Annex 2 Emissions of ozone-precursors

A2.1 Emissions of ozone-precursors

383. Under Chapter 6 of this report, the performance of ozone models has been discussed. The accuracy of historic and future emissions is just as important to making reliable decisions as the accuracy of the models themselves. Historical emissions can be tested through model evaluation, though the complexity of ozone production and destruction in the atmosphere means that it is not a completely rigorous process. However the reliability of future emission estimates scenarios is much more difficult to establish. AQEG recommend that the use of a future emissions estimate should be a transparent process in which a decision maker can clearly see what are the assumptions behind an estimate. The decision maker can then decide which scenario is more appropriate, or to decide to use more than one emission scenario to obtain a range of results. This Annex has been provided to help this process.

384. Later in the Annex, examples where emission estimates are subject to great uncertainty will be pointed out. These include differences between the IPCC and IIASA emission projections, the VOC speciation, biogenic VOC emissions and natural emissions.

385. Ozone-precursor emissions at different spatial scales have been reported and interpreted throughout the report to support the answers to each question.

386. Emission projections for the precursor pollutants CO, CH_4, NMVOCs and NO_x have been considered on the global or northern hemispheric scale in order to interpret trends in global background ozone levels in the UK in Chapter 3, the impacts of climate change Chapter 4 and the impacts on future global background ozone in Chapter 8. The analysis has drawn on the “Current Legislation” (CLE) and the “Maximum Technically Feasible Reduction” (MFR) global emission scenarios reported by IIASA and the SRES scenarios reported by the Intergovernmental Panel on Climate Change (IPCC).

387. Historic and future emission trends in NO_x and NMVOC emissions have been considered on a European scale in order to interpret temporal and spatial patterns in background and peak ozone levels in the UK in Chapter 2 on the interpretation of trends in urban and rural network ozone concentration data; in Chapter 4 on climate change impacts on ozone; in Chapter 7 on integrated assessment modelling of the ozone response to European emission reductions; and in Chapter 8 on the effects of UK and European emission control measures.

388. Historic and future emission trends in NO_x and NMVOC emissions have been considered on a UK scale to interpret temporal and spatial trends in background and peak ozone levels in Chapter 2. Trends in urban UK NO_x emissions from traffic have been used to interpret the urban ozone decrement through the NO_x titration effect in Chapter 5. This question also required consideration of trends in UK NMVOC emissions as potential drivers in local photochemical events. Projected UK NO_x and NMVOC emissions have provided the platform for discussions and quantitative analysis on effective control options to reduce UK population exposure to ozone discussed in Chapter 8.

389. This section gives a brief overview of the sources of emissions data on a global, European and UK scale used in the report.

390. When comparing and evaluating emission projections provided from different sources it is important to understand the differences in scenarios and assumptions used. Each organisation reporting emission projections have considered more than one set of core assumptions and generated emissions for a range of future scenarios. Versions of

emission projections are periodically updated and changed by the same organisation that first developed them as the basic input parameters are better refined, so it is important to note which version of emission projections are used in any analysis. This report has stated several times that models have shown how future emissions are the most sensitive parameters affecting future trends in ozone concentrations.

A2.2 Global emission projections

391. On a global scale, the report has made particular reference to the CO, CH_4 and NO_x projections reported by IIASA. Using a global version of the RAINS model, IIASA has generated two anthropogenic emission scenarios known as the "Current Legislation" (CLE) scenario and the "Maximum Technically Feasible Reduction" scenario (MFR). Details of each of these scenarios were given in Chapter 1 and they have been widely applied in published modelling studies. Very recently, during 2007, IIASA have updated their precursor emissions estimates for 2000 and for the CLE and MFR scenarios going forward and preliminary modelling studies using these new IIASA emission estimates are referred to specifically in Chapter 4. (Note that none of the IIASA scenarios include estimates of emissions from aviation or shipping).

392. The IPCC Special Report on Emission Scenarios (IPCC, 2000) also provides global emission projections of ozone-precursor gases for a wide range of scenarios covering the main emission driving forces from demographic to technical and economic development. These are broadly grouped into four families following different "storylines", each assuming a distinctly different direction for future developments. One of these, the SRES A2 scenario, has been referred to in this report as a more pessimistic, high growth scenario. The SRES A2 scenario describes a very heterogeneous world based on self-reliance, regional differences in economic and technological development and continuous increase in global population.

A2.2.1 Global methane emissions

393. Figures A2.1 and A2.2 show the IIASA global anthropogenic emission projections of CH_4 by source sector for the CLE and MFR scenarios, respectively (Cofala *et al.*, 2006).

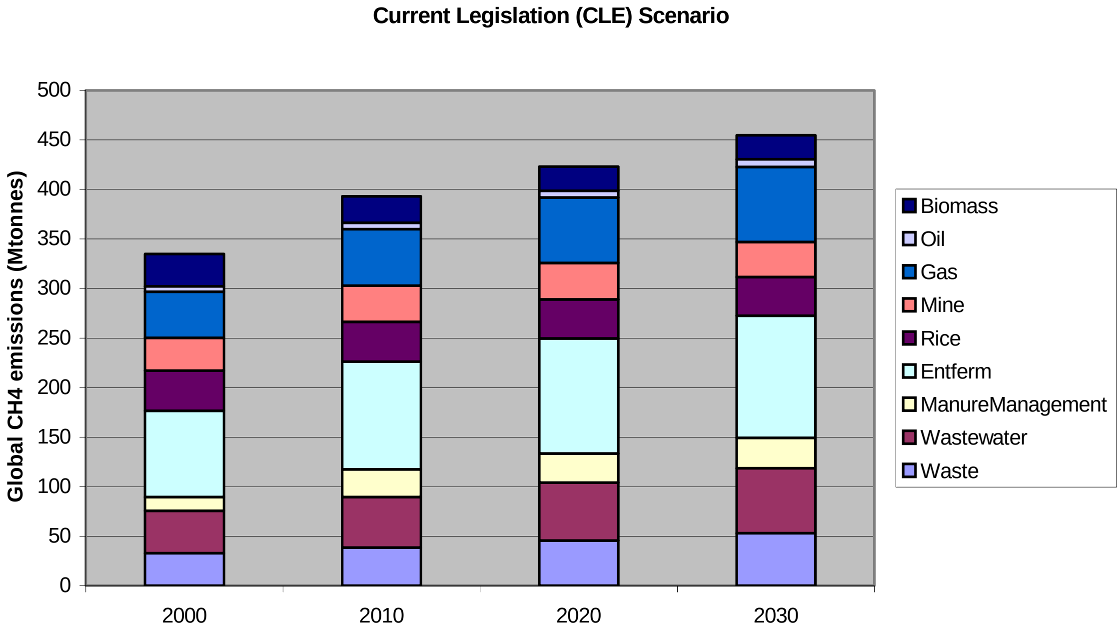

Figure A2.1 Global anthropogenic CH_4 emissions by source sector for IIASA CLE scenario

394. The CLE scenario predicts a growth in global methane emissions of around 36% between 2000 and 2030 due mainly to increases in emissions from enteric fermentation, losses from natural gas distribution and waste treatment. In the MFR scenario, methane emissions fall in the short term, but then increase to levels in 2030 about 6% lower than 2000 levels. The differences in the MFR and CLE scenario emissions in 2030 are mainly due to lower emissions from enteric fermentation and waste water treatment in the MFR scenario.

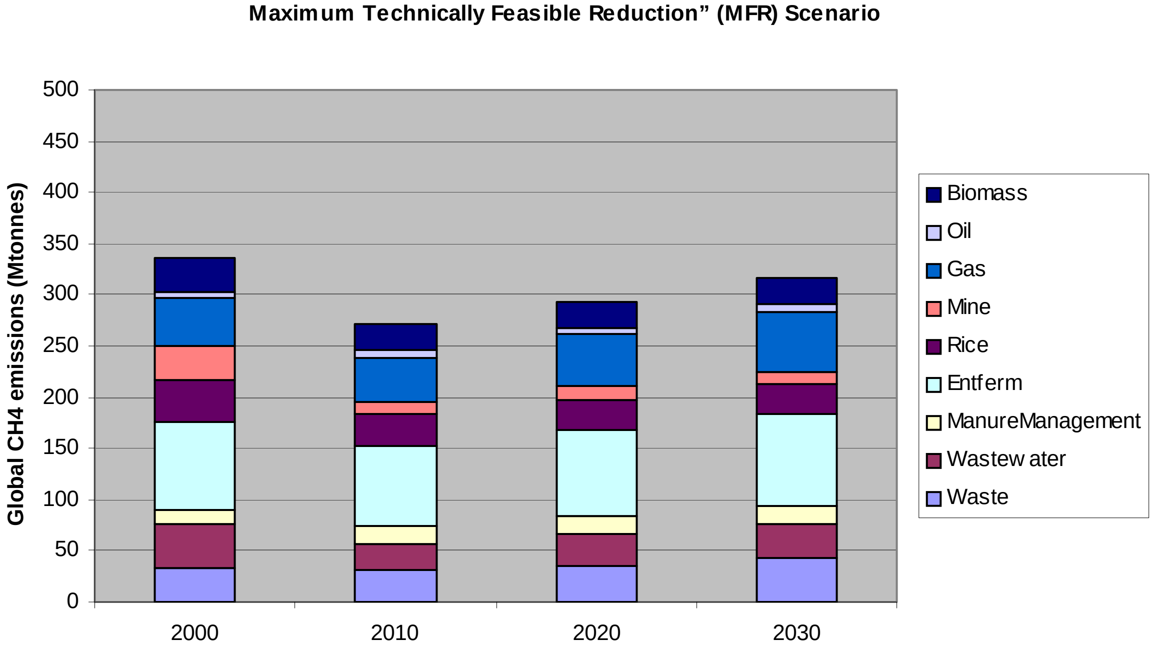

Figure A2.2 Global anthropogenic CH_4 emissions by source sector for IIASA MFR scenario

395. Figure A2.3 shows global anthropogenic emissions of CH_4 projected to 2030 by world region from the IIASA-RAINS model and compares with the SRES A2 scenario. From a similar 2000 base, the more pessimistic SRES A2 scenario predicts a faster growth (51%) in global methane emissions to 2030 than the CLE scenario.

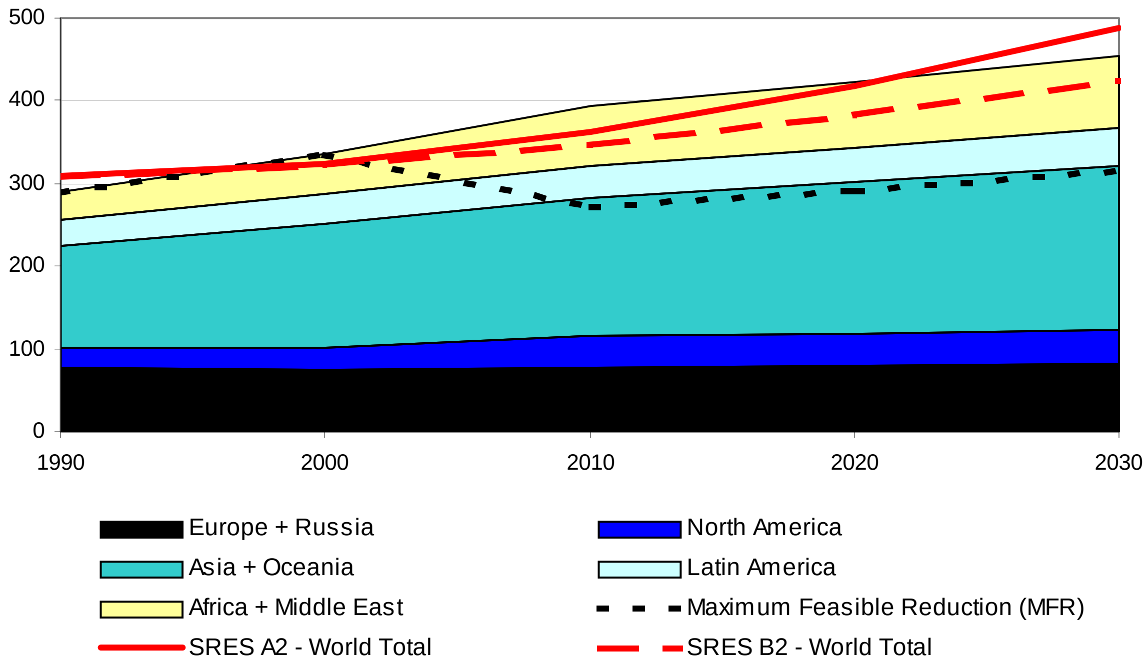

Figure A2.3 Global anthropogenic emissions of CH_4 showing a comparison of IIASA-RAINS CLE projections with IPCC SRES projections

A2.2.2 Global carbon monoxide emissions

396. Figures A2.4 and A2.5 show the IIASA global anthropogenic emission projections of CO by source sector for the CLE and MFR scenarios, respectively (Cofala *et al.*, 2006).

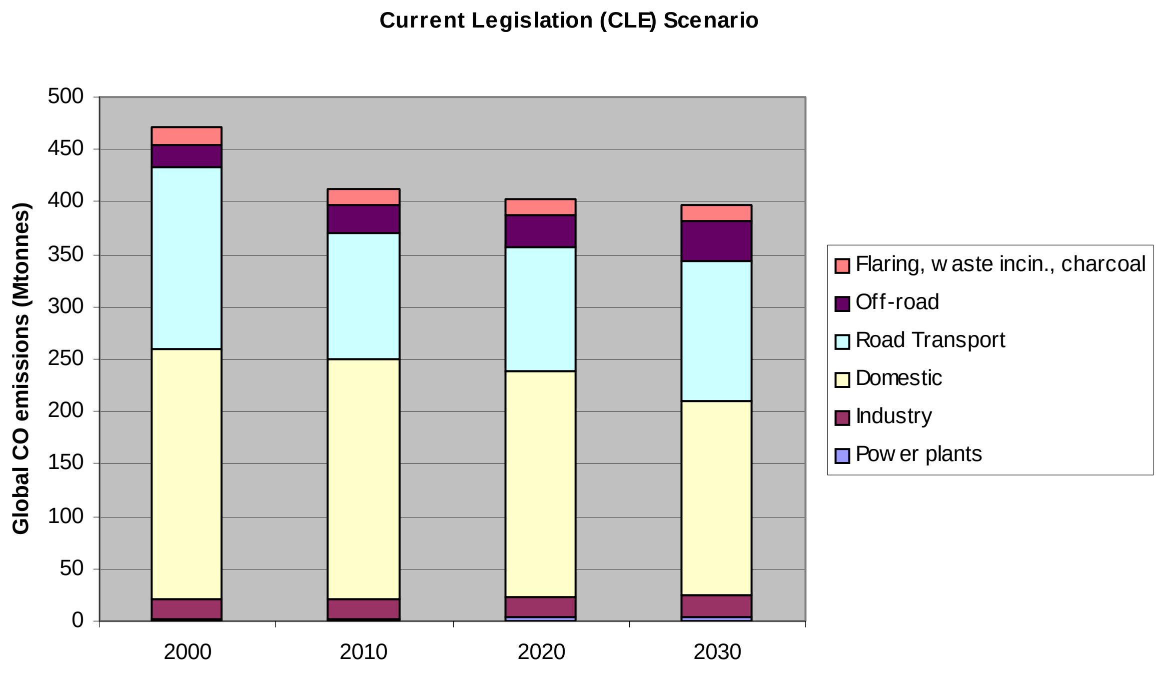

Figure A2.4 Global anthropogenic CO emissions by source sector for IIASA CLE scenario

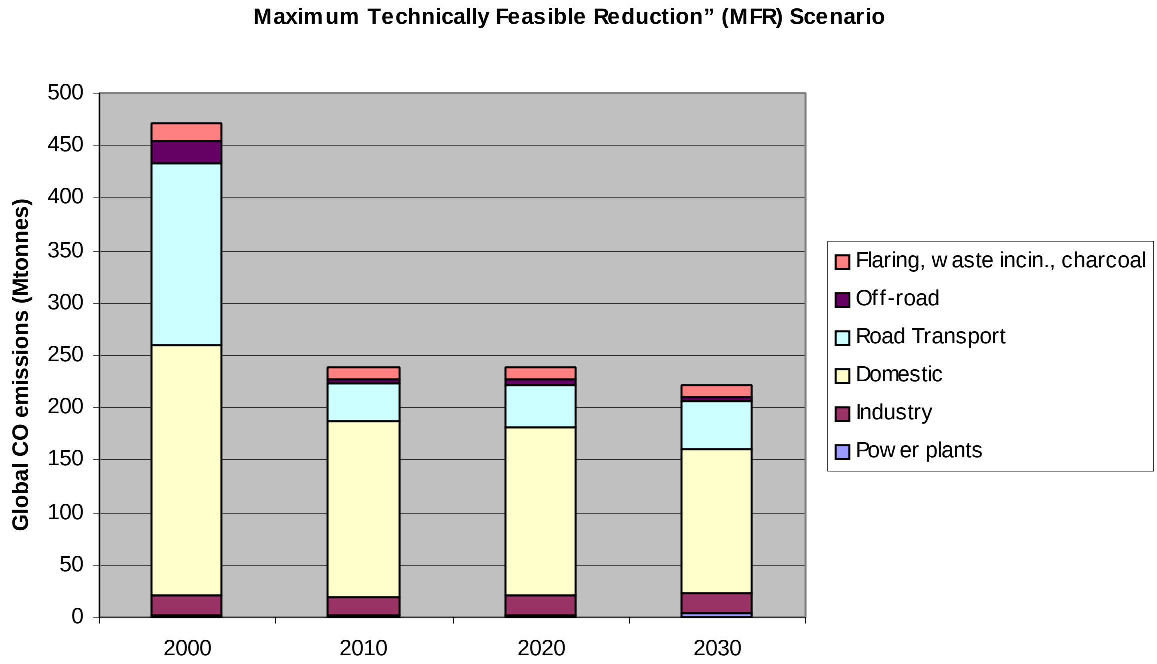

Figure A2.5 Global anthropogenic CO emissions by source sector for IIASA MFR scenario

397. The CLE scenario predicts a fall in global CO emissions of around 14% between 2000 and 2030 due mainly to a decrease in domestic combustion and road transport emissions, although transport emissions are on the rise again after initially falling substantially in the first decade to 2010. The MFR scenario predicts a more significant 53% reduction in global CO emissions due to bigger falls in the road transport and domestic combustion sector. In both scenarios, the decline in emissions occurs by 2010, with little further overall decline after this in either scenario.

398. Figure A2.6 shows global emissions of CO projected to 2030 by world region from the IIASA-RAINS model and compares with the SRES A2 scenario. From a rather lower 2000 base than the IIASA global emissions inventory, the more pessimistic SRES A2 scenario predicts a doubling in global CO emissions to 2030.

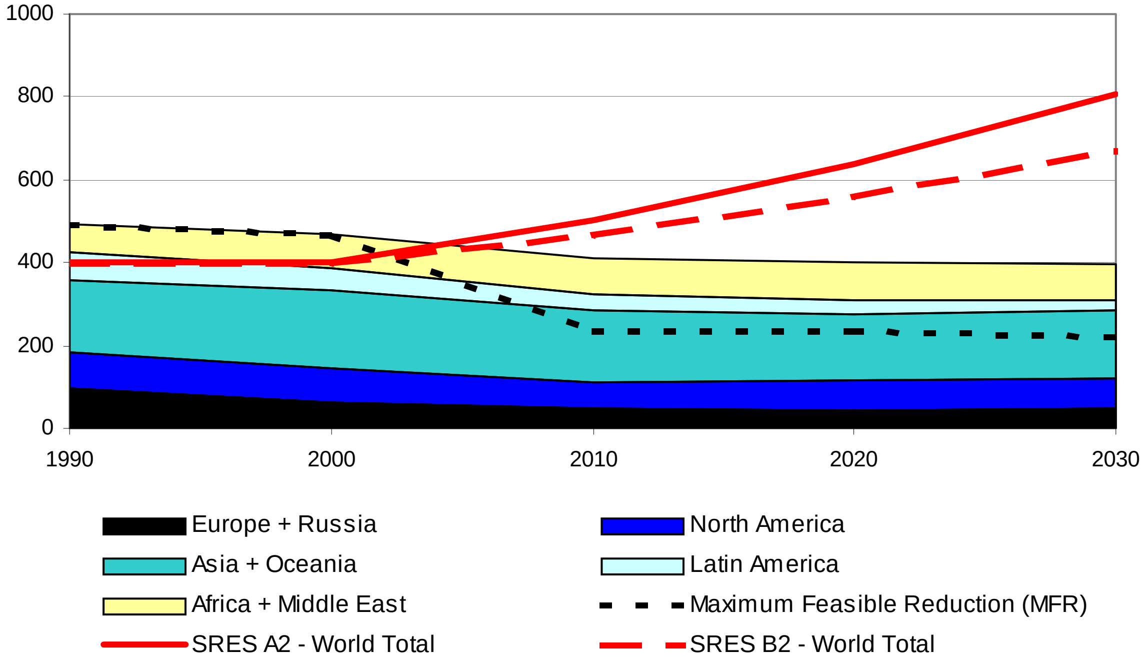

Figure A2.6 Global anthropogenic emissions of CO showing a comparison of IIASA-RAINS CLE projections with IPCC SRES projections

A2.2.3 Global nitrogen oxide emissions

399. Figures A2.7 and A2.8 show the IIASA global anthropogenic emission projections of NO_x by source sector for the CLE and MFR scenarios, respectively (Cofala *et al.*, 2006).

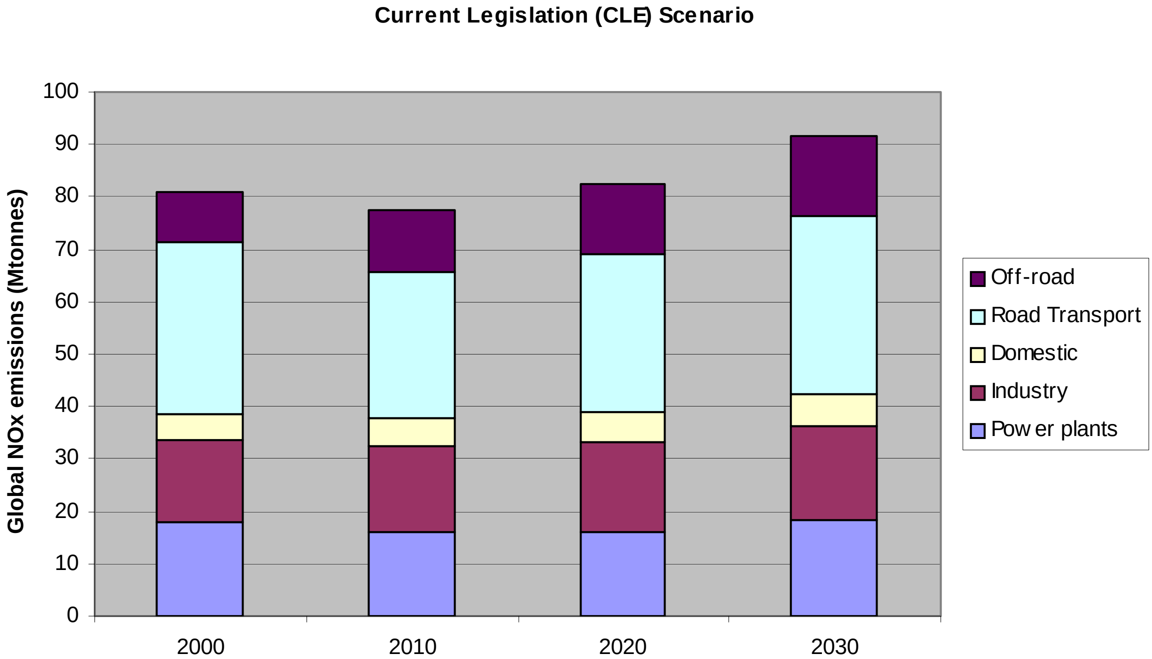

Figure A2.7 Global anthropogenic NO_x emissions by source sector for IIASA CLE scenario

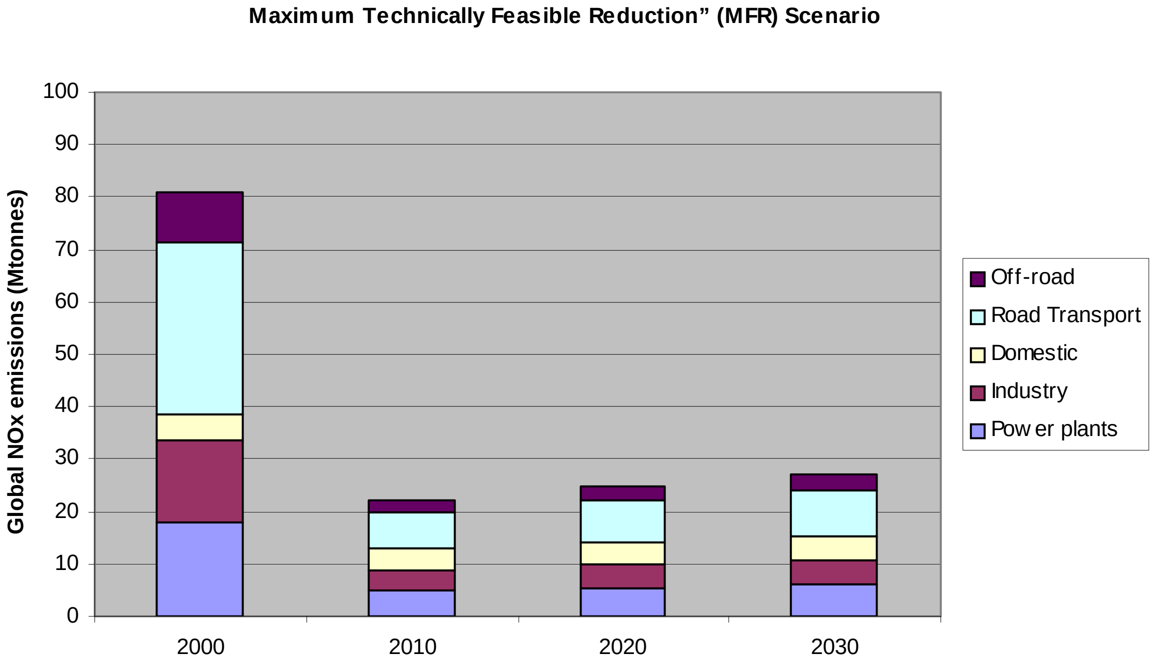

Figure A2.8 Global anthropogenic NO_x emissions by source sector for IIASA MFR scenario

400. The CLE scenario predicts a growth in global NO_x emissions of around 13% between 2000 and 2030. The dominant sector is road transport, but it is growth in emissions from off-road transport and machinery that is mainly responsible for the overall increase in global emissions over this time horizon, although after initially falling during the first decade, road transport emissions are increasing, surpassing 2000 levels by 2030. In the MFR scenario, NO_x emissions fall significantly, to levels in 2030 that are 66% lower than 2000 levels. The MFR scenario involves significant falls in emissions from all sectors, but the largest fall is from the road transport sector.

401. Figure A2.9 shows global emissions of NO_x projected to 2030 by world region from the IIASA-RAINS model and compares with the SRES A2 scenario. From a similar 2000 base, the more pessimistic SRES A2 scenario predicts an almost doubling (94% increase) in global NO_x emissions to 2030.

A2.2.4 Global non-methane volatile organic compound emissions

402. There are no assessments of global NMVOC emission projections from IIASA-RAINS. However, Dentener *et al.* (2005) suggested anthropogenic emissions of NMVOCs would closely follow the development of CO emissions given the importance of road transport to both pollutants. Dentener et al. suggested global emissions of NMVOCs of around 250 Mtonnes in 2000 (including biomass burning) that would increase by 17% to 2030 in a CLE scenario and would decrease by 10% to 2030 in a MFR scenario. The more pessimistic SRES A2 scenario predicts a 43% increase in global NMVOC emissions over this period (IPCC, 2001).

A2.2.5 Global emissions from international shipping and aviation

403. In modeling the impact of global emission controls on tropospheric ozone, Dentener *et al.* (2005) considered the changes in emissions from international sea traffic and aviation. International shipping makes an important contribution to global NO_x emissions and

Dentener *et al.* assumed a 1.5% yr^{-1} growth in activity. Global aviation emissions of NO_x were predicted to rise from 2.6 Mtonnes in 2000 to 5.7 Mtonnes in 2030. This would be around 20% of global NO_x emissions from other anthropogenic sources of NO_x in the MFR scenario for 2030.

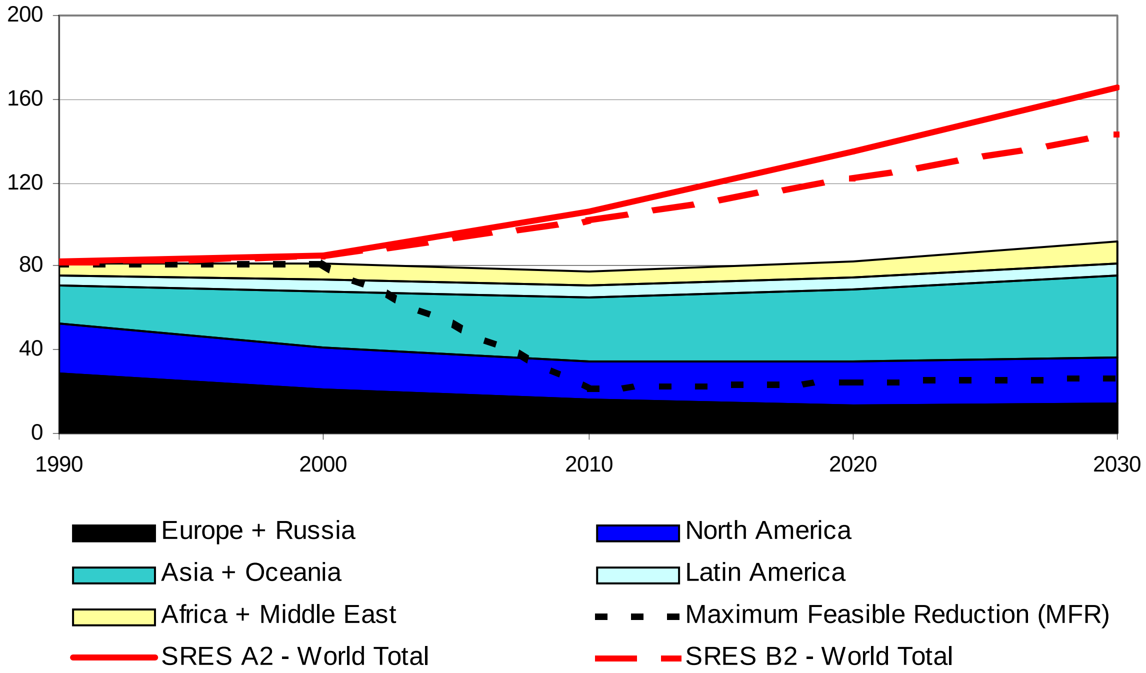

Figure A2.9 Global anthropogenic emissions of NO_x showing a comparison of IIASA-RAINS CLE projections with IPCC SRES projections

A2.3 European emission projections

404. Emission projections for the ozone-precursors NO_x and NMVOCs, as well as NH_3, SO_2, PM and CO_2, have been generated on the European scale by IIASA up to 2020. The projections were calculated from the GAINS-Europe model (Greenhouse Gas-Air Pollution Interactions and Synergies), an extension of the RAINS model, and are available on-line at http://www.iiasa.ac.at/web-apps/apd/RainsWeb/ .

405. Several different versions of emission projections have been produced for individual European countries and regions following the CLE scenario. This report will focus on the NEC02 Version which contains recent scenarios used for the analysis of the revision of the National Emissions Ceilings Directive (NECD). In particular, these scenarios include all information that has been collected during the bilateral consultations between IIASA and the teams of national experts during 2005/2006. It contains the Baseline scenarios for the revision of the NEC Directive as well as emission control scenarios that meet the objectives of the Thematic Strategy on Air Pollution. Data are shown here from the national baseline CLE scenario, referred to as NEC_NAT_CLE4REV which uses national baseline activity paths (as of December 2006) with emission controls reflecting current legislation on national and international emission, fuel quality, and product standards.

406. Regional-scale ozone forecasting models generally apply the IIASA European emission projections by sector and country to the EMEP 50km x 50km emission grids for the current years.

A2.3.1 European NO_x and NMVOC emissions by source sector

407. Figures A2.10 and A2.11 show the latest projections of anthropogenic NO_x and NMVOC emissions from the EU27 countries by source sector at SNAP1 level.

408. NO_x emissions are predicted to decline by 43% in 2020 relative to 2000 levels. This reduction is mostly due to reductions in emissions from road transport as petrol and diesel vehicles meeting the tighter European emission standards penetrate the European fleet. Road transport contributed 45% of EU27 NO_x emissions in 2000 and emissions from this sector are projected to fall by 67% by 2020. Small reductions are expected in emissions from power generation and from other transport and off-road machinery.

409. NMVOC emissions are also predicted to decline by 43% in 2020 relative to 2000 levels. This reduction is also mostly due to reductions in emissions from road transport as petrol and diesel vehicles meeting the tighter European emission standards penetrate the European fleet. However, there are also predicted to be significant reductions from solvent use, with implementation of the Solvent Emissions Directive, and from domestic and non-industrial combustion. Solvent use made the largest contribution to EU27 NMVOC emissions in 2000 and emissions from this sector are projected to fall by 30% by 2020. Road transport contributed 28% of EU27 NMVOC emissions in 2000 and emissions from this sector are projected to fall by 81% by 2020.

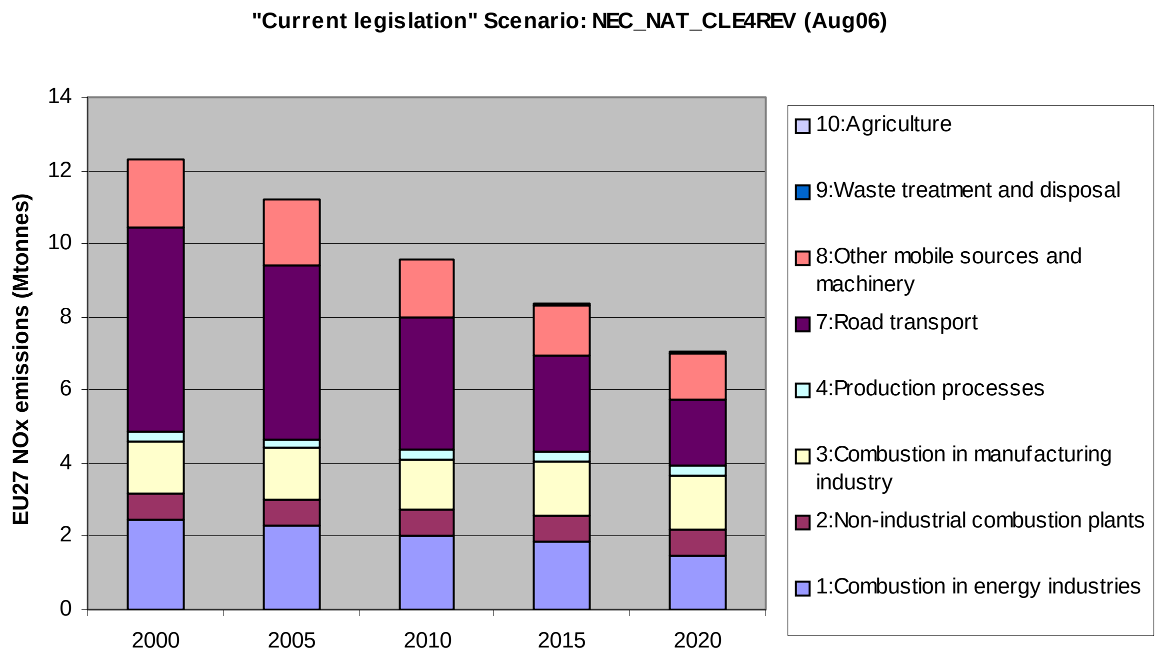

Figure A2.10 Anthropogenic NO_x emissions for EU27 countries by source sector for CLE scenario

A2.3.2 Emissions from shipping in European waters

410. The EU27 emission projections presented above do not include emissions from shipping in European sea regions, but these have been estimated for sea traffic within the EMEP area, provided for EMEP models by the Centre for Integrated Assessment Modelling (CIAM, see Expert Emissions at http://webdab.emep.int/). The EMEP international shipping emissions are divided into five regions: Baltic Sea, Black Sea, Mediterranean Sea, North Sea (including the English Channel) and the remaining North-East Atlantic Ocean within the EMEP region. For NO_x, the EMEP projections suggest the sum of

international shipping emissions for these five sea regions will increase from 3.35 Mtonnes in 2000 to 3.99 Mtonnes in 2020, an increase of 19%. By 2020, the shipping emissions will be 57% of land-based anthropogenic emissions for the EU27 countries. For NMVOCs, the EMEP projections suggest the sum of international shipping emissions for these five sea regions will decrease from 0.114 Mtonnes in 2000 to 0.070 Mtonnes in 2020, a decrease of 38%, but shipping makes a very small contribution to NMVOC emissions relative to land-based anthropogenic emissions. By 2020, the shipping emissions will be 1% of land-based anthropogenic emissions for the EU27 countries.

411. A more detailed investigation into European shipping emissions has been carried out by Entec for the European Commission (Entec, 2005). This study provided estimates of European shipping emissions projected out to 2020 broken down in various forms of country assignment. The different assignments distinguished where international shipping emissions actually occur to which country is responsible on the basis of, for example, the ship's flag, sale of fuel, country of departure and destination, among various other methods of assignment. For modelling ozone, it is the location of the emissions that is obviously the most relevant.

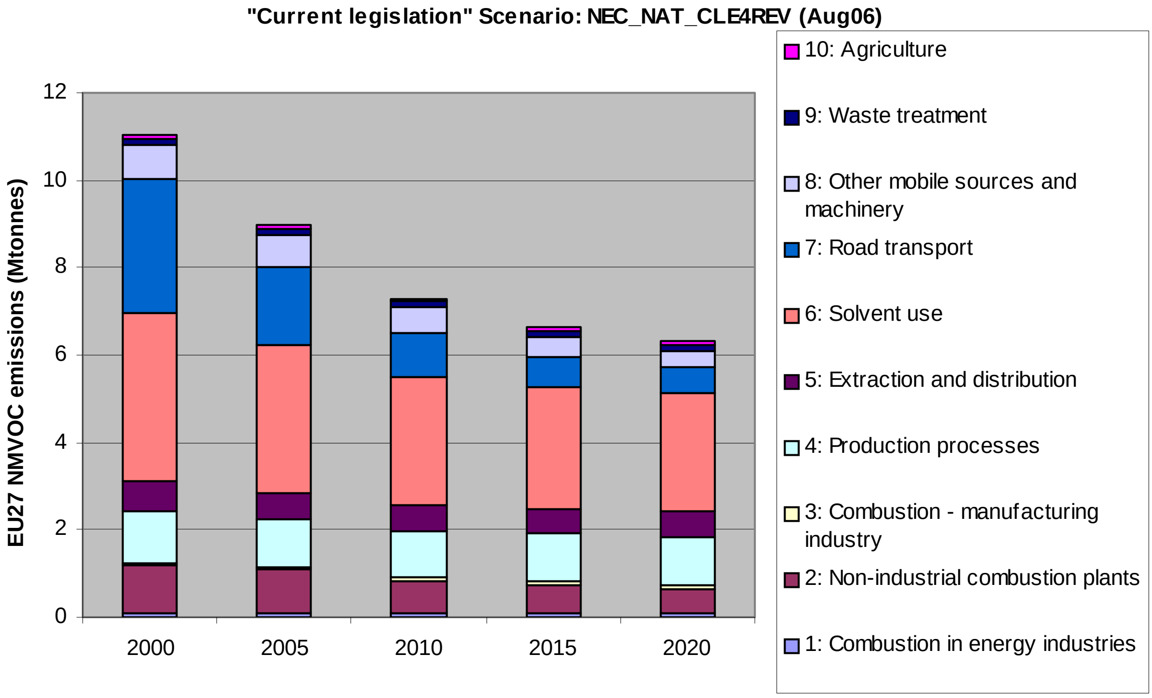

Figure A2.11 NMVOC emissions for EU27 countries by source sector for CLE scenario

412. Method A in the Entec study referred to assignment according to location of emissions within a 12 mile zone area that equates to territorial waters and within what is referred to in a UN Convention on the Law of the Sea (UNCLOS) as a 200 mile zone area known as an Exclusive Economic Zone. The amount of emissions occurring in the 12-mile or 200-mile zones cannot be directly compared with the EMEP international shipping emissions that cover whole sea regions. However, the Entec study indicated NO_x emissions from shipping within the 200-mile zones for the EU27 countries plus Turkey and Croatia would increase from 2.81 Mtonnes in 2000 to 4.06 Mtonnes in 2020, an increase of 45%. This is greater than the relative increase in international shipping emissions for the five sea regions predicted by EMEP. Emissions of NMVOCs from shipping in the same area were predicted to increase from 0.099 Mtonnes in 2000 to 0.165 Mtonnes in 2020, an increase of 67%, in contrast to a decline in international shipping emissions of NMVOCs for the five sea regions predicted by EMEP. The Entec study indicates that these zonal shipping emissions of NMVOCs are very small compared with land-based anthropogenic

emissions for these countries (2.5% of EU27 emissions in 2020), but the zonal shipping emissions of NO_x are very significant compared with land-based anthropogenic emissions for these countries, reaching 58% of EU27 emissions in 2020. This is similar to the situation predicted by EMEP for the 5 sea regions. Moreover, for the 12 mile zones Entec concluded that the UK has the highest emissions assigned from ships.

A2.4 UK emission projections

413. The National Atmospheric Emissions Inventory (NAEI, www.naei.org.uk/) provides UK emission projections for the ozone-precursors NO_x and NMVOCs and all the other NECD pollutants, SO_2 and NH_3, and PM_{10}. The projections are primarily based on BERR (formerly DTI) energy forecasts (by fuel and sector), DfT traffic forecasts and various other economic drivers. The BERR energy forecasts limit the emission projections to extending out to 2020, though the road transport projections go further to 2025.

414. The NAEI emission projections are updated each time the BERR updates its energy projections or the DfT updates its traffic forecasts. The projections used in most of the modelling referred to in the report are based on BERR's UEP26 "Favourable to Coal" energy scenario and are from a 2004 base. For NMVOCs, the projections are based on the slightly older BERR UEP21 scenario, as these had not been run for the UEP26 scenario. However, the main differences between UEP 21 and 26 projections are in the forecasts of coal and gas use for power station and domestic consumption which make a relatively small contribution to NMVOC emissions, so the UEP26 projections for NMVOC emissions will not be significantly different to the UEP21 projections.

A2.4.1 UK NO_x and NMVOC emissions by source sector

415. Figures A2.12 and A2.13 show UK projections of anthropogenic NO_x and NMVOCs.

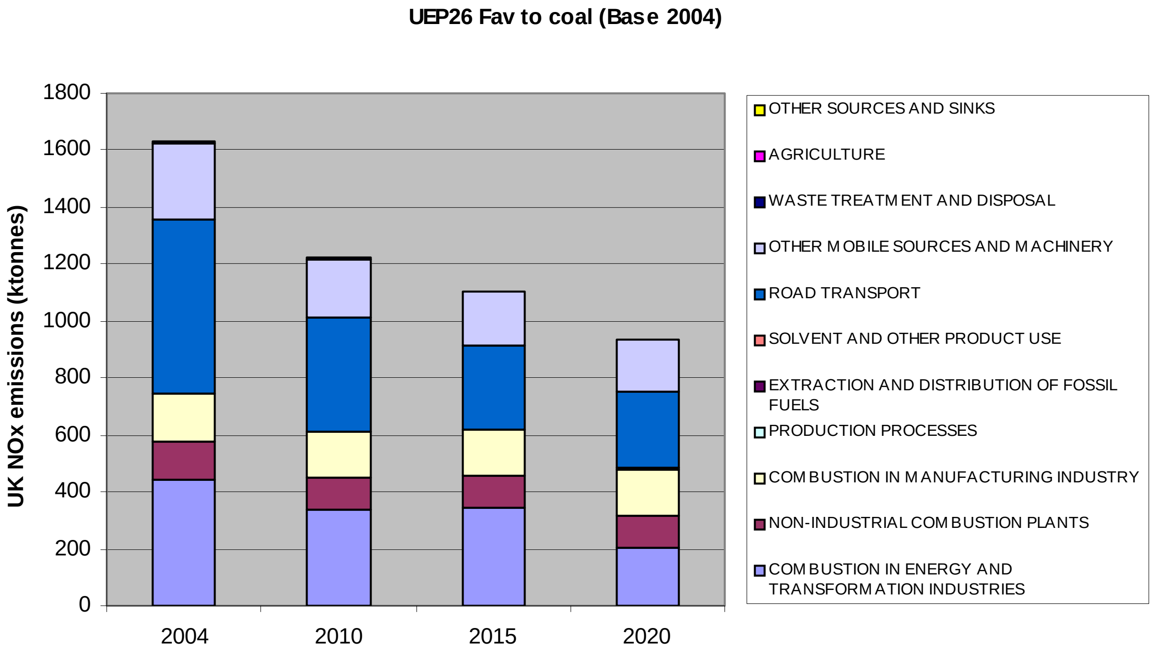

Figure A2.12 UK anthropogenic NO_x emissions (UEP26) from the NAEI (2004 base)

416. UK anthropogenic NO_x emissions are predicted to fall by 42% from a 2004 base by 2020. This is mainly due to the reduction in emissions from road transport which are predicted to

fall by 56% over this time period due to the penetration of new vehicles meeting the tighter European emission standards in the UK fleet. The road transport emission projections presented here and used in all the air quality modelling work described in this report exclude the recently agreed Euro 5 and 6 emission standards for light duty vehicles that will further reduce emissions of NO_x and NMVOCs from the road transport sector after 2010. After road transport, emissions from power generation are the next largest source of NO_x emissions and these too are expected to have decreased significantly (by 54%) by 2020. In urban areas, road transport emissions will further dominate NO_x emissions and a decrease in urban road transport emissions of 58% is expected between 2004 and 2020 (Murrells and Hobson, 2006), contributing to the reduction in the NO_x titration effect on ozone in urban areas.

417. A smaller reduction in UK NMVOC emissions is predicted: 15% from a 2004 base by 2020. Solvent use is the largest source of NMVOC emissions in the UK, but this is only forecast to decline by 9% over this time period. Reductions in road transport emissions are the major contributor to the overall reductions in NMVOC emissions. Emissions from this sector are expected to decrease by 63% over this time period.

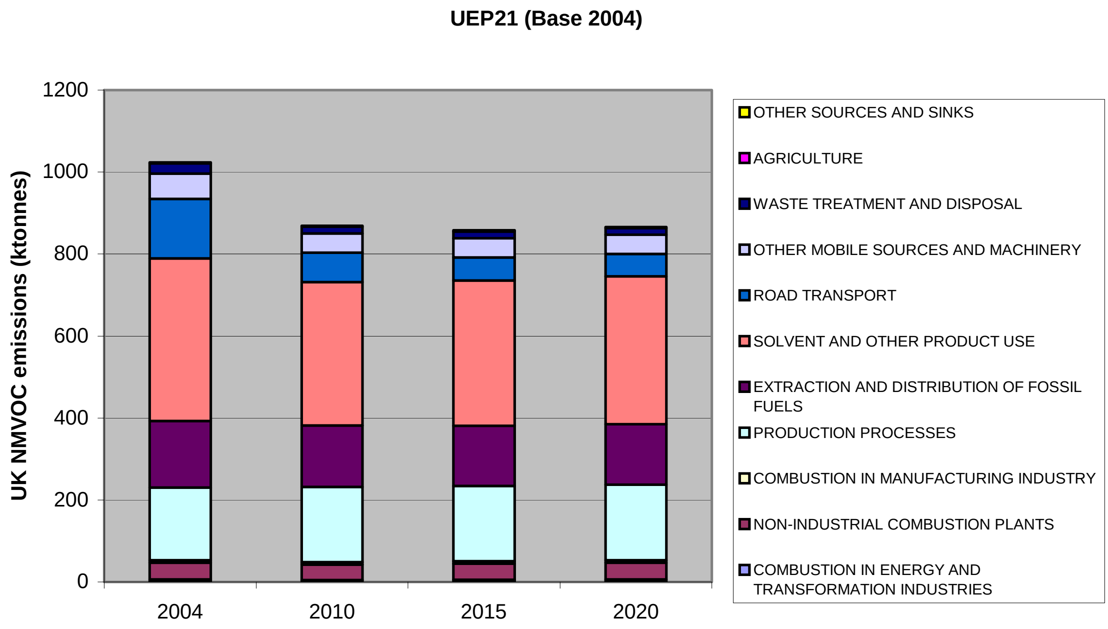

Figure A2.13 UK anthropogenic NMVOC emissions (UEP21) from the NAEI (2004 base)

A2.4.2 Speciated anthropogenic VOC emissions

418. The NAEI produces a speciated VOC inventory that is widely used in UK ozone models, including the Photochemical Trajectory Model and the Ozone Source Receptor Model. A profile is constructed for around 250 different sources in the inventory involving altogether 664 individual or groups of VOCs. Each year when a new VOC emissions inventory is compiled for the UK on the basis of total VOC emission factors and activity data, the speciation profile is applied to provide a new speciated VOC inventory for that year. An assumption is made that with the exception of benzene and 1,3-butadiene, which are modelled explicitly, the speciation profile for a given source sector remains unchanged each year.

419. The speciation profile was last reviewed in 2002 by Passant (2002). The report provides the mass fraction of individual VOCs emitted by each individual source, together with their Photochemical Ozone Creation Potential values.

420. The speciation profile for each sector comes from a number of sources. One of these is the US EPA, mainly for the combustion sources. More UK-specific sources are used for solvents and the chemicals industry. These are based on discussions with industry representatives, site measurements and product data. Profiles for road transport sources are taken from the European road transport emission factor model, COPERT III (EEA, 2000).

421. A considerable amount of uncertainty must be assigned to some of the sources. The profiles known with most accuracy are likely to be for the solvents sector as this industry has knowledge of the chemical constituents of the solvents. Some other sources associated with process industries are also known with reasonable accuracy because the industries are aware of the chemicals involved in the processes. For other sources, the profiles can be quite varied. For example, the profile for petrol vapour will vary to a certain degree with refinery source and also with time of year (e.g. winter blends of petrol are more volatile than summer blends and contain more lighter butanes). The chemical composition of petroleum fuels can vary with year in order to comply with European fuel quality directives.

422. The UK's speciation profile for VOCs is currently the one most widely used across Europe.

A2.5 Emissions from natural sources and biomass burning

A2.5.1 Biogenic NMVOC emissions

423. Biogenic NMVOCs describe a wide range of compounds, of which only a few are generally of interest and represented in chemical-transport models. Isoprene is the compound of most importance for ozone modelling for example. Emissions of the various terpenes (e.g. α- and β-pinene) are also important, for both ozone and aerosol formation. The remaining NMVOC species (these are termed in inventories as 'other VOC', or OVOC, and are non-methane VOC species other than isoprene and monoterpenes emitted by vegetation, including oxygenated VOCs, but also non-oxygenated species) play some role, but little is known about the chemistry of many components or the quantitative emissions of individual species. Emissions may be large, however.

424. The emission flux of biogenic NMVOCs for all types of vegetation is most often described on an hourly basis by the algorithm (Guenther *et al.*, 1996):

$$\text{Flux} \ (\mu g \ m^{-2} \ yr^{-1}) = \int \varepsilon \ D \ \gamma \ dt$$

where ε is the average emission potential ($\mu g \ g^{-1} \ h^{-1}$) for the particular species, D is the foliar biomass density (g dry weight foliage m^{-2}), and γ is a dimensionless environmental correction factor representing the effects of short-term (e.g. hourly) temperature and solar radiation changes on emissions. Guenther et al. (1991, 1993) had previously shown that, to a very good approximation, the short-term (hourly) variations in emissions of isoprene could be described by the product of a light dependent factor, C_L and a temperature dependent factor, C_T. This is the basis of the Biogenic Emission Inventory System (BEIS) (see http://www.epa.gov/asmdnerl/biogen.html) and the calculation of biogenic NMVOC emissions in most current models for ozone (including 'one-atmosphere' models such as the EMEP Unified and the US CMAQ models). As such, annual emission estimates are not a routine input or output, making it difficult (if not impossible) to compare the emission estimates used in different models.

A2.5.1.1 Global biogenic emissions

425. The Global Emission Inventory Activity (GEIA) provides global emission inventories on a one degree grid for the entire world for a number of atmospheric species, including NMVOC emissions from biogenic sources. The NMVOC emissions from biogenic sources are available as monthly datasets for 1990 (http://www.geiacenter.org/). This inventory dataset is effectively that of Guenther *et al.* (1995). The EDGAR database - Emission Database for Global Atmospheric Research - only considers NMVOC emissions from biomass burning (http://www.mnp.nl/edgar/).

426. For the 3rd IPCC Assessment, emissions of isoprene, monoterpenes, and other VOC were calculated using the GLOBEIS model of Guenther *et al.* (1999) (see http://www.globeis.com/). The foliar densities, emission capacities, and algorithms used to determine emissions activities for both 2000 and 2100 were the same as those described by Guenther *et al.* (1995). One difference between this work and that of Guenther *et al.* (1995) was the use of hourly temperatures for each hour of a month to determine the monthly average emission rate whereas Guenther *et al.* (1995) used monthly average temperatures to drive emission algorithms. This resulted in about a 20% increase in isoprene emissions in 2000 and 10% increase in emissions of other biogenic VOC. Global annual emissions of isoprene for 2000 were ~600 Mtonnes (compared to 506 Mtonnes in Guenther *et al.* (1995)) and emissions of monoterpenes for 2000 were 146 Mtonnes (compared to the estimate of 127 Mtonnes in Guenther *et al.* (1995)). These increase by 23% for 2100 relative to the 2000 scenario.

427. Dentener *et al.* (2005) considered global contributions from natural sources in their study on the impact of emission controls on tropospheric ozone. They estimated 507 Mtonnes NMVOC emissions from vegetation (predominantly isoprene) in 2000, approximately double the global anthropogenic emissions in 2000 (including biomass).

A2.5.1.2 European biogenic emissions

428. Simpson *et al.* (1995) used the BEIS emission algorithms, together with meteorological data from the EMEP MSC-W ozone model, to generate estimates of the emissions of isoprene from European forests and agricultural crops over several summer periods. European isoprene emissions were estimated to be about 4,000 ktonne C per annum, approximately 50%–100% greater than previous estimates. Estimates were also made of the emissions of OVOCs from forests. These estimates were broken down by country by Simpson et al. (1999) and were the basis of Table 2.1 in Chapter 11 of the CORINAIR Emission Inventory Guidebook (CORINAIR, 2002).

429. As part of the EU PELCOM project, Winiwarter *et al.* (2001) used the land cover dataset derived in the project to improve existing information on emissions of terpenes and isoprene from forests. As there was insufficient discrimination between deciduous/mixed/coniferous forest types in the land cover dataset, the total PELCOM forest coverage was used and combined with a detailed forest species distribution taken from an assessment by TNO (Nijenhuis, 1999). A forest atlas was produced to derive species percentages on a 1° x 2° grid over Europe. Table A2-1 gives the biogenic NMVOC emissions derived by Winiwarter *et al.* (2001) by country for nine tree species classes, using the same country environmental correction factors as Simpson *et al.* (1999). The emission totals are in good agreement with the earlier estimates of Simpson *et al.* (1999). The table also includes reported national estimates of NMVOCs from man-made sources in 1990 and the National Emission Ceilings for 2010 agreed in the Gothenburg Protocol. To put into context, the biogenic NMVOC emissions for the EU27 countries from Winiwarter *et al.* (2001) in Table A2-1 are 65% of the anthropogenic emissions from this region in 2005 shown in Section 2.6.

430. The recently completed EU NATAIR project (Improving and Applying Methods for the Calculation of Natural and Biogenic Emissions and Assessment of Impacts on Air Quality, http://natair.ier.uni-stuttgart.de/) has been developing a new high-resolution (10 km) inventory for all relevant pollutant emissions from natural and biogenic sources in Europe. The emission database will cover a number of current and future years (including 2000 and 2010) with hourly temporal resolution. No results are yet available.

A2.5.1.3 UK biogenic emissions

431. The current estimate of UK biogenic NMVOC emissions by the National Atmospheric Emission Inventory (NAEI) programme for the 2003 and 2004 emission inventory years is 91 ktonne per annum[6] and this emission estimate is used for all years in the emission time series. This estimate is based on the work of Stewart *et al.* (2003), who combined land-use information with the plant and tree species likely to be found in each class, based on the NERC Countryside Survey. Stewart *et al.* also developed a database of the NMVOC emission potentials of around 1000 plant species, obtained from the literature, although in practise only around 50 species were of importance for the UK. The meteorological parameters required (temperature and photosynthetically-active radiation flux) were modelled for the year 1998 using output from the MM5 mesoscale meteorological model on a 12 km x 12 km grid with hourly resolution. The estimates had a high uncertainty (up to a factor of four). Dore *et al.* (2003) undertook a detailed comparison of the inventory of Stewart *et al*. (2003) with the inventory derived in the PELCOM project for the UK (Winiwarter *et al.*, 2001). The NAEI estimates are compared with these other estimates in Table A2-2.

432. Hayman (2006) used the Ozone Source-receptor Model (OSRM) to estimate the UK NMVOC emissions from biogenic sources (trees and forests) for the years 1997 to 2003 using the emission potential inventory described by Dore *et al.* (2003). The calculated annual emissions of isoprene, terpenes and other volatile organic compounds (OVOCs) are also presented in Table A2-2.

433. The isoprene and total emissions derived from the OSRM appear to be in good agreement with the current NAEI estimates. The lower terpene emissions are offset by the OVOC emissions, which were not estimated by Stewart *et al.* (2003). The previous NAEI estimate of 178 ktonne per annum was taken from the work of Simpson et al. (1999) and the emissions of isoprene, terpenes and OVOCs were estimated to be 58, 31 and 89 ktonne per annum, respectively. The OSRM isoprene and OVOC emission estimates are lower but the terpene emissions are higher. It should be noted that the OVOC emissions derived by Simpson *et al.* (1999) included emissions of 43.6 and 25.7 ktonnes per annum from pasture and crops, respectively; certainly the former and possibly the latter are not included in the OSRM inventory. These are not large sources of isoprene and terpenes in the UK.

434. The OSRM terpene and OVOC emissions are reasonably consistent with those given in Table 2-1 of Chapter 11 on natural emissions in the EMEP/CORINAIR handbook (CORINAIR, 2002) but the isoprene emission estimate is significantly lower. Part of the difference in the emission estimates is almost certainly due to the environmental correction factors used.

435. The NAEI 2003 and OSRM estimates of UK biogenic emissions are both around 9% of anthropogenic sources of NMVOCs in the UK in 2005. The rather lower PELCOM figure implies biogenic emissions being around 7% of anthropogenic sources of NMVOCs in the UK in 2005.

[6] For the 2002 and earlier emission inventory years, the estimate was 178 ktonne per annum.

Table A2-1 Comparison of the emissions of volatile organic compounds by tree species and country derived in the PELCOM project with the estimate of Simpson *et al.* (1999), national estimates of NMVOCs from man-made sources in 1990 and the National Emission Ceilings as given in the Gothenburg Protocol for 2010. Units: ktonnes per year.

Emission	Coniferous				Deciduous					Total	Simpson et al.	Anthropogenic	
Species / Country	Pine	Spruce Fir	Larch	Other	Quercus ssp.	Quercus ilex	Beech	Birch, Poplar	Other			1990	2010
Albania	1	2	1	-	28	14	1	-	2	51	54	-	-
Austria	8	95	9	-	14	2	2	-	1	132	125	351	159
Belarus	117	57	-	-	45	-	-	35	5	260	150	533	309
Belgium	2	10	1	-	23	-	1	-	-	38	34	324	144
Bosnia and Herzegovina	2	20	5	1	28	4	5	-	4	68	72	-	-
Bulgaria	25	12	2	-	173	12	5	-	4	234	104	217	185
Croatia	3	13	2	1	42	9	6	-	4	80	47	105	90
Czech Republic	18	83	5	1	18	-	1	-	1	127	108	435	220
Denmark	1	10	-	1	3	-	-	-	-	15	15	178	85
Estonia	19	22	-	-	4	-	-	-	2	47	4	-	-
Finland	149	146	-	-	-	-	-	12	2	309	341	209	130
France	119	71	49	8	593	66	11	2	17	935	1050	2957	1100
Germany	84	236	25	1	88	1	9	1	3	448	377	3195	995
Greece	24	13	9	1	136	61	2	-	2	248	153	373	261
Hungary	6	18	2	-	74	-	2	-	4	107	101	205	137
Ireland	2	7	-	-	1	-	-	-	-	11	13	197	55
Italy	25	57	19	1	210	70	10	-	13	405	114	2213	1159
Latvia	32	22	-	-	5	-	-	3	2	64	59	152	136
Lithuania	22	21	-	-	5	-	-	2	1	52	0	103	92
Luxembourg	-	1	-	-	3	-	-	-	-	5	3	20	9
Macedonia	3	1	-	-	25	11	1	-	1	43	30	-	-
Netherlands	4	2	1	-	5	-	-	-	-	12	7	502	191
Norway	30	60	-	-	2	-	-	3	1	95	160	310	195
Poland	164	61	11	-	42	1	3	2	5	288	232	831	800
Portugal	62	-	-	2	138	45	-	-	3	251	140	640	202
Republic of Moldova	-	1	-	0	24	-	-	-	1	27	-	157	100
Romania	1	118	17	0	167	-	12	-	9	323	197	616	523
Russia	732	1452	6	5	282	-	2	3033	23	5534	5125	3566	-
Russia - PEMA	-	-	-	-	-	-	-	-	-	-	-	203	165
Serbia and Montenegro	6	16	4	1	105	9	9	-	7	158	112	-	-
Slovakia	7	40	6	1	24	-	3	-	2	83	86	149	140
Slovenia	3	17	2	-	12	4	2	-	1	41	19	42	40
Spain	337	-	11	9	406	302	5	1	12	1083	511	1094	669
Sweden	120	285	-	-	17	-	1	14	4	441	581	526	241
Switzerland	1	16	6	1	3	1	1	-	-	29	31	292	144
Turkey	115	19	25	11	248	11	4	-	9	443	-	-	-
Ukraine	98	90	12	-	243	-	5	24	11	484	474	1369	797
United Kingdom	15	36	7	1	6	-	1	1	1	67	77	2555	1200
Sum	2357	3130	237	46	3242	623	104	3133	157	13038	10716		
Sum without Turkey	2242	3111	212	35	2994	612	100	3133	148	12595			
Sum Simpson (without Turkey)	2036	4356	137	159	2408	360	56	994	211	10716			

Table A2-2 Comparison of annual UK NMVOC emission estimates from biogenic sources (ktonne per annum).

Inventory Estimate	Isoprene	Terpene	OVOC	Total Emissions
EMEP/CORINAIR (2002)	53	39	27	119
NAEI 2002 Inventory [(1)]	58	31	89	178
NAEI 2003 Inventory [(2)]	8	83	-	91
Stewart et al. (2003)	8 [(3)]	83 [(3)]	-	-
PELCOM (Winiwarter et al, 2001)	-	-	-	67
OSRM – 1997	6.7	49.0	34.8	90.5
OSRM – 1998	5.7	46.0	33.0	84.7
OSRM – 1999	6.6	47.0	33.4	87.0
OSRM – 2000	6.3	46.0	32.8	85.1
OSRM – 2001	6.5	45.8	32.7	85.0
OSRM – 2002	6.3	48.4	34.5	89.3
OSRM – 2003	7.1	51.7	36.7	95.5

Notes [(1)] See Dore *et al.* (2004), biogenic NMVOC emissions taken from paper of Simpson *et al.* (1999); [(2)] Passant (2006), biogenic NMVOC emissions taken from work of Stewart *et al.* (2003); [(3)] Emissions reported for 1998 in ktonne carbon per annum.

A2.5.2 Emissions from biomass burning

436. Dentener *et al.* (2005) also considered contributions from biomass burning in their study based on the EDGAR database and other sources. The amounts of biomass burning are not well-established and fluctuate from year to year, but it does make a particularly large contribution to global CO emissions and to a lesser, but still important extent to NO_x and NMVOC emissions. Dentener *et al*. made estimates of global CO, NO_x and NMVOC emissions from biomass burning in 2000, which are 122%, 33% and 47% of global anthropogenic emissions of these pollutants from other sources, respectively. Emissions of NO_x and CO are dominated by biomass burning in much of Africa and South America.

A2.5.3 Emissions from other natural sources

437. Global emission estimates have been made for other natural sources such as soils, wetlands, oceans and lightning. The ACCENT website has links to a number of global emission inventory datasets (POET, EDGAR, RETRO) covering these sources (http://www.aerojussieu.fr/projet/ACCENT/database.php).

438. The paper of Dentener *et al.* (2005) provides estimates of global emissions from various natural sources. These included:

- 38 Mtonnes NO_x emissions from soils and lightning - 47% of global anthropogenic emissions in 2000
- 150 Mtonnes CO emissions from soils and oceans - 32% of global anthropogenic emissions in 2000;
- 240 Mtonnes CH_4 emissions from wetlands and termites - 72% of global anthropogenic emissions in 2000.