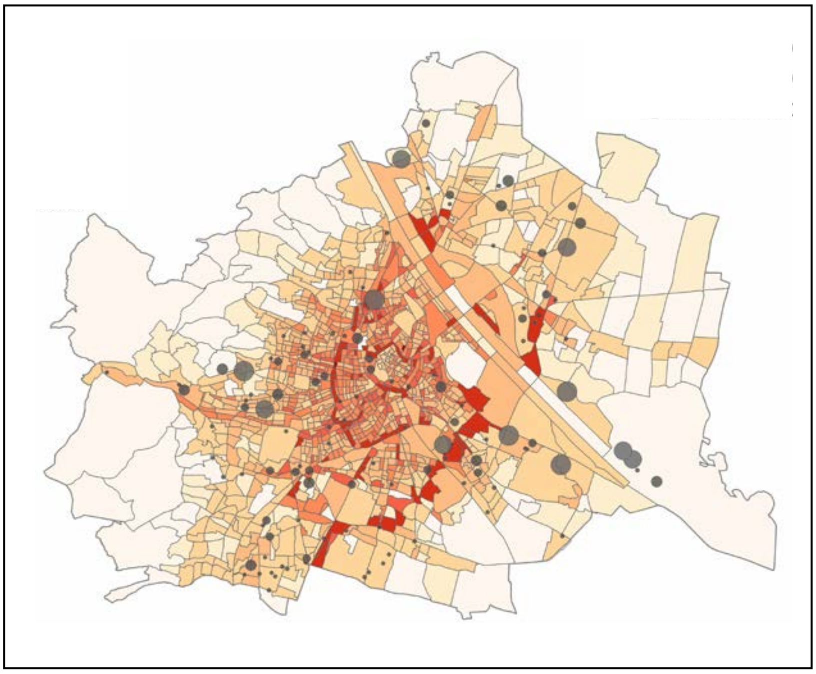
# Recommendations for improvements of urban scale emission studies



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***Front page picture:***
*$NO_x$ emissions in Vienna 2005. Source: emikat.at, MA 22, Austrian Research Centers, Umweltbundesamt*

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## DISCLAIMER

This ETC/ACM paper is intended to improve the comparability between urban and regional or national inventories, and to support developers of urban inventories by providing technical information and references to further technical documentation.
It has not been subjected to European Environment Agency (EEA) member country review. It does not represent the formal views of the EEA and should not be seen as an EEA or ETC/ACM endorsed guidance document for urban inventories.


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# 1 Introduction

Urban emission inventories have been and are developed as a key element of air quality management and are the basis of local and regional climate change action plans. Air quality management according to the Air Quality Directive (Dir. 2008/50/EC) comprises:

- the assessment of the air quality within a zone or agglomeration,
- to inform the public on the state of the air quality and on possible exceedances of air quality objectives,
- the development of air quality plans in case certain air quality objectives are exceeded, and
- short-term forecasts of pollutant levels.

Usually, air quality management is based on or supported by air quality modelling, for which a fine scale local/regional emission inventory is a prerequisite. However, neither in the current Air Quality Directive nor in the undergoing review of it, air quality modelling or developing an urban emission inventory is mandatory or is currently suggested to become mandatory (even though FAIRMODE strongly recommends the use of models, FAIRMODE 2012).

Many cities in Europe have already developed emission inventories to support air quality management and climate change policies for several years. However, there is still a number of cities where emission inventories are either in a premature state and thus rather incomplete or outdated or where an inventory is currently not available. The reason might be that either the city does not suffer from substantial air quality problems or is lacking in capacity to build up an air quality management system (ETC/ACM, 2013a; Umweltbundesamt, 2010).

Various projects and initiatives identified the need for a guidance document for supporting compilers of urban emission inventories (FAIRMODE 2010; EEA 2013a, 2013b; ETC/ACM 2012a, 2013a). The goal of this report is to provide recommendations and guidance for:

(i) improvement of city inventory compilation in relation to consistent air pollution and greenhouse gas (GHG) emission estimates,

(ii) improving the consistency and comparability between city inventories within Europe

(iii) linking city inventories with national total inventories (and vice versa)

(iv) requirements which the city inventory data should fulfil for use in local and regional air quality modelling activities.

As a first step this report provides an overview of selected emission inventory initiatives and projects for developing urban inventories (section 2.1) and describes common difficulties encountered during developing these inventories methods (section 2.2).

Chapter 3 provides an overview on available definitions, data sources, methodologies and information on activity data and emission factors.

Chapter 4 describes the requirements urban emission inventories should fulfil to provide useful input for air quality models. Special focus is laid on the principles of good practice: transparency, accuracy, completeness, consistency, comparability (TACCC) of the underlying data. In addition, emission factors, projections and classification systems are discussed. In addition, requirements for quality assurance and quality control systems for urban inventories are presented (section 4.2.6). Based on these requirements, recommendations are provided and sources of information are given how these requirements can be fulfilled.

Finally, chapter 5 draws conclusions from the previous chapters and provides recommendations based on these conclusions.

# 2 Overview of emission inventories on local scale

There are several initiatives, projects, studies and guidance documents available that describe the compilation of inventories on urban or local scale and provide support for emission inventory compilers. This chapter gives an overview of selected examples, difficulties and solutions described in previous work.

## 2.1 *Descriptions and analysis of selected emission inventory initiatives and projects*

In this section, selected examples of initiatives, studies, projects and guidance documents are listed. These examples give an overview of recent developments in establishing air pollution and GHG emission inventories on urban scale. Further information can be obtained on the respective websites.

**Table 1: Overview of selected urban emission inventory initiatives and projects.**

| Name of Project | Participating cities | Pollutants | Link |
|---|---|---|---|
| Cite Air II | General information | $CO_2$, $PM_{10}$, $NO_x$, $NO_2$ | http://www.citeair.eu |
| FAIRMODE | General information | $NO_2$- and draft PM modelling guide | http://fairmode.ew.eea.europa.eu/ |
| Air Implementation Pilot | Berlin, Dublin, Madrid, Malmö, Milan, Ploiesti, Prague, Vienna, Antwerp, Paris, Plovdiv, Vilnius | various GHG and air pollutants depending on city | http://www.eea.europa.eu/themes/air/activities/the-air-implementation-pilot-project |
| Covenant of Mayors | 5008 signatories within the EU | $CO_2$, $CH_4$, $N_2O$ | http://www.covenantofmayors.eu/ |
| MEGAPOLI | London, Paris, the Rhine-Ruhr and Po Valley regions, Moscow, Istanbul | various GHG and air pollutants depending on the city | http://megapoli.dmi.dk/ |
| TRANSPHORM | General information | various GHG and air pollutants | http://www.transphorm.eu |
| London Atmospheric Emissions Inventory | London | $CO_2$, $NO_2$, $NO_x$, $PM_{10}$, $PM_{2.5}$, $CH_4$, $SO_2$, NMVOC, CO, Benzene, Butadiene, $N_2O$, lead and hydrocarbons | http://data.london.gov.uk/datastore/package/london-atmospheric-emissions-inventory-2010 |

### 2.1.1 CITE AIR II

CITE AIR II was an EU funded project that ran from 2008 to 2011. Its aim was the provision of up-to-date information on air quality, greenhouse gases and emissions in European cities and the enhancement of comparability. The project also aimed at providing information to the public on measures to improve air quality, promote sustainable transport and reduce greenhouse gas emissions. It also aimed at informing the public on air quality in different cities using a European Air Quality Index. CITEAIR II established an enhanced user community to assess the relevance of good practices identified within the project and ensure their applicability elsewhere in Europe. These good practices inform the preparation of guidebooks and validated solutions for implementation in cities.

One of the main outputs was a guidebook on integrated urban emission inventories addressing the integration of greenhouse gases and air pollutant emissions inventories at the local scale by covering $CO_2$, $PM_{10}$, $NO_x$ and $NO_2$.

The guidebook and further information can be found on the CITE AIR II homepage: http://www.citeair.eu

### 2.1.2 FAIRMODE

The Forum for Air Quality Modelling (FAIRMODE) is a joint response action of the European Environment Agency (EEA) and the European Commission Joint Research Centre (JRC). Its aim is to bring together air quality modellers and users in order to promote and support the harmonised use of models by EU member countries, with emphasis on their application to the European Air Quality Directive. Subgroup 3 (SG3) of working group 2 is focused on urban emissions and projections to support AQ modelling applications.

A "background document on the emission needs on local scale" is available that describes key issues for urban emission inventories. Also an $NO_2$ and a draft PM modelling guide and several presentations are provided that give guidance for emission inventories on urban scale (ETC/ACM, 2011, 2013e).

Further information can be found in section 2.2 and 4.2.

### 2.1.3 Air Implementation Pilot

The Air Implementation Pilot (AIP) was a project undertaken jointly by the EEA and the European Commission. The project sought to explore an enhanced role for the EEA in supporting the implementation of the European Union's environment policy. It focused on what cities need in order to better implement EU air quality legislation.

Twelve cities (Antwerp, Berlin, Dublin, Madrid, Malmö, Milan, Paris, Ploiesti, Plovdiv, Prague, Vienna, and Vilnius) participated in this project and five workstreams in air quality implementation were examined:

- local emission inventories,
- modelling activities,
- urban air quality monitoring networks,
- urban air quality management plans and programmes and
- public information quality in the city.

The current state of the cities in each of these areas was analysed and those problems were identified, where additional support is needed from or can be given to other cities.

The report and the technical paper to this project offer an overview of the cities' inventories, lessons learnt from this project and conclusions where central questions are answered that appeared in this project, see section 2.2 for more details on the outcome concerning urban emission inventories (ETC/ACM, 2012a; EEA, 2013a, 2013b).

Further information to this project can be found on http://www.eea.europa.eu/themes/air/activities/the-air-implementation-pilot-project

### 2.1.4 Covenant of Mayors

After the adoption of the EU Climate and Energy Package in 2008, the European Commission launched the Covenant of Mayors (CoM) to endorse and support the efforts of local authorities in the implementation of sustainable energy policies.

In the Sustainable Energy Action Plan (SEAP) the signatory of the covenant outlines how the $CO_2$ reduction target can be reached by 2020. To this end, a guidebook was established to support the cities. This guidebook not only describes the development of a SEAP but also provides in Part II information about the development of a baseline emission inventory for greenhouse gases (GHG) on urban level. For the purpose of establishing this inventory, the guidebook presents an approach based on emission factors from the IPCC 2006 Guidelines as well as an approach using Life Cycle Assessment (LCA)[1] emission factors. Advice for activity data collection and help to use existing tools are provided in this manual.

Further information can be found at http://www.covenantofmayors.eu/.

### 2.1.5 MEGAPOLI

MEGAPOLI (Megacities: Emissions, urban, regional and Global Atmospheric POLlution and climate effects, and Integrated tools for assessment and mitigation) is a project within the Seventh Framework Programme (FP7) of the European Union. The main objectives of this project are:

- to assess impacts of megacities and large air pollution hot-spots on local, regional and global air quality,
- to quantify feedbacks among megacity air quality, local and regional climate, and global climate change,
- to develop improved integrated tools for prediction of air pollution in megacities.

One of the subtasks is the development and evaluation of integrated methods to improve emission data from megacities. Focus was laid on the comparison between European emission inventories and emission inventories of four megacities. The challenges and conclusions are described in the Final Report. The comparison between emission inventories shows that the allocation of emissions in regional top-down inventories can deviate substantially from bottom-up inventories. Major

[1] http://lca.jrc.ec.europa.eu/lcainfohub/introduction.vm

discrepancies were discovered for PM and VOCs, minor discrepancies were detected for $NO_x$. These discrepancies are explained by the allocation and spatial distribution of emissions.

The project also demonstrated that the combination of local bottom-up inventories with national and regional inventories is possible. This provides a consistent set for air quality modelling and policy assessments[2].

The authors recommend considering the following questions when developing city / local inventories (MEGAPOLI, 2011):

- There is a risk that unregulated sources (e.g. cooking) are overlooked as there is less motivation to know their emissions accurately.

- None of the inventories includes resuspension emissions from traffic. This is expected to be a major contributor to concentration levels near busy roads.

- There are large differences in ratios between pollutants by source sector between local and national scale, even for key sources. The authors attribute these differences to the use of different emission factors. Due to the lack of documentation, these emission factors are unknown.

MEGAPOLI identified gaps that need further research:

- The assumption of emission distributions accorded to gridded population density maps instead of the actual location of the emitting processes. This has an important influence in the development of emission databases.

- The understanding of differences in emissions per capita in the various megacities, in order to be able to reduce those emissions.

Information to this project can be found at: http://megapoli.dmi.dk/

### 2.1.6 TRANSPHORM

TRANSPHORM (Transport related Air Pollution and Health impacts - Integrated Methodologies for Assessing Particulate Matter) is an EU FP7 funded project. Its aim is to provide advanced knowledge on the impact of transport emissions on human health in Europe.

Sub Project 1 (SP1) focuses on the improvement of emission estimates from transport sources especially in areas where existing data is uncertain or lacking.

Deliverable 1.1.3 deals with the improvement, determination and harmonization of road transport non-exhaust PM emission factors (EFs), expressed as mass and some other characteristics such as elemental carbon (EC) and organic matter (OM). The final result is displayed in the Emission Factor Database which can be downloaded under ftp://transphorm:trans123@155.207.23.130. (TRANSPHORM, 2013)

[2] Reported in Deliverable 1.6 in Work package 1

Information of this project is available under http://www.transphorm.eu/.

#### 2.1.7 London Atmospheric Emissions Inventory 2010 (LAEI) (Example for EI on urban scale)

The Greater London Authority (GLA) and the Transport for London (TfL) developed a tool to model emissions and air quality in London. The main pollutants of the inventory are $CO_2$, $NO_2$, $NO_x$, $PM_{10}$, $PM_{2.5}$, $CH_4$, $SO_2$, NMVOC, CO, Benzene, Butadiene, $N_2O$, Lead and Hydrocarbons. The results are summarised in two ways: at central, inner and outer borough level (Group A) and at grid level (Group B).

The methodology report provides information about the methodology in calculating emissions and describes improvements for all point sources and area sources (Mayor of London, 2010). E.g., the emission factor updates are based on the National Atmospheric Emissions Inventory to improve comparability.

From the Atmospheric Emissions Inventory website all documents mentioned above and the database for emissions and concentrations can be downloaded.

The Progress Report of the Cleaner Air for London initiative gives information on recent air quality monitoring and modelling activities, updates on transport and non-transport policies and next steps in implementing strategies and additional air quality measures. (Mayor of London, 2013)

## *2.2 Comparability & consistency*

In its recommendations, FAIRMODE highlight the role urban emission inventory play in supporting air quality planning. FAIRMODE also states that current emission inventories are made at different levels (local, national, international), are often not consistent and may cause discrepancies in impact assessments at the different scales. The present compilation methods do not always allow relating emission sources with their abatement potential. FAIRMODE also identified a need for more detailed emission inventory compilation methods and better QA/QC methods to account for the identified discrepancies in the different scales (FAIRMODE, 2012).
As described in the Air Implementation Project (AIP) emission inventories on urban scale are often not directly and easily comparable with each other. Main reasons are differences in:

- source classification schemes,
- pollutants covered,
- spatial resolutions,
- years of latest data, frequency of compilation
- activity data and emission factors,
- inclusion of fugitive and secondary emissions
- QA/QC-systems
- the underlying type of database.

Therefore only some urban emission inventories are comparable to other cities' inventories within a Member State or to regional or national emission inventories. (ETC/ACM, 2012a)

The availability of reliable activity data and emission factors or other relevant parameters on urban scale is limited and therefore difficult to gain. It is described as a critical factor for the assessment of the effects of measures. Used data for activities and/or EF is often derived from other regions/technology stocks and national statistical distributions are often the only possibility to specify sources. Part of the local emission data is often not available at a local scale and needs to be estimated as a fraction of a national total which leads to higher uncertainties. (European Regional Development Fund, 2008)

In the Air Implementation Project (AIP) the participating cities reported:

- that the availability of historical and current data,
- very low quality data
- sustainability of data
- availability of emission factors for specific sources

are among the main difficulties in providing emission inventories.

With respect to emission factors, one of the main challenges described in this project are the uncertainties in emission factors for wood burning, construction activity and fugitive sources in general, as well as in real world emissions and future vehicles. (ETC/ACM, 2012a)

Another common problem in inventorying is the **double counting of emissions**. This can occur by the use of different methodologies for the same emission sources (bottom-up and top-down approach). If two or more different kinds of activity data are being used, there is some double counting in the EI (e.g. the different counting's used for kilometres for car use and the counting of fuel used). (European Regional Development Fund, 2008)

# 3 Emission inventories

This chapter gives an overview of definition of city boundaries, the source and sink categories basic methodology (top-down, bottom-up), and the description of activity data and emission factors that have to be considered for establishing emission inventories on urban scale.

## *3.1 Terms and definitions*

The following definitions are provided according to the IPCC guidelines and the EMEP/EEA air pollutant emission inventory guidebook (IPCC, 2006; EMEP/EEA, 2013). The main focus of the underlying conventions and protocols lies, however on a national scale.

### Pollutants and sectors

Emission inventories of air pollutants and greenhouse gases (GHG)

- need to be comparable between countries, regions, cities, etc.
- do not contain double counting or omissions, and
- time series reflect actual changes in emissions .

Currently (until 2014) inventories cover emissions from six sectors - Energy, Industrial processes, Solvents and Other Product use, Agriculture, LULUCF[3], Waste -, and for all years from the base year[4] or period to the most recent year.

National air pollutant inventories cover all the substances that Parties to the UNECE/LRTAP[5] Convention's protocols should report, plus a number of additional substances for which reporting is voluntary[6]:

1. Main pollutants: $SO_x$, $NO_x$, $NH_3$, NMVOC, CO
2. Particulate matter: $PM_{2.5}$, $PM_{10}$, TSP
3. Heavy metals: Pb, Cd, Hg, As, Cr, Cu, Ni, Se, Zn
4. Persistent Organic Pollutants (POPs): Hexachlorobenzene (HCB), hexachlorocyclohexane (HCH), polychlorinated biphenyls (PCBs), dioxins/furans (PCDD/F), polycyclic aromatic hydrocarbons (PAHs)

National greenhouse gas (GHG) [7] inventories cover all gases that Parties to the United Nations Framework Convention on Climate Change and the Kyoto protocol shall report (UN, 1998; UNFCCC

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[3] Land Use, Land-Use Change and Forestry (LULUCF)

[4] A specific year against which a party's emissions are tracked over time. Targets for reducing emissions are usually defined in relation to the base year.

[5] Convention on Long-range Transboundary Air Pollution under the United Nations Economic Commission for Europe. Currently, the Convention comprises eight protocols

[6] as defined in the LRTAP Reporting Guidelines - Revised Emission Reporting Guidelines - ECE/EB.AIR/97 (UNECE, 2009).

2006). National GHG inventories cover emissions and removals of direct GHGs: $CO_2$, $CH_4$, $N_2O$, HFCs, PFCs and $SF_6$.

The air pollutants most relevant for cities are in general $NO_2/NO_x$, $PM_{2.5}$, $PM_{10}$, ozone (and VOC as precursors) and polycyclic aromatic hydrocarbons (PAHs), as exceedances of air quality thresholds often concern these pollutants.

$SO_x$, $NH_3$, NMVOC, CO, Pb, Cd, As, Ni are described in the Air Quality Directive (AQD), the National Emission Ceilings (NEC) and 4th Daughter Directive (4DD), but are often of minor importance for AQ in cities. NMVOC and CO are however necessary for more complex chemical transport models for ozone.

All other pollutants (TSP, Hg, Cr, Cu, Se, Zn, Hexachlorobenzene (HCB), hexachlorocyclohexane (HCH), polychlorinated biphenyls (PCBs), dioxins/furans (PCDD/F)) might be considered when they are relevant for the city.

In Europe air pollutant inventories and greenhouse gas (GHG) inventories are similar in structure of source categories, the applied methods (Emission = Activity data * Emission factor), quality criteria (TACCC), frequency of reporting, inventory management systems etc.

Air pollutant inventories and greenhouse gas (GHG) inventories are different, e.g. in terms of consideration of emission abatement technologies and emission-related information derived from facility reporting.

## Good practice

In order to promote the development of high-quality inventories a collection of methodological principles, actions and procedures have been defined and collectively referred to as *good practice*. Inventories consistent with *good practice* are those that contain neither overestimate nor underestimate, so far as can be judged, and in which uncertainties are reduced as far as practicable. *Good Practice*[8] covers choice of estimation methods appropriate to national circumstances, quality assurance and quality control at the national, regional or local level, quantification of uncertainties and data archiving and reporting to promote transparency.

## Decision trees

Decision trees, for each category, help the inventory compiler navigate through the guidance and select the appropriate tiered methodology for their circumstances based on their assessment of key categories. In general, it is good practice to use higher tier methods for key categories[9], unless the resource requirements to do so are prohibitive.
It is beyond the scope of this project to develop decision trees.

[7] See Updated UNFCCC reporting guidelines on annual inventories following incorporation of the provisions of decision 14/CP.11; http://unfccc.int/resource/docs/2006/sbsta/eng/09.pdf

[8] Good practice principles have been first set-up in the document IPCC, 2000. The 2006 IPCC Guidelines further refined the concept of good practice.

[9] A key category is one that is prioritized within the national inventory system because its estimate has a major influence on a country's total inventory of direct GHGs in terms of the absolute level of emissions, or trends in emissions, or both.

## Definition of City Boundaries

While for preparing a national inventory the full geographical coverage is relevant, when defining the boundaries of a city it has to be considered that there are different ways of determining the geographical extent.

According to the Covenant of Mayors (CoM) the geographical boundaries are described by the administrative boundaries of the local authority (CoM, 2010).

Other approaches to describe city boundaries are summarized in the Air Implementation Project which is described in chapter 2.1 (EEA, 2013a, 2013b). One possibility is making use of Air Quality zones, which were established by the Member States according to the Air Quality Directive (Dir. 2008/50/EC) and the 4th Daughter Directive (Dir. 2004/107/EC). The AQ zone is defined as 'a part of the territory of a Member State, as delimited by that Member State for the purposes of air quality assessment and management'. The 'agglomeration' is a special zone category. It is defined as 'a zone that is a conurbation with a population in excess of 250 000 inhabitants or, where the population is 250 000 inhabitants or less, with a given population density per km² to be established by the Member States'.

A further complexity in terms of defining boundaries comes from the project Urban Audit[10]. This project aims at collecting comparable statistics and indicators for European cities, and considers three different spatial levels:

- the city
- the larger urban zone (LUZ) - The goal was to establish an area from where a significant share of residents commute into the city, a concept known as the “functional urban region”.
- the sub-city district (SCD) - to analyse disparities within cities; the Urban Audit cities have been divided in sub-city districts.

The city levels were defined using political boundaries. In many countries, these boundaries are clearly established and well known. As a result, for most cities, the boundaries used in the Urban Audit correspond to the general understanding of that city (EEA, 2013a).

## Natural, geogenic, biogenic, marine sources

Emissions of natural origin, which can be of relevance in urban areas (at least during episodes), comprise geogenic, biogenic and marine sources (JRC, 2007; Commission Staff Working Paper, 2011)[11]:

- Sea spray
- Volcanic eruptions & seismic activities
- Wild-land fires

[10] http://www.urbanaudit.org

[11] According to the Air Quality Directive contributes from natural sources can be subtracted when comparing pollution levels with limit values. The European Commission provides guidance documents about which sources can be regarded as natural and on methods for subtraction and comparison

- Transport of natural particles from dry regions
- Primary Biological Aerosol Particles
- Secondary Organic Biogenic Aerosols (relevant for chemical transport models).

Whereas wild-land fires can often be regarded as a natural source, forest fires are most often human-induced. Therefore forest fires aren't natural sources in the strict sense. Also wind erosion of dry land can not *a priori* attributed to natural sources.

The EMEP/EEA guidebook of 2013 provides emission factors *inter alia* for the following natural, sources, which might be relevant for urban inventories (EMEP/EEA, 2013):

- Volcanoes
- Forest fires
- VOC emissions from non-managed & managed forests, natural grassland and other vegetation

### *3.2 Data sources*

The bottom-up, top-down and hybrid approach are the main methods to obtain emission data. According to the results of an urban emissions questionnaire of FAIRMODE the hybrid approach is the most used method among those who compile emission inventories on urban scale (ETC/ACM, 2013e).

- Bottom up

The bottom-up emission inventory is activity and location based. Emissions for each activity within a defined area are estimated. The inventory is constructed from the more detailed knowledge of source types, locations and their specific measured emissions or calculated on the base of fuel consumption data or production data. Stakeholder organisations, international registries of point sources (e.g. the European Pollutant Release and Transfer Register E-PRTR[12]; Large combustion plants, LCP[13]), emission factor databases, international, national or local experts, scientific and technical articles and reference libraries may be used as data sources. Typical emission sources for local inventories are traffic, large industrial and power plants, and residential heating plants.

The advantages of the bottom-up approach are additional information compared to top-down approaches, the easier analysis and formulation of regional or local policies. Disadvantages are the higher amount of work, especially regarding input-data collection, and the overall risk of incompleteness. Due to the high efforts associated with the compilation of bottom-up inventories, updates are carried out irregularly; time series are often incomplete or inconsistent due to methodological changes and difficulties in the operation of recalculations.

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[12] http://ec.europa.eu/environment/air/pollutants/stationary/eper/legislation.htm

[13] Directive 2001/80/EC on the limitation of emissions of certain pollutants into the air from large combustion plants; http://ec.europa.eu/environment/air/pollutants/stationary/lcp/legislation.htm

- Top-down

A top-down inventory is based on statistical data collected over a larger region (e.g. a country) as well as plant-specific data regularly reported by the operators on the basis of national and international reporting obligations. Typical data sources are national and regional statistics which can be collected from statistic agencies. Emission sources addressed using top-down data are typically energy consumption, transport, agriculture and forestry and waste management.

The strength of this method is its consistency to national statistics and other official country-specific data. The comprehensive top-down approach causes a high level on completeness; yearly updated input data are available to ensure that emission inventories easily can be held up-to-date. A break-down to the regional level can be used for the validation of bottom-up inventory and the filling of data gaps. National inventories are regularly reviewed which ensures the comparability on national and international level.

However, national inventories may lack local details as they use typical country-wide behavioural patterns which may be different on urban scale.

- Hybrid approach (Combined Approach)

Pure top-down or bottom-up approaches hardly exist and often a mixture is used. The exclusive use of bottom-up emissions fails due to lack of available input data while exclusive top-down methods will not lead to an adequate level of accuracy.

It has to be noted that using the hybrid approach contains a high risk of double counting or omitting emissions. (European Regional Development Fund, 2008)

The bottom-up approach is preferred when there is enough information to support a very detailed emission estimation (complete and exhaustive description of individual emitters), but a top-down approach in combination with an updated high-resolution land use/population cover can provide a more accurate picture of general emission distribution pattern. (ETC/ACM, 2013e)

To summarise, the following list gives an overview of data sources available for bottom-up, top-down and/or hybrid approaches. Although the list is not exhaustive, it provides a starting point for possible sources of country, regional and local-specific data:

- National and regional statistics agencies[14]
- emission data may sometimes be used for estimating emissions from industrial installations and reported to
    - European Pollutant Release and Transfer Register (E-PRTR),
    - Emissions Trading Registry (EU Emissions Trading Scheme);
    - Large combustion plants (LCP) Directive;
    - Industrial Emissions Directive[15];

[14] N.B. For European Union countries and regions, activity statistics are available also from Eurostat); IEA International Energy Agency, Food and Agriculture Organization of the United Nations FAO

[15] Directive 2010/75/EU on industrial emissions (integrated pollution prevention and control); http://ec.europa.eu/environment/air/pollutants/stationary/ied/legislation.htm

- VOC Solvents Emissions Directive[16];
  - Paints Directive[17].
- national/regional/local sectoral inventory experts,
- other country national/regional/local experts;
- other international experts;
- Emission Factor Databases;
- reference libraries (national libraries);
- scientific and technical articles in environmental books, journals and reports;
- universities; research institutions, stakeholder organisations (e.g. associations);
- web search for organisations and specialists;
- inventory reports from other parties, regions, cities.

## 3.3 Methodology

The methods described in the of the EMEP/EEA air pollutant emission inventory guidebook provide the most common estimation approach as the combination of the extent to which an anthropogenic activity takes place (Activity Data, AD) and the coefficients that quantify the emissions or removals per unit activity (Emission Factors, EF).

Therefore the basic equation to estimate emissions (E) is:

$$E_{AP,,GHG} = AD \times EF_{AP,,GHG}$$

$E_{AP,,GHG}$ = annual emission of pollutant or GHG
$AD$ = activity rate by fuel consumption
$EF_{AP,,GHG}$ = emission factor of pollutant or GHG

For estimating emissions, a tiered approach is recommended). Methodological choice for individual source categories is important in managing the overall inventory quality and minimising uncertainty (EMEP/EEA, 2013).

- Tier 1: This method uses a simple linear relation between readily available statistical information for AD and “typical” or “averaged” EFs.

[16] Directive 1999/13/EC on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain activities and installations; http://ec.europa.eu/environment/air/pollutants/stationary/solvents/legislation.htm

[17] Directive 2004/42/EC of the European Parliament and of the Council of 21 April 2004 on the limitation of emissions of volatile organic compounds due to the use of organic solvents in decorative paints and varnishes and vehicle refinishing products and amending Directive 1999/13/EC.

- Tier 2: This more complex method uses EFs developed based on the knowledge of specific processes and types of conditions.
- Tier 3: this more detailed method than Tier 2 uses facility level data and sophisticated models.

### Emission Factors (EF):

Emission Factors are used to derive estimates of air pollutant or greenhouse gas emissions. They can be based on a sample of measurement data averaged to develop a representative rate of emission for a given activity level under a given set of operating conditions. (European Regional Development Fund, 2008). EFs can be based also on model results.

In the definition of the UNFCCC "an emission factor is defined as the average emission rate of a given GHG for a given source, relative to units of activity"[18].

Following sources provide emission factors (see also the brochure developed within the Air Implementation Pilot, EEA, 2013b):

| Literature Type | Where to find it | Comments |
|---|---|---|
| **IPCC Guidelines** | **IPCC** | **Provide agreed default factors for Tier 1 methods but may not be representative of national circumstances.** |
| **IPCC Emission Factor Database (EFDB)** | **IPCC** | **Described in more detail below. May not be representative of processes in your country or appropriate for *key category* estimates.** |
| **EMEP/EEA air pollutant emission inventory guidebook (previously known as EMEP/CORINAIR Emission Inventory Guidebook)** | **EEA (European Environment Agency)** | **Useful defaults or for first estimates and cross-checking. May not be representative of processes in your country or appropriate for *key category* estimates.** |
| COPERT IV | COPERT | Road transport emissions software |
| Handbook Emission Factors Road Transport, HBEFA | HBEFA | Developed for Germany, Switzerland, Austria, Sweden, Norway, and France |
| CollectER III | CollectER | A tool for national air emission experts by ETC/ACM |
| Project TRANSPHORM (see chapter 2.1) | TRANSPHORM database: ftp://155.207.23.130/ | Database for transport emission factors |
| Country-specific data from international or national peer reviewed journals | National reference libraries, environmental press, environmental news journals | Reliable if representative. Can take time to be published. |

[18] http://unfccc.int/ghg_data/online_help/definitions/items/3817.php

| | | |
|---|---|---|
| Emission factors for other countries | Inventory reports from other parties, web search, national libraries | Appropriate for emissions inventory use. Useful defaults or for crosschecking. May not be representative of processes in your country or appropriate for Key Category estimates |
| Emission factors or other estimation parameters for other countries | National Inventory Reports from Parties to UNFCCC, Informative Inventory Report (IIR) from Parties to the UNECE/LRTAP available at the Centre on Emission Inventories and Projections (CEIP). Other inventory documentation, web search, national library | Appropriate for inventory use. Useful defaults or for cross-checking. May not be representative of processes in your country or appropriate for *key category* estimates. |
| Emission regulating authority records and papers or pollution release and transfer registries | Industrial process regulating authority | Regularly updated and plant-specific. Quality is dependent on the regulatory requirements, which may not extend to the methods used for estimating/measuring |
| Industry technical and trade papers | Specific trade association publications, libraries, and Web search | Sector-specific and up-to-date. QA/QC is needed to check for bias in data and to ensure the test conditions and measurement standards are understood |
| International Emission Factor Databases: USEPA AP 42, Compilation of Air Pollutant Emission Factors | USEPA AP42 | Useful defaults or for cross-checking. May not be representative of processes in your country or appropriate for *key category* estimates. |
| International Emission Factor Databases: OECD | OECD | Useful defaults or for cross-checking. May not be representative of processes in your country or appropriate for *key category* estimates. |
| National testing facilities (e.g. road traffic testing facilities) | National laboratories | Reliable. Need to make sure the factors are representative and that standard methods are used |
| Other specific studies, census, survey, measurement and monitoring data | Universities (environmental, measurement and monitoring departments) | Need to make sure the factors are representative and that standard methods are used |

*Source: EMEP/EEA air pollutant emission inventory guidebook 2013 and 2006 IPCC Guidelines for National Greenhouse Gas Inventories*

As described in the AIP project, there are uncertainties of EFs for wood burning, construction activity and fugitive sources in general as well as for real world emissions and future vehicles (EEA, 2013a).

Relevant differences between the city and the countryside have influence on the EFs, for example differences in the traffic situation, the car fleet and heating systems (community heating, wood, gas,…). It has to be considered that these EFs sometimes have to be adapted.

**Activity Data (AD):**

According to the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, activity data are defined as data on the magnitude of human activity resulting in emissions or removals taking place during a given period of time[19]. The Covenant of Mayors (see chapter 2.1 for further information) identifies following key issues regarding Activity Data (CoM, 2010):

- Activity Data should be relevant to the particular situation of the local authority (e.g. data based on national statistics would not be appropriate, as in the future, they would only reflect trends occurring at national level)

- The methodology of data collection should be constant through the years. If methodology changes, this has to be documented very precisely.

- Data sources should be available in the future,

- Data should be accurate or at least represent a vision of reality.

- Data sources and collection should be well documented to assure transparency for stakeholders.

There are different approaches to identify the activity data (European Regional Development Fund, 2008):

- Plant Level Data/Facility Level Data

The plant and facility level data is a bottom-up approach and is one of the most detailed data source for emissions. Most of these data sets contain only emissions and basic information on activity (e.g. NACE[20] or E-PRTR main activity) and no further information on the underlying processes. However some countries do have detailed registers of national emission sources but these are usually not accessible for the public.

- National Statistics

Using National Statistics is a top-down-approach and used for those sources where facility or plant level data is not available. The IPCC Guidelines and the EMEP/EEA air pollutant emission inventory guidebook provide source category specific information on how activity data can be derived from available statistics.

- International Statistics

If none of the data mentioned above is available, international statistics have to be used. UN statistical data[21] , EUROSTAT[22] and IEA[23] can be used as data sources.

- Proxies

If appropriate data cannot be found or is not available a proxy variable can help to derive rough estimates of the activity rate. It is data that is not directly related to the data needed but might have a good correlation with it (e.g. population size, gross domestic product).

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[19] UNFCCC homepage http://unfccc.int/ghg_data/online_help/definitions/items/3817.php
[20] Nomenclature statistique des activités économiques dans la Communauté européenne
[21] http://unstats.un.org/unsd/default.htm
[22] http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/
[23] http://www.iea.org/

### 3.4 Nomenclature for emission categories

Comparability and consistency with local, regional and national inventories have to be considered when a reporting format for the emission inventory is chosen. There are defined emission categories under CLRTAP[6], i.e. Nomenclature for Reporting (NFR) and Selected Nomenclature for Air Pollution (SNAP) to be used for emission estimation (UNECE, 2009). Under UNFCCC the Common Reporting Format (CRF) is used (UNFCCC, 2006). Both systems (NFR and CRF) are consistent. Nevertheless it is also possible to create a customized reporting format for the emission inventory.

The EMEP/EEA air pollutant emission inventory guidebook is structured by SNAP categories, the IPCC Guidelines are structured by CRF categories.

If another nomenclature is used, for example a customized one or SNAP, the comparability to other emission inventories has to be considered.

# 4 Urban emissions data used for air quality modelling

### 4.1 Introduction

Air quality modelling in general is used for supporting air quality management in order to implement the Air Quality Directive and the 4th Daughter Directive (see e.g. ETC/ACM 2011, 2013b, 2013e): Air quality modelling provides:

- mapping of pollutant levels throughout the region of concern (for planning and/or reporting);
- assessment of contributions from different sources to the pollutant levels (source apportionment);
- air quality forecasting, and
- assessment of the impact of measures.

Chemical-meteorological AQ models (in contrast to empirical models) require certain input data (ETC/ACM 2013e):

- Emission data;
- Meteorology;
- Boundary and initial conditions, and
- Land cover.

In this chapter the focus lies on requirements and recommendations for emission data for (urban) air quality modelling.

In general, it is necessary to spatially, temporally, chemically and vertically allocate emission data to the resolution needed by the air quality models (US EPA, 2007). The emission data might be necessary not only for a base year, which is usually in the past, but also for future years. This requires projection of the activity data and emission factors (see section 4.2.1). Also the emission data in many cases needs to cover additional sources that are usually not required for emission reporting (Figure 4.1). These are e.g. resuspension of road dust, windblown dust, natural sources, but also the share of $NO_2$ in $NO_x$.

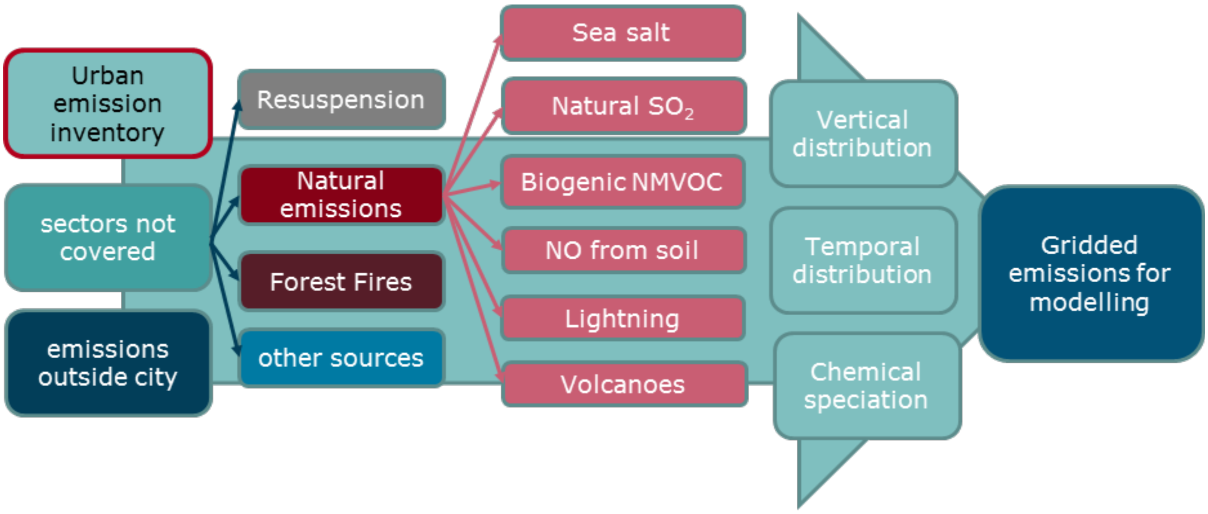



**Figure 4.1: Scheme of emission data for air quality modelling.**

There is a variety of models for a number of different purposes, ranging from small scale street canyon models to regional chemical transport models. The emission data needed will be different for each model. These differences include all aspects of emission inventories: the spatial, vertical and temporal resolution of the emission data, the reporting format, the pollutants covered and the level of detail for the sectors. This guidance document cannot cover all different requirements of different model types, but rather has to stay on a more general level and guide the user to additional more specific sources of information.

The following section 4.2 lays down the requirements of models concerning emission data and provides recommendations on how an urban emission inventory can fulfil these requirements.

## *4.2 Requirements and recommendations for urban emission inventories used for modelling*

The requirements urban emission inventories should fulfil to be used in air quality models have been discussed in different fora, projects and studies. Amongst others these are:

- FAIRMODE Working Group 2 on Quality assurance of models, subgroup 3 (urban emissions and projects) published in 2010 a “Background document on the emission needs at local scale” (FAIRMODE, 2010). **The specific requirements of inventories used for modelling are**:
    - o Spatial allocation of emission sources
    - o Temporal allocation
    - o Chemical speciation

The general requirement of emission inventories is said to be their representativeness, which implies:

- o an adequate cover of emission sources and pollutants,

  - reliable emission estimates and
  - an appropriate spatial and temporal resolution.

- ETC/ACM technical paper 2013/4: Air Implementation Pilot: Assessing the modelling activities (ETC/ACM, 2013b). A questionnaire was sent to the pilot cities to collect information on how specific issues of emission inventories used for modelling are dealt with. These issues, which reflect the requirements, are:
  - Spatial and temporal resolution of emission data (including the source height of domestic heating;
  - Inclusion of all relevant sources;
  - Detailed information on traffic (e.g. congestion; traffic counts and speed per vehicle class; fleet composition, $NO/NO_2$ speciation);
  - PM speciation.
- FAIRMODE guide modelling $NO_2$ (ETC/ACM, 2011). The requirements and recommendations for $NO_2$ modelling are amongst other:
  - The use of established, supported and harmonised emission databases is highly recommended;
  - Local and urban sources often have to be covered; therefore consistency of emission data across different scales is important;
  - The emission inventory development and adaptation process has to be transparent and well documented;
  - Spatial and temporal distribution of emissions down to a temporal resolution of an hour is needed;
  - Reflection of the emission uncertainties is necessary to allow for indication of the uncertainties of predictions;
  - $NO_2/NO_x$ emission ratios of traffic emissions and their changes in time is required;
  - The emission factors and emission inventories need to be updated regularly.
- FAIRMODE draft particulate matter modelling report (ETC/ACM, 2013e). This guidance report provides similar requirements and recommendations as that for $NO_2$. In addition the following issues are highlighted:
  - PM episodes are sometimes caused by spatial and temporal changes in emissions due to e.g. increased wood burning during exceptional cold days in wintertime, intensive fertilizer use in spring time, biogenic volatile organic compounds in summer, winter sanding in winter time.
  - Resuspension of road dust and non-exhaust emissions in general are required for modelling PM. Also windblown dust, other natural sources, wildfires, primary organic aerosol are important for PM modelling.
- Presentations given at FAIRMODE meetings;
- IPCC, GHG protocol guidance (IPCC, 2010; C40, 2012): Principles and methods developed by the IPCC should be used. These include *inter alia*:
  - Inventories should be transparent, consistent, comparable, complete and accurate. They should be sufficiently disaggregated and consistent to enable effective policy development.
  - The most recent guidelines should be used;

- Distinction of direct and indirect emissions that occur at sources outside the city is important.
- Reporting principles should be followed.

- Covenant of Mayors Sustainable Energy Action Plans guidance (CoM, 2010), which provides similar (even though more detailed) recommendations as the IPCC and GHG protocol guidance. Special attention is paid to the source categories that should be included and the discrimination between direct and indirect emissions. Guidance is provided on how to collect relevant data on a city level. Regular (annual) updates are encouraged.
- FP7 projects such as Megapoli, BRIDGE, URGENCHE, TRANSPHORM
- US EPA modelling guidance (US EPA 2007). The guidance provides recommendations *inter alia* for emission inventories in a stepwise approach for ozone and $PM_{2.5}$ modelling for a base and future years:
  - On a state level a base-inventory needs to be compiled, which for ozone should include a complete accounting of anthropogenic and biogenic VOC, $NO_x$ and CO; for $PM_{2.5}$ it should also include $SO_2$, $NH_3$, $PM_{2.5}$ (speciated), and PM coarse.
  - Ancillary data is needed to describe the spatial, temporal, and chemical speciation information.
  - Growth rates and existing control programs are needed for projecting future emissions.
  - Emission reductions due to abatement measures have to be reflected in the inventory.
  - Modellers should also pay attention to elevated point sources, to advanced approaches for mobile source modelling and to quality assurance.

### 4.2.1 Spatial and temporal allocation of urban emissions

## Temporal allocation

In contrast to national inventories and especially to GHG inventories, emission inventories for modelling require a higher than annual temporal resolution, **ideally hourly data.** Therefore profiles representing the average daily, weekly and annual variation of emissions are necessary to fully cover the temporal variability of emissions.

**The temporal emission profiles** have to be specified for each pollutant and different source categories (see Figure 4.2); in some cases of specific industrial or power plants, individual temporal profiles derived from effective operation times or from continuous emission monitoring can be used. The accuracy with which the profiles are described should reflect the relevance of the source. E.g. for $NO_2$ modelling, traffic profiles for passenger cars, light and heavy duty vehicles and buses are most important (which not necessarily are the same). Next to these profiles also those for residential heating and in some cases industry and power plants might be necessary, which usually impact on the urban background levels. For $PM_{10}$ (and also $PM_{2.5}$ and benzo(a)pyren) traffic is of importance, even though further sources such as residential heating, industry, construction activity might be equally relevant.

The profiles for traffic, residential heating, industry and power plants are usually rather stable and can therefore also be extrapolated for future assessments. In contrast, some sources, which are mainly relevant for PM, are temporally very irregular and sometimes even unpredictable. These are amongst other (see also section 4.2.3):

- construction activity,
- off-road machinery,
- industrial accidents/leakages

which are of relevance for most cities.

Especially for northern and central European cities resuspension of road dust due to winter sanding might be of relevance.

In southern Europe ,

- wind erosion,
- Saharan dust episodes,
- forest fires,

are often important sources during episodes.

In some cases volcanoes and further natural / biogenic sources are of relevance.

For the modelling of annual means, some of these sources are of less importance, but in some cases important for shorter periods of time, and have to be dealt with individually. Therefore, their variability should be reflected in the inventory and the profiles.

Temporal profiles can be calculated by applying specific scaling factors to annual total emissions (top-down-approach) or by directly calculating emissions via specific hourly activity data and emission factors (bottom-up-approach).

Diurnal profiles can vary substantially between sectors (Figure 4.2, left) and cities (Figure 4.2, right).

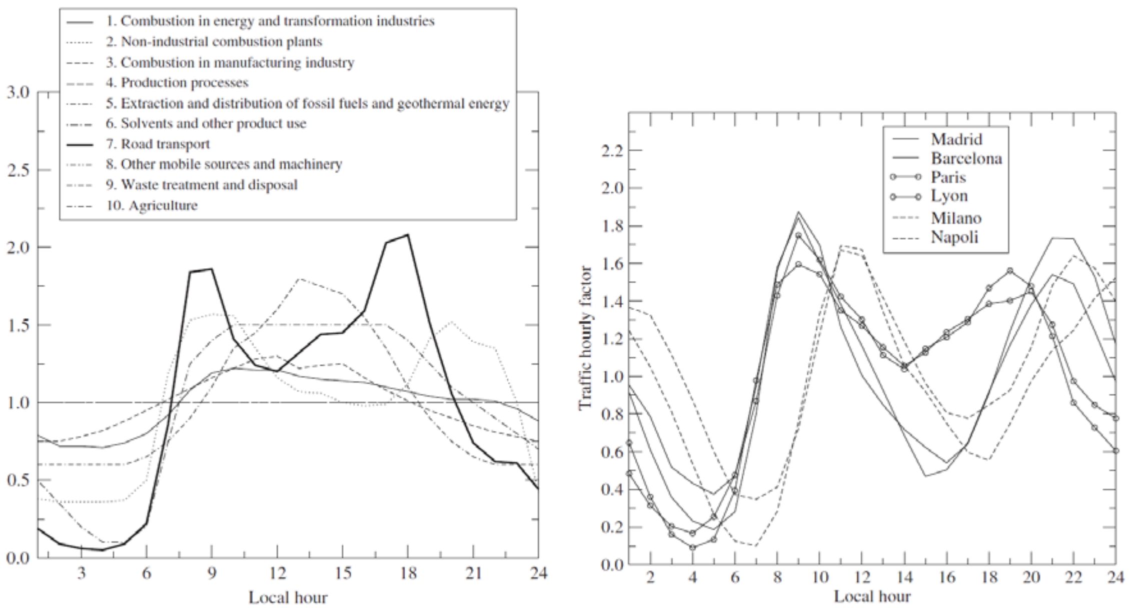



**Figure 4.2: Emissions hourly factors of the 10 SNAP anthropogenic activities sectors (left). Hourly factors estimated for different cities in various countries, for Monday (source: Menut et al 2012).**

The most prominent diurnal profile exhibits the sector road transport, also domestic heating (SNAP 2 non-industrial combustion plants) show a clear diurnal variation, which might be even more pronounced during wintertime.

In general most effort in developing temporal profiles should be put into those sectors that contribute most to the pollutant levels, which are usually road transport, domestic heating and industry.

For large point sources hour-specific data from continuous emission monitoring may be used if available.

For traffic at main roads data from traffic counts should be used.

US EPA has developed an extensive database[24] of monthly, weekly, and diurnal profiles, which can be applied to the specific situation.

Menut et al. describe in their paper how annual EMEP emissions are converted to hourly data and how the conversion factors used vary between different regions in Europe (Menut et al., 2012).

## Projections and forecasts

Emission projections are a prerequisite for assessing future pollutant levels and scenario analysis. They can help to forecast short and long term developments and are a key requirement for designing mitigation policies. Extensive guidance documents are available on inventories of air pollutant and especially greenhouse gas emissions and can be used as well for projections, because they do not differ technically (FAIRMODE, 2010).There exist simple projections methods without spatial mapping (see the chapter on projections of the EMEP/EEA Guidebook[25]) and projection including spatial mappings (see e.g. Documentation of London Air Emission Inventory[26]) Anyway, especially in the latter case there is still little experience with city projections.

As a data basis emission projections require a robust inventory. The start year for projections modelling usually is the most recent year of the inventory. The sectoral structure of the projections should correspond to the inventory structure, likewise all ancillary information that has been used. It is recommended to develop at least two scenarios, a baseline scenario (with current measures) and policy scenario (with additional measures). The models mostly applied are energy models which use activity data (fuel types and shares) from the energy balance and consider technological development. It is an advantage if the same computation algorithms are used for inventories and projections.[27]

As a good practice example for projections, the London air emission inventory 2010 (LAEI) [28] can be taken which includes spatial mapping. In this case projection factors were derived from statistical analysis of historical trends (this includes consumption data at regional and local level from 2005-2010). As a base year for the projections the year 2010 has been chosen, and the years 2012, 2015,

[24] http://www.epa.gov/ttn/chief/emch/temporal/
[25] http://www.eea.europa.eu/publications/emep-eea-guidebook-2013/part-a-general-guidance-chapters/8-projections
[26] http://data.london.gov.uk/datafiles/environment/0-Documentation.zip
[27] FAIRMODE (2010): Working Group 2 on Quality assurance of models in relation to the Air Quality Directive (AQD). Urban emission and projections (subgroup 3) Background document on the emission needs at local scale: http://fairmode.ew.eea.europa.eu/fol404948/sg3_background_document_oct10_draft.pdf/download
[28] http://data.london.gov.uk/datastore/package/london-atmospheric-emissions-inventory-2010

2020 were projected. Some simplifications were necessary, e.g. factors such as combustion temperature and efficiency have not been considered directly. The spatial resolution was set to 1km². The methodology distinguishes point sources emissions (process emissions and boiler emissions) and area emissions (e.g. domestic combustion of natural gas). The Department of Energy &Climate Change collects all data concerning gas consumption on sub-national levels[29]. In the case of natural gas, a linear annual reduction of gas use (domestic) was assumed (average reduction between 2005 and 2010) and applied for future years. Other fuels, e.g. coal, were assumed to remain constant due to a lack of more detailed information. In another case, scaling factors from the national projections were used. To model traffic emissions, the grid was refined. The LAEI applies the most recent emission factors from EMEP/EEA Guidebook.

**The CITEAIR II Good Practices Guide on Urban Air Quality Forecast[30] is** a handbook describing different methods for short-term forecasts which are compared to projections focussing on meteorological conditions to predict near future developments, whereas projections deal with long-term assessments and are driven rather by economic developments. Good practice guide distinguishes three different levels of complexity depending on the available sources and provides the following approaches:

- Statistical forecast: It is the simplest approach and based on statistics and existing links between pollutant concentrations, meteorological and physical parameters. The most common techniques used are e.g. linear regressions, classification and regression trees (CART) and neural networks, but also other types of methods can be applied. The advantage of this forecasting approach is the simplicity and that only few input data is required. It is quickly computed and less expensive compared to other approaches.

- Deterministic forecast: Such models are more complex and provide air quality information for a given time period related to a geographical area. One example is the Eulerian model which computes concentration levels over a grid (resolution of a few kilometres). They require mathematic equations that describe physical and chemical processes which influence pollutant concentrations. Gaussian models compute the concentration levels at specific points.

- Hybrid forecast: This approach makes use of measurements and model outputs. It combines the statistical approach with the deterministic forecast.

In general, it can be said, that similar to inventories, city projections and forecasts as well have difficulties to deal with spatial planning developments and the distinction between urban and non-urban areas (changes in energy supply). There is high uncertainty and the risk of double counting emissions at e.g. grid borders. Another problem is how to deal with multi scales in scenarios (EU policies vs. local policies). It can be summarized that the main challenge is the lack of appropriate data and the large effort that is necessary to compile cities' projections.

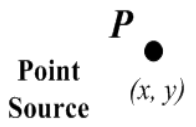
[29] https://www.gov.uk/government/collections/sub-national-gas-consumption-data
[30] http://www.citeair.eu/fileadmin/Deliverables_and_documents/Guidebook_Air_Quality_Forecast_-_final.pdf

## Spatial allocation and resolution

The accurate spatial allocation of emissions is of even importance as the overall emissions. Urban emission inventories usually should be divided in geographical features, which will be used to represent the emission sources. These features will define the geographical structure and are defined as point, line and area sources.

Point sources:

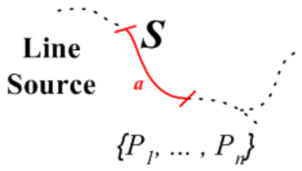
A point source is an emission source at a known location, represented by x and y coordinates that indicate the main point of an emission, such as stacks of larger industrial facilities, power plants and district heating plants.




For some sources such as large industrial facilities or airports it might be necessary to split one facility into several point and/or area sources.

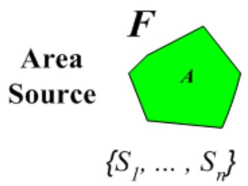
Line sources:

A line source is an emission source that exhibits a line type of geography and is represented by vectors with a starting node and an end node specifying an x, y location for each, e.g. roads, railways, waterways.




Area sources:

An area source covers all other source types which cannot be allocated at specific points or lines. Domestic heating emissions as well as traffic on minor roads are usually represented as area sources; in addition, industrial emissions not originating from single stacks or outlets (including mining activities) are represented as area sources. The delimitation of area sources should group emissions with similar temporal profiles within one “area”.




The spatial resolution of area sources should be high enough to reflect significant changes of emissions within a certain area and to reflect the spatial resolution of the model used. Area sources can also be represented in a regular grid of identically-sized polygon or grids.

This different spatial forms needs to be combined into a unifying format. This is usually a regular grid at a resolution appropriate to the spatial accuracy of the data inputs. The Air Implementation Pilot project investigated the spatial scales of the models and the underlying emission inventories (EEA, 2013a, 2013b; ETC/ACM, 2012a, 2013a, 2013b). The spatial scales range from 10x10 m² for high resolution modelling in Vienna up to 4x4 km² for large modelling areas such as Po valley.

Spatial emission data must be allocated to these grids to form emission maps. This is generally done by resolving the different spatial forms to a common grid so that different sectors/sources can be aggregated:

- Point sources can be allocated directly to the grid within which they are contained by converting the point source coordinate values to that of the coordinates used to geo-reference the grid or by intersecting the point with the grid.

- Intersecting line features with the grid will produce a dataset of shorter line lengths contained within each grid. The fraction of the original line length of the new line can be used to distribute the emissions from the original line to the grid cells.

- Intersecting area sources with the grid will produce a dataset of polygons contained within each grid. The fraction of the area of the new polygons can be used to distribute the emissions from the original polygon to the grid cells.

A detailed description how spatial emission mapping can be done is available in chapter 7 of the EMEP/EEA air pollutant emission inventory guidebook.

### Vertical resolution

The vertical resolution of the emission data is relevant with respect to the vertical model resolution. Stack heights and effective plume heights have to be specified for point sources; for area sources, the emission height has to be specified depending on the building height. Road traffic emissions are located immediately near ground.

Point sources and partly also area sources have to be allocated to the appropriate model layer. To each point source the stack height and the effective plume height has to be allocated. Emissions from domestic heating are usually handled as an area source. Nevertheless, a proper allocation of the release height, e.g. from multi storey apartment buildings can have a relevant impact on the quality of the modelling results.

### 4.2.2 Pollutants

Modelling usually is done for a subset of pollutants included in an inventory. Nevertheless, the inventory should cover those pollutants for which legal requirements exist, e.g. in the Air Quality Directive, the 4$^{th}$ Daughter Directive, and the NEC Directive, see section 3.1.

Next to these pollutants the inventory might also cover pollutants that become more and more important such as Black Carbon or ultrafine particles. The EMEP/EEA air pollutant emission inventory guidebook from 2013 provides information on Emission Factors for Black Carbon. The inventory should not only cover those pollutants for which modelling are performed in the short term. Next to air pollutants the inventory should also cover greenhouse gases. This allows for cross checking of data among pollutants.

Data on speciation of PM and VOC is necessary for chemical transport models. US EPA provides an extensive database[31] of chemical speciation of a large number of PM and VOC sources. But also $NO_x$ needs to be separated in NO and $NO_2$. For traffic, both COPERT and HBEFA 3.1 provide $NO_x$, NO and $NO_2$ emission data. In addition biogenic emissions might be necessary for VOC and PM.

### 4.2.3 Sectors

The sectors covered by the urban emission inventory should cover all that contribute relevantly to overall emissions of the main pollutants in a city. Usually, an emission inventory does not cover all sectors that contribute to pollutant levels (Figure 4.1). Dependent on the air quality model, the pollutant to be modelled and the extent of the model domain the emission data has to include additional sources, such as natural, biogenic or geogenic sources.

The necessary level of detail with respect to sectors can vary between pollutants, dependent on their relevance, which can sometimes be rather specific for individual cities (e.g. certain heating installations or structure of the vehicle fleet). The sub sectors and source categories should be detailed enough to allow for analysing the impact of abatement measures and different scenarios. It is also important to be aware of and document missing sources, such as natural ones, resuspension, etc.

Models in general require data on additional sources, which are often not covered in emission inventories. Sectors that might be of relevance (especially for PM modelling) are (ETC/ACM, 2013e):

- Resuspension of road dust, which is especially important for southern European cities during dry weather conditions and in northern and central European cities due to winter sanding. Resuspension and non-exhaust emissions become even more important in future due to a decline of exhaust emissions;
- Natural sources (volcanoes, sea salt, marine, biogenic NO and VOC, pollen, plant debris, lightning...) are mainly important for chemical transport models;
- Geogenic sources (wind erosion, Saharan dust) are of importance especially in southern European cities during episodes (mostly relevant for forecasting);
- Forest fires, where the Mediterranean basin and Portugal are often affected. Also Finland is impacted by forest fires in Russia (mostly relevant for forecasting).

It is beyond the scope of this guidance document to cover all of these sectors, but to focus on those known to be the most critical ones:

### Resuspension of road dust

Resuspended particles might contribute considerably to ambient $PM_{10}$ levels. However, due to the open discussion with regard to the definition of resuspension as a primary source, and the uncertainty in the methods used for the estimation of its effect, no methodology to estimate PM concentrations from resuspension is provided in the EMEP/EEA guidebook.[32] Nevertheless, there are some studies and projects from which emission factors might be derived.

The TRANSPHORM project developed a database for exhaust and non-exhaust vehicle emissions including resuspension and emissions due to studded tyres (TRANSPHORM 2013). Table 2 shows an excerpt of this database.

[31] http://www.epa.gov/ttn/chief/emch/speciation/

[32] EMEP/EEA emission inventory guidebook 2013: Chapter 1.A.3.b.vi Road vehicle tyre and brake wear 1.A.3.b.vii Road surface wear

**Table 2: $PM_{10}$ and $PM_{2.5}$ emission factors for resuspension of road dust for different vehicle types and driving modes (EF: emission factor in mg/km; SD: standard deviation of the EF in mg/km; PC: passenger car; LDV: light duty vehicle; HDV: heavy duty vehicle. Source: TRANSPHORM 2013).**

| | $PM_{10}$ | | | | | |
|---|---|---|---|---|---|---|
| | **Urban** | | **Rural** | | **Highway** | |
| **Vehicle** | EF | SD | EF | SD | EF | SD |
| **PCs and LDVs** | 40 | 50 | 400 | 500 | 800 | 1000 |
| **HDVs and Buses** | 60 | 80 | 510 | 650 | 1160 | 1400 |
| | $PM_{2.5}$ | | | | | |
| | **Urban** | | **Rural** | | **Highway** | |
| **Vehicle** | EF | SD | EF | SD | EF | SD |
| **PCs and LDVs** | 3.5 | 4 | 12 | 15 | 13 | 15 |
| **HDVs and Buses** | 5.2 | 7 | 16 | 22 | 18 | 25 |

The German consultant Lohmeyer[33] published various studies on resuspension of road dust, which can be of use in central Europe (Table 3). The latest study also gives an overview of further national projects, especially from Switzerland (Ingenieurbüro Lohmeyer GmbH & Co. KG, 2011). The numbers provided are different than those of the TRANSPHORM project. Whereas according to TRANSPHORM the highest emission factors apply to highways, these are lowest according to Ingenieurbüro Lohmeyer GmbH & Co. KG, 2011.

**Table 3: $PM_{10}$ emission factors in mg/km for non-exhaust emissions (wear and resuspension) for different vehicle types and driving modes**
(PC: passenger car; LDV: light duty vehicle; HDV: heavy duty vehicle. Source: after Ingenieurbüro Lohmeyer GmbH & Co. KG, 2011).

| **Driving mode** | **Non-exhaust emission factors in mg/km** | |
|---|---|---|
| | **PC and LDV** | **HDV** |
| Rural, highway | 30 | 130 |
| Urban main road | 26 | 100 |
| Urban main road heavy traffic | 33 | 350 |
| Urban main road congested | 40 | 700 |
| Urban minor roads | 45 | 1200 |

[33] http://www.lohmeyer.de/de/content/downloads/publikationen

In Southern Europe road dust resuspension is often higher due to higher dust loads and prevalence of dry weather conditions. Studies are available from Spain that provide emission factors for paved roads including the effects of street cleaning (Amato et al. 2010, 2012).

For a Mediterranean highway the estimated $PM_{10}$ emission factors varied from (Amato et al., 2012):

- 12 to 47 mg/km for all vehicle types with an average value of 22.7 ± 14.2 mg/km.
- 33-131 mg/km for heavy and light duty vehicles,
- 9.4-36.9 mg/km passenger cars and
- 0.8-3.3 mg/km for motorbikes.

These numbers are close to that from Table 3 by Lohmeyer.

For a street canyon in Switzerland the exhaust and non-exhaust emission factors are (Amato et al., 2010):

- LDV: 24 ± 8 mg/km,
- HDV: 498 ± 86 mg/km,

21% of these emissions were assigned to brake wear, 38% to resuspended road dust and 41% to exhaust emissions.

For a freeway the following numbers are provided:

- LDV: 50 ± 13 mg/km,
- HDV: 288 ± 72 mg/km.

### 4.2.4 Frequency of updates

Urban emission inventories are usually mainly of bottom up type and therefore are updated less frequently and regularly as national inventories (ETC/ACM 2013a). Nevertheless, the data for relevant sectors have to be up-to-date and should match those of other input parameters for models, especially meteorology and air quality data.

### 4.2.5 Comparability, consistency

The urban emission inventory should be consistent to the national and regional inventories as well as urban inventories for other cities to the extent possible (which currently is not the case, see section 2.2). This includes the underlying data, emission factors, projections, classification system and date of latest emission date. By establishing consistency it is possible to nest emission inventories or model results on different spatial scales.

### 4.2.6 Quality assurance and quality control

The quality assurance and quality control (QA/QC) measures for an urban emission inventory can in principle align to that of regional or national inventories – Parties to the United Nations Framework Convention on Climate Change (UNFCCC) and to LRTAP Convention as well have to produce and regularly updated national GHG respectively AP inventories that have to comply with stringent standards related to:

- transparency,
- accuracy,
- consistency,
- comparability and
- completeness

**Transparency** means that the data sources, assumptions and methodologies used for an inventory should be clearly explained, in order to facilitate the replication and assessment of the inventory by users of the reported information (sufficient and clear documentation). The transparency of inventories is fundamental to the success of the process for the communication and consideration of the information. The use of the

- Air pollutants: Nomenclature For Reporting (NFR) tables and the preparation of a structured Informative Inventory Report (IIR) and Inventory report of region/city, respectively.
- GHG: Common reporting format (CRF) tables and the preparation of a structured National Inventory report (NIR) and Inventory report of region/city, respectively.

contribute to the transparency of the information and facilitate regional, national and international reviews.

**Accuracy** is a relative measure of the exactness of an emission or removal estimate. Estimates should be accurate in the sense that they are systematically neither over nor under true emissions or removals, as far as can be judged, and that uncertainties are reduced as far as practicable. Appropriate methodologies should be used to promote accuracy in inventories.

**Comparability** means that estimates of emissions reported by Parties, Regions or Cities in their inventories should be comparable. For that purpose, Parties, Regions or Cities should use the accepted methodologies as elaborated in the Guidebooks and Guidelines as well NFR/CRF formats for making estimations and reporting their inventories.

**Completeness'** means that an annual inventory covers at least all sources and sinks, for all air pollutants/GHGs, for which methodologies are provided in the relevant Guidebooks and Guidelines[34].

**Completeness** also means the full geographical coverage of the sources of a Party, Region, and City. Where numerical information on emissions under any source category is not provided, the appropriate

[34] Air pollutant emission inventory: latest version of the EMEP/EEA air pollutant emission inventory guidebook 2013
GHG inventory: Mandatory are the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry.
The (mandatory) use by Parties of the 2006 IPCC Guidelines for national greenhouse gas inventories (2006 IPCC Guidelines) is expected in 2015; for several sources the 2006 IPCC guidelines can already be used.

notation key defined in the Reporting Guidelines should be used when filling in the reporting template and their absence should be documented.

**Consistency** means that an annual inventory should be internally consistent for all reported years in all its elements across sectors, categories and air pollutants / GHGs. An inventory is consistent if the same methodologies are used for all years of the inventory and if consistent data sets are used to estimate emissions. For projections, consistency means that a year of the submitted inventory is used as a basis.

To achieve these quality objectives, a QA/QC system should be in place that consists among others of general (Tier 1) and source category-specific QC (Tier 2) procedures, QA procedures (internal/external reviews, audits) as well as procedures regarding inventory improvement, reporting, documentation (references, assumptions, etc.) archiving. A further issue to be considered is the treatment of confidential data. The Table 6.1 in Volume 1 of the IPCC Good Practice Guidance (GPG) provides an overview of general QC checks to be made when compiling an inventory. These procedures apply to national emission inventories, but can partly also be taken as template for QC activities on urban emission inventories:

A fundamental element of a QA/QC system is a plan outlining QA/QC activities. In developing and implementing such a QA/QC plan, it is recommended where possible to refer to relevant standards, for example ISO 14064 (specifications for quantification, monitoring and reporting of GHG emissions in organizations) and/or ISO 9001 (requirements for Quality Management Systems)[35], promoting a process approach when developing, implementing and improving the effectiveness of a QMS to enhance customer satisfaction.

When used for air quality modelling, the model has to fulfil the **data quality objectives** (DQO) described in the Air Quality Directive, even though these apply only to the assessment of the current air quality, but not for other applications such as planning or forecasting. Nevertheless, emission inventories obviously play an important role in achieving these DQO.

FAIRMODE describes following checks as a minimum to locate possible biases (FAIRMODE, 2010):

- sources included in the inventory
- comparison of emission factors used for the main sectors and pollutants
- references and comparison of statistics used, differences in the statistical information used as activity rates (sources, criteria, updates)
- aggregation of the bottom-up inventory to a common geographic reference and comparison with the top-down approach.

[35] The IPCC Guidelines also provide a list of ISO standards that apply for the establishment of Emission Inventories. (Volume 1, Chapter 6).

- All this issues must be properly referred to or documented so that the inventory is transparent and it is possible to understand the reasons for potential differences, limitations and implications/recommendations for the interpretation of the modeling results based on this input. In addition, transparency plays a vital role on the exchange of information that may be relevant for other inventories/areas.

# 5 Conclusion & Recommendations

The following conclusions and recommendations for urban emission inventories, their comparability, open issues and needs from country/city perspective can be drawn:

Various European initiatives and projects provide valuable information for developing urban emission inventories. The main focus lies in general on greenhouse-gas emissions; however, air pollutants are often covered as well. Nevertheless, no single source of information exists that might cover all necessary information for urban inventories.

The main difficulties identified in these projects are comparability, consistency over time and completeness for the urban emission data. The adequate spatial and temporal allocation of these emission data is of high importance for air quality modelling.. Various approaches exist, but might be adapted to the specific needs of cities. Critical emission sources in this respect are those that are spatially and/or temporally variable and for which emission factors are of high uncertainty. This includes *inter alia* resuspension of road dust, construction activity, natural sources in general and biogenic sources in particular. Also activity data and emission factors for biomass burning are rather uncertain even though this source contributes considerably to pollutant levels in many cities.

On the other hand, national inventories reported under CLRTAP/UNFCCC are prevailingly of good quality[36] and comparable among the countries particularly for EU Member States.However spatial distribution of such inventories is actually available only by 50x50km² grid (0.1x0.1 degree from 2015 onwards) and temporal resolution is not reported.

Urban inventories often serve different purposes than national inventories. There are no reporting requirements for urban inventories; their main purpose is in general to support urban air quality management and GHG reduction programmes. This is done by scenario analysis to evaluate the impact of abatement measures for both air pollutants and GHG and by dispersion modelling for air pollutants. Therefore completeness of the inventory is often regarded being less important than their being "fit for purpose". Hence compared to national inventories, for urban inventories often less effort may be put in QA/QC and harmonisation with other cities or regions.

Nevertheless, urban inventory developers can benefit from the vast expertise gained for national inventories and should make effort to achieve consistency and comparability with national inventories. Even though QA/QC procedures and the pursuit of comparability and consistency of data require some effort, this is expected to be outweighed by the improved quality, comparability and consistency in the long run.

In general the recent EMEP/EEA air pollutant emission inventory guidebook 2013 provides a complete set of methods for developing a good quality urban emission inventory particularly for point

[36] See country review reports at http://www.ceip.at/review-of-inventories/stage-3-country-reports-2008-2013/

sources and area sources, however further improvement/development of locally relevant EFs might be needed for individual cities. Tier 3 methods also allow estimating emissions from the transport sector. The completeness and accuracy of activity data is considered critical for the development of urban inventories. Additional effort is necessary to cover the following sources, which can be of importance in some cities during specific periods of times (mainly relevant for PM modelling):

- Resuspension of road dust (also due to winter sanding)
- Sea salt
- Saharan dust, wind erosion
- Biogenic sources (primary and secondary)

Next to additional sources, urban emission inventories require additional effort compared to national inventories in order to cover the specific needs of urban air quality management:

- Spatial and temporal allocation of emission sources
- Chemical speciation of PM and VOC for chemical transport models
- Scenario analysis for evaluating the impact of measures

Concerning spatial resolution, the EMEP Guidebook provides guidance and approaches to derive spatially resolved data sets. The same principles can be used when developing urban inventories even if a finer scale of data is required than on national level.

# 6 References

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# 7 List of abbreviations

4DD................. 4th Daughter Directive
AD................... Activity Data
AIP .................. Air Implementation Pilot
AQ................... Air Quality
AQD................ Air Quality Directive
CITEAIR......... Common Information to European Air
CoM ............... Covenant of Mayors
COPERT ........ Computer Programme to calculate Emissions from Road Transport
CRF................. Common reporting format
DQO................ data quality objectives
EEA................. European Environment Agency
EF.................... Emission Factor
EI..................... Emission Inventory
EMEP............. Co-operative programme for monitoring and evaluation of the long-range transmissions of air pollutants in Europe
E-PRTR........... European Pollutant Release and Transfer Register
ETC/ACM....... European Topic Centre for Air Pollution and Climate Change Mitigation
EUROSTAT.... Statistical office of the European Union
FAIRMODE.... Forum for Air Quality Modelling
FAO ................ Food and Agriculture Organization of the United Nations
FP7.................. Seventh Framework Programme of the European Union
GHG................ GreenHouse Gas
HBEFA ........... Handbook Emission Factors for Road Transport
HDV................ heavy duty vehicle
IEA.................. International Energy Agency
IIR ................... Informative Inventory Report
IPCC................ Intergovernmental Panel on Climate Change
LAEI ............... London Atmospheric Emissions Inventory
LCP ................. Large combustion plants
LDV ................ light duty vehicle
LRTAP............ Convention on Long-range Transboundary Air Pollution
LULUCF Land Use, Land-Use Change and Forestry
LUZ................. larger urban zone
MEGAPOLI.... Megacities: Emissions, urban, regional and Global Atmospheric POLlution and climate effects, and Integrated tools for assessment and mitigation
NACE.............. Nomenclature statistique des activités économiques dans la Communauté européenne (Statistical Classification of Economic Activities in the European Community)
NEC ................ National Emission Ceilings
NFR................. Nomenclature for Reporting
OECD.............. Organisation for Economic Co-operation and Development
PC.................... Passenger Car
QA/QC ............ Quality Assurance/Quality Control
SCD................. sub-city district
SEAP............... Sustainable Energy Action Plan
SNAP .............. Selected Nomenclature for Air Pollution
TACCC ........... Transparency, Accuracy, Completeness, Consistency, Comparability
TRANSPHORM Transport related Air Pollution and Health impacts - Integrated Methodologies for Assessing Particulate Matter
UNECE ........... United Nations Economic Commission for Europe
UNFCCC ........ United Nations Framework Convention on Climate Change
USEPA............ United States Environmental Protection Agency

## Abbreviations of pollutants

As ............... Arsenic

B(a)P .......... Benzo[a]pyrene
BC .............. Black carbon
benzene ...... Benzene

Cd............... Cadmium
$CH_4$............. Methane
CO .............. Carbon monoxide
$CO_2$............. Carbon dioxide
Cr ............... Chromium
Cu............... Copper

EC .............. Elemental carbon

HCB ........... Hexachlorobenzene
HCH ........... Hexachlorocyclohexane
HFCs .......... Hydrofluorocarbons
Hg............... Mercury

$N_2O$ ............ Nitrous oxide
$NH_3$ ............ Ammonia
Ni ............... Nickel
NMVOC..... Non methane volatile organic compounds
NO.............. Nitrogen oxide
$NO_2$ ............ Nitrogen dioxide
$NO_x$ ............ Nitrogen oxides

OM ............. Organic matter

PAH ........... Polycyclic aromatic hydrocarbons
Pb ............... Lead
PCB............ Polychlorinated biphenyl
PCDD/F ..... Polychlorinated dibenzo-p-dioxins and Polychlorinated dibenzofurans
PFCs........... Perfluorinated compounds
PM.............. Particulate matter
$PM_{10}$ ........... Particulate matter < 10 µm
$PM_{2.5}$........... Particulate matter < 2.5 µm
POPs........... Persistent organic pollutants

Se ............... Selenium
$SF_6$.............. Sulfur hexafluoride
$SO_2$ ............. Sulfur dioxide

TSP............. Total suspended particles

VOC ........... Volatile organic compounds

Zn ............... Zinc