# SEVENTH INTERIM REPORT

## Cost-effective Control of Acidification and Ground-level Ozone

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Seventh Interim Report to the European Commission, DG-XI

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# Cost-effective Control of Acidification and Ground-level Ozone

## Seventh Interim Report

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# 1 Introduction

There is substantial concern about the environmental impacts of air pollution on the local, regional and global scale. It has been shown that observed levels of various air pollutants can threaten human health, vegetation, wild life, and cause damage to materials. In order to limit the negative effects of air pollution, measures to reduce emissions from a variety of sources have been initiated.

Once emitted, many air pollutants remain in the atmosphere for some time before they are finally deposited on the ground. During this time, they are transported with the air mass over long distances, often crossing national boundaries. As a consequence, at a given site the concentration of pollutants and their deposition on the ground is influenced by a large number of emission sources, frequently in many different countries. Thus, action to efficiently abate air pollution problems has to be coordinated internationally.

Over the last decade several international agreements have been reached in Europe to reduce emissions in a harmonized way. Protocols under the Convention on Long-range Transboundary Air Pollution focus on reducing emissions of sulfur dioxide ($SO_2$), nitrogen oxides ($NO_x$) and volatile organic compounds (VOC). Several directives of the European Union prescribe emission standards for large combustion plants, for mobile sources, and limit the sulfur content in liquid fuels.

Most of the current agreements determine required abatement measures solely in relation to technical and economic characteristics of the sources of emissions, such as available abatement technologies, costs, historic emission levels, etc. No relation is established to the actual environmental impacts of emissions. For achieving overall cost-effectiveness of strategies, however, the justification of potential measures in relation to their environmental benefits must also be taken into account. Recently, progress has been made in quantifying the environmental sensitivities of various ecosystems. Critical loads and critical levels have been established reflecting the maximum exposure of ecosystems to one or several pollutants not leading to environmental damage in the long run. Such threshold values have been determined on a European scale, focusing on acidification and eutrophication as well as on vegetation damage from tropospheric ozone.

It is generally expected that the current policies on emission reductions will greatly reduce the levels of tropospheric ozone. However, the measures will not be sufficient to eliminate the problem everywhere in Europe. To meet the environmental long-term targets aiming at the protection of human health and vegetation, as they are currently discussed in the context of the Commission’s ozone strategy, additional- measures will be necessary. Since most of the low-cost options for abating emissions are already adopted in the current strategies, further action aiming at the sustainability of Europe’s ecosystems will have to embark on more costly measures. Cost-effectiveness will be an important argument for gaining acceptance of proposed policies.

## 1.1 Structure of this Report

This Interim Report to the European Commission is a further step in a series of reports analyzing the features of cost-effective approaches to control European air quality. The first two Interim Reports focused on acidification-related aspects and provided input to the Commission's Acidification Strategy. The following Third and Fourth Interim Reports drew attention to ground-level ozone: The Third Report illustrated the different chemical and meteorological regimes of ozone formation prevailing in Europe and assessed the consequences on strategy development. The Fourth Report explored alternative principles of setting environmental targets and the implication on the distribution of costs and environmental benefits to different regions in Europe. The Fifth Interim Report examined the interaction of acidification and ground-level ozone, while the Sixth Interim Report explored, for a medium ambition environmental ambition level, the robustness of optimized emission ceilings against a number of modified input assumptions and discussed the potential influence of general model uncertainties.

Following the presentation of the Sixth Interim Report, the Commission requested a number of refinements to reflect recent policy decisions taken at the Commission. Consequently, this Seventh Interim Report revisits the central scenarios supporting the proposed emission ceilings, taking into account recent agreements on sulfur in heavy fuel oil, an improved quantitative interpretation of the results of the conciliation process between the European Commission and the European Parliament on the Auto/Oil proposal, and the Council decision on emission standards for heavy duty trucks. Furthermore, it reflects the recent decision of the UN/ECE Working Group on Strategies about the starting point of the negotiations on further emission reductions for the non-EU countries.

This report focuses on scenario results for the modified input assumptions. Descriptions of the general modeling approach, the database and the target setting principles can be found in Part A of the Sixth Interim Report (Amann et al., 1998). Up-to-date detailed information and documentation of the cost curves and the optimization algorithm is available on the Internet under http://www.iiasa.ac.at/~rains.

Section 2 reviews the starting point for the scenario analysis, i.e., the situation in 1990, the expected outcome of the current legislation and the theoretical case, if all available technical emission control measures were applied to the entire stock of emission sources.

Section 3 recalls the environmental interim targets for acidification and ground-level ozone developed in the earlier Interim Reports and presents the revised cost-optimized set of emission reductions to achieve the targets of the central H1 scenario of the Sixth Interim Report. The impacts of modified environmental ambition levels on optimized emission reductions are reported in Section 4, and Section 5 discusses the implications of extending the scope of emission controls beyond the EU-15 countries.

## 1.2 Changes Since the Sixth Interim Report

Since the Sixth Interim Report (Amann *et al*., 1998), the following changes were introduced into the database:

- Change of the REF scenario to reflect the Directive 98/70/EC of the European Parliament and of the Council of 13 October 1998 relating to the quality of petrol and diesel and amending Council Directive 93/12/EEC (OJ, 1998).
- Change of the REF scenario to reflect Directive 98/69/EC of the European Parliament and of the Council of 13 October 1998 relating to measures to be taken against air pollution from motor vehicles and amending Council Directive 70/220/EEC (OJ, 1998).
- Implementation of post-2005 standards for heavy-duty vehicles in the REF scenario reflecting the Common Position reached in December 1998 between the European Parliament and the Council on amending the Directive 88/77/EEC (on the approximation of laws of the Member States relating to the measures to be taken against the emissions of gaseous and particulate pollutants from diesel engines for use in vehicles). For the REF scenario the stricter standards were implemented in two stages (2005/2006 and 2008/2009), and the removal efficiencies have been changed according to the standards in the above document.
- Change of the REF scenario to limit the sulfur content of gas oil for stationary sources to 0.1 percent (Directive on sulfur in liquid fuels).
- Updates of the 'Current Reduction Plans' according to recent information provided by the UN/ECE in December 1998.
- For the non-EU countries, the REF scenario was changed to reflect the decisions taken at the UN/ECE Working Group on Strategies at their August 1998 session. Thereby, for non-EU countries, the CLE estimates are used as the starting point for the optimization.
- Based on detailed discussion with French experts, the emission factors for France for off-road sources and maritime activities (seagoing ships) for 2010 have been revised.
- Modifications to the VOC databases for Ireland, UK, Sweden, Germany and France taking into account latest national information.
- Updates of the French and Dutch ammonia databases.
- For Denmark, the assumptions about the applicability of $NO_x$ control for gas fired power stations were modified to incorporate additional information on size distribution, boiler types, etc. provided by national experts.
- For Belgium, the applicability of some $SO_2$ and $NO_x$ control technologies were modified to reflect findings of the recent assessments performed by Belgium experts.
- For Germany, the national energy scenario was updated with the latest projections on power capacity expansion.
- Poland provided more information to update the VOC database.

These changes, in particular the incorporation of the recent traffic-related decisions, lead in general to lower $NO_x$ emissions for the REF scenario, but, due to the slower implementation schedule, to less overall $NO_x$ reduction potential in the year 2010 than in the previous reports.

# 2 The Situation in 1990, the Expected Impacts of the Current Policies and the Maximum Technically Feasible Reductions

## *2.1 Projected Emissions and Control Costs*

### 2.1.1 The Reference (REF) Scenario for the Year 2010

A Reference scenario has been constructed in order to assess the likely environmental impacts of the current emission control strategies in the year 2010. The scenario takes into account national and international legislation (the CLE case). For the EU-15 countries, emissions resulting from this CLE case were replaced by officially announced emission ceilings (the so-called 'CRP' values), if they were lower than the CLE estimate.

Emissions and control costs for $NO_x$ and VOC in this scenario are presented in Table 2.1. For the EU-15, the revised REF scenario results in a 48 percent cut of $NO_x$ and a 49 percent cut of VOC emissions, compared to 1990.

Table 2.1 also presents costs for $NO_x$ and VOC reductions, given jointly for $NO_x$ and VOC because control technologies used in the transport sector simultaneously reduce the emissions of the two pollutants. European emission control costs for $NO_x$ and VOC emissions amount to 53 billion EURO/year, out of which 47 billion emerge in the EU-15 countries.

Emissions and control costs for $SO_2$ and $NH_3$ in REF scenario are presented in Table 2.2. The REF scenario implies a 71 percent decrease of $SO_2$ emissions of the EU-15 and a 55 percent cut in the non-EU countries. $SO_2$ control costs, calculated from the RAINS cost curves, reach 14 billion EURO/year, of which 77 percent occur in the EU countries. For ammonia, the overall reduction is about 12 percent compared to 1990, and it is evenly distributed between EU and non-EU countries. In many countries reductions are achieved due to decline in the number of animals projected for 2010. The total cost for ammonia reduction in the REF scenario is about 0.7 billion EURO/year.

Table 2.1: Emissions and control costs for $NO_x$ and VOC for 1990 and the Reference (REF) scenario (emissions in kilotons, costs in million EURO/year).

| | $NO_x$ | | | VOC | | | Costs |
|---|---|---|---|---|---|---|---|
| | 1990 | REF | *Change* | 1990 | REF | *Change* | of REF |
| Austria | 192 | 103 | *-46%* | 352 | 205 | *-42%* | 902 |
| Belgium | 351 | 191 | *-46%* | 374 | 193 | *-48%* | 1278 |
| Denmark | 274 | 128 | *-53%* | 182 | 85 | *-53%* | 484 |
| Finland | 276 | 152 | *-45%* | 213 | 110 | *-48%* | 642 |
| France | 1867 | 858 | *-54%* | 2382 | 1223 | *-49%* | 7383 |
| Germany | 2662 | 1184 | *-56%* | 3122 | 1137 | *-64%* | 10549 |
| Greece | 345 | 344 | *0%* | 336 | 267 | *-21%* | 1048 |
| Ireland | 113 | 70 | *-38%* | 110 | 55 | *-50%* | 477 |
| Italy | 2037 | 1130 | *-45%* | 2055 | 1159 | *-44%* | 7868 |
| Luxembourg | 22 | 10 | *-55%* | 19 | 7 | *-63%* | 71 |
| Netherlands | 542 | 280 | *-48%* | 490 | 233 | *-52%* | 1731 |
| Portugal | 208 | 177 | *-15%* | 212 | 144 | *-32%* | 1349 |
| Spain | 1162 | 847 | *-27%* | 1008 | 669 | *-34%* | 5658 |
| Sweden | 338 | 190 | *-44%* | 511 | 290 | *-43%* | 1125 |
| UK | 2839 | 1186 | *-58%* | 2667 | 1351 | *-49%* | 6695 |
| EU-15 | 13226 | 6849 | *-48%* | 14031 | 7128 | *-49%* | 47258 |
| | | | | | | | |
| Albania | 24 | 36 | *50%* | 31 | 41 | *32%* | 0 |
| Belarus | 402 | 316 | *-21%* | 371 | 309 | *-17%* | 0 |
| Bosnia-H. | 80 | 60 | *-25%* | 51 | 48 | *-6%* | 1 |
| Bulgaria | 355 | 297 | *-16%* | 195 | 190 | *-3%* | 4 |
| Croatia | 82 | 91 | *11%* | 103 | 111 | *8%* | 1 |
| Czech Rep. | 546 | 296 | *-46%* | 442 | 305 | *-31%* | 568 |
| Estonia | 84 | 73 | *-13%* | 45 | 49 | *9%* | 0 |
| Hungary | 219 | 198 | *-10%* | 204 | 160 | *-22%* | 420 |
| Latvia | 117 | 118 | *1%* | 63 | 56 | *-11%* | 0 |
| Lithuania | 153 | 138 | *-10%* | 111 | 105 | *-5%* | 0 |
| Norway | 220 | 178 | *-19%* | 297 | 195 | *-34%* | 567 |
| Poland | 1217 | 879 | *-28%* | 797 | 807 | *1%* | 2487 |
| Moldova | 87 | 66 | *-24%* | 50 | 42 | *-16%* | 0 |
| Romania | 518 | 458 | *-12%* | 503 | 504 | *0%* | 2 |
| Russia | 3486 | 2653 | *-24%* | 3542 | 2787 | *-21%* | 21 |
| Slovakia | 219 | 132 | *-40%* | 151 | 140 | *-7%* | 331 |
| Slovenia | 60 | 36 | *-40%* | 55 | 40 | *-27%* | 93 |
| Switzerland | 163 | 79 | *-52%* | 278 | 144 | *-48%* | 831 |
| FYR Macedonia | 39 | 29 | *-26%* | 19 | 19 | *0%* | 1 |
| Ukraine | 1888 | 1433 | *-24%* | 1161 | 851 | *-27%* | 0 |
| Yugoslavia | 211 | 152 | *-28%* | 142 | 139 | *-2%* | 3 |
| Non-EU | 10170 | 7718 | *-24%* | 8609 | 7041 | *-18%* | 5332 |
| | | | | | | | |
| Total | 23396 | 14567 | *-38%* | 22640 | 14169 | *-37%* | 52590 |

Table 2.2: Emissions and control costs for $SO_2$ and $NH_3$ for 1990 and the Reference (REF) scenario (emissions in kilotons, costs in million EURO/year).

| | $SO_2$ 1990 | $SO_2$ REF | $SO_2$ *Change* | Costs of REF | $NH_3$ 1990 | $NH_3$ REF | $NH_3$ *Change* | Costs of REF |
|---|---|---|---|---|---|---|---|---|
| Austria | 93 | 40 | *-57%* | 191 | 77 | 67 | *-13%* | 0 |
| Belgium | 336 | 193 | *-43%* | 426 | 97 | 96 | *-1%* | 0 |
| Denmark | 182 | 90 | *-51%* | 138 | 77 | 72 | *-6%* | 0 |
| Finland | 226 | 116 | *-49%* | 247 | 40 | 31 | *-23%* | 0 |
| France | 1250 | 448 | *-64%* | 1276 | 807 | 777 | *-4%* | 0 |
| Germany | 5280 | 581 | *-89%* | 3264 | 757 | 571 | *-25%* | 0 |
| Greece | 504 | 546 | *8%* | 434 | 80 | 74 | *-8%* | 0 |
| Ireland | 178 | 66 | *-63%* | 132 | 127 | 126 | *-1%* | 9 |
| Italy | 1679 | 567 | *-66%* | 1776 | 462 | 432 | *-6%* | 0 |
| Luxembourg | 14 | 4 | *-71%* | 13 | 7 | 7 | *0%* | 15 |
| Netherlands | 201 | 73 | *-64%* | 340 | 233 | 136 | *-42%* | 196 |
| Portugal | 284 | 141 | *-50%* | 181 | 71 | 67 | *-6%* | 0 |
| Spain | 2189 | 774 | *-65%* | 809 | 352 | 353 | *0%* | 28 |
| Sweden | 119 | 67 | *-44%* | 316 | 61 | 48 | *-21%* | 113 |
| UK | 3805 | 980 | *-74%* | 1269 | 329 | 297 | *-10%* | 0 |
| EU-15 | 16339 | 4687 | *-71%* | 10813 | 3578 | 3154 | *-12%* | 361 |
| | | | | | | | | |
| Albania | 72 | 55 | *-24%* | 0 | 32 | 35 | *9%* | 0 |
| Belarus | 843 | 494 | *-41%* | 0 | 219 | 163 | *-26%* | 0 |
| Bosnia-H. | 487 | 415 | *-15%* | 0 | 31 | 23 | *-26%* | 0 |
| Bulgaria | 1842 | 846 | *-54%* | 153 | 141 | 126 | *-11%* | 0 |
| Croatia | 180 | 70 | *-61%* | 52 | 40 | 37 | *-8%* | 0 |
| Czech Rep. | 1873 | 366 | *-80%* | 411 | 107 | 108 | *1%* | 0 |
| Estonia | 275 | 175 | *-36%* | 0 | 29 | 29 | *0%* | 0 |
| Hungary | 913 | 546 | *-40%* | 166 | 120 | 137 | *14%* | 0 |
| Latvia | 121 | 104 | *-14%* | 0 | 43 | 35 | *-19%* | 0 |
| Lithuania | 213 | 107 | *-50%* | 0 | 80 | 81 | *1%* | 0 |
| Norway | 52 | 32 | *-38%* | 56 | 23 | 21 | *-9%* | 0 |
| Poland | 3001 | 1397 | *-53%* | 855 | 505 | 541 | *7%* | 0 |
| Moldova | 197 | 117 | *-41%* | 0 | 47 | 48 | *2%* | 0 |
| Romania | 1331 | 594 | *-55%* | 155 | 292 | 304 | *4%* | 0 |
| Russia | 5012 | 2344 | *-53%* | 694 | 1282 | 894 | *-30%* | 0 |
| Slovakia | 548 | 137 | *-75%* | 91 | 60 | 47 | *-22%* | 0 |
| Slovenia | 200 | 71 | *-65%* | 35 | 23 | 21 | *-9%* | 0 |
| Switzerland | 43 | 26 | *-40%* | 118 | 72 | 66 | *-8%* | 0 |
| FYR Macedonia | 107 | 81 | *-24%* | 0 | 17 | 16 | *-6%* | 0 |
| Ukraine | 3706 | 1488 | *-60%* | 328 | 729 | 649 | *-11%* | 0 |
| Yugoslavia | 585 | 269 | *-54%* | 88 | 90 | 82 | *-9%* | 0 |
| Non-EU | 21599 | 9732 | *-55%* | 3202 | 3980 | 3462 | *-13%* | 0 |
| | | | | | | | | |
| Total | 37938 | 14419 | *-62%* | 14016 | 7558 | 6616 | *-12%* | 361 |

### 2.1.2 Full Implementation of Current Control Technologies in the Year 2010

A further scenario, the Maximum Feasible Reductions (MFR) scenario has been constructed to illustrate the potential of a full application of current control technologies and to quantify possible progress towards the ultimate target of full achievement of the environmental long-term targets.

Based on the baseline energy scenario, the MFR scenario presented in this report simulates the hypothetical case with a complete implementation of the currently available most efficient emission control technologies to the entire stock of emission sources. In contrast to the assumptions in the previous reports, constraints imposed by current legislation and historically observed turnover rates of the capital stock are ignored in this 'ultimate' MFR scenario. However, by definition, changes to the structure and the levels of economic activities and energy consumption, e.g., as reactions to excessive emission control costs or the effects of non-technical instruments to control emissions, are excluded.

It is important to stress that this hypothetical 'maximum potential' scenario assumes a complete penetration of the presently best available emission control techniques. This implies that also presently installed equipment that has lower reduction efficiencies will be replaced by more efficient measures, and that this replacement might occur before the end of its normal technical lifetime.

In reality, however, the limited turnover of capital stock is an important factor determining the achievable emission reductions. The methodology for deriving the cost curves in the RAINS model takes full account of these limitations and distinguishes different emission control efficiencies for the several vintages of emission control equipment (e.g., for flue gas desulfurization and mobile sources). Furthermore, the cost curves constructed by RAINS exclude early retirement of already existing equipment. Consequently, these cost curves which were used in the subsequent optimization analyses do not reflect the full theoretical potential for reducing emissions.

Table 2.3 lists the resulting emissions of $NO_x$ and VOC for the REF and the 'ultimate' MFR scenarios. For all of Europe, the MFR scenario results in an 80 percent cut of $NO_x$ emissions relative to 1990, and a 75 percent decline in VOC emissions. Total costs amount to more than 110 billion EURO/year.

Table 2.4 presents the same type of information for $SO_2$ and ammonia. For $SO_2$, the achievable emission reductions for entire Europe are about 90 percent at costs of about 23 billion EURO/year. For ammonia, maximum reductions could cut the emissions by 42 percent compared to 1990 at costs of 22 billion EURO/year. An 11 percent reduction (0.8 million tons $NH_3$) is caused by the projected decline in livestock numbers; the remaining 31 percent (2.3 million tons $NH_3$) is calculated as the consequence of technical control measures.

Table 2.3: $NO_x$ and VOC emissions for the REF case and the hypothetical maximum technically feasible reductions (MFR) scenario (percentage changes relate to the year 1990). Emission control costs for the MFR scenario in million EURO/yr

| | $NO_x$ emissions | | | | VOC emissions | | | | Costs |
|---|---|---|---|---|---|---|---|---|---|
| | REF | | $MFR_{ult}$ | | REF | | $MFR_{ult}$ | | $NO_x$&VOC |
| | kt | *Change* | kt | *Change* | kt | *Change* | kt | *Change* | $MFR_{ult}$ |
| Austria | 103 | *-46%* | 54 | *-72%* | 205 | *-42%* | 97 | *-72%* | 1496 |
| Belgium | 191 | *-46%* | 81 | *-77%* | 193 | *-48%* | 85 | *-77%* | 2101 |
| Denmark | 128 | *-53%* | 49 | *-82%* | 85 | *-53%* | 49 | *-73%* | 808 |
| Finland | 152 | *-45%* | 56 | *-80%* | 110 | *-48%* | 49 | *-77%* | 1026 |
| France | 858 | *-54%* | 383 | *-79%* | 1223 | *-49%* | 658 | *-73%* | 11734 |
| Germany | 1184 | *-56%* | 622 | *-77%* | 1137 | *-64%* | 644 | *-79%* | 15258 |
| Greece | 344 | *0%* | 127 | *-63%* | 267 | *-21%* | 100 | *-70%* | 2220 |
| Ireland | 70 | *-38%* | 27 | *-76%* | 55 | *-50%* | 30 | *-73%* | 716 |
| Italy | 1130 | *-45%* | 396 | *-81%* | 1159 | *-44%* | 617 | *-70%* | 12482 |
| Luxembourg | 10 | *-55%* | 4 | *-80%* | 7 | *-63%* | 5 | *-76%* | 110 |
| Netherlands | 280 | *-48%* | 127 | *-77%* | 233 | *-52%* | 136 | *-72%* | 2735 |
| Portugal | 177 | *-15%* | 51 | *-76%* | 144 | *-32%* | 68 | *-68%* | 2226 |
| Spain | 847 | *-27%* | 263 | *-77%* | 669 | *-34%* | 365 | *-64%* | 8798 |
| Sweden | 190 | *-44%* | 75 | *-78%* | 290 | *-43%* | 128 | *-74%* | 1899 |
| UK | 1186 | *-58%* | 521 | *-82%* | 1351 | *-49%* | 841 | *-68%* | 11063 |
| EU-15 | 6849 | *-48%* | 2836 | *-79%* | 7128 | *-49%* | 3872 | *-72%* | 74672 |
| Albania | 36 | *50%* | 6 | *-74%* | 41 | *32%* | 9 | *-72%* | 165 |
| Belarus | 316 | *-21%* | 56 | *-86%* | 309 | *-17%* | 71 | *-81%* | 1071 |
| Bosnia-H. | 60 | *-25%* | 11 | *-86%* | 48 | *-6%* | 11 | *-79%* | 222 |
| Bulgaria | 297 | *-16%* | 61 | *-83%* | 190 | *-3%* | 37 | *-81%* | 1100 |
| Croatia | 91 | *11%* | 16 | *-81%* | 111 | *8%* | 25 | *-76%* | 416 |
| Czech Rep. | 296 | *-46%* | 78 | *-86%* | 305 | *-31%* | 102 | *-77%* | 1821 |
| Estonia | 73 | *-13%* | 13 | *-85%* | 49 | *9%* | 9 | *-80%* | 269 |
| Hungary | 198 | *-10%* | 50 | *-77%* | 160 | *-22%* | 50 | *-75%* | 1436 |
| Latvia | 118 | *1%* | 23 | *-81%* | 56 | *-11%* | 11 | *-82%* | 346 |
| Lithuania | 138 | *-10%* | 25 | *-83%* | 105 | *-5%* | 33 | *-70%* | 505 |
| Norway | 178 | *-19%* | 49 | *-78%* | 195 | *-34%* | 124 | *-58%* | 1063 |
| Poland | 879 | *-28%* | 266 | *-78%* | 807 | *1%* | 284 | *-64%* | 6974 |
| Moldova | 66 | *-24%* | 14 | *-84%* | 42 | *-16%* | 10 | *-80%* | 215 |
| Romania | 458 | *-12%* | 100 | *-81%* | 504 | *0%* | 126 | *-75%* | 1826 |
| Russia | 2653 | *-24%* | 527 | *-85%* | 2787 | *-21%* | 644 | *-82%* | 10431 |
| Slovakia | 132 | *-40%* | 42 | *-81%* | 140 | *-7%* | 57 | *-62%* | 1011 |
| Slovenia | 36 | *-40%* | 8 | *-87%* | 40 | *-27%* | 12 | *-78%* | 285 |
| Switzerland | 79 | *-52%* | 41 | *-75%* | 144 | *-48%* | 72 | *-74%* | 1270 |
| FYR Maced. | 29 | *-26%* | 5 | *-86%* | 19 | *0%* | 4 | *-79%* | 102 |
| Ukraine | 1433 | *-24%* | 325 | *-83%* | 851 | *-27%* | 165 | *-86%* | 4587 |
| Yugoslavia | 152 | *-28%* | 27 | *-87%* | 139 | *-2%* | 26 | *-82%* | 600 |
| Non-EU | 7718 | *-24%* | 1744 | *-83%* | 7041 | *-18%* | 1883 | *-78%* | 35715 |
| Total | 23396 | *-38%* | 4580 | *-80%* | 14169 | *-37%* | 5755 | *-75%* | 110387 |

Table 2.4: Emissions and control costs for REF and the Maximum technically feasible reductions (MFR) for $SO_2$ and $NH_3$. Percentage changes relate to the year 1990.

| | $SO_2$ emissions | | | | | $NH_3$ emissions | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | REF | | $MFR_{ult}$ | | | REF | | $MFR_{ult}$ | | |
| | kt | *Change* | kt | *Change* | Costs | kt | *Change* | kt | *Change* | Costs |
| Austria | 40 | *-57%* | 30 | *-68%* | 207 | 67 | *-13%* | 48 | -38% | 362 |
| Belgium | 193 | *-43%* | 60 | *-82%* | 627 | 96 | *-1%* | 57 | -42% | 496 |
| Denmark | 90 | *-51%* | 19 | *-90%* | 268 | 72 | *-6%* | 40 | -47% | 693 |
| Finland | 116 | *-49%* | 67 | *-71%* | 393 | 31 | *-23%* | 23 | -43% | 143 |
| France | 448 | *-64%* | 165 | *-87%* | 1605 | 777 | *-4%* | 541 | -33% | 2217 |
| Germany | 581 | *-89%* | 311 | *-94%* | 3719 | 571 | *-25%* | 353 | -53% | 1816 |
| Greece | 546 | *8%* | 87 | *-83%* | 809 | 74 | *-8%* | 59 | -26% | 222 |
| Ireland | 66 | *-63%* | 21 | *-88%* | 191 | 126 | *-1%* | 111 | -13% | 464 |
| Italy | 567 | *-66%* | 194 | *-88%* | 2067 | 432 | *-6%* | 282 | -39% | 683 |
| Luxembourg | 4 | *-71%* | 2 | *-84%* | 15 | 7 | *0%* | 7 | -4% | 15 |
| Netherlands | 73 | *-64%* | 47 | *-76%* | 343 | 136 | *-42%* | 105 | -55% | 1072 |
| Portugal | 141 | *-50%* | 29 | *-90%* | 285 | 67 | *-6%* | 46 | -36% | 374 |
| Spain | 774 | *-65%* | 166 | *-92%* | 1251 | 353 | *0%* | 225 | -36% | 2043 |
| Sweden | 67 | *-44%* | 52 | *-56%* | 423 | 48 | *-21%* | 44 | -28% | 230 |
| UK | 980 | *-74%* | 286 | *-92%* | 2647 | 297 | *-10%* | 218 | -34% | 770 |
| EU-15 | 4687 | *-71%* | 1535 | *-91%* | 14850 | 3154 | *-12%* | 2156 | -40% | 11600 |
| Albania | 55 | *-24%* | 7 | *-91%* | 44 | 35 | *9%* | 25 | -23% | 60 |
| Belarus | 494 | *-41%* | 49 | *-94%* | 288 | 163 | *-26%* | 103 | -53% | 433 |
| Bosnia-H. | 415 | *-15%* | 23 | *-95%* | 143 | 23 | *-26%* | 17 | -45% | 78 |
| Bulgaria | 846 | *-54%* | 130 | *-93%* | 365 | 126 | *-11%* | 86 | -39% | 295 |
| Croatia | 70 | *-61%* | 17 | *-91%* | 102 | 37 | *-8%* | 22 | -46% | 119 |
| Czech Rep. | 366 | *-80%* | 100 | *-95%* | 582 | 108 | *1%* | 72 | -33% | 411 |
| Estonia | 175 | *-36%* | 13 | *-95%* | 114 | 29 | *0%* | 16 | -45% | 88 |
| Hungary | 546 | *-40%* | 286 | *-69%* | 331 | 137 | *14%* | 73 | -40% | 493 |
| Latvia | 104 | *-14%* | 18 | *-85%* | 80 | 35 | *-19%* | 19 | -56% | 113 |
| Lithuania | 107 | *-50%* | 22 | *-90%* | 84 | 81 | *1%* | 49 | -38% | 246 |
| Norway | 32 | *-38%* | 17 | *-68%* | 67 | 21 | *-9%* | 17 | -27% | 108 |
| Poland | 1397 | *-53%* | 367 | *-88%* | 2096 | 541 | *7%* | 367 | -27% | 1527 |
| Moldova | 117 | *-41%* | 19 | *-90%* | 69 | 48 | *2%* | 29 | -39% | 127 |
| Romania | 594 | *-55%* | 93 | *-93%* | 420 | 304 | *4%* | 206 | -30% | 834 |
| Russia | 2344 | *-53%* | 539 | *-89%* | 1888 | 894 | *-30%* | 571 | -55% | 2943 |
| Slovakia | 137 | *-75%* | 68 | *-88%* | 147 | 47 | *-22%* | 30 | -50% | 173 |
| Slovenia | 71 | *-65%* | 10 | *-95%* | 79 | 21 | *-9%* | 12 | -49% | 64 |
| Switzerland | 26 | *-40%* | 12 | *-72%* | 151 | 66 | *-8%* | 54 | -25% | 187 |
| FYR Maced. | 81 | *-24%* | 5 | *-95%* | 71 | 16 | *-6%* | 11 | -34% | 43 |
| Ukraine | 1488 | *-60%* | 368 | *-90%* | 1035 | 649 | *-11%* | 406 | -44% | 2126 |
| Yugoslavia | 269 | *-54%* | 29 | *-95%* | 387 | 82 | *-9%* | 54 | -40% | 346 |
| Non-EU | 9732 | *-55%* | 2193 | *-90%* | 8544 | 3462 | *-13%* | 2237 | -44% | 10813 |
| Total | 14419 | *-62%* | 3728 | *-90%* | 23394 | 6616 | *-12%* | 4394 | -42% | 22413 |

## 2.2 Environmental Effects

### 2.2.1 Ground-level Ozone

There are several statistics against which improvement in ozone exposure could be evaluated. This report provides the following analyses:

- In order to present the improvements in generally understandable notions, maps indicate the remaining days on which the WHO health guideline (60 ppb) and the 90 ppb levels are exceeded. For each of these criteria, two maps are provided: one map displays the highest value (number of days) out of the five years meteorological regimes, while the second presents the maximum of the three-years moving averages over the five years.
- The second series of maps shows the AOT60 values, which were used as a surrogate health-risk indicator for the optimization. For the AOT60, the second highest value out of the five years meteorologies is presented.
- The third series of maps presents the excess AOT40 over the critical level of 3000 ppb.hours, in order to relate to the critical level for vegetation protection.

#### 2.2.1.1 Health-related Ozone Exposure

Figure 2.1 displays the number of days on which the WHO health guideline value (60 ppb, eight-hours moving average) was exceeded with the 1990 emissions. The map shows the three-years average moving over the meteorological conditions of the five available year. Most frequent excess is calculated for Italy (about 60 days), while northern France experienced about 50 days and Germany 30-40 days. Spain and Portugal, Greece, Ireland and the UK are mainly between 10 and 20, while Scandinavia show typically below 10 days excess.

The emission controls calculated for the REF case ($NO_x$ - 48 percent, VOC -49 percent compared to 1990) are expected to have profound impacts on ozone exposure. The maximum number of violations is expected to decline to 35 in France, about 30 in Italy and approximately 25 in Germany (Figure 2.2).

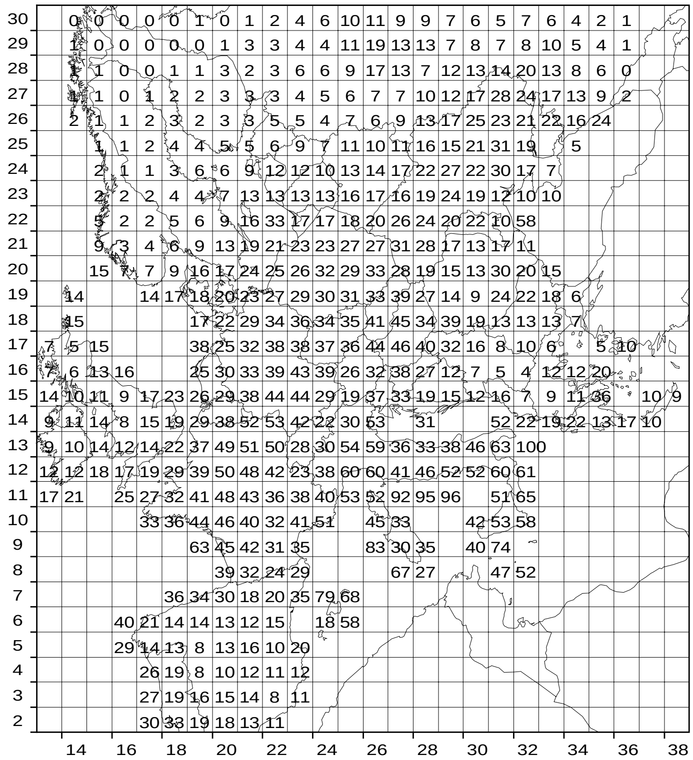

Figure 2.1: Number of days with ozone above 60 ppb, emissions of 1990, maximum of the three-years moving average over the five meteorological years

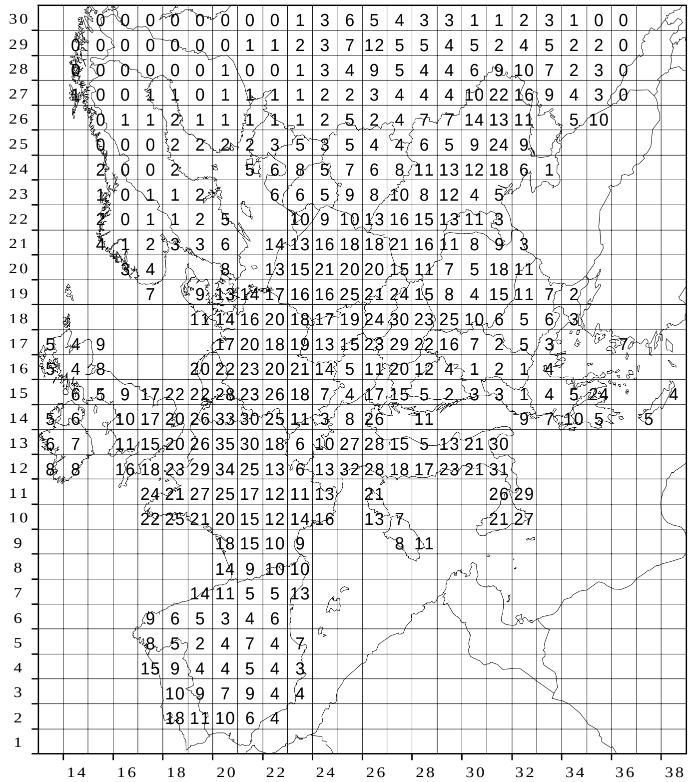

Figure 2.2: Number of days with ozone above 60 ppb, emissions of the REF case, maximum of the three-years moving average over the five meteorological years

For comparison, Figure 2.3 and Figure 2.4 present the situation for days exceeding a 90 ppb eight-hour mean concentration. While in 1990 the maximum was at about 10 days in the Benelux region, the frequency is expected to decline to not more than 3 days.

Figure 2.5 illustrates that for the emissions of 1990 and using the meteorological conditions of five years, the second highest (rural) AOT60 of more than 6 ppm.hours occurred in northern France, Belgium and Germany. In many other parts of France, Germany and Benelux, the AOT60 was modeled in a range of 7-8 ppm.hours. Typical rural values in the UK and Austria were between 2 and 3 ppm.hours, while the highest AOT60 in Spain and Greece was between 1 and 2 ppm.hours. Portugal is estimated at 2 ppm.hours, while Scandinavia did not experience significant excess of the AOT60.

It is interesting to note that there is not a 1:1 relationship between the AOT60 and the number of days across all regions in Europe, indicating that the amount by which the 60 ppb criterion is exceeded varies over Europe. Whereas the highest AOT60 is expected for the northern part of Europe (France/Belgium/Germany), large numbers of days exceeding the 60 ppb threshold are also found in Italy, where the AOT60 is typically 20 to 30 percent lower than in northern Europe. A detailed analysis of the available monitoring results is presented in van Hout (1998). This phenomenon underlines the observation that ozone exposure shows different temporal characteristics in different parts of Europe, a fact which is important to take into account when designing emission control strategies.

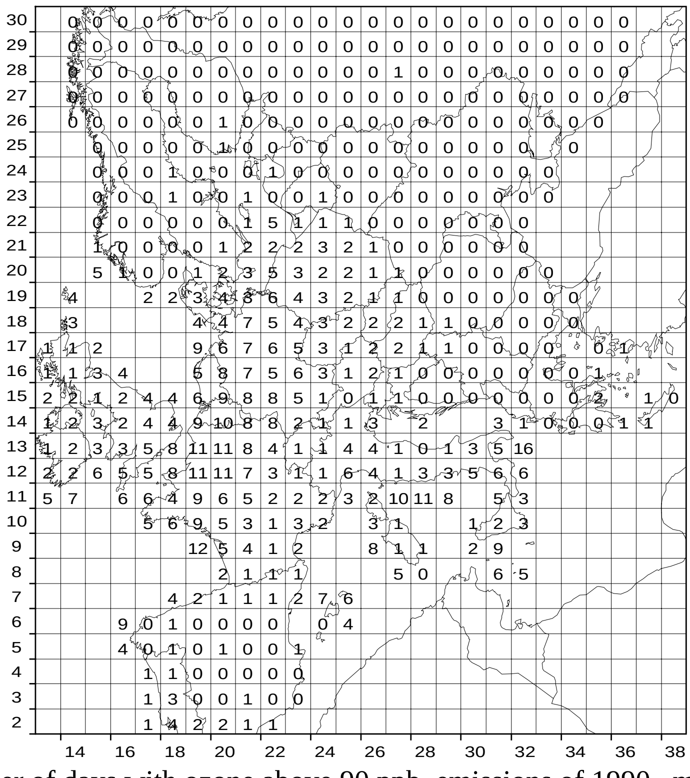


Figure 2.3: Number of days with ozone above 90 ppb, emissions of 1990, maximum of the three-years moving average over the five meteorological years

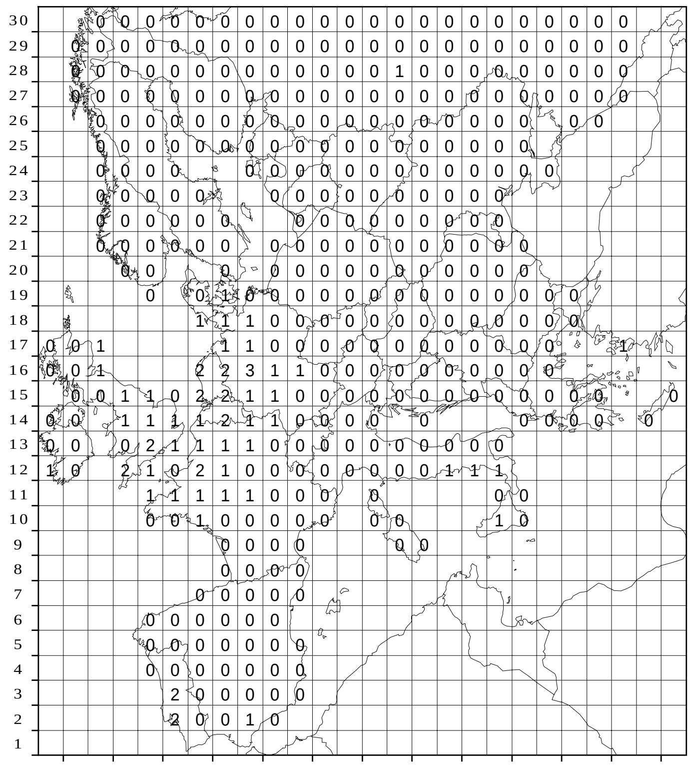


Figure 2.4: Number of days with ozone above 90 ppb, emissions of the REF case, maximum of the three-years moving average over the five meteorological years

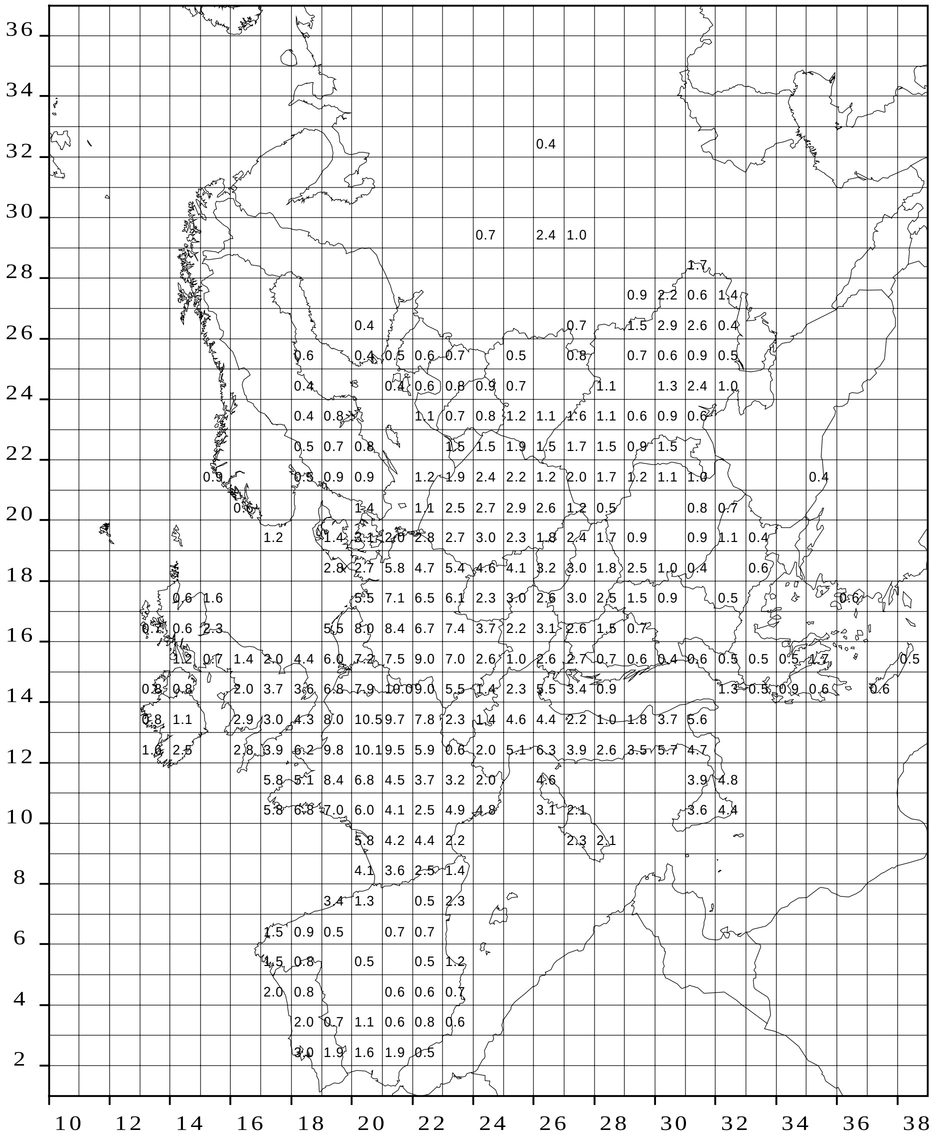


Figure 2.5: The AOT60 modelled for the emissions of 1990, second highest value of five years meteorologies (in ppm.hours)

Table 2.5 presents two different types of population exposure for the AOT60. The cumulative index reflects for each country the total exposure of a population and is expressed in person.ppm.hours. The RAINS model calculates these indices on a grid basis (using gridded data on AOT60 and population); in a second step these grid values are aggregated to the country level. The indices presented in this report use the AOT60 concentrations per grid, representing the rural ozone concentrations, and the total population per grid in 1990. Inaccuracies may occur for grids with major urban areas, where the rural ozone concentrations used for these analysis present an upper bound for the concentrations in the cities, and are lower than the concentrations occurring in the city plumes (Kindbom and Grennfelt, 1998). The 'average' indicator reflects the average exposure of a person in a country, calculated from gridded data. It is important to stress that these indices may not be used to derive estimates of health damage, for which more detailed information is deemed necessary. In the context of this report, these indices provide relative measures to enable a quick comparison of different scenarios.

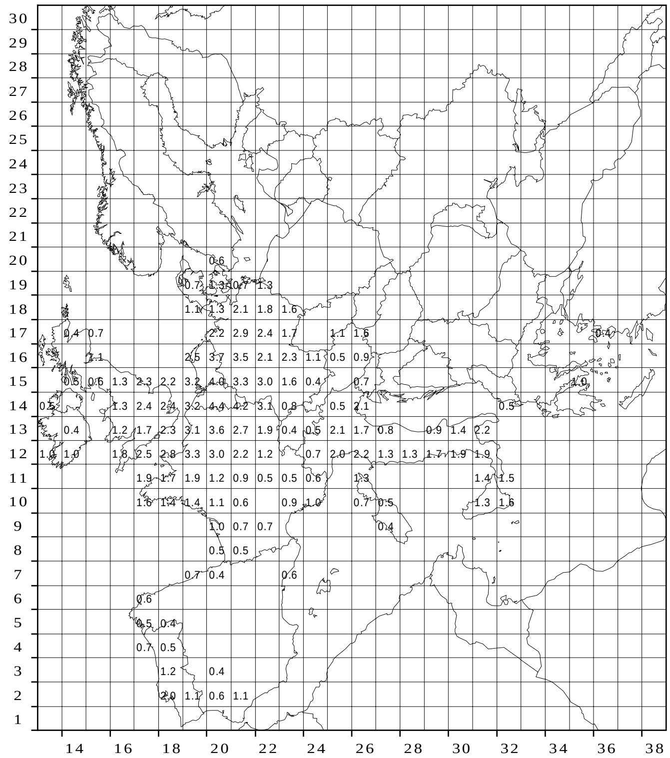


Figure 2.6: The AOT60 modelled for the emissions of the REF case, second highest value of five years meteorologies (in ppm.hours)

As shown in the table, in 1990 the average exposure was highest in Luxembourg, Belgium, France, Germany and the Netherlands; the highest cumulative exposure (due to the large population) occurred in Germany, France, Italy and the UK. The cumulative exposure of the population in the EU-15 countries is expected to decline by 58 percent as a result of the current policy. Larger improvements occur in Austria (-81 percent) and the Scandinavian countries (60-70 percent), while for the UK and Netherlands a decrease in AOT60 by about 40 percent could be expected.

Table 2.5: Population exposure indices for 1990, REF and the ultimate MFR scenario

| | Cumulative population exposure index (million persons.ppm.hours) | | | Average population exposure index (ppm.hours) | | |
|---|---|---|---|---|---|---|
| | 1990 | REF | $MFR_{ult}$ | 1990 | REF | $MFR_{ult}$ |
| Austria | 16 | 3 | 0 | 2.0 | 0.5 | 0.0 |
| Belgium | 71 | 34 | 7 | 6.5 | 3.1 | 0.6 |
| Denmark | 9 | 3 | 0 | 1.8 | 0.5 | 0.0 |
| Finland | 0 | 0 | 0 | 0.1 | 0.0 | 0.0 |
| France | 310 | 89 | 9 | 5.5 | 1.6 | 0.2 |
| Germany | 405 | 140 | 17 | 5.1 | 1.8 | 0.2 |
| Greece | 7 | 4 | 0 | 0.7 | 0.4 | 0.0 |
| Ireland | 3 | 1 | 0 | 0.8 | 0.3 | 0.0 |
| Italy | 183 | 63 | 0 | 3.2 | 1.1 | 0.0 |
| Luxembourg | 3 | 1 | 0 | 8.5 | 3.0 | 0.6 |
| Netherlands | 73 | 38 | 9 | 4.9 | 2.6 | 0.6 |
| Portugal | 16 | 8 | 0 | 1.6 | 0.8 | 0.0 |
| Spain | 35 | 7 | 0 | 0.9 | 0.2 | 0.0 |
| Sweden | 4 | 0 | 0 | 0.4 | 0.0 | 0.0 |
| UK | 125 | 77 | 12 | 2.2 | 1.3 | 0.2 |
| EU-15 | 1259 | 466 | 53 | 3.5 | 1.3 | 0.1 |
| | | | | | | |
| Albania | 1 | 0 | 0 | 0.4 | 0.0 | 0.0 |
| Belarus | 4 | 1 | 0 | 0.4 | 0.1 | 0.0 |
| Bosnia-H | 3 | 0 | 0 | 0.7 | 0.1 | 0.0 |
| Bulgaria | 4 | 1 | 0 | 0.4 | 0.1 | 0.0 |
| Croatia | 8 | 3 | 0 | 1.8 | 0.6 | 0.0 |
| Czech Rep. | 34 | 11 | 0 | 3.3 | 1.0 | 0.0 |
| Estonia | 0 | 0 | 0 | 0.2 | 0.0 | 0.0 |
| Hungary | 27 | 12 | 0 | 2.6 | 1.1 | 0.0 |
| Latvia | 1 | 0 | 0 | 0.4 | 0.1 | 0.0 |
| Lithuania | 2 | 0 | 0 | 0.6 | 0.1 | 0.0 |
| Norway | 1 | 0 | 0 | 0.1 | 0.0 | 0.0 |
| Poland | 91 | 36 | 0 | 2.4 | 0.9 | 0.0 |
| R.of Moldova | 3 | 1 | 0 | 0.7 | 0.2 | 0.0 |
| Romania | 17 | 6 | 0 | 0.8 | 0.3 | 0.0 |
| Russia | 21 | 7 | 0 | 0.2 | 0.1 | 0.0 |
| Slovakia | 15 | 6 | 0 | 2.8 | 1.1 | 0.0 |
| Slovenia | 4 | 1 | 0 | 2.2 | 0.7 | 0.0 |
| Switzerland | 14 | 2 | 0 | 2.1 | 0.3 | 0.0 |
| FYR of Maced. | 0 | 0 | 0 | 0.1 | 0.0 | 0.0 |
| Ukraine | 45 | 14 | 0 | 0.9 | 0.3 | 0.0 |
| Yugoslavia | 8 | 3 | 0 | 0.7 | 0.2 | 0.0 |
| Non-EU | 306 | 103 | 0 | 1.0 | 0.3 | 0.0 |
| | | | | | | |
| Total | 1565 | 570 | 53 | 2.3 | 0.8 | 0.1 |

It is important to mention that there are some areas where, despite - or because of - the anticipated emission reductions of the REF scenario, for individual years the AOT60 is expected to slightly increase as a result of current policy. Using mean meteorology, however, masks the increase occurring in individual years.

The explanation for this increase is related to the ozone formation chemistry. Put in a rather simplistic way, very high NO concentrations (in areas with high $NO_x$ emissions) have, i.a., two effects: (a) they lead to the titration of ozone, i.e., the conversion of ozone and NO into $NO_2$, and (b) they cause a (partial) depletion of OH radicals. This resulting shortage of OH radicals at such high $NO_x$ levels limits ozone production. Reducing $NO_x$ emissions from such a high level will increase the available OH radicals, and more ozone will be produced, until $NO_x$ emissions are so low that the ozone production will be limited by the available $NO_2$ molecules. As indicated in Part A of the Sixth Interim Report, reducing $NO_x$ will lead for some time to increased ozone. Beyond a certain $NO_x$ reduction level, however, ozone will decline again.

Figure 2.7 supports this explanation by illustrating the emission densities in 1990. It is important to realize that the emissions in the areas where the increase occurs (UK, Belgium, Netherlands, etc.) are up to a factor of 10 higher than in other industrialized European regions (compare e.g., southern Germany).

It is also important to realize that this ozone increase disappears for the maximum feasible emission reductions. This means that sufficiently high $NO_x$ reductions (which are considered as technically feasible) can overcome the temporary ozone increase everywhere.

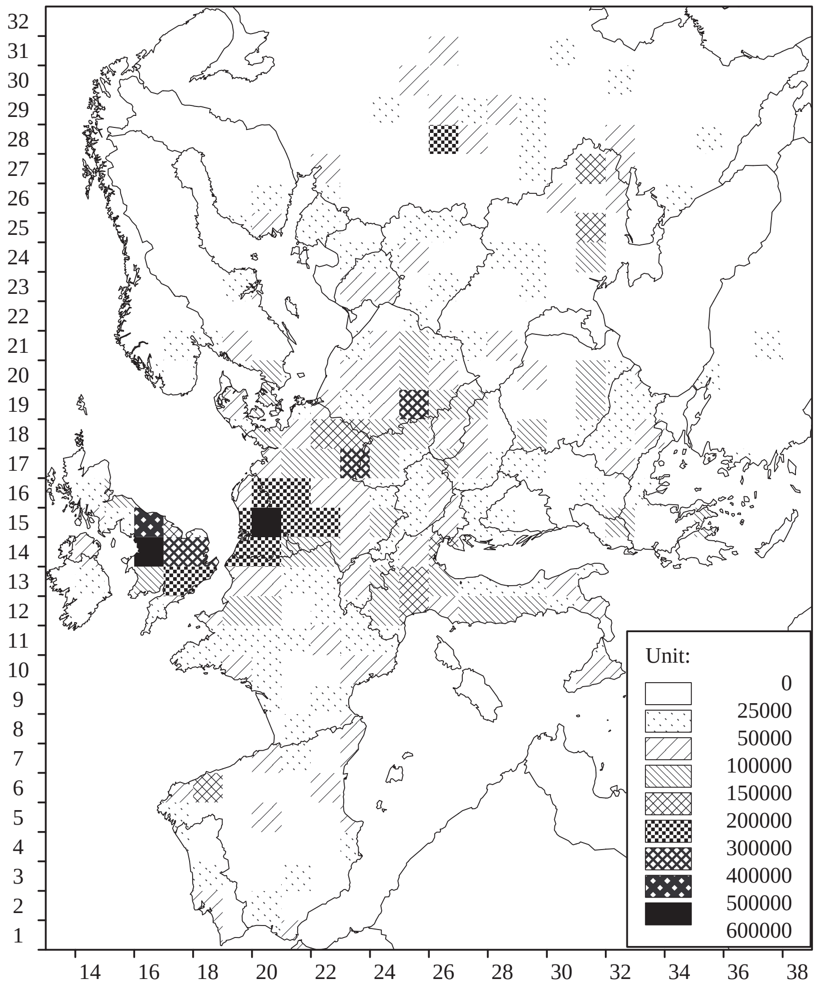


Figure 2.7: $NO_x$ emissions per EMEP grid cell in 1990 (in tons)

## 2.2.1.2 Vegetation-related Ozone Exposure

Figure 2.8 displays the excess AOT40 (over the critical level of 3 ppm.hours) calculated for the emissions of the year 1990 using the five years mean meteorology. The map clearly shows that in most countries the critical level for vegetation was exceeded. The only exceptions occur in parts of the Scandinavian countries and of Russia. In an area extending from Paris over Belgium and Netherlands to Germany the excess AOT40 reached 16 ppm.hours, i.e., it exceeded the critical level by more than a factor of five. It is important to note that ozone levels in many areas, which do not experience significant excess of the AOT60, exceed the AOT40 criterion considerably. This applies particularly to the Mediterranean countries and some Alpine regions.

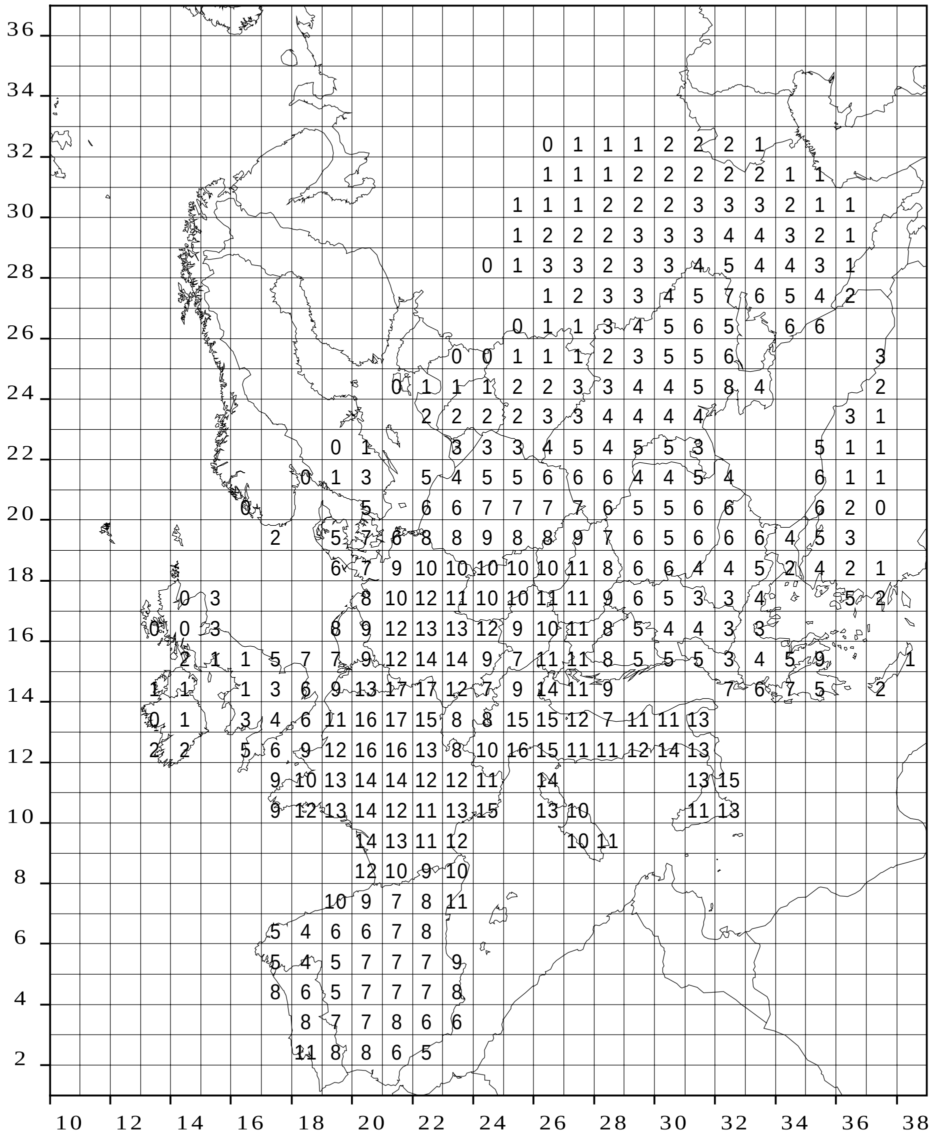


Figure 2.8: Excess AOT40 (above the critical level of 3 ppm.hours) for the emissions of 1990, in ppm.hours

The emission reductions of the Reference scenario will generally lead to a decline of the excess AOT40, but will not significantly increase the protected area (Figure 2.9). Peak levels are in a range of 10-12 ppm.hours.

Table 2.6 introduces two vegetation-related exposure indices. The cumulative vegetation exposure index is calculated as the excess AOT40 (i.e., the AOT40 in excess of the critical level of 3 ppm.hours) multiplied by the area of ecosystems that is exposed to the excess concentration. The index is calculated on a grid resolution, considering agricultural land, natural vegetation and forest areas. The average vegetation exposure index reflects the average excess AOT40 (over all grids in a country). The estimate of these indices is based on rural ozone concentrations.

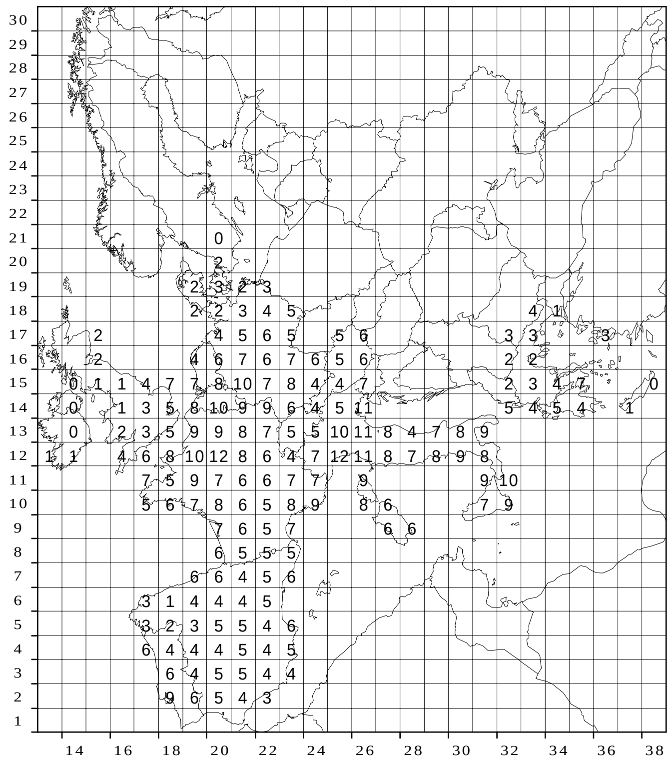


Figure 2.9: Excess AOT40 (above the critical level of 3 ppm.hours) for the emissions of the REF scenario, in ppm.hours

Table 2.6: Vegetation exposure indices for 1990, the REF and the ultimate MFR case

| | Cumulative vegetation exposure index (1000 km$^2$.excess ppm.hours) | | | Average vegetation exposure index (excess ppm.hours) | | |
|---|---|---|---|---|---|---|
| | 1990 | REF | $MFR_{ult}$ | 1990 | REF | $MFR_{ult}$ |
| Austria | 468 | 257 | 37 | 9.0 | 5.0 | 0.7 |
| Belgium | 177 | 141 | 82 | 11.4 | 9.1 | 5.3 |
| Denmark | 141 | 53 | 0 | 4.7 | 1.8 | 0.0 |
| Finland | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 |
| France | 4158 | 2345 | 743 | 12.9 | 7.3 | 2.3 |
| Germany | 2344 | 1204 | 340 | 11.1 | 5.7 | 1.6 |
| Greece | 231 | 170 | 9 | 4.3 | 3.1 | 0.2 |
| Ireland | 25 | 8 | 0 | 1.1 | 0.3 | 0.0 |
| Italy | 1773 | 1186 | 422 | 11.3 | 7.5 | 2.7 |
| Luxembourg | 25 | 14 | 5 | 16.6 | 9.3 | 3.5 |
| Netherlands | 109 | 79 | 42 | 8.4 | 6.1 | 3.3 |
| Portugal | 379 | 274 | 24 | 6.5 | 4.7 | 0.4 |
| Spain | 2037 | 1281 | 99 | 6.6 | 4.2 | 0.3 |
| Sweden | 116 | 18 | 0 | 0.4 | 0.1 | 0.0 |
| UK | 192 | 153 | 72 | 2.3 | 1.9 | 0.9 |
| EU-15 | 12174 | 7183 | 1875 | 6.5 | 3.8 | 1.0 |
| | | | | | | |
| Albania | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 |
| Belarus | 186 | 78 | 0 | 2.1 | 0.9 | 0.0 |
| Bosnia-H | 244 | 162 | 11 | 6.4 | 4.2 | 0.3 |
| Bulgaria | 344 | 281 | 0 | 4.6 | 3.8 | 0.0 |
| Croatia | 330 | 214 | 45 | 9.3 | 6.0 | 1.3 |
| Czech Rep. | 570 | 311 | 36 | 10.2 | 5.6 | 0.7 |
| Estonia | 2 | 0 | 0 | 0.1 | 0.0 | 0.0 |
| Hungary | 631 | 404 | 22 | 9.7 | 6.2 | 0.3 |
| Latvia | 43 | 6 | 0 | 1.0 | 0.1 | 0.0 |
| Lithuania | 75 | 23 | 0 | 1.8 | 0.6 | 0.0 |
| Norway | 3 | 1 | 0 | 0.0 | 0.0 | 0.0 |
| Poland | 1512 | 829 | 8 | 6.6 | 3.6 | 0.0 |
| R.of Moldova | 83 | 56 | 0 | 4.9 | 3.3 | 0.0 |
| Romania | 844 | 623 | 1 | 5.4 | 4.0 | 0.0 |
| Russia | 1733 | 983 | 0 | 0.9 | 0.5 | 0.0 |
| Slovakia | 342 | 215 | 11 | 9.6 | 6.0 | 0.3 |
| Slovenia | 139 | 94 | 25 | 10.7 | 7.2 | 1.9 |
| Switzerland | 155 | 85 | 25 | 8.7 | 4.8 | 1.4 |
| FYR of Maced. | 52 | 40 | 0 | 3.3 | 2.5 | 0.0 |
| Ukraine | 1759 | 1206 | 5 | 4.5 | 3.1 | 0.0 |
| Yugoslavia | 327 | 248 | 6 | 4.8 | 3.7 | 0.1 |
| Non-EU | 9373 | 5860 | 196 | 2.7 | 1.7 | 0.1 |
| | | | | | | |
| Total | 21547 | 13043 | 2071 | 4.0 | 2.4 | 0.4 |

## 2.2.2 Acidification

Figure 2.10 displays the percentage of ecosystems for which, for the emissions of 1990, acid deposition is calculated to exceed the critical loads. Least protection occurred in a band ranging from northern France over Germany to the Czech Republic and Poland. Overall, critical loads were exceeded in about 93 million hectares of ecosystems, out of which 37 million hectares were located in the EU-15 (see Table 2.7).

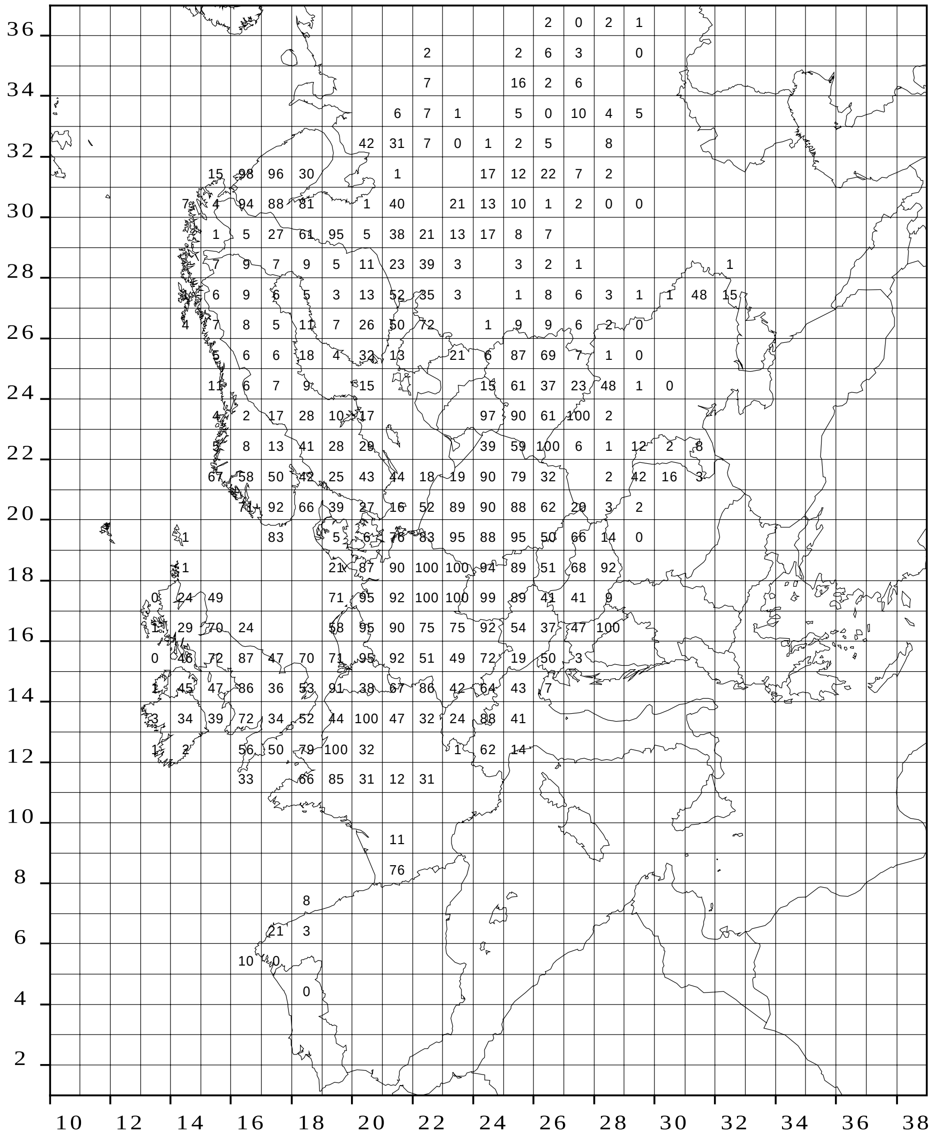


Figure 2.10: Percentage of ecosystems with acid deposition above their critical loads for acidification, 1990

The emission reductions anticipated in the REF scenario are expected to significantly improve the situation and to decrease the unprotected ecosystems to about 17 million hectares, out of which 6.4 million hectares are located in the EU-15 (Figure 2.11). There is clear indication that the overall area where critical loads are exceeded will decline, and many areas where the situation was not extreme will achieve full protection. On the other hand there are some regions (northern Germany, southern Norway, northern Sweden, Hungary, Kola) where the improvement will not exceed 10 to 30 percent.

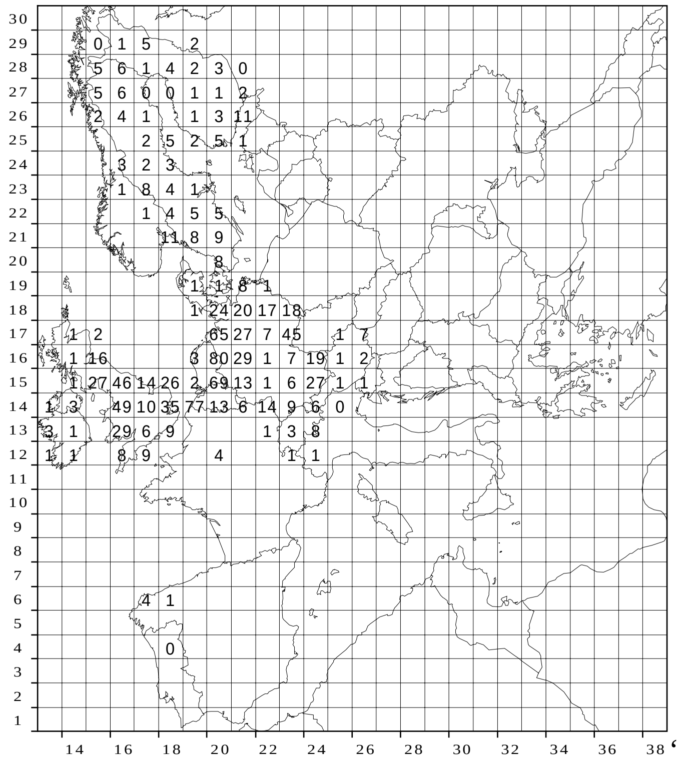


Figure 2.11: Percentage of ecosystems with acid deposition above their critical loads, REF case

Table 2.7: Ecosystems with acid deposition above their critical loads for acidification for 1990, REF and the ultimate MFR scenario

| | 1000 hectares | | | Percent of ecosystems | | |
|---|---|---|---|---|---|---|
| | 1990 | REF | $MFR_{ult}$ | 1990 | REF | $MFR_{ult}$ |
| Austria | 2376 | 162 | 35 | 47.6 | 3.3 | 0.7 |
| Belgium | 410 | 155 | 7 | 58.4 | 22.1 | 0.9 |
| Denmark | 54 | 9 | 1 | 13.8 | 2.3 | 0.4 |
| Finland | 4693 | 1183 | 152 | 17.2 | 4.3 | 0.6 |
| France | 8194 | 218 | 4 | 25.8 | 0.7 | 0.0 |
| Germany | 8158 | 1617 | 119 | 79.5 | 15.8 | 1.2 |
| Greece | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 |
| Ireland | 97 | 12 | 6 | 10.7 | 1.3 | 0.7 |
| Italy | 2065 | 74 | 43 | 19.6 | 0.7 | 0.4 |
| Luxembourg | 58 | 5 | 0 | 66.7 | 5.9 | 0.1 |
| Netherlands | 285 | 193 | 30 | 89.3 | 60.4 | 9.5 |
| Portugal | 1 | 1 | 0 | 0.0 | 0.0 | 0.0 |
| Spain | 78 | 17 | 0 | 0.9 | 0.2 | 0.0 |
| Sweden | 6341 | 1605 | 457 | 16.4 | 4.1 | 1.2 |
| UK | 4117 | 1182 | 65 | 43.0 | 12.3 | 0.7 |
| EU-15 | 36928 | 6433 | 919 | 24.7 | 4.3 | 0.6 |
| | | | | | | |
| Albania | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 |
| Belarus | 2709 | 1048 | 0 | 53.9 | 20.9 | 0.0 |
| Bosnia-H | 132 | 131 | 0 | 9.1 | 9.1 | 0.0 |
| Bulgaria | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 |
| Croatia | 7 | 0 | 0 | 2.7 | 0.0 | 0.0 |
| Czech Rep. | 2394 | 474 | 12 | 90.1 | 17.9 | 0.5 |
| Estonia | 312 | 11 | 0 | 16.5 | 0.6 | 0.0 |
| Hungary | 144 | 65 | 10 | 50.7 | 22.9 | 3.6 |
| Latvia | 127 | 0 | 0 | 4.7 | 0.0 | 0.0 |
| Lithuania | 817 | 78 | 0 | 43.1 | 4.1 | 0.0 |
| Norway | 5313 | 2573 | 771 | 24.0 | 11.6 | 3.5 |
| Poland | 12634 | 1357 | 14 | 72.8 | 7.8 | 0.1 |
| R.of Moldova | 84 | 29 | 0 | 7.1 | 2.4 | 0.0 |
| Romania | 230 | 51 | 6 | 3.7 | 0.8 | 0.1 |
| Russia | 27072 | 4073 | 31 | 7.8 | 1.2 | 0.0 |
| Slovakia | 1033 | 295 | 110 | 51.5 | 14.7 | 5.5 |
| Slovenia | 363 | 19 | 3 | 40.1 | 2.1 | 0.3 |
| Switzerland | 508 | 57 | 26 | 41.1 | 4.6 | 2.1 |
| FYR of Maced. | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 |
| Ukraine | 2397 | 643 | 5 | 29.1 | 7.8 | 0.1 |
| Yugoslavia | 2 | 2 | 0 | 0.1 | 0.1 | 0.0 |
| Non-EU | 56280 | 10908 | 989 | 13.1 | 2.5 | 0.2 |
| | | | | | | |
| Total | 93209 | 17341 | 1909 | 16.1 | 3.0 | 0.3 |

## 2.2.3 Eutrophication

Figure 2.12 shows that in 1990 eutrophication was a wide-spread phenomenon in many parts of central Europe. The majority of grid cells in France, Germany, Poland, Romania and Bulgaria experienced excess deposition for all of their ecosystems. In the EU-15, critical loads for eutrophication were exceeded in more than 165 million hectares.

The emission reductions anticipated from the REF scenario will relieve the situation to some extent, but will still leave 116 million hectares unprotected (Figure 2.13). In many parts of mainland Europe they will not be sufficient to increase the unprotected ecosystems substantially. Statistics about individual countries are presented in Table 2.8.

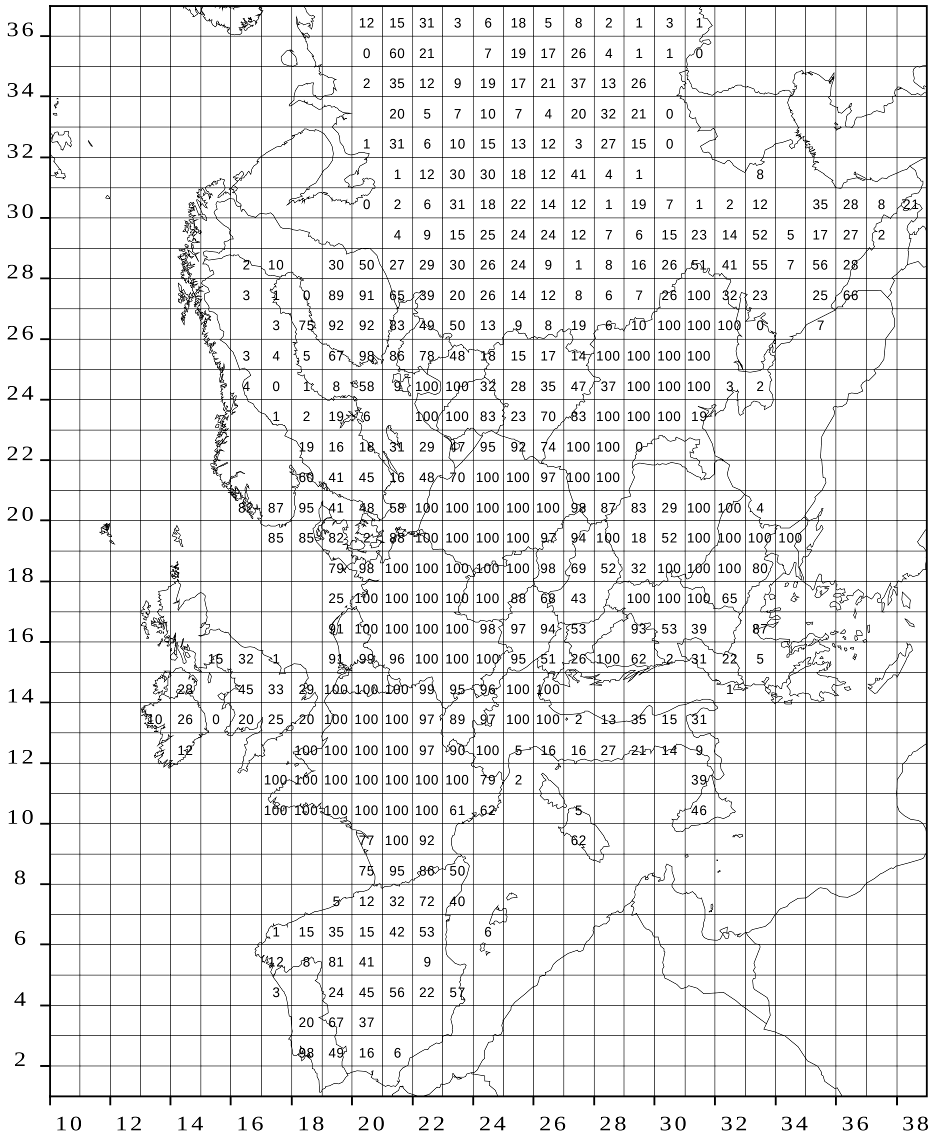


Figure 2.12: Percentage of ecosystems area with nitrogen deposition above their critical loads for eutrophication, for the emissions of 1990

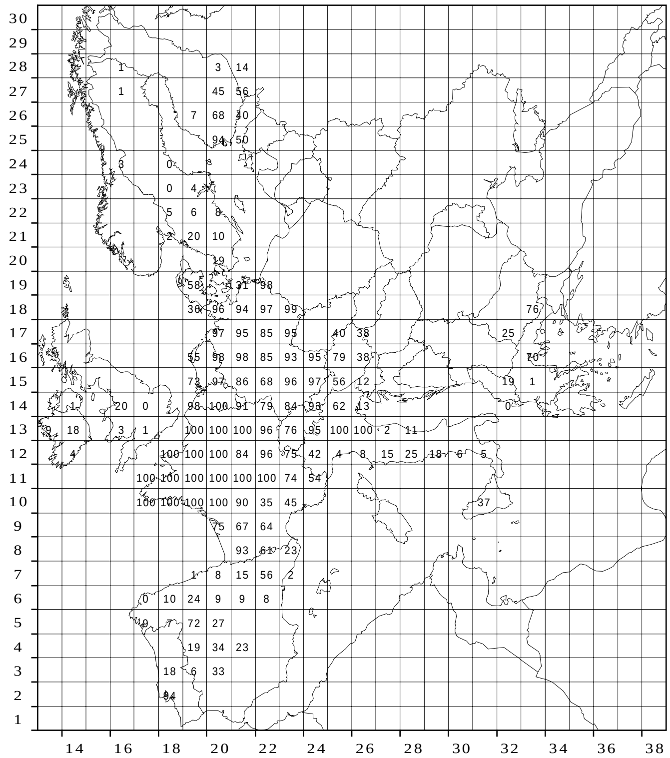


Figure 2.13: Percentage of ecosystems area with nitrogen deposition above their critical loads for eutrophication, for the emissions of the REF scenario

Table 2.8: Ecosystems with nitrogen deposition above their critical loads for eutrophication for 1990, the REF and the ultimate MFR case

| | 1000 hectares | | | Percent of ecosystems | | |
|---|---|---|---|---|---|---|
| | 1990 | REF | $MFR_{ult}$ | 1990 | REF | $MFR_{ult}$ |
| Austria | 5392 | 3441 | 572 | 90 | 58 | 9.6 |
| Belgium | 700 | 677 | 335 | 100 | 96 | 47.8 |
| Denmark | 197 | 119 | 4 | 63 | 38 | 1.3 |
| Finland | 7386 | 2538 | 10 | 45 | 15 | 0.1 |
| France | 29322 | 25160 | 13079 | 92 | 79 | 41.2 |
| Germany | 10157 | 9184 | 3590 | 99 | 90 | 35.0 |
| Greece | 295 | 236 | 8 | 12 | 10 | 0.3 |
| Ireland | 91 | 58 | 23 | 10 | 6 | 2.5 |
| Italy | 5921 | 3795 | 1382 | 49 | 32 | 11.5 |
| Luxembourg | 88 | 80 | 45 | 100 | 91 | 50.8 |
| Netherlands | 312 | 291 | 252 | 98 | 91 | 79.0 |
| Portugal | 913 | 709 | 0 | 32 | 25 | 0.0 |
| Spain | 2390 | 1158 | 8 | 28 | 14 | 0.1 |
| Sweden | 2588 | 891 | 64 | 14 | 5 | 0.3 |
| UK | 1030 | 126 | 0 | 11 | 1 | 0.0 |
| EU-15 | 66782 | 48461 | 19372 | 55 | 40 | 16.1 |
| | | | | | | |
| Albania | 240 | 200 | 60 | 23 | 19 | 5.7 |
| Belarus | 2049 | 1293 | 370 | 41 | 26 | 7.4 |
| Bosnia-H | 1104 | 725 | 115 | 76 | 50 | 8.0 |
| Bulgaria | 3964 | 3396 | 123 | 80 | 69 | 2.5 |
| Croatia | 70 | 18 | 0 | 26 | 7 | 0.0 |
| Czech Rep. | 2608 | 2312 | 491 | 98 | 87 | 18.5 |
| Estonia | 1296 | 738 | 30 | 69 | 39 | 1.6 |
| Hungary | 166 | 150 | 85 | 58 | 53 | 29.8 |
| Latvia | 2260 | 1553 | 90 | 83 | 57 | 3.3 |
| Lithuania | 1462 | 1357 | 74 | 77 | 72 | 3.9 |
| Norway | 2053 | 281 | 2 | 15 | 2 | 0.0 |
| Poland | 16875 | 16218 | 7726 | 97 | 93 | 44.5 |
| R.of Moldova | 1 | 0 | 0 | 0 | 0 | 0.0 |
| Romania | 3450 | 2495 | 1194 | 55 | 40 | 19.2 |
| Russia | 47704 | 26263 | 1254 | 14 | 8 | 0.4 |
| Slovakia | 1874 | 1507 | 241 | 93 | 75 | 12.0 |
| Slovenia | 489 | 156 | 44 | 54 | 17 | 4.9 |
| Switzerland | 2105 | 1887 | 823 | 92 | 83 | 36.1 |
| FYR of Maced. | 242 | 158 | 45 | 23 | 15 | 4.2 |
| Ukraine | 6181 | 5331 | 1808 | 75 | 65 | 22.0 |
| Yugoslavia | 2306 | 1994 | 945 | 68 | 58 | 27.7 |
| Non-EU | 98499 | 68032 | 15520 | 23 | 16 | 3.7 |
| | | | | | | |
| Total | 165282 | 116494 | 34892 | 30 | 21 | 6.4 |

# 3 A Central Scenario for Reducing Acidification and Ground-level Ozone (Scenario H1)

## *3.1 Environmental Targets Derived from the Acidification and Ozone Strategies*

It is demonstrated in Part A of this report that currently adopted emission controls are expected to significantly reduce harmful excess exposure to ground-level ozone and acidification by the year 2010. However, without further measures there will still be significant areas in Europe where health- and vegetation protection will not be achieved. It is furthermore a robust conclusion of the model analysis that the presently available technical emission control measures will not be sufficient to meet the no-damage levels everywhere in Europe within the next one or two decades without interfering with the 'business as usual' expectations on economic development and energy consumption.

Therefore, the acidification strategy of the EU and the recent discussions on the EU ozone strategy formulated environmental interim targets, which should guide the next step towards the full achievement of the environmental long-term objectives. Scenario H1 adopts these interim targets and explores, with the latest data set on energy use, emissions, control costs and critical loads, the cost-optimal allocation of emission reductions to simultaneously achieve the acidification and ozone targets.

For the individual environmental problems, the environmental constraints to be achieved by the optimized emission reductions can be summarized as follows:

**For acidification:**

**The general target of the EU acidification strategy is to reduce in the year 2010 the area of ecosystems not protected against acidification everywhere by at least 50 percent compared to 1990. This results in about 4.3 million hectares of unprotected ecosystems in the EU15**

> In the optimization routine, a scenario based on a 95 percent gap closure of the accumulated excess acidity[1] which achieves the 50 percent area gap closure target was implemented. In order to increase the cost-effectiveness of the scenario, so that single ecosystems might not demand excessively expensive measures, some spatial flexibility in achieving the overall target was introduced. A balancing mechanism now allows limited violation of the targets at single grid cells, as long as they are compensated by additional improvements (in terms of accumulated excess acidity) in other grid cells in the same country.

[1] Acid deposition in excess of the critical loads, accumulated for all ecosystems in a grid cell. The purpose of using the accumulated excess is to avoid the focus on a specific ecosystem (percentile of the cumulative critical load distribution) and thus increase the robustness of the modeling results.

**<u>For health-relevant ozone exposure:</u>**

**The principal interim target for moving towards the environmental long-term objective is a relative reduction of the AOT60 (the surrogate indicator for health-related excess ozone exposure) by two thirds between 1990 and 2010.**

> In order to minimize the influence of existing model uncertainties and to increase the robustness of the optimized solution, this 67 percent 'gap closure' is defined in relation to a model confidence interval. Furthermore, within certain limits, violations of these targets are allowed for individual grid cells or meteorological years, if the excess is compensated by additional improvements in other years or other grid cells in the same country (on a population-weighted basis).

**In addition, highest excess ozone in the EU15 is addressed by introducing an absolute ceiling on the AOT60 of 2.9 ppm.hours.**

> In order to minimize the influence of rare and perhaps untypical meteorological conditions and to tailor the strategy for maximum effectiveness for the most frequent meteorological ozone regimes, this ceiling must be maintained under the meteorological conditions of four out of the five years, for which model analyses are available. This means that for each grid cell the meteorological conditions of the year in which improvements are most difficult to achieve is neglected.

**<u>For vegetation-relevant ozone exposure:</u>**

**The general objective is to reduce the excess AOT40 (the indicator for vegetation-related excess ozone) by one third between 1990 and 2010.**

> The definition of the AOT40 relates to the average meteorological conditions over a five years period. Violations of the gap closure targets are allowed for individual grid cells, if the excess is compensated by additional improvements in other grid cells in the same country (on an ecosystems area-weighted basis).

**In addition, the highest excess AOT40 in the EU15 is limited to an absolute ceiling of 10.0 ppm.hours.**

> Since the definition of the AOT40 already refers to the average meteorological conditions and considers extreme meteorological conditions only on a weighted basis, no exceptions are applied to this target.

Details on the target setting rules can be found in Section 5 of Part A of the Sixth Interim Report to the Commission (Amann *et al*., 1998).

## 3.2 Main Input Assumptions

The main input assumptions for the H1 scenario relate to the energy development in the EU countries. It is assumed that energy consumption follows the 'baseline' scenario, i.e., the projections provided by Member States to the Commission or, if no national submissions were received, the 'Business as usual' scenario of DGXVII. For the non-EU countries, the 'Official Energy Pathway' of the UN/ECE database was used.

It is furthermore assumed that the current legislation on emission reductions will not be reversed. This means that for the EU countries the REF scenario is taken as the upper bound for emissions (i.e., the optimization may not result in higher emissions than produced by the REF scenario), and the cost curves for emission reductions consider only the measures not already taken by the REF scenario.

The same assumption on the REF as the minimum reduction level also holds for the non-EU countries. With the exception of the H4 scenario, however, no further emission reductions are assumed for the non-EU countries, so that in practice the emissions of these countries are fixed at the REF (i.e., the current legislation) level.

A further assumption relates to $SO_2$ and $NO_x$ emissions from ships on the sea, which are kept uncontrolled throughout this report. It should be mentioned that the calculations in this report ignore, due to a complete lack of data, all VOC emissions from ships, and also $SO_2$ and $NO_x$ emissions from the Mediterranean. Furthermore, the data for the Baltic Sea include merely the shipping into and out of the basin (EMEP, 1998)

For acidification, grid cells shared with non-EU countries, where (a) the low percentiles of critical loads (i.e., the sensitive ecosystems) are located in non-EU countries, or (b) the deposition is vastly dominated by emissions from non-EU countries, are excluded from the optimization. This applies to grid cells 24/13 on the Italian/Swiss border with low critical loads values in the Swiss Ticino, to grid cell 26/17 (Austria/Slovakia/Hungary) with most sensitive ecosystems in Slovakia, and to grid cells 16/30 and 17/30 at the Finnish/Russian border, where sulfur deposition results mainly from a few nickel smelters in the Russian part of the Kola peninsula.

## 3.3 Cost-minimal Emission Reductions

In order to simultaneously achieve the environmental targets outlined in Section 3.1, further emission reductions beyond the REF case are necessary for all four pollutants. For the EU-15, $SO_2$ emissions would be reduced from 71 percent to 78 percent (compared to 1990), $NO_x$ emissions from 48 percent to 55 percent, VOC from 49 to 60 percent and ammonia from 12 to 21 percent (Table 3.1). This would increase total emission control costs from 58 billion EURO/year to 66 billion EURO, i.e., by 14 percent (Table 3.2). Out of this 7.5 billion EURO extra costs, 11 percent would be spent for additional $SO_2$ control, 60 percent for further measures to reduce $NO_x$ and VOC, and 29 percent for ammonia.

The significant spatial differences in (a) the severity of the ozone and acidification problems and (b) in the extent to which emission controls are already implemented are the main factors explaining that additional measures for individual pollutants are not uniformly allocated across all Member States. Significant further $SO_2$ controls (increasing control costs by more than 10 percent) emerge for Belgium, France, Ireland and the UK, while for the other countries the optimized measures are at or close to the REF case. Stricter $NO_x$ and VOC controls are more widespread. Further $NO_x$ and VOC measures are calculated for Austria, Belgium, France, Greece, Germany, Italy, Luxembourg, Netherlands, Portugal and Sweden; for Ireland and Spain only $NO_x$ would be a priority, and for the UK further control of VOC emissions. Limitations to ammonia emissions emerge as important for Belgium, France, Germany, Ireland, Netherlands and the UK.

Table 3.1: Emissions for the central scenario H1 compared to the REF case. Percentage changes relate to the year 1990.

| | $SO_2$ | | | | $NO_x$ | | | | VOC | | | | $NH_3$ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | REF | | H1 | | REF | | H1 | | REF | | H1 | | REF | | H1 | |
| | kt | *Change* | kt | *Change* | kt | *Change* | kt | *Change* | kt | *Change* | kt | *Change* | kt | *Change* | kt | *Change* |
| Austria | 40 | *-57%* | 40 | *-57%* | 103 | *-46%* | 91 | *-53%* | 205 | *-42%* | 129 | *-63%* | 67 | *-13%* | 67 | *-13%* |
| Belgium | 193 | *-43%* | 76 | *-77%* | 191 | *-46%* | 127 | *-64%* | 193 | *-48%* | 102 | *-73%* | 96 | *-1%* | 57 | *-41%* |
| Denmark | 90 | *-51%* | 77 | *-58%* | 128 | *-53%* | 127 | *-54%* | 85 | *-53%* | 85 | *-53%* | 72 | *-6%* | 71 | *-8%* |
| Finland | 116 | *-49%* | 116 | *-49%* | 152 | *-45%* | 152 | *-45%* | 110 | *-48%* | 110 | *-48%* | 31 | *-23%* | 31 | *-23%* |
| France | 448 | *-64%* | 218 | *-83%* | 858 | *-54%* | 679 | *-64%* | 1223 | *-49%* | 932 | *-61%* | 777 | *-4%* | 718 | *-11%* |
| Germany | 581 | *-89%* | 463 | *-91%* | 1184 | *-56%* | 1051 | *-61%* | 1137 | *-64%* | 924 | *-70%* | 571 | *-25%* | 413 | *-45%* |
| Greece | 546 | *8%* | 546 | *8%* | 344 | *0%* | 264 | *-23%* | 267 | *-21%* | 173 | *-49%* | 74 | *-8%* | 74 | *-8%* |
| Ireland | 66 | *-63%* | 28 | *-84%* | 70 | *-38%* | 59 | *-48%* | 55 | *-50%* | 55 | *-50%* | 126 | *-1%* | 123 | *-3%* |
| Italy | 567 | *-66%* | 566 | *-66%* | 1130 | *-45%* | 869 | *-57%* | 1159 | *-44%* | 962 | *-53%* | 432 | *-6%* | 430 | *-7%* |
| Luxembourg | 4 | *-71%* | 3 | *-79%* | 10 | *-55%* | 8 | *-64%* | 7 | *-63%* | 6 | *-68%* | 7 | *0%* | 7 | *0%* |
| Netherlands | 73 | *-64%* | 50 | *-75%* | 280 | *-48%* | 238 | *-56%* | 233 | *-52%* | 156 | *-68%* | 136 | *-42%* | 104 | *-55%* |
| Portugal | 141 | *-50%* | 141 | *-50%* | 177 | *-15%* | 144 | *-31%* | 144 | *-32%* | 102 | *-52%* | 67 | *-6%* | 67 | *-6%* |
| Spain | 774 | *-65%* | 746 | *-66%* | 847 | *-27%* | 781 | *-33%* | 669 | *-34%* | 662 | *-34%* | 353 | *0%* | 353 | *0%* |
| Sweden | 67 | *-44%* | 67 | *-44%* | 190 | *-44%* | 152 | *-55%* | 290 | *-43%* | 219 | *-57%* | 48 | *-21%* | 48 | *-21%* |
| UK | 980 | *-74%* | 497 | *-87%* | 1186 | *-58%* | 1181 | *-58%* | 1351 | *-49%* | 964 | *-64%* | 297 | *-10%* | 264 | *-20%* |
| EU-15 | 4687 | *-71%* | 3637 | *-78%* | 6849 | *-48%* | 5922 | *-55%* | 7128 | *-49%* | 5581 | *-60%* | 3154 | *-12%* | 2826 | *-21%* |

Table 3.2: Emission control costs for the central scenario H1 compared to the REF case. Control costs in million EURO/year.

| | $SO_2$ | | | $NO_x$/VOC | | | $NH_3$ | | | Total | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | REF | H1 | Total | REF | H1 | Total | REF | H1 | Total | REF | H1 | Total |
| Austria | 191 | 0 | 191 | 902 | 119 | 1021 | 0 | 0 | 0 | 1093 | 119 | 1212 |
| Belgium | 426 | 127 | 553 | 1278 | 459 | 1737 | 0 | 467 | 467 | 1704 | 1053 | 2757 |
| Denmark | 138 | 5 | 143 | 484 | 0 | 484 | 0 | 0 | 0 | 623 | 6 | 629 |
| Finland | 247 | 0 | 247 | 642 | 0 | 642 | 0 | 0 | 0 | 889 | 0 | 889 |
| France | 1276 | 136 | 1412 | 7383 | 739 | 8122 | 0 | 41 | 41 | 8659 | 916 | 9575 |
| Germany | 3264 | 244 | 3508 | 10549 | 1048 | 11597 | 0 | 854 | 854 | 13813 | 2147 | 15960 |
| Greece | 434 | 0 | 434 | 1048 | 338 | 1386 | 0 | 0 | 0 | 1482 | 338 | 1820 |
| Ireland | 132 | 20 | 152 | 477 | 4 | 481 | 9 | 20 | 29 | 618 | 44 | 662 |
| Italy | 1776 | 0 | 1776 | 7868 | 403 | 8271 | 0 | 0 | 0 | 9644 | 403 | 10047 |
| Luxembourg | 13 | 1 | 14 | 71 | 4 | 75 | 15 | 0 | 15 | 98 | 4 | 102 |
| Netherlands | 340 | 19 | 359 | 1731 | 211 | 1942 | 196 | 741 | 937 | 2267 | 971 | 3238 |
| Portugal | 181 | 0 | 181 | 1349 | 57 | 1406 | 0 | 0 | 0 | 1530 | 57 | 1587 |
| Spain | 809 | 9 | 818 | 5658 | 13 | 5671 | 28 | 0 | 28 | 6495 | 22 | 6517 |
| Sweden | 316 | 0 | 316 | 1125 | 87 | 1212 | 113 | 0 | 113 | 1554 | 87 | 1641 |
| UK | 1269 | 299 | 1568 | 6695 | 1026 | 7721 | 0 | 23 | 23 | 7964 | 1348 | 9312 |
| EU-15 | 10813 | 861 | 11674 | 47258 | 4508 | 51766 | 361 | 2146 | 2507 | 58433 | 7514 | 65947 |

## 3.4 Environmental Impacts of the H1 Scenario

In line with the environmental targets set to the optimization, all environmental indicators selected for the analysis experience a distinct improvement compared to the situation in 1990. The following graphs provide detailed information on the spatial distribution at which the improvements occur.

### 3.4.1 Acidification

For acidification, the overall target was a 50 percent gap closure in terms of unprotected ecosystems compared to 1990 or, phrased differently, a 50 percent reduction of the ecosystems with acid deposition above their critical loads. As explained in Section 3.1, a compensation mechanism was introduced in order to increase the cost-effectiveness of the overall strategy by relaxing the strict 50 percent gap closure targets for single grid cells where this improvement would be most costly to achieve. Figure 3.1 displays for the emissions of the H1 scenario the resulting gap closure (in terms of ecosystems area). The map clearly indicates that most grid cells achieve the minimum target of a 50 percent improvement, and many achieve even better results. There are, however, a number of areas where the gap closure remains below the nominal 50 percent target. In some of them, the compensation mechanism allows a violation of the target (grid cell 20/17 Netherlands/Germany), while in others the 95 percent gap closure of the accumulated excess acidity is still achieved (13/13 (Ireland), 18/6 (Spain), 23/17 (France/Italy/Switzerland) and four grid cells in central and northern Sweden[2]).

Table 3.3: Gap closure and percent of unprotected ecosystems for grid cells, where the original gap closure target is not achieved by the optimized emission reductions.

| Grid cell | Country | Gap closure achieved by H1 | Percent of ecosystems remaining unprotected in H1 |
|---|---|---|---|
| 13/13 | IRE | 20 % | 3 % |
| 15/27 | SWE | 12 % | 5 % |
| 15/28 | SWE | 34 % | 5 % |
| 16/24 | SWE/NOR | 47 % | 1 % |
| 16/27 | SWE | 36 % | 6 % |
| 16/28 | SWE | 39 % | 6 % |
| 16/30 | FIN/RUS | 16 % | 80 % |
| 17/30 | FIN/RUS | 8 % | 81 % |
| 18/6 | SPA | 49 % | 1 % |
| 20/17 | D/NL | 45 % | 53 % |
| 23/12 | F/ITA/CH | 44 % | 1 % |

[2] The 50 percent gap closure is also not achieved on the Finnish/Russian border (Kola). Due to the bilateral nature of this local problem and the limited extent to which it is linked to the EU emissions, no targets were specified for these grid cells in the EU-15 optimization runs.

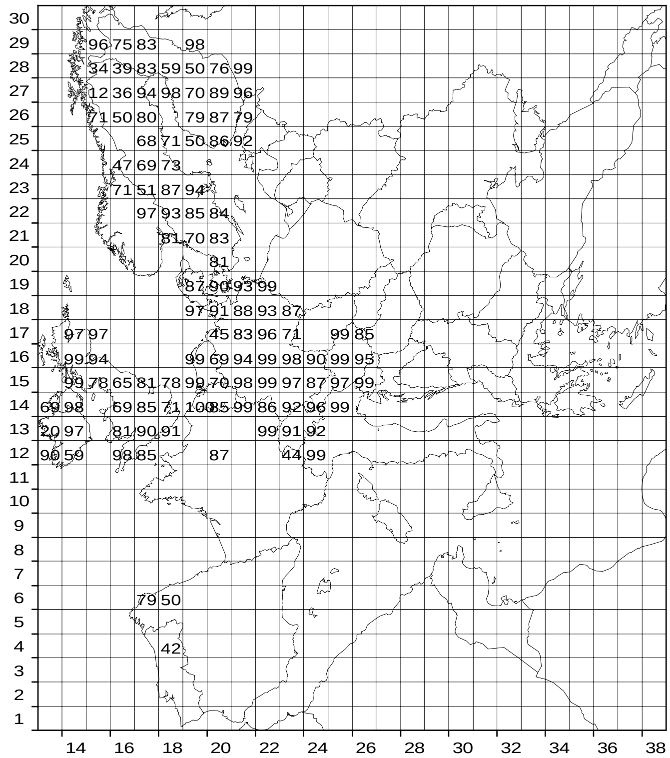


Figure 3.1: Gap closure in terms of unprotected ecosystems area (acidification) for the emissions of the H1 scenario. Areas left blank had no excess deposition in 1990.

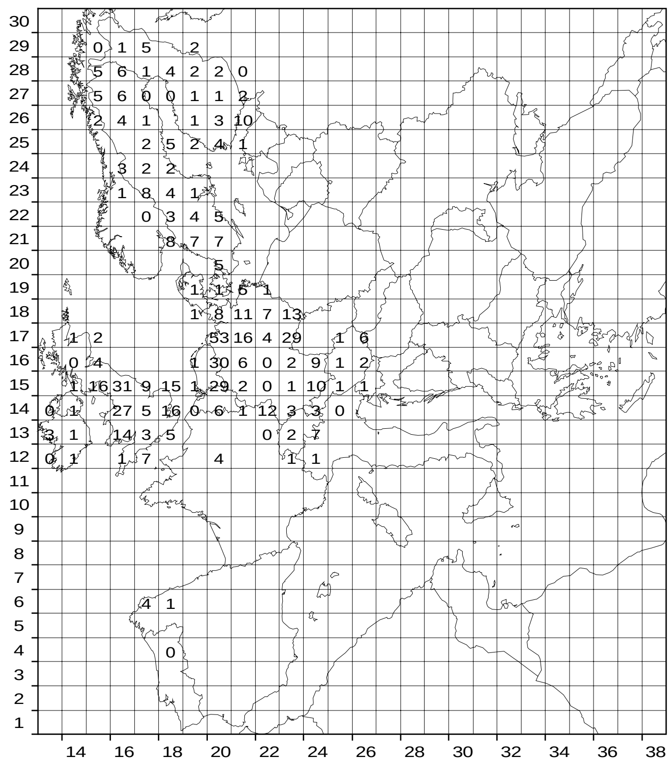


Figure 3.2: Percentage of ecosystems with acid deposition above their critical loads for the emissions of the H1 scenario

While the relative improvement (in terms of gap closure) is a practical means for setting environmental targets, it does not always provide an unequivocal picture of the actual environmental situation. Figure 3.2 presents for Scenario H1 the remaining percentage of ecosystems with acid deposition above their critical loads. Except for the Kola region, which is excluded from this analysis, the area with least protection on the German/Dutch border (53 percent) coincides with a failed 50 percent gap closure target. There are, however, regions in south-east Germany and the UK, where despite a gap closure of 60 to 80 percent still about 30 percent of the ecosystems receive acid deposition above their critical loads.

Another way of evaluating the ecological situation from a given emission pattern is to examine for a given percentile of the ecosystems the remaining excess deposition. For scenario H1 Figure 3.3 displays this information for the 2-percentile, i.e., for the ecosystem where two percent of the ecosystems in the same grid cell have lower critical loads and 98 percent of the ecosystems in the grid cell have higher critical loads. The map clearly indicates that, despite the significant emission reductions, there remain ecosystems where acid deposition is 500 to 1000 eq/ha above their critical loads, i.e., where the critical loads are exceeded by a factor of two and more. Such high levels of excess deposition would occur on the German/Dutch border, in southern UK and in some border grids between Italy/ Switzerland, and Austria/Hungary. On the other hand, excess deposition in northern Sweden, where the gap closure is down to 12 percent, is comparatively low.

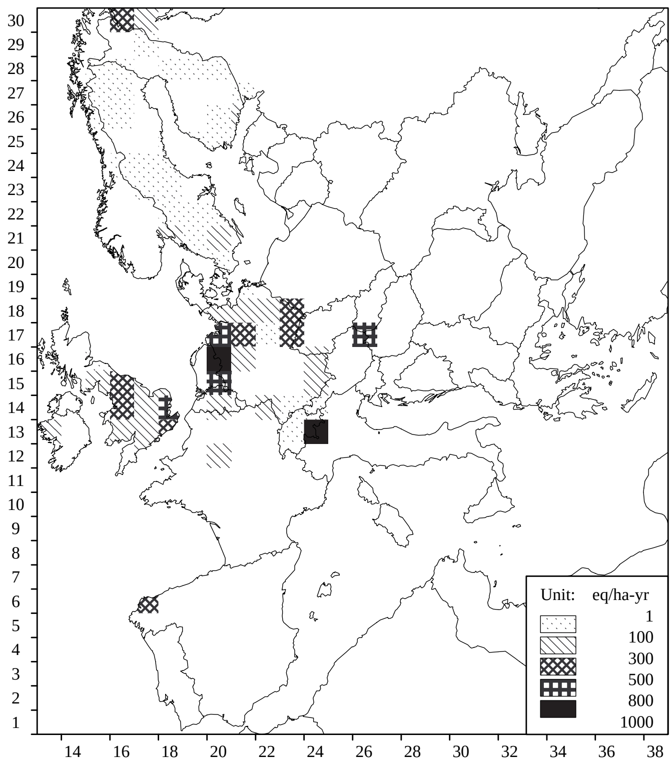


Figure 3.3: Excess deposition for the 2-percentile ecosystems for the emissions of the H1 scenario

Finally, Table 3.4 provides the country statistics of ecosystems protection. The emission reductions of the H1 scenario would reduce in the EU-15 the unprotected area from 6.4 million hectares in the REF case to 4.3 million hectares, a number, which is comparable to the ambition level put forward in the EU acidification strategy. On a national scale, least ecosystems protection occurs in the Netherlands (with 24 percent of the ecosystems having acid deposition above critical loads), followed by Belgium, Germany and UK with about seven percent.

Table 3.4: Ecosystems with acid deposition above their critical loads for acidification for the H1 and the REF scenarios.

| | 1000 ha | | Percent of ecosystems | |
|---|---|---|---|---|
| | REF | H1 | REF | H1 |
| Austria | 162 | 99 | 3.3% | 2.0% |
| Belgium | 155 | 52 | 22.1% | 7.4% |
| Denmark | 9 | 6 | 2.3% | 1.5% |
| Finland | 1183 | 1150 | 4.3% | 4.2% |
| France | 218 | 88 | 0.7% | 0.3% |
| Germany | 1617 | 727 | 15.8% | 7.1% |
| Greece | 0 | 0 | 0.0% | 0.0% |
| Ireland | 12 | 9 | 1.3% | 1.0% |
| Italy | 74 | 58 | 0.7% | 0.6% |
| Luxembourg | 5 | 1 | 5.9% | 0.9% |
| Netherlands | 193 | 76 | 60.4% | 23.7% |
| Portugal | 1 | 1 | 0.0% | 0.0% |
| Spain | 17 | 17 | 0.2% | 0.2% |
| Sweden | 1605 | 1420 | 4.1% | 3.7% |
| United Kingdom | 1182 | 649 | 12.3% | 6.8% |
| EU-15 | 6433 | 4351 | 4.3% | 2.9% |

### 3.4.2 Ground-level Ozone

There are several statistics against which improvement in ozone exposure could be evaluated. This report provides the following analyses:

- In order to present the improvements in generally understandable notions, maps indicate the remaining days on which the WHO health guideline (60 ppb) and the 90 ppb levels are exceeded. Two maps are provided: One map displays the highest value (number of days) out of the five years meteorological regimes (for 60 ppb), while the second present the maximum of the three-years moving averages over the five years (for both thresholds).
- The second series of maps shows the AOT60 values, which were used as a surrogate health-risk indicator for the optimization. For the AOT60, the second highest value out of the five years meteorologies is presented.
- The third series of maps presents the excess AOT40 over the critical level of 3000 ppb.hours averaged over five years, in order to relate to the critical level for vegetation protection.

### 3.4.2.1 Number of Days with Ozone above 60 and 90 ppb

As to be expected from the stringency of the environmental targets, ozone exposure resulting from the H1 emissions is clearly lower than in 1990. If measured as three-year moving averages over the five years with data, the number of days with ozone above the WHO guideline value would decline, e.g., in northern France from about 55 in 1990, through 35 for REF, to about 25 in the H1 scenario. For Italy, exceedances decline from 60 to about 20 days, in Germany/Netherlands from 30-40 days down to 15-20 days (Figure 3.4). The maximum exceedance, if averaged over three years, declines for H1 from about 60 days[3] in 1990 (at the German/French border and in Italy) to about 27 in the Benelux region.

As shown in Figure 3.6, the emission reductions of the H1 scenario would eliminate ozone in excess of 90 ppb (eight hours mean) almost entirely, at least if measured as the moving average over three years. Calculations suggest that only two grid cells in Germany and the Benelux region would experience more than one day with excess of the 90 ppb level.

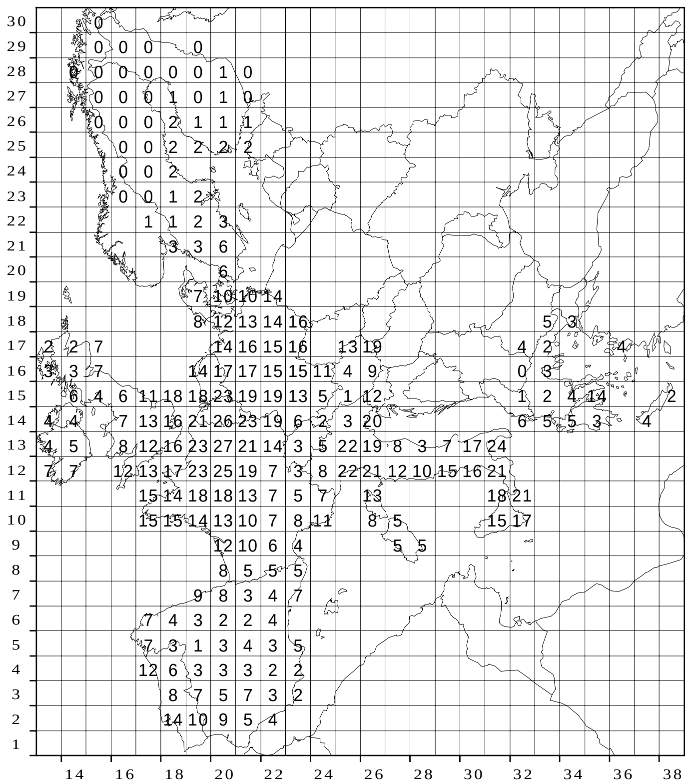


Figure 3.4: Number of days with excess of the WHO guideline value of 60 ppb resulting from the emissions of the H1 scenario, three-years moving average over five years.

[3] for land-based grid cells only

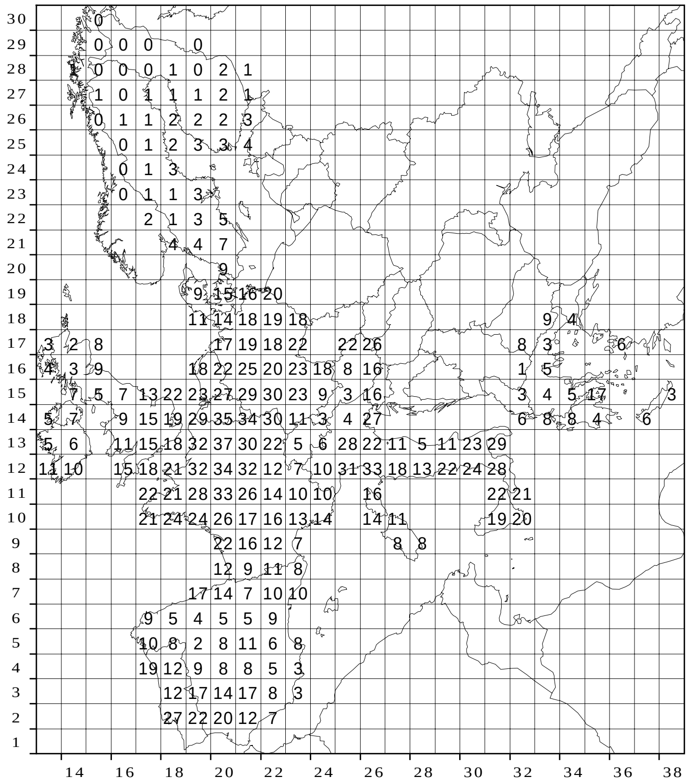


Figure 3.5: Number of days with excess of the WHO guideline value of 60 ppb resulting from the emissions of the H1 scenario, highest occurrence in five years meteorological conditions

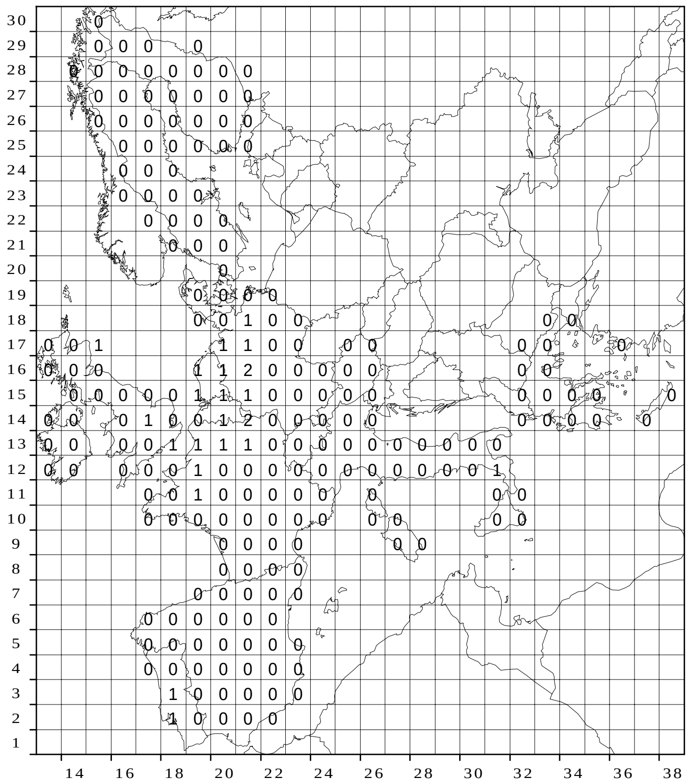


Figure 3.6: Number of days with ozone above 90 ppb for the emissions of the H1 scenario, mean of the three highest occurrences in five years

### 3.4.2.2 AOT60

For completeness, Figure 3.7 presents the AOT60 expressed as the second highest value from the five meteorological years. The map clearly indicates that only grid cells 20/14 and 21/14 at the Belgium/French border hit the absolute exposure limit of 2.9 ppm.hours, which was imposed on the optimization, while all other regions experience lower AOT60. It is further noteworthy that the spatial distribution of the AOT60 and the number of days with excess of 60 ppb do not fully coincide. While the number of days is comparable for the 'high ozone' areas north and south of the Alps, the regions north of the Alps have a higher AOT60 than in the Mediterranean countries. This indicates that the severity of the episodes (i.e., the degree to which the 60 ppb level is exceeded) is - and according to the model calculations will remain - higher in the north-western part of Europe.

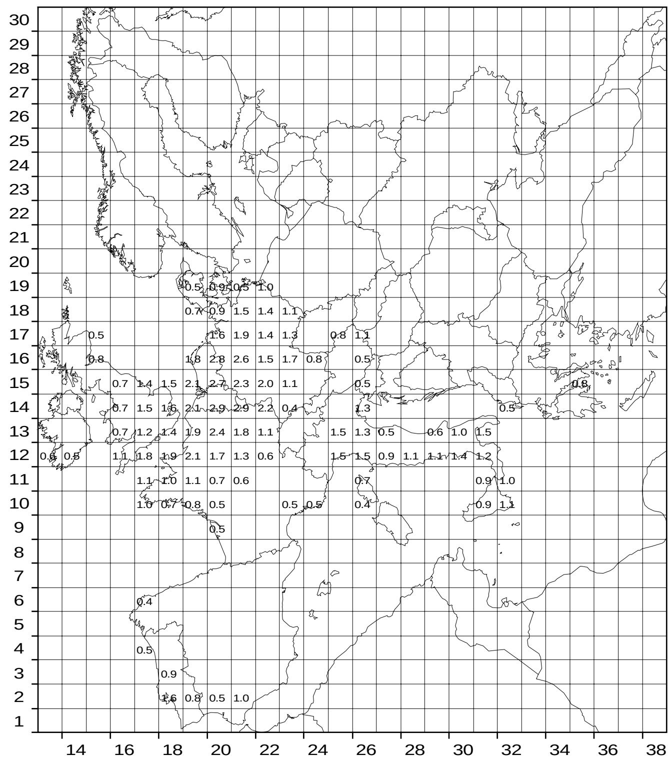


Figure 3.7: The AOT60 resulting from the emission reductions of the H1 scenario, second highest values of five years meteorologies (in ppm.hours)

Figure 3.8 displays the gap closure achieved in terms of AOT60 by the H1 scenario in comparison to 1990. The map clearly shows that, although a 67 percent improvement was set as the overall target, the compensation mechanism allows violations of these targets in Netherlands, UK, Spain and Portugal (these grid cells are cross-hatched in the map).

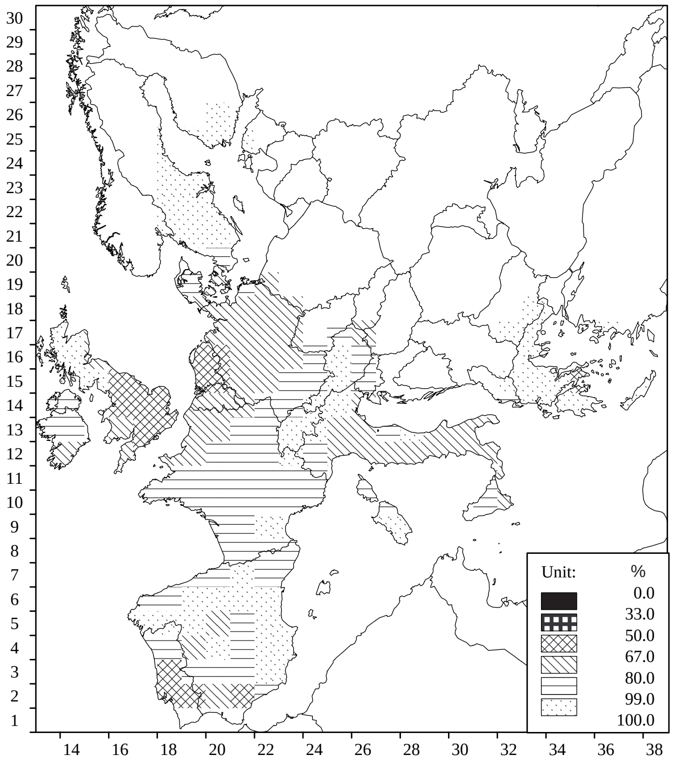


Figure 3.8: Percentage reduction of the AOT60 achieved by the H1 scenario, compared to 1990

Table 3.5 presents the population exposure indices for the REF and the H1 emissions. These indices are calculated by multiplying the AOT60 value of each grid cell with the population in the same grid belonging to the respective country. When interpreting results, the following aspects must be kept in mind:

- The indices are based on results of the reduced-form regression model, which has been constructed from calculations of the EMEP model. The EMEP model produces ozone levels for rural areas; these are usually higher than ozone levels observed within cities, but underestimate the levels occurring in the city plumes. Therefore, the presented values can provide only rough summary indications to enable quick comparisons of alternative scenarios on a highly aggregated basis. In-depth analyses with more detailed models are absolutely necessary to derive robust conclusions on the exposure of the population to ozone.
- As outlined before, the reduced-form model does not produce reliable results for AOT60 values below 0.4 ppm.hours. Therefore, low values of average exposure must be interpreted with care.

For the H1 scenario, the EU-15 average population exposure declines from 1.3 to 0.8 ppm.hours compared to the REF case. Compared to 1990, this relates to a 76 percent gap closure, if calculated against the model confidence interval. While on a grid basis a 67 percent improvement was specified as the minimum requirement (not taking into account the compensation mechanism), improvements on a country basis are always higher. Least overall gap closures occur in the UK, Belgium and Portugal.

Table 3.5: Population exposure indices for the REF and the H1 scenarios

| | Cumulative population exposure index (million person ppm.hours) | | Average population exposure index (excess ppm.hours) | | Gap closure between 1990 and the model uncertainty range[1)] |
|---|---|---|---|---|---|
| | REF | H1 | REF | H1 | H1 |
| Austria | 3 | 2 | 0.5 | 0.3 | -94% |
| Belgium | 34 | 23 | 3.1 | 2.1 | -72% |
| Denmark | 3 | 1 | 0.5 | 0.3 | -91% |
| Finland | 0 | 0 | 0.0 | 0.0 | - |
| France | 89 | 53 | 1.6 | 0.9 | -86% |
| Germany | 140 | 99 | 1.8 | 1.3 | -81% |
| Greece | 4 | 2 | 0.4 | 0.2 | -83% |
| Ireland | 1 | 0 | 0.3 | 0.1 | -94% |
| Italy | 63 | 38 | 1.1 | 0.7 | -87% |
| Luxembourg | 1 | 1 | 3.0 | 2.1 | -78% |
| Netherlands | 38 | 27 | 2.6 | 1.8 | -68% |
| Portugal | 8 | 6 | 0.8 | 0.6 | -72% |
| Spain | 7 | 4 | 0.2 | 0.1 | -94% |
| Sweden | 0 | 0 | 0.0 | 0.0 | -98% |
| United Kingdom | 77 | 45 | 1.3 | 0.8 | -71% |
| EU-15 | 466 | 300 | 1.3 | 0.8 | -76% |

Note [1]): Reduction of ozone exposure exceeding the model confidence range of 0.4 ppm.hours)

### 3.4.2.3 AOT40

The excess AOT40 as a vegetation-related exposure criterion is presented in Figure 3.9. The emission reductions of the H1 scenario cut the highest excess exposure from 17 to about 10 ppm.hours (in excess of the critical level of 3 ppm.hours). The peak excess remains in France and northern Italy. Figure 3.10 highlights the AOT40 gap closures achieved in the various Member States. Evidently, the 33 percent target for individual grids is violated (and compensated by additional improvements) in the UK, the Benelux countries, Germany, Portugal and Greece.

The vegetation exposure indices are presented in Table 3.6. Highest average excess exposure occurs in Belgium, France, Italy and Luxembourg, and the overall gap closure (in terms of these exposure indices) reaches 53 percent. It is noteworthy that, in absolute terms, France, Germany, Spain and Italy will continue to have the highest cumulative exposure for their ecosystems.

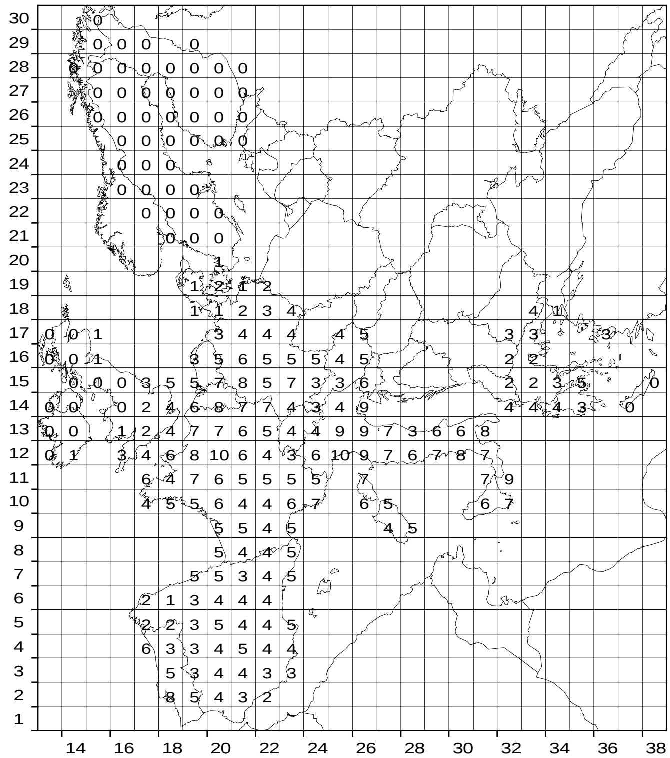

Figure 3.9: Excess AOT40 (above 3 ppm.hours) for the emissions of the H1 scenario (in ppm.hours)

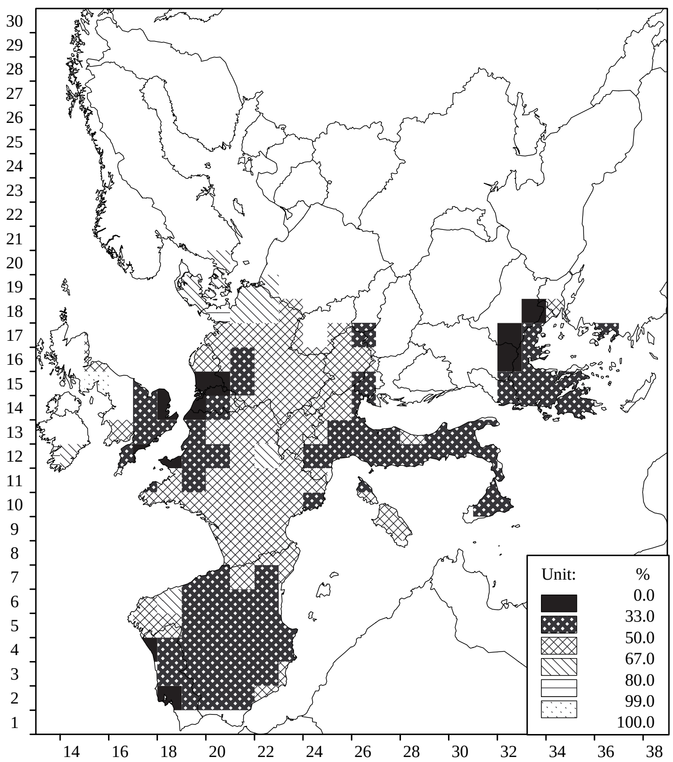


Figure 3.10: Percentage reduction of the excess AOT40 achieved by the H1 scenario compared to 1990

Table 3.6: Vegetation exposure indices for the REF and the H1 scenarios

| | Cumulative vegetation exposure index (1000 km$^2$.excess ppm.hours) | | Average vegetation exposure index (excess ppm.hours) | | Change compared to 1990 |
|---|---|---|---|---|---|
| | REF | H1 | REF | H1 | H1 |
| Austria | 257 | 213 | 5.0 | 4.1 | -55% |
| Belgium | 141 | 115 | 9.1 | 7.4 | -35% |
| Denmark | 53 | 36 | 1.8 | 1.2 | -74% |
| Finland | 0 | 0 | 0.0 | 0.0 | - |
| France | 2345 | 1816 | 7.3 | 5.6 | -56% |
| Germany | 1204 | 943 | 5.7 | 4.4 | -60% |
| Greece | 170 | 137 | 3.1 | 2.5 | -41% |
| Ireland | 8 | 3 | 0.3 | 0.1 | -88% |
| Italy | 1186 | 996 | 7.5 | 6.3 | -44% |
| Luxembourg | 14 | 11 | 9.3 | 7.3 | -56% |
| Netherlands | 79 | 63 | 6.1 | 4.8 | -42% |
| Portugal | 274 | 233 | 4.7 | 4.0 | -39% |
| Spain | 1281 | 1093 | 4.2 | 3.6 | -46% |
| Sweden | 18 | 9 | 0.1 | 0.0 | -92% |
| United Kingdom | 153 | 96 | 1.9 | 1.2 | -50% |
| EU-15 | 7183 | 5765 | 3.8 | 3.1 | -53% |

### 3.4.3 Eutrophication

Although no specific environmental targets were introduced for eutrophication, the $NO_x$ and ammonia emission reductions taken for the sake of acidification and ground-level ozone have an influence on the eutrophication situation. Figure 3.11 presents the percentage of ecosystems, which still receive nitrogen deposition above their critical loads despite the emission reductions of the H1 scenario. A comparison with the situation in the year 1990 clearly indicates that, when using the 'protected area' criterion, there is in some regions only little improvement observable. To some extent this low improvement can be linked to insufficient emission reductions; another factor having significant impact on the 'protected area' measure is the distribution of critical loads supplied by the countries to the Coordination Centre for Effects. While for acidification the mapping work conducted by national experts resulted in relatively large variations of critical loads within each grid cell (ranging from low critical loads for most sensitive ecosystems to significantly higher critical loads for others), for eutrophication some countries provided only a very small number of samples with negligible variation of sensitivities within grid cells. Obviously, such minor differences in sensitivities might by caused by ecological factors or by insufficient knowledge to firmly quantify possible differences in environmental sensitivities.

In the context of an area gap closure approach, however, this missing spread of critical loads distribution can only lead to 'flip/flop' solutions, i.e., either everything is unprotected, or everything is protected. Intermediate gap closures cannot be realized.

The recently developed 'accumulated excess' concept overcomes this problem by offering a continuous measure for excess deposition. The gap closure, expressed in accumulated excess deposition above the critical loads for eutrophication of all ecosystems in each grid cell is presented in Figure 3.12. In areas with high nitrogen deposition in the Benelux region, improvements range up to 70 percent; for northern Italy with a comparable situation the gap closure is only 34 percent, while for France the lowest relative improvements range between 30 and 40 percent. Overall, the average improvement in the EU-15 is in the range of about 50 percent.

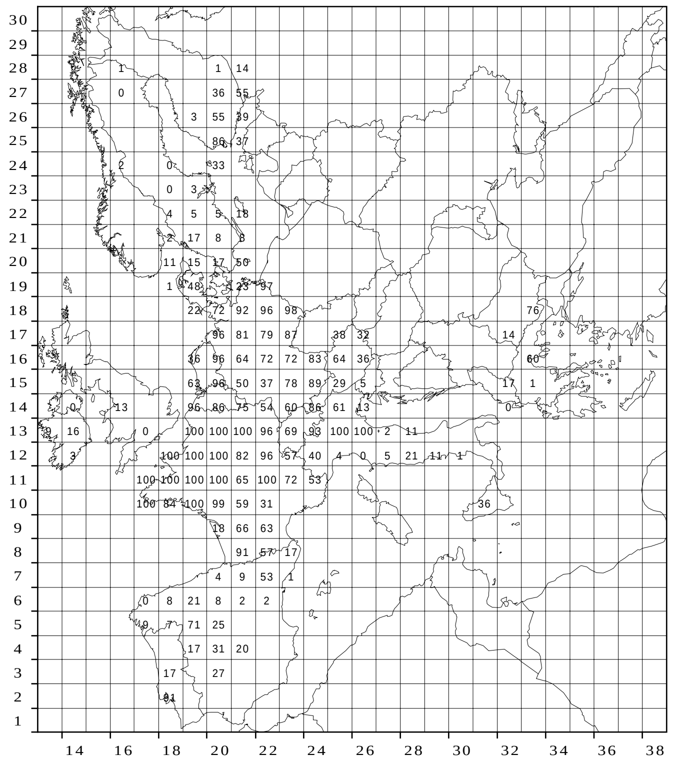


Figure 3.11: Percentage of ecosystems with nitrogen deposition above their critical loads for the emissions of the H1 scenario

Figure 3.13 displays the excess nitrogen deposition for the 'two percentile' ecosystems. Peak excess deposition occurs on the German/Dutch border and in northern Italy, where it exceeds the critical loads for these ecosystems by a factor of two and more.

Finally, Table 3.7 presents the country statistics for ecosystems protection. Compared to 1990, the H1 scenario would reduce the unprotected ecosystems from 66 million hectares to 42 million hectares, i.e., by 29 percent. Despite this improvement, about 35 percent of all ecosystems in the EU would still receive nitrogen deposition above the critical loads for eutrophication.

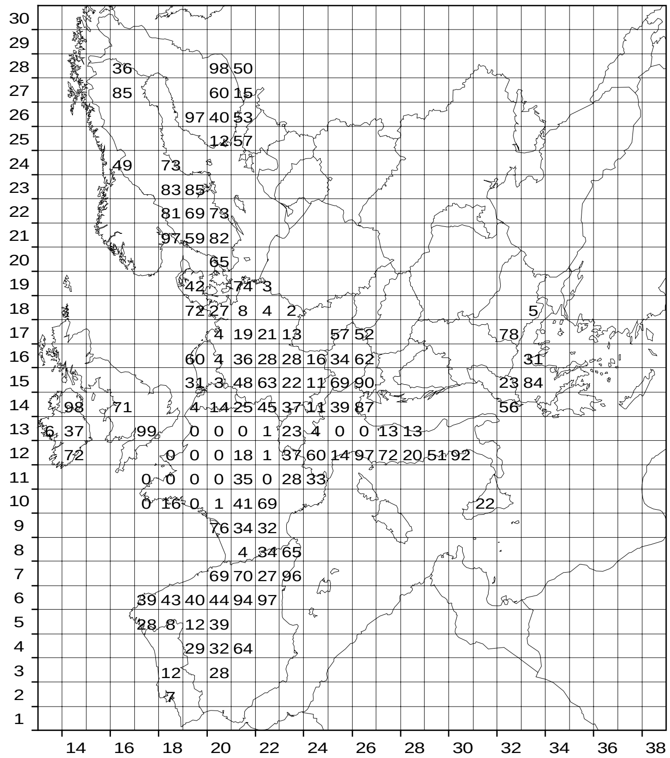


Figure 3.12: Gap closure in terms of unprotected ecosystems area (for eutrophication) achieved by the emission reductions of the H1 scenario

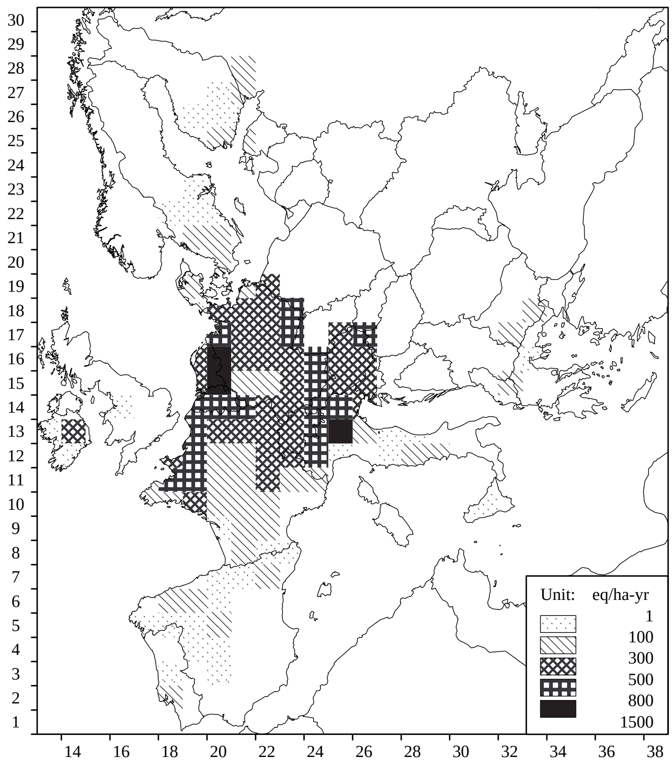


Figure 3.13: Excess nitrogen deposition for the 2-percentile ecosystems for the emissions of the H1 scenario

Table 3.7: Ecosystems with nitrogen deposition above their critical loads for eutrophication for the H1 and the REF scenarios.

| | 1000 ha | | Percent of ecosystems | |
|---|---|---|---|---|
| | REF | H1 | REF | H1 |
| Austria | 3441 | 2773 | 57.6% | 46.5% |
| Belgium | 677 | 586 | 96.4% | 83.4% |
| Denmark | 119 | 91 | 37.6% | 28.9% |
| Finland | 2538 | 2163 | 15.4% | 13.1% |
| France | 25160 | 22524 | 79.2% | 70.9% |
| Germany | 9184 | 7474 | 89.5% | 72.9% |
| Greece | 236 | 211 | 9.6% | 8.6% |
| Ireland | 58 | 54 | 6.4% | 5.9% |
| Italy | 3795 | 3452 | 31.7% | 28.8% |
| Luxembourg | 80 | 66 | 91.3% | 75.1% |
| Netherlands | 291 | 278 | 91.0% | 87.0% |
| Portugal | 709 | 683 | 25.1% | 24.2% |
| Spain | 1158 | 964 | 13.6% | 11.3% |
| Sweden | 891 | 737 | 4.7% | 3.9% |
| United Kingdom | 126 | 64 | 1.4% | 0.7% |
| | | | | |
| EU-15 | 48461 | 42117 | 40.2% | 34.9% |

### 3.4.4 'Binding Effects'

Although the non-linear optimization routine, which is used to identify the cost-minimal allocation of emission reductions, is a highly complex mathematical procedure, the results obtained by such an optimization can subsequently be analyzed according to a number of criteria in order to gain insight into which factors (e.g., cost curves) and (environmental) constraints drive a particular solution.

A key explanatory factor which explains at least parts of the cost-optimized solution is the set of environmental targets which are most difficult to attain by the emission reductions and which therefore 'drive' the optimized solution. Figure 3.14 displays for which areas which of the environmental constraints (on acidification, AOT60 and AOT40) are most difficult to attain and are therefore, together with their interaction with other pollutants, responsible for stringency and the overall balance of optimized emission reductions. The map indicates that the targets specified for acidification are driving forces at the German/Dutch border,in Ireland and to a limited extent in Spain. Health-related ozone targets dominate the need for measures in the UK, France, the Benelux countries, in some parts of Germany and in Portugal. Vegetation related ozone targets are drivers for Mediterranean countries. It is important to mention that the dominance of a particular type of constraint in a region does not imply that there are no other problems in this region; the only conclusion is that the targets selected for a particular problem are more difficult to attain than the targets for other problems.

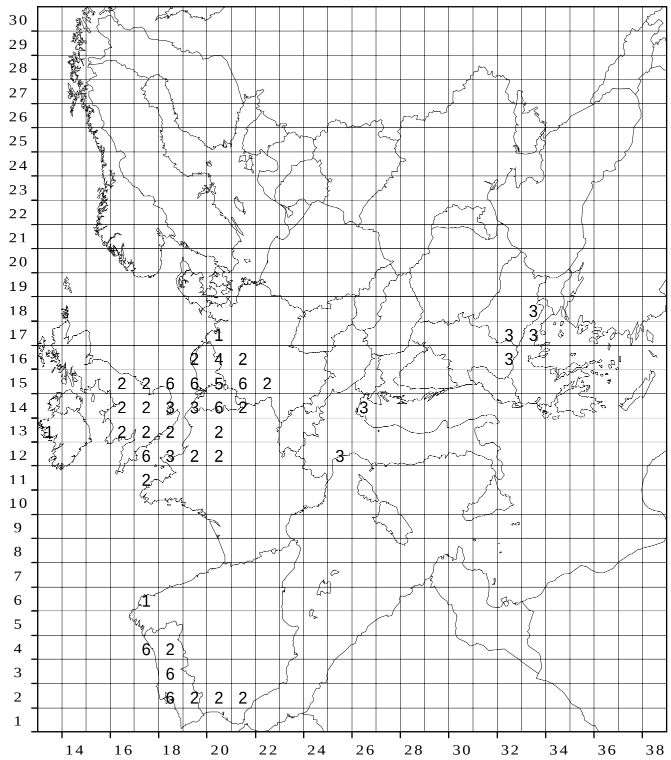


Figure 3.14: The environmental constraints which are most difficult to achieve in the various parts of Europe (1 ..acidification, 2 .. AOT60, 3 .. AOT40, 4 .. acidification and AOT60, 5 .. acidification and AOT60 and AOT40, 6 .. AOT60 and AOT40)

## 3.5 Comparison of Per-capita Emission Control Costs against Environmental Indices

The optimization analysis follows an effect-based rationale by identifying the cost-minimal set of emission controls to achieve the imposed environmental targets. Therefore, all measures are justified by actual environmental improvements; emission controls that would not improve the environment in a cost-effective way are not selected by the optimization. It is in the nature of the effect-based rationale, however, that other allocation criteria (e.g., equity across countries and/or economic sectors) are not in order to ensure the overall cost-effectiveness.

The analysis presented in this section provides an initial assessment of the international distribution of emission control costs implied by the H1 scenario. Additional analysis of the costs and of some monetized benefits and their international distribution is the subject of Part B of this report.

For reasons of simplicity, total emission control costs were selected as the criterion against which the international distribution will be compared. This measure enables one to easily add up the efforts for the four pollutants without the need for defining necessarily arbitrary weights for the individual pollutants. Furthermore, in order to adjust for the differences in individual countries, total abatement costs were related to the 1997 population of the countries.

The resulting per-capita costs (both of the REF case, white boxes, and the H1 case (filled boxes) - on the y-axis - were then plotted against the average exposure indices for acidification, ozone population exposure, and ozone vegetation exposure of the REF scenario (on the x-axis). It is important to note that these graphs present total emission control costs (for all three environmental problems), although the environmental indices on the x-axis can only relate to one individual problem.

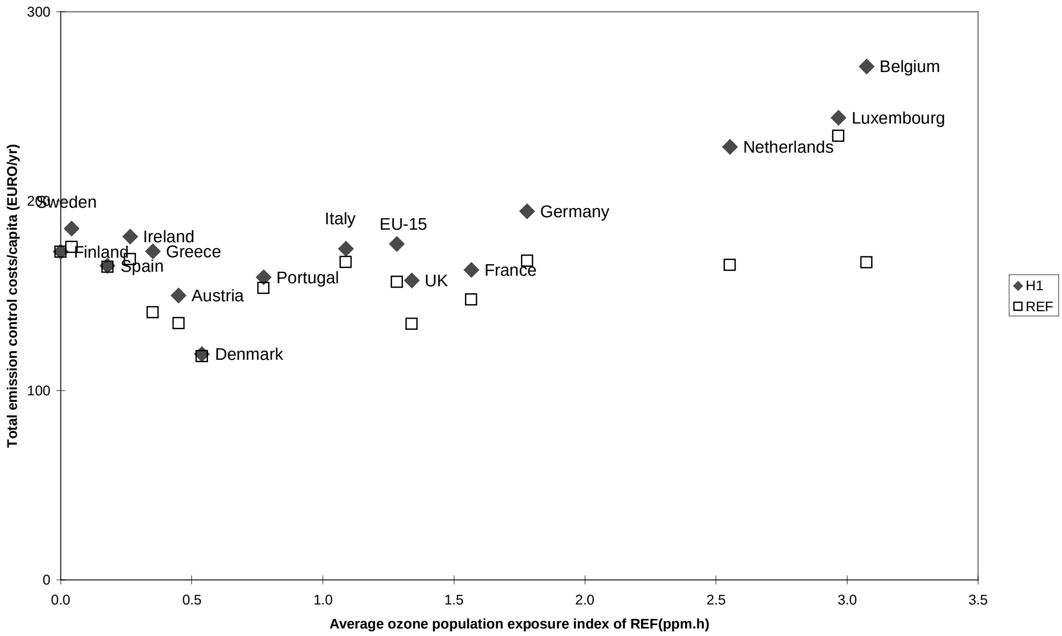


Figure 3.15: Total per-capita emission control costs of the REF and H1 scenarios (for $SO_2$, $NO_x$, VOC and $NH_3$ emissions) plotted against the average ozone population exposure indices of the REF case

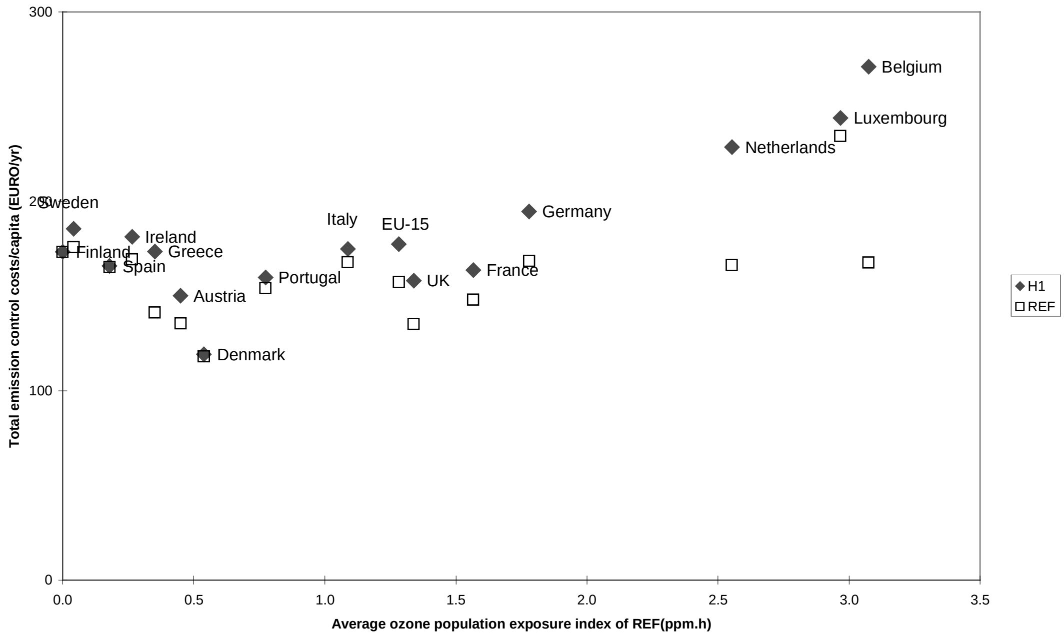


Figure 3.15 plots the per-capita emission control costs (for all four pollutants) of the REF and the H1 cases against the average population exposure indices. There is clear evidence that[4], the per-capita emission control costs for the REF case stay within a relatively narrow band, independent of the actual severity of the environmental problem. The low per-capita costs for Denmark can be explained by the fact that, in contrast so most other countries, Denmark submitted a 'low $CO_2$' energy scenario as the basis for the calculations. For the H1 scenario, however, countries with a more severe ozone problem are charged with higher additional costs.

A similar graph is presented in Figure 3.16 for vegetation-related ozone exposure. Again, also when evaluated against this criterion, REF costs show no relation to the environmental problem; in the H1 scenario, higher costs are related to higher ozone exposure. Figure 3.17 presents the analysis for acidification with similar results.

[4] The numbers for Luxembourg should be treated with care; due to the very small numbers numerical and statistical artifacts are not negligible.

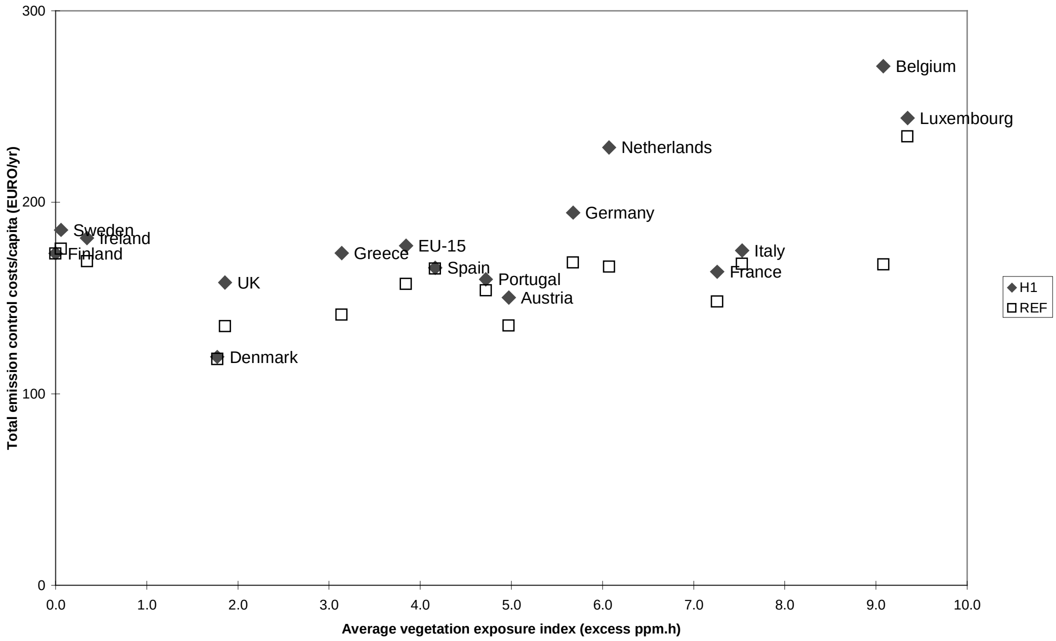


Figure 3.16: Total per-capita emission control costs of the REF and H1 scenarios (for $SO_2$, $NO_x$, VOC and $NH_3$ emissions) plotted against the average vegetation ozone exposure indices of the REF scenario

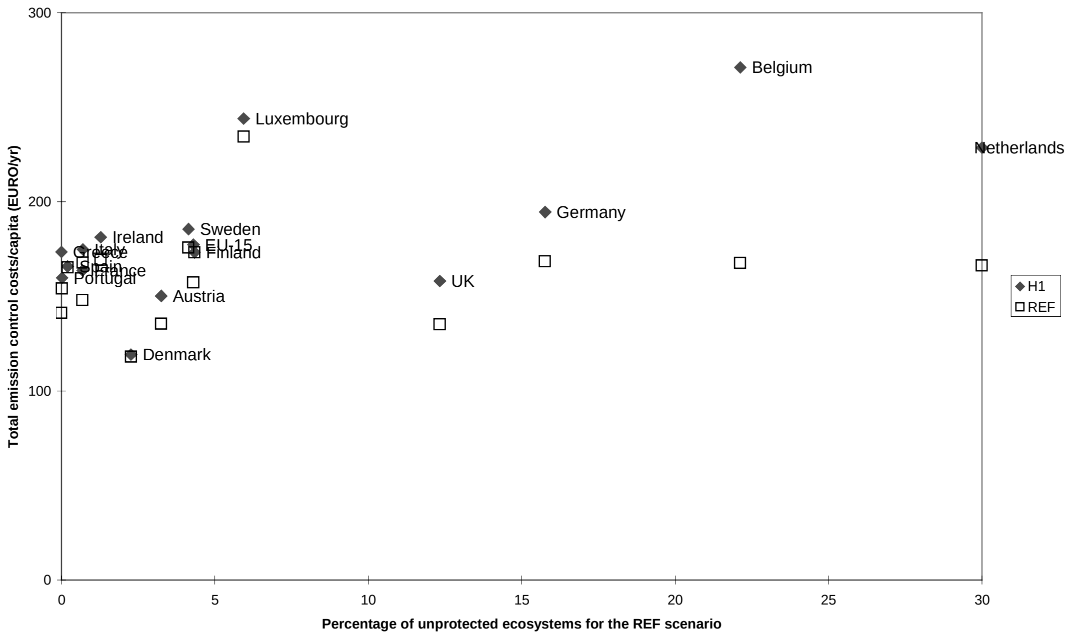


Figure 3.17: Total per-capita emission control costs of the REF and H1 scenarios (for $SO_2$, $NO_x$, VOC and $NH_3$ emissions) plotted against the percentage of unprotected ecosystems (acidification) for the REF scenario

# 4 Variation of Ambition Levels (Scenarios H2 and H3)

Two scenarios were calculated with modified environmental ambition levels. For the 'low ambition' case (H2), the lower targets identified in the Fifth Interim Reports were adopted, while for the 'high ambition case' (H3), the AOT60 ceiling of the F5 scenario had to be relaxed due to feasibility considerations. Compared to the central H1 case, the low ambition scenario H2 generally lower gap closure percentages and lower exposure ceilings were selected. For H3, the acidification gap closure target of H1 was maintained, while a stricter emission ceiling was introduced. For ozone, both gap closure and ceiling targets were tightened (Table 4.1).

Table 4.1: Summary of the environmental targets for the scenarios with modified ambition levels

| | Low ambition (H2) | Central scenario (H1) | High ambition (H3) |
|---|---|---|---|
| **Acidification** | | | |
| Gap closure on accumulated excess acidity | 90 % | 95 % | 95 % |
| Maximum excess deposition for the 2-percent of the most sensitive ecosystems | (900 eq/ha) | (850 eq/ha) | 800 eq/ha |
| **Health-related ozone** | | | |
| Gap closure on AOT60 | 60 % | 67 % | 70 % |
| Maximum AOT60, to be achieved in 4 out of 5 years | 3.0 ppm.h | 2.9 ppm.h | 2.8 ppm.h |
| **Vegetation-related ozone** | | | |
| Gap closure on AOT40 | 30 % | 33 % | 35 % |
| Maximum excess AOT40, mean over five years | 10.5 ppm.h | 10 ppm.h | 9.5 ppm.h |
| **Eutrophication** | | | |
| Gap closure on accumulated excess nitrogen deposition | | (50 %) | (50%) |
| Maximum excess deposition for the 2-percent of the most sensitive ecosystems | (1400 eq/ha) | (1300 eq/ha) | (1000 eq/ha) |

Results of the analyses are provided in Table 4.2 to Table 4.4 (emissions and costs) and Table 4.5 to Table 4.8 (environmental indices). With 7.5 billion EURO/year the overall costs of the central scenario H1 lie well within the range spanned by the low ambition (4.2 billion EURO/year) and the high ambition (16.2 billion EURO/year). There are interesting differences in emission controls: For $SO_2$, modifying the environmental ambition level changes total EU-15 emission by -4/+3 percent; for $NO_x$, variations range from -2 to + 6 percent. For VOC, only ±1-2 percent differences occur, and ammonia could be 5 percent lower or 8 percent higher than in the central scenario.

Table 4.2: $NO_x$ and VOC emissions for the variations in the ambition. Percentage changes relate to the year 1990.

| | $NO_x$ | | | | | | | | VOC | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | REF | | H2 low ambition | | H1 central | | H3 high ambition | | REF | | H2 low ambition | | H1 central | | H3 high ambition | |
| | kt | *Change* | kt | *Change* | kt | *Change* | kt | *Change* | kt | *Change* | kt | *Change* | kt | *Change* | kt | *Change* |
| Austria | 103 | *-46%* | 92 | *-52%* | 91 | *-53%* | 89 | *-54%* | 205 | *-42%* | 129 | *-63%* | 129 | *-63%* | 129 | *-63%* |
| Belgium | 191 | *-46%* | 127 | *-64%* | 127 | *-64%* | 127 | *-64%* | 193 | *-48%* | 103 | *-72%* | 102 | *-73%* | 101 | *-73%* |
| Denmark | 128 | *-53%* | 128 | *-53%* | 127 | *-54%* | 96 | *-65%* | 85 | *-53%* | 85 | *-53%* | 85 | *-53%* | 84 | *-54%* |
| Finland | 152 | *-45%* | 152 | *-45%* | 152 | *-45%* | 151 | *-45%* | 110 | *-48%* | 110 | *-48%* | 110 | *-48%* | 110 | *-48%* |
| France | 858 | *-54%* | 706 | *-62%* | 679 | *-64%* | 633 | *-66%* | 1223 | *-49%* | 1015 | *-57%* | 932 | *-61%* | 771 | *-68%* |
| Germany | 1184 | *-56%* | 1081 | *-59%* | 1051 | *-61%* | 930 | *-65%* | 1137 | *-64%* | 925 | *-70%* | 924 | *-70%* | 912 | *-71%* |
| Greece | 344 | *0%* | 253 | *-27%* | 264 | *-23%* | 317 | *-8%* | 267 | *-21%* | 169 | *-50%* | 173 | *-49%* | 188 | *-44%* |
| Ireland | 70 | *-38%* | 63 | *-44%* | 59 | *-48%* | 46 | *-59%* | 55 | *-50%* | 55 | *-50%* | 55 | *-50%* | 54 | *-51%* |
| Italy | 1130 | *-45%* | 900 | *-56%* | 869 | *-57%* | 842 | *-59%* | 1159 | *-44%* | 962 | *-53%* | 962 | *-53%* | 893 | *-57%* |
| Luxembourg | 10 | *-55%* | 7 | *-68%* | 8 | *-64%* | 6 | *-73%* | 7 | *-63%* | 5 | *-74%* | 6 | *-68%* | 5 | *-74%* |
| Netherlands | 280 | *-48%* | 280 | *-48%* | 238 | *-56%* | 213 | *-61%* | 233 | *-52%* | 157 | *-68%* | 156 | *-68%* | 152 | *-69%* |
| Portugal | 177 | *-15%* | 177 | *-15%* | 144 | *-31%* | 144 | *-31%* | 144 | *-32%* | 113 | *-47%* | 102 | *-52%* | 102 | *-52%* |
| Spain | 847 | *-27%* | 847 | *-27%* | 781 | *-33%* | 587 | *-49%* | 669 | *-34%* | 669 | *-34%* | 662 | *-34%* | 642 | *-36%* |
| Sweden | 190 | *-44%* | 158 | *-53%* | 152 | *-55%* | 147 | *-57%* | 290 | *-43%* | 219 | *-57%* | 219 | *-57%* | 215 | *-58%* |
| UK | 1186 | *-58%* | 1181 | *-58%* | 1181 | *-58%* | 859 | *-70%* | 1351 | *-49%* | 1023 | *-62%* | 964 | *-64%* | 953 | *-64%* |
| EU-15 | 6849 | *-48%* | 6152 | *-53%* | 5922 | *-55%* | 5185 | *-61%* | 7128 | *-49%* | 5739 | *-59%* | 5581 | *-60%* | 5310 | *-62%* |

Table 4.3: $SO_2$ and $NH_3$ emissions for the variations in the ambition levels of the scenarios with different ambition levels. Percentage changes relate to the year 1990.

| | $SO_2$ | | | | | | | | $NH_3$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | REF | | H2 low ambition | | H1 central | | H3 high ambition | | REF | | H2 low ambition | | H1 central | | H3 high ambition | |
| | kt | *Change* | kt | *Change* | kt | *Change* | kt | *Change* | kt | *Change* | kt | *Change* | kt | *Change* | kt | *Change* |
| Austria | 40 | *-57%* | 40 | *-57%* | 40 | *-57%* | 33 | *-65%* | 67 | *-13%* | 67 | *-13%* | 67 | *-13%* | 66 | *-14%* |
| Belgium | 193 | *-43%* | 82 | *-76%* | 76 | *-77%* | 75 | *-78%* | 96 | *-1%* | 80 | *-18%* | 57 | *-41%* | 57 | *-41%* |
| Denmark | 90 | *-51%* | 90 | *-51%* | 77 | *-58%* | 25 | *-86%* | 72 | *-6%* | 71 | *-8%* | 71 | *-8%* | 65 | *-16%* |
| Finland | 116 | *-49%* | 116 | *-49%* | 116 | *-49%* | 116 | *-49%* | 31 | *-23%* | 31 | *-23%* | 31 | *-23%* | 31 | *-23%* |
| France | 448 | *-64%* | 318 | *-75%* | 218 | *-83%* | 163 | *-87%* | 777 | *-4%* | 771 | *-4%* | 718 | *-11%* | 530 | *-34%* |
| Germany | 581 | *-89%* | 514 | *-90%* | 463 | *-91%* | 444 | *-92%* | 571 | *-25%* | 513 | *-32%* | 413 | *-45%* | 366 | *-52%* |
| Greece | 546 | *8%* | 546 | *8%* | 546 | *8%* | 546 | *8%* | 74 | *-8%* | 74 | *-8%* | 74 | *-8%* | 74 | *-8%* |
| Ireland | 66 | *-63%* | 28 | *-84%* | 28 | *-84%* | 23 | *-87%* | 126 | *-1%* | 126 | *-1%* | 123 | *-3%* | 123 | *-3%* |
| Italy | 567 | *-66%* | 566 | *-66%* | 566 | *-66%* | 295 | *-82%* | 432 | *-6%* | 432 | *-6%* | 430 | *-7%* | 430 | *-7%* |
| Luxembourg | 4 | *-71%* | 4 | *-71%* | 3 | *-79%* | 2 | *-86%* | 7 | *0%* | 7 | *0%* | 7 | *0%* | 7 | *0%* |
| Netherlands | 73 | *-64%* | 50 | *-75%* | 50 | *-75%* | 50 | *-75%* | 136 | *-42%* | 119 | *-49%* | 104 | *-55%* | 104 | *-55%* |
| Portugal | 141 | *-50%* | 141 | *-50%* | 141 | *-50%* | 141 | *-50%* | 67 | *-6%* | 67 | *-6%* | 67 | *-6%* | 67 | *-6%* |
| Spain | 774 | *-65%* | 744 | *-66%* | 746 | *-66%* | 197 | *-91%* | 353 | *0%* | 353 | *0%* | 353 | *0%* | 346 | *-2%* |
| Sweden | 67 | *-44%* | 67 | *-44%* | 67 | *-44%* | 66 | *-45%* | 48 | *-21%* | 48 | *-21%* | 48 | *-21%* | 48 | *-21%* |
| UK | 980 | *-74%* | 718 | *-81%* | 497 | *-87%* | 422 | *-89%* | 297 | *-10%* | 293 | *-11%* | 264 | *-20%* | 224 | *-32%* |
| EU-15 | 4687 | *-71%* | 4026 | *-75%* | 3637 | *-78%* | 2600 | *-84%* | 3154 | *-12%* | 3051 | *-15%* | 2826 | *-21%* | 2537 | *-29%* |

Table 4.4: Emission control costs for the variations in the ambition levels, in million EURO/year.

| | $SO_2$ | | | | $NO_x$/VOC | | | | $NH_3$ | | | | Total | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | REF | H2 | H1 | H3 | REF | H2 | H1 | H3 | REF | H2 | H1 | H3 | REF | H2 | H1 | H3 |
| | | low | central | high | | low | central | high | | low | central | high | | low | central | high |
| Costs | total | on top of REF | | | total | on top of REF | | | total | on top of REF | | | total | on top of REF | | |
| Austria | 191 | 0 | 0 | 7 | 902 | 117 | 119 | 129 | 0 | 0 | 0 | 0 | 1093 | 117 | 119 | 136 |
| Belgium | 426 | 93 | 127 | 154 | 1278 | 455 | 459 | 499 | 0 | 43 | 467 | 467 | 1704 | 591 | 1053 | 1120 |
| Denmark | 138 | 0 | 5 | 61 | 484 | 0 | 0 | 37 | 0 | 0 | 0 | 25 | 623 | 0 | 6 | 123 |
| Finland | 247 | 0 | 0 | 0 | 642 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 889 | 0 | 0 | 0 |
| France | 1276 | 47 | 136 | 348 | 7383 | 374 | 739 | 2455 | 0 | 0 | 41 | 1467 | 8659 | 421 | 916 | 4270 |
| Germany | 3264 | 60 | 244 | 331 | 10549 | 929 | 1048 | 2584 | 0 | 111 | 854 | 1460 | 13813 | 1100 | 2147 | 4376 |
| Greece | 434 | 0 | 0 | 0 | 1048 | 449 | 338 | 119 | 0 | 0 | 0 | 0 | 1482 | 449 | 338 | 119 |
| Ireland | 132 | 20 | 20 | 40 | 477 | 1 | 4 | 36 | 9 | 3 | 20 | 20 | 618 | 24 | 44 | 96 |
| Italy | 1776 | 0 | 0 | 83 | 7868 | 313 | 403 | 648 | 0 | 0 | 0 | 0 | 9644 | 313 | 403 | 731 |
| Luxembourg | 13 | 0 | 1 | 3 | 71 | 11 | 4 | 30 | 15 | 0 | 0 | 0 | 98 | 11 | 4 | 33 |
| Netherlands | 340 | 19 | 19 | 19 | 1731 | 88 | 211 | 495 | 196 | 247 | 741 | 741 | 2267 | 354 | 971 | 1255 |
| Portugal | 181 | 0 | 0 | 0 | 1349 | 21 | 57 | 57 | 0 | 0 | 0 | 0 | 1530 | 21 | 57 | 57 |
| Spain | 809 | 10 | 9 | 303 | 5658 | 0 | 13 | 295 | 28 | 0 | 0 | 7 | 6495 | 10 | 22 | 605 |
| Sweden | 316 | 0 | 0 | 0 | 1125 | 73 | 87 | 116 | 113 | 0 | 0 | 0 | 1554 | 73 | 87 | 117 |
| UK | 1269 | 92 | 299 | 580 | 6695 | 647 | 1026 | 2138 | 0 | 2 | 23 | 445 | 7964 | 741 | 1348 | 3163 |
| EU-15 | 10813 | 342 | 861 | 1931 | 47258 | 3479 | 4508 | 9639 | 361 | 406 | 2146 | 4632 | 58433 | 4227 | 7514 | 16202 |

Table 4.5: Ecosystems with acid deposition above their critical loads for acidification for the central scenario H1 and for the scenarios with modified ambition levels

| | 1000 ha | | | | Percent of ecosystems | | | |
|---|---|---|---|---|---|---|---|---|
| | REF | H2 | H1 | H3 | REF | H2 | H1 | H3 |
| Ambition | | Low | Central | High | | Low | Central | High |
| Austria | 162 | 122 | 99 | 78 | 3.3 | 2.5 | 2.0 | 1.6 |
| Belgium | 155 | 99 | 52 | 24 | 22.1 | 14.0 | 7.4 | 3.4 |
| Denmark | 9 | 7 | 6 | 4 | 2.3 | 1.8 | 1.5 | 1.1 |
| Finland | 1183 | 1164 | 1150 | 1130 | 4.3 | 4.3 | 4.2 | 4.1 |
| France | 218 | 111 | 88 | 38 | 0.7 | 0.4 | 0.3 | 0.1 |
| Germany | 1617 | 1110 | 727 | 515 | 15.8 | 10.8 | 7.1 | 5.0 |
| Greece | 0 | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Ireland | 12 | 9 | 9 | 8 | 1.3 | 1.0 | 1.0 | 0.9 |
| Italy | 74 | 62 | 58 | 52 | 0.7 | 0.6 | 0.6 | 0.5 |
| Luxembourg | 5 | 4 | 1 | 0 | 5.9 | 4.3 | 0.9 | 0.5 |
| Netherlands | 193 | 134 | 76 | 63 | 60.4 | 41.8 | 23.7 | 19.8 |
| Portugal | 1 | 1 | 1 | 1 | 0.0 | 0.0 | 0.0 | 0.0 |
| Spain | 17 | 17 | 17 | 0 | 0.2 | 0.2 | 0.2 | 0.0 |
| Sweden | 1605 | 1494 | 1420 | 1236 | 4.1 | 3.9 | 3.7 | 3.2 |
| UK | 1182 | 926 | 649 | 288 | 12.3 | 9.7 | 6.8 | 3.0 |
| EU-15 | 6433 | 5259 | 4351 | 3437 | 4.3 | 3.5 | 2.9 | 2.3 |

Table 4.6: Ozone population exposure for the central scenario H1 and for the scenarios with modified ambition levels

| | Cumulative population exposure index (million.persons.ppm.h) | | | | Average population exposure index (ppm.h) | | | |
|---|---|---|---|---|---|---|---|---|
| | REF | H2 | H1 | H3 | REF | H2 | H1 | H3 |
| Ambition | | Low | Central | High | | Low | Central | High |
| Austria | 3 | 2 | 2 | 2 | 0.5 | 0.3 | 0.3 | 0.3 |
| Belgium | 34 | 24 | 23 | 21 | 3.1 | 2.2 | 2.1 | 1.9 |
| Denmark | 3 | 2 | 1 | 1 | 0.5 | 0.3 | 0.3 | 0.2 |
| Finland | 0 | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 | 0.0 |
| France | 89 | 56 | 53 | 45 | 1.6 | 1.0 | 0.9 | 0.8 |
| Germany | 140 | 102 | 99 | 88 | 1.8 | 1.3 | 1.3 | 1.1 |
| Greece | 4 | 2 | 2 | 2 | 0.4 | 0.2 | 0.2 | 0.2 |
| Ireland | 1 | 0 | 0 | 0 | 0.3 | 0.1 | 0.1 | 0.1 |
| Italy | 63 | 40 | 38 | 33 | 1.1 | 0.7 | 0.7 | 0.6 |
| Luxembourg | 1 | 1 | 1 | 1 | 3.0 | 2.2 | 2.1 | 1.8 |
| Netherlands | 38 | 28 | 27 | 25 | 2.6 | 1.9 | 1.8 | 1.7 |
| Portugal | 8 | 6 | 6 | 5 | 0.8 | 0.6 | 0.6 | 0.5 |
| Spain | 7 | 4 | 4 | 1 | 0.2 | 0.1 | 0.1 | 0.0 |
| Sweden | 0 | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 | 0.0 |
| UK | 77 | 49 | 45 | 42 | 1.3 | 0.9 | 0.8 | 0.7 |
| EU-15 | 466 | 317 | 300 | 267 | 1.3 | 0.9 | 0.8 | 0.7 |

Table 4.7: Ozone vegetation exposure indices for the central scenario H1 and for the scenarios with modified ambition levels

| | Cumulative vegetation exposure index (1000 km$^2$ppm.h) | | | | Average vegetation exposure index (ppm.h) | | | |
|---|---|---|---|---|---|---|---|---|
| | REF | H2 | H1 | H3 | REF | H2 | H1 | H3 |
| Ambition | | Low | Central | High | | Low | Central | High |
| Austria | 257 | 217 | 213 | 201 | 5.0 | 4.2 | 4.1 | 3.9 |
| Belgium | 141 | 117 | 115 | 113 | 9.1 | 7.5 | 7.4 | 7.3 |
| Denmark | 53 | 38 | 36 | 29 | 1.8 | 1.3 | 1.2 | 1.0 |
| Finland | 0 | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 | 0.0 |
| France | 2345 | 1897 | 1816 | 1658 | 7.3 | 5.9 | 5.6 | 5.1 |
| Germany | 1204 | 966 | 943 | 883 | 5.7 | 4.6 | 4.4 | 4.2 |
| Greece | 170 | 136 | 137 | 145 | 3.1 | 2.5 | 2.5 | 2.7 |
| Ireland | 8 | 4 | 3 | 2 | 0.3 | 0.2 | 0.1 | 0.1 |
| Italy | 1186 | 1017 | 996 | 945 | 7.5 | 6.5 | 6.3 | 6.0 |
| Luxembourg | 14 | 11 | 11 | 10 | 9.3 | 7.4 | 7.3 | 6.8 |
| Netherlands | 79 | 63 | 63 | 63 | 6.1 | 4.9 | 4.8 | 4.9 |
| Portugal | 274 | 254 | 233 | 215 | 4.7 | 4.4 | 4.0 | 3.7 |
| Spain | 1281 | 1197 | 1093 | 865 | 4.2 | 3.9 | 3.6 | 2.8 |
| Sweden | 18 | 10 | 9 | 7 | 0.1 | 0.0 | 0.0 | 0.0 |
| UK | 153 | 102 | 96 | 101 | 1.9 | 1.2 | 1.2 | 1.2 |
| EU-15 | 7183 | 6029 | 5765 | 5237 | 3.8 | 3.2 | 3.1 | 2.8 |

Table 4.8: Ecosystems with nitrogen deposition above their critical loads for eutrophication for the central scenario H1 and for the scenarios with modified ambition levels

| | 1000 ha | | | | Percent of ecosystems | | | |
|---|---|---|---|---|---|---|---|---|
| | REF | H2 | H1 | H3 | REF | H2 | H1 | H3 |
| Ambition | | Low | Central | High | | Low | Central | High |
| Austria | 3441 | 3172 | 2773 | 2583 | 58 | 53 | 46 | 43 |
| Belgium | 677 | 644 | 586 | 471 | 96 | 92 | 83 | 67 |
| Denmark | 119 | 99 | 91 | 57 | 38 | 32 | 29 | 18 |
| Finland | 2538 | 2291 | 2163 | 1858 | 15 | 14 | 13 | 11 |
| France | 25160 | 23936 | 22524 | 17884 | 79 | 75 | 71 | 56 |
| Germany | 9184 | 8489 | 7474 | 6283 | 90 | 83 | 73 | 61 |
| Greece | 236 | 206 | 211 | 219 | 10 | 8 | 9 | 9 |
| Ireland | 58 | 57 | 54 | 47 | 6 | 6 | 6 | 5 |
| Italy | 3795 | 3557 | 3452 | 3338 | 32 | 30 | 29 | 28 |
| Luxembourg | 80 | 75 | 66 | 54 | 91 | 86 | 75 | 62 |
| Netherlands | 291 | 284 | 278 | 271 | 91 | 89 | 87 | 85 |
| Portugal | 709 | 708 | 683 | 578 | 25 | 25 | 24 | 20 |
| Spain | 1158 | 1097 | 964 | 487 | 14 | 13 | 11 | 6 |
| Sweden | 891 | 813 | 737 | 589 | 5 | 4 | 4 | 3 |
| UK | 126 | 98 | 64 | 0 | 1 | 1 | 1 | 0 |
| EU-15 | 48461 | 45527 | 42117 | 34720 | 40 | 38 | 35 | 29 |

The cost-effectiveness ratio of the sensitivity scenarios are presented for the various environmental indicators in Figure 4.1 to Figure 4.3. For completeness, the graphs also include the Reference scenario and the 'ultimate' maximum feasible emission reduction case. It should be noted that the ultimate MFR estimate is of hypothetical value, since it would require fundamental changes in the stock of presently existing plants.

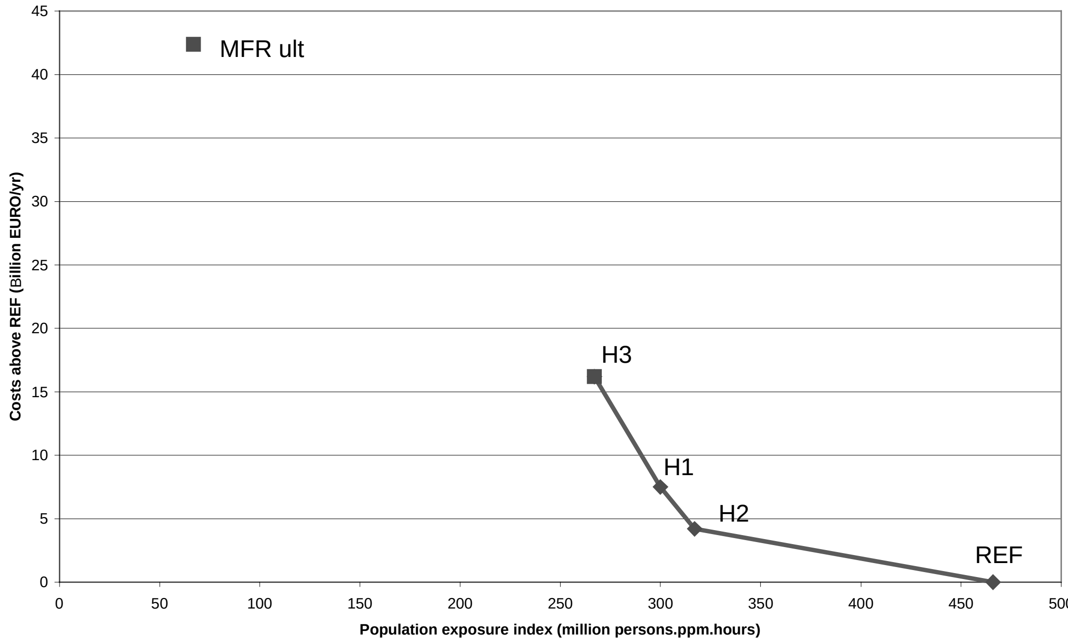


Figure 4.1: Cost-effectiveness of the scenarios with modified environmental ambition levels in relation to changes of the cumulative population exposure index

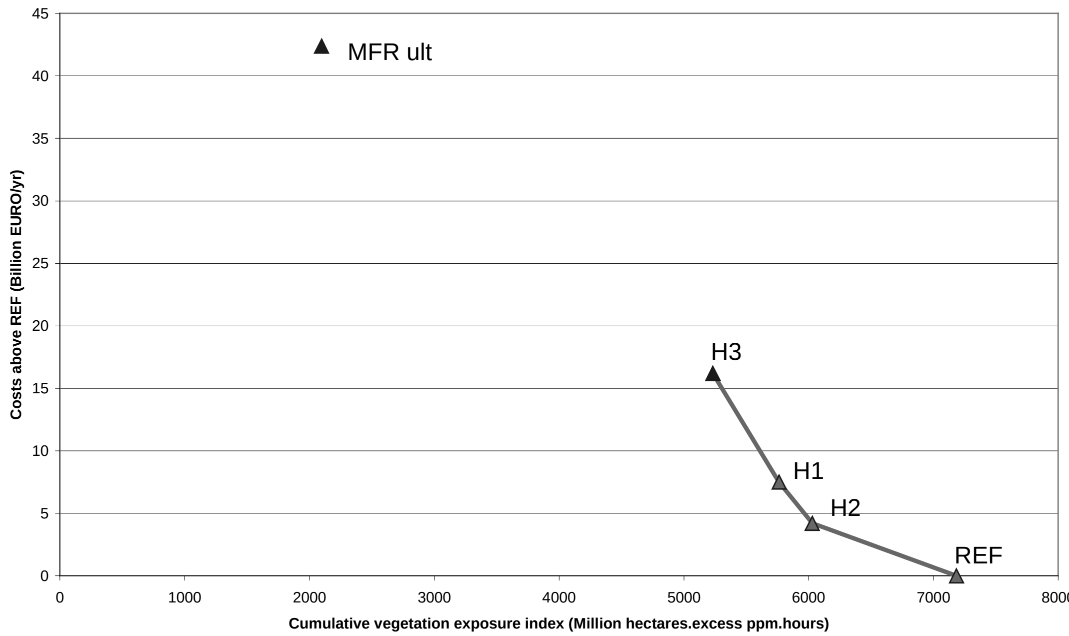


Figure 4.2: Cost-effectiveness of the scenarios with modified environmental ambition levels in relation to changes of the cumulative vegetation exposure index

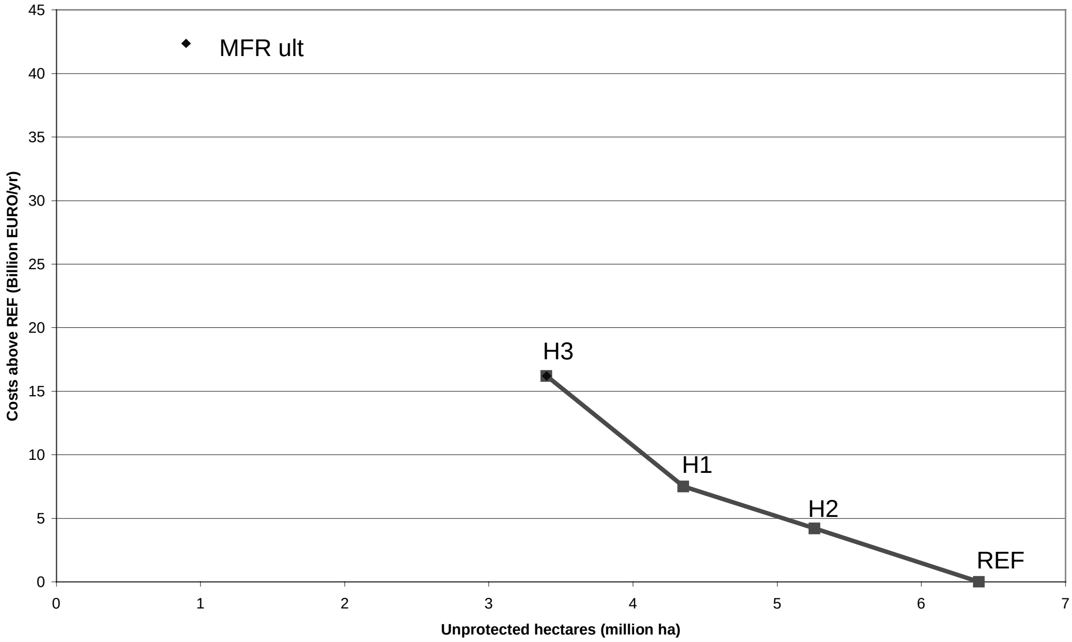


Figure 4.3: Cost-effectiveness of the scenarios with modified environmental ambition levels in relation to the ecosystems area unprotected against acidification

# 5 ECE-wide Targets and Measures (Scenario H4)

Scenario H4 explores the changes in emission ceilings and control costs for the EU-15, if the strategy with the same targets as in the H1 scenario included the entire European ECE-region. This means that the targets of the H1 scenario are applied Europe-wide, and emission controls in all ECE member states are considered in the optimization.

The extension of the geographical scope means that environmental targets are specified for all land-based grid cells in the ECE. For the EU-15 this implies that border grid cells, which were excluded in the earlier EU-15 scenarios (i.e., the Kola region, grid 24/13 at the Italian/Swiss border, and grid 26/17 at the Austrian/Slovakian/Hungarian border) are now included. Following the recent discussions at the UN/ECE level, acidification targets for two grid cells in southern Norway were set at an 85 percent gap closure in terms of accumulated excess acidity.

The results of the joint (multi-effect/multi-pollutant) optimization clearly indicate that there is a certain degree of interaction between the emissions of the EU-15 and the non-EU countries. Depending on the selected ambition level, this interaction could work in both directions. Given the particular environmental targets, emission reductions in the non-EU countries reduce the required efforts in the EU-15 (costs decline from 7.5 billion EURO/year to 5.6 billion EURO/year, i.e. by 25 percent). Most interestingly, the overall costs for all countries incurred in the H4 scenario are slightly lower than the costs of the H1 case, which relate to the EU-15 only.

Significant cost savings would occur for countries at the EU border (Austria, Germany, Greece), where additional reductions would shift to neighboring non-EU countries. Via the atmospheric long-range transport, these reductions relieve background pollution also for France, Netherlands, Sweden and the UK, so that the most expensive measures in these countries could be relaxed.  Due to sensitive ecosystems in Switzerland, however, further reductions would be necessary in Italy.

Most of the cost-savings occur for further $NO_x$ and VOC controls, while in the EU-15 abatement costs for sulfur slightly increase (due to the sensitive ecosystems in Switzerland and Slovakia),

It is further interesting to note that about two thirds of the additional costs of the non-EU countries occur in 'first round' accession countries (the Czech Republic, Hungary, Poland, and Slovenia).

Detailed results are presented in Table 5.1 to Table 5.10.

Table 5.1: $NO_x$ emissions for the EU-wide central scenario H1 and the sensitivity case with measures in all ECE countries (H4). Percentage changes relate to the year 1990.

| | REF | | H1 Central case, EU15 | | H4 ECE wide | |
|---|---|---|---|---|---|---|
| | kt | *Change* | kt | *Change* | kt | *Change* |
| Austria | 103 | *-46%* | 91 | *-53%* | 91 | *-53%* |
| Belgium | 191 | *-46%* | 127 | *-64%* | 127 | *-64%* |
| Denmark | 128 | *-53%* | 127 | *-54%* | 113 | *-59%* |
| Finland | 152 | *-45%* | 152 | *-45%* | 152 | *-45%* |
| France | 858 | *-54%* | 679 | *-64%* | 705 | *-62%* |
| Germany | 1184 | *-56%* | 1051 | *-61%* | 1095 | *-59%* |
| Greece | 344 | *0%* | 264 | *-23%* | 344 | *0%* |
| Ireland | 70 | *-38%* | 59 | *-48%* | 58 | *-49%* |
| Italy | 1130 | *-45%* | 869 | *-57%* | 902 | *-56%* |
| Luxembourg | 10 | *-55%* | 8 | *-64%* | 8 | *-64%* |
| Netherlands | 280 | *-48%* | 238 | *-56%* | 266 | *-51%* |
| Portugal | 177 | *-15%* | 144 | *-31%* | 144 | *-31%* |
| Spain | 847 | *-27%* | 781 | *-33%* | 758 | *-35%* |
| Sweden | 190 | *-44%* | 152 | *-55%* | 163 | *-52%* |
| United Kingdom | 1186 | *-58%* | 1181 | *-58%* | 1181 | *-58%* |
| EU-15 | 6849 | *-48%* | 5922 | *-55%* | 6107 | *-54%* |
| Albania | 36 | *50%* | 36 | *50%* | 36 | *50%* |
| Belarus | 316 | *-21%* | 316 | *-21%* | 305 | *-24%* |
| Bosnia-H. | 60 | *-25%* | 60 | *-25%* | 57 | *-29%* |
| Bulgaria | 297 | *-16%* | 297 | *-16%* | 252 | *-29%* |
| Croatia | 91 | *11%* | 91 | *11%* | 91 | *11%* |
| Czech Rep. | 296 | *-46%* | 296 | *-46%* | 197 | *-64%* |
| Estonia | 73 | *-13%* | 73 | *-13%* | 73 | *-13%* |
| Hungary | 198 | *-10%* | 198 | *-10%* | 142 | *-35%* |
| Latvia | 118 | *1%* | 118 | *1%* | 118 | *1%* |
| Lithuania | 138 | *-10%* | 138 | *-10%* | 138 | *-10%* |
| Norway | 178 | *-19%* | 178 | *-19%* | 142 | *-35%* |
| Poland | 879 | *-28%* | 879 | *-28%* | 803 | *-34%* |
| Moldova | 66 | *-24%* | 66 | *-24%* | 66 | *-24%* |
| Romania | 458 | *-12%* | 458 | *-12%* | 369 | *-29%* |
| Russia | 2653 | *-24%* | 2653 | *-24%* | 2653 | *-24%* |
| Slovakia | 132 | *-40%* | 132 | *-40%* | 118 | *-46%* |
| Slovenia | 36 | *-40%* | 36 | *-40%* | 34 | *-43%* |
| Switzerland | 79 | *-52%* | 79 | *-52%* | 76 | *-53%* |
| FYR Macedonia | 29 | *-26%* | 29 | *-26%* | 29 | *-26%* |
| Ukraine | 1433 | *-24%* | 1433 | *-24%* | 1333 | *-29%* |
| Yugoslavia | 152 | *-28%* | 152 | *-28%* | 152 | *-28%* |
| Non-EU | 7718 | *-24%* | 7718 | *-24%* | 7184 | *-29%* |
| Total | 14567 | *-38%* | 13640 | *-42%* | 13291 | *-43%* |

Table 5.2: VOC emissions for the EU-wide central scenario H1 and the sensitivity case with measures in all ECE countries (H4). Percentage changes relate to the year 1990.

| | REF | | H1 Central case, EU15 | | H4 ECE wide | |
|---|---|---|---|---|---|---|
| | kt | *Change* | kt | *Change* | kt | *Change* |
| Austria | 205 | *-42%* | 129 | *-63%* | 142 | *-60%* |
| Belgium | 193 | *-48%* | 102 | *-73%* | 103 | *-72%* |
| Denmark | 85 | *-53%* | 85 | *-53%* | 85 | *-53%* |
| Finland | 110 | *-48%* | 110 | *-48%* | 110 | *-48%* |
| France | 1223 | *-49%* | 932 | *-61%* | 972 | *-59%* |
| Germany | 1137 | *-64%* | 924 | *-70%* | 987 | *-68%* |
| Greece | 267 | *-21%* | 173 | *-49%* | 265 | *-21%* |
| Ireland | 55 | *-50%* | 55 | *-50%* | 55 | *-50%* |
| Italy | 1159 | *-44%* | 962 | *-53%* | 1006 | *-51%* |
| Luxembourg | 7 | *-63%* | 6 | *-68%* | 7 | *-63%* |
| Netherlands | 233 | *-52%* | 156 | *-68%* | 157 | *-68%* |
| Portugal | 144 | *-32%* | 102 | *-52%* | 102 | *-52%* |
| Spain | 669 | *-34%* | 662 | *-34%* | 645 | *-36%* |
| Sweden | 290 | *-43%* | 219 | *-57%* | 241 | *-53%* |
| United Kingdom | 1351 | *-49%* | 964 | *-64%* | 1084 | *-59%* |
| | | | | | | |
| EU-15 | 7128 | *-49%* | 5581 | *-60%* | 5959 | *-58%* |
| | | | | | | |
| Albania | 41 | *32%* | 41 | *32%* | 41 | *32%* |
| Belarus | 309 | *-17%* | 309 | *-17%* | 298 | *-20%* |
| Bosnia-H. | 48 | *-6%* | 48 | *-6%* | 48 | *-6%* |
| Bulgaria | 190 | *-3%* | 190 | *-3%* | 175 | *-10%* |
| Croatia | 111 | *8%* | 111 | *8%* | 97 | *-6%* |
| Czech Rep. | 305 | *-31%* | 304 | *-31%* | 186 | *-58%* |
| Estonia | 49 | *9%* | 49 | *9%* | 49 | *9%* |
| Hungary | 160 | *-22%* | 160 | *-22%* | 139 | *-32%* |
| Latvia | 56 | *-11%* | 56 | *-11%* | 56 | *-11%* |
| Lithuania | 105 | *-5%* | 105 | *-5%* | 105 | *-5%* |
| Norway | 195 | *-34%* | 195 | *-34%* | 195 | *-34%* |
| Poland | 807 | *1%* | 807 | *1%* | 475 | *-40%* |
| Moldova | 42 | *-16%* | 42 | *-16%* | 42 | *-16%* |
| Romania | 504 | *0%* | 504 | *0%* | 464 | *-8%* |
| Russia | 2787 | *-21%* | 2786 | *-21%* | 2675 | *-24%* |
| Slovakia | 140 | *-7%* | 140 | *-7%* | 140 | *-7%* |
| Slovenia | 40 | *-27%* | 40 | *-27%* | 40 | *-27%* |
| Switzerland | 144 | *-48%* | 144 | *-48%* | 144 | *-48%* |
| FYR Macedonia | 19 | *0%* | 19 | *0%* | 19 | *0%* |
| Ukraine | 851 | *-27%* | 851 | *-27%* | 756 | *-35%* |
| Yugoslavia | 139 | *-2%* | 139 | *-2%* | 137 | *-4%* |
| | | | | | | |
| Non-EU | 7041 | *-18%* | 7041 | *-18%* | 6283 | *-27%* |
| | | | | | | |
| Total | 14169 | *-37%* | 12622 | *-44%* | 12242 | *-46%* |

Table 5.3: $SO_2$ emissions for the EU-wide central scenario H1 and the sensitivity case with measures in all ECE countries (H4). Percentage changes relate to the year 1990.

| | REF | | H1 Central case, EU15 | | H4 ECE wide | |
|---|---|---|---|---|---|---|
| | kt | *Change* | kt | *Change* | kt | *Change* |
| Austria | 40 | *-57%* | 40 | *-57%* | 34 | *-63%* |
| Belgium | 193 | *-43%* | 76 | *-77%* | 76 | *-77%* |
| Denmark | 90 | *-51%* | 77 | *-58%* | 34 | *-81%* |
| Finland | 116 | *-49%* | 116 | *-49%* | 116 | *-49%* |
| France | 448 | *-64%* | 218 | *-83%* | 219 | *-82%* |
| Germany | 581 | *-89%* | 463 | *-91%* | 457 | *-91%* |
| Greece | 546 | *8%* | 546 | *8%* | 546 | *8%* |
| Ireland | 66 | *-63%* | 28 | *-84%* | 28 | *-84%* |
| Italy | 567 | *-66%* | 566 | *-66%* | 261 | *-84%* |
| Luxembourg | 4 | *-71%* | 3 | *-79%* | 3 | *-79%* |
| Netherlands | 73 | *-64%* | 50 | *-75%* | 50 | *-75%* |
| Portugal | 141 | *-50%* | 141 | *-50%* | 141 | *-50%* |
| Spain | 774 | *-65%* | 746 | *-66%* | 747 | *-66%* |
| Sweden | 67 | *-44%* | 67 | *-44%* | 66 | *-45%* |
| United Kingdom | 980 | *-74%* | 497 | *-87%* | 496 | *-87%* |
| EU-15 | 4687 | *-71%* | 3637 | *-78%* | 3276 | *-80%* |
| Albania | 55 | *-24%* | 55 | *-24%* | 55 | *-24%* |
| Belarus | 494 | *-41%* | 494 | *-41%* | 494 | *-41%* |
| Bosnia-H. | 415 | *-15%* | 415 | *-15%* | 77 | *-84%* |
| Bulgaria | 846 | *-54%* | 846 | *-54%* | 378 | *-79%* |
| Croatia | 70 | *-61%* | 70 | *-61%* | 20 | *-89%* |
| Czech Rep. | 366 | *-80%* | 366 | *-80%* | 282 | *-85%* |
| Estonia | 175 | *-36%* | 175 | *-36%* | 175 | *-36%* |
| Hungary | 546 | *-40%* | 546 | *-40%* | 296 | *-68%* |
| Latvia | 104 | *-14%* | 104 | *-14%* | 104 | *-14%* |
| Lithuania | 107 | *-50%* | 107 | *-50%* | 107 | *-50%* |
| Norway | 32 | *-38%* | 32 | *-38%* | 18 | *-65%* |
| Poland | 1397 | *-53%* | 1397 | *-53%* | 721 | *-76%* |
| Moldova | 117 | *-41%* | 117 | *-41%* | 42 | *-79%* |
| Romania | 594 | *-55%* | 594 | *-55%* | 148 | *-89%* |
| Russia | 2344 | *-53%* | 2344 | *-53%* | 2155 | *-57%* |
| Slovakia | 137 | *-75%* | 137 | *-75%* | 92 | *-83%* |
| Slovenia | 71 | *-65%* | 71 | *-65%* | 14 | *-93%* |
| Switzerland | 26 | *-40%* | 26 | *-40%* | 23 | *-47%* |
| FYR Macedonia | 81 | *-24%* | 81 | *-24%* | 81 | *-24%* |
| Ukraine | 1488 | *-60%* | 1488 | *-60%* | 1460 | *-61%* |
| Yugoslavia | 269 | *-54%* | 269 | *-54%* | 62 | *-89%* |
| Non-EU | 9732 | *-55%* | 9732 | *-55%* | 6804 | *-68%* |
| Total | 14419 | *-62%* | 13369 | *-65%* | 10080 | *-73%* |

Table 5.4: $NH_3$ emissions for the EU-wide central scenario H1 and the sensitivity case with measures in all ECE countries (H4). Percentage changes relate to the year 1990.

| | REF | | H1 Central case, EU15 | | H4 ECE wide | |
|---|---|---|---|---|---|---|
| | kt | *Change* | kt | *Change* | kt | *Change* |
| Austria | 67 | *-13%* | 67 | *-13%* | 66 | *-14%* |
| Belgium | 96 | *-1%* | 57 | *-41%* | 57 | *-41%* |
| Denmark | 72 | *-6%* | 71 | *-8%* | 69 | *-10%* |
| Finland | 31 | *-23%* | 31 | *-23%* | 31 | *-23%* |
| France | 777 | *-4%* | 718 | *-11%* | 718 | *-11%* |
| Germany | 571 | *-25%* | 413 | *-45%* | 413 | *-45%* |
| Greece | 74 | *-8%* | 74 | *-8%* | 74 | *-8%* |
| Ireland | 126 | *-1%* | 123 | *-3%* | 124 | *-2%* |
| Italy | 432 | *-6%* | 430 | *-7%* | 362 | *-22%* |
| Luxembourg | 7 | *0%* | 7 | *0%* | 7 | *0%* |
| Netherlands | 136 | *-42%* | 104 | *-55%* | 104 | *-55%* |
| Portugal | 67 | *-6%* | 67 | *-6%* | 67 | *-6%* |
| Spain | 353 | *0%* | 353 | *0%* | 353 | *0%* |
| Sweden | 48 | *-21%* | 48 | *-21%* | 48 | *-21%* |
| United Kingdom | 297 | *-10%* | 264 | *-20%* | 264 | *-20%* |
| EU-15 | 3154 | *-12%* | 2826 | *-21%* | 2757 | *-23%* |
| Albania | 35 | *9%* | 35 | *9%* | 35 | *9%* |
| Belarus | 163 | *-26%* | 163 | *-26%* | 163 | *-26%* |
| Bosnia-H. | 23 | *-26%* | 23 | *-26%* | 22 | *-29%* |
| Bulgaria | 126 | *-11%* | 126 | *-11%* | 126 | *-11%* |
| Croatia | 37 | *-8%* | 37 | *-8%* | 29 | *-28%* |
| Czech Rep. | 108 | *1%* | 108 | *1%* | 105 | *-2%* |
| Estonia | 29 | *0%* | 29 | *0%* | 29 | *0%* |
| Hungary | 137 | *14%* | 137 | *14%* | 77 | *-36%* |
| Latvia | 35 | *-19%* | 35 | *-19%* | 35 | *-19%* |
| Lithuania | 81 | *1%* | 81 | *1%* | 81 | *1%* |
| Norway | 21 | *-9%* | 21 | *-9%* | 21 | *-9%* |
| Poland | 541 | *7%* | 541 | *7%* | 515 | *2%* |
| Moldova | 48 | *2%* | 48 | *2%* | 48 | *2%* |
| Romania | 304 | *4%* | 304 | *4%* | 274 | *-6%* |
| Russia | 894 | *-30%* | 894 | *-30%* | 894 | *-30%* |
| Slovakia | 47 | *-22%* | 47 | *-22%* | 39 | *-35%* |
| Slovenia | 21 | *-9%* | 21 | *-9%* | 17 | *-26%* |
| Switzerland | 66 | *-8%* | 66 | *-8%* | 63 | *-13%* |
| FYR Macedonia | 16 | *-6%* | 16 | *-6%* | 16 | *-6%* |
| Ukraine | 649 | *-11%* | 649 | *-11%* | 649 | *-11%* |
| Yugoslavia | 82 | *-9%* | 82 | *-9%* | 76 | *-16%* |
| Non-EU | 3462 | *-13%* | 3462 | *-13%* | 3313 | *-17%* |
| Total | 6616 | *-12%* | 6288 | *-17%* | 6070 | *-20%* |

Table 5.5: Emission control costs for $SO_2$ and $NO_x$ for the EU-wide central scenario H1 and the sensitivity case with measures in all ECE countries (H4), in million EURO/year.

| | $SO_2$ | | | $NO_x$ & VOC | | |
|---|---|---|---|---|---|---|
| | REF | H1 | H4 | REF | H1 | H4 |
| Costs | | on top of REF | | total | on top of REF | |
| Austria | 191 | 0 | 5 | 902 | 119 | 70 |
| Belgium | 426 | 127 | 124 | 1278 | 459 | 452 |
| Denmark | 138 | 5 | 35 | 484 | 0 | 8 |
| Finland | 247 | 0 | 0 | 642 | 0 | 0 |
| France | 1276 | 136 | 133 | 7383 | 739 | 465 |
| Germany | 3264 | 244 | 248 | 10549 | 1048 | 472 |
| Greece | 434 | 0 | 0 | 1048 | 338 | 1 |
| Ireland | 132 | 20 | 20 | 477 | 4 | 5 |
| Italy | 1776 | 0 | 107 | 7868 | 403 | 268 |
| Luxembourg | 13 | 1 | 0 | 71 | 4 | 2 |
| Netherlands | 340 | 19 | 19 | 1731 | 211 | 112 |
| Portugal | 181 | 0 | 0 | 1349 | 57 | 57 |
| Spain | 809 | 9 | 9 | 5658 | 13 | 29 |
| Sweden | 316 | 0 | 0 | 1125 | 87 | 40 |
| United Kingdom | 1269 | 299 | 302 | 6695 | 1026 | 417 |
| EU-15 | 10813 | 861 | 1004 | 47258 | 4508 | 2397 |
| Albania | 0 | 0 | 0 | 0 | 0 | 0 |
| Belarus | 0 | 0 | 0 | 0 | 0 | 1 |
| Bosnia-H. | 0 | 0 | 82 | 1 | 0 | 1 |
| Bulgaria | 153 | 0 | 58 | 4 | 0 | 25 |
| Croatia | 52 | 0 | 22 | 1 | 0 | 1 |
| Czech Rep. | 411 | 0 | 36 | 568 | 0 | 149 |
| Estonia | 0 | 0 | 0 | 0 | 0 | 0 |
| Hungary | 166 | 0 | 113 | 420 | 0 | 94 |
| Latvia | 0 | 0 | 0 | 0 | 0 | 0 |
| Lithuania | 0 | 0 | 0 | 0 | 0 | 0 |
| Norway | 56 | 0 | 10 | 567 | 0 | 12 |
| Poland | 855 | 0 | 284 | 2487 | 0 | 177 |
| Moldova | 0 | 0 | 28 | 0 | 0 | 0 |
| Romania | 155 | 0 | 137 | 2 | 0 | 33 |
| Russia | 694 | 0 | 65 | 21 | 0 | 1 |
| Slovakia | 91 | 0 | 25 | 331 | 0 | 5 |
| Slovenia | 35 | 0 | 23 | 93 | 0 | 1 |
| Switzerland | 118 | 0 | 1 | 831 | 0 | 2 |
| FYR Macedonia | 0 | 0 | 0 | 1 | 0 | 0 |
| Ukraine | 328 | 0 | 7 | 0 | 0 | 13 |
| Yugoslavia | 88 | 0 | 150 | 3 | 0 | 0 |
| Non-EU | 3202 | 0 | 1042 | 5332 | 0 | 515 |
| Total | 14016 | 861 | 2047 | 52590 | 4508 | 2912 |

Table 5.6: Emission control costs (on top of REF) for $NH_3$ and total costs for the EU-wide central scenario H1 and the sensitivity cases with measures in all ECE countries (H4), in million EURO/year.

| | $NH_3$ | | | TOTAL | | |
|---|---|---|---|---|---|---|
| | REF | H1 | H4 | REF | H1 | H4 |
| Costs | | on top of REF | | total | on top of REF | |
| Austria | 0 | 0 | 1 | 1093 | 119 | 76 |
| Belgium | 0 | 467 | 467 | 1704 | 1053 | 1043 |
| Denmark | 0 | 0 | 2 | 623 | 6 | 44 |
| Finland | 0 | 0 | 0 | 889 | 0 | 0 |
| France | 0 | 41 | 41 | 8659 | 916 | 640 |
| Germany | 0 | 854 | 845 | 13813 | 2147 | 1565 |
| Greece | 0 | 0 | 0 | 1482 | 338 | 1 |
| Ireland | 9 | 20 | 18 | 618 | 44 | 43 |
| Italy | 0 | 0 | 77 | 9644 | 403 | 452 |
| Luxembourg | 15 | 0 | 0 | 98 | 4 | 2 |
| Netherlands | 196 | 741 | 699 | 2267 | 971 | 830 |
| Portugal | 0 | 0 | 0 | 1530 | 57 | 57 |
| Spain | 28 | 0 | 0 | 6495 | 22 | 38 |
| Sweden | 113 | 0 | 0 | 1554 | 87 | 40 |
| United Kingdom | 0 | 23 | 23 | 7964 | 1348 | 742 |
| EU-15 | 361 | 2146 | 2172 | 58433 | 7514 | 5574 |
| Albania | 0 | 0 | 0 | 0 | 0 | 0 |
| Belarus | 0 | 0 | 0 | 0 | 0 | 1 |
| Bosnia-H. | 0 | 0 | 0 | 1 | 0 | 83 |
| Bulgaria | 0 | 0 | 0 | 157 | 0 | 83 |
| Croatia | 0 | 0 | 3 | 52 | 0 | 26 |
| Czech Rep. | 0 | 0 | 2 | 979 | 0 | 188 |
| Estonia | 0 | 0 | 0 | 0 | 0 | 0 |
| Hungary | 0 | 0 | 319 | 586 | 0 | 526 |
| Latvia | 0 | 0 | 0 | 0 | 0 | 0 |
| Lithuania | 0 | 0 | 0 | 0 | 0 | 0 |
| Norway | 0 | 0 | 3 | 623 | 0 | 25 |
| Poland | 0 | 0 | 6 | 3342 | 0 | 467 |
| Moldova | 0 | 0 | 0 | 0 | 0 | 28 |
| Romania | 0 | 0 | 6 | 157 | 0 | 176 |
| Russia | 0 | 0 | 0 | 715 | 0 | 66 |
| Slovakia | 0 | 0 | 7 | 423 | 0 | 38 |
| Slovenia | 0 | 0 | 2 | 128 | 0 | 25 |
| Switzerland | 0 | 0 | 6 | 949 | 0 | 9 |
| FYR Macedonia | 0 | 0 | 0 | 1 | 0 | 0 |
| Ukraine | 0 | 0 | 0 | 328 | 0 | 20 |
| Yugoslavia | 0 | 0 | 2 | 92 | 0 | 152 |
| Non-EU | 0 | 0 | 356 | 8534 | 0 | 1913 |
| Total | 361 | 2146 | 2528 | 66967 | 7514 | 7487 |

Table 5.7: Ecosystems with acid deposition above their critical loads, comparison of the joint scenario H1 (limited to the EU countries) with the ECE-wide scenario H4

| | 1000 ha | | | Percent of ecosystems | | |
|---|---|---|---|---|---|---|
| | REF | H1 | H4 | REF | H1 | H4 |
| Austria | 162 | 99 | 70 | 3.3 | 2.0 | 1.4 |
| Belgium | 155 | 52 | 52 | 22.1 | 7.4 | 7.4 |
| Denmark | 9 | 6 | 4 | 2.3 | 1.5 | 1.2 |
| Finland | 1183 | 1150 | 653 | 4.3 | 4.2 | 2.4 |
| France | 218 | 88 | 87 | 0.7 | 0.3 | 0.3 |
| Germany | 1617 | 727 | 585 | 15.8 | 7.1 | 5.7 |
| Greece | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 |
| Ireland | 12 | 9 | 9 | 1.3 | 1.0 | 1.0 |
| Italy | 74 | 58 | 51 | 0.7 | 0.6 | 0.5 |
| Luxembourg | 5 | 1 | 1 | 5.9 | 0.9 | 0.8 |
| Netherlands | 193 | 76 | 76 | 60.4 | 23.7 | 23.7 |
| Portugal | 1 | 1 | 1 | 0.0 | 0.0 | 0.0 |
| Spain | 17 | 17 | 17 | 0.2 | 0.2 | 0.2 |
| Sweden | 1605 | 1420 | 1148 | 4.1 | 3.7 | 3.0 |
| United Kingdom | 1182 | 649 | 643 | 12.3 | 6.8 | 6.7 |
| EU-15 | 6433 | 4351 | 3395 | 4.3 | 2.9 | 2.3 |
| Albania | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 |
| Belarus | 1048 | 1033 | 574 | 20.9 | 20.5 | 11.4 |
| Bosnia-H. | 131 | 131 | 0 | 9.1 | 9.1 | 0.0 |
| Bulgaria | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 |
| Croatia | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 |
| Czech Rep. | 474 | 285 | 92 | 17.9 | 10.7 | 3.5 |
| Estonia | 11 | 10 | 8 | 0.6 | 0.5 | 0.4 |
| Hungary | 65 | 54 | 37 | 22.9 | 18.9 | 13.0 |
| Latvia | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 |
| Lithuania | 78 | 77 | 0 | 4.1 | 4.1 | 0.0 |
| Norway | 2573 | 2239 | 1891 | 11.6 | 10.1 | 8.6 |
| Poland | 1357 | 1117 | 202 | 7.8 | 6.4 | 1.2 |
| Moldova | 29 | 29 | 10 | 2.4 | 2.4 | 0.9 |
| Romania | 51 | 51 | 17 | 0.8 | 0.8 | 0.3 |
| Russia | 4073 | 4060 | 634 | 1.2 | 1.2 | 0.2 |
| Slovakia | 295 | 261 | 150 | 14.7 | 13.0 | 7.5 |
| Slovenia | 19 | 19 | 4 | 2.1 | 2.1 | 0.4 |
| Switzerland | 57 | 40 | 36 | 4.6 | 3.2 | 2.9 |
| FYR Macedonia | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 |
| Ukraine | 643 | 636 | 265 | 7.8 | 7.7 | 3.2 |
| Yugoslavia | 2 | 2 | 0 | 0.1 | 0.1 | 0.0 |
| Non-EU | 10908 | 10043 | 3919 | 2.5 | 2.3 | 0.9 |
| Total | 17341 | 14394 | 7315 | 3.0 | 2.5 | 1.3 |

Table 5.8: Population exposure indices, comparison of the joint scenario H1 (limited to the EU countries) with the ECE-wide scenario H4

| | Cumulative population exposure index (million persons.ppm.h) | | | Average population exposure index (ppm.h) | | |
|---|---|---|---|---|---|---|
| | REF | H1 | H4 | REF | H1 | H4 |
| Austria | 3 | 2 | 2 | 0.5 | 0.3 | 0.2 |
| Belgium | 34 | 23 | 23 | 3.1 | 2.1 | 2.1 |
| Denmark | 3 | 1 | 1 | 0.5 | 0.3 | 0.3 |
| Finland | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 |
| France | 89 | 53 | 54 | 1.6 | 0.9 | 1.0 |
| Germany | 140 | 99 | 93 | 1.8 | 1.3 | 1.2 |
| Greece | 4 | 2 | 3 | 0.4 | 0.2 | 0.3 |
| Ireland | 1 | 0 | 0 | 0.3 | 0.1 | 0.1 |
| Italy | 63 | 38 | 39 | 1.1 | 0.7 | 0.7 |
| Luxembourg | 1 | 1 | 1 | 3.0 | 2.1 | 2.1 |
| Netherlands | 38 | 27 | 27 | 2.6 | 1.8 | 1.8 |
| Portugal | 8 | 6 | 6 | 0.8 | 0.6 | 0.6 |
| Spain | 7 | 4 | 4 | 0.2 | 0.1 | 0.1 |
| Sweden | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 |
| United Kingdom | 77 | 45 | 49 | 1.3 | 0.8 | 0.9 |
| EU-15 | 466 | 300 | 301 | 1.3 | 0.8 | 0.8 |
| Albania | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 |
| Belarus | 1 | 1 | 0 | 0.1 | 0.1 | 0.0 |
| Bosnia-H. | 0 | 0 | 0 | 0.1 | 0.1 | 0.0 |
| Bulgaria | 1 | 1 | 0 | 0.1 | 0.1 | 0.0 |
| Croatia | 3 | 2 | 2 | 0.6 | 0.4 | 0.3 |
| Czech Rep. | 11 | 8 | 6 | 1.0 | 0.8 | 0.6 |
| Estonia | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 |
| Hungary | 12 | 10 | 7 | 1.1 | 1.0 | 0.7 |
| Latvia | 0 | 0 | 0 | 0.1 | 0.0 | 0.0 |
| Lithuania | 0 | 0 | 0 | 0.1 | 0.1 | 0.0 |
| Norway | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 |
| Poland | 36 | 29 | 21 | 0.9 | 0.8 | 0.5 |
| Moldova | 1 | 1 | 0 | 0.2 | 0.1 | 0.1 |
| Romania | 6 | 5 | 2 | 0.3 | 0.2 | 0.1 |
| Russia | 7 | 6 | 5 | 0.1 | 0.1 | 0.1 |
| Slovakia | 6 | 5 | 4 | 1.1 | 1.0 | 0.7 |
| Slovenia | 1 | 1 | 1 | 0.7 | 0.4 | 0.4 |
| Switzerland | 2 | 0 | 1 | 0.3 | 0.1 | 0.1 |
| FYR Macedonia | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 |
| Ukraine | 14 | 13 | 8 | 0.3 | 0.3 | 0.2 |
| Yugoslavia | 3 | 2 | 1 | 0.2 | 0.2 | 0.1 |
| Non-EU | 103 | 86 | 57 | 0.3 | 0.3 | 0.2 |
| Total | 570 | 385 | 358 | 0.8 | 0.6 | 0.5 |

Table 5.9: Vegetation exposure indices, comparison of the joint scenario H1 (limited to the EU countries) with the ECE-wide scenario H4

| | Cumulative vegetation exposure index (100 $km^2$.ppm.h) | | | Average vegetation exposure index (ppm.h) | | |
|---|---|---|---|---|---|---|
| | REF | H1 | H4 | REF | H1 | H4 |
| Austria | 257 | 213 | 198 | 5.0 | 4.1 | 3.8 |
| Belgium | 141 | 115 | 115 | 9.1 | 7.4 | 7.4 |
| Denmark | 53 | 36 | 32 | 1.8 | 1.2 | 1.1 |
| Finland | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 |
| France | 2345 | 1816 | 1867 | 7.3 | 5.6 | 5.8 |
| Germany | 1204 | 943 | 915 | 5.7 | 4.4 | 4.3 |
| Greece | 170 | 137 | 147 | 3.1 | 2.5 | 2.7 |
| Ireland | 8 | 3 | 3 | 0.3 | 0.1 | 0.1 |
| Italy | 1186 | 996 | 993 | 7.5 | 6.3 | 6.3 |
| Luxembourg | 14 | 11 | 11 | 9.3 | 7.3 | 7.4 |
| Netherlands | 79 | 63 | 63 | 6.1 | 4.8 | 4.8 |
| Portugal | 274 | 233 | 231 | 4.7 | 4.0 | 4.0 |
| Spain | 1281 | 1093 | 1074 | 4.2 | 3.6 | 3.5 |
| Sweden | 18 | 9 | 7 | 0.1 | 0.0 | 0.0 |
| United Kingdom | 153 | 96 | 109 | 1.9 | 1.2 | 1.3 |
| EU-15 | 7183 | 5765 | 5766 | 3.8 | 3.1 | 3.1 |
| Albania | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 |
| Belarus | 78 | 69 | 54 | 0.9 | 0.8 | 0.6 |
| Bosnia-H. | 162 | 143 | 130 | 4.2 | 3.7 | 3.4 |
| Bulgaria | 281 | 270 | 229 | 3.8 | 3.6 | 3.1 |
| Croatia | 214 | 205 | 178 | 6.0 | 5.8 | 5.0 |
| Czech Rep. | 311 | 263 | 227 | 5.6 | 4.7 | 4.1 |
| Estonia | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 |
| Hungary | 404 | 370 | 305 | 6.2 | 5.7 | 4.7 |
| Latvia | 6 | 4 | 3 | 0.1 | 0.1 | 0.1 |
| Lithuania | 23 | 17 | 12 | 0.6 | 0.4 | 0.3 |
| Norway | 1 | 1 | 1 | 0.0 | 0.0 | 0.0 |
| Poland | 829 | 721 | 590 | 3.6 | 3.2 | 2.6 |
| Moldova | 56 | 54 | 46 | 3.3 | 3.2 | 2.7 |
| Romania | 623 | 594 | 489 | 4.0 | 3.8 | 3.1 |
| Russia | 983 | 960 | 889 | 0.5 | 0.5 | 0.5 |
| Slovakia | 215 | 196 | 161 | 6.0 | 5.5 | 4.5 |
| Slovenia | 94 | 82 | 78 | 7.2 | 6.2 | 6.0 |
| Switzerland | 85 | 68 | 70 | 4.8 | 3.9 | 3.9 |
| FYR Macedonia | 40 | 36 | 33 | 2.5 | 2.3 | 2.1 |
| Ukraine | 1206 | 1166 | 1034 | 3.1 | 3.0 | 2.6 |
| Yugoslavia | 248 | 230 | 198 | 3.7 | 3.4 | 2.9 |
| Non-EU | 5860 | 5449 | 4726 | 1.7 | 1.6 | 1.4 |
| Total | 13043 | 11214 | 10492 | 2.4 | 2.1 | 2.0 |

Table 5.10: Ecosystems with nitrogen deposition above their critical loads for eutrophication, comparison of the central scenario H1 (limited to the EU countries) with the ECE-wide scenario H4

| | 1000 ha | | | Percent of ecosystems | | |
|---|---|---|---|---|---|---|
| | REF | H1 | H4 | REF | H1 | H4 |
| Austria | 3441 | 2773 | 2537 | 58 | 46 | 43 |
| Belgium | 677 | 586 | 589 | 96 | 83 | 84 |
| Denmark | 119 | 91 | 86 | 38 | 29 | 27 |
| Finland | 2538 | 2163 | 1988 | 15 | 13 | 12 |
| France | 25160 | 22524 | 22514 | 79 | 71 | 71 |
| Germany | 9184 | 7474 | 7479 | 90 | 73 | 73 |
| Greece | 236 | 211 | 193 | 10 | 9 | 8 |
| Ireland | 58 | 54 | 54 | 6 | 6 | 6 |
| Italy | 3795 | 3452 | 2589 | 32 | 29 | 22 |
| Luxembourg | 80 | 66 | 66 | 91 | 75 | 76 |
| Netherlands | 291 | 278 | 278 | 91 | 87 | 87 |
| Portugal | 709 | 683 | 682 | 25 | 24 | 24 |
| Spain | 1158 | 964 | 934 | 14 | 11 | 11 |
| Sweden | 891 | 737 | 691 | 5 | 4 | 4 |
| United Kingdom | 126 | 64 | 64 | 1 | 1 | 1 |
| EU-15 | 48461 | 42117 | 40744 | 40 | 35 | 34 |
| Albania | 200 | 185 | 183 | 19 | 17 | 17 |
| Belarus | 1293 | 1261 | 1225 | 26 | 25 | 24 |
| Bosnia-H. | 725 | 672 | 525 | 50 | 46 | 36 |
| Bulgaria | 3396 | 3256 | 2716 | 69 | 66 | 55 |
| Croatia | 18 | 17 | 10 | 7 | 6 | 4 |
| Czech Rep. | 2312 | 2199 | 2107 | 87 | 83 | 79 |
| Estonia | 738 | 679 | 669 | 39 | 36 | 35 |
| Hungary | 150 | 147 | 128 | 53 | 52 | 45 |
| Latvia | 1553 | 1542 | 1504 | 57 | 57 | 55 |
| Lithuania | 1357 | 1353 | 1342 | 72 | 71 | 71 |
| Norway | 281 | 58 | 52 | 2 | 0 | 0 |
| Poland | 16218 | 16062 | 15609 | 93 | 93 | 90 |
| Moldova | 0 | 0 | 0 | 0 | 0 | 0 |
| Romania | 2495 | 2442 | 2011 | 40 | 39 | 32 |
| Russia | 26263 | 25877 | 24778 | 8 | 8 | 7 |
| Slovakia | 1507 | 1424 | 1054 | 75 | 71 | 53 |
| Slovenia | 156 | 110 | 89 | 17 | 12 | 10 |
| Switzerland | 1887 | 1674 | 1568 | 83 | 73 | 69 |
| FYR Macedonia | 158 | 138 | 133 | 15 | 13 | 13 |
| Ukraine | 5331 | 5303 | 4982 | 65 | 64 | 60 |
| Yugoslavia | 1994 | 1910 | 1778 | 58 | 56 | 52 |
| Non-EU | 68032 | 66311 | 62463 | 16 | 16 | 15 |
| Total | 116494 | 108428 | 103208 | 21 | 20 | 19 |

# 6 Conclusions

This report presents a central emission control scenario to achieve the environmental targets that were discussed in the context of the EU acidification and ozone strategies. In particular, the scenario aims at reducing

- the area of ecosystems not protected against acidification by half,
- the health-relevant excess ozone exposure by two thirds, and
- the vegetation-relevant excess ozone exposure by one third.

Additional targets control the highest ozone levels in the European Union.

Based on a 'business as usual' pre-Kyoto energy projection and a 'pre-CAP reform' agricultural scenario, the optimized set of emission reductions to achieve these targets would cut $SO_2$ and $NO_x$ emissions by seven percent below the 'current legislation' case, VOC by 11 percent and ammonia emissions by nine percent. These measures would increase total emission control costs by 7.5 billion EURO/year, i.e., by 14 percent compared to the Reference (current legislation) case. Of the additional costs, 11 percent would be allocated to $SO_2$ control, 63 percent to $NO_x$ and VOC control, and 26 percent for ammonia.

If a strategy to achieve the same environmental targets included also countries outside the present EU-15 (while aiming for the same environmental improvements also for these regions), control costs for the EU-15 would drop by 25 percent. About two thirds of the costs for measures in non-EU countries are allocated to the 'first-round' accession candidates.

The robustness of the optimized emission ceilings against changes in exogeneous input assumptions was analyzed in detail in the Sixth Interim Report. The national emission levels resulting from this central scenario were subjected to several sensitivity analyses, exploring the implications of

- single-effect strategies (ground-level ozone and acidification individually),
- variations in the environmental ambition levels,
- modifications of the main economic drivers (a low $CO_2$ ' energy and an 'low $NH_3$ ' agricultural projection), and
- the involvement of emission sources from international maritime transport.

The analysis showed that in all cases the emission ceilings of the central scenario are within the range spanned by the various sensitivity cases. More importantly, in many cases they are at the upper end of the ranges, i.e., none of the sensitivity cases resulted in higher emissions.

It has been further shown in the Sixth Report that modified input assumptions on the main economic drivers (energy scenarios and agricultural projections) have a profound impact on the costs for achieving the environmental targets (-40 percent for a low $CO_2$ scenario), but do not significantly change emission levels calculated from the baseline scenario.

While the sensitivity of optimized emission levels towards changes in input assumptions could be assessed for the above-mentioned cases, lack of supporting information and of resources prevented a systematic quantitative assessment of the impact of model and data uncertainties on the optimization results. In-depth studies on certain aspects support the qualitative conclusion that, for a number of reasons, the present model results (emission reductions) are conservative in the sense that they might not be sufficient to fully achieve the specified environmental targets in reality.

# 7 References

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# 8 Annex 1: Emissions and Control Costs of Single-effect Scenarios

## *8.1 Three Ambition Levels for Ground-level ozone (H5)*

Three sensitivity cases explore the emission reductions for achieving the ozone related targets of the Scenarios H2, H1 and H3.

Table 8.1: $NO_x$ and VOC emissions for variations in ambition levels for ground-level ozone (Scenarios H5/1, H5/2 and H5/3). Percentage changes relate to the year 1990.

| | $NO_x$ | | | | | | | | VOC | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | REF | | H5/1 Low ambition | | H5/2 Central | | H5/3 High ambition | | REF | | H5/1 Low ambition | | H5/2 Central | | H5/3 High ambition | |
| | kt | *Change* | kt | *Change* | kt | *Change* | kt | *Change* | kt | *Change* | kt | *Change* | kt | *Change* | kt | *Change* |
| Austria | 103 | *-46%* | 91 | *-53%* | 91 | *-53%* | 89 | *-54%* | 205 | *-42%* | 129 | *-63%* | 129 | *-63%* | 123 | *-65%* |
| Belgium | 191 | *-46%* | 127 | *-64%* | 127 | *-64%* | 127 | *-64%* | 193 | *-48%* | 103 | *-72%* | 102 | *-73%* | 101 | *-73%* |
| Denmark | 128 | *-53%* | 128 | *-53%* | 128 | *-53%* | 128 | *-53%* | 85 | *-53%* | 85 | *-53%* | 85 | *-53%* | 83 | *-54%* |
| Finland | 152 | *-45%* | 152 | *-45%* | 152 | *-45%* | 152 | *-45%* | 110 | *-48%* | 110 | *-48%* | 110 | *-48%* | 110 | *-48%* |
| France | 858 | *-54%* | 706 | *-62%* | 682 | *-63%* | 648 | *-65%* | 1223 | *-49%* | 1015 | *-57%* | 932 | *-61%* | 849 | *-64%* |
| Germany | 1184 | *-56%* | 1086 | *-59%* | 1086 | *-59%* | 1071 | *-60%* | 1137 | *-64%* | 925 | *-70%* | 924 | *-70%* | 916 | *-71%* |
| Greece | 344 | *0%* | 253 | *-27%* | 261 | *-24%* | 291 | *-16%* | 267 | *-21%* | 168 | *-50%* | 173 | *-49%* | 179 | *-47%* |
| Ireland | 70 | *-38%* | 70 | *-38%* | 70 | *-38%* | 66 | *-42%* | 55 | *-50%* | 55 | *-50%* | 55 | *-50%* | 55 | *-50%* |
| Italy | 1130 | *-45%* | 900 | *-56%* | 863 | *-58%* | 839 | *-59%* | 1159 | *-44%* | 962 | *-53%* | 962 | *-53%* | 811 | *-61%* |
| Luxembourg | 10 | *-55%* | 7 | *-68%* | 6 | *-73%* | 6 | *-73%* | 7 | *-63%* | 5 | *-74%* | 5 | *-74%* | 5 | *-74%* |
| Netherlands | 280 | *-48%* | 280 | *-48%* | 280 | *-48%* | 280 | *-48%* | 233 | *-52%* | 157 | *-68%* | 153 | *-69%* | 153 | *-69%* |
| Portugal | 177 | *-15%* | 160 | *-23%* | 144 | *-31%* | 129 | *-38%* | 144 | *-32%* | 113 | *-47%* | 102 | *-52%* | 102 | *-52%* |
| Spain | 847 | *-27%* | 847 | *-27%* | 803 | *-31%* | 726 | *-38%* | 669 | *-34%* | 669 | *-34%* | 657 | *-35%* | 645 | *-36%* |
| Sweden | 190 | *-44%* | 158 | *-53%* | 158 | *-53%* | 152 | *-55%* | 290 | *-43%* | 219 | *-57%* | 219 | *-57%* | 216 | *-58%* |
| UK | 1186 | *-58%* | 1181 | *-58%* | 1181 | *-58%* | 1181 | *-58%* | 1351 | *-49%* | 1023 | *-62%* | 974 | *-63%* | 957 | *-64%* |
| EU-15 | 6849 | *-48%* | 6148 | *-54%* | 6032 | *-54%* | 5886 | *-55%* | 7128 | *-49%* | 5738 | *-59%* | 5581 | *-60%* | 5303 | *-62%* |

Table 8.2: $SO_2$ and $NH_3$ emissions for variations in ambition levels for ground-level ozone (Scenarios H5/1, H5/2 and H5/3). Percentage changes relate to the year 1990.

| | $SO_2$ | | | | | | | | $NH_3$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | REF | | H5/1 Low ambition | | H5/2 Central | | H5/3 High ambition | | REF | | H5/1 Low ambition | | H5/2 Central | | H5/3 High ambition | |
| | kt | *Change* | kt | *Change* | kt | *Change* | kt | *Change* | kt | *Change* | kt | *Change* | kt | *Change* | kt | *Change* |
| Austria | 40 | *-57%* | 40 | *-57%* | 40 | *-57%* | 40 | *-57%* | 67 | *-13%* | 67 | *-13%* | 67 | *-13%* | 67 | *-13%* |
| Belgium | 193 | *-43%* | 193 | *-43%* | 193 | *-43%* | 193 | *-43%* | 96 | *-1%* | 96 | *-1%* | 96 | *-1%* | 96 | *-1%* |
| Denmark | 90 | *-51%* | 90 | *-51%* | 90 | *-51%* | 90 | *-51%* | 72 | *-6%* | 72 | *-6%* | 72 | *-6%* | 72 | *-6%* |
| Finland | 116 | *-49%* | 116 | *-49%* | 116 | *-49%* | 116 | *-49%* | 31 | *-23%* | 31 | *-23%* | 31 | *-23%* | 31 | *-23%* |
| France | 448 | *-64%* | 448 | *-64%* | 448 | *-64%* | 448 | *-64%* | 777 | *-4%* | 777 | *-4%* | 777 | *-4%* | 777 | *-4%* |
| Germany | 581 | *-89%* | 581 | *-89%* | 581 | *-89%* | 581 | *-89%* | 571 | *-25%* | 571 | *-25%* | 571 | *-25%* | 571 | *-25%* |
| Greece | 546 | *8%* | 546 | *8%* | 546 | *8%* | 546 | *8%* | 74 | *-8%* | 74 | *-8%* | 74 | *-8%* | 74 | *-8%* |
| Ireland | 66 | *-63%* | 66 | *-63%* | 66 | *-63%* | 66 | *-63%* | 126 | *-1%* | 126 | *-1%* | 126 | *-1%* | 126 | *-1%* |
| Italy | 567 | *-66%* | 566 | *-66%* | 566 | *-66%* | 566 | *-66%* | 432 | *-6%* | 432 | *-6%* | 432 | *-6%* | 432 | *-6%* |
| Luxembourg | 4 | *-71%* | 4 | *-71%* | 4 | *-71%* | 4 | *-71%* | 7 | *0%* | 7 | *0%* | 7 | *0%* | 7 | *0%* |
| Netherlands | 73 | *-64%* | 73 | *-64%* | 73 | *-64%* | 73 | *-64%* | 136 | *-42%* | 136 | *-42%* | 136 | *-42%* | 136 | *-42%* |
| Portugal | 141 | *-50%* | 141 | *-50%* | 141 | *-50%* | 141 | *-50%* | 67 | *-6%* | 67 | *-6%* | 67 | *-6%* | 67 | *-6%* |
| Spain | 774 | *-65%* | 774 | *-65%* | 774 | *-65%* | 774 | *-65%* | 353 | *0%* | 353 | *0%* | 353 | *0%* | 353 | *0%* |
| Sweden | 67 | *-44%* | 67 | *-44%* | 67 | *-44%* | 67 | *-44%* | 48 | *-21%* | 48 | *-21%* | 48 | *-21%* | 48 | *-21%* |
| UK | 980 | *-74%* | 980 | *-74%* | 980 | *-74%* | 980 | *-74%* | 297 | *-10%* | 297 | *-10%* | 297 | *-10%* | 297 | *-10%* |
| EU-15 | 4687 | *-71%* | 4687 | *-71%* | 4687 | *-71%* | 4687 | *-71%* | 3154 | *-12%* | 3154 | *-12%* | 3154 | *-12%* | 3154 | *-12%* |

Table 8.3: Emission control costs for variations in ambition levels for ground-level ozone (Scenarios H5/1, H5/2 and H5/3), in million EURO/year.

| | $SO_2$ | | | | $NO_x$/VOC | | | | $NH_3$ | | | | Total | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | REF | H5/1 Low ambition | H5/2 Central | H5/3 High ambition | REF | H5/1 Low ambition | H5/2 Central | H5/3 High ambition | REF | H5/1 Low ambition | H5/2 Central | H5/3 High ambition | REF | H5/1 Low ambition | H5/2 Central | H5/3 High ambition |
| Costs | total | on top of REF | | | total | on top of REF | | | total | on top of REF | | | total | on top of REF | | |
| Austria | 191 | 0 | 0 | 0 | 902 | 118 | 120 | 169 | 0 | 0 | 0 | 0 | 1093 | 118 | 120 | 169 |
| Belgium | 426 | 0 | 0 | 0 | 1278 | 455 | 459 | 499 | 0 | 0 | 0 | 0 | 1704 | 455 | 459 | 499 |
| Denmark | 138 | 0 | 0 | 0 | 484 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 623 | 0 | 0 | 1 |
| Finland | 247 | 0 | 0 | 0 | 642 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 889 | 0 | 0 | 0 |
| France | 1276 | 0 | 0 | 0 | 7383 | 373 | 719 | 1366 | 0 | 0 | 0 | 0 | 8659 | 373 | 719 | 1366 |
| Germany | 3264 | 0 | 0 | 0 | 10549 | 918 | 933 | 1140 | 0 | 0 | 0 | 0 | 13813 | 918 | 933 | 1140 |
| Greece | 434 | 0 | 0 | 0 | 1048 | 455 | 363 | 202 | 0 | 0 | 0 | 0 | 1482 | 455 | 363 | 202 |
| Ireland | 132 | 0 | 0 | 0 | 477 | 0 | 0 | 0 | 9 | 0 | 0 | 0 | 618 | 0 | 0 | 0 |
| Italy | 1776 | 0 | 0 | 0 | 7868 | 313 | 420 | 971 | 0 | 0 | 0 | 0 | 9644 | 313 | 420 | 971 |
| Luxembourg | 13 | 0 | 0 | 0 | 71 | 12 | 30 | 30 | 15 | 0 | 0 | 0 | 98 | 12 | 30 | 30 |
| Netherlands | 340 | 0 | 0 | 0 | 1731 | 89 | 140 | 140 | 196 | 0 | 0 | 0 | 2267 | 89 | 140 | 140 |
| Portugal | 181 | 0 | 0 | 0 | 1349 | 22 | 57 | 98 | 0 | 0 | 0 | 0 | 1530 | 22 | 57 | 98 |
| Spain | 809 | 0 | 0 | 0 | 5658 | 0 | 10 | 44 | 28 | 0 | 0 | 0 | 6495 | 0 | 10 | 44 |
| Sweden | 316 | 0 | 0 | 0 | 1125 | 73 | 73 | 92 | 113 | 0 | 0 | 0 | 1554 | 73 | 73 | 92 |
| UK | 1269 | 0 | 0 | 0 | 6695 | 648 | 957 | 1071 | 0 | 0 | 0 | 0 | 7964 | 648 | 957 | 1071 |
| EU-15 | 10813 | 0 | 0 | 0 | 47258 | 3476 | 4280 | 5823 | 361 | 0 | 0 | 0 | 58433 | 3476 | 4280 | 5823 |

## *8.2 Three Ambition Levels for Acidification (H6)*

This annex provides optimization results for three scenarios with different ambition levels for acidification, corresponding to the acidification targets of the H2, H1 and H3 scenarios.

Table 8.4: $NO_x$ and VOC emissions for variations in ambition levels for acidification (Scenarios H6/1, H6/2 and H6/3). Percentage changes relate to the year 1990.

| | $NO_x$ | | | | | | | | VOC | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | REF | | H6/1 Low ambition | | H6/2 Central | | H6/3 High ambition | | REF | | H6/1 Low ambition | | H6/2 Central | | H6/3 High ambition | |
| | kt | *Change* | kt | *Change* | kt | *Change* | kt | *Change* | kt | *Change* | kt | *Change* | kt | *Change* | kt | *Change* |
| Austria | 103 | *-46%* | 103 | *-46%* | 103 | *-46%* | 100 | *-48%* | 205 | *-42%* | 205 | *-42%* | 205 | *-42%* | 205 | *-42%* |
| Belgium | 191 | *-46%* | 167 | *-52%* | 144 | *-59%* | 127 | *-64%* | 193 | *-48%* | 193 | *-48%* | 192 | *-49%* | 192 | *-49%* |
| Denmark | 128 | *-53%* | 128 | *-53%* | 127 | *-54%* | 97 | *-65%* | 85 | *-53%* | 85 | *-53%* | 85 | *-53%* | 84 | *-54%* |
| Finland | 152 | *-45%* | 152 | *-45%* | 152 | *-45%* | 152 | *-45%* | 110 | *-48%* | 110 | *-48%* | 110 | *-48%* | 110 | *-48%* |
| France | 858 | *-54%* | 855 | *-54%* | 738 | *-60%* | 675 | *-64%* | 1223 | *-49%* | 1223 | *-49%* | 1220 | *-49%* | 1218 | *-49%* |
| Germany | 1184 | *-56%* | 1180 | *-56%* | 1138 | *-57%* | 965 | *-64%* | 1137 | *-64%* | 1137 | *-64%* | 1136 | *-64%* | 1129 | *-64%* |
| Greece | 344 | *0%* | 344 | *0%* | 344 | *0%* | 344 | *0%* | 267 | *-21%* | 267 | *-21%* | 267 | *-21%* | 267 | *-21%* |
| Ireland | 70 | *-38%* | 63 | *-44%* | 58 | *-49%* | 46 | *-59%* | 55 | *-50%* | 55 | *-50%* | 55 | *-50%* | 54 | *-51%* |
| Italy | 1130 | *-45%* | 1130 | *-45%* | 1130 | *-45%* | 1063 | *-48%* | 1159 | *-44%* | 1159 | *-44%* | 1159 | *-44%* | 1159 | *-44%* |
| Luxembourg | 10 | *-55%* | 10 | *-55%* | 9 | *-59%* | 8 | *-64%* | 7 | *-63%* | 7 | *-63%* | 7 | *-63%* | 7 | *-63%* |
| Netherlands | 280 | *-48%* | 276 | *-49%* | 237 | *-56%* | 198 | *-63%* | 233 | *-52%* | 233 | *-52%* | 232 | *-53%* | 232 | *-53%* |
| Portugal | 177 | *-15%* | 177 | *-15%* | 177 | *-15%* | 168 | *-19%* | 144 | *-32%* | 144 | *-32%* | 144 | *-32%* | 144 | *-32%* |
| Spain | 847 | *-27%* | 847 | *-27%* | 803 | *-31%* | 726 | *-38%* | 669 | *-34%* | 669 | *-34%* | 669 | *-34%* | 669 | *-34%* |
| Sweden | 190 | *-44%* | 190 | *-44%* | 190 | *-44%* | 167 | *-51%* | 290 | *-43%* | 290 | *-43%* | 290 | *-43%* | 290 | *-43%* |
| UK | 1186 | *-58%* | 1186 | *-58%* | 1094 | *-61%* | 816 | *-71%* | 1351 | *-49%* | 1351 | *-49%* | 1351 | *-49%* | 1341 | *-50%* |
| EU-15 | 6849 | *-48%* | 6808 | *-49%* | 6444 | *-51%* | 5651 | *-57%* | 7128 | *-49%* | 7128 | *-49%* | 7120 | *-49%* | 7102 | *-49%* |

Table 8.5: $SO_2$ and $NH_3$ emissions for variations in ambition levels for acidification (Scenarios H6/1, H6/2 and H6/3). Percentage changes relate to the year 1990.

| | $SO_2$ | | | | | | | | $NH_3$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | REF | | H6/1 Low ambition | | H6/2 Central | | H6/3 High ambition | | REF | | H6/1 Low ambition | | H6/2 Central | | H6/3 High ambition | |
| | kt | *Change* | kt | *Change* | kt | *Change* | kt | *Change* | kt | *Change* | kt | *Change* | kt | *Change* | kt | *Change* |
| Austria | 40 | *-57%* | 40 | *-57%* | 40 | *-57%* | 37 | *-60%* | 67 | *-13%* | 67 | *-13%* | 67 | *-13%* | 66 | *-14%* |
| Belgium | 193 | *-43%* | 82 | *-76%* | 76 | *-77%* | 75 | *-78%* | 96 | *-1%* | 80 | *-18%* | 57 | *-41%* | 57 | *-41%* |
| Denmark | 90 | *-51%* | 90 | *-51%* | 72 | *-60%* | 27 | *-85%* | 72 | *-6%* | 71 | *-8%* | 71 | *-8%* | 68 | *-12%* |
| Finland | 116 | *-49%* | 116 | *-49%* | 116 | *-49%* | 116 | *-49%* | 31 | *-23%* | 31 | *-23%* | 31 | *-23%* | 31 | *-23%* |
| France | 448 | *-64%* | 318 | *-75%* | 193 | *-85%* | 163 | *-87%* | 777 | *-4%* | 771 | *-4%* | 682 | *-15%* | 555 | *-31%* |
| Germany | 581 | *-89%* | 514 | *-90%* | 462 | *-91%* | 444 | *-92%* | 571 | *-25%* | 513 | *-32%* | 413 | *-45%* | 373 | *-51%* |
| Greece | 546 | *8%* | 546 | *8%* | 546 | *8%* | 546 | *8%* | 74 | *-8%* | 74 | *-8%* | 74 | *-8%* | 74 | *-8%* |
| Ireland | 66 | *-63%* | 28 | *-84%* | 28 | *-84%* | 23 | *-87%* | 126 | *-1%* | 125 | *-2%* | 124 | *-2%* | 124 | *-2%* |
| Italy | 567 | *-66%* | 566 | *-66%* | 566 | *-66%* | 295 | *-82%* | 432 | *-6%* | 432 | *-6%* | 430 | *-7%* | 430 | *-7%* |
| Luxembourg | 4 | *-71%* | 4 | *-71%* | 3 | *-79%* | 2 | *-86%* | 7 | *0%* | 7 | *0%* | 7 | *0%* | 7 | *0%* |
| Netherlands | 73 | *-64%* | 50 | *-75%* | 50 | *-75%* | 50 | *-75%* | 136 | *-42%* | 114 | *-51%* | 104 | *-55%* | 104 | *-55%* |
| Portugal | 141 | *-50%* | 141 | *-50%* | 141 | *-50%* | 141 | *-50%* | 67 | *-6%* | 67 | *-6%* | 67 | *-6%* | 67 | *-6%* |
| Spain | 774 | *-65%* | 744 | *-66%* | 746 | *-66%* | 198 | *-91%* | 353 | *0%* | 353 | *0%* | 353 | *0%* | 353 | *0%* |
| Sweden | 67 | *-44%* | 67 | *-44%* | 67 | *-44%* | 66 | *-45%* | 48 | *-21%* | 48 | *-21%* | 48 | *-21%* | 48 | *-21%* |
| UK | 980 | *-74%* | 718 | *-81%* | 496 | *-87%* | 422 | *-89%* | 297 | *-10%* | 290 | *-12%* | 264 | *-20%* | 229 | *-30%* |
| EU-15 | 4687 | *-71%* | 4026 | *-75%* | 3604 | *-78%* | 2607 | *-84%* | 3154 | *-12%* | 3043 | *-15%* | 2790 | *-22%* | 2586 | *-28%* |

Table 8.6: Emission control costs for variations in ambition levels for acidification (Scenarios H6/1, H6/2 and H6/3), in million EURO/year.

| | $SO_2$ | | | | $NO_x$/VOC | | | | $NH_3$ | | | | Total | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | REF | H6/1 Low ambition | H6/2 Central | H6/3 High ambition | REF | H6/1 Low ambition | H6/2 Central | H6/3 High ambition | REF | H6/1 Low ambition | H6/2 Central | H6/3 High ambition | REF | H6/1 Low ambition | H6/2 Central | H6/3 High ambition |
| Costs | total | on top of REF | | | total | on top of REF | | | total | on top of REF | | | total | on top of REF | | |
| Austria | 191 | 0 | 0 | 3 | 902 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1093 | 0 | 0 | 4 |
| Belgium | 426 | 93 | 129 | 154 | 1278 | 10 | 66 | 220 | 0 | 43 | 467 | 467 | 1704 | 146 | 662 | 841 |
| Denmark | 138 | 0 | 8 | 48 | 484 | 0 | 0 | 36 | 0 | 0 | 0 | 6 | 623 | 0 | 8 | 90 |
| Finland | 247 | 0 | 0 | 0 | 642 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 889 | 0 | 0 | 0 |
| France | 1276 | 47 | 209 | 348 | 7383 | 1 | 104 | 460 | 0 | 0 | 135 | 1104 | 8659 | 48 | 448 | 1912 |
| Germany | 3264 | 60 | 246 | 331 | 10549 | 1 | 63 | 1295 | 0 | 111 | 860 | 1385 | 13813 | 172 | 1170 | 3011 |
| Greece | 434 | 0 | 0 | 0 | 1048 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1482 | 0 | 0 | 0 |
| Ireland | 132 | 20 | 20 | 40 | 477 | 1 | 5 | 36 | 9 | 6 | 14 | 11 | 618 | 27 | 40 | 87 |
| Italy | 1776 | 0 | 0 | 83 | 7868 | 0 | 0 | 11 | 0 | 0 | 0 | 0 | 9644 | 0 | 0 | 94 |
| Luxembourg | 13 | 0 | 1 | 3 | 71 | 0 | 1 | 4 | 15 | 0 | 0 | 0 | 98 | 0 | 1 | 7 |
| Netherlands | 340 | 19 | 19 | 19 | 1731 | 2 | 123 | 618 | 196 | 342 | 741 | 741 | 2267 | 363 | 883 | 1379 |
| Portugal | 181 | 0 | 0 | 0 | 1349 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1530 | 0 | 0 | 1 |
| Spain | 809 | 10 | 9 | 301 | 5658 | 0 | 4 | 31 | 28 | 0 | 0 | 0 | 6495 | 10 | 13 | 332 |
| Sweden | 316 | 0 | 0 | 0 | 1125 | 0 | 0 | 10 | 113 | 0 | 0 | 0 | 1554 | 0 | 0 | 10 |
| UK | 1269 | 92 | 301 | 580 | 6695 | 0 | 98 | 1605 | 0 | 4 | 23 | 314 | 7964 | 96 | 422 | 2499 |
| EU-15 | 10813 | 342 | 942 | 1911 | 47258 | 15 | 464 | 4328 | 361 | 506 | 2241 | 4028 | 58433 | 863 | 3647 | 10267 |