3 Emissions, Sources and Abatement Costs

3.1 Introduction

As indicated before, the problem of ground level ozone is difficult to model. On the one hand, the formation of ozone from two different precursor substances and the implicit non-linearities require a sophisticated model approach to relate emissions to resulting ambient concentrations. This modelling approach will be discussed in depth in the next chapter.

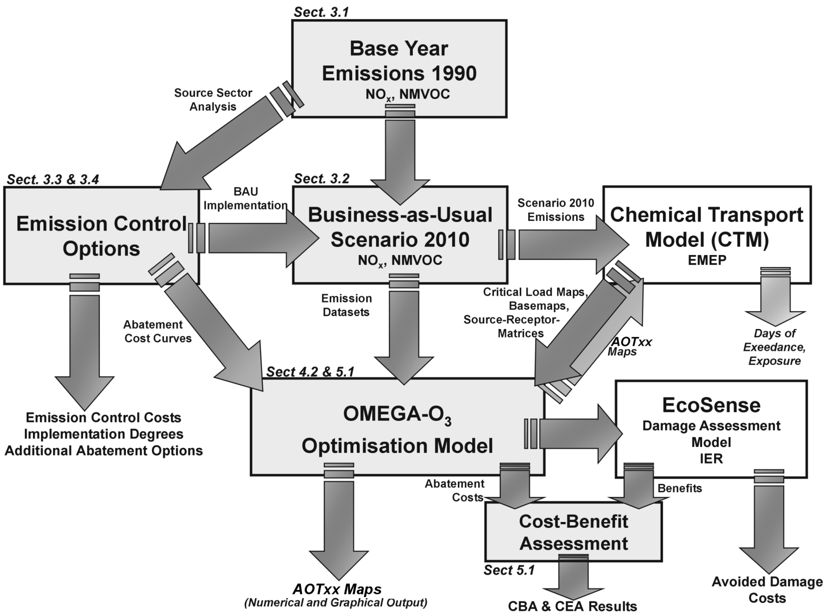

Fig. 3.1. Overview of the modelling framework (grey boxes: model development)

To run such a complex model, detailed sets of input data are needed, which provide, among others

- emission data (*Sect. 3.1* and *3.2*),
- information on emission control options and related costs (*Sect. 3.3* and *3.4*) and
- parameters for model operation and evaluation (e.g. source-receptor matrices).

Fig. 3.1 illustrates how the different data sets are linked and how data flows have to be organised to finally conduct the cost-effectiveness and cost-benefit assessment which is the core aim of the analysis here.

One of the critical issues is the assessment of emissions and the potential and applicability of emission control options. Even though there are various scenarios and analyses for specific sectors available (e.g. energy scenarios for the EU, projections of the development of vehicle fleets etc.), it has proven impossible to simply take one of these as direct input into the model. The reasons for this are mainly the general availability of numbers and scenario results, but typically no information on the methods and inputs that have been used are given. Thus, it is not feasible for instance to assess the reduction potential of abatement measures which go beyond the business-as-usual (BAU) development, since implementation degrees in the BAU case are not stated. The following sections describe in detail, how the analysis of the current and future emission situation as well as the portfolio of available emission control options have been assessed and a comprehensive data set was developed to operate the optimisation model.

3.2 Emission Analysis

3.2.1 Anthropogenic and Biogenic Emission Sources

Emissions of the ozone precursors NO_x and NMVOC mainly originate from anthropogenic sources, as the following sections will demonstrate. Other trace gases such as carbon monoxide and methane do contribute to ozone formation in the long term and thus contribute to the formation of background ozone concentrations. This has been excluded in this study, as the short term ozone formation which is in particular important for the assessment of peak ozone concentrations in summer is more or less driven by the availability of NO_x and NMVOC alone.

Biogenic emissions of NMVOCs from vegetation contribute a considerable share of total NMVOC. But as the focus of the emission analysis here was to identify abatement potentials, biogenic sources of emissions have also been excluded from the analysis. However, biogenic emissions have been implicitly included in the modelling of ozone concentrations by the Lagrangian EMEP Model.

A major problem for the analysis of emission sources was the availability of a consistent, correct and comprehensive emission data set, which at the same time provided a sufficient sectoral resolution to address important source groups directly. At the time being, only the CORINAIR emission inventory for the year 1990 complies with all these requirements. CORINAIR 94 still does not have emission data in all relevant sectors provided by countries, and CORINAIR 97 is even less complete yet. Thus, CORINAIR 90 was used as the basis for the sectoral analysis and hence as the basis for the calculation of the business-as-usual Trend Scenario for the year 2010.

Still, as 1990 is already more than 10 years past by now, CORINAIR 94 and the most recent complete emission data set from EMEP for the year 1998 and beyond was used in an ex-post analysis, to validate the analysis conducted on CORINAIR 90 data and on the other hand to check, whether the changes in emissions from 1990 to 1998 manage to support the development which has been projected until 2010.

Finally, it is important to state, that the emissions calculated for the trend scenario 2010 should not be evaluated as a *forecast* of future emissions levels, that will in any case be met. It is more a scenario which, assuming a specific development of implementing air pollution control legislation currently in place and in pipeline, gives a possible picture of ozone precursor emissions for the trend year. The path of this anticipated development can easily be changed, so will probably the National Emission Ceilings Directive itself, by setting more stringent emission limits per country than ever before, have a significant influence on the development in the next ten years. It has to be anticipated, that a number of additional – national and EC – activities will be taken by the member states to achieve their limits, and hence the expected trend scenario emissions will probably be undercut by reality. For this reason, the assessment of the future situation later on will always use the ozone situation resulting from an implemented NEC Directive in addition to that of the trend scenario and reduction scenarios, to give the full picture.

3.2.2 Sectoral Analysis

In order to develop strategies for ozone abatement, it is vital to know the structure and shares of all emission sources of ozone precursor substances, namely NO_x and NMVOC. In this case, the CORINAIR[1] emission inventory for Europe was taken as a basis.

This inventory provides a detailed collection of emission data, distinguishing the main sectors of activity relevant to air pollutant emissions. These SNAP[2] groups are

1.CORINAIR is a programme to establish an inventory of emissions of air pollutants in-Europe. It was initiated by the European Environment Agency Task Force and was part of the CORINE (Coordination of information on the environment) work programme set up by the European Council of Ministers in 1985

2. SNAP = Selected Nomenclature for Air Pollutants

usually subdivided down to activity level and present the best currently available information base for European emission data. *Fig. 3.2.* and *Fig. 3.3.* show the contribution of different source sectors (for the 15 European Union Member States) to total emissions of NO_x and NMVOCs for the EMEP 1998 data sets, the most recent inventory available. For a more detailed analysis of the emission sources, see below. For NO_x, three relevant source groups can be identified, stationary combustion, road transport and other mobile sources.

In the case of NMVOCs, the picture is somewhat different with road transport, solvent use and biogenic emissions being the main source categories. In addition to anthropogenic sources, biogenic emissions amount to approximately 15% of total EU15 NMVOC emissions according to *Simpson et al. 1999*. However, emission estimates for biogenic sources are still subject to vast uncertainties, since the data situation on emission potentials and biomass are still scarce, even though the quality and availability of land-use data has been improved in recent years. Finally, these emissions are not available for applying abatement measures, so remaining NO_x emissions could lead to ozone formation even if no anthropogenic NMVOC would be emitted.

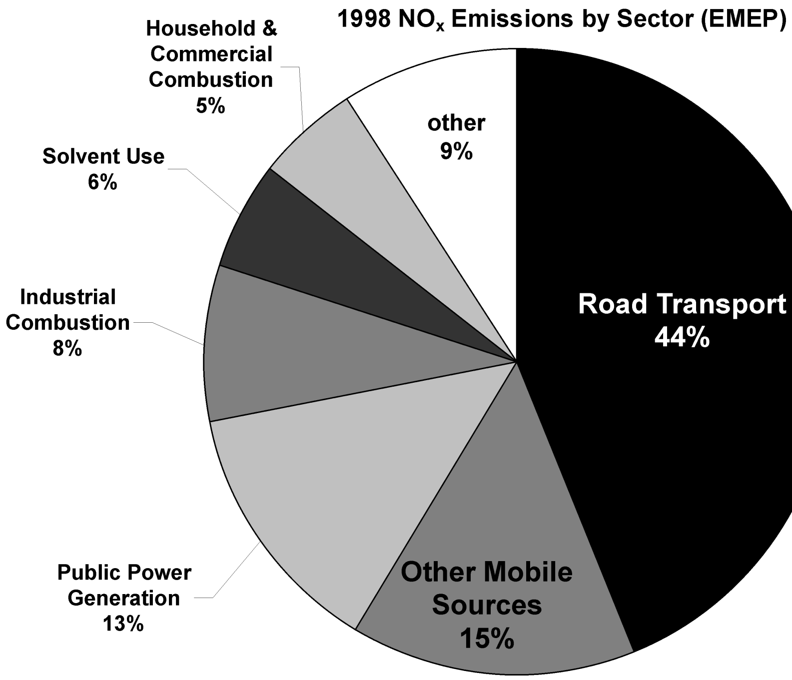

Fig. 3.2. Sectoral contribution to anthropogenic EU15 NO_x emissions according to EMEP in 1998

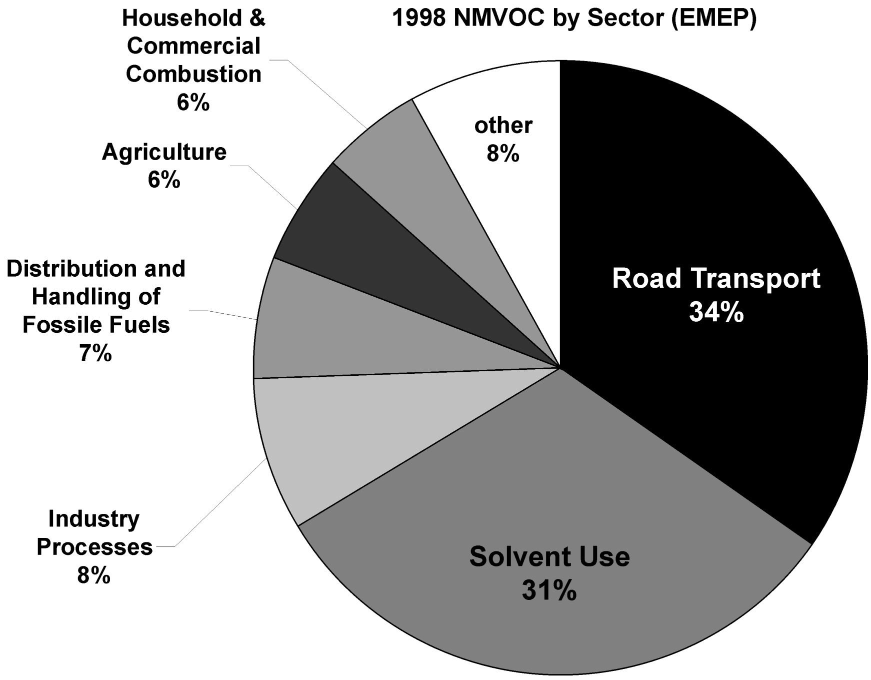

Fig. 3.3. Sectoral contribution to anthropogenic EU15 NMVOC emissions according to EMEP in 1998 (excluding biogenic NMCOV emissions, which account for approx. 15% of total NMVOC emissions in the 15 EU Member States)

Table 3.1. Shares of sectoral anthropogenic emissions of NO_x in the EU15 1998 (Source: *EMEP 1998*)

Source sector	Share
Road transport	44.0%
Other mobile sources and machinery	14.6%
Public Power, co-generation and district heating	13.4%
Industrial Combustion	7.9%
Solvent use	5.7%
Commercial, institutional and residential combustion	5.2%
Agriculture	4.0%
Production Processes	2.6%
Extraction and distribution of fossil fuels	1.3%
Waste treatment and disposal	1.3%

3.2.2.1 Sources of NO_x Emissions

NO_x emissions originate almost exclusively from combustion of fossil fuels. As well nitrogen from the air used for combustion (thermal and prompt NO) as nitrogen contained in the fuel (fuel NO) is oxidised. NO_x stands for the sum of nitrogen monoxide (NO) and nitrogen dioxide (NO_2). The main product of combustion is NO, that is further oxidised to NO_2 in the atmosphere. The formation of NO_x in combustion processes is determined by the air-fuel-ratio, the temperature of combustion and the time spent in the combustion chamber. In addition to that, organic nitrogen compounds in fuels are partly oxidised to NO as well. The sectoral structures may vary considerably between the countries (see *Annex B*), reflecting differences in e.g. the vehicle fleets, the main fuels used for power generation, differing requirements to space heating due to average annual temperatures and so on (*Table 3.1.*).

In the following part the most important sectors are analysed in more detail:

- *road transport:* passenger cars cause 54% of the NO_x emissions of the transport sector, with the share coming from gasoline fuelled vehicles varying between 85% and 99% reflecting the different market shares of gasoline and diesel fuelled vehicles in EU countries. Heavy duty vehicles are responsible for 38% of transport emissions, being almost exclusively diesel operated. The contribution of light duty vehicles amounts to about 7%, while NO_x emissions of mopeds and motorcycles are negligible.
- *public power, co-generation and district heating:* the lion's share of sectoral NO_x emissions (91%) originates from large combustion plants with more than 300 MW thermal capacity. According to EUROPROG data for 1990 (EUROPROG 1996), solid fuels (hard coal and peat) were used in the bulk of the combustion plants, though natural gas shares were already increasing. Fuel oil only plays a minor role, with the exception of Italy and Portugal (see *Fig. 3.4.*). Power plants between 50 and 300 MW cause 4% of sectoral emissions only, the contribution of plants < 50 MW is insignificant in this sector.
- *other mobile sources or machinery:* about 50% of the emissions of this sector come from vehicles in agriculture, forestry, industry or the military. With a share of 34%, marine sources (i.e. ships and harbour activities) present the second largest source group, followed by railways (7%), airports (5%) and activities on inland waterways (4%).
- *industrial combustion:* this sector comprises industrial combustion plants for heat and power generation as well as process furnaces. Heat and power generation plants emit about 58% of the NO_x of this sector, but in contrast to the size distribution of plants in public power generation, most of the plants have a thermal power ≤ 50 MW. Process furnaces, where the processed good is in direct contact with the fuel, cause 33%, those without direct contact 9% of the NO_x emissions of this sector.

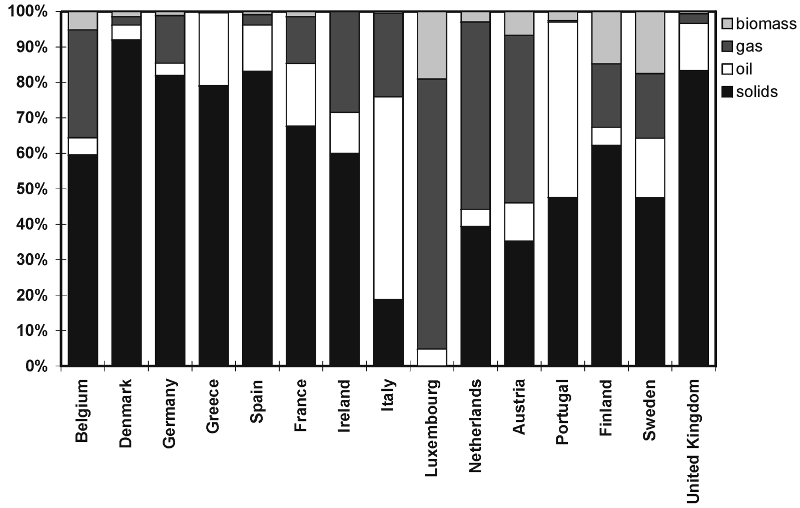

Fig. 3.4. Shares of fossil fuels for power generation in Europe 1990 (Source: IEA 1992)

- *residential and commercial combustion:* as can be expected for this sector, 99% of emissions come from plants ≤50 MW, representing the large number of household or commercial combustion systems, that mainly generate heat and warm water. Even though the share of this sector is not significant in comparison to the main source sectors, it is comparatively easy to reduce NO_x emissions from these plants, as will be described later.

3.2.2.2 Sources of NMVOC Emissions

Analysing NMVOC emissions, a vital difference to NO_x emission sources has to be noted. With an overall share of about 15% of total NMVOC emissions (*see Table 3.2.*) in the 15 EC Member States, biogenic emissions play a major role and should not be neglected. Again, the prominent role of road transport is evident, which contributes almost 41% of total anthropogenic NMVOC emissions, if emissions from the distribution of gasoline from SNAP 5 are taken into account and added to emissions from the operation of vehicles. The use of organic solvents for various applications is the source of about 32% of anthropogenic NMVOC emissions, followed by industrial production processes (8%).

The in depth analysis of the main source sectors provides the following results:

- *road transport:* as the most important difference to the analysis of NO_x emissions from this sector, NMVOC emissions almost exclusively originate from gasoline operated vehicles. In addition to that, emissions from the operation of the vehicles have to be distinguished from emissions due to gasoline evaporation from parked cars. Almost 52% of the transport NMVOC emissions come from the operation of passenger cars (between 95% and 99% from gasoline operated cars in individual countries), another 24% from the evaporation of gasoline from passenger cars, light duty vehicles and two-wheelers. Mopeds and motorcycles are responsible for 10% of the NMVOC emissions from transport, heavy duty vehicles for 9% and light duty vehicles for the remaining 5%solvent use: this sector is marked by a very diffuse source structure, covering industrial applications in almost all industry sectors and even the domestic use of solvent based products. The main sources of NMVOC emissions from solvent use are paint application (41 %), comprising the use of paints and varnishes in industry and car manufacturing as well as for construction and buildings and the domestic use. Manufacturing and processing of chemical products cause 13% of sectoral emissions, followed by solvent applications in degreasing and dry cleaning (10%). Domestic use of solvents (other than paint application) amounts to 13%, printing industry to 8% of the NMVOC emissions from solvent use.

- *production processes:* a vast number of individual processes are summed up in this sector, with the organic chemicals industry emitting the largest share of the emissions (31 %), followed by the petroleum industries (21%). The bulk of NMVOC emissions (34%) comes from a conglomeration of processes containing, among others, beverages and food production, paper pulp and chipboard production and road paving with asphalt.
- *extraction and distribution of fossil fuels:* as was already mentioned above, the major share of NMVOC emissions of this sector originates from gasoline distribution (50%), covering the whole process from refinery dispatch to refuelling operations at filling stations. The land and off-shore based extraction and first treatment of liquid fossil fuels causes 26%, that of gaseous fossil fuels another 13% of total NMVOC emissions of this sector. Finally, the gas distribution networks (pipelines, compressor stations and the final distribution to end-users) are responsible for 9%.
- *residential and commercial combustion:* as it has been already stated for NO_x emissions, almost all (98%) of the NMVOC emissions originate from plants $\leq$50 MW. These emissions are highly fuel dependent, with solid fuels (coal, lignite, wood) having between 50 to 200 times higher specific NMVOC emissions per TJ than natural gas or fuel oil.

Within the sector *other mobile sources*, off-road vehicles and machinery (60%) and marine sources (20%) emit the largest shares of sectoral NMVOC.

Table 3.2. Shares of emissions of NMVOC in the EU15 1998 (Source: EMEP)

Source sector	Anthropogenic emissions share	Share of total emissions[a]
Road transport	34.7%	29.6%
Solvent use	31.6%	26.9%
Natural sources	–	14.6%
Production Processes	7.9%	6.7%
Extraction and distribution of fossil fuels	6.6%	5.6%
Commercial/institutional/residential combustion	5.8%	5.0%
Agriculture	5.6%	4.7%
Other mobile sources and machinery	5.0%	4.2%
Waste treatment and disposal	1.9%	1.7%
Industrial combustion	0.6%	0.5%
Public power generation	0.5%	0.4%

a. including natural and biogenic sources

3.3 Country Analysis

3.3.1 Emissions per Country

Fig. 3.5. and *Fig. 3.6.* show that the five largest countries (France, Germany, Italy, Spain and the United Kingdom) cause 77% of NO_x and even 81% of NMVOC emissions in 1998. Relative shares of the most relevant source sectors are similar for all countries, major differences can be identified for the energy sector, reflecting the shares of fossil and other fuels in *power generation,* e.g. a larger than average share of nuclear power generation like in France.

3.3.2 Per Capita Emissions

The analysis of per capita emissions in each country for the year 1990 shows a split image and is used here to indicate the significant differences in relative emissions by country and hence potential starting points for the development of abatement strategies. Depending on several influencing factors, specific emissions vary between about 15 to almost 50 kilograms per capita, at an EU15 average of 30 kg/per capita.

France has a comparatively large share of nuclear power in electricity generation and thus less NO_x emissions from that sector compared to countries with a similar

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