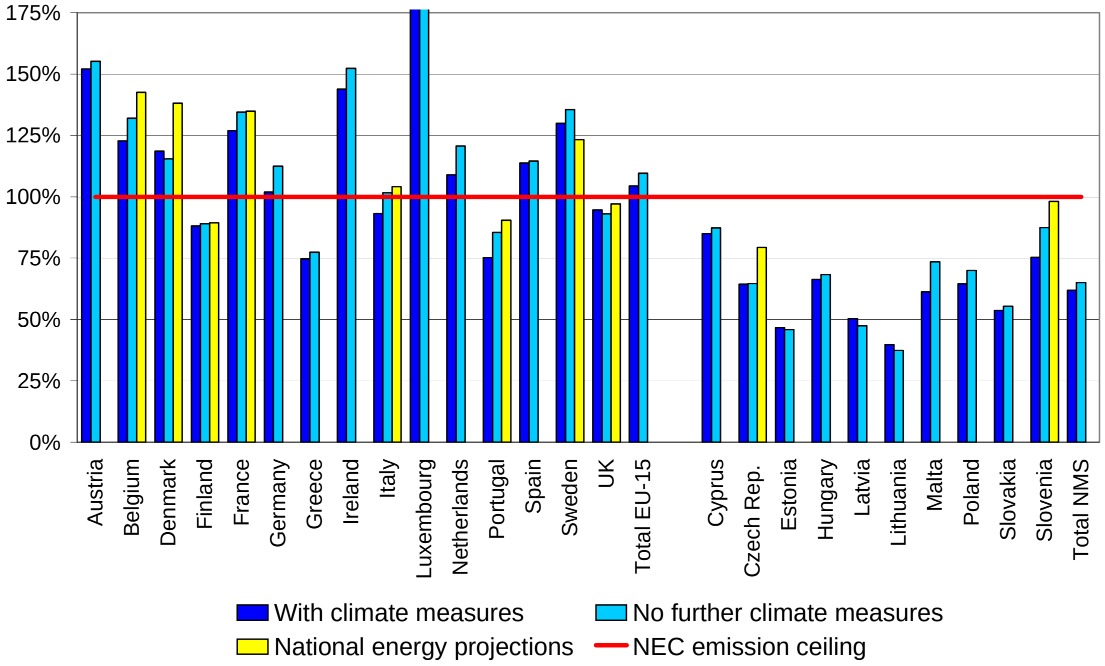

Figure 4.11: Projected NO_x emissions for the year 2010 compared with the national emission ceilings

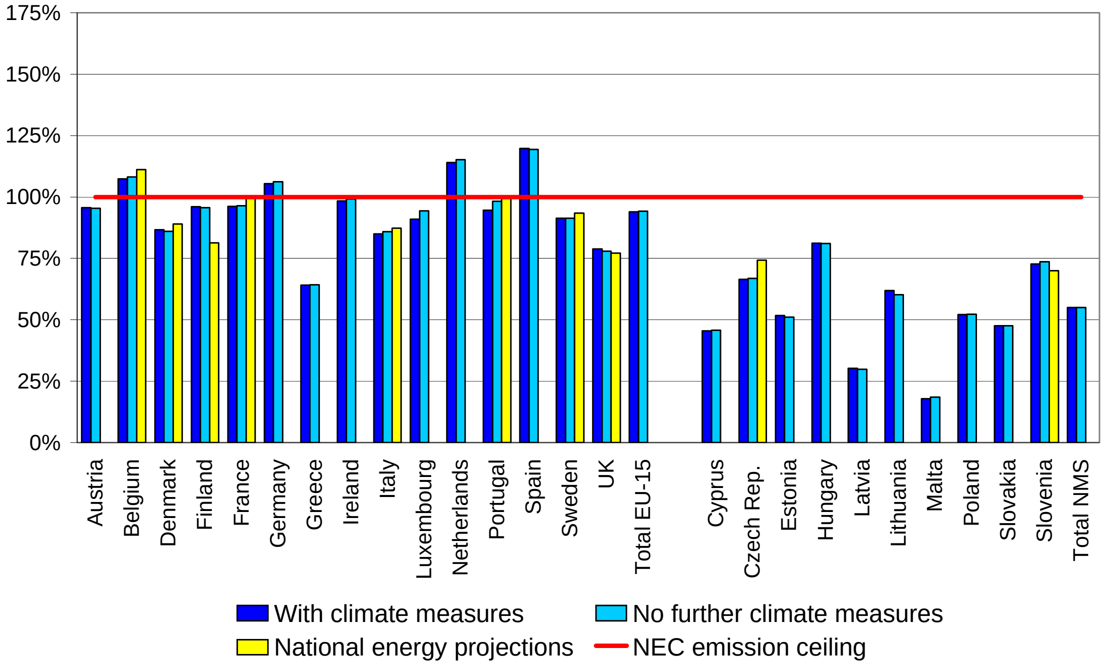

Figure 4.12: Projected VOC emissions for the year 2010 compared with the national emission ceilings

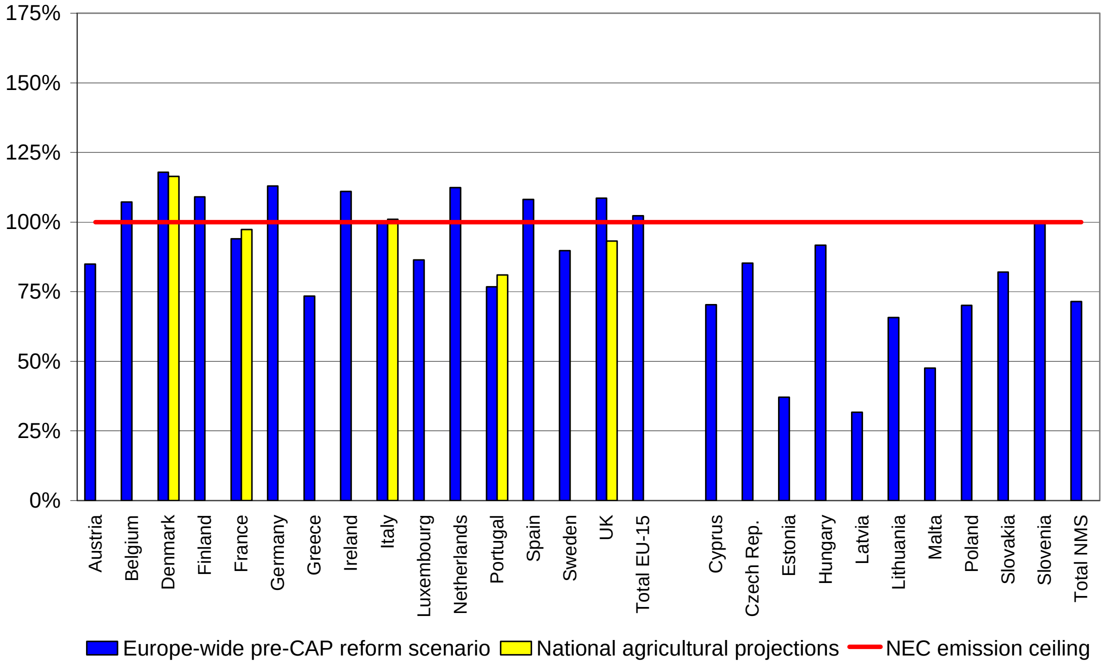

Figure 4.13: Projected NH_3 emissions for the year 2010 compared with the national emission ceilings, for the EU-15

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. The analysis addressed two questions:

- How robust are optimized emission reductions in view of alternative projections on energy consumption and agricultural activities? In other words, how would emission reductions derived from a particular projection change for another projection? Or, how could optimized emission reductions change if another energy and agricultural projection would be used?
- Given that the optimization has been carried out for a particular energy and agricultural projection, what can one say about the feasibility of calculated reductions if energy and agricultural development would develop differently?

To explore these questions, the CAFE optimization has been repeated with the cost curves resulting from the national energy and agricultural projections for the countries which have submitted such data. For all other countries the "with further climate measures" baseline scenario has been applied. The optimization analysis then identified the cost-minimal allocation of emission control measures for the recomputed environmental targets of the central CAFE scenario. 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.

A comparison with the costs of the "with climate measures" scenario (Table 4.9) reveals that for this particular sensitivity analysis the achievement of the environmental targets derived from the same target setting principles involves lower costs for the low ambition (Case A) scenario, but higher costs for the medium (Case B) and high (Case C) ambition levels (Table 4.10).

Table 4.9: Costs of the single-effect and joint optimization runs based on the national energy and agricultural projections (million €/year)

	Policy scenarios			
	Case "A"	Case "B"	Case "C"	MTFR
PM optimized	4897	11280	21570	40216
Eutrophication optimized	1778	4310	7118	40216
Acidification optimized	1779	3630	5652	40216
Ozone optimized	949	3131	5078	40216
Joint optimization	5395	12310	22990	40216

Table 4.10: Costs of the single-effect and joint optimization runs based on the PRIMES CAFE baseline energy projections (million €/year)

	Policy scenarios			
	Case “A”	Case “B”	Case “C”	MTFR
PM optimized	4976	8079	11424	39720
Eutrophication optimized	3937	6840	9892	39720
Acidification optimized	3792	5696	8057	39720
O_3 optimized	2903	5096	6944	39720
Joint optimization	5923	10679	14852	39720

Emission reductions for individual countries and pollutants are displayed in Figure 4.14 to Figure 4.18. These graphs compare for the two alternative projections the resulting scopes for further emission reductions between the current legislation (baseline) and maximum technically feasible reductions. The range implied by the PRIMES projections is indicated in blue, and for the national projections in red. Because many national energy projections assume higher coal consumption than the PRIMES scenario (which assumes a carbon price of 20 €/t CO_2), the reduction potential, especially for SO_2 emissions, is smaller in many national projections. Consequently, in some cases the SO_2 emission levels that have been optimized on the basis of the PRIMES energy projections are beyond the technical feasibility if the coal consumption that is foreseen in the (pre-Kyoto) national energy projections materialized. With very few exceptions, this situation does not occur for other pollutants. Thus, the uncertainty on the future levels of coal consumption will be crucial for developing robust emission reduction targets, especially for SO_2.

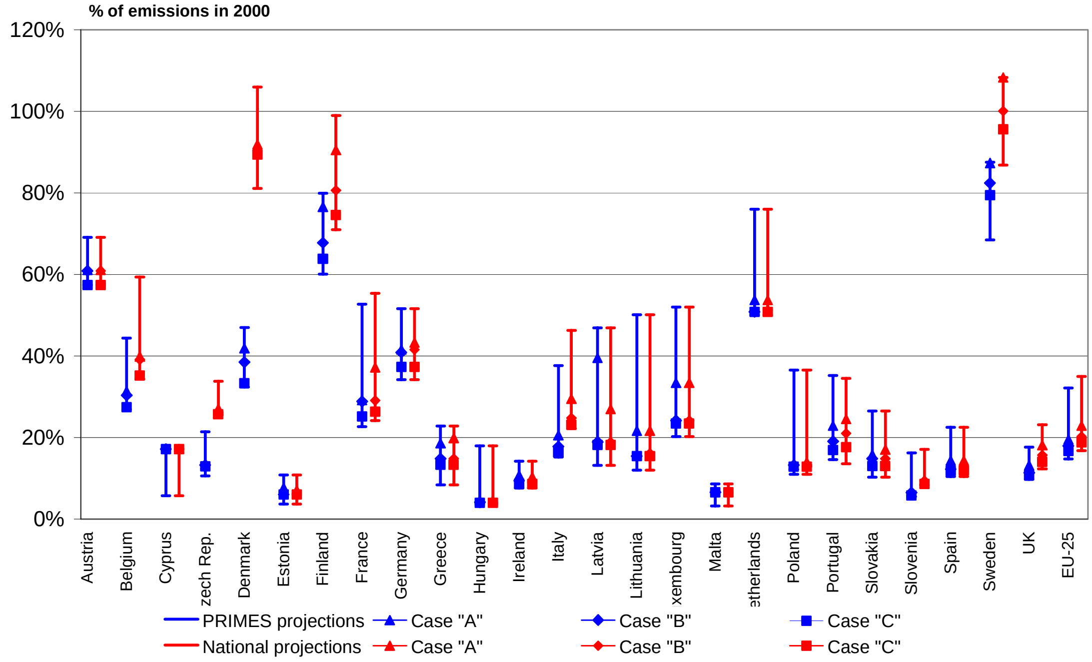

Figure 4.14: SO_2 emissions optimized for the CAFE environmental objectives, for the PRIMES energy projections and for the national energy and agricultural projections, relative to the emissions of the year 2000 (=100%)

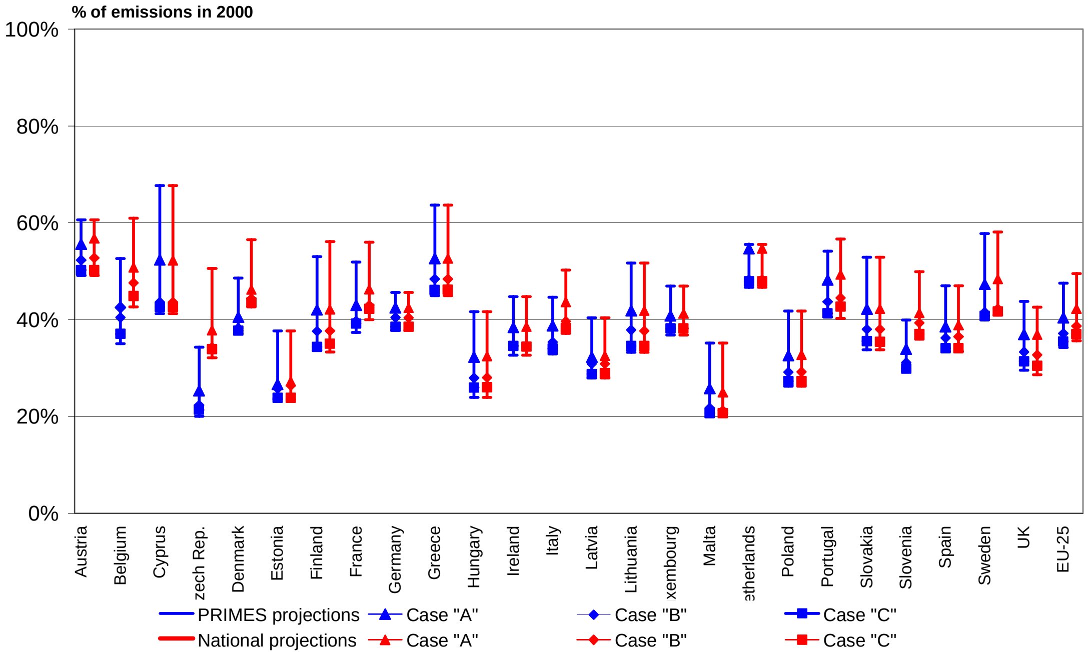

Figure 4.15: NO_x emissions for the CAFE environmental objectives, optimized for the PRIMES energy projections and for the national energy and agricultural projections, relative to the emissions of the year 2000 (=100%)

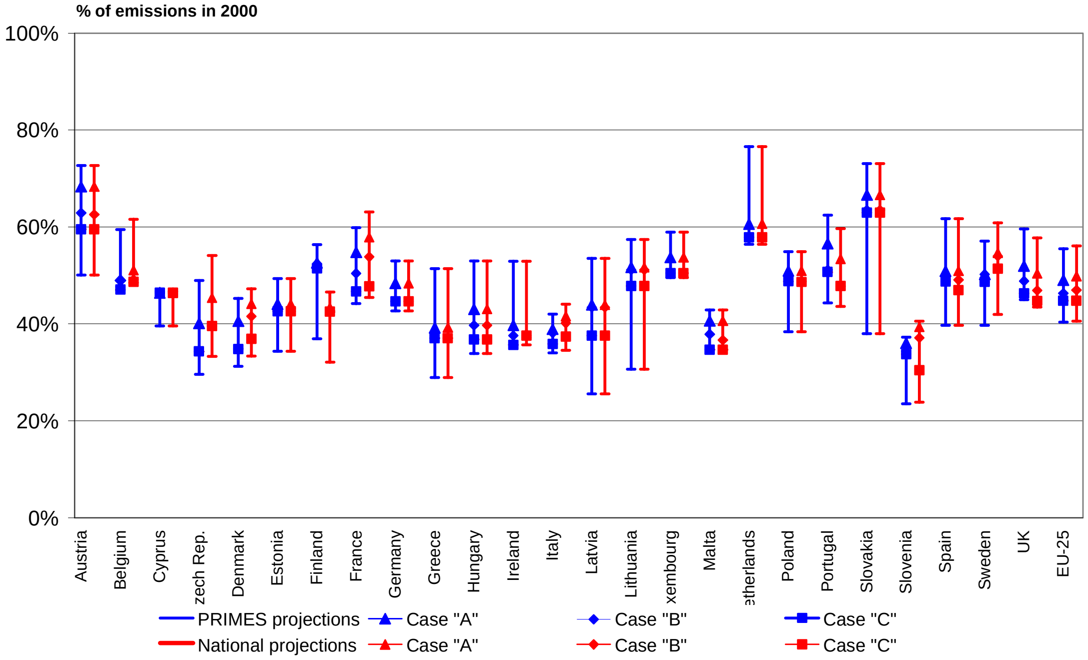

Figure 4.16: VOC emissions for the CAFE environmental objectives, optimized for the PRIMES energy projections and for the national energy and agricultural projections, relative to the emissions of the year 2000 (=100%)

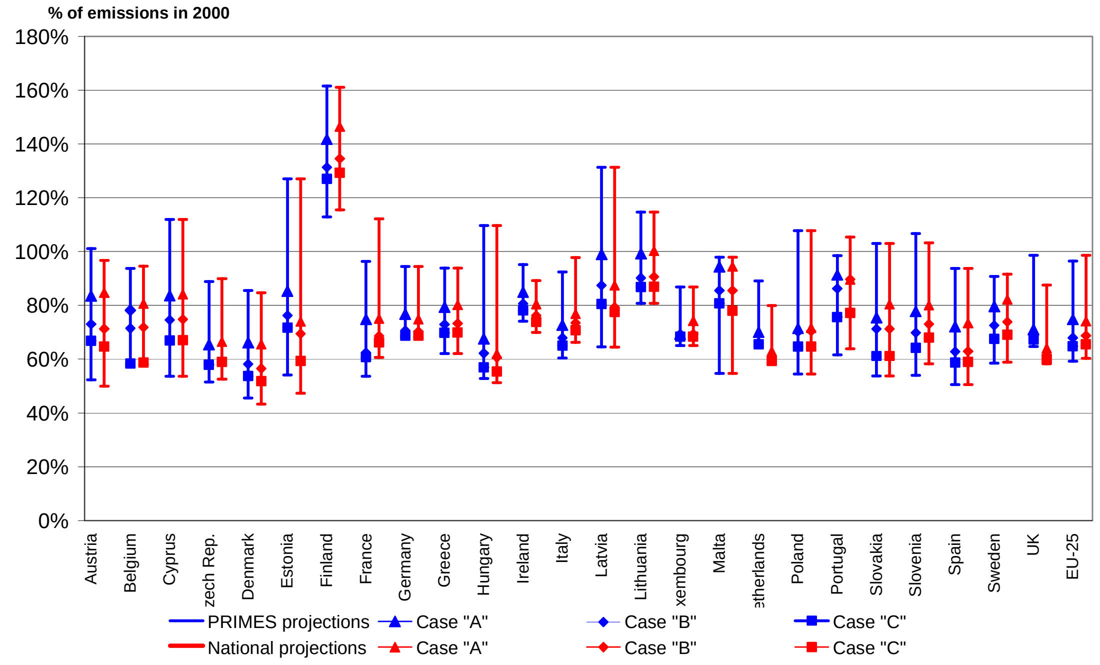

Figure 4.17: NH_3 emissions for the CAFE environmental objectives, optimized for the PRIMES energy projections and for the national energy and agricultural projections, relative to the emissions of the year 2000 (=100%)

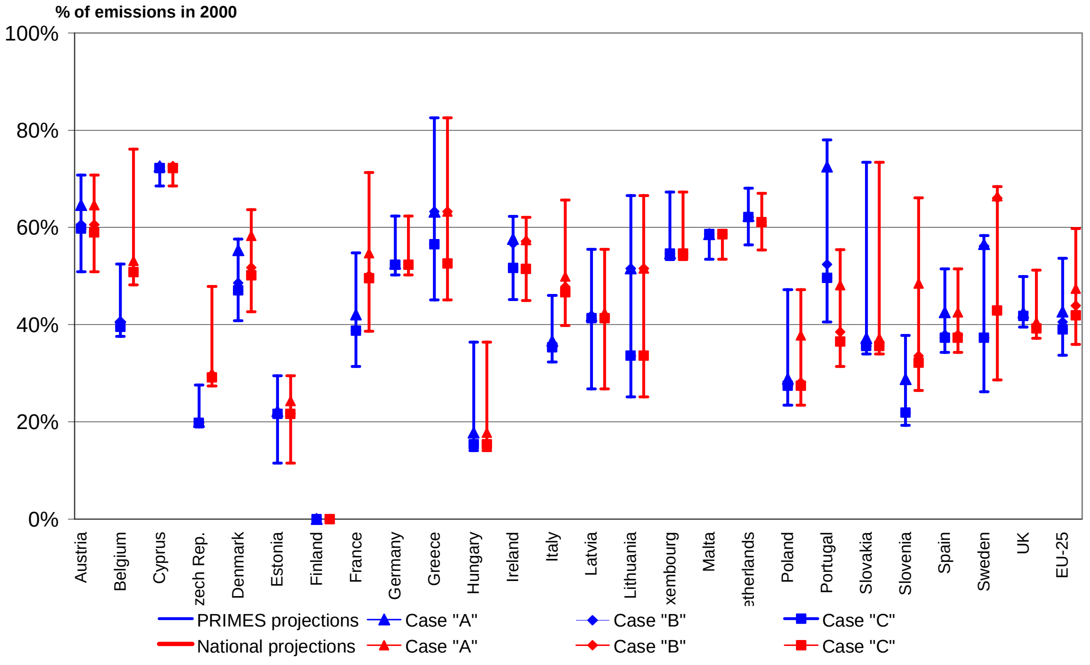

Figure 4.18: PM2.5 emissions for the CAFE environmental objectives, optimized for the PRIMES energy projections and for the national energy and agricultural projections, relative to the emissions of the year 2000 (=100%)

4.6 Uncertainties in agricultural emission projections

There is only insufficient quantitative understanding of some important factors that determine future ammonia emissions and emission control potentials. Major uncertainties are related to some ongoing policy initiatives, which do not per-se relate to emissions of air pollutants, but could have important side impacts on ammonia emissions from the agricultural sector. This applies to the reform of the Common Agricultural Policy, which will influence future livestock numbers in individual Member States, to the Integrated Pollution Prevention and Control (IPPC) Directive that will affect agricultural practices and to the Nitrate Directive. While there is only insufficient information available to analyse these uncertainties in quantitative terms, additional calculations have been carried out to explore potential biases in the optimization results that could be caused by the neglect of these policies.

4.6.1 Potential implications of the CAP reform

Obviously, future livestock numbers have a crucial impact on the potential for and costs of reducing ammonia emissions. The CAFE baseline scenario employs livestock and fertilizer use projections that do not consider potential implications of the CAP reform. Ten Member States (Austria, Denmark, France, Ireland, Italy, Latvia, Netherlands, Portugal, Slovenia, and United Kingdom) have supplied their national expectations as an alternative for the CAFE analysis, but also most of these projections do not yet quantify the implications of the CAP reform. As a third variant, projections developed for the EEA agricultural outlook study (EEA, 2004) have been implemented.

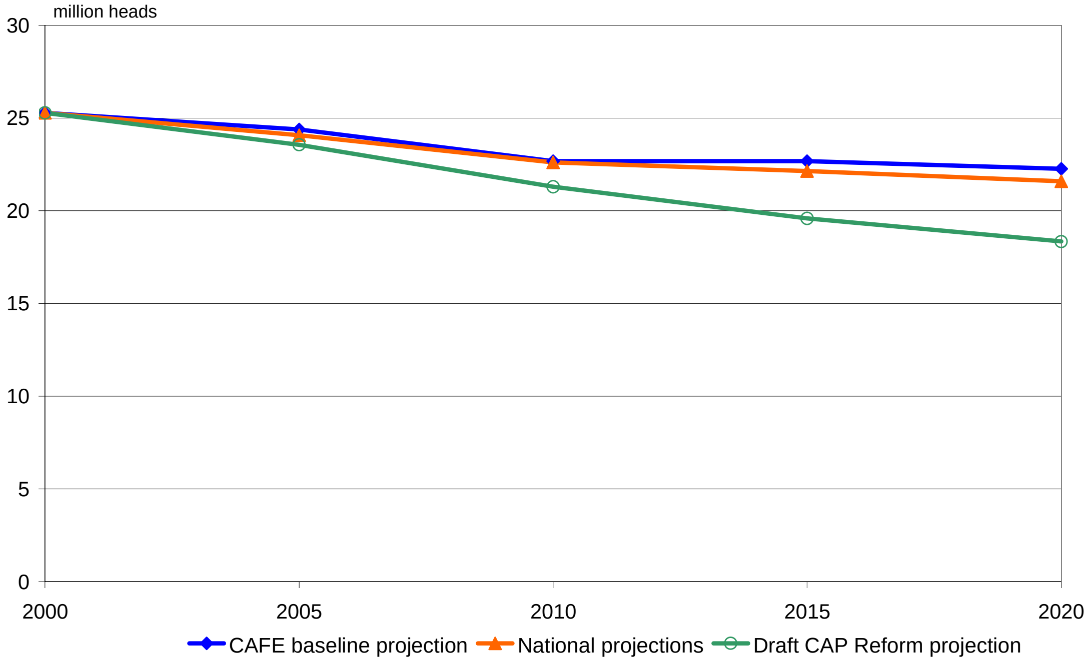

Figure 4.19: Livestock projections for dairy cattle

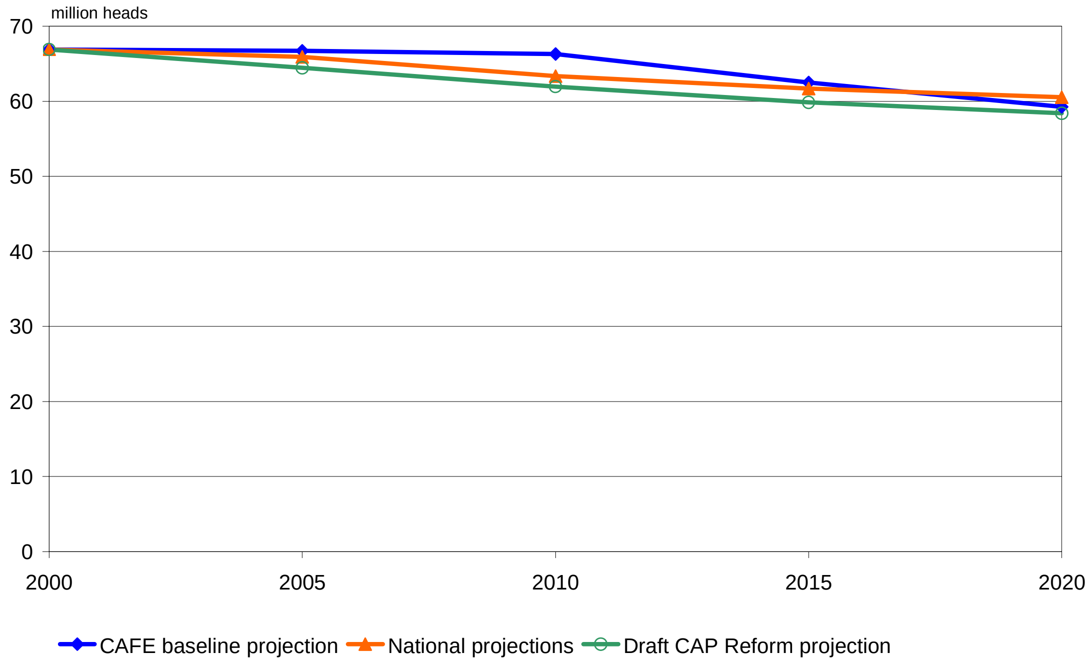

Figure 4.20: Livestock projections for other cattle

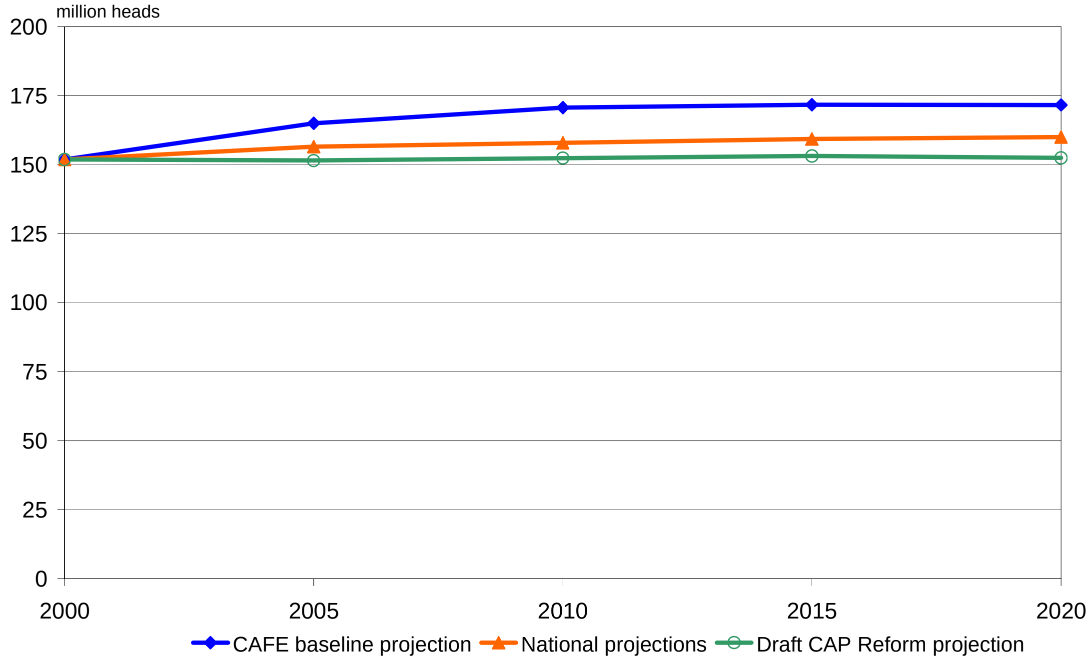

Figure 4.21: Livestock projections for pigs

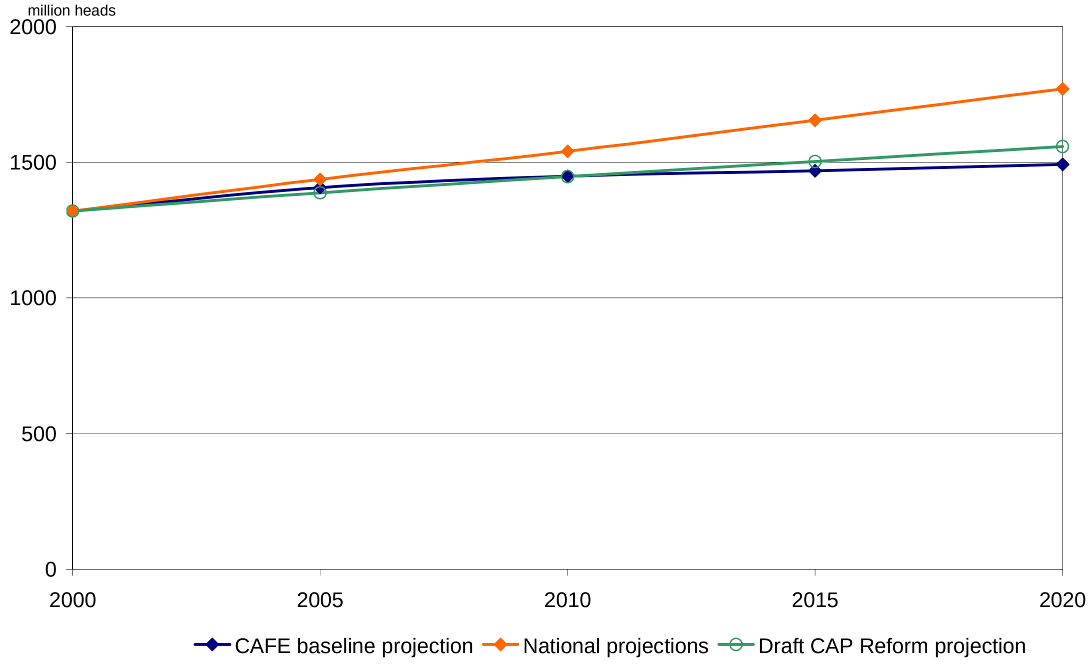

Figure 4.22: Livestock projections for poultry

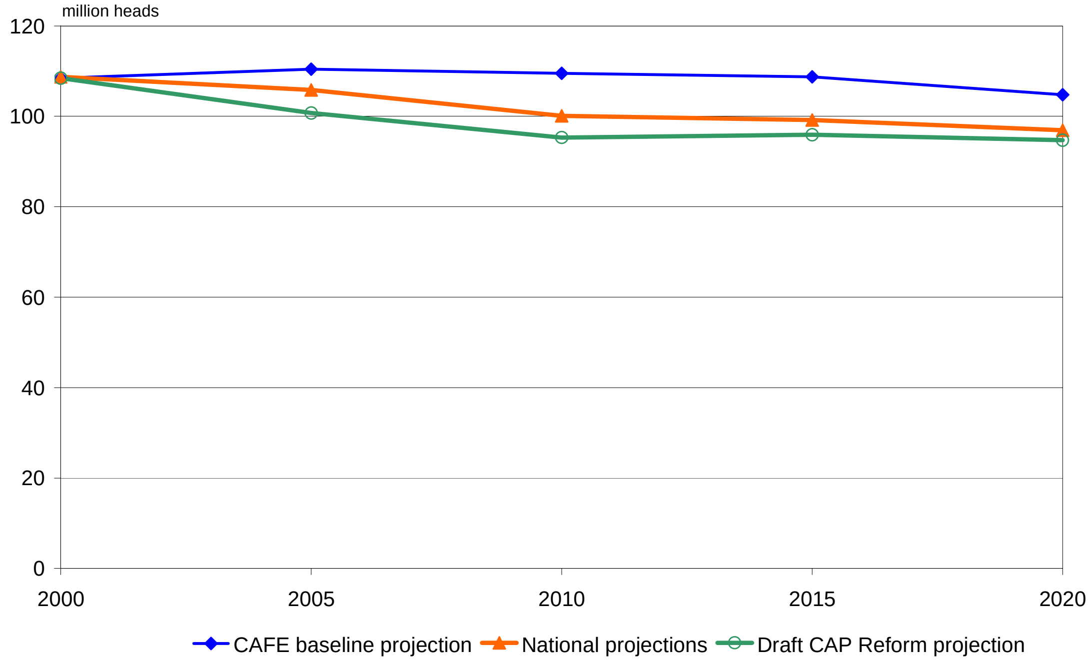

Figure 4.23: Livestock projections for sheep

As a general feature, the draft CAP reform projections of the EEA foresee lower livestock numbers than the national projections and the CAFE baseline projections (with the exception of poultry).

If such lower livestock numbers materialize, ammonia emissions would be lower than projected in the CAFE baseline and costs for achieving lower ammonia emissions would decline. An initial analysis conducted for the medium ambition Case "B" suggests ammonia emissions would decline in the EU-25 - without further measures – by approximately 120 to 150 kt. While for 2020 lower emissions are calculated for 18 Member States, the EEA projection implies higher emissions for seven Member States.

The ammonia reduction implied by the CAP reform projection corresponds to approximately 10 percent of the ammonia control measures computed for Case B, and it would decrease the annual compliance costs for reaching the "medium" ambition Case B by approximately 0.5 billion €/year. Further analysis will be necessary to confirm a number of assumptions in these calculations, especially in relation to the interpretation of the EEA agricultural outlook study (EEA, 2004). In addition, the implementation of CAP reform will have implications on the use of mineral nitrogen fertilizers, which could have further impacts on the costs of achieving lower ammonia emissions in Europe. Lack of information, however, has prohibited a full analysis of this aspect up to now.

4.6.2 Implications of the IPPC Directive

A further assessment addressed the implications of the IPPC Directive on agricultural emissions. This analysis is based on the draft CAP reform scenario, so that the estimated effects add to those discussed above.

In the absence of detailed information on the IPPC implementation in the Member States, a number of simplifying assumptions has been made for this analysis. Based on data from EUROSTAT (EUROSTAT, 2005) and results of the agricultural questionnaire prepared by the UNECE Task Force on Emission Inventories (Klimont et al., 2005), the proportion of animals kept in holdings subject to IPPC provisions was derived. Further, it has been assumed that low ammonia application methods for slurry and solid manures will be applied at these large farms. Low emission housing will penetrate further, assuming an average lifetime of building of about 20 years and consequently an average replacement rate of five percent per year. Consequently, in 2020 about 65 percent of housing under the IPPC Directive would be low emission housing, reducing by 2020, in an optimistic interpretation, between 150 and 230 kilotons of ammonia per year. If these costs are attributed to the implementation of the IPPC Directive, additional costs of the CAFE-induced measures would decline by another 600 to 900 million €/year.

4.6.3 Implications of the Nitrate Directive

A quantitative assessment of the impacts of the Nitrate Directive turned out to be difficult. While direct impacts of this directive on emissions of ammonia are not expected, a potential restriction of applying certain effective ammonia abatement measures, e.g. deep injection of slurry, might lead to higher emissions of ammonia and consequently would require additional (more expensive) options to compensate for this effect. Other possible effects include changes in the spatial and temporal distribution of emissions. With the present data, a quantitative assessment could not be performed.

4.6.4 Recent information on emission control measures

Since the construction of the CAFE baseline scenario, new information has become available on the costs of treating solid pig and cattle manures, suggesting costs of such measures applied in the medium ambition Case "B" to be 0.6 billion €/yr lower than the original estimate.

4.6.5 Summary

In summary, a number of factors have been identified that have not yet been considered in the quantitative central CAFE analysis. While at present an exact quantification of the implied cost changes is difficult without further information, a preliminary assessment suggests that the costs for ammonia control as computed in the central CAFE analysis could decline by 40 to 50 percent (Table 4.11).

Table 4.11: Change in compliance costs for ammonia of the CAFE medium ambition Case "B" due to updated cost data, the implications of the CAP reform and a full implementation of the IPPC Directive

	Annual cost in 2020			
	Lower estimate		Higher estimate	
	billion €/yr	%	billion €/yr	%
Original estimate of the compliance costs to reach the Case "B" ambition level'	3.77		3.77	
• CAP reform	-0.46	-12%	-0.46	-12%
• Implementation of the IPPC directive	-0.60	-16%	-0.85	-23%
• Updated cost information on manure management	-0.60	-16%	-0.60	-16%
Sub-total cost reduction	-1.66	-44%	-1.91	-51%
Compliance cost for the Case "B" ambition level taking into account all uncertainties	2.11		1.86	

5 Conclusions

Once the present European legislation on emission controls is fully implemented, air quality in Europe will significantly improve. It is estimated that in 2020the forthcoming reductions in European emissions will extend statistical life expectancy in Europe by approximately 2.5 months and reduce premature mortality attributable to ground-level ozone by more than 3,500 cases per year. Acid deposition will fall below harmful levels at an additional 120,000 km^2 of European forests and enable sustainable ecological conditions at many nature protection areas in the EU-25.

Despite this significant progress, air quality problems will not completely disappear. Even for the year 2020, exposure to fine particulate matter from anthropogenic sources is estimated to shorten life of the European population by five to six months on average. Ground-level ozone will still cause several thousand cases of premature death every year. 120,000 km^2 of forests will continue to receive unsustainable amounts of acid deposition from the atmosphere and many Scandinavian lakes will not be able to recover from past acidification. Biodiversity will remain endangered at approximately 600,000 km^2 (45 percent of European ecosystems) due to excessive nitrogen deposition.

This report explores cost-effective options for further reducing the impacts of air pollution envisaged for the year 2020. Based on the finding that in 2020 the complete elimination of all damage from air pollution will be difficult and costly to achieve with presently available control technology, a range of environmental interim targets has been developed to guide the cost-effectiveness analysis on further emission control steps. Following the focus of the Clean Air For Europe (CAFE) programme, interim targets have been defined for health impacts attributable to fine particulate matter, eutrophication of terrestrial ecosystems, acidification of soils and freshwater bodies, and for health- and vegetation impacts from ground-level ozone.

For each of these environmental endpoints, three cases have been analysed. These reflect three environmental ambition levels covering the remaining range of emission reductions once present legislation is fully implemented. In practice, the environmental objectives aim for the year 2020 at a gain in statistical life expectancy between 1.1 and 1.5 months (or 27 to 38 million life years gained) beyond the improvements expected from full implementation of current legislation. For eutrophication, nitrogen deposition should decline below the sustainable critical loads at an additional 165,000 to 243,000 km^2 of natural ecosystems. On top of current legislation, 52,000 to 64,000 km^2 of European forests should be protected against acid deposition, and between 1300 and 2000 cases of premature death connected to ground-level ozone should be avoided.

For each of these cases, the optimization routine of the RAINS model has identified the set of control measures for SO_2, NO_x, VOC, NH_3 and PM2.5 emissions in the various sectors of the EU Member States that achieve the specified environmental targets at least cost. To reach the environmental objectives, costs have been computed at 5.9, 10.7 and 14.8 billion €/year, respectively. For the medium ambition Case “B” with costs of 10.7 billion €/yr, 32 percent of emission control costs would emerge in the transport sector, 30 percent in agriculture, 27 percent in industry, seven percent in the domestic sector and five percent in power generation. For the various sectors the measures have been identified that would be crucial for achieving the emission reductions.

A number of sensitivity analyses have been conducted to examine the robustness of the optimization results against important exogenous assumptions and fundamental uncertainties. It is found that overall costs would decline if some of the required emission reductions were implemented at seagoing ships, which in turn would relieve the most expensive requirements for land-based sources.

Vice versa, European emission control costs would be higher if further measures to control PM and NO_x emissions from diesel vehicles were excluded. Maintaining for the low ambition Case "A" the same environmental objectives, stationary sources would have to take compensatory measures that would increase their costs by 50 percent. The environmental objectives of the two more ambitious cases could not be achieved at all, even if stationary sources would implement all available control measures.

Emission control measures in the agricultural sector, which make important contributions to eutrophication, acidification and fine particulate matter, play a crucial role in all three scenarios. However, there is only limited understanding of some important factors that determine future ammonia emissions and emission control potentials. Major uncertainties are related to some ongoing policy initiatives, the reform of the Common Agricultural Policy, the implementation of the Integrated Pollution Prevention and Control (IPPC) Directive, and the Nitrate Directive. While a precise quantification of their impacts is difficult, additional calculations point out that these factors could most likely reduce emission control costs in the agricultural sector by between 40 and 50 percent.

There are still significant shortcomings in the scientific understanding of the exact mechanisms how fine particles damage human health. Consequently, up to now it is not possible to establish which chemical fraction of the particle is responsible for health damage, and thus to focus emission controls on the sources of these specific particles. In the absence of scientific certainty, a sensitivity analysis was carried out to explore the robustness of emission control strategies against alternative health impact hypotheses. The central assumption in the CAFE assessment follows the advice received from the World Health Organization that there is yet insufficient information to single out a specific fraction of fine particles, and thus total concentrations of all PM2.5 should be reduced. The sensitivity analyses explored the implications of a hypothesis that only primary PM2.5 from anthropogenic emissions are harmful, and that secondary inorganic aerosols resulting from SO_2, NO_x and NH_3 emissions would not cause health damage. The sensitivity analysis demonstrates that for such a hypothesis, in a multi-effect context as adopted in CAFE, emission reduction requirements for the various pollutants differ only marginally compared to the central CAFE scenarios.

A final sensitivity case explored environmental objectives that determine the marginal level of emission reductions for the various pollutants. The analysis shows a balance between the driving forces, linking the levels of SO_2 and PM2.5 reductions to health concerns and the resulting cuts in NOx and VOC emissions steered at the margin by the environmental objectives. The need for ammonia reductions is linked to both the health and the environmental targets.

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Annex 1: Assumptions on further measures to reduce emissions from road vehicles

Table 5.1: 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 5.2: 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

Annex 2: Further emission control measures adopted in the scenarios

The tables in the Annex indicate in which sectors additional measures (on top of the “current legislation”) are required in order to reach the cost –optimal emission reductions in the scenarios with three ambition levels.

The contribution of measures to total reductions is shown in four ranges:

- empty field – no reduction from a given sector
- <10% - sector contributes less than 10 percent of total national reduction required in a given scenario
- 10-20% - sector contributes between 10 and 20 percent
- >30% - more than 30 percent of total reduction originates from that sector.

Definition of SO_2, NO_x and PM emitting sectors used in the tables:

Conversion	Fuel production and conversion other than power generation
Domestic	Combustion in the residential and commercial sector
Industry	Industry, combustion in boilers and furnaces, except combustion in CHP plants
Power plants	Public power plants and CHP plants of autoproducers
Process	Non-combustion industrial processes
Transport	Road transport, non-road mobile sources and machines, national sea traffic and national fishing
Waste	Waste treatment and disposal
Other	Other emission sources (material storage and handling, agricultural activities, fugitive emissions form small sources etc.)

Definition of NMVOC emitting sectors used in the tables s:

Conversion	Fuel production and conversion other than power generation (including extraction and distribution of oil and gas, processing and storage at refineries), gasoline distribution
Domestic	Combustion in the residential and commercial sector
Processes	Processes in organic chemical industries, food and drink production, iron and steel industry, road paving with asphalt, other
Coatings	Use of coatings (excluding varnishes in printing) in industrial applications (vehicle manufacturing, coil, wire, leather, wood and other industrial applications) and decorative paints (professional and DIY)

Solvents	Degreasing, printing, adhesive application, pharmaceutical industry, polystyrene processing, production of shoes, tyres, paints, adhesives, synthetic rubber, and wood preservation)
Waste	Waste treatment and disposal
Transport	Exhaust and evaporative emissions from transport
Other	Combustion in power plants and industry

Definition of NH_3 emitting sectors used in the tables:

Dairy cows	Dairy cows
Other cattle	Other cattle
Pigs	Sows and fattening pigs
Poultry	Laying hens and other poultry
Other animals	Other animals (including sheep, goats, horses, fur animals)
Fertilizer use	Application of mineral N fertilizers, specifically distinguishing urea and other N fertilizers
Processes	Production of mineral N fertilizers
Other	Includes emissions from stationary combustion, mobile sources, humans, pets, waste treatment, other.

Table 5.3: Measures to reduce SO_2 emissions – low ambition Case “A”

	Conversion	Domestic	Industry	Power plants	Process	Waste	Transport	Total reduction, kt
Austria			>30%					3
Belgium	<10%	<10%	>30%	<10%	>30%		<10%	24
Cyprus								0
Czech Rep.	10-30%	<10%	>30%	<10%	>30%			20
Denmark	10-30%		>30%				10-30%	1
Estonia			>30%		10-30%			3
Finland			>30%				10-30%	3
France	>30%	<10%	10-30%		>30%	<10%	<10%	154
Germany	>30%		<10%	10-30%	<10%	<10%		65
Greece	>30%		<10%	>30%	<10%			20
Hungary	10-30%	<10%	10-30%	>30%	10-30%	<10%		65
Ireland		10-30%	>30%				10-30%	4
Italy	10-30%		<10%	10-30%	10-30%	<10%	>30%	128
Latvia		<10%		>30%				1
Lithuania	>30%	<10%	<10%	10-30%	10-30%	<10%		12
Luxembourg			>30%		>30%			1
Malta				>30%				1
Netherlands	>30%		<10%				>30%	19
Poland	10-30%	<10%	10-30%	>30%	10-30%	<10%	<10%	353
Portugal	>30%		10-30%		10-30%			28
Slovakia	10-30%	<10%	<10%	<10%	>30%	<10%		13
Slovenia	>30%		10-30%		>30%			9
Spain	>30%	<10%	<10%		>30%	<10%	<10%	121
Sweden								0
UK	10-30%	<10%	10-30%		>30%		10-30%	52
Baseline emissions, kt	645	202	435	606	693	7	217	2805
Reduction from Baseline, kt	325	23	191	199	261	4	98	1102
% of total reduction	*30%*	*2%*	*17%*	*18%*	*24%*	*9%*	*0%*	*100%*

Table 5.4: Measures to reduce SO_2 emissions – medium ambition Case “B”

	Conversion	Domestic	Industry	Power plants	Process	Waste	Transport	Total reduction, kt
Austria			>30%					3
Belgium	<10%	<10%	10-30%	<10%	>30%		<10%	26
Cyprus								0
Czech Rep.	10-30%	<10%	>30%	<10%	>30%			20
Denmark	10-30%		>30%	>30%			10-30%	2
Estonia		<10%	>30%	<10%	10-30%			4
Finland			>30%	10-30%			<10%	9
France	>30%	<10%	10-30%		>30%	<10%	<10%	156
Germany	>30%		<10%	10-30%	<10%	<10%		69
Greece	10-30%		<10%	10-30%	<10%	<10%	10-30%	38
Hungary	10-30%	<10%	10-30%	>30%	10-30%	<10%		68
Ireland		10-30%	>30%	<10%	10-30%		<10%	6
Italy	10-30%		<10%	10-30%	10-30%	<10%	>30%	148
Latvia		<10%	>30%	10-30%		<10%		5
Lithuania	>30%	<10%	<10%	<10%	10-30%	<10%		15
Luxembourg		10-30%	>30%		10-30%			1
Malta				>30%				1
Netherlands	>30%	<10%	<10%				>30%	21
Poland	10-30%	<10%	10-30%	>30%	10-30%	<10%	<10%	353
Portugal	>30%		10-30%		10-30%	<10%		37
Slovakia	10-30%	<10%	<10%	<10%	>30%	<10%		15
Slovenia	>30%		10-30%	<10%	>30%			9
Spain	>30%	<10%	<10%		>30%	<10%	<10%	152
Sweden	>30%		10-30%	10-30%				3
UK	>30%	<10%	10-30%		10-30%		10-30%	74
Baseline emissions, kt	645	202	435	606	693	7	217	2805
Reduction from Baseline, kt	356	24	221	208	294	5	130	1238
% of total reduction	*29%*	*2%*	*18%*	*17%*	*24%*	*11%*	*0%*	*100%*

Table 5.5: Measures to reduce SO_2 emissions – high ambition Case “C”

	Conversion	Domestic	Industry	Power plants	Process	Waste	Transport	Total reduction, kt
Austria		10-30%	>30%					4
Belgium	<10%	10-30%	10-30%	10-30%	>30%		<10%	32
Cyprus								0
Czech Rep.	10-30%	<10%	>30%	<10%	>30%			21
Denmark	<10%		10-30%	10-30%			>30%	4
Estonia		<10%	>30%	<10%	10-30%			4
Finland			>30%	>30%			<10%	12
France	10-30%	<10%	10-30%	<10%	>30%	<10%	<10%	180
Germany	>30%	10-30%	<10%	10-30%	<10%	<10%		92
Greece	10-30%		<10%	10-30%	10-30%	<10%	10-30%	46
Hungary	10-30%	<10%	10-30%	>30%	10-30%	<10%		68
Ireland	<10%	10-30%	>30%	<10%	10-30%		<10%	7
Italy	10-30%	<10%	<10%	10-30%	10-30%	<10%	>30%	159
Latvia		<10%	>30%	10-30%		<10%		5
Lithuania	>30%	<10%	<10%	<10%	10-30%	<10%		15
Luxembourg		10-30%	>30%		10-30%			1
Malta				>30%				1
Netherlands	>30%	<10%	<10%				>30%	21
Poland	10-30%	<10%	10-30%	>30%	10-30%	<10%	<10%	359
Portugal	>30%		10-30%		10-30%	<10%	<10%	42
Slovakia	10-30%	<10%	<10%	10-30%	>30%	<10%		17
Slovenia	>30%	<10%	10-30%	<10%	>30%			10
Spain	>30%	<10%	<10%	<10%	>30%	<10%	<10%	159
Sweden	>30%	<10%	10-30%	>30%				5
UK	>30%	<10%	10-30%	<10%	10-30%		10-30%	79
Baseline emissions, kt	645	202	435	606	693	7	217	2805
Reduction from Baseline, kt	364	63	229	240	304	5	138	1344
% of total reduction	*27%*	*5%*	*17%*	*18%*	*23%*	*10%*	*0%*	*100%*

Table 5.6: Measures to reduce NO_x emissions – low ambition Case “A”

	Conversion	Domestic	Industry	Power plants	Process	Waste	Transport	Total reduction, kt
Austria	<10%	<10%	10-30%		10-30%		>30%	21
Belgium	<10%	<10%	>30%	<10%	10-30%		>30%	49
Cyprus	<10%		10-30%	<10%	>30%		10-30%	5
Czech Rep.	<10%		10-30%	>30%	10-30%	<10%	10-30%	32
Denmark	10-30%	<10%	10-30%	10-30%	<10%		10-30%	21
Estonia			10-30%	>30%	10-30%	<10%	10-30%	5
Finland	<10%	<10%	>30%	10-30%	<10%		10-30%	28
France	<10%	<10%	10-30%	<10%	10-30%	<10%	>30%	198
Germany	10-30%		<10%	<10%	10-30%	<10%	>30%	109
Greece	<10%		10-30%	10-30%	>30%	<10%	10-30%	40
Hungary	<10%		10-30%	<10%	>30%	10-30%	10-30%	23
Ireland	<10%	<10%	10-30%	<10%	10-30%		>30%	13
Italy	<10%	<10%	10-30%	<10%	>30%	<10%	>30%	124
Latvia			10-30%	<10%	>30%	<10%	10-30%	4
Lithuania	10-30%		10-30%	10-30%	10-30%	10-30%	10-30%	6
Luxembourg		<10%	10-30%		10-30%		>30%	4
Malta				>30%			10-30%	1
Netherlands	<10%		<10%	<10%	<10%		>30%	21
Poland	<10%		>30%	>30%	10-30%	<10%	10-30%	89
Portugal	<10%		10-30%	<10%	>30%	<10%	>30%	29
Slovakia	<10%		10-30%	>30%	10-30%	<10%	10-30%	16
Slovenia	<10%	<10%	10-30%	10-30%	10-30%	<10%	10-30%	5
Spain	10-30%	<10%	10-30%	<10%	10-30%	<10%	>30%	166
Sweden	<10%	<10%	>30%	10-30%	<10%		10-30%	31
UK	10-30%	<10%	10-30%	<10%	10-30%	<10%	10-30%	169
Baseline emissions, kt	264	596	660	801	538	15	3013	5888
Reduction from Baseline, kt	118	10	284	112	286	12	388	1210
% of total reduction	*10%*	*1%*	*23%*	*9%*	*24%*	*1%*	*32%*	*100%*

Table 5.7: Measures to reduce NO_x emissions – medium ambition Case “B”

Country	Conversion	Domestic	Industry	Power plants	Process	Waste	Transport	Total reduction, kt
Austria	<10%	<10%	10-30%	10-30%	10-30%		>30%	27
Belgium	<10%	<10%	>30%	<10%	10-30%		10-30%	56
Cyprus	<10%		10-30%	>30%	>30%		10-30%	7
Czech Rep.	<10%	<10%	10-30%	>30%	10-30%	<10%	<10%	42
Denmark	10-30%	<10%	10-30%	>30%	<10%		10-30%	26
Estonia		<10%	10-30%	>30%	10-30%	<10%	10-30%	5
Finland	<10%	<10%	>30%	10-30%	<10%		10-30%	38
France	<10%	<10%	10-30%	10-30%	10-30%	<10%	10-30%	244
Germany	10-30%	<10%	10-30%	<10%	10-30%	<10%	>30%	143
Greece	<10%	<10%	10-30%	10-30%	>30%	<10%	<10%	54
Hungary	<10%	<10%	10-30%	10-30%	10-30%	<10%	10-30%	31
Ireland	<10%	<10%	10-30%	10-30%	10-30%		10-30%	18
Italy	<10%	<10%	10-30%	10-30%	10-30%	<10%	10-30%	172
Latvia		<10%	10-30%	<10%	10-30%	<10%	10-30%	4
Lithuania	10-30%	<10%	10-30%	10-30%	10-30%	<10%	10-30%	8
Luxembourg		<10%	10-30%	<10%	10-30%		>30%	5
Malta				>30%			10-30%	1
Netherlands	<10%		<10%	>30%	<10%		>30%	47
Poland	<10%	<10%	>30%	>30%	10-30%	<10%	<10%	119
Portugal	<10%	<10%	10-30%	<10%	>30%	<10%	>30%	41
Slovakia	<10%	<10%	10-30%	10-30%	10-30%	<10%	10-30%	20
Slovenia	<10%	<10%	10-30%	>30%	10-30%	<10%	10-30%	6
Spain	10-30%	<10%	10-30%	<10%	10-30%	<10%	10-30%	198
Sweden	<10%	<10%	>30%	10-30%	<10%		10-30%	46
UK	10-30%	<10%	10-30%	10-30%	10-30%	<10%	10-30%	233
Baseline emissions, kt	264	596	660	801	538	15	3013	5888
Reduction from Baseline, kt	160	63	375	271	322	13	388	1591
% of total reduction	*10%*	*4%*	*24%*	*17%*	*20%*	*1%*	*24%*	*100%*

Table 5.8: Measures to reduce NO_x emissions – high ambition Case “C”

Country	Conversion	Domestic	Industry	Power plants	Process	Waste	Transport	Total reduction, kt
Austria	<10%	<10%	10-30%	10-30%	10-30%		>30%	31
Belgium	<10%	<10%	>30%	10-30%	10-30%		10-30%	67
Cyprus	<10%		10-30%	>30%	>30%		10-30%	7
Czech Rep.	<10%	<10%	10-30%	>30%	10-30%	<10%	<10%	45
Denmark	10-30%	<10%	10-30%	>30%	<10%		10-30%	27
Estonia		<10%	10-30%	>30%	<10%	<10%	<10%	6
Finland	<10%	<10%	>30%	>30%	<10%		10-30%	44
France	<10%	<10%	10-30%	10-30%	10-30%	<10%	10-30%	252
Germany	10-30%	<10%	10-30%	10-30%	10-30%	<10%	>30%	174
Greece	<10%	<10%	10-30%	10-30%	>30%	<10%	<10%	61
Hungary	<10%	<10%	10-30%	10-30%	10-30%	<10%	10-30%	35
Ireland	<10%	<10%	10-30%	10-30%	10-30%		10-30%	18
Italy	<10%	<10%	10-30%	10-30%	10-30%	<10%	10-30%	190
Latvia		<10%	10-30%	10-30%	10-30%	<10%	10-30%	5
Lithuania	10-30%	<10%	<10%	>30%	10-30%	<10%	10-30%	10
Luxembourg		<10%	10-30%	<10%	10-30%		>30%	5
Malta				>30%			10-30%	2
Netherlands	<10%		10-30%	>30%	<10%		>30%	48
Poland	<10%	<10%	>30%	>30%	10-30%	<10%	<10%	134
Portugal	<10%	<10%	10-30%	10-30%	10-30%	<10%	10-30%	47
Slovakia	<10%	<10%	10-30%	>30%	10-30%	<10%	10-30%	23
Slovenia	<10%	<10%	10-30%	>30%	10-30%	<10%	10-30%	7
Spain	10-30%	<10%	10-30%	10-30%	10-30%	<10%	10-30%	226
Sweden	<10%	<10%	>30%	>30%	<10%		10-30%	48
UK	10-30%	<10%	10-30%	10-30%	10-30%	<10%	10-30%	268
Baseline emissions, kt	264	596	660	801	538	15	3013	5888
Reduction from Baseline, kt	174	71	404	403	327	13	388	1781
% of total reduction	*10%*	*4%*	*23%*	*23%*	*18%*	*1%*	*22%*	*100%*

Table 5.9: Measures to reduce PM 2.5 emissions – low ambition Case "A"

Country	Conversion	Domestic	Industry	Power plants	Process	Waste	OTHER	Transport	Total reduction, kt
Austria		10-30 %			10-30 %	10-30 %		10-30 %	3.1
Belgium	<10%	10-30 %	<10%		>30%	<10%		10-30 %	6.4
Cyprus									0.1
Czech Rep.		10-30 %	<10%	>30%	10-30 %	10-30 %		<10%	5.2
Denmark				10-30 %	10-30 %	10-30 %		>30%	0.8
Estonia				>30%		>30%			1.6
Finland					>30%	10-30 %		>30%	1.1
France	<10%	>30%	<10%	<10%	10-30 %	<10%	<10%	10-30 %	43.2
Germany	<10%	>30%	<10%		>30%	<10%	<10%	10-30 %	20.5
Greece				>30%	<10%	>30%		<10%	9.7
Hungary		<10%		10-30 %	<10%	>30%		<10%	11.5
Ireland		10-30 %		10-30 %		10-30 %		>30%	1.1
Italy	<10%	10-30 %	<10%	<10%	>30%	10-30 %	<10%	10-30 %	22.3
Latvia						>30%			1.1
Lithuania		10-30 %		10-30 %		>30%		<10%	2.7
Luxembourg					>30%			10-30 %	0.5
Malta									0.0
Netherlands	10-30 %	10-30 %			10-30 %	<10%	<10%	>30%	3.2
Poland	<10%	>30%	<10%	<10%	<10%	<10%	<10%	<10%	40.1
Portugal				<10%	10-30 %	>30%		10-30 %	3.4
Slovakia				>30%	<10%	>30%		<10%	6.9
Slovenia				>30%	10-30 %	>30%			1.4
Spain	<10%	<10%		<10%	>30%	>30%	<10%	10-30 %	18.4
Sweden					>30%	10-30 %		10-30 %	1.5
UK	<10%	10-30 %	<10%	<10%	>30%	<10%	<10%	10-30 %	12.3
Baseline emissions, kt	15	319	12	55	213	46	112	194	964
Reduction from Baseline, kt	3	70	4	22	49	42	3	26	218
% of total reduction	*1%*	*32%*	*2%*	*10%*	*22%*	*19%*	*2%*	*12%*	*100%*

Table 5.10: Measures to reduce PM 2.5 emissions – medium ambition Case “B”

Country	Conversion	Domestic	Industry	Power plants	Process	Waste	OTHER	Transport	Total reduction, kt
Austria		>30%			10-30 %	10-30 %		10-30 %	4.6
Belgium	<10%	10-30 %	<10%		>30%	<10%		10-30 %	6.8
Cyprus									0.1
Czech Rep.		10-30 %	<10%	>30%	10-30 %	10-30 %		<10%	5.2
Denmark		>30%		<10%	<10%	<10%		10-30 %	2.3
Estonia				>30%		>30%			1.7
Finland					>30%	10-30 %		10-30 %	1.3
France	<10%	>30%	<10%	<10%	10-30 %	<10%	<10%	10-30 %	52.6
Germany	<10%	>30%	<10%		>30%	<10%	<10%	10-30 %	20.7
Greece				>30%	<10%	>30%		<10%	9.7
Hungary		10-30 %		10-30 %	<10%	>30%		<10%	12.8
Ireland		10-30 %		10-30 %		10-30 %		>30%	1.2
Italy	<10%	10-30 %	<10%	<10%	>30%	10-30 %	<10%	10-30 %	23.5
Latvia						>30%			1.1
Lithuania		10-30 %		10-30 %		>30%		<10%	2.7
Luxembourg					>30%			10-30 %	0.5
Malta									0.0
Netherlands	10-30 %	10-30 %			10-30 %	<10%	<10%	>30%	3.3
Poland	<10%	>30%	<10%	<10%	<10%	<10%	<10%	<10%	41.7
Portugal		>30%		<10%	<10%	<10%		<10%	12.7
Slovakia		<10%		>30%	<10%	>30%		<10%	7.2
Slovenia		>30%		10-30 %	<10%	10-30 %			2.4
Spain	<10%	10-30 %	<10%	<10%	10-30 %	10-30 %	<10%	10-30 %	26.3
Sweden					>30%	10-30 %		10-30 %	1.7
UK	<10%	10-30 %	<10%	<10%	>30%	<10%	<10%	10-30 %	13.1
Baseline emissions, kt	15	319	12	55	213	46	112	194	964
Reduction from Baseline, kt	3	104	4	22	51	42	3	26	255
% of total reduction	*1%*	*41%*	*2%*	*9%*	*20%*	*16%*	*1%*	*10%*	*100%*

Table 5.11: Measures to reduce PM 2.5 emissions – high ambition case “C”

Country	Conversion	Domestic	Industry	Power plants	Process	Waste	OTHER	Transport	Total reduction, kt
Austria		>30%		<10%	10-30 %	<10%		10-30 %	4.9
Belgium	<10%	10-30 %	<10%		>30%	<10%		10-30 %	6.8
Cyprus									0.1
Czech Rep.		10-30 %	<10%	>30%	10-30 %	10-30 %		<10%	5.3
Denmark		>30%		<10%	<10%	<10%		<10%	2.6
Estonia				>30%		>30%			1.7
Finland					>30%	10-30 %		10-30 %	1.3
France	<10%	>30%	<10%	<10%	10-30 %	<10%	<10%	10-30 %	52.8
Germany	<10%	>30%	<10%		>30%	<10%	<10%	10-30 %	21.0
Greece		10-30 %		>30%	<10%	>30%		<10%	13.0
Hungary		10-30 %		10-30 %	<10%	>30%		<10%	12.9
Ireland		>30%		10-30 %		10-30 %		10-30 %	1.9
Italy	<10%	10-30 %	<10%	<10%	>30%	10-30 %	<10%	10-30 %	25.1
Latvia		10-30 %				>30%			1.1
Lithuania		>30%		<10%		>30%		<10%	5.9
Luxembourg					>30%			10-30 %	0.5
Malta									0.0
Netherlands	10-30 %	10-30 %			10-30 %	<10%	<10%	>30%	3.3
Poland	<10%	>30%	<10%	<10%	<10%	<10%	<10%	<10%	43.1
Portugal	<10%	>30%		<10%	<10%	<10%		<10%	14.0
Slovakia		<10%		>30%	<10%	>30%		<10%	7.2
Slovenia		>30%		10-30 %	<10%	10-30 %			2.4
Spain	<10%	>30%	<10%	<10%	10-30 %	10-30 %	<10%	10-30 %	27.3
Sweden		>30%	<10%		<10%	<10%		<10%	14.4
UK	<10%	10-30 %	<10%	<10%	>30%	<10%	<10%	10-30 %	13.2
Baseline emissions, kt	15	319	12	55	213	46	112	194	964
Reduction from Baseline, kt	4	127	5	22	52	42	3	26	282
% of total reduction	*1%*	*45%*	*2%*	*8%*	*18%*	*15%*	*1%*	*9%*	*100%*

Table 5.12: Measures to reduce NMVOC emissions – low ambition Case “A”

Country	Conversion	Domestic	Processes	Coatings	Solvents	Waste	Transport	Other	Total reduction, kt
Austria			>30%	10-30%	<10%	<10%			8
Belgium	<10%		>30%	10-30%	10-30%	<10%			25
Cyprus									-
Czech Rep.	<10%		>30%	<10%	>30%				21
Denmark	<10%			>30%	>30%				6
Estonia			>30%		<10%	10-30%			2
Finland	10-30%		>30%	>30%	<10%				6
France	<10%	<10%	10-30%	>30%	10-30%	<10%			77
Germany	10-30%		10-30%	>30%	>30%	<10%			70
Greece	10-30%		<10%	<10%	>30%	10-30%			34
Hungary	10-30%		<10%	<10%	<10%	>30%			17
Ireland	10-30%	<10%		>30%	>30%				12
Italy		<10%	10-30%	>30%	<10%				55
Latvia			>30%		>30%	10-30%			5
Lithuania	>30%		<10%		10-30%	10-30%			4
Luxembourg			>30%	10-30%	10-30%				1
Malta				>30%					0
Netherlands		<10%	>30%	10-30%	<10%	<10%			42
Poland	>30%	<10%	>30%	<10%					23
Portugal	10-30%		>30%	<10%	10-30%				15
Slovakia	10-30%					>30%			6
Slovenia	10-30%		>30%			>30%			1
Spain	<10%		>30%	<10%	10-30%	<10%			121
Sweden	<10%		>30%	10-30%	<10%				21
UK	10-30%	<10%	<10%	>30%	>30%	<10%			113
Baseline emissions, kt	763	531	880	1008	1402	182	1036	114	5916
Reduction from Baseline, kt	80	5	219	183	156	42	0	0	685
% of total reduction	*12%*	*1%*	*32%*	*27%*	*23%*	*6%*	*0%*	*0%*	*100%*

Table 5.13: Measures to reduce NMVOC emissions – medium ambition Case “B”

Country	Conversion	Domestic	Processes	Coatings	Solvents	Waste	Transport	Other	Total reduction, kt
Austria	<10%	<10%	>30%	>30%	>30%	<10%			19
Belgium	<10%		>30%	>30%	10-30%	<10%			29
Cyprus									-
Czech Rep.	<10%		10-30%	10-30%	>30%				35
Denmark	<10%	>30%		>30%	10-30%				13
Estonia			>30%			>30%			2
Finland	10-30%		>30%	10-30%	<10%				7
France	<10%	<10%	<10%	>30%	>30%	<10%			145
Germany	<10%		10-30%	>30%	10-30%	<10%			127
Greece	10-30%		<10%	10-30%	>30%	10-30%			40
Hungary	10-30%	<10%	<10%	<10%	<10%	>30%			23
Ireland	10-30%	10-30%		10-30%	>30%				13
Italy	<10%	<10%	10-30%	>30%	10-30%	<10%			68
Latvia			>30%		>30%	10-30%			5
Lithuania	>30%		<10%		<10%	>30%			5
Luxembourg			10-30%	>30%	10-30%				1
Malta									0
Netherlands		<10%	>30%	10-30%	<10%	<10%			49
Poland	>30%	<10%	>30%	<10%	10-30%	<10%			36
Portugal	10-30%	<10%	>30%	10-30%	10-30%				28
Slovakia	10-30%	<10%	<10%	<10%	10-30%	>30%			8
Slovenia	10-30%		10-30%	>30%		>30%			2
Spain	<10%	<10%	>30%	10-30%	10-30%	<10%			142
Sweden	<10%		>30%	10-30%	<10%				21
UK	>30%	<10%	<10%	10-30%	>30%	<10%			158
Baseline emissions, kt	763	531	880	1008	1402	182	1036	114	5916
Reduction from Baseline, kt	125	16	239	300	246	51	0	0	978
% of total reduction	*13%*	*2%*	*24%*	*31%*	*25%*	*5%*	*0%*	*0%*	*100%*

Table 5.14: Measures to reduce NMVOC emissions – high ambition Case “C”

Country	Conversion	Domestic	Processes	Coatings	Solvents	Waste	Transport	Other	Total reduction, kt
Austria	<10%	<10%	10-30%	10-30%	>30%	<10%			25
Belgium	<10%		>30%	>30%	10-30%	<10%			30
Cyprus									-
Czech Rep.	<10%	<10%	10-30%	10-30%	>30%				35
Denmark	<10%	>30%		>30%	10-30%				13
Estonia			>30%			>30%			2
Finland	<10%		>30%	10-30%	10-30%				8
France	<10%	10-30%	<10%	>30%	10-30%	<10%			203
Germany	<10%		10-30%	>30%	10-30%	<10%			127
Greece	10-30%	<10%	<10%	10-30%	>30%	10-30%			40
Hungary	10-30%	<10%	<10%	10-30%	<10%	>30%			27
Ireland	10-30%	10-30%	10-30%	10-30%	>30%				15
Italy	<10%	<10%	10-30%	>30%	10-30%	<10%			107
Latvia			10-30%	>30%	10-30%	10-30%			8
Lithuania	>30%	<10%	<10%	<10%	10-30%	>30%			7
Luxembourg			10-30%	>30%	10-30%				1
Malta				>30%					0
Netherlands		<10%	>30%	10-30%	<10%	<10%			49
Poland	>30%	<10%	>30%	<10%	10-30%	<10%			36
Portugal	10-30%	<10%	>30%	10-30%	10-30%				29
Slovakia	10-30%	<10%	<10%	<10%	10-30%	>30%			9
Slovenia	<10%	<10%	10-30%	>30%	<10%	>30%			2
Spain	<10%	<10%	>30%	10-30%	10-30%	<10%			145
Sweden	<10%	<10%	>30%	10-30%	10-30%				26
UK	>30%	<10%	<10%	10-30%	10-30%	<10%			196
Baseline emissions, kt	763	531	880	1008	1402	182	1036	114	5916
Reduction from Baseline, kt	167	73	244	335	269	55	0	0	1144
% of total reduction	*15%*	*6%*	*21%*	*29%*	*24%*	*5%*	*0%*	*0%*	*100%*

Table 5.15: Measures to reduce NH_3 emissions – low ambition Case “A”

Country	Dairy cows	Other cattle	Pigs	Poultry	Other anim.	Fertilizer use	Processes	Other	Total reduction, kt
Austria		10-30%	>30%	>30%	<10%	<10%	<10%		9.4
Belgium	10-30%	10-30%	>30%	10-30%		<10%	<10%		12.6
Cyprus			10-30%	>30%					1.6
Czech Rep.	10-30%	10-30%	10-30%	>30%		<10%			17.3
Denmark	10-30%	<10%	>30%	10-30%		<10%			17.6
Estonia				<10%		>30%			4.0
Finland	>30%			>30%		<10%	<10%		3.9
France	<10%		10-30%	>30%		10-30%			156.3
Germany	>30%	<10%	<10%	<10%	<10%	>30%	<10%		112.9
Greece				>30%		10-30%			7.9
Hungary			<10%	>30%		10-30%			32.7
Ireland	10-30%		10-30%	10-30%		>30%			12.9
Italy				>30%		>30%			85.3
Latvia				10-30%		>30%			3.9
Lithuania	10-30%	10-30%	10-30%	10-30%			10-30%		7.7
Luxembourg	>30%	>30%	<10%			10-30%			1.1
Malta									-
Netherlands	10-30%	10-30%	10-30%	>30%	<10%	<10%	<10%		29.6
Poland	10-30%	<10%	10-30%	10-30%		>30%			112.0
Portugal				>30%		>30%			4.9
Slovakia			10-30%	>30%		10-30%			8.7
Slovenia		10-30%	<10%	>30%		10-30%			5.3
Spain	10-30%		<10%	>30%		>30%			85.3
Sweden	>30%	10-30%	10-30%	>30%					6.0
UK	10-30%	<10%	10-30%	>30%		10-30%	<10%		86.8
Baseline emissions, kt	644	676	800	470	166	660	54	215	3686
Reduction from Baseline, kt	122	44	110	267	2	275	5	0	826
% of total reduction	*14.8%*	*5.4%*	*13.3%*	*32.3%*	*0.3%*	*33.3%*	*0.6%*	*0.0%*	*100.0%*

Table 5.16: Measures to reduce NH_3 emissions – medium ambition Case “B”

Country	Dairy cows	Other cattle	Pigs	Poultry	Other anim.	Fertilizer use	Processes	Other	Total Reduction, kt
Austria	10-30%	<10%	10-30%	10-30%	<10%	<10%	<10%		15
Belgium	10-30%	10-30%	>30%	10-30%		<10%	<10%		18
Cyprus			>30%	>30%					2
Czech Rep.	10-30%	<10%	>30%	>30%		<10%	<10%		23
Denmark	10-30%	<10%	>30%	10-30%		<10%	<10%		25
Estonia		<10%	<10%	10-30%		>30%			5
Finland	>30%	10-30%	<10%	10-30%		<10%	<10%		6
France	10-30%	10-30%	10-30%	>30%	<10%	10-30%			247
Germany	>30%	10-30%	<10%	<10%	<10%	>30%	<10%		152
Greece		<10%	10-30%	>30%		<10%	<10%		12
Hungary	<10%	<10%	<10%	>30%		10-30%	<10%		37
Ireland	10-30%	10-30%	10-30%	<10%		>30%			18
Italy	<10%	<10%	<10%	10-30%		>30%			106
Latvia		10-30%	10-30%	10-30%		>30%			5
Lithuania	10-30%	10-30%	10-30%	10-30%			>30%		12
Luxembourg	>30%	>30%	<10%			10-30%			1
Malta				>30%					0
Netherlands	10-30%	10-30%	10-30%	>30%	<10%	<10%	<10%		36
Poland	10-30%	<10%	10-30%	10-30%		>30%	<10%		116
Portugal				>30%		>30%			8
Slovakia		10-30%	10-30%	>30%		10-30%			10
Slovenia	10-30%	10-30%	10-30%	>30%		10-30%			7
Spain	10-30%		10-30%	10-30%		>30%	10-30%		122
Sweden	>30%	10-30%	10-30%	10-30%	<10%				10
UK	10-30%	10-30%	10-30%	10-30%		10-30%	<10%		94
Baseline emissions, kt	644	676	800	470	166	660	54	215	3686
Reduction from Baseline, kt	174.0	150.1	182.5	272.3	7.1	275.4	26.3	0	1088
% of total reduction	*16%*	*14%*	*17%*	*25%*	*1%*	*25%*	*2%*	*0%*	*100%*

Table 5.17: Measures to reduce NH_3 emissions – high ambition Case “C”

Country	Dairy cows	Other cattle	Pigs	Poultry	Other anim.	Fertilizer use	Processes	Other	Total Reduction, kt
Austria	10-30%	10-30%	>30%	10-30%	<10%	<10%	<10%		18
Belgium	<10%	<10%	>30%	<10%		<10%	<10%		29
Cyprus			>30%	>30%					3
Czech Rep.	10-30%	<10%	>30%	>30%		<10%	<10%		23
Denmark	10-30%	<10%	>30%	10-30%		<10%	<10%		29
Estonia	<10%	<10%	<10%	10-30%		>30%			5
Finland	>30%	10-30%	10-30%	10-30%		<10%	<10%		7
France	10-30%	10-30%	10-30%	>30%	<10%	10-30%	<10%		259
Germany	>30%	10-30%	10-30%	<10%	<10%	10-30%	<10%		164
Greece	<10%	<10%	10-30%	>30%		<10%	<10%		13
Hungary	<10%	<10%	10-30%	>30%	<10%	10-30%	<10%		41
Ireland	10-30%	>30%	10-30%	<10%		10-30%			22
Italy	<10%	<10%	10-30%	10-30%		>30%	<10%		118
Latvia	<10%	10-30%	<10%	10-30%		>30%			6
Lithuania	10-30%	<10%	10-30%	10-30%			>30%		14
Luxembourg	>30%	>30%	10-30%			10-30%			1
Malta				>30%					0
Netherlands	10-30%	10-30%	10-30%	>30%	<10%	<10%	<10%		37
Poland	10-30%	<10%	>30%	10-30%		>30%	<10%		133
Portugal	10-30%	10-30%	10-30%	>30%		10-30%			16
Slovakia	<10%	10-30%	10-30%	>30%		<10%	<10%		13
Slovenia	10-30%	10-30%	10-30%	>30%		10-30%			8
Spain	<10%		10-30%	10-30%	<10%	10-30%	<10%		138
Sweden	10-30%	10-30%	10-30%	10-30%	<10%				12
UK	10-30%	10-30%	10-30%	10-30%		10-30%	<10%		98
Baseline emissions, kt	644	676	800	470	166	660	54	215	3686
Reduction from Baseline, kt	199.1	160.8	250.3	273.7	11.7	275.4	37.6	0	1209
% of total reduction	*16%*	*13%*	*21%*	*23%*	*1%*	*23%*	*3%*	*0%*	*100%*