International Institute for
Applied Systems Analysis
Schlossplatz 1
A-2361 Laxenburg, Austria

Tel: +43 2236 807 536
Fax: +43 2236 807 503
E-mail: riley@iiasa.ac.at
Web: www.iiasa.ac.at

# Emissions of Air Pollutants for the World Energy Outlook 2009 Energy Scenarios

## Final Report

Janusz Cofala, Peter Rafaj, Wolfgang Schöpp,
Zbigniew Klimont, and Markus Amann

*Submitted to the*

International Energy Agency, Paris, France

August 2009

## Glossary of terms used in this report

| | |
|---|---|
| $CO_2$ | Carbon dioxide |
| GAINS | Greenhouse gas - Air pollution INteractions and Synergies model |
| IEA | International Energy Agency |
| IIASA | International Institute for Applied Systems Analysis |
| NEC | National Emission Ceilings Directive |
| $NO_x$ | Nitrogen oxides |
| PM2.5 | Fine particles with an aerodynamic diameter of less than 2.5 µm |
| RAINS | Regional Air Pollution Information and Simulation model |
| SNAP | Selected Nomenclature for Air Pollutants; Sector aggregation used in the CORINAIR emission inventory system |
| $SO_2$ | Sulphur dioxide |
| WEM | World Energy Model |
| YOLLs | Years of life lost attributable to the PM2.5 exposure from anthropogenic sources |

# Table of Contents

## Abstract

This report examines global emissions of major air pollutants ($SO_2$, $NO_x$, PM2.5) resulting from energy scenarios developed for the World Energy Outlook 2009 (OECD/IEA, 2009). Estimates include emissions for 27 regions according to the aggregation used in the IEA World Energy Model (WEM). Emissions have been estimated using the IIASA GAINS model.

The 2009 Outlook discusses two energy pathways for the next 20 years: the Reference Scenario that reflects unchanged governmental energy and climate policies and the 450 Scenario, which assumes implementation of climate policies that allow limitation of the increase in global average temperature to about $2^o$ C. These pathways were implemented into the GAINS model. Next, emissions of air pollutants were calculated. Calculations take into account the current air pollution control policies in each country or region as adopted or in the pipeline by mid-2009.

Presented in this report estimates do not include emissions form international shipping as well as cruising emissions from aviation. They also do not include emissions from biomass burning (deforestation, savannah burning, and vegetation fires).

In 2005, world emissions of $SO_2$ from sources covered in this report were about 95 million tons. OECD countries contributed 30 percent of this total. Implementation of current policies on air pollution control for the Reference Scenario causes a 14 percent decrease in world emissions of $SO_2$ in 2020 compared with 2005, which is a result of more than halving of emissions from the OECD countries and a moderate decrease in other countries. After 2020 emissions from the non-OECD countries start to rise, which causes an increase of world emissions by about four million tons until 2030. The corresponding world emissions of $NO_x$ are: 85 million tons in 2005 (of which 43 percent originated from the OECD countries), decrease until 2020 by 13 percent and next increase until 2030 by about 10 million tons. Emissions of PM2.5 (38.5 million tons in 2005) are dominated by the sources from non-OECD countries – 90 percent of total. In 2020 and 2030 the world emissions are by 3 – 4 percent higher, which is again due to the increase of emissions from the non-OECD countries.

The 450 Scenario causes an important reduction in emissions of air pollutants. By 2030, the emissions of $SO_2$ are 29 percent lower than in the Reference case. Emissions of $NO_x$ decrease by 19 percent and those of PM2.5 by nine percent.

Costs of the "current policy" air pollution controls are about 155 billion €/a in 2005[1]. Until 2030 these costs increase in the Reference Scenario by a factor of three, which is due to higher activity levels and increasing stringency of controls. In 2030, more than 60 percent of the total control costs are the expenditures on reducing emissions from road transport. The 450 Scenario brings 17 percent cost savings in 2030 compared with the Reference.

The Study also estimated health impacts of air pollution in Europe, China and India in terms of life years lost (YOLLs) attributable to the exposure from anthropogenic emissions of PM2.5. In 2005 about 3.4 billion of life-years were lost in those countries due to PM exposure[2]. This estimate is dominated by impacts in China and India, which together contribute more than 90 percent of YOLLs


[1] All costs are calculated in € 2005 using international prices of pollution control equipment and four percent real interest rate.

[2] The estimates do not include exposure to indoor air pollution.

in 2005. The Reference Scenario implies an increase of the YOLLs indicator in 2030 by about 70 percent to 5.7 billion. The 450 Scenario saves 1.2 billion life-years in 2030.

Lower impact indicators and lower air pollution control costs in the 450 Scenario compared with the Reference clearly demonstrate important co-benefits of climate policies for air pollution.

# 1 Introduction

This report describes the work executed by IIASA for the Office of the Chief Economist at the International Energy Agency (IEA) to provide a set of emission trends that correspond to the World Energy Model analysis developed by the IEA for the World Energy Outlook 2009 (OECD/IEA, 2009). IIASA calculated emissions of major air pollutants: $SO_2$, $NO_x$, and PM2.5 for two energy scenarios: the Reference Scenario that reflects unchanged governmental energy and climate policies and the 450 Scenario, which assumes implementation of policies that allow limitation of the increase in average temperature of the globe to about $2^o$ C.

The analysis employs as the central analytical tool the IIASA GAINS model. Methodology for air pollution calculations within GAINS is described in Amann, 2004. Estimates include emissions for 27 regions according to the aggregation used in the IEA's World Energy Model. The national assessment does not include the emissions form international shipping as well as cruising emissions from aviation. Also emissions from biomass burning (deforestation, savannah burning, and vegetation fires) are not included in national totals.

The remainder of the report is organized as follows: Section 2 shortly summarizes activity scenarios included in the analysis. It also explains assumptions about emission control legislation adopted for individual countries/country groups. Section 3 presents emission projections by country group and by economic sector. In Section 4 emission control costs are discussed. Section 5 discusses health impacts of the scenarios. Conclusions are drawn in Section 6.

# 2 Activity projections

The 2009 World Energy Outlook discusses two energy pathways for the next 20 years, namely:

- The Reference Scenario and
- The 450 Scenario.

Both scenarios were developed with the World Energy Model and include 27 world regions. Regions are either individual countries or groups of countries with similar policies and emission characteristics. Countries who are major energy consumers (and $CO_2$ emitters) are treated on an individual basis. The scenarios provide details for the period up to 2030 with particular focus on 2020, which is essential for the decisions about the mid-term development of the world energy system and the climate-negotiations process. The assessment includes the effects of recent global economic downturn and demonstrates its impacts on the emissions of energy-related $CO_2$.

Coverage of each region is explained in Appendix I. The Reference Scenario reflects unchanged governmental energy and climate policies. This scenario is unsustainable and puts the globe on a path to double the $CO_2$ concentrations, which might result in an increase of global average temperature by up to $6^o$ C with all negative impacts of such an increase. The alternative scenario assumes implementation of new policies, which induce important structural changes in the world energy system. These changes induce limitation of energy-related $CO_2$ emissions to a level that stabilizes the concentration of greenhouse gases at about 450 ppm, which corresponds to the increase in global average temperature of about $2^o$ C.

Details on energy consumption structure for the WEO 2009 energy scenarios, together with major macroeconomic characteristics (population, GDP and value added by major economic sector) have been provided to IIASA by the IEA and next implemented into GAINS using a special interface routine. Missing information has been completed based on scenarios already available in GAINS. In particular, this included development of national energy scenarios for countries that are aggregated into a country group within the WEM, derivation of transport sector-specific data (vehicle-kilometres, vehicle numbers) and estimation of activities causing process emissions (production of energy-intensive products, agricultural activities, storage and handling of materials, waste treatment, etc.).

# 3 Emission projections

Calculation of emissions of air pollutants has been performed assuming in each country (or country group) the “current policies” air pollution control legislation. In particular, for Europe all emission limit values and fuel quality standards have been included, as used in the analysis for the revision of the National Emission Ceilings (NEC) Directive - Amann *et al.*, 2008. For other countries policies have been assessed based on available literature (compare Cofala *et al.*, 2007). They take into account recent updates done in collaboration with national expert teams (Klimont, 2009). In addition, assumptions about emission controls in the power plant sector have been cross-checked with detailed information from the database on world coal fired power plants (IEACCC, 2009). Important role in air pollution abatement is played by controlling emissions from mobile sources. Again, for Europe the same assumptions have been made as for the modelling work for the revision of the NEC Directive. For other countries information from DieselNet, 2009 and national sources was used.

## *3.1 Reference Scenario*

Emissions of $SO_2$, $NO_x$ and PM2.5 by country group up to 2030 for the Reference Scenario are presented in Table 3.1 to Table 3.3. Emissions by sector (according to the SNAP aggregation) separated by OECD and non-OECD countries can be found in Table 3.4 to Table 3.6. Values for 2007 have been derived through interpolation.

In 2005, world emissions of $SO_2$ were about 95 million tons. OECD countries contributed 30 percent to this total. Dominating sources are power plants and industrial emissions. Implementation of current policies on air pollution control for the Reference Scenario causes a 14 percent decrease in world emissions of $SO_2$ emissions in 2020 compared with 2005. This is a combined effect of the decrease of emissions from the OECD region (minus 54 percent) and only a slight increase from the rest of the world. Growth of emissions in non-OECD countries in the period 2005 – 2020 is limited to only three percent because of implementation of emission control measures according to the “current legislation” assumptions. However, after 2020 the emissions in non-OECD countries increase by more than four million tons, mainly due to higher coal consumption in poorly controlled power plants in Southeast Asia and other developing world.

According to the GAINS assessment, world emissions of $NO_x$ were 85 million tons in 2005, of which 43 percent originated from the OECD countries. Road transport was responsible for about one third of $NO_x$ emissions. Until 2020 the emissions decrease by 13 percent, which is a combined effect of nearly 50 percent decrease of emissions form the OECD countries and a 14 percent increase from the rest of the world. It needs to be stressed that majority of non-OECD countries are currently implementing emission standards on road transport sources, which importantly slows down the pace of increase of $NO_x$ emissions. After 2020 the world emissions increase, and are about 10 million tons higher in 2030 than in 2020.

Emissions of PM2.5 (38.5 million tons in 2005) are dominated by the sources from non-OECD countries – 90 percent of total. On a global scale, the highest contributors are residential and commercial combustion (49 percent of total) and industrial emissions (27 percent). In 2020 and 2030 the world emissions are by 3 – 4 percent higher. This relatively low increase of emissions is due to the changes in fuel use patterns by households (replacement of solid fuels with other energy forms) and better controls on sources in the power plant sector, industry and road transport.

Table 3.1: Emissions of $SO_2$ by country group[3] in the Reference Scenario, thousand tons/year

| WEM region | 2005 | 2007 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|
| China | 31557 | 31525 | 31477 | 34566 | 33191 | 31013 | 28998 |
| India | 5929 | 6263 | 6763 | 8534 | 10255 | 12334 | 14804 |
| South Africa | 2125 | 1951 | 1690 | 1436 | 1315 | 1452 | 1586 |
| Russia | 5416 | 5532 | 5706 | 5030 | 4455 | 4791 | 5103 |
| Brazil | 1070 | 1076 | 1086 | 1162 | 1212 | 1308 | 1400 |
| Middle East | 4754 | 4601 | 4372 | 4128 | 3929 | 3754 | 3976 |
| Indonesia | 1071 | 1060 | 1045 | 960 | 1004 | 1101 | 1192 |
| Malaysia | 229 | 228 | 226 | 208 | 205 | 208 | 219 |
| Philippines | 374 | 335 | 277 | 231 | 244 | 265 | 296 |
| Thailand | 547 | 478 | 375 | 331 | 341 | 364 | 388 |
| OASEAN | 549 | 527 | 493 | 574 | 657 | 734 | 859 |
| EU-8 | 1926 | 1475 | 799 | 357 | 340 | 360 | 371 |
| US | 13789 | 11301 | 7571 | 5539 | 4415 | 3861 | 3780 |
| CAN | 2189 | 2053 | 1849 | 1649 | 1601 | 1585 | 1585 |
| Mexico | 1790 | 1391 | 792 | 627 | 605 | 513 | 443 |
| Japan | 811 | 717 | 575 | 560 | 539 | 532 | 530 |
| Korea | 555 | 532 | 498 | 517 | 513 | 512 | 513 |
| AUNZ | 1438 | 1424 | 1403 | 1367 | 1369 | 1377 | 1381 |
| OE4 | 1536 | 1517 | 1489 | 1435 | 1485 | 1586 | 1757 |
| EUG4 | 2129 | 1712 | 1085 | 1091 | 1023 | 977 | 954 |
| EU015 | 3962 | 3080 | 1758 | 1559 | 1385 | 1352 | 1300 |
| ETEnonEU | 2006 | 1909 | 1764 | 1887 | 1775 | 1717 | 1954 |
| ATE | 2410 | 2423 | 2444 | 2593 | 2716 | 2859 | 2781 |
| RODA | 2053 | 2108 | 2190 | 2781 | 3421 | 4374 | 5870 |
| OLAM | 2312 | 2287 | 2250 | 2197 | 2022 | 2148 | 2229 |
| NAFR | 1029 | 981 | 908 | 724 | 643 | 698 | 834 |
| OAFR | 1646 | 1809 | 2055 | 1550 | 1313 | 1336 | 1315 |
| OECD | 28199 | 23728 | 17020 | 14345 | 12936 | 12294 | 12244 |
| Non-OECD | 67003 | 66569 | 65918 | 69248 | 69039 | 70818 | 74173 |
| World | 95202 | 90297 | 82939 | 83593 | 81975 | 83112 | 86417 |

[3] Aggregation of countries to the WEO 2009 groups is explained in Appendix 1

Table 3.2: Emissions of $NO_x$ by country group in the Reference Scenario, thousand tons/year

| WEM region | 2005 | 2007 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|
| China | 15760 | 16902 | 18615 | 21261 | 21570 | 22686 | 24253 |
| India | 3942 | 4113 | 4371 | 4965 | 6024 | 7524 | 9495 |
| South Africa | 1276 | 1265 | 1248 | 1247 | 1263 | 1491 | 1785 |
| Russia | 4903 | 4645 | 4256 | 3932 | 3612 | 3395 | 3440 |
| Brazil | 2348 | 2306 | 2245 | 2355 | 2400 | 2460 | 2718 |
| Middle East | 4186 | 4040 | 3822 | 4246 | 4581 | 4984 | 5556 |
| Indonesia | 1704 | 1666 | 1610 | 1581 | 1560 | 1766 | 2040 |
| Malaysia | 626 | 595 | 549 | 579 | 570 | 560 | 592 |
| Philippines | 449 | 406 | 343 | 289 | 287 | 320 | 379 |
| Thailand | 1006 | 968 | 913 | 982 | 1125 | 1290 | 1479 |
| OASEAN | 873 | 826 | 756 | 841 | 943 | 1116 | 1381 |
| EU-8 | 719 | 629 | 492 | 445 | 390 | 375 | 376 |
| US | 17191 | 15225 | 12275 | 9198 | 7507 | 6668 | 6435 |
| CAN | 1585 | 1451 | 1252 | 1096 | 989 | 945 | 973 |
| Mexico | 1439 | 1355 | 1229 | 1121 | 1080 | 1138 | 1203 |
| Japan | 2163 | 1926 | 1569 | 1267 | 1008 | 868 | 824 |
| Korea | 1439 | 1362 | 1247 | 1158 | 988 | 922 | 885 |
| AUNZ | 1303 | 1243 | 1153 | 1030 | 952 | 939 | 939 |
| OE4 | 1219 | 1160 | 1071 | 988 | 999 | 1068 | 1188 |
| EUG4 | 5265 | 4691 | 3831 | 3283 | 2575 | 2224 | 2135 |
| EU015 | 4870 | 4305 | 3458 | 2948 | 2373 | 2098 | 2002 |
| ETEnonEU | 1501 | 1415 | 1287 | 1243 | 1195 | 1227 | 1346 |
| ATE | 1114 | 1157 | 1222 | 1367 | 1423 | 1581 | 1699 |
| RODA | 1820 | 1777 | 1711 | 1979 | 2260 | 2632 | 3123 |
| OLAM | 3292 | 3242 | 3166 | 3105 | 2908 | 3150 | 3489 |
| NAFR | 1369 | 1375 | 1383 | 1405 | 1456 | 1648 | 1885 |
| OAFR | 1741 | 1736 | 1728 | 1824 | 1852 | 1978 | 2087 |
| OECD | 36475 | 32719 | 27085 | 22088 | 18472 | 16870 | 16583 |
| Non-OECD | 48629 | 49064 | 49717 | 53648 | 55417 | 60183 | 67121 |
| World | 85104 | 81783 | 76801 | 75737 | 73888 | 77053 | 83704 |

Table 3.3: Emissions of PM2.5 by country group in the Reference scenario, thousand tons/year

| WEM region | 2005 | 2007 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|
| China | 12553 | 13100 | 13920 | 13188 | 12150 | 11517 | 10941 |
| India | 5098 | 5139 | 5201 | 5409 | 5647 | 5947 | 6308 |
| South Africa | 411 | 419 | 430 | 449 | 468 | 482 | 503 |
| Russia | 1113 | 1098 | 1076 | 1154 | 1164 | 1192 | 1229 |
| Brazil | 900 | 888 | 871 | 872 | 876 | 856 | 835 |
| Middle East | 642 | 657 | 679 | 713 | 729 | 671 | 623 |
| Indonesia | 1570 | 1604 | 1657 | 1689 | 1715 | 1735 | 1754 |
| Malaysia | 149 | 147 | 145 | 141 | 133 | 120 | 114 |
| Philippines | 224 | 222 | 220 | 218 | 214 | 208 | 205 |
| Thailand | 354 | 351 | 347 | 344 | 338 | 323 | 315 |
| OASEAN | 1171 | 1199 | 1241 | 1279 | 1315 | 1339 | 1362 |
| EU-8 | 275 | 247 | 205 | 204 | 204 | 210 | 217 |
| US | 1027 | 946 | 825 | 761 | 722 | 697 | 696 |
| CAN | 157 | 147 | 133 | 126 | 117 | 112 | 111 |
| Mexico | 404 | 378 | 340 | 329 | 331 | 342 | 355 |
| Japan | 199 | 184 | 161 | 149 | 136 | 129 | 126 |
| Korea | 171 | 167 | 160 | 159 | 156 | 157 | 158 |
| AUNZ | 179 | 174 | 166 | 164 | 160 | 159 | 160 |
| OE4 | 380 | 375 | 368 | 376 | 405 | 440 | 481 |
| EUG4 | 686 | 641 | 575 | 537 | 511 | 489 | 494 |
| EU015 | 734 | 685 | 611 | 572 | 543 | 523 | 527 |
| ETEnonEU | 539 | 522 | 496 | 505 | 495 | 509 | 580 |
| ATE | 140 | 137 | 134 | 148 | 162 | 174 | 164 |
| RODA | 1622 | 1639 | 1664 | 1779 | 1873 | 1995 | 2118 |
| OLAM | 1178 | 1161 | 1134 | 1121 | 1110 | 1108 | 1118 |
| NAFR | 408 | 421 | 440 | 448 | 457 | 425 | 400 |
| OAFR | 6242 | 6472 | 6816 | 7244 | 7604 | 7877 | 8062 |
| OECD | 3935 | 3697 | 3341 | 3175 | 3082 | 3047 | 3108 |
| Non-OECD | 34589 | 35424 | 36675 | 36905 | 36654 | 36688 | 36847 |
| World | 38524 | 39121 | 40016 | 40080 | 39736 | 39735 | 39956 |

Table 3.4: Emissions of $SO_2$ by SNAP sector for the Reference Scenario, thousand tons/year

**OECD**

| SNAP sector | 2005 | 2007 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|
| 1: Power generation | 17844 | 14144 | 8594 | 6155 | 4765 | 4073 | 4001 |
| 2: Domestic | 1328 | 1141 | 861 | 799 | 753 | 710 | 661 |
| 3: Industrial combust. | 3906 | 3664 | 3302 | 3327 | 3348 | 3382 | 3410 |
| 4: Industrial processes | 4047 | 3941 | 3782 | 3651 | 3653 | 3717 | 3762 |
| 5: Fuel extraction | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6: Solvents | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7: Road traffic | 403 | 264 | 57 | 41 | 38 | 37 | 37 |
| 8: Off-road sources | 635 | 535 | 386 | 334 | 342 | 339 | 337 |
| 9: Waste management | 14 | 14 | 14 | 13 | 13 | 12 | 12 |
| 10: Agriculture | 24 | 24 | 24 | 24 | 24 | 23 | 25 |
| Sum | 28199 | 23728 | 17020 | 14345 | 12936 | 12294 | 12244 |

**Non-OECD**

| SNAP sector | 2005 | 2007 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|
| 1: Power generation | 37775 | 36328 | 34158 | 36430 | 35771 | 35750 | 37019 |
| 2: Domestic | 4467 | 4419 | 4347 | 4553 | 4562 | 4523 | 4450 |
| 3: Industrial combust. | 13305 | 14049 | 15166 | 17399 | 18744 | 20206 | 21991 |
| 4: Industrial processes | 9412 | 9877 | 10576 | 9038 | 8010 | 8170 | 8296 |
| 5: Fuel extraction | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6: Solvents | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7: Road traffic | 777 | 634 | 419 | 423 | 457 | 572 | 702 |
| 8: Off-road sources | 955 | 945 | 930 | 1076 | 1162 | 1261 | 1377 |
| 9: Waste management | 185 | 187 | 189 | 188 | 186 | 181 | 177 |
| 10: Agriculture | 127 | 130 | 134 | 141 | 148 | 154 | 162 |
| Sum | 67003 | 66569 | 65918 | 69248 | 69039 | 70818 | 74173 |

**World**

| SNAP sector | 2005 | 2007 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|
| 1: Power generation | 55619 | 50472 | 42752 | 42585 | 40535 | 39823 | 41020 |
| 2: Domestic | 5795 | 5560 | 5207 | 5352 | 5315 | 5233 | 5111 |
| 3: Industrial combust. | 17211 | 17714 | 18468 | 20726 | 22092 | 23588 | 25401 |
| 4: Industrial processes | 13458 | 13818 | 14358 | 12689 | 11663 | 11887 | 12058 |
| 5: Fuel extraction | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6: Solvents | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7: Road traffic | 1180 | 898 | 475 | 464 | 495 | 610 | 739 |
| 8: Off-road sources | 1589 | 1480 | 1316 | 1410 | 1504 | 1600 | 1714 |
| 9: Waste management | 200 | 201 | 204 | 201 | 199 | 194 | 188 |
| 10: Agriculture | 151 | 154 | 158 | 166 | 172 | 178 | 187 |
| Sum | 95202 | 90297 | 82939 | 83593 | 81975 | 83112 | 86417 |

Table 3.5: Emissions of $NO_x$ by SNAP sector for the Reference Scenario, thousand tons/year

**OECD**

| SNAP sector | 2005 | 2007 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|
| 1: Power generation | 9250 | 8139 | 6471 | 5363 | 4512 | 4355 | 4365 |
| 2: Domestic | 1969 | 1875 | 1733 | 1749 | 1772 | 1820 | 1867 |
| 3: Industrial combust. | 4297 | 4141 | 3907 | 4031 | 4062 | 4159 | 4256 |
| 4: Industrial processes | 1051 | 1033 | 1007 | 987 | 979 | 963 | 945 |
| 5: Fuel extraction | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6: Solvents | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7: Road traffic | 14562 | 12568 | 9576 | 5996 | 3580 | 2455 | 2283 |
| 8: Off-road sources | 5262 | 4881 | 4308 | 3883 | 3489 | 3044 | 2791 |
| 9: Waste management | 25 | 25 | 24 | 22 | 21 | 20 | 19 |
| 10: Agriculture | 59 | 59 | 59 | 58 | 57 | 55 | 58 |
| Sum | 36475 | 32719 | 27085 | 22088 | 18472 | 16870 | 16583 |

**Non-OECD**

| SNAP sector | 2005 | 2007 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|
| 1: Power generation | 12796 | 12912 | 13087 | 14932 | 15898 | 17560 | 19595 |
| 2: Domestic | 2961 | 3015 | 3096 | 3240 | 3318 | 3385 | 3427 |
| 3: Industrial combust. | 9203 | 10030 | 11272 | 12571 | 13205 | 14095 | 15095 |
| 4: Industrial processes | 1227 | 1239 | 1257 | 1345 | 1420 | 1486 | 1548 |
| 5: Fuel extraction | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6: Solvents | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7: Road traffic | 14740 | 13927 | 12707 | 12405 | 12176 | 13390 | 15778 |
| 8: Off-road sources | 7316 | 7547 | 7892 | 8737 | 8969 | 9827 | 11225 |
| 9: Waste management | 186 | 187 | 189 | 188 | 186 | 181 | 177 |
| 10: Agriculture | 200 | 206 | 216 | 232 | 245 | 258 | 275 |
| Sum | 48629 | 49064 | 49717 | 53648 | 55417 | 60183 | 67121 |

**World**

| SNAP sector | 2005 | 2007 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|
| 1: Power generation | 22046 | 21051 | 19558 | 20295 | 20409 | 21915 | 23960 |
| 2: Domestic | 4930 | 4890 | 4829 | 4989 | 5090 | 5205 | 5295 |
| 3: Industrial combust. | 13500 | 14171 | 15179 | 16601 | 17268 | 18254 | 19351 |
| 4: Industrial processes | 2278 | 2272 | 2264 | 2332 | 2399 | 2450 | 2493 |
| 5: Fuel extraction | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6: Solvents | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7: Road traffic | 29302 | 26495 | 22283 | 18401 | 15756 | 15844 | 18061 |
| 8: Off-road sources | 12578 | 12427 | 12200 | 12619 | 12458 | 12871 | 14016 |
| 9: Waste management | 210 | 212 | 213 | 210 | 207 | 201 | 196 |
| 10: Agriculture | 259 | 265 | 275 | 290 | 302 | 313 | 333 |
| Sum | 85104 | 81783 | 76801 | 75737 | 73888 | 77053 | 83704 |

Table 3.6: Emissions of PM2.5 by SNAP sector for the Reference Scenario, thousand tons/year

**OECD**

| SNAP sector | 2005 | 2007 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|
| 1: Power generation | 338 | 305 | 256 | 254 | 251 | 255 | 263 |
| 2: Domestic | 1202 | 1152 | 1076 | 1066 | 1044 | 1027 | 1041 |
| 3: Industrial combust. | 361 | 342 | 312 | 322 | 340 | 368 | 401 |
| 4: Industrial processes | 471 | 461 | 446 | 452 | 466 | 478 | 488 |
| 5: Fuel extraction | 16 | 16 | 16 | 17 | 17 | 18 | 18 |
| 6: Solvents | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7: Road traffic | 634 | 548 | 419 | 299 | 241 | 226 | 232 |
| 8: Off-road sources | 435 | 396 | 339 | 286 | 242 | 197 | 175 |
| 9: Waste management | 185 | 186 | 187 | 189 | 191 | 193 | 194 |
| 10: Agriculture | 293 | 291 | 290 | 291 | 290 | 285 | 297 |
| Sum | 3935 | 3697 | 3341 | 3175 | 3082 | 3047 | 3108 |

**Non-OECD**

| SNAP sector | 2005 | 2007 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|
| 1: Power generation | 2078 | 2130 | 2207 | 2674 | 2976 | 3308 | 3682 |
| 2: Domestic | 17858 | 18149 | 18586 | 18743 | 18513 | 18060 | 17425 |
| 3: Industrial combust. | 6677 | 6931 | 7313 | 6850 | 6509 | 6471 | 6539 |
| 4: Industrial processes | 2765 | 3006 | 3367 | 3361 | 3302 | 3238 | 3207 |
| 5: Fuel extraction | 56 | 61 | 68 | 73 | 77 | 86 | 95 |
| 6: Solvents | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7: Road traffic | 985 | 895 | 762 | 651 | 624 | 703 | 839 |
| 8: Off-road sources | 685 | 700 | 723 | 757 | 718 | 760 | 867 |
| 9: Waste management | 931 | 952 | 984 | 1024 | 1066 | 1099 | 1137 |
| 10: Agriculture | 2555 | 2599 | 2666 | 2772 | 2868 | 2963 | 3057 |
| Sum | 34590 | 35424 | 36675 | 36905 | 36655 | 36688 | 36847 |

**World**

| SNAP sector | 2005 | 2007 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|
| 1: Power generation | 2416 | 2435 | 2463 | 2928 | 3227 | 3563 | 3945 |
| 2: Domestic | 19060 | 19301 | 19662 | 19808 | 19558 | 19087 | 18466 |
| 3: Industrial combust. | 7038 | 7273 | 7625 | 7172 | 6850 | 6839 | 6939 |
| 4: Industrial processes | 3237 | 3467 | 3812 | 3813 | 3769 | 3716 | 3695 |
| 5: Fuel extraction | 72 | 77 | 84 | 89 | 94 | 104 | 114 |
| 6: Solvents | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7: Road traffic | 1619 | 1443 | 1180 | 950 | 864 | 929 | 1071 |
| 8: Off-road sources | 1120 | 1096 | 1061 | 1043 | 960 | 957 | 1041 |
| 9: Waste management | 1116 | 1138 | 1171 | 1214 | 1258 | 1292 | 1331 |
| 10: Agriculture | 2847 | 2891 | 2956 | 3062 | 3158 | 3249 | 3354 |
| Sum | 38524 | 39121 | 40016 | 40080 | 39736 | 39735 | 39955 |

## 3.2 450 Scenario

Emissions for the 450 Scenario by country group are shown in Table 3.7 to Table 3.9. Emissions by SNAP sector are presented in Table 3.10 to Table 3.12. Policies aimed at reduction of energy-related $CO_2$ emissions, as in the 450 Scenario, cause an important reduction of emission of air pollutants. By 2030, the $SO_2$ emissions are 25 million tons (or 29 percent) lower than in the Reference Scenario. Majority of that reduction (22 million tons) occurs in non-OECD countries. In case of $NO_{x,}$, the emissions are 19 percent lower. In absolute terms this means 16 million tons of $NO_x$ less, of which 13 million tons is due to lower emissions from non-OECD countries. Also PM2.5 decrease compared with the Reference Scenario. In 2030 they are 3.8 million tons (or nine percent) lower. It is characteristic, that the emissions from the OECD region are slightly higher (by 0.5 million tons) in the 450 Scenario, which is due to higher use of biomass fuels in the residential sector. Emissions from the non-OECD countries decrease by 4.2 million tons.

Figure 3.1 to Figure 3.3 compare the emissions of air pollutants by major countries/country groups for the two scenarios. Figures clearly demonstrate the dominance of emissions from the non-OECD countries in the world emissions of air pollutants.

Table 3.7: Emissions of $SO_2$ by country group in the 450 Scenario, thousand tons/year

| WEM region | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|
| China | 32936 | 29524 | 23747 | 19558 |
| India | 8353 | 9158 | 9230 | 9376 |
| South Africa | 1436 | 1315 | 1452 | 1586 |
| Russia | 4913 | 3976 | 3854 | 3739 |
| Brazil | 1130 | 1161 | 1114 | 1141 |
| Middle East | 4075 | 3614 | 2989 | 2892 |
| Indonesia | 942 | 977 | 998 | 966 |
| Malaysia | 206 | 202 | 204 | 211 |
| Philippines | 229 | 242 | 262 | 290 |
| Thailand | 329 | 338 | 364 | 392 |
| OASEAN | 563 | 634 | 694 | 796 |
| EU-8 | 330 | 318 | 324 | 326 |
| US | 5281 | 3827 | 2747 | 2669 |
| CAN | 1537 | 1432 | 1384 | 1381 |
| Mexico | 577 | 505 | 413 | 311 |
| Japan | 541 | 523 | 507 | 487 |
| Korea | 498 | 483 | 463 | 435 |
| AUNZ | 1301 | 1204 | 1122 | 1081 |
| OE4 | 1348 | 1177 | 1031 | 1011 |
| EUG4 | 1054 | 955 | 839 | 821 |
| EU015 | 1496 | 1295 | 1195 | 1147 |
| ETEnonEU | 1866 | 1522 | 1451 | 1445 |
| ATE | 2615 | 2657 | 2626 | 2236 |
| RODA | 2659 | 3016 | 3466 | 3996 |
| OLAM | 2154 | 1911 | 1912 | 1864 |
| NAFR | 705 | 582 | 532 | 526 |
| OAFR | 1541 | 1286 | 1198 | 1087 |
| OECD | 13633 | 11400 | 9702 | 9344 |
| Non-OECD | 66981 | 62435 | 56416 | 52428 |
| World | 80614 | 73835 | 66117 | 61772 |

Table 3.8: Emissions of $NO_x$ by country group in the 450 Scenario, thousand tons/year

| WEM region | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|
| China | 20437 | 19518 | 18102 | 17274 |
| India | 4838 | 5517 | 6315 | 7431 |
| South Africa | 1247 | 1263 | 1491 | 1785 |
| Russia | 3842 | 3396 | 2986 | 2797 |
| Brazil | 2297 | 2291 | 2246 | 2414 |
| Middle East | 4052 | 4311 | 4526 | 4871 |
| Indonesia | 1519 | 1485 | 1583 | 1681 |
| Malaysia | 563 | 547 | 534 | 556 |
| Philippines | 280 | 274 | 300 | 346 |
| Thailand | 947 | 1062 | 1201 | 1358 |
| OASEAN | 815 | 893 | 1031 | 1245 |
| EU-8 | 427 | 372 | 350 | 343 |
| US | 8875 | 6895 | 5613 | 5180 |
| CAN | 1034 | 883 | 804 | 804 |
| Mexico | 1083 | 1009 | 1023 | 1031 |
| Japan | 1198 | 930 | 770 | 697 |
| Korea | 1116 | 922 | 771 | 627 |
| AUNZ | 960 | 811 | 728 | 689 |
| OE4 | 951 | 919 | 942 | 1020 |
| EUG4 | 3157 | 2396 | 1985 | 1874 |
| EU015 | 2830 | 2222 | 1880 | 1771 |
| ETEnonEU | 1220 | 1130 | 1140 | 1216 |
| ATE | 1334 | 1351 | 1442 | 1467 |
| RODA | 1911 | 2103 | 2332 | 2609 |
| OLAM | 3041 | 2758 | 2856 | 3031 |
| NAFR | 1368 | 1392 | 1509 | 1668 |
| OAFR | 1769 | 1757 | 1818 | 1869 |
| OECD | 21204 | 16986 | 14516 | 13694 |
| Non-OECD | 51907 | 51420 | 51761 | 53961 |
| World | 73111 | 68406 | 66277 | 67655 |

Table 3.9: Emissions of PM2.5 by country group in the 450 Scenario, thousand tons/year

| WEM region | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|
| China | 12892 | 11451 | 10276 | 9313 |
| India | 5309 | 5347 | 5356 | 5398 |
| South Africa | 449 | 468 | 482 | 503 |
| Russia | 1142 | 1115 | 1092 | 1056 |
| Brazil | 870 | 875 | 846 | 825 |
| Middle East | 708 | 725 | 667 | 619 |
| Indonesia | 1679 | 1696 | 1695 | 1688 |
| Malaysia | 139 | 129 | 116 | 109 |
| Philippines | 214 | 207 | 196 | 190 |
| Thailand | 341 | 334 | 317 | 306 |
| OASEAN | 1239 | 1212 | 1176 | 1141 |
| EU-8 | 202 | 207 | 218 | 229 |
| US | 795 | 820 | 883 | 1050 |
| CAN | 129 | 131 | 140 | 166 |
| Mexico | 324 | 328 | 362 | 410 |
| Japan | 144 | 130 | 121 | 116 |
| Korea | 157 | 153 | 150 | 144 |
| AUNZ | 160 | 148 | 148 | 156 |
| OE4 | 369 | 382 | 391 | 412 |
| EUG4 | 535 | 515 | 498 | 522 |
| EU015 | 573 | 565 | 570 | 612 |
| ETEnonEU | 507 | 490 | 512 | 582 |
| ATE | 148 | 164 | 178 | 152 |
| RODA | 1723 | 1740 | 1768 | 1784 |
| OLAM | 1128 | 1119 | 1117 | 1126 |
| NAFR | 446 | 453 | 419 | 393 |
| OAFR | 7105 | 7228 | 7242 | 7169 |
| OECD | 3186 | 3171 | 3262 | 3589 |
| Non-OECD | 36242 | 34959 | 33674 | 32583 |
| World | 39428 | 38131 | 36937 | 36171 |

Table 3.10: Emissions of $SO_2$ by SNAP sector for the 450 Scenario, thousand tons/year

**OECD**

| SNAP sector | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|
| 1: Power generation | 5703 | 3629 | 2046 | 1766 |
| 2: Domestic | 779 | 709 | 635 | 581 |
| 3: Industrial combust. | 3102 | 3022 | 2934 | 2876 |
| 4: Industrial processes | 3651 | 3653 | 3717 | 3762 |
| 5: Fuel extraction | 0 | 0 | 0 | 0 |
| 6: Solvents | 0 | 0 | 0 | 0 |
| 7: Road traffic | 40 | 35 | 33 | 32 |
| 8: Off-road sources | 321 | 315 | 301 | 290 |
| 9: Waste management | 13 | 13 | 12 | 12 |
| 10: Agriculture | 24 | 24 | 23 | 25 |
| Sum | 13633 | 11400 | 9702 | 9344 |

**Non-OECD**

| SNAP sector | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|
| 1: Power generation | 34728 | 30429 | 24793 | 20529 |
| 2: Domestic | 4420 | 4253 | 3942 | 3525 |
| 3: Industrial combust. | 17017 | 17887 | 17508 | 17912 |
| 4: Industrial processes | 9038 | 8010 | 8170 | 8296 |
| 5: Fuel extraction | 0 | 0 | 0 | 0 |
| 6: Solvents | 0 | 0 | 0 | 0 |
| 7: Road traffic | 401 | 420 | 514 | 616 |
| 8: Off-road sources | 1048 | 1102 | 1153 | 1213 |
| 9: Waste management | 188 | 186 | 181 | 177 |
| 10: Agriculture | 141 | 148 | 154 | 162 |
| Sum | 66981 | 62435 | 56416 | 52428 |

**World**

| SNAP sector | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|
| 1: Power generation | 40431 | 34058 | 26839 | 22295 |
| 2: Domestic | 5199 | 4962 | 4577 | 4106 |
| 3: Industrial combust. | 20119 | 20910 | 20442 | 20788 |
| 4: Industrial processes | 12689 | 11663 | 11887 | 12058 |
| 5: Fuel extraction | 0 | 0 | 0 | 0 |
| 6: Solvents | 0 | 0 | 0 | 0 |
| 7: Road traffic | 441 | 455 | 547 | 648 |
| 8: Off-road sources | 1369 | 1417 | 1455 | 1502 |
| 9: Waste management | 201 | 199 | 194 | 188 |
| 10: Agriculture | 166 | 172 | 178 | 187 |
| Sum | 80614 | 73835 | 66117 | 61772 |

Table 3.11: Emissions of $NO_x$ by SNAP sector for the 450 Scenario, thousand tons/year

**OECD**

| SNAP sector | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|
| 1: Power generation | 5005 | 3822 | 2972 | 2589 |
| 2: Domestic | 1713 | 1718 | 1738 | 1778 |
| 3: Industrial combust. | 3906 | 3890 | 3919 | 3976 |
| 4: Industrial processes | 987 | 979 | 963 | 945 |
| 5: Fuel extraction | 0 | 0 | 0 | 0 |
| 6: Solvents | 0 | 0 | 0 | 0 |
| 7: Road traffic | 5745 | 3270 | 2170 | 1981 |
| 8: Off-road sources | 3768 | 3230 | 2680 | 2348 |
| 9: Waste management | 22 | 21 | 20 | 19 |
| 10: Agriculture | 58 | 57 | 55 | 58 |
| Sum | 21204 | 16986 | 14516 | 13694 |

**Non-OECD**

| SNAP sector | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|
| 1: Power generation | 14239 | 13776 | 12655 | 11572 |
| 2: Domestic | 3156 | 3117 | 3050 | 2941 |
| 3: Industrial combust. | 12411 | 12866 | 12879 | 13305 |
| 4: Industrial processes | 1345 | 1420 | 1486 | 1548 |
| 5: Fuel extraction | 0 | 0 | 0 | 0 |
| 6: Solvents | 0 | 0 | 0 | 0 |
| 7: Road traffic | 11832 | 11315 | 12220 | 14135 |
| 8: Off-road sources | 8504 | 8496 | 9032 | 10006 |
| 9: Waste management | 188 | 186 | 181 | 177 |
| 10: Agriculture | 232 | 245 | 258 | 275 |
| Sum | 51907 | 51421 | 51761 | 53961 |

**World**

| SNAP sector | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|
| 1: Power generation | 19244 | 17597 | 15627 | 14162 |
| 2: Domestic | 4869 | 4835 | 4787 | 4719 |
| 3: Industrial combust. | 16318 | 16756 | 16797 | 17281 |
| 4: Industrial processes | 2332 | 2399 | 2450 | 2493 |
| 5: Fuel extraction | 0 | 0 | 0 | 0 |
| 6: Solvents | 0 | 0 | 0 | 0 |
| 7: Road traffic | 17577 | 14585 | 14390 | 16117 |
| 8: Off-road sources | 12272 | 11726 | 11712 | 12355 |
| 9: Waste management | 210 | 207 | 201 | 196 |
| 10: Agriculture | 290 | 302 | 313 | 333 |
| Sum | 73111 | 68406 | 66277 | 67655 |

Table 3.12: emissions of PM2.5 by SNAP sector for the 450 Scenario, thousand tons/year

**OECD**

| SNAP sector | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|
| 1: Power generation | 232 | 184 | 108 | 78 |
| 2: Domestic | 1120 | 1238 | 1435 | 1755 |
| 3: Industrial combust. | 318 | 336 | 363 | 396 |
| 4: Industrial processes | 452 | 466 | 478 | 488 |
| 5: Fuel extraction | 17 | 17 | 18 | 18 |
| 6: Solvents | 0 | 0 | 0 | 0 |
| 7: Road traffic | 286 | 219 | 199 | 199 |
| 8: Off-road sources | 280 | 229 | 184 | 163 |
| 9: Waste management | 189 | 191 | 193 | 194 |
| 10: Agriculture | 291 | 290 | 285 | 297 |
| Sum | 3186 | 3171 | 3262 | 3589 |

**Non-OECD**

| SNAP sector | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|
| 1: Power generation | 2536 | 2517 | 2264 | 1984 |
| 2: Domestic | 18283 | 17393 | 16362 | 15229 |
| 3: Industrial combust. | 6834 | 6475 | 6322 | 6347 |
| 4: Industrial processes | 3361 | 3302 | 3238 | 3207 |
| 5: Fuel extraction | 73 | 77 | 86 | 95 |
| 6: Solvents | 0 | 0 | 0 | 0 |
| 7: Road traffic | 620 | 577 | 639 | 749 |
| 8: Off-road sources | 739 | 683 | 701 | 777 |
| 9: Waste management | 1024 | 1066 | 1099 | 1137 |
| 10: Agriculture | 2772 | 2868 | 2963 | 3057 |
| Sum | 36242 | 34959 | 33674 | 32582 |

**World**

| SNAP sector | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|
| 1: Power generation | 2769 | 2701 | 2371 | 2062 |
| 2: Domestic | 19403 | 18631 | 17797 | 16984 |
| 3: Industrial combust. | 7153 | 6811 | 6685 | 6743 |
| 4: Industrial processes | 3813 | 3769 | 3716 | 3695 |
| 5: Fuel extraction | 89 | 94 | 104 | 114 |
| 6: Solvents | 0 | 0 | 0 | 0 |
| 7: Road traffic | 906 | 797 | 838 | 949 |
| 8: Off-road sources | 1019 | 912 | 885 | 940 |
| 9: Waste management | 1214 | 1258 | 1292 | 1331 |
| 10: Agriculture | 3062 | 3158 | 3249 | 3354 |
| Sum | 39428 | 38131 | 36937 | 36171 |

Figure 3.1: Emissions of $SO_2$ in the Reference Scenario (RS) and the 450 Scenario (450) by country group, million tons

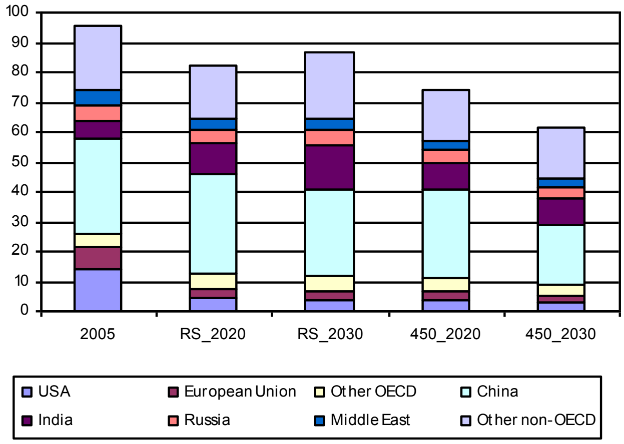



Figure 3.2: Emissions of $NO_x$ in the Reference Scenario (RS) and the 450 Scenario (450) by country group, million tons

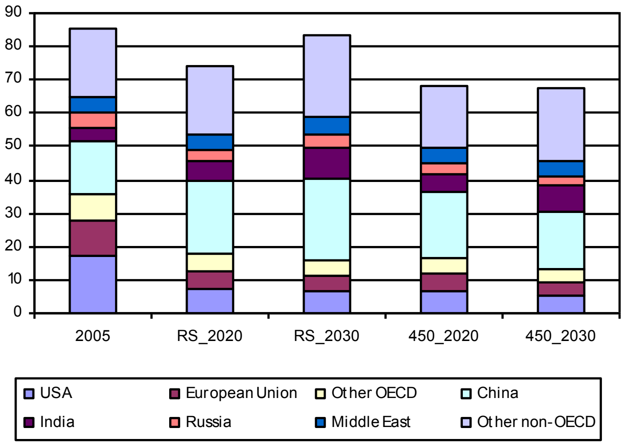
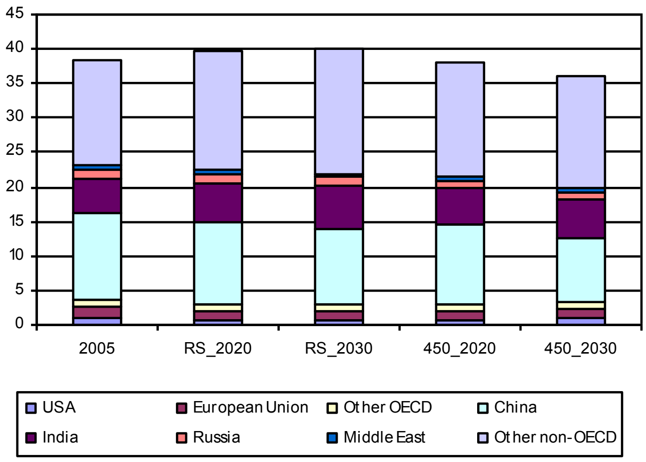



Figure 3.3: Emissions of PM2.5 in the Reference Scenario (RS) and the 450 Scenario (450) by country group, million tons



# 4 Air pollution control costs

GAINS has calculated air pollution control costs for the two emission scenarios presented in the previous sections. Calculations include international costs of pollution control equipment and have been done using the four percent (social) real interest rate. All costs and prices are expressed in constant € 2005 and include "current policy" pollution control legislation.

Under such assumptions control costs were about 155 billion €/a in 2005. Until 2030 these costs increase in the Reference Scenario by a factor of three, which is due to higher activity levels (e.g., higher energy consumption, higher car ownership) and increasing stringency of controls. In 2030, more than 60 percent of total are the costs of reducing emissions from road transport sources.

The 450 Scenario brings 17 percent cost savings in 2030 compared with the Reference. Details by country group are presented in Table 4.1 and Table 4.2. Costs by sector (SNAP aggregation) are shown in Table 4.3 and Table 4.4.

Figure 4.1 presents once more the costs for the most important countries/world regions and compares the values for the 450 Scenario with the Reference case.

Figure 4.1: Air pollution control costs in the Reference Scenario (RS) and in the 450 Scenario (450) by country group, billion €/year

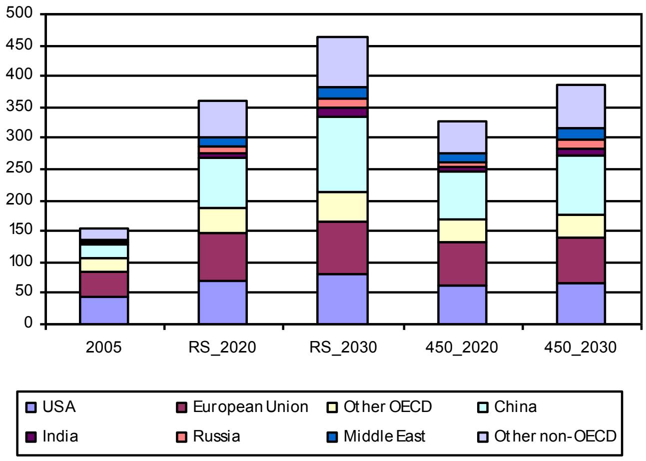


Table 4.1: Air pollution control costs by country group in the Reference Scenario, billion €/year

| WEM region | 2005 | 2007 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|
| China | 19.2 | 25.6 | 35.2 | 58.6 | 82.5 | 103.4 | 120.4 |
| India | 1.7 | 2.1 | 2.8 | 5.9 | 8.2 | 11.4 | 15.7 |
| South Africa | 0.9 | 1.2 | 1.6 | 2.5 | 3.9 | 5.0 | 6.3 |
| Russia | 3.8 | 4.4 | 5.1 | 7.2 | 9.7 | 12.1 | 13.6 |
| Brazil | 2.5 | 3.2 | 4.4 | 7.1 | 9.2 | 11.6 | 13.2 |
| Middle East | 3.4 | 4.8 | 7.1 | 11.6 | 15.7 | 19.1 | 21.5 |
| Indonesia | 1.2 | 1.5 | 2.1 | 3.2 | 4.0 | 4.9 | 5.8 |
| Malaysia | 0.7 | 0.9 | 1.1 | 1.5 | 1.9 | 2.3 | 2.5 |
| Philippines | 0.3 | 0.4 | 0.6 | 0.9 | 1.2 | 1.5 | 1.8 |
| Thailand | 1.5 | 1.7 | 2.0 | 2.5 | 3.2 | 3.7 | 4.3 |
| OASEAN | 0.4 | 0.5 | 0.7 | 1.2 | 1.9 | 2.5 | 3.4 |
| EU-8 | 1.7 | 2.3 | 3.1 | 4.0 | 4.5 | 5.1 | 5.5 |
| US | 42.3 | 46.0 | 51.5 | 62.8 | 70.3 | 76.8 | 82.2 |
| CAN | 3.3 | 3.8 | 4.4 | 5.6 | 6.5 | 7.1 | 7.6 |
| Mexico | 3.0 | 3.6 | 4.5 | 5.5 | 6.3 | 6.8 | 7.2 |
| Japan | 12.7 | 13.3 | 14.2 | 15.3 | 15.5 | 15.6 | 15.4 |
| Korea | 3.5 | 4.0 | 4.7 | 6.0 | 6.8 | 7.1 | 7.4 |
| AUNZ | 3.5 | 3.8 | 4.2 | 5.0 | 5.7 | 6.0 | 6.1 |
| OE4 | 2.3 | 3.0 | 4.1 | 6.0 | 8.6 | 10.7 | 12.7 |
| EUG4 | 23.2 | 25.3 | 28.6 | 33.5 | 38.3 | 40.7 | 42.1 |
| EU015 | 15.8 | 18.7 | 23.0 | 27.9 | 33.3 | 36.2 | 37.3 |
| ETEnonEU | 1.4 | 1.5 | 1.8 | 2.3 | 2.8 | 3.2 | 3.7 |
| ATE | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.3 | 0.2 |
| RODA | 2.0 | 2.2 | 2.4 | 2.6 | 2.7 | 2.9 | 3.3 |
| OLAM | 2.5 | 3.3 | 4.6 | 7.0 | 9.6 | 11.2 | 12.7 |
| NAFR | 1.0 | 1.4 | 2.0 | 2.8 | 3.4 | 4.2 | 4.9 |
| OAFR | 0.7 | 0.9 | 1.1 | 1.9 | 2.9 | 3.7 | 4.7 |
| OECD | 109.7 | 121.5 | 139.3 | 167.5 | 191.2 | 207.0 | 218.0 |
| Non-OECD | 45.1 | 58.2 | 77.9 | 123.2 | 167.5 | 208.0 | 243.6 |
| World | 154.8 | 179.7 | 217.1 | 290.7 | 358.7 | 415.0 | 461.6 |

Table 4.2: Air pollution control costs by country group in the 450 Scenario, billion €/year

| WEM region | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|
| China | 56.5 | 76.0 | 88.4 | 96.1 |
| India | 5.7 | 7.6 | 10.2 | 13.7 |
| South Africa | 2.5 | 3.9 | 5.0 | 6.3 |
| Russia | 7.0 | 8.9 | 10.5 | 11.4 |
| Brazil | 6.8 | 8.6 | 10.3 | 11.5 |
| Middle East | 10.9 | 14.8 | 17.9 | 20.0 |
| Indonesia | 3.0 | 3.7 | 4.2 | 4.5 |
| Malaysia | 1.4 | 1.8 | 2.0 | 2.2 |
| Philippines | 0.9 | 1.1 | 1.4 | 1.6 |
| Thailand | 2.4 | 2.9 | 3.4 | 3.8 |
| OASEAN | 1.2 | 1.8 | 2.3 | 3.0 |
| EU-8 | 3.7 | 4.2 | 4.7 | 5.1 |
| US | 60.9 | 63.5 | 59.8 | 65.4 |
| CAN | 5.3 | 5.8 | 6.2 | 6.8 |
| Mexico | 5.3 | 5.8 | 6.1 | 6.1 |
| Japan | 14.3 | 14.0 | 13.2 | 11.9 |
| Korea | 5.8 | 6.4 | 6.3 | 5.9 |
| AUNZ | 4.7 | 4.8 | 4.6 | 4.5 |
| OE4 | 5.8 | 7.8 | 9.2 | 10.8 |
| EUG4 | 32.0 | 34.9 | 35.3 | 36.7 |
| EU015 | 26.5 | 30.4 | 31.2 | 31.9 |
| ETEnonEU | 2.3 | 2.7 | 3.0 | 3.5 |
| ATE | 0.2 | 0.2 | 0.2 | 0.2 |
| RODA | 2.5 | 2.4 | 2.3 | 2.3 |
| OLAM | 6.9 | 9.0 | 10.3 | 11.5 |
| NAFR | 2.7 | 3.1 | 3.8 | 4.3 |
| OAFR | 1.8 | 2.6 | 3.3 | 4.1 |
| OECD | 160.7 | 173.4 | 172.0 | 180.0 |
| Non-OECD | 118.4 | 155.3 | 183.3 | 205.2 |
| World | 279.1 | 328.7 | 355.4 | 385.2 |

Table 4.3: Air pollution control costs by SNAP sector for the Reference Scenario, billion €/year

**OECD**

| SNAP sector | 2005 | 2007 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|
| 1: Power generation | 33.9 | 35.6 | 38.1 | 40.1 | 39.6 | 39.2 | 38.7 |
| 2: Domestic | 6.5 | 7.1 | 8.0 | 9.3 | 11.1 | 12.7 | 14.4 |
| 3: Industrial combust. | 4.9 | 5.4 | 6.1 | 6.5 | 6.7 | 6.8 | 7.0 |
| 4: Industrial processes | 7.5 | 7.9 | 8.6 | 9.0 | 9.5 | 9.8 | 10.1 |
| 5: Fuel extraction | 1.2 | 1.2 | 1.2 | 1.3 | 1.3 | 1.3 | 1.4 |
| 6: Solvents | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 7: Road traffic | 53.9 | 61.8 | 73.5 | 93.7 | 111.4 | 121.3 | 127.3 |
| 8: Off-road sources | 1.6 | 2.4 | 3.7 | 7.5 | 11.5 | 15.7 | 19.0 |
| 9: Waste management | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 10: Agriculture | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Sum | 109.7 | 121.5 | 139.3 | 167.5 | 191.2 | 207.0 | 218.0 |

**Non-OECD**

| SNAP sector | 2005 | 2007 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|
| 1: Power generation | 9.9 | 12.9 | 17.4 | 24.2 | 29.1 | 34.8 | 40.2 |
| 2: Domestic | 1.8 | 1.9 | 2.2 | 2.7 | 3.1 | 3.5 | 4.2 |
| 3: Industrial combust. | 10.1 | 11.4 | 13.4 | 15.6 | 16.8 | 18.1 | 19.4 |
| 4: Industrial processes | 6.1 | 6.9 | 7.9 | 8.2 | 8.3 | 8.4 | 8.5 |
| 5: Fuel extraction | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| 6: Solvents | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 7: Road traffic | 16.0 | 23.2 | 34.0 | 65.2 | 95.5 | 124.7 | 153.0 |
| 8: Off-road sources | 0.9 | 1.6 | 2.6 | 7.0 | 14.5 | 18.2 | 18.0 |
| 9: Waste management | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 10: Agriculture | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Sum | 45.1 | 58.2 | 77.9 | 123.2 | 167.5 | 208.0 | 243.6 |

**World**

| SNAP sector | 2005 | 2007 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|
| 1: Power generation | 43.8 | 48.5 | 55.5 | 64.2 | 68.6 | 74.0 | 78.9 |
| 2: Domestic | 8.3 | 9.1 | 10.2 | 12.0 | 14.2 | 16.2 | 18.6 |
| 3: Industrial combust. | 15.0 | 16.8 | 19.6 | 22.2 | 23.5 | 24.9 | 26.4 |
| 4: Industrial processes | 13.6 | 14.8 | 16.5 | 17.2 | 17.8 | 18.2 | 18.6 |
| 5: Fuel extraction | 1.3 | 1.4 | 1.4 | 1.5 | 1.5 | 1.6 | 1.6 |
| 6: Solvents | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 7: Road traffic | 69.9 | 85.0 | 107.5 | 158.9 | 206.8 | 246.0 | 280.3 |
| 8: Off-road sources | 2.5 | 4.0 | 6.3 | 14.5 | 26.0 | 33.9 | 37.0 |
| 9: Waste management | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 10: Agriculture | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| Sum | 154.8 | 179.7 | 217.1 | 290.7 | 358.7 | 415.0 | 461.6 |

Table 4.4: Air pollution control costs by SNAP sector for the 450 Scenario, billion €/year

**OECD**

| SNAP sector | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|
| 1: Power generation | 37.3 | 31.0 | 17.4 | 15.1 |
| 2: Domestic | 9.6 | 12.9 | 16.6 | 22.0 |
| 3: Industrial combust. | 6.4 | 6.5 | 6.6 | 6.7 |
| 4: Industrial processes | 9.0 | 9.5 | 9.8 | 10.1 |
| 5: Fuel extraction | 1.3 | 1.3 | 1.3 | 1.4 |
| 6: Solvents | 0.0 | 0.0 | 0.0 | 0.0 |
| 7: Road traffic | 89.7 | 101.4 | 106.4 | 109.2 |
| 8: Off-road sources | 7.3 | 10.8 | 13.8 | 15.4 |
| 9: Waste management | 0.0 | 0.0 | 0.0 | 0.0 |
| 10: Agriculture | 0.1 | 0.1 | 0.1 | 0.1 |
| Sum | 160.7 | 173.4 | 172.0 | 180.0 |

**Non-OECD**

| SNAP sector | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|
| 1: Power generation | 22.7 | 24.7 | 24.5 | 23.1 |
| 2: Domestic | 2.7 | 3.0 | 3.6 | 4.4 |
| 3: Industrial combust. | 15.4 | 16.3 | 16.0 | 16.3 |
| 4: Industrial processes | 8.2 | 8.3 | 8.4 | 8.5 |
| 5: Fuel extraction | 0.2 | 0.2 | 0.2 | 0.2 |
| 6: Solvents | 0.0 | 0.0 | 0.0 | 0.0 |
| 7: Road traffic | 62.2 | 88.8 | 113.8 | 137.1 |
| 8: Off-road sources | 6.9 | 14.0 | 16.7 | 15.5 |
| 9: Waste management | 0.0 | 0.0 | 0.0 | 0.0 |
| 10: Agriculture | 0.0 | 0.0 | 0.0 | 0.0 |
| Sum | 118.4 | 155.3 | 183.3 | 205.2 |

**World**

| SNAP sector | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|
| 1: Power generation | 60.0 | 55.7 | 42.0 | 38.2 |
| 2: Domestic | 12.3 | 15.9 | 20.2 | 26.5 |
| 3: Industrial combust. | 21.8 | 22.8 | 22.6 | 23.0 |
| 4: Industrial processes | 17.2 | 17.8 | 18.2 | 18.6 |
| 5: Fuel extraction | 1.5 | 1.5 | 1.6 | 1.6 |
| 6: Solvents | 0.0 | 0.0 | 0.0 | 0.0 |
| 7: Road traffic | 151.9 | 190.1 | 220.1 | 246.3 |
| 8: Off-road sources | 14.2 | 24.7 | 30.5 | 30.9 |
| 9: Waste management | 0.0 | 0.0 | 0.0 | 0.0 |
| 10: Agriculture | 0.2 | 0.2 | 0.2 | 0.2 |
| Sum | 279.1 | 328.7 | 355.4 | 385.2 |

# 5 Health impacts

Comprehensive assessment of all health and environmental impacts of energy scenarios analyzed in this report was not possible for all countries due to lack of data. Thus the analysis was limited to the estimates of life years lost (YOLLs) attributable to the exposure from anthropogenic emissions of PM2.5 in Europe, China and India. Together, countries included cover more than 45 percent of world population. It needs to be stressed that the estimates include only effects of concentration of PM2.5 in ambient air and do not consider negative effects of human exposure to indoor air pollution.

In 2005 about 3.4 billion of life years were lost in those countries due to PM exposure - Table 5.1. This estimate is dominated by impacts in China and India, which together contribute more than 90 percent of YOLLs in 2005. The Reference Scenario implies an increase of the YOLLs indicator until 2030 by about 70 percent to 5.7 billion. The 450 Scenario saves 1.2 billion life-years in 2030, of which 560 million in China and 600 million in India.

Table 5.1: Life years lost (YOLLs) due to exposure to anthropogenic emissions of PM2.5, million life years

| WEM | | | | Reference scenario | | | | 450 scenario | | |
|---|---|---|---|---|---|---|---|---|---|---|
| region | 2005 | 2007 | 2010 | 2015 | 2020 | 2025 | 2030 | 2020 | 2025 | 2030 |
| China | 2233 | 2368 | 2570 | 2801 | 2903 | 2907 | 2897 | 2707 | 2505 | 2340 |
| India | 865 | 933 | 1033 | 1304 | 1637 | 2057 | 2647 | 1522 | 1745 | 2044 |
| Russia (1) | 47 | 46 | 45 | 46 | 45 | 45 | 47 | 43 | 42 | 41 |
| EU-8 | 18 | 15 | 12 | 11 | 10 | 10 | 11 | 10 | 10 | 10 |
| OE4 (2) | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 |
| EUG4 | 110 | 98 | 80 | 73 | 66 | 62 | 62 | 63 | 58 | 58 |
| EU015 | 78 | 69 | 55 | 50 | 46 | 44 | 44 | 45 | 42 | 43 |
| ETEnonEU | 34 | 31 | 26 | 26 | 25 | 25 | 27 | 23 | 23 | 24 |

(1) Only European part

(2) Does not include Turkey

# 6 Summary and conclusions

This report presents emissions of air pollutants for energy scenarios analyzed in the World Energy Outlook 2009. Estimations have been done with the IIASA GAINS model. The study covers emissions from 27 regions of the world, consistent with the aggregation of countries in the IEA's World Energy Model. The national assessment does not include emissions form international shipping as well as cruising emissions from aviation. Also emissions from biomass burning (deforestation, savannah burning, and vegetation fires) are not included in national totals.

The assessment takes into account current policies in each country with regard to controlling emissions of air pollutants. In the Reference Scenario the world emissions of $SO_2$ decrease until 2030 by nine percent compared with 2005 levels. $NO_x$ emissions decrease by two percent. Emissions of fine particles (PM2.5) increase by four percent compared with 2005. The 450 Scenario, with stringent policies to reduce energy-related $CO_2$ emissions, causes important reductions of emissions of air pollutants compared with the Reference. In 2030 this reduction is 29 % for $SO_2$, 19 percent for $NO_x$, and nine percent for PM2.5. Expenditures on air pollution control are reduced in 2030 by 76 billion €/a compared with the Reference case. Also impact of air pollution on human health is much lower for the scenario with stringent climate policies. Life years lost in Europe, China and India attributable to the exposure from anthropogenic emissions of PM2.5 decrease by 20 percent, which means saving of about 1.2 billion life years in 2030.

These numbers clearly demonstrate the importance of co-benefits of climate policies for air pollution. These co-benefits should be taken into account in the process of developing strategies and targets for reducing emissions of climate-relevant gases.

# References

Amann, M. (2004). The RAINS model: Documentation of the model approach prepared for the RAINS peer review 2004. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria, http://www.iiasa.ac.at/rains/review/review-full.pdf

Amann, M., I. Bertok, J. Cofala, C. Heyes, Z. Klimont, P. Rafaj, W. Schöpp and F. Wagner (2008). National Emission Ceilings for 2020 taking account of the Commission's proposal on the 2008 Climate and Energy Package International Institute for Applied Systems Analysis (IIASA) Laxenburg, Austria,

Cofala, J., M. Amann, Z. Klimont, K. Kupiainen and L. Höglund-Isaksson (2007). Scenarios of Global Anthropogenic Emissions of Air Pollutants and Methane until 2030. Atmospheric Environment **Vol 41/38**: 8486-8499.

DieselNet (2009). Emission Standards. Summary of worldwide diesel emission standards.

IEACCC (2009). Coal Power Database. IEA Clean Coal Centre, London,

Klimont, Z., J. Cofala, J. Xing, W. Wei, C. Zhang, S. Wang, J. Kejun, P. Bhandari, R. Mathur, P. Purohit, P. Rafaj, A. Chambers, M. Amann, J. Hao (2009). Projections of SO2, NOx and carbonaceous aerosols emissions in Asia. Tellus B **Published Online: May 20 2009 1:42AM**: (p 602-617).

OECD/IEA (2009). World energy Outlook 2009. International Energy Agency, Paris, France

# Appendix 1

## Breakdown of world regions

| WEM region | GAINS EQUIVALENT |
|---|---|
| China | China |
| India | India |
| South Afric | South Africa |
| Russia | Russia |
| Brazil | Brazil |
| Middle East | Middle East |
| Indonesia | Indonesia |
| Malaysia | Malaysia |
| Philippines | Philippines |
| Thailand | Thailand |
| OASEAN | Brunei+Cambodia+Myanmar+Singapore+Vietnam |
| EU-8 | Bulgaria+Cyprus+Estonia+Latvia+Lithuania+Malta+Romania+Slovenia |
| US | United States of America |
| CAN | Canada |
| Mexico | Mexico |
| Japan | Japan |
| Korea | Korea (South) |
| AUNZ | Australia+New Zealand |
| OE4 | Norway+Switzerland+Turkey (Iceland unavailable) |
| EUG4 | France+Germany+Italy+United Kingdom |
| EU015 | Austria+Belgium+Czech Republic + Denmark+Finland+ Greece +Hungary +Ireland+Luxembourg+ Netherlands+Poland+ Portugal+Slovak Republic +Spain+Sweden |
| ETEnonEU | Albania+Belarus+Bosnia and Herzogovina+Croatia+Macedonia+ Republic of Moldova+Serbia and Montenegro+Ukraine (Gibraltar unavailable) |
| ATE | Armenia+Georgia+Kazakhstan+Kyrgyzstan+Other USSR Asia |
| RODA | Bangladesh+Korea(North)+Mongolia+Nepal+Pakistan+Sri Lanka+Taiwan (Other Asia unavailable) |
| OLAM | Argentina+Chile+Other Latin America |
| NAFR | Egypt+North Africa |
| OAFR | Other Africa |