The Art of Emission Inventorying

TNO | Innovation for Life

Tinus Pulles and Dick Heslinga

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A pragmatic approach to Emission Inventories for various applications

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Preface

Emission inventories have been, and still are being, compiled for a broad range of applications by an ever increasing number of institutions and scientists as they constitute the basic information that is needed for any study on the environmental issues of air pollution and climate change. Over time many - more or less independent - emission inventorying approaches have emerged while, at the same time, the requirements demanded of these inventories have been elaborated. The result is a rather confused and diverse picture of emission inventorying as a more or less scientific and technical activity.

Since 1974 the Netherlands Organisation for Applied Scientific Research TNO has been involved in the development of methods for emission inventorying, having applied these methods in emission inventories on different temporal and spatial scales. Over these last 35 years, TNO has gained broad understanding of the possibilities, difficulties and pitfalls of emission inventories.

Emission inventorying is not a simple task: it takes a lot of time and effort before a complete inventory is compiled. Inventories always seem to be available at a very late point in time or, when they are on time, tend to require updates and recalculations later on. Furthermore, one can almost always imagine missing sources or, at least, suppose these exist. Therefore, the emission inventories are easily seen as the scapegoat if a mismatch is found between modelled and observed concentrations of air pollutants.

The recent publication of the next generation of emission inventorying guidance documents for greenhouse gases (IPCC 2006 Guidelines for national greenhouse gas inventories [1]) and air pollutants (the revised EMEP/EEA Guidebook for air pollutant emission inventories [2]) contain important contributions to both sets of improved emission estimation methods by TNO's experts. TNO provided a coordinating lead author for the energy volume of the IPCC 2006 Guidelines and authors for many other volumes. The revision of the EMEP/EEA Guidebook was commissioned by the European Commission to a consortium, led by TNO. We expect these recently updated guidelines to stabilise the requirements for national emissions reporting for the coming years and so this seems to be an excellent moment to provide the emission inventorying community with an overview and summary of all aspects of emission inventorying, taking into account the most recent developments and understanding in both the IPCC and EMEP emission inventorying methods.

This publication aims at distilling and presenting a pragmatic and practical approach of emission inventorying, which could support the emission inventorying community in its continuous effort to improving inventories for many applications, both in policy and in science. This will increase mutual understanding between the scientific and policy communities using well developed inventories for their respective purposes. Those countries and experts that are in the initial stages of setting up inventories and inventory systems can use the approaches presented here to quickly and efficiently move forward in a direction that is comparable and consistent with the approaches taken by other countries.

We hope that this publication, in which TNO makes its long-standing experience and expertise in this field available for anyone compiling or improving emission inventories, will also contribute to a broader understanding and a better harmonisation of the many different inventories that are available in various countries.

Tinus Pulles,

Contents

Index of Figures

Index of Tables

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The picture in Figure 1-1 was kindly provided by ***Stichting Johan Dijkstra*** in Groningen.

1 Introduction

1.1 Emissions: setting the stage

1.1.1 Emissions in the environment

The first documented person to suffer irreversible health effects of air pollution is reputedly Caius Plinius Secundus, (AD 23 – August 24, AD 79), better known as Plinius the Elder. Although some doubt has been expressed as to whether the fumes emitted by the eruption from the Vesuvius volcano in the year 79 may have caused his death [3], many believe that he was indeed the first person known to have died from air pollution, as described in a series of letters from his nephew Plinius the Younger [4]. One could argue, therefore, that the relationship between emissions and health effects, in this case the death of Plinius the Elder, has been known for almost 2000 years.

From the onset of the industrial revolution smoking stacks were seen as evidence of the growing possibilities of the developing technology and a key indicator of the increasing wealth in the industrialised world. Triggered by the London smog of 1952, the perception of the health problems and damage caused by air pollution from smoking stacks made citizens and policymakers understand that this was a problem that had to be tackled. So almost 2000 years after the account of Plinius the Younger, the relationship between emissions and health was again observed.

Figure 1-1 The Industry in Enschede, Johan Dijkstra; an image used in schools in the Netherlands in the 1930s

Although emissions were already recognised as the primary cause of air pollution, it was not until the early 1970s, with the arrival of computers and electronic databases, that systematic attempts were undertaken to quantify the emissions of air pollutants into the atmosphere.

Understanding emissions is therefore at the core of understanding the environmental pollution that is due to societal and economic activities. Emissions represent the ***pressures*** that result from the activities, or ***drivers***. These pressures cause the ***state*** of the environment to change, producing ***impacts*** on health and ecosystems as well as economic damage (the so-called DPSIR approach [5]; Figure 1-2). Both public and private decision makers can ***respond*** to this by influencing the drivers, the pressures caused by the drivers (emission standards) and, sometimes, the influence of the emissions on the concentrations in the environment ("high stack policy"). In some cases, responses can also be directed towards reducing impacts or adapting to them.

This DPSIR approach is elaborated below for two environmental themes to explain the role of emission inventories:

1) climate change (section 1.1.2)
2) air pollution (section 1.1.3)

Section 1.1.4 presents some ideas on so-called integrated or multi media inventories, containing data on emissions to water and land in addition to air. However, the scope of this publication is restricted to air emission inventories.

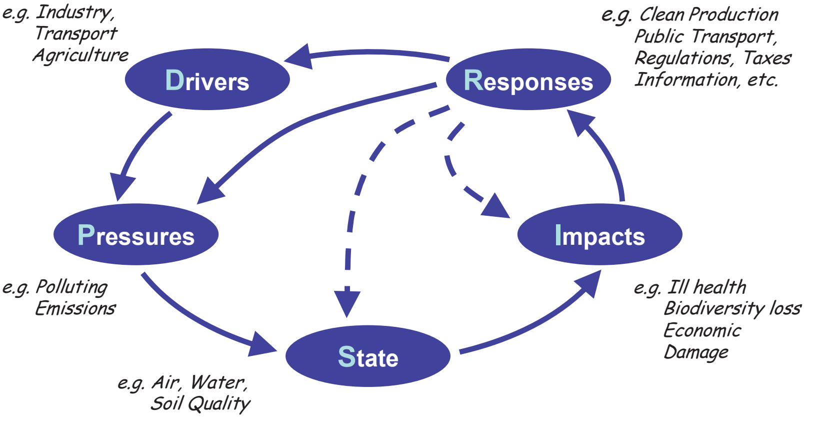

Figure 1-2 The so-called DPSIR model of the causal chain in environmental pollution; adapted from [5]

1.1.2 Climate Change

The anthropogenic emissions of so-called greenhouse gases to the atmosphere change the thermal properties of the atmosphere such that, on average, a slightly higher proportion of the incoming radiation from the sun is absorbed. This causes the atmosphere to warm. The Assessment Reports of the Intergovernmental Panel on Climate Change [6, 7] describe the science of this complicated system in detail.

Since climate change is a global scale problem, where the processes show long time scales and large geographical scales, the DPSIR scheme needs to be applied at these larger temporal and spatial scales.

- ***Drivers***: Activities contributing to the emissions of greenhouse gases are mainly fossil-fuel combustion processes. Some specific industrial processes (including primary steel, cement, apidic acid production), agriculture and waste treatment have relatively minor, but important, contributions.
- ***Pressures***: Due to the activities, emissions of greenhouse gases (carbon dioxide, methane, nitrous oxide, a series of fluorinated gases) take place. In Climate Change studies emissions are generally presented as global or continental totals whereas national emission totals are the most relevant in policy studies.
- ***State***[1]: Anthropogenic emissions of greenhouse gases shift the global equilibrium of "natural" emissions and uptakes towards higher concentrations of greenhouse gases in the atmosphere as well as the radiation balance of the global atmospheric system.

[1] The distinction between "state" and "impact" here is a matter of taste. We interpret "state" as concentrations of pollutants or gases. The impact then is the effects of the changing heat balance of the atmosphere on climate, ecosystems and human societies.

- *Impact*[1]: The changing heat balance of the atmosphere leads to climate changes: an increase in average temperatures, shift in precipitation intensities and more frequent extreme weather events, all of which have substantial effects on ecosystems and human societies.
- ***Responses*** in the field of climate change can be:
  - the reduction of emissions (***mitigation***), either by reducing the use of fossil fuels or by capturing the greenhouse gases from flue gas streams. Once the greenhouse gases are released, no realistic possibilities are available to influence the resulting concentrations in the atmosphere and the impacts on the climate[2].
  - careful spatial planning and developing the physical infrastructure (***adaptation***) can help to reduce the impact of changing climate on ecosystems and human societies.

In the climate change field, emission data are used both in monitoring the development of national and global emissions and as inputs to climate models.

1.1.3 Air Pollution

Air pollution problems show a wide variety of temporal and spatial scales, from very short-term and local problems of odorants to the continental scale problems of acidification with time scales of several days to weeks whereby a series of physical processes is relevant (see Figure 1-3):

- ***Emissions*** result from economic and societal activities like industry, transport, residential heating and product use, agriculture and waste treatment. Each of these activities is associated with the emissions of a range of pollutants to ambient air.

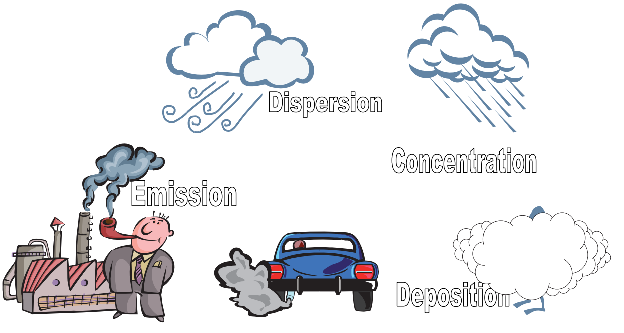

Figure 1-3 Emission, dispersion and concentrations in air pollution

- Once in the atmosphere, the pollutants are ***dispersed*** with the wind and diluted manly due to turbulences in the air flow.
- This dispersion transports and dilutes pollutants in the ambient air. In general, the ***concentrations*** of these pollutants will be lower the more distant they are from the source.

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2 Richard Branson announced a prize of $25m for whoever can demonstrate a commercially viable design that results in the removal of anthropogenic, atmospheric greenhouse gases so as to contribute materially to the stability of Earth's climate (http://www.virginearth.com/).

- Pollutants dispersed in the atmosphere will also be washed out by precipitation or be absorbed on surfaces or in biomass. These processes are known respectively as wet and dry ***deposition***.

In terms of the DPSIR model, the emissions again represent the ***pressures*** caused by the ***drivers***. Dispersion and deposition are responsible for the ***state***, expressed as concentrations in the ambient air or accumulated pollutant mass on the surface or in biomass. ***Impacts*** will occur when polluted air is inhaled or is absorbed by anything that is on the surface. This could lead to adverse health and damages to ecosystems or the built environment.

The options for ***response*** available to public and private decision makers will depend on the scale of the air pollution problem. For all scales, the response could be to reduce the intensity of the drivers responsible for the emissions or to implement abatement technology to reduce the emissions per unit of activity. In the case of relatively short temporal or spatial scales, the concentrations can be influenced by increasing the height of the emission point (high stacks). Also careful spatial planning could ensure that sensitive ecosystems or humans are not exposed to the highest concentrations.

1.1.4 Multi media inventories

Apart from emission to air, emissions to land and water might also be caused by the same activities and the DPSIR approach would also allow such emissions, caused by the same or different drivers, to be dealt with in emission inventories. This suggests that it could be helpful to develop integrated emission inventories, comprising emissions and releases to all relevant media: air, surface water, sewage systems and land. The latter would also include the off-site transport of solid and liquid waste streams.

Pollutant Release and Transfer Registers (see section 1.3.3 below) might be seen as such integrated inventories although this possibility has not been investigated nor implemented to any significant level for national inventories with the exception of the Netherlands. In the Dutch Emission Registration emissions to water have been included since the very outset of the inventorying activities.

1.2 Emission Inventorying

As indicated above, emission data are at the core of understanding environmental problems. Such emission data are collected in emission inventories that have been used in environmental policymaking since the early 1970s. They have developed in more or less explorative activities aimed at understanding the emerging problems of air pollution in highly industrialised areas such as the Ruhr in Germany and Rijnmond near Rotterdam [8] as well as in the USA [9]. The aim of such activities was to establish the causes of "***a foul and pestilent congregation of vapours***" (see Emission Inventories have been and are still being compiled for a broad range of applications in the policy environment and in scientific studies:

- Emission Inventories constitute a basic tool in monitoring progress of environmental policy. These applications include national submissions of inventory data to international conventions and protocols (***policy applications***);
- ***Scientific applications*** of emission inventories occur in most cases as inputs for both retrospective and prospective assessments of environmental pressures, ambient concentrations of pollutants and impacts.

Table 1 presents some typical examples of these different types of inventory applications.

Box 1) that made living in such industrialised areas less pleasant and unhealthy due to the fumes and smoke emitted from industry, transport and other economic and societal activities.

From the early 1980s onwards, emission inventories have also been used as input information in air quality modelling studies, mainly from a local air quality management perspective and later also in continental air pollution studies.

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Box 1 Hamlet, Prince of Wales in Act II, scene II of Shakespeare's Hamlet

"... I have of late--but wherefore I know not--lost all my mirth, forgone all custom of exercises; and indeed it goes so heavily with my disposition that this goodly frame, the earth, seems to me a sterile promontory, this most excellent canopy, the air, look you, this brave o'erhanging firmament, this majestical roof fretted with golden fire, why, it appears no other thing to me than a foul and pestilent congregation of vapours. "'What piece of work is a man!"' how noble in reason! how infinite in faculty! in form and moving how express and admirable! in action how like an angel! in apprehension how like a god! the beauty of the world! the paragon of animals! And yet, to me, what is this quintessence of dust? man delights not me: no, nor woman neither, though by your smiling you seem to say so".

Table 1-1 Examples of emission inventories for different types of applications

Type of application	Inventory examples
Policy applications	National greenhouse gas inventories, submitted to the United Nations Framework Convention on Climate Change (UNFCCC [10])
	National air pollutant inventories submitted to the United Nations Economic Commission for Europe's Convention on Long Range Transboundary air Pollution (LRTAP [11])
	Pollutant Release and Transfer Registers (PRTR) like the USA Toxics Release Inventory (TRI, [12]) and the European Union's EPER system (EPER [13])
Scientific applications	The GEIA emission databases (GEIA [14])
	The EDGAR emission inventories (EDGAR [15])
	The TNO Emissions Assessment Model (TEAM [16, 17]

Emission Inventories for both types of applications tend to be large sets of numbers describing the contributions of many individual sources to the emissions of certain pollutants at certain locations or areas at a certain point in time. The emissions of all these sources are estimated using data from different origins and entering these in mostly, rather simple emission estimation models, assuming a linear relationship between the intensity of the activity in a source and the resulting emission. The proportionality constants in these simple models are broadly known as ***Emission Factors***.

Compiling an emission inventory is not a simple task, due to the usually large amount of data, the various origins of the data sources and the difficulties in finding applicable and appropriate emission factors for all these different sources at different locations and different times. The purpose of this publication is to provide a pragmatic approach to emission inventorying and an overview of all contingent aspects for inventories applied both in policy processes and in scientific studies.

1.3 Emission Inventories in Environmental Policy

Within several international conventions and protocols, parties have agreed to regularly report emission inventories. In many cases, the European Union has developed legislation derived from these international conventions and protocols.

Emission inventories have been and are used in:

- identifying and characterising an environmental policy problem
- negotiating emission reduction targets
- monitoring progress towards meeting these targets

Emission inventories for air pollutants have been developed since the 1970s, whereas emission inventorying for greenhouse gases only started developing in the 1990s.

1.3.1 Air Pollutants

Information on emissions of air pollutants has been used since the early 1970s to study the causes and effects of air pollution problems. Some of the oldest emission inventory programmes date from this time. The ***Emissieregistratie*** in the Netherlands was one of these early inventories [8].

<u>UNECE Convention on Long Range Transboundary Air Pollution</u>

As a consequence of the so-called acid rain issue, the United Nations Economic Commission for Europe (UNECE) led the development of a convention on Long Range Transboundary Air Pollution (LRTAP) and a series of protocols within this convention [11]. Emission inventories have been instrumental to the development of this convention and the protocols as they allowed the contributions of different sources to the problem to be analysed. Emission inventories are used in integrated assessment models to identify optimal abatement strategies in terms of national emission targets, enabling the parties to the convention to negotiate and establish such emission reduction targets.

Once the targets have been accepted, emission inventories are used to monitor progress towards meeting these targets. Parties to the convention and the protocols are obliged to report their national inventories annually, following the provisions of the LRTAP Emission Reporting Guidelines [18]. Within the framework of the LRTAP Convention a set of emission estimation methods has been developed and published by the EMEP Task Force on Emission Inventories and Projections, based on earlier work within the European CORINAIR project [19, 20]. This document is known as the (EMEP/CORINAIR or EMEP/EEA) ***Guidebook*** [21,2] that provides procedural guidance and includes a provision that requests parties to the LRTAP Convention to use the Guidebook as a source of methods (Figure 1-4).

	What, when, how? Commitment	*How to do what you committed yourself to do?*
	Procedural Guidance	**Technical Guidance**
Climate Change	UNFCCC Guidelines for Reporting and Review	IPCC Guidelines (1996 + GPG)
Air Pollutants	LRTAP Emission Reporting Guidelines	EMEP/EEA Guidebook

Figure 1-4 Procedural and technical Guidance in emission inventory reporting for international conventions and protocols

1.3.2 Climate Change

Emission inventories are also at the core of the international agreements on climate change. The use of inventories to monitor progress towards the agreed emission targets in particualr is an important application both in the convention and under the Kyoto protocol.

<u>UN Framework Convention on Climate Change (UNFCCC) and Kyoto protocol</u>

The so-called Annex I Parties[3] to the UNFCCC have agreed to report their national total emissions of greenhouse gases annually. UNFCCC has set out very detailed guidelines on how to report such annual emissions. These UNFCCC Guidelines for reporting and review [22] define what needs to be reported, how the reports should appear and the deadlines. In addition, it arranges for an independent review of the national submissions.

One of the requirements of the UNFCCC Reporting Guidelines is to apply the methods as provided by IPCC, and more precise the "***methods as described in the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories [**23**] as further elaborated in the IPCC Good Practice Guidance [**24**,** 25**]***". Together these documents provide the technical guidance to be used to report to the Climate Convention. It is similar, albeit a bit more formalised, to the LRTAP Convention (see Figure 1-4).

The parties of the Kyoto Protocol have to report a limited amount of additional data and in almost all[4] cases they add this to the report under the Convention thereby combining the two reporting obligations.

In 2006 IPPC published a new set of technical guidelines, the ***2006 IPCC Guidelines*** for National Greenhouse Gas Inventories [1]. These updated guidelines were developed by IPCC upon request by the UNFCCC in preparation for the negotiations for the "post-Kyoto commitments". Reporting under the Kyoto Protocol, however, should still use the 1996 Guidelines, since the commitments have been negotiated and agreed on the basis of the earlier version.

1.3.3 Pollutant Release and Transfer Register: PRTR

Inventories based on a "Community Right to Know" or "Public Access to Information" principles are compiled from a different perspective [26]. In many countries industrial facilities need a permit to operate processes that cause environmental pressures. Authorities

[3] Annex I of the Climate Convention lists the industrialised countries that have obliged themselves to abate climate change

[4] France reports differently to the UNFCCC and to the Kyoto Protocol as a consequence of France's reservation when ratifying the Kyoto Protocol: the *collectivités d'outre-mer* are not included in the Kyoto Protocol, whereas they are included in the Convention.

have to balance the interests of different actors when issuing such permits and will reflect this balance in the conditions and requirements included in the permit. Civilians living near the facilities generally have quite different levels of understanding and information on the processes and the environmental impact compared to the companies applying for the permit. In a democratic context, however, a level playing field for all actors involved in permitting decisions is paramount to acceptance of the decisions. ***Pollutant Release and Transfer Registers*** (***PRTR***) have been developed to inform the interested citizen in this type of policy processes.

PRTRs typically compile emission data by (electronic) questionnaires at the level of individual industrial facilities or plants. Data are published on easily accessible websites as soon as they have been collected and, in most cases, validated by competent authorities.

The ***UNECE Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters*** was adopted on 25th June 1998 in the Danish city of Aarhus [27]. Parties to this convention have agreed to establish a Pollutant Release and Transfer Register (PRTR; PRTR Protocol [28]) which, amongst others

- is publicly accessible through Internet, free of charge
- is searchable according to separate parameters (facility, pollutant, location, medium, etc.)
- has limited confidentiality provisions
- allows for public participation in its development and modification.

Examples of these PRTRs are the US Environmental Protection Agency's Toxics Release Inventory (TRI [12]; see also [29]) and the European Pollutant Emission Register (EPER, [13]). A number of other countries have established similar systems.

Integrating or even reconciling data collected in a PRTR into a national inventory is not trivial, mainly because the PRTRs have been developed fully independently of national emission inventories. Due to this historical fact, definitions of different relevant concepts in the inventories are incompatible in some cases. Data collected within the framework of a PRTR, therefore, may or may not be used in compiling a national inventory as described in the previous section.

1.3.4 European Union

The European Union has played an active role in the early development of emission inventories [19, 20] by facilitating and coordinating the CORINAIR inventory in the mid 1980s and early 1990s.

At present, the European Union is a party to the LRTAP, the UNFCCC and the Arhus Conventions and, as a consequence, has to produce its own inventories. To enable this, the European Union has developed legislation requiring member states to regularly report their emissions also to the European Commission. The main legislative instruments for this are:

- The Monitoring Mechanism of Community CO_2 and other Greenhouse Gas Emissions [30], implementing the reporting requirements for UNFCCC and the Kyoto Protocol within European law
- The National Emission Ceilings Directive [31], which amongst others is translating the reporting requirements of the UNECE LRTAP Convention into European legislation
- The E-PRTR decision [32] to establish a European wide PRTR.

1.3.5 National and local policies

National and local climate and air pollution policies need information on emissions. Whenever national policy needs additional information on top of the national obligatory reports to the conventions, this can and, in most cases, is included in the national inventory compilation processes. In addition, sub-national regions might develop their own inventories. Actually, in a number of countries inventories have originally been set up to match national policy demands for information.

The need for the intra-national harmonisation of inventories to allow comparisons and negotiations has increased the importance of international guidance above national requirements. In many countries, but not all, the structure of the inventory systems has indeed been adapted to international requirements. In some countries (including the Netherlands and France) the inventory systems have been expanded, sometimes with complicated allocation mechanisms to transpose the national information to the international guidance.

In the EU member states, as in most countries with a reasonably well functioning environmental programme, the IPPC Directive [33] requires a permitting system for major sources of air pollutants. The permits are aimed at restricting the environmental pressure caused by the activities and include technical details of the (industrial) processes. Many older emission inventory systems are therefore based on a technical description of the (industrial) world. Inventories based on these systems contain information on process units, installations, stacks and abatement technologies. They also contain information on flows, temperatures and pollutant concentrations. While this information is scarcely used in international emissions reporting, it is very useful in establishing emission reduction programmes.

1.4 Emission Inventories in Science

The major applications of emission inventories in science are those of input data needed for air quality (atmospheric transport and chemistry models) or atmospheric energy balance studies (climate models). As opposed to the emission inventories used in reporting to international obligations, scientific inventories do not need to comply with the procedural and technical guidance (Figure 1-4) used under these conventions.

Usually, national inventories submitted to UNFCCC and LRTAP or published in PRTRs are the only more or less publicly and freely available complete data, which makes them an important source of information available to all scientific studies. The scientist must, however, always be aware that these data have not been collected on the basis of scientific reasoning but are only meant to support a specific policy process [26].

Scientific applications of inventories also frequently require a higher resolution, both geographical and temporal, depending on the specification of the atmospheric transport and chemistry models used. The spatial and temporal resolution of these models is, in its turn, generally determined by the type of scientific questions that must be answered.

One of these models, the LOTOS/EUROS model [34], for instance, uses a temporal resolution of one hour and a spatial resolution down to 5 to 10 km grid cells. The model obviously needs both meteorological data and emissions at the same temporal and spatial resolutions as the inputs. The spatial resolution of national emission inventories is increased by distributing emissions by means of proxy variables [35] while preparing the input data for this model. The temporal resolution is increased in the model based on monthly, weekly and hourly patterns of activities [34].

2 Data quality

2.1 Perspectives on data quality

The characterisation of data quality is dependent on the final application and use of the data. The intended use is therefore relevant for any analysis of this concept with respect to emission inventories. As indicated above, two major fields of application of emission inventory data can be discerned:

- for scientific purposes, including the assessment of the effectiveness of abatement strategies
- for policy purposes:
  - monitoring of progress of environmental policy;
  - compliance checking, both of individual polluters with respect to permits and emission standards and of countries in relation to international treaties and protocols.

Users in scientific applications will be very eager to know the quality of the data in terms of the true values. If data are being used in (inter)national policy making, users will be mainly interested in the acceptance of the data by the different institutions involved in a specific policy process. In compliance setting the convincing power of the information will be crucial. From this we might derive three different perspectives on the concept of data quality in emission inventories. Table 2-1 presents the perspectives of the scientist, the policymaker and the lawyer.

Table 2-1 Perspectives on data quality depends on the intended user of the data

	Perspective	High quality if …
Scientist	Scientific debate: search for weaknesses and errors; falsification	… it produces predictions that are confirmed
Policymaker	Political debate: search for consensus and agreement; compromise	… everybody involved agrees
Lawyer	Judicial debate: search for proof or doubt; persuasion	… it convinces a judge or jury

The ***scientist*** is looking for the truth by trying to find weak spots in theory and data and by falsification. The data quality will be high if the data or predictions based on them are confirmed by independent estimates. If falsification occurs, the scientist will work on it until he or she understands the reasons and has derived better data or a better theory.

A ***policymaker*** is looking for agreement and will therefore be more inclined towards reaching consensus and compromise. In many cases a policymaker does not have enough time to wait until all scientific problems are solved: a company might have asked for a permit for a new activity and regulations prescribe a decision to be made within a given period of time or a country has to report its emissions according to a protocol before a certain fixed date. The policymaker will have to decide despite the presence of a number of uncertainties and a number of phenomena that might not be fully understood.

The ***lawyer*** has a different perspective again. He or she might be involved in compliance checking and will consider the data of high quality if they are convincing.

These perspectives on data quality will also influence the “truth” and “quality” perspectives and hence *verification* and *validation* of emission inventory data. The next section will analyse these concepts against the perspectives of the different users.

2.2 Quality criteria

2.2.1 Policy oriented quality criteria: TCCCA

As indicated above, a high quality inventory from the perspective of policy applications should be one in which all parties involved agree upon the methods used. This emphasises the importance of the procedural [18, 22] and technical guidance [21, 23, 24, 25, 1] developed under the conventions.

These guidelines also define the quality criteria that apply to national inventory submissions. These quality criteria (also called TCCCA) were first developed and defined as part of the UNFCCC process [22] and include:

Transparency: the assumptions and methodologies used for an inventory should be clearly explained. Transparency of inventories is fundamental to the success of the process for the communication and consideration of information.

Consistency: an inventory should be internally consistent in all its elements with inventories of other years. An inventory is consistent if the same methodologies are used for all subsequent years and if consistent data sets are used to estimate emissions or removals from sources or sinks.

Comparability: estimates of emissions and removals reported by parties in inventories should be comparable. The allocation of different source/sink categories should follow the IPCC Guidelines classification [23, 1].

Completeness: means that an inventory covers all sources and sinks, as well as all gases, included in the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories.

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.

The recent revisions of the procedural [18] and technical guidance [21] for inventories under the LRTAP convention have also adopted these quality criteria for air pollutants, slightly amending the definitions to air pollutant emissions without changing each criterion in itself.

As a result of this, the policy oriented user of a validated inventory compiled according to the guidelines can trust that such an inventory complies with the convention or protocol and hence can be used in judging whether the targets, as set in the conventions and protocols, are met.

Although the policy oriented perspective on data quality does not guarantee that the data are scientifically true or reflective of the latest scientific achievements, one cannot conclude that the inventories are inappropriate in delivering what they are meant for: confidence that the parties to an international convention report their progress towards the targets in a transparent, consistent, comparable, complete and accurate way [36]. The difference between the policy approach and the scientific approach here boils down to the difference between “***good***

enough" for the policy application and "***the best***" according to the latest scientific understanding.

By freezing the reporting guidelines, both procedurally and technically during the commitment period of a convention, the parties also can be sure that the rules do not change during the between the times of agreeing to the commitment and the final compliance checks.

2.2.2 Science oriented quality criteria: "true"

Following on from the above distinction between policy oriented and science oriented quality perspectives, the scientific quality of an emission inventory is tested by producing some kind of predictions that can be tested experimentally. An example of such a study can be found in [37], but more similar studies (see also [34]) have been published.

In the study by Van Aardenne et al [37] a spatially disaggregated emission inventory is used together with atmospheric transport modelling to predict ambient air concentrations as a function of wind direction. The predicted wind dependent concentration for specific pollutants are then compared with the observed wind direction dependent concentrations at specific ambient air quality measuring sites. Differences between the predicted and the observed wind direction dependencies are then interpreted as indications of problems, errors or mistakes in the inventory.

Schaap et al [34] tested the quality of the LOTOS/EUROS model, including the emission data used as input for this model, comparing its output to observed concentrations as well but at a more aggregated level than Van Aardenne et al. [37]. These authors formulate their conclusions in terms of the model overestimating or underestimating the observed concentrations. It is quite difficult to draw conclusions in terms of the quality of the emissions database, the model algorithms or the measurements separately.

2.2.3 "Good Enough" versus "The Best"

Most, if not all, inventories are compiled in a project environment that needs to deliver a result with a predefined quality within the boundaries of limited resources and time. In practice, therefore, the inventory compiler will need to make decisions and trade-offs to ensure the quality objectives are met within the available time and budgets. Inventory compilation for international obligations is typically embedded within an annual cycle. All international emissions reporting obligations allow for "recalculation" of previously reported data in subsequent submissions. This mechanism can be used to gradually improve the quality of the inventory.

It also allows the development of a very pragmatic approach aimed at compiling an inventory that is good enough (i.e. meets the reporting obligation's quality requirements) rather than the "best". In other words, it suggests a mechanism to prioritise the work that has to be done and plan it in a way that the required quality is achieved within the available time and resource constraints.

In scientific applications of inventories, it is also possible to define the required quality of the inventory beforehand. For applications in ambient air quality monitoring such quality criteria tend to be defined in terms of activity, spatial, chemical or temporal resolutions: the models require a specific detail in the ***why***, ***where***, ***what*** and ***when*** dimensions of the inventory (chapter 3, Dimensions of the Inventory). With such a quality requirement the inventory can either be built from scratch or developed from inventories as submitted to international conventions by aggregating or speciating where needed to match the model's input requirements.

So in both types of application, the intended use of the inventory data is the main factor determining the detail and quality to be obtained. An emission inventory is thus best compiled for a clearly defined purpose (the "client"). The resulting inventory should be ***fit for purpose***.

2.3 Verification and Validation

With respect to emission inventories, two more or less independent quality concepts are crucial: ***Verification*** and ***Validation***. These two concepts are related to the science and policy oriented perspectives on data quality respectively. The definitions, taken from the glossary of the IPCC Good Practice Guidance [24], are presented in Figure 2-1. These are fully consistent with those used in the EMEP/EEA Guidebook [2].

In Figure 2-2 the difference between validation and verification is explained schematically and placed in relation to the development of emission inventories and inventory guidance. Validation checks whether or not the guidelines have been applied; verification checks whether the data resemble the real world emissions (are ***true***).

VALIDATION

Inventory definition: Validation is the establishment of sound approach and foundation. In the context of emission inventories, validation involves checking to ensure that the inventory has been compiled correctly in line with reporting instructions and guidelines. It checks the internal consistency of the inventory. The legal use of validation is to give an official confirmation or approval of an act or product. [6]

VERIFICATION

Inventory definition: Verification refers to the collection of activities and procedures that can be followed during the planning and development, or after completion of an inventory that can help to establish its reliability for the intended applications of that inventory. Typically, methods external to the inventory are used to check the truth of the inventory, including comparisons with estimates made by other bodies or with emission and uptake measurements determined from atmospheric concentrations or concentration gradients of these gases.[6]

Figure 2-1 Definitions of Validation and Verification from the IPCC Good Practice Guidance [24]

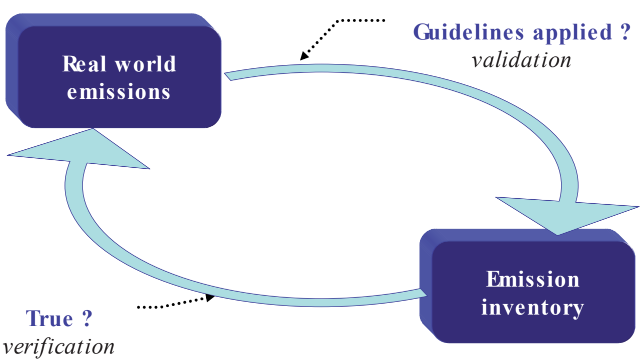


Figure 2-2 Schematic representation of the concepts of validation and verification

When the inventory is validated, it has been shown that the guidelines have been correctly applied and so the emissions report is accepted for compliance purposes. If, subsequently, verification then shows that the emissions report does not accurately reflect true emissions, the emissions determination guidelines need to be changed.

Over the long term, verification will improve the emissions data quality by improving the technical guidance and so help to ensure that the methods to determine emissions reflect true emissions. In the short term, however, ensuring that reporting follows the guidelines will give the user sufficient confidence in the application of the inventory in any policy process.

3 Dimensions of the Inventory

An emission inventory should be regarded as a collection of numbers, each having four independent attributes or dimensions:

- the (chemical and/or physical) identity of the ***pollutant*** or ***gas*** that is emitted
- the (economic and/or societal) ***activity*** or ***sector and fuel*** that causes the emission
- the ***time*** dependence of the emission
- the (geographical) ***location*** of the emission

These dimensions define the ***What***, ***Why***, ***When*** and ***Where*** of the environmental pressure resulting from the emissions. This chapter will deal with these four dimensions of an emission inventory separately.

3.1 What: Pollutants or gases

3.1.1 Pollutants or gases in various environmental themes

Emission inventories collect data for specific environmental themes or problems such as Climate Change, Transboundary Air Pollution and dispersion of toxic substances. Each of these themes deals with a specific set of pollutants or gases:

- in the Climate Change arena the ***what*** in emission inventories is called ***gases***, mainly because participants in this arena claim that the chemical CO_2 is not a pollutant [23] and hence the material released cannot be called “pollutant”;
- in the transboundary air pollution arena, this dimension is called ***pollutants***, mainly because particulates cannot be called a gas [21] and hence the term “pollutant” has been chosen;
- to avoid this discrepancy in terminology, the EPER and E-PRTR facility level emission inventory activities use the term ***substances*** to include both pollutants and gases [32].

Apart from this semantic issue, another more important issue arises with respect to the ***what*** dimension of any inventory, especially when such an inventory is (to be) compiled for policy applications. This issue is directly related to the fact that most policymakers are not specifically educated in chemistry and physics. This might result in pollutant or gas definitions that do not necessarily refer to a distinct chemical but might be a group of chemicals or physically defined substances like particulates. Table 3-1 presents some examples.

Table 3-1 Some examples of pollutants or gases that in fact are (weighted) mixtures of other groups an/or chemicals

Environmental theme	Pollutant or Gas	Is the (weighted) sum of …
Climate change	greenhouse gases	CO_2, N_2O, CH_4, PFCs, CFCs, SF_6
	PFCs	CF_4, C_2F_6, C_3F_8, C_4F_{10}, c-C_4F_8, C_5F_{12}, C_6F_{14}
	CFCs	HFC-23, HFC-32, HFC-41, HFC-43-10mee, HFC-125, HFC-134, HFC-134a, HFC-152a, HFC-143, HFC-143a, HFC-227ea, HFC-236fa, HFC-245ca
Transboundary air pollution	Acidifying pollutants	NO_x, SO_2, NH_3
	NO_x	NO, NO_2
	NMVOC	The sum of all volatile organic compounds, except methane
Toxics	PAH	The sum of (six [Borneff, 38] or ten [”VROM”]) individual polycyclic aromatic hydrocarbons
	PCDD/F	The weighted sum of a number of polychlorinated dibenzo-p-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF)

The examples in Table 3-1 show the policy relevant substances in the second column. The third column more or less translates these into measurable chemical and physical terms.

The relationship between the definitions used in both policy oriented and scientific inventories and the definitions usually applied by chemists and physicists is rather complex. Some measurement techniques provide data on total mass of a set of organic chemicals (NMVOC) directly whereas other detection and measurement methods are very specific for individual chemicals. Other chemicals are in equilibrium with each other. Once in the atmosphere the equilibrium starts to shift in one or another direction. An example of this is NO and NO_2, frequently indicated as NO_x in many policy documents and scientific studies.

3.1.2 Speciation

Especially in scientific applications more detailed chemical or physical characteristics of the pollutant or gas is needed than is available in policy oriented emission inventories in many cases (chemical speciation). An important example of these is the fact that atmospheric chemistry models need the NMVOCs speciated in a series of individual chemicals. Speciation of emission inventory data can be achieved along two pathways:

1) deriving emission estimation methods (emission factors, see section 4.1 onder) at the level of the individual substances rather than at the level of the aggregated substance
2) using source-specific chemical profiles to disaggregate the aggregated substance towards the individual chemicals that are included. In this approach, the speciation is, in fact, a “post processor” on the inventory compilation. Whether this is as part of the inventory development or as part of the models used during inventory data applications is a matter of preference.

3.1.3 Aggregation

In many policy applications the effects of a series of substances are aggregated to one major environmental issue, such as:

- Climate change
- Acidification
- Tropospheric ozone formation
- Particulate formation

Each of these environmental issues is influenced by a mixture of different primarily emitted substances. To calculate the contributions of the emissions of different substances to such an environmental issue, the weighted sum of the contributing substances is calculated. Table 3-2 provides some examples of such weighting factors.

Table 3-2 Weighting factors for aggregation of substance emissions towards environmental issues (from [23] and [39])

	Climate change	Acidification	Particulate formation	Tropospheric ozone formation
	Global Warming Potential (CO_2 eq [23])	**Acidifying Equivalents (eq. H^+/kg [39])**	**Aerosol formation factor (AF_x [39])**	**Ozone formation potential (TOPF [39])**
CH_4	21			0.014
CO				0.11
CO_2	1			
N_2O	310			
NH_3		58.82	0.64	
NMVOC	- (*)			1
NO_x		21.74	0.54	1.22
SO_2		31.25	0.88	

(*) The IPCC 1996 Guidelines [23] require reporting emissions of NMVOC, since these pollutants are ultimately oxidised to CO2 and as such contribute to global warming.

3.2 Why: The Source

Since the origin or cause of the emissions is important in both policy and science oriented inventories, the emissions are estimated for all relevant causes or activities. This means that such activities must be identified and defined. Over time different sets of activity definitions have been developed. Some of these are quite specific for certain inventories, while others are connected to the guidance as provided within the framework of international conventions or protocols. In the case of fuel combustion as a source category, the type of fuel is also important.

3.2.1 Source categories

In understanding the use of sector or activity definitions in emission inventories, it is essential to be aware of the fact that such sector definitions are used in two different settings, resulting in two different types of sector definitions:

1) ***The inventory compiler's perspective***: definitions of sources used in the emission estimation process aim at defining homogeneous groups of individual sources that could be estimated by using one single method and one single emission factor.
2) ***The inventory user's perspective***: definition of sources aimed at using the emission reporting for mostly policy applications in many cases aim at
   - recognising economic activities or different actors in society
   - making the reports among different countries comparable.

An additional factor is the fact that emissions from combustion activities are strongly influenced by the type of fuel used, which implies that the definition of any combustion process should include a reference to a fuel for emission inventorying purposes (see section 3.2.2 onder).

3.2.1.1 Policy oriented sector definitions

In the early years of developing emission inventories (the mid 1980s for transboundary air pollutants and the early 1990s for greenhouse gases) two different approaches to emission inventorying were developed, each with its own set of definitions:

1) Within the air pollutants community a set of sector definitions was developed, based on the technical properties of the possible sources. This set of sector definitions is known as SNAP [21]. This approach is of the first type aimed at homogenous groupings with respect to emission factors facilitating inventory compilation.
2) Within the climate change arena a set of sector definitions was developed, based on available energy statistics data. This set of definitions is known as the IPCC sector definitions [23] and was originally more or less based on energy-economic definitions.

These two sets of activity or sector definitions have been used as the core of the reporting procedures and formats in the major international conventions that require annual emissions reporting at national level: the UNECE Convention on Long Range Transboundary Air Pollution (LRTAP [11]) and the United Nations Framework Convention on Climate Change (UNFCCC, [10]) respectively.

Since the mid 1990s national experts compiling emission inventories within both policy fields have worked on harmonising these two sets of definitions to enable a more cost-effective and integrated inventorying process within each country. In response to this, the LTRAP Convention has adopted a new set of sector definitions that is fully harmonised with that of the UNFCCC [18].

In 2006, IPCC [1] published an adapted and improved set of sector definitions that further elaborate a number of source categories defined in the earlier version. For reporting under the Climate Convention, however, the 1996 IPCC source categories are to be used for reporting at least until the end of the first commitment period (the ***Kyoto Protocol***) in 2014 when emissions in 2012 are to be reported.

3.2.1.2 Science oriented sector definitions

Science oriented inventories are not bound to the requirements of the conventions. Most inventories compiled for scientific applications, therefore, have defined their own set of sector definitions. These definitions in most cases follow the lines of aggregating emission sources in homogeneous groups of sources where a specific emission factor or set of other emission characteristics can be used.

3.2.1.3 Relating science oriented and policy oriented sector definitions

From the above it is quite clear that the scientific application tends to use definitions aimed at estimating emissions homogenously whereas policy applications are driven by reporting obligations and hence tend to apply sector definitions derived from the reporting formats. The first type of definition is technology oriented whereas the second is aimed at recognising economical or societal activities ("actors").

Unfortunately, there can not be a one-to-one relation between the two: some technologies will occur in several economic or societal sectors and many economic or societal activities will use more than one technology. This means that a simple link table to translate one type of definition to the other is not possible.

To solve this problem and to make the inventory applicable both in policy oriented and in science oriented studies, the inventory compiler needs to ensure that both types of sector definition can be used. This can be done as follows:

1) Apply the ***user's perspective*** to select a set of sector definitions as the basic ***why*** dimension of the inventory. This will ensure that the data collected can be directly used.
2) Where needed, define sub-sectors on the basis of the ***compiler's perspective*** to be able to represent a further sector split to represent groups of sources that could be treated homogeneously but that are part of the same economic activity.

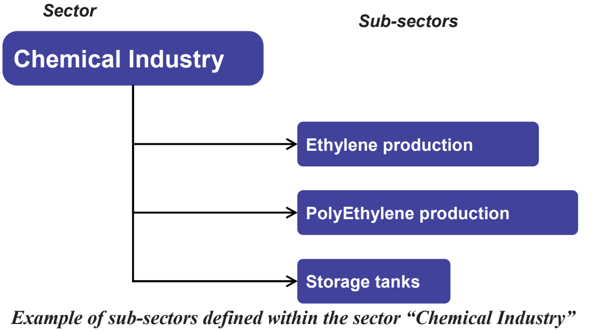


Figure 3-1 Example of sub-sectors defined within the sector "Chemical Industry"

An example is presented in Figure 3-1 for a chemical facility with a series of different production plants, each with associated emissions to air. We note that this procedure aims only at making a set of sector definitions available to the inventory compiler allowing for homogenous treatment of each (sub-) sector. In this case three sub-sectors can be defined: the ethylene production, the polymerisation plants and the storage tanks. This does not mean that within such a (sub-) sector all sources are similar. Some might have abatement technology installed or apply a different process technology, resulting in different emissions. This might be the case for the storage tanks, where some might have fixed and others floating roofs. A method that takes this into account is presented below (section 4.4.2).

3.2.2 Fuels

For many pollutants and greenhouse gases, source categories related to the combustion of fuels are a major contributor to the total emissions. Moreover, the type of fuel is an important determinant for the total mass of the pollutant emitted due to its combustion. For such sources, therefore, the type of fuel should be included in the definition of a source, so the technical guidance for greenhouse gas [1] and air pollutant [21] reporting both contain a set of fuel definitions grouped into:

- Fossil fuels:
  - Solid fossil fuels: coal, lignite etc., although some of these fuels are gaseous (as in blast furnace gas)
  - Crude oil derived fuels, often called ”liquid fuels”, although some of these fuels again are gaseous (as in refinery gas, LPG)
  - Natural gas
- Peat (given the difficulties of classifying this fuel as ”fossil” it was decided to assign peat to a specific group)
- Biomass
- Waste

All fuels within each group give rise to different levels of emissions. The grouping is mainly used in many policy applications where these major fuel types are frequently used and well understood.

3.2.3 International aviation and navigation

A special group of sources that may be vital in scientific studies though disregarded in many policy oriented inventories is international shipping and aviation. Since most international conventions and protocols have not decided on how to account for emissions from these activities, they are either not reported by national inventories or are given a special status (“memo item”) and not included in the national total emissions.

3.3 When: Temporal resolution

3.3.1 Annual totals

Most, if not all, emission inventories compiled in policy processes aim at estimating the total mass of one or more emitted substances within one specified year, with the resulting emissions ideally expressed in mass units per year. Most emission reports, however, express the resulting emissions in mass units only.

In an annual inventory the ***when*** dimension should obviously correspond to the year for which the estimate is valid and should not be confused with the year in which the inventory is compiled and reported. Both the reporting requirements of UNFCCC and of LRTAP allow for just over a year after the end of a specific year to submit the inventory.

3.3.2 Increasing temporal resolution

In many scientific applications higher temporal resolutions are needed to account for factors such as:

- seasonal effects (summer time heating demand is below winter time heating demand)
- the differences between working days and weekends
- the influence of rush hours and the differences between night and day.

Since most inventories are essentially based on annual activity data, increasing the temporal resolution of the inventory entails the temporal distribution of the annual activity data towards the required temporal structure.

DISAGGREGATING TOWARDS HIGHER TEMPORAL RESOLUTION

If the intensity of an activity is known at time t_i within a year t, the emission at time t_i can be derived from the annual total for year t as follows:

Equation 1

$$E_{pollutant}(t_i) = \frac{Activity(t_i)}{\sum_i Activity(t_i)} \times E_{pollutant}(t)$$

with $\sum_i t_i$ covers 1 year

$\sum_i Activity(t_i)$ total activity in the year

This approach can be repeated to successively derive successively the seasonal, week and day patterns from an annual total.

One could argue whether this disaggregation towards time resolutions that are higher than the original emission inventory is part of the inventorying activity or part of the application activity. In either case, it involves a simple mathematical model to distribute the emissions over time.

3.4 Where: Spatial resolution

3.4.1 National totals

Emission inventories for national totals of greenhouse gases and air pollutants are compiled in almost all industrialised countries. Apart from this, a number sub-national authorities also compile emission inventories for their regions or cities.

In scientific approaches, any scale of emission inventories can be found. To allow comparison of continental or global scale inventories with policy oriented emission inventories, it is helpful to always have a country-level geographical resolution.

3.4.2 Point sources

A special group of sources where emissions data are frequently available is the so-called point sources, generally large industrial facilities or even individual smoke stacks that typically emit large masses of some substances via one or a few distinctive ducts (stacks, vents, etc.).

Since point sources are typically large contributors to the overall emissions, the scientific use of the inventory in atmospheric transport and chemistry models need these point source emissions to be better localised than the grid or national data generally permit.

3.4.3 Increasing spatial resolution: gridding

In many studies emission inventories collected at higher spatial aggregations need to be converted to a geographical map distribution, typically a square or rectangular grid. Similar to increasing the temporal resolution, one could argue whether this disaggregation towards spatial resolutions higher than the original emission inventory is part of the inventorying activity or part of the application activity. In either case, it involves a simple mathematical model to distribute the emissions over time.

DISAGGREGATING TOWARDS HIGHER SPATIAL RESOLUTION

The algorithm to disaggregate emissions towards a higher spatial resolution ($L_{x,y}$) from a national total for country L is similar to the one used in increasing the temporal resolution (Equation 1):

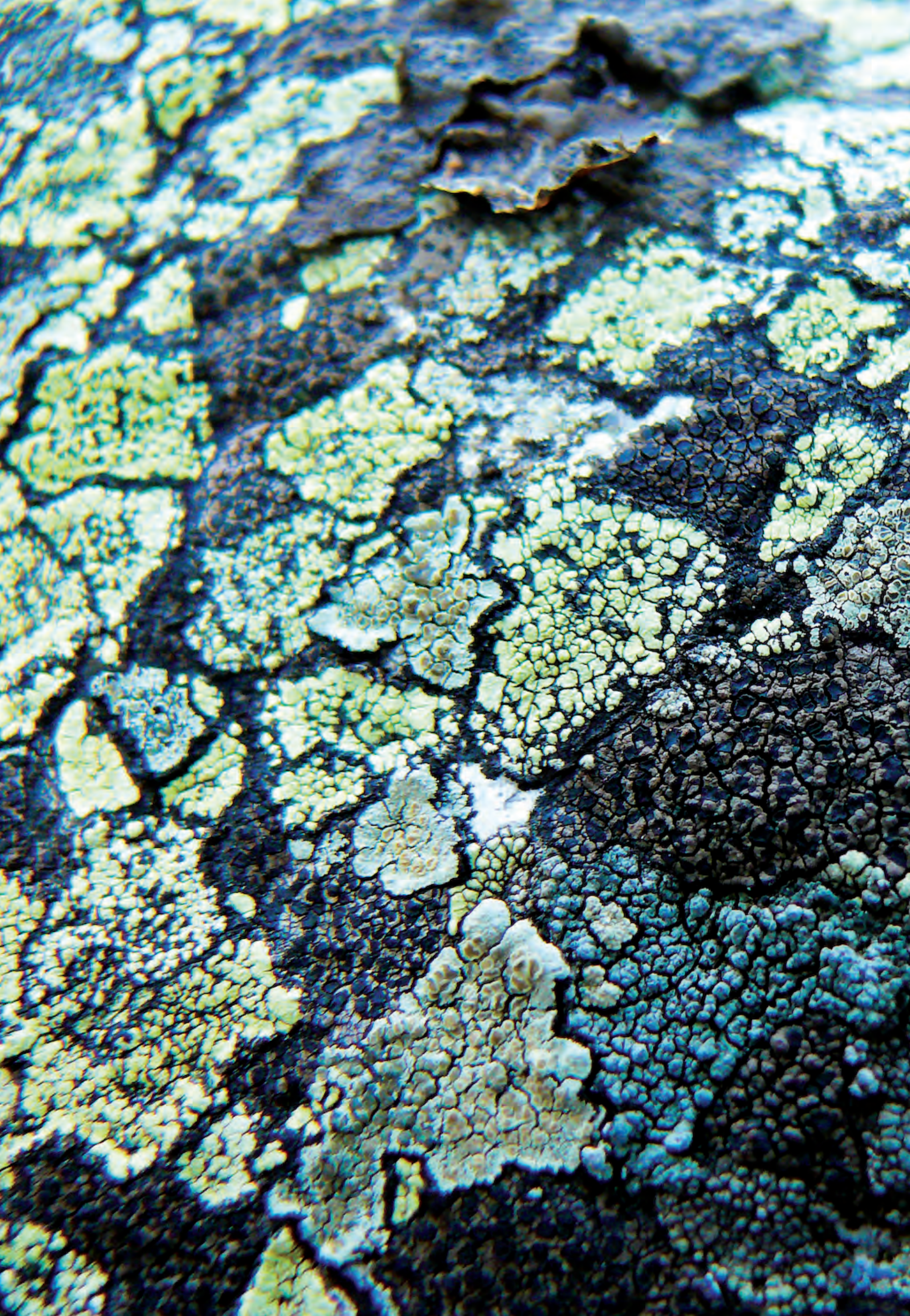
Equation 2

$$E_{pollutant}(L_{x,y}) = \frac{Activity(L_{x,y})}{\sum_{x,y} Activity(L_{x,y})} \times E_{pollutant}(L)$$

$$\begin{array}{lll} with & \sum_{x,y} L_{x,y} = L & covers\ the\ country \\ & \sum_{x,y} Activity(L_{x,y}) & total\ activity\ in\ the\ country \end{array}$$

To apply this algorithm, the spatial distribution of the activities must be known or estimated. In many cases this can be done by using:

- any point source information available. Data might be available for point sources activity but if these are not available, it might be difficult if not impossible to reconcile point source emissions with national level statistics.
- so-called proxies to model the spatial distribution of the activity in other sources than point sources. These proxies might include population density maps (residential heating, urban traffic intensities), land use maps (agriculture), road maps (highway and rural traffic intensities) and many more.



4 Inventory structure

4.1 A general approach

4.1.1 The "traditional" inventory model

Most emission inventories estimate emissions for each pollutant using the equation

Equation 3

$$Emission_{pollutant} = \sum_{activities}\left(AR_{activity} \times EF_{pollutant,activity}\right)$$

This equation assumes a linear relationship between the intensity of an activity $AR_{activity}$ ("Activity Rate") and the emission ($E_{pollutant}$) for each activity. The emission factor ($EF_{activity, pollutant}$) is the proportionality constant. In this classical approach, compilation of a global emission inventory is typically the collection of (time series of) country-level activity data and country-specific emission factors. Time dependency is implicit in this approach.

4.1.2 An improved emission inventory model

This classical approach of emission inventories as represented by the above formula only implicitly represents one important aspect of the historical developments of emissions: the selection of and changes in technology and abatement can only be modelled in this approach by applying externally generated time series of emission factors. The same is recognised in the guidance provided by the EMEP/EEA Guidebook [21] to produce emission projections. Both in retrospective and prospective ("projections") time series of emissions it is crucial, however, to take the technological developments explicitly into account.

Figure 4-1, based on the algorithm proposed by the Guidebook, indicates schematically how economic, technological and behavioural aspects can be included in the basic approach of an emission estimate:

- Changes in structure and production in the economy come under "Activity". Apart from the economic sectors, activity data relate to activities like households and transport. Time series of activity data then model economic growth.
- The Emission Factor describes the relationship between the intensity of the activity and the emissions for a given technology used to perform the activity. The replacement of one technology by another is reflected in a changing emission factor. These changing emission factors therefore model the technological development of innovation.
- The selection of certain technologies for specific activities is modelled by "Penetration". Its value indicates the percentage of the activity that uses a specific technology with associated emission factors. The changes in penetration reflect the effects of investments in new or improved technologies.

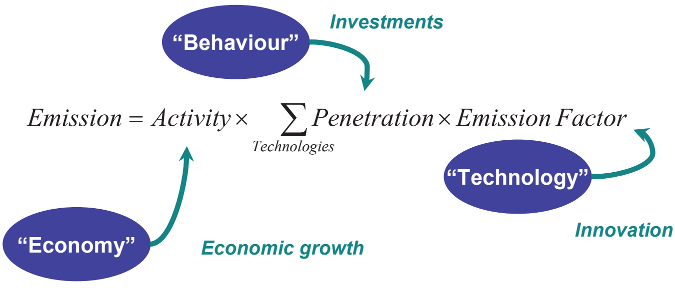


Figure 4-1 The three aspects of estimating emissions: economy, technology and behaviour

In our approach we explicitly model the introduction of alternative technologies into the emission inventory by applying the following equation:

Equation 4

$$E_{pollutant}(t) = \sum_{activities}\left(\sum_{technologies}\left(AR_{activity}(t) \times P_{activity,technology}(t) \times EF_{technology,\,pollutant}\right)\right)$$

$$with \quad \forall activities, \forall\, t: \quad \sum_{technologies} P_{activity,technology}(t) = 100\%$$

Similar to other studies on time series of emissions, the activity rate changes over time. In most inventories these data are organised in database tables, providing an activity rate for each relevant activity for each time step (in most cases each year). The temporal resolution of the activity data also determines the temporal resolution of the inventory. In principle, the activity data will also be location dependent and the spatial resolution of the activity data will also define the spatial resolution of the inventory.

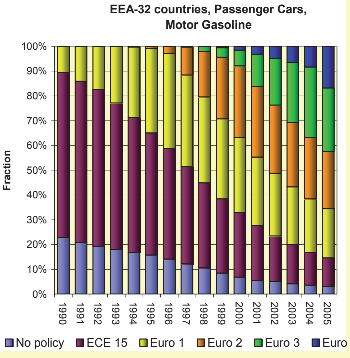
The penetration $P_{activity,\ technology}$ is modelled as the percentage of the activity that is performed by applying the relevant technology for a specific activity. Penetration is obviously dependent upon the activity and the technology and will change over time when one technology is gradually introduced to replace another. The condition ensures that at all times all of the activity is associated with a technology. Obviously, the spatial resolution of the penetration should follow the spatial resolution of the activity data.

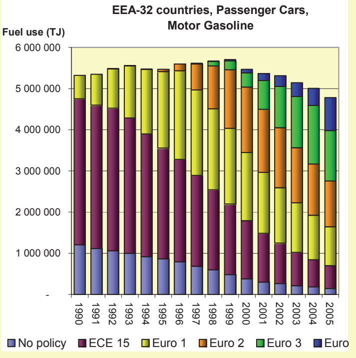
By introducing the penetration of technologies into the model, the emission factors become independent of time and location. In this approach, the emission factors for the different substances are a property of the technology and not of the activity. Emission factors are also independent of time and location. The apparent or implied emission factors that are used in the classical approach are related to our emission factors as being the averaged value of all technologies applied for a certain activity. As a result of this, these apparent or implied emission factors could be dependent on time and location. To avoid any confusion, we propose to use the expression "emission rate" whenever we refer to these "apparent" or "implied emission factors".

Every technology could, in principle, be applied for different activities. Examples of these are combustion technologies that can be essentially similar in public power generation, oil refineries and many industrial manufacturing industries.

PENETRATION OF TECHNOLOGIES: AN EXAMPLE

The graphs below show the gradual introduction of the EURO emissions standards for petrol fuelled passenger cars over time. The graph to the left provides the percentage of cars in Europe, complying with each specific EURO standard ("***penetration***"), whereas the graph to the right shows the distribution of the activity data (fuel use) over the different technologies by combining the penetration with the fuel use from energy statistics data (adapted from [40])





Compiling an emission inventory is similar to the classical approach and consists of collecting activity data for the full time period under study and building a database of technologies with associated emission factors. The Emission Inventory Model is, in this new approach, completed by the selection of one or more technologies for each relevant activity for every time step in the time series. The model consists of three main components:

1) The ***economic aspect***, represented by a table of the activity rates ($AR_{activity}$) as in the classical inventory approach; these activity rates will be given for all relevant source activities, for each geographical unit and for every year in the inventory.
2) The ***technological aspect*** represented by a table of all relevant technologies that can be used to perform the activity in any geographical unit of any year; each technology is accompanied by emission factors ($EF_{technology,\ pollutant}$) for each relevant pollutant; this approach is fully consistent with the new structure and format of the EMEP/EEA Guidebook [2], where in all emission factor tables a complete set of emission factors is provided for each averaged (***Tier 1***, see section 7.1.1, Key sources and tiers) or technology specific emission (***Tier 2***) estimation method.
3) The ***behavioural aspect***, linking one or more technologies to each activity in every country and every year. This technology selection ($P_{activity,technology}$) could either be a table, listing the penetration of each technology for every activity, or a selection algorithm in, for instance, what-if studies.

4.2 Relational database

As is indicated above (section 4.1) a general approach for an emission inventory activity can be described as in Equation 4. This formula is to be applied for any location that is included in the inventory. Since the summations in these formulas might include a long list of activities, the most suited tool for emission inventorying is a ***database*** tool.

Consistent with Equation 4 and Figure 4-1, three main data tables should be included in this database:

1) A table of activity rates providing information on the intensity of each activity or sector at every relevant location and at every relevant time period;
2) A table of emission factors, linked to a table of all available technologies;
3) A table selecting one or more technologies for each activity in the database.

Figure 4-2 presents an overview of the relationships (indicated by arrows) between these four core tables in a generalised database structure.

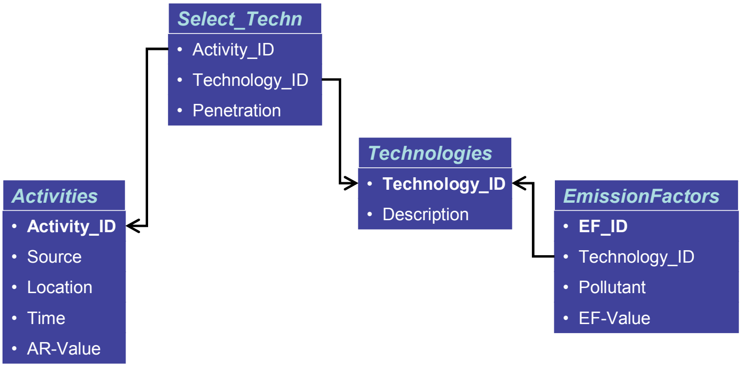


Figure 4-2 ***General diagram of a pragmatic Emission Inventory Model (italics indicate table names, bold fields indicate unique identifiers and arrows indicate many to one relationships)***

An inventory structure, designed along these lines in a relational database system, has important advantages above a more classical approach (section 4.1.1) of simple tables:

1) The structure closely follows the real world:
   a) In most cases several alternative technologies are available to perform a certain activity. In many cases these different technologies will indeed be implemented in a certain country or area;
   b) The technology applied determines the emission factor, not the activity itself.
2) The structure is directly related to the algorithm described above. The emissions can be calculated by a straightforward query on this database.
3) The structure ensures a consistent inventory over different pollutants or gases.
4) The structure allows for easy scenario and what-if applications by simply replacing the select technologies table by another one.

Below some additional issues for each of the main data tables are described and some additional thoughts provided on implementing the dimensions of the inventory as described in Chapter 3 in definition tables in the database structure.

4.3 Definition tables

4.3.1 Why: Sources, sectors and fuels

As is indicated in the general database structure of Figure 4-2, each activity needs to be given for a ***source***. As described above (section 3.2), a source is defined by a number of attributes, including a source category and, in combustion sources, a fuel.

In a relational database structure this can be implemented by including a table defining all ***sources*** in the inventory. Each of these sources links to (see Figure 4-3)

- a specific ***source category***, as defined in an additional source categories definition table
- a specific ***fuel***, as defined in the fuels table.

The fuel is obviously not relevant for non-combustion sources; this can be implemented in the database by either defining a dummy fuel, called "no fuel", or by allowing a ***nil*** value in the fuels field of the sources table.

The main advantage of using the relational database structure is that it

- implements safeguarding against entry of non-existing source categories or fuels
- allows for editing names and codes in one single record in the relevant definition tables, rather than in each record in the activities table.

In Figure 4-3 it is proposed to define the unit in which to express the activity rate in the sources definitions table rather than in the activity rates table thereby forcing the inventory compiler to use the same unit for the activity rates for a specific source in all locations and all years in the inventory.

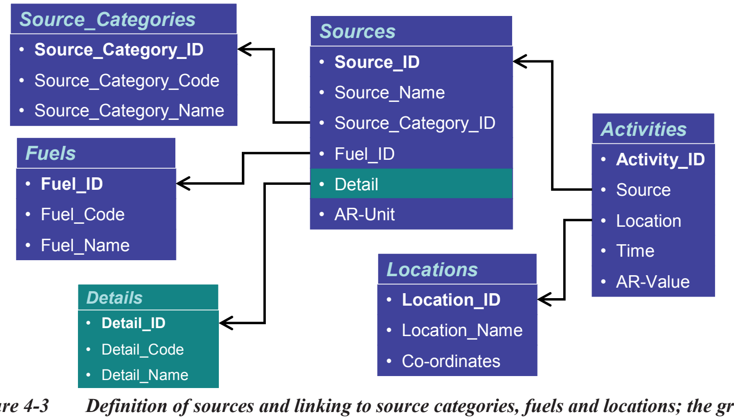


***Figure 4-3** Definition of sources and linking to source categories, fuels and locations; the green Details table is optional*

In many inventories the compiler might need to stratify certain source categories and fuel combinations into more specific sources (see also section 4.4.2). An example of this might be the application of the so-called SNAP nomenclature [21] to large industrial combustion source categories. SNAP splits these source categories into three or more boiler size dependent sub-categories. The easiest and safest way to implement this into the database structure is to add an additional table, defining all deeper details (in this case the SNAP) and an additional field in the sources table, linking to these details. This optional additional table is indicated in green in Figure 4-3.

A similar mechanism could be used to link specific sources to, for instance, economic sectors. Each source could, in this case, refer to a table defining the economic sectors (NACE in Europe [41] and/or ISIC in UN statistics [42]). This would make the use of the inventory in economic studies directly possible.

4.3.2 Where: Locations

Each source might occur on one or more ***locations*** in the database. As for the sources, the implementation in a relational database includes a link to a separate locations definitions table. This table could define both geographical areas (countries, provinces, municipalities) and point sources.

Locations might be needed in different levels of aggregation. If provinces, municipalities or point source locations are needed they are obviously part of the whole country. If this indeed is the case in the inventory, care must be taken that no double counting occurs. Emissions attributed to individual point sources should not be included in the emissions attributed to other geographical units unless specific provisions are included in the database structure and queries that prevent double counting when aggregating. A straightforward way of achieving this is to define a location in the country called "non-point sources in country X" in the locations table and to use this "location" for those source categories where point source data are also available.

In a national totals inventory, without point source allocation, there might be only one location, the country for which the inventory is compiled. In such a case it is obviously not necessary to include a location field and definition table since only one entry will be allowed here.

In the past, countries have regularly ceased to exist and new countries emerged. This happened and is still happening in the Balkans and the former Soviet Union. A relatively simple way of dealing with this is to add a creation and end date to each location, ensuring that the successor countries never overlap with the predecessor countries and that all of the geographical area is covered for all time periods in the inventory.

4.3.3 What: Pollutants

All emission factors in an emission inventory will be valid for one specific ***pollutant***. As for the other dimensions, this can be implemented by linking each emission factor to a pollutants definitions table (Figure 4-4).

This figure proposes the inclusion in the pollutants definitions table of a pollutant unit in which the calculated emissions will be reported. Section 4.5.2 describes a mechanism that can ensure that units are properly converted when calculating emissions in the inventory.

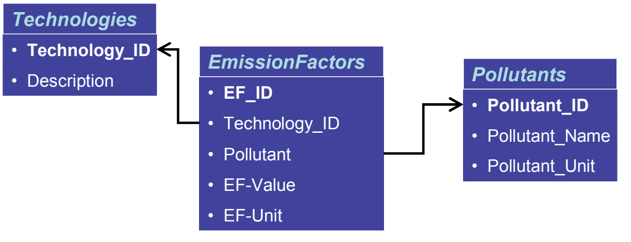


Figure 4-4 Emission factors and pollutant definitions

As indicated in Table 3-1 some substances used in environmental policy or studies actually include a number of specific compounds that can be aggregated towards a higher level of environmental pressure indicators. This could give rise to similar approaches as in the Locations.

4.3.4 When: Time periods

It might be wise to also add a table of all valid ***years*** (or other time periods) in the inventory and link the time field of the activities table to this table of valid time periods. This would prevent data entry for time periods outside the intended range.

4.4 Data tables

4.4.1 Activity rate data

For each source the intensity of the activity needs to be estimated for all relevant locations and each of the years in the inventory. To do this, several approaches are available – in many cases these must be combined. One could argue that the following approaches yield a decreasing level of accuracy or confidence of correctly representing the real activities.

<u>Plant level data</u>

The most detailed data that could serve as sources for activity data are facility level or even plant or installation level production data. Such data are not frequently available. Most facility level data sets, including EPER [13], contain emissions only and no information on the underlying processes. In the case of combustion processes fuel quantities can be calculated with reasonable accuracy from the CO_2 emissions, using the IPCC default emission factors [1], provided that the type of fuel combusted is known (see also [43]).

The use of facility level data in emission inventorying is often called a ***bottom-up approach.***

<u>National statistics</u>

For those sources, where facility level data are not available, activity data are preferably derived from (national) energy and production statistics. Both the IPCC Guidelines [1] and the EMEP/EEA Guidebook [21] provide source category specific information on how activity data can be derived from readily available statistics.

This approach, using national statistics, is often referred to as the ***top-down approach***.

For those source categories, where facility level data are available for only a fraction of the activity rate, the difference between the (national) statistics and the total activity rates in the point sources should be used as the activity rate for non-point sources. This automatically reconciles the inventory with the data in the (national) statistics.

<u>International statistics</u>

When national statistics are not available, several international statistical services can be used to find activity data for different sources. These include:

- UN Statistical data [44] (free of charge);
- EUROSTAT [45] (free of charge);
- IEA [46].

Many more useful data sets can be found on the internet.

Proxies

In some cases appropriate data cannot be found. In other cases the available data sets might contain gaps for specific locations or time periods. In such cases application of a so-called ***proxy variable*** can help to derive at least a rough estimate of the activity rate.

A proxy variable is a variable that is not directly related to the data that are needed, but might have a good correlation with such data. Such proxy data could be the population size or gross domestic product or other high-level indicators of the size and the economic activities in a country or region.

When using a proxy, one has to assume or derive a relationship between the value of the data searched for and the value of the proxy in countries or years where data are available. The estimates for the gaps then follow from the application of this relationship.

4.4.2 Technology and emission factors

The concept of ***technologies*** as in the structure of Figure 4-2 is basically used to organise emission factors in a comprehensive and logical way, ensuring that emission factors for different pollutants are consistent. For this purpose the technology definitions table does not need more fields than an identifier and a name or description.

An important aspect of using the concept of technologies is the level of aggregation of these. In principle, every individual source in the cruel dirty world outside might be different from all the others. The inventory compiler will lump a number of individual sources together in many cases and use a typical or aggregated technology with associated emission factors for all of these. The highest level of aggregation is defined by the source categories and fuels that are defined in the database. For important sources the inventory compiler might stratify the source category to model different technologies applied within specific source category – fuel combinations. In principle, there is no conceptual limit to such stratifications.

Provided that the necessary information and data are available, the general feeling is that increasing the details in the inventory will improve the quality of the estimate. This means that the inventory compiler has to find a trade-off between more detail and the accuracy of the inventory.

To support this trade-off, inventory guidance for both the greenhouse gases [1] and air pollutants [21] have designed ***tiers*** to implement this in the inventory compilation process (see also section 7.1.1).

Emission factors are crucial for any emission inventory and the selection of appropriate emission factors for each technology applied in all activities in the inventory is a major task for the inventory compiler. Some important resources for emission factors are:

- Greenhouse gases
  - IPCC Guidelines [23, 24, 25, 1]
  - IPCC Emission Factor Database [47]
- Air Pollutants
  - EMEP/EEA Guidebook [21]
  - US EPA, Clearinghouse for Inventories & Emissions Factors [48]

These resources generally provide sufficient information for the inventory compiler to decide which emission factors might be most appropriate for use in the inventory under construction.

In some cases, mainly for large facilities, emission data are directly available from measurements at specific individual sources. Obviously the compiler will wish to use these data in the inventory. To be able to do so, additional background information on the determinants of the emission (activity data, process types, abatement installed, etc.) is crucial to smoothly integrate such data into a full inventory.

4.4.3 Selecting Technologies

The final data table in the proposed database structure provides the link between the activities and the emission factors by selecting one or more technologies that are applied for a specific source in a specific location in a specific year (see Figure 4-2). This table implements the time dependency of aggregated emission factors by allowing the stratification over different technologies to change over time.

In the case of a tier 1 estimate for a certain source, no stratification is applied and the full activity is to be linked to one single typical or averaged technology with the associated tier 1 emission factors: the fraction in the Select Technologies table is set to 100 %.

In a higher tier approach one or more specific technologies with the associated tier 2 or tier 3 emission factors are selected.

4.5 Supporting tables

Apart from tables, defining the dimensions of the inventory and the data tables in the inventory, several supporting or auxiliary tables in the relational structure can help to screen data during input or import.

4.5.1 Applicable Technologies

The database structure as proposed above allows, in principle, every technology to be applied in every source category and fuel combination. It may be desirable to limit this possibility to those technologies that are actually usable for such sources by introducing an auxiliary table listing all possible combinations (Figure 4-5).

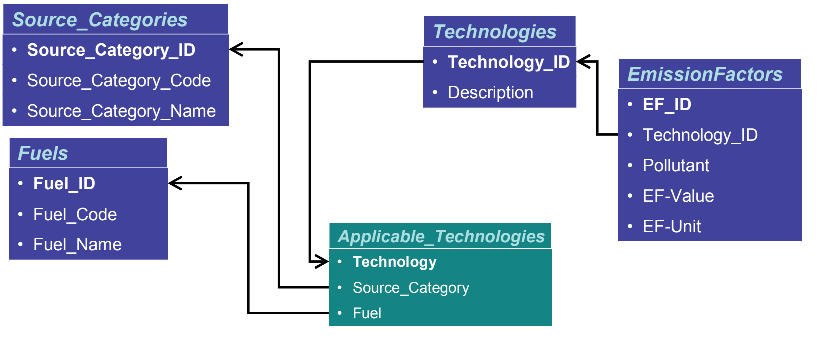


Figure 4-5 Auxiliary table to define which technologies could be applied in specific source categories and fuel combinations

4.5.2 Units

As in all scientific data sets, units for all parameters and values are crucial. Several systems of units are in use throughout the world. The 11th General Conference on Weights and Measures [49] recommended a practical system of units of measurement for universal use. This system is known as ***Système International d'Unités*** or ***International System of Units*** (international abbreviation ***SI***).

Although this system was accepted internationally almost 50 years ago, many national and international statistics still are in non-SI units. Since emission inventories are compiled using many different data sources, the careful treatment of units is essential. An auxiliary table, as indicated in Figure 4-6, defining all the valid units in the inventory could be very helpful.

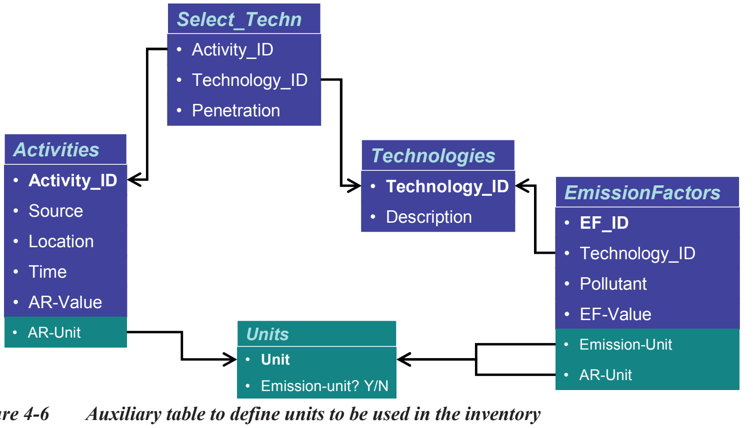


Figure 4-6 Auxiliary table to define units to be used in the inventory

Units are used in two important places in the inventory:

- to indicate the unit of measure for the activity data
- to indicate the derived unit[5] of measure for the emission factors consisting of a mass unit, to express the emission, divided by an activity rate unit. The clearest way of including this in the database is to add two unit fields to each emission factor record, defining these two parts of the derived unit (Figure 4-6).

  Only mass units can be used as emission unit, whereas many different ones can be used as activity units: volume, mass, surface of product or feedstock, energy units, area planted with crops, length of pipelines, etc. For this reason, the ***Units*** table as proposed in Figure 4-6 includes a flag, indicating whether the unit may be used for the emission mass flow or for the activity rate (but not for both)..

To minimise confusion and to allow easy exchange of information, it is advisable to use only SI units in any emission inventory.

Prefixes might be used with any unit to indicate decimal multiples and submultiples of SI units. The SI system defines such prefixes[6] in the range of 10^{-24} to 10^{+24} [49].

[5] Derived units are products of powers of base units [49].

[6] The most recent list of prefixes can be found at http://www.bipm.org/en/si/si_brochure/chapter3/prefixes.html

Activity rate units

Energy units, frequently used in sources where fuel is combusted, might occur in many different forms. Some of the units refer to the mass or volume (gaseous fuels) of the fuel combusted. Apart from the units covered in the IEA Energy Statistics Manual one might find such units as a "cord" of wood [50]. Other units use such concepts as the "tonne of oil equivalent", which is basically an energy unit, indicating how many tonnes of oil would represent the same energy.

For international emissions reporting these non-standard units need to be converted into multiples of the standard SI unit for energy: the ***joule*** (symbol J).

Emission units

Most of the emissions data are expressed in metric mass units: kg, Mg (=tonne), Gg (=ktonne) or similar. The USEPA still reports air pollutant emissions in pounds (lbs)[7].

Many emission factors therefore are still expressed in other mass units like pounds per ton of fuel [51]. The IEA Energy Statistics Manual [52] provides factors to convert energy units from one to another[8].

ALWAYS USE SI UNITS

We strongly advise any inventory compiler to convert all units in both activity data and emission factors into the SI unit system, thereby avoiding all kinds of unit transformations during calculations in and use of the inventory.

Emission calculation

Once the database is completed, the emissions must be calculated, using the algorithm as outlined in section 4.1.2, Equation 4. The units must now match. When different units are employed in activity data and emission factors, appropriate conversions must be used.

[7] US Toxics Release Inventory: http://www.epa.gov/tri/

[8] Unit converters can also be found on internet. Examples are http://digitaldutch.com/unitconverter/energy.htm and http://www.unitconversion.org/

5 Uncertainties

5.1 Importance of uncertainties

An emission inventory is a model of the real world, designed to estimate the emissions of greenhouse gases and air pollutants caused by economic and societal activities in a specific region and a specific year. Since we will never know whether or not this estimate is indeed the value of the "real emissions" we want to know, the estimate will necessarily be ***uncertain***. In other words, uncertainties in emission inventories are unavoidable, as they are in all other quantitative scientific activities.

<u>Accuracy and Precision</u>

Following the definitions in the 2006 IPCC Guidelines [1] there are two important concepts to understanding uncertainties and hence the quality of a reported inventory:

Accuracy Agreement between the true value and the average of repeated measured observations or estimates of a variable. An accurate measurement or prediction lacks bias or, equivalently, systematic error.

Precision Agreement among repeated measurements of the same variable. Better precision means less random error. Precision is independent of accuracy

Uncertainties have a different impact in scientific and in policy applications of emission inventories:

<u>Uncertainties in scientific applications</u>

Uncertainties are important in science and uncertainty analysis should always be part of any quantitative scientific study. Scientific applications of emission inventories therefore require such uncertainty information.

This uncertainty information will help the scientist to understand the quality of the results and might help to explain observed differences between the inventory and field measurements.

<u>Uncertainties in policy applications</u>

In policy applications, uncertainties have become an important part in annual emissions reporting. The UNFCCC reporting guidelines explicitly ask the parties to the convention to estimate and report the uncertainties associated with the inventory.

In contrast to the scientific community, the policy community is not very interested in the uncertainties as such: a "maybe" is not an acceptable answer to whether or not a decision must be taken or whether or not targets have been met. Such policy questions must be answered by a "yes" or a "no". Uncertainty information is primarily needed to assess where the inventory might need improvement.

5.2 Applying uncertainties

5.2.1 Scientific applications

In some scientific studies, where the overall effects of policy measures or economic developments are under study, an overall uncertainty estimate for a complete inventory might be enough. When, however, an inventory is used to generate input data for atmospheric transport and chemistry models, the uncertainties should be available at the level of disaggregation used in the emissions input files. This would include the source categories and the spatial and temporal resolutions as used in the model.

Some studies have tried to assess the scientific uncertainties by comparing ambient air quality measurements with the expected concentrations, calculated by atmospheric dispersion and chemistry models in combination with emission inventories [37].

<u>Accuracy</u>

An emission inventory deals with uncertain numbers and, in many cases, estimates of both the "best" value and 95% confidence ranges based on limited information and underlying (measurement) data. This sets limits to the accuracy that can or even should be reached.

<u>Precision</u>

Precision is reflected in the number of significant digits that are presented in a quantitative estimate. It is good scientific practice to not use more significant digits than the uncertainty would allow. In the Dutch emissions inventory a practice has been adopted to not report more than a specific number of significant digits [53]. This might lead to summary tables not exactly reproducing the sum of all values reported for the more detailed source categories.

5.2.2 Policy applications

In policy applications the uncertainty of the emission inventory in itself is not the important issue. Uncertainty assessment is included in the guidance for emission inventory compilation and reporting as a tool for inventory improvement. To enable this, emission inventory reports are requested to include an overview of the major contributions to the overall uncertainties with a view to identifying the major causes of the inventory uncertainty. This information should be used to prioritise inventory improvements. The major contributors to the overall inventory uncertainty obviously are the ones that could be improved first.

Many national inventory reports, as submitted to the Climate Convention [10] present uncertainty information on greenhouse gas inventories. A more scientific study estimating the uncertainties in greenhouse gas emissions can be found in Winniwarter and Rypdal [54] and for dioxins and furans in [17].

BOX 2 DIOXIN EMISSIONS IN CENTRAL EUROPE - ACCURACY

In a recent study [17] we developed a dioxin emission inventory for the Central European countries, including a complete uncertainty analysis. Despite the high uncertainty in the emission estimates, as expected, the study did lead to clear policy recommendations. The main sources appeared to be waste incineration and small scale waste and solid fuel combustion. Even with the high uncertainty in absolute levels of emissions, it was quite clear that abatement policies should be addressed (and in fact were already being addressed) for these two sources.

5.3 Causes of uncertainties

Uncertainty arises from the notion that the result obtained from an inventorying activity might contain an unknown error. By its very nature, an error is a perturbation, unknown with respect to magnitude and sign. Such an error or perturbation in emission inventories might be caused by:

- the limited applicability of the emission estimation method for the process under study
- stochastic errors in the input activity data or emission factors used whereby the latter might be based on measurement uncertainties when deriving the emission factors from field measurements
- a natural variability of an emitting process whereby such natural variability may cause an estimate based on averaged circumstances to be different from the actual emission

These causes of uncertainties more or less follow the systematic approach of uncertainties as developed by Van Aardenne [55].

5.4 Quantifying uncertainties

Uncertainty analysis tends to provide a range surrounding a point estimate of a value under study. This range is, in fact, a probability distribution of the real value as derived from the observation or calculation (the "point estimate"). The uncertainty or margin of error of a measurement or calculation is thus stated by giving a range of values which are likely to encompass the true value. In most cases the range is given as the standard deviation of this probability distribution or as an x% confidence interval: the boundaries between which the real value will be with a probability of x%. The value of x is in most cases 90% or 95%.

An emission inventory is typically a large collection of more or less independent numbers, each with its own uncertainty range. Using more or less standard error or uncertainty propagation methods (either analytical or by means of Monte Carlo simulations), the overall uncertainty in the total emissions in the inventory can be derived. Chapter 6 of the IPCC Good Practice Guidance [56] provides relatively simple methods to do this. This approach has been incorporated in the EMEP/EEA Guidebook [21, 2].

<u>Uncertainty in an emission estimate</u>

The basic and most common method to estimate emissions is a multiplication of a certain activity rate (stratified over different technologies, if needed) and the specific emission factors for the technology applied. To obtain the uncertainty in the resulting emission estimate, uncertainty data for the activity rate, the technology stratification ("penetration") and the technology-dependent emission factors must be available. For emission factors this type of information is now generally available, since both the 2006 IPCC Guidelines [1] and the 2009 version of the EMEP/EEA Guidebook [2] provide uncertainty ranges with all emission factors included.

Uncertainty in activity data and penetration

Activity data and penetrations are generally obtained from national or international statistics offices. In many cases uncertainties surrounding such data are not published. Both the 2006 IPCC Guidelines [1] and the 2009 version of the EMEP/EEA Guidebook [2] provide some assumptions that could be used to quantify these uncertainties.

Probability distributions

To allow estimation of percentiles, obviously a probability distribution must be known. In practice, normal distributions, uniform distributions and lognormal distributions for various sources could occur [24, 1].

A uniform distribution is highly unlikely. It would mean that all values between the upper and lower limits are equally probable and all values outside this range have zero probability. Therefore, we propose not to use the uniform distribution in emission inventories

Emission factors, activity rates and emissions are normally non-negative values. If uncertainties are rather high, a normal distribution will lead to non-zero probabilities for negative values. A log-normal distribution does not have this problem.

In practice, the normal and lognormal distributions for lower uncertainty ranges are quite similar. The figure below shows two examples (95% confidence intervals of ±20% and ±200% of the point estimate respectively) of cumulative probability distribution functions. Both lines are quite close for the lower uncertainty. At higher uncertainties the normal distribution clearly cannot be applied anymore. This suggests that the log normal distribution can always be used in emissions inventories.

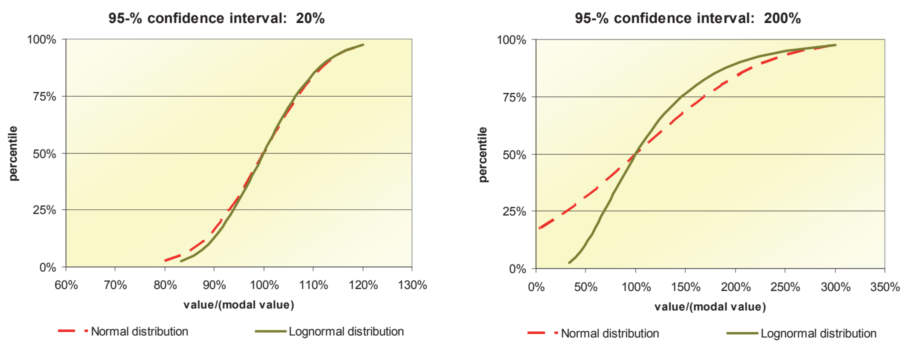


Figure 5-1 Cumulative normal and lognormal distributions

Error propagation

Chapter 6 of the IPCC Good Practice Guidance [56] and the EMEP/EEA Guidebook [21, 2] provide relatively simple methods to calculate the overall inventory uncertainty from the uncertainties for each separate source category and fuel:

Approach 1: A simple ***error propagation*** method:

This method assumes that all errors in all variables follow a normal distribution. This is most probably not true since many emission factors or activity data might have large uncertainties. This is not really a problem if indeed the uncertainty analysis is aimed at identifying the major contributors to inventory uncertainty rather than quantitative estimating the level of uncertainty.

Hence, although the uncertainty estimate will not be quantitatively correct, the approach will still identify the larger contributors to this uncertainty and will allow its use in inventory improvement.

Approach 2: ***Monte Carlo simulation***:

This method estimates the overall uncertainty in an inventory by generating many estimates with a random choice of all parameters and variables from pre-defined error distribution functions. The estimates together generate the probability distribution for the overall uncertainty.

This method does not suffer from the assumption that all distributions are normal. To apply the method, however, error distribution functions for each parameter and variable must be known.

The method can be applied by using commercially available add-ons to spreadsheet programs.

6 Inventory process management

An emission inventory brings together information on many different source categories in very different parts of the society and economy. Therefore, compiling an emission inventory is usually a complicated process involving many data providers and many different experts along with careful management of the process.

Maintaining good inventory management principles will ensure the efficient and timely delivery of sufficiently high quality inventory data within the available budgets and constraints. To do this an inventory management system could be established including:

1) A ***clear inventory process*** so that key activities and resources can be focused towards delivery deadlines and delivery quality
2) ***Institutional arrangements***: clearly defined roles and responsibilities for delivering the inventory to time and quality
3) A ***quality framework*** to ensure that the data is fit for purpose

This is generally the goal of the so-called Quality Assurance / Quality Control (also referred to as ***QA/QC***) systems (see the chapter on Inventory Management, Improvement and QA/QC in [2] and section 6.2 onder)

Obviously this is just adequate project management but it is important to see that compiling and reporting an emission inventory would fit best in a cyclic project, with clearly defined quality objectives, well developed data flow arrangements and systems and proper QA/QC systems in place to ensure that the resulting inventory is of the required quality.

6.1 Inventory Process

Emission inventories, especially those compiled for international reporting by countries, are frequently embedded in an annual cycle. In many cases updates of earlier inventories can be and are submitted in subsequent years together with an inventory for an additional year.

This cyclic process allows for inventory improvement over time. In fact, good practice guidance in both the greenhouse gas and air pollution reporting systems requires continuous attention to possibilities to improve the emission estimates. Figure 6-1, taken from the EMEP/EEA Guidebook [2], translates this requirement in an annual quality management cycle.

This cyclic management process starts with an annual QA/QC plan, detailing all procedures and activities needed to ensure that the inventory collected within the current year is of the planned quality. The QA/QC plan includes a prioritisation of the improvements identified as necessary or desirable and all checking and reviewing activities that are foreseen for the current inventory compilation and reporting process. The cycle is completed by the production of a formal or informal inventory management report, assessing the process and identifying any improvements in the process that are desirable or necessary for the next cycle.

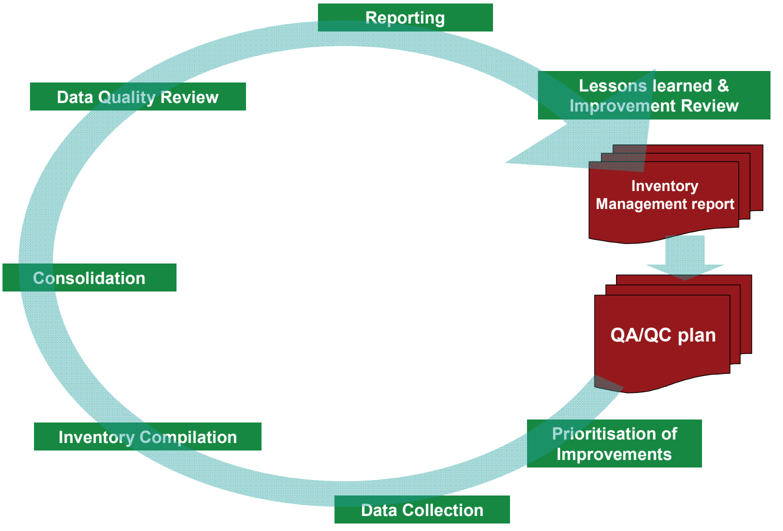


Figure 6-1 Annual emission inventory quality management cycle; from [2]

6.2 Quality framework

Two more concepts, originating from quality management are important for inventory quality. These concepts are often referred to as ***QA/QC*** or ***quality assurance*** and ***quality control***. Figure 6-2 reproduces the definitions of these concepts as provided by IPCC [24]. These concepts are closely related to the management of the inventory compilation process and aim at ensuring that appropriate methods are applied as tested by internal and external reviews and that data flows and calculations are without errors.

QUALITY ASSURANCE (QA)

Inventory definition: Quality Assurance (QA) activities include a planned system of review procedures conducted by personnel not directly involved in the inventory compilation/development process to verify that data quality objectives were met, ensure that the inventory represents the best possible estimate of emissions and sinks given the current state of scientific knowledge and data available, and support the effectiveness of the quality control (QC) programme.

QUALITY CONTROL (QC)

Inventory definition: Quality Control (QC) is a system of routine technical activities, to measure and control the quality of the inventory as it is being developed. The QC system is designed to:

(i) Provide routine and consistent checks to ensure data integrity, correctness, and completeness;

(ii) Identify and address errors and omissions;

(iii) Document and archive inventory material and record all QC activities.

QC activities include general methods such as accuracy checks on data acquisition and calculations and the use of approved standardised procedures for emission calculations, measurements, estimating uncertainties, archiving information and reporting. Higher tier QC activities include technical reviews of source categories, activity and emission factor data, and methods.

Figure 6-2 Definitions of QA and QC from the IPCC Good Practice Guidance [24]

6.2.1.1 Quality Assurance

Following the definition presented in Figure 6-2, quality assurance activities will always involve independent external expertise. To facilitate such independent review the inventory compilation process might include independent estimates and uncertainty assessments.

In a number of cases inventory compilers can produce two independent estimates and compare the results. This might include an estimate based on a "top-down" approach, using a national energy balance and national averaged emission factors and a "bottom-up" approach, using detailed facility level data and energy consumption statistics. The greenhouse gas inventory submissions require a "sectoral approach" based on energy consumption to calculate the national total and to report a "reference approach" estimate based on the carbon balance derived from the national energy balance.

Uncertainty analysis is a strong tool that can be used to assess the quality of the inventory, not so much to provide the overall uncertainty in the inventory but rather to identify weak areas in the inventory. Inventory uncertainty is described in more detail in chapter 5.

BOX 3 REFERENCE APPROACH AND SECTORAL APPROACH

In energy statistics two more or less independent data sets are collected:

- One can work top-down by building an energy balance of production, import and export statistics, leading to an estimate of the energy supply to a country's final users.
- One can also work bottom-up by collecting data on fuels sold and purchased for all economic sectors and activities. Such data will lead to an estimate of a country's demand for energy by the final users.

Within the framework of the IPCC inventorying guidance [23, 24, 1] these two statistical data sets are used to implement a quality check for the emission of CO_2 from fuel combustion estimated from the fuel used (demand statistics) in all economic and societal sectors, the so-called Sectoral Approach. The IPCC recommends the use of the so-called Reference Approach, based on the supply statistics as an independent check of the Sectoral Approach, which is assumed to be more precise because of the higher level of detail and a lower need for additional assumptions.

6.2.1.2 Quality Control

Compiling an emission inventory is a complicated activity where data from many sources are interpreted and used and cover a wide range of activities. Typically quite a lot of data will be transferred between different data owners and data providers in spreadsheets and databases. These data need to be imported into the inventory compiler's systems, leading to many instances where typos, errors or mistakes can be made. It is therefore crucial to have

- procedures in place that check and double check all of the subsequent steps of the data compilation, transfer, import and use during the inventory compilation phase and
- a well organised and designed documentation system that stores information on data deliveries, data manipulations and analyses.

7 Emission Inventory in Practice

7.1 Focusing resources to key source categories

7.1.1 Key sources and tiers

As in many activities a general 20/80 rule applies: 20% of effort for 80% of results. Emission inventorying is no exception. Emissions from the largest sources are generally also more easily defined and calculated. Figure 7-1 shows the contribution of all 100 + source categories defined in the Dutch emissions inventory system to the national total emissions of two greenhouse gases (CO_2 and N_2O) and four air pollutants (NO_x, SO_x, Lead and Cadmium). In all these cases about 10 to 20 source categories contribute to more than 90% of the national emissions, while the remaining 80 to 90 source categories contribute less than 10%. Similar graphs can be produced for most, if not all, air emissions.

The graphs in Figure 7-1 also show that an error or uncertainty of a few per cent in the largest 10 to 20 source categories is much more of a problem than an order of magnitude error or uncertainty in the smallest source categories.

Both observations together are consistent with the methodological choice approach prescribed by both the IPCC [23, 24, 1] and Guidebook guidance [21, 2]. This approach

1) defines the concept of "***Key Category***". A key category is one that is to be prioritised within the national inventory system because it is significantly important for the national total or the trend (see section 7.3 onder).
2) discerns three levels or "***Tiers***" of emission estimation methods, reproduced in Table 7-1.

Table 7-1 Definition of methodological Tiers (from [2])

	Description
Tier 1	is a method using readily available statistical data on the intensity of processes ("activity rates") and default emission factors. These emission factors assume a linear relationship between the intensity of the process and the resulting emissions. The Tier 1 default emission factors also assume an average or typical process description. This method is the Simplest Method, has the highest level of uncertainty and should not be used to estimate emissions from key categories *(see below for definition)*.
Tier 2	is similar to Tier 1 but uses more specific emission factors developed on the basis of knowledge of the types of processes and specific process conditions that apply in the country for which the inventory is being developed. Tier 2 methods are more complex, will reduce the level of uncertainty and are considered adequate for estimating emissions for key categories.
Tier 3	is defined as any methodology that is more detailed than Tier 2. This means that there could be a wide range of Tier 3 methodologies. At one end of the range are methodologies similar to Tier 2 (i.e. activity data x emission factor) but with a greater disaggregation of activity data and emission factors. At the other end of the range are complex, dynamic models in which the processes leading to emissions are described in great detail.

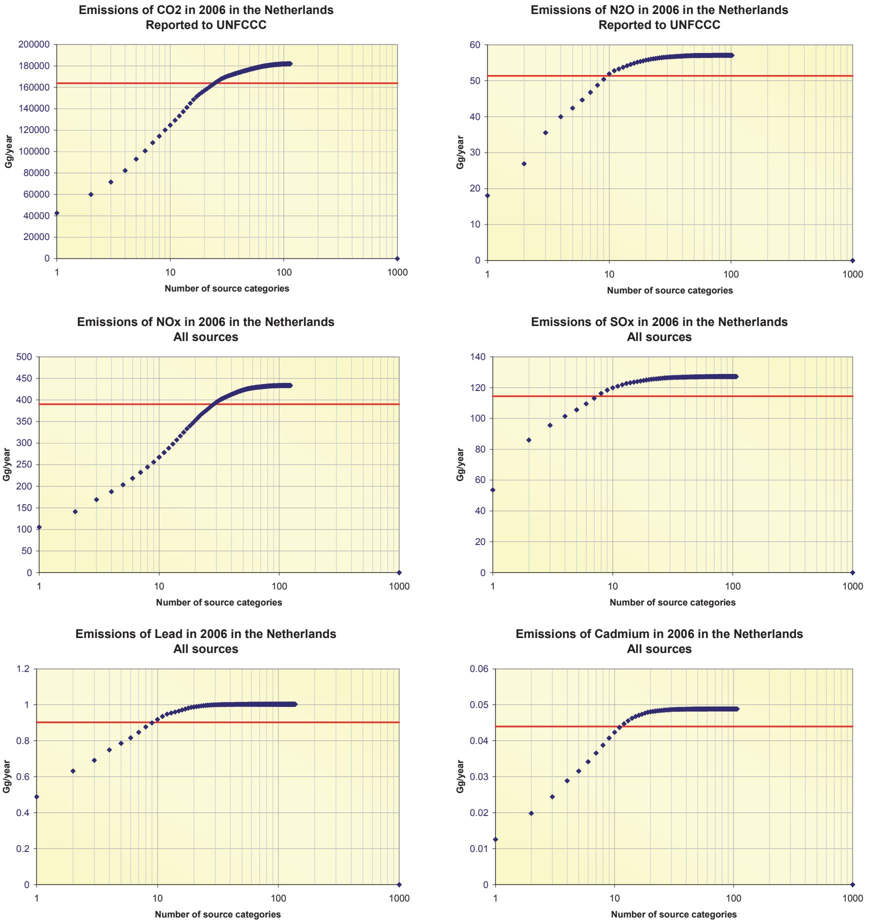


Figure 7-1 ***Cumulative distribution of source category emissions for different greenhouse gases and air pollutants in the Netherlands; the red line indicates 90% of total emissions (Data from the Dutch Emissions Register)***

With this approach an inventory compiler can relatively easily select appropriate methods while prioritising work on the most important source categories. The following decision path could be taken:

- If detailed information is available such that higher tiered methods can be employed, use it.
- If the source category is not a Key Category apply a simple Tier 1 default method.
- If the source category is a key category, a Tier 2 or better method should be applied and detailed input data should be collected.

The alternative to applying a Tier 3 method, using detailed process modelling, is not explicitly prescribed but could replace a Tier 2 method, provided that the Tier 3 method is adequately documented and that it can be shown that it results in a better estimate than the Tier 1 approach.

7.1.2 A higher Tier or a more detailed source categorisation

When a source category is (expected to be) key, a Tier 2 method should be applied. This could be done as follows:

Stratify the source category to model the different types of processes and specific process conditions that apply in the country into the inventory by

- o defining the production using each of the separate types of processes and specific process conditions (together called “technologies” in the formulae below) separately and
- o applying technology specific emission factors for each type of process and process conditions:

$$E_{pollutant} = \sum_{technologies} AR_{production,technology} \times EF_{technology,pollutant}$$

Where, within this source category:

$AR_{production,technology}$	= the production rate, using this specific technology
$EF_{technology,pollutant}$	= the emission factor for this technology and this pollutant

This approach is mathematically equivalent to splitting the source category in more detail, reflecting the different process types and process conditions. In other words, there is a certain level of subjectivity about when to define further detail in the source categorisation or to use technology specific Tier 2 methods. In practice, the source categorisation is almost always determined by the reporting requirement and inventory compilers might stratify within this system when they need or want to apply a Tier 2 or higher method. The alternative, applied in the Netherlands, is to use a country specific source categorisation and aggregate towards the reporting system. Both approaches are fully equivalent.

A country where only one technology is implemented is a special case where the algorithm above reduces to:

$$E_{pollutant} = AR_{production} \times EF_{technology,pollutant}$$

where:

$E_{pollutant}$	= the emission of the specified pollutant
$AR_{production}$	= the activity rate for the source category
$EF_{pollutant}$	= the emission factor for this pollutant for the technology implemented in the country

7.2 Top-down and Bottom-up Inventories

7.2.1 Facility level data

In a typical inventory some of the source category emission estimates include data, obtained from individual industrial facilities, mainly in response to facility level emission reporting obligations as prescribed in the facility permit. Two examples are given in Figure 7-2. Both examples show that a relatively few facilities are responsible for the major part of the emissions in the source category. This seems to be more the case for the power plant NO_x emissions than for N_2O from waste water treatment.

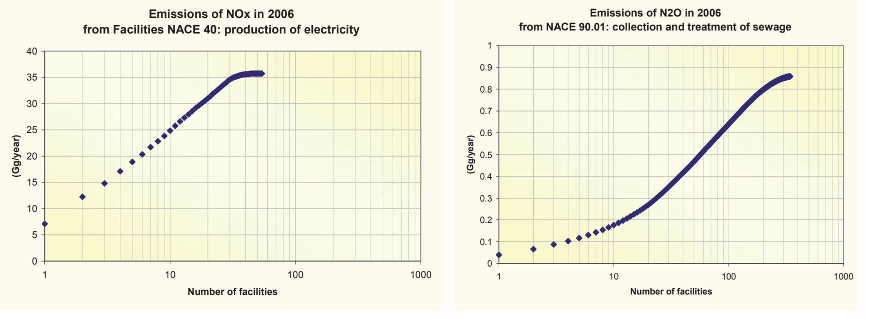


Figure 7-2 ***Cumulative distribution of facility level emissions for NO_x from power plants and N_2O from waste water treatment in the Netherlands (Data from the Dutch Emissions Register)***

A closer inspection of the exact methods applied does suggest a reason for this:

1) The emissions of NO_X from the 53 power plants, included in the source category "Facilities NACE 40: production of electricity", tend to be based on continuous monitoring and therefore reflect the emissions as they occurred at these individual facilities.
2) The emissions on N_2O from the 343 facilities included in source category "NACE 90.01: collection and treatment of sewage" are calculated from the throughput applying an emission factor; in 322 cases the emission factor was 10 kg N_2O/tonne of N in the waste water, in 19 cases it was 20 kg/tonne and in 2 cases it was 30 kg/tonne; the higher emission factors are not used for the largest 60 or so facilities in terms of throughput.

In the first case the data are indeed facility specific, whereas in the second case the data largely reflect the distribution of sizes of the individual facilities rather than facility specific emissions data. The latter is even more the case if we realise that the uncertainty range in N2O emission factors for this source category is about three orders of magnitude (Chapter 6 in the Waste volume of the 2006 IPCC Guidelines [1]). In other words, the facilities with relatively high emissions are not discerned from those with relatively low emissions and hence the size distribution does not reflect the real contribution of each single facility. As a consequence, there is mathematically (almost) no difference with the case where first all throughputs are aggregated to a national total and then multiplied with a (default) emission factor.

In those cases where really independent emission estimates are produced at the level of individual facilities, again relatively few facilities are responsible for a large fraction of the emissions and so it is wise to invest the greater effort in more accurately estimating the emissions of these larger facilities. It might be a good, cost-effective idea to use simple extrapolation methods starting from these larger sources towards the full source category.

7.2.2 Matching Top-down and Bottom-up inventories

In many cases a bottom-up approach, starting from individual processes at individual plants, does not cover all facilities. Some facilities might fail to report and others might have emissions below a threshold, set in the permit or other legislation. In such cases, the total of the bottom-up facility level data are not complete. The remaining emissions, mostly around 10% of the total in the source category, will have to be estimated (for some compounds this part may be 30% to 50%). This can be extrapolated using the (*activity rate*) x (*emission factor*) calculation. Generally, emission factors can be found in handbooks or guidelines. Another possibility is the use of the individually registered emissions to derive a country specific emission factor. This has the advantage of incorporating technology developments in the industry, although there is the question of how representative this is.

7.2.3 Technology based versus activity based inventorying

The earliest inventories were mainly technology based: the inventory agency assessed the technologies applied in all processes in industry and society from an engineering point of view. The source classifications in these early inventories, therefore, were also very much technology based. These inventories are in essence bottom-up inventories, identifying all relevant sources from a technical point of view.

When inventories gained political interest, especially due to the increasing awareness of climate change, a different strain of inventories emerged. The early greenhouse gas inventories are typically top-down inventories, starting from a country's national energy or rather carbon balance. These inventories have a more economic foundation, based on the flows of fossil fuels through a national economy.

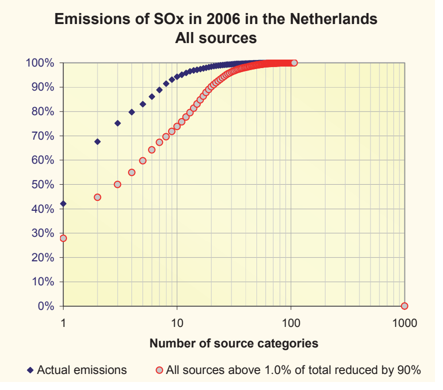
The inventory structure as proposed in this document tries to unify these two approaches into one single database structure by introducing the concept of source details, very similar to the use of the technology based SNAP source classification [21] in relation to the more economy based source classifications of NFR [2] and IPCC [23, 1].

7.3 Time series and trends

7.3.1 Emission abatement

Emissions will change over time as abatement measures and policies are implemented. Emissions from the largest sources will be reduced first. Figure 1-1 shows, as an example of what happens, the effects on the source contributions if all sources contributing more then 1 % to the total emission are reduced by 90% for both NO_x and SO_x. Such a hypothetical reduction policy would lead to

- smaller sources becoming relatively more important (to be expected anyway)
- an increase of the ***number of Key Categories*** that contribute to 90% of total emission.



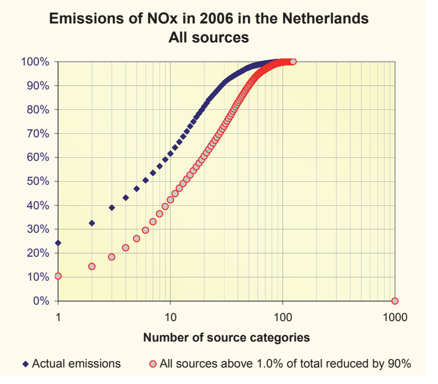


Figure 7-3 ***Effect of hypothetical emission reduction measures for the largest sources on the cumulative distribution of emissions over source categories***

As a result, more and smaller source categories become key and should be estimated by using higher tier methods. So, while the emissions decrease, the compilation of an inventory becomes more difficult and possibly more costly: we need to know more about a smaller problem! In the Netherlands this issue arose in the latest inventories on priority substances and future policy but has not been fully discussed and solved yet.

7.3.2 Economic growth

A second key issue is economic growth. In principle, any abatement emissions measure can, at least in part, be counteracted by the increasing activity intensity as a consequence of, for instance, economic growth. As long as economies grow physically (such as more transport at higher speed over larger distances) emission factors will have to decrease continuously to keep up with growth. The emission inventories for a series of years should be able to show separately the effects of economic growth and the introduction of abatement measures.

Figure 7-4 shows the trend of particulate emissions from diesel fuelled passenger cars in the Netherlands. The emissions, as reported in the Dutch inventory for this source category, fell from 3800 Gg in 1990 to about 1700 Gg in 2006 (green bars in Figure 7-4). At the same time, the amount of diesel fuel used by passenger cars almost doubled from about 84,000 TJ in 1990 to about 158,000 TJ in 2006 (red circles).

To separate the effects of the increasing use of diesel for passenger cars and the implementation of emission abatement (EURO standards), Figure 7-4 also presents two fictive trends:

1) the effect of the increasing diesel use by multiplying the fuel use in each year by the 1990 emission factor (yellow bars)
2) the effect of improving technology by multiplying the (implied) emission factor for each year by the fuel use in 1990 (pale green bars).

From this it can easily be seen that in the 16 years between 1990 and 2006, emissions fell by a factor of four due to improving technology. About one third of this, however, is counteracted by the near doubling of the fuel use.

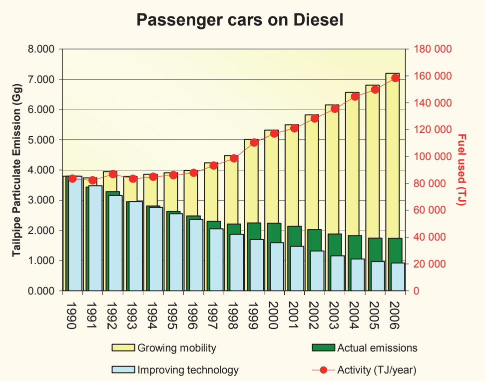


Figure 7-4 ***Trend in exhaust particulate emissions from diesel fuelled passenger cars in the Netherlands (dark green); emissions that would have occurred if the use of diesel had remained constant since 1990 (pale green) or abatement had not been implemented since 1990 (yellow bars)***

7.4 Inventory Completeness

7.4.1 Missing sources

You don't know what you don't know. So, in principle, it is impossible to prove that an inventory is complete. There might, however, be a number of reasons why some sources might have been missed:

- o No data or method available:
  - Illegal activities like cable burning in open air or backyard waste burning,
  - Incidental releases (spills, valves, flares, …)
  - Accidental fires (buildings, cars, containers, …)
  - Agricultural/nature emissions (i.e. VOC from agriculture is only reported by one country in Europe)
- o Sources overlooked
  - Start-up and shut-down emissions of industrial installations
  - Small-scale activities aside from big (industrial) complexes or installations such as cleaning tanks, storages, emissions from buildings, etc.
  - Utilities in joint ventures
- o Unknown sources
  - Sources that have not (yet) be identified

If an inventory is compiled along the provisions of official guidance documents, the easiest way of checking completeness is to see whether all source categories that are defined in the Guidelines or Guidebook are indeed treated in the inventory and, if not, that this source category is shown not to occur in the country.

Comparing air quality calculations with observed measurements is probably the only independent method that will be able to at least provide some insight into whether or not an inventory is missing major sources. Although inventories, models and air quality measurements do have their uncertainties, it is the best way to identify gaps.

At the procedural level, comparison between different countries and between different years can help to identify any missing sources. In both cases one should be able to explain why differences occur.

7.4.2 Double counting

Double counting of emissions is a common problem in inventories. It might be caused by the use of different methodologies for different emission sources. Examples include:

- emissions from the use of coke oven and blast furnace gas when used outside of the integrated steel works while the emissions of the steel works themselves are calculated from the coke input
- process emissions and combustion emissions from industrial facilities might not be discernable as required by the reporting obligations, for instance, because such emissions are measured at one central stack at the facility where waste gases are released from both the combustion and non-combustion processes. In such cases, the emissions might be double counted when the combustion emissions at the national level are reconciled with national statistics.

The inventory guidance, both for greenhouse gases [1] and for air pollutants [2], include warnings at many source categories where double counting can easily occur.

7.5 Gridding

For air quality calculations, emission sources must have a location that is more specific than the national total. For major sources where facility level data are available, the location of the stack will also generally be available. For the remainder of the sources, a series of methods is available to spatially disaggregate the emissions. The latest version of the EMEP/EEA Guidebook [2] does include a special chapter on “Gridding” where relatively simple methods and advice can be found.

References

1 **IPCC (2006)**, *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

2 **TFEIP (2009)**, *EMEP/EEA Emission Inventory Guidebook – 2009*, http://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009

3 **Conway Zirkle (1967)**, *The Death of Gaius Plinius Secundus (23-79 A.D.)*, Isis, Vol. 58, No. 4 (Winter, 1967), pp. 553-559

4 **Gaius Plinius Caecilius Secundus**, better known as Plinius the Younger (http://la.wikipedia.org/wiki/Gaius_Plinius_Caecilius_Secundus) describes the death of his uncle Gaius Plinius Secundus (Plinius the Elder) (http://la.wikipedia.org/wiki/Gaius_Plinius_Secundus) due to the eruption of Mount Vesuvius in the year 79 in a series of letters to Tacitus (http://la.wikipedia.org/wiki/Cornelius_Tacitus). The letters from Plinius the younger can be found at http://www.gutenberg.org/browse/authors/p#a1036

5 **European Environment Agency (2003**), *Europe's environment: the third assessment*; available at http://reports.eea.eu.int/environmental_assessment_report_2003_10/en/

6 **IPCC (2001)**, *Climate Change 2001: The Scientific Basis; Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change* in **J. T. Houghton, Y. Ding, D.J. Griggs, M. Noguer, P. J. van der Linden and D. Xiaosu** (Eds.), Cambridge University Press, UK. available at: http://www.ipcc.ch/pub/reports.htm

7 **IPCC (2007)**, *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* in **Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.),** Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA., available at http://www.ipcc.ch/ipccreports/ar4-wg1.htm

8 **Wachters, L.H.J (1973)**, *Emissie-registratie van luchtverontreiniging met behulp van het door TÜV-Rheinland e.V. ontwikkelde registratiesysteem*, TNO-rapport 73-01259

9 **Southerland, J.H. (2005)**, *An Abridged History of Emission Inventory and Emission Factor Activities*, 14th International Emission Inventory Conference "Transforming Emission Inventories - Meeting Future Challenges Today" http://www.epa.gov/ttn/chief/conference/ei14/session9/southerland.pdf

10 **UNFCCC (2003)**, All national submissions of Greenhouse Gas Emission inventories and National inventory Reports in 2004 can be found at UNFCCC's web site http://unfccc.int/national_reports/annex_i_ghg_inventories/items/2715.php

11 **LRTAP (1979)**, *UNECE Convention on Long Range Transboundary Air Pollution*. http://www.unece.org/env/lrtap/welcome.html; National data submitted under this convention can be found at http://webdab.emep.int/

12 **US EPA**, *Toxics Release Inventory TRI*, URL: http://www.epa.gov/tri/

13 **European Commission**, *European Pollutant Emissions Register EPER*, URL: http://www.eper.ec.europa.eu/

14 *GEIA web site* http://www.geiacenter.org/

15 *EDGAR web site* http://arch.rivm.nl/env/int/coredata/edgar/

16 **Pulles, T, M. van het Bolscher, R. Brand and A. Visschedijk (2007),** *Assessment of global emissions from fuel combustion in the final decades of the 20th century*, TNO

Report 2007-A-R0132/B; URL: http://www.tno.nl/content.cfm?context=markten&content=publicatie&laag1=186&laag2=1&item_id=215

17 **Pulles, T, H Kok and U Quass (2006)**, *Application of the emission inventory model TEAM: Uncertainties in dioxin emission estimates for central Europe*, Atmospheric Environment, vol 40, pp 2321–2332

18 **UNECE (2007)**, *Draft 2007 Guidelines for Estimating and Reporting Emission Data*, Document ECE/EB.AIR/GE.1/2007/15 will be updated after 32nd session of SB http://www.emep-emissions.at/reporting-instructions/draft-2007-reporting-guidelines/

19 **Bouscaren R., C. Veldt, K.H. Zierock and B. Lübkert (1987)**, *CORINAIR project, Programme CORINE, National Experts Meeting held in Brussels*, 7-8 May 1987.

20 **Bouscaren, R (1990)**, *Inventaire des Emissions de Pollutants dans L'Atmosphere dans La Communate Europeenne en 1985*. CITEPA, 1990.

21 **TFEIP (2007)**, *EMEP/CORINAIR Emission Inventory Guidebook – 2007*, http://reports.eea.europa.eu/EMEPCORINAIR5/en/page002.html

22 **UNFCCC (2004)**, *Guidelines for the preparation of national communications by Parties included in Annex I to the Convention, Part I: UNFCCC reporting guidelines on annual inventories (following incorporation of the provisions of decision 13/CP.9)*, FCCC/SBSTA/2004/8 http://unfccc.int/resource/docs/2004/sbsta/08.pdf

23 **IPCC (1996),** *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.html

24 **IPCC (2000),** *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, http://www.ipcc-nggip.iges.or.jp/public/gp/english/

25 **IPCC (2003)**, *Good Practice Guidance for Land Use,Land-Use Change and Forestry*, http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf.html

26 **Pulles, T (2008)**, *Quality of emission data: Community right to know and national reporting*, Environmental Sciences, Volume http://www.informaworld.com/smpp/title~content=t713682447~db=all~tab=issueslist~branches=5 - v55, Issue 3, pages 151 – 160, DOI: 10.1080/15693430802141357

27 **UNECE (1998)**, *Aarhus Convention, Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters*, see http://www.unece.org/env/pp/

28 **UNECE (2003)**, *Protocol on Pollutant Release and Transfer Registers*, see http://www.unece.org/env/pp/prtr.htm

29 **Hamilton, J.T. (2005)**, *Regulation through Revelation*, Cambridge University Press, New York

30 **European Union (1999)**, *Council Decision of 26 April 1999 amending Decision 93/389/EEC for a monitoring mechanism of Community CO2 and other greenhouse gas emissions*, Official Journal of the European Union, L 117/35, 5. 5. 1999, page 1 http://eur-lex.europa.eu/LexUriServ/site/en/oj/1999/l_117/l_11719990505en00350038.pdf

31 **European Union (2006)**, *Directive 2001/81/EC of the European Parliament and of the Council of 23 October 2001 on National Emission Ceilings for Certain Atmospheric Pollutants*, Official Journal of the European Union, L 309/22, 27.11.2001, page 1 http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2001:309:0022:0030:EN:PDF

32 **European Union (2006)**, *Regulation (EC) No 166/2006 of the European Parliament and of the Council of 18 January 2006 concerning the establishment of a European*

Pollutant Release and Transfer Register and amending Council Directives 91/689/EEC and 96/61/EC, Official Journal of the European Union, L 33, 4.2.2006, page 1 http://www.eper.ec.europa.eu/eper/documents/E-PRTR%20Regulation.pdf

33 **European Union** (2008) *Directive 2008/1/EC of the Eopean Parliament and of the Council of 15 January 2008 concerning integrated pollution prevention and control* http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:024:0008:0029:EN:PDF

34 **Schaap, M., Timmermans, R.M.A., Roemer, M., Boersen, G.A.C., Builtjes, P.J.H. Sauter, F.J., Velders, G.J.M. and Beck, J.P. (2008)**. *The LOTOS–EUROS model: description, validation and latest developments*. Int. J. Environment and Pollution 32 (2): 270-290

35 **Visschedijk, A.J.H. and Denier van der Gon, H.A.C. (2005),** *Gridded European anthropogenic emission data for NOx, SOx, NMVOC, NH3, CO, PPM10, PPM2.5 and CH4 for the year 2000*, TNO-Report B&O-A R 2005/106

36 **Swart, R, P. Bergamaschi, T. Pulles and F. Raes (2007)**, *Are national greenhouse gas emissions reports scientifically valid?*, Climate Policy, vol 7, pp 535–538

37 **van Aardenne, JA, PJH Builtjes, L Hordijk, C Kroeze, MPJ Pulles (2002)**, *Using wind-direction-dependent differences between model calculations and field measurements as indicator for the inaccuracy of emission inventories*, Atmospheric Environment Volume 36, Issue 7, Pages 1195-1204 (http://www.sciencedirect.com/science/article/B6VH3-44GM9HM-3/2/a8ae1bc19a2cb4ff25abb3692aef2545)

38 **Borneff, J. and H. Kunte (1979)**, *Analysis of polycyclic aromatic hydrocarbons in water using thin layer chromatography and spectrofluorometry*. In: **H. Egan, M. Castegnaro, P. Bogoviski, H. Kunte and E.A. Walker**, Editors, *Environmental Carcinogens: Selected Methods of Analysis. Vol. 3: Analysis of Polycyclic Aromatic Hydrocarbons in Environmental Samples*, International Agency for Research on Cancer, Lyon, France (1979), pp. 129–139.

39 **De Leeuw, FAAM (2002)**, *A set of emission indicators for long-range transboundary air pollution*, Environmental Science & Policy, vol 5, pp 135-145

40 **European Environment Agency (2010)**. *Impact of selected past measures on Europe's air quality*, EEA Technical Report, in preparation.

41 **EUROSTAT** *Statistical Classification of Economic Activities in the European Community, Rev. 2* (NACE Rev. 2): http://ec.europa.eu/eurostat/ramon/

42 **United Nations**, *International Standard Industrial Classification of All Economic Activities, Revision 3.1*, (ISIC Rev. 3.1) http://unstats.un.org/unsd/cr/registry/regcst.asp?Cl=17&Lg=1

43 **European Environment Agency (2007)**, Air pollution from electricity-generating large combustion plants, Technical report No 4/2008, http://reports.eea.europa.eu/technical_report_2008_4/en

44 **UN Statistics**, *UN Data a World of Information*, URL: http://data.un.org/

45 **EUROSTAT**, *European Data Portal*, http://epp.eurostat.ec.europa.eu

46 **International Energy Agency**, *IEA Online Data Service*, http://data.iea.org/ieastore/default.asp?

47 **IPCC National Greenhouse Gas Inventories Program**, *Emission Factor Database*, http://www.ipcc-nggip.iges.or.jp/EFDB/main.php

48 **US Environmental Protection Agency**, *Clearinghouse for Inventories & Emissions Factors*, http://www.epa.gov/ttn/chief/

49 **General Conference on Weights and Measures, (1960),** *Resolution 12 of the 11th meeting of the CGPM,*, http://www.bipm.org/jsp/en/ViewCGPMResolution.jsp?CGPM=11&RES=12
50 http://www.woodheat.org/firewood/cord.htm
51 **Swab, CL, S Otterson and JG Stocum, (2008)** *Oregon 2005 Residential Wood Combustion Emissions Inventory: Revised Interpretation of Wood Burning Survey Data Resulting in Emissions Estimates Reductions,* 17th Annual International Emission Inventory Conference, Portland Oregon, June 2-5 2008, http://www.epa.gov/ttn/chief/conference/ei17/session2/christopher.pdf
52 **IEA, (2004)**, *Energy Statistics Manual,* http://www.iea.org/Textbase/nppdf/free/2004/statistics_manual.pdf
53 Nederlandse Emissieregistratie: URL: http://www.emissieregistratie.nl/erpubliek/bumper.en.aspx
54 **Winiwarter, W., Rypdal, K., (2001)**, *Assessing the uncertainty associated with national greenhouse gas emission inventories: a case study for Austria*. Atmospheric Environment 35, pp 5425–5440
55 **Aardenne, J.A. van (2002)**, *Uncertainties in emission inventories*, Thesis Wageningen University, Wageningen, Netherlands
56 **IPCC 2000**, *Quantifying Uncertainties In Practice, chapter* 6 in [24] http://www.ipcc-nggip.iges.or.jp/public/gp/english/6_Uncertainty.pdf

Glossary

Within the Emission Inventory Community a long list of concepts, acronyms, abbreviations and symbols are used. This glossary provides an overview. Where relevant a web-link[9] is provided and the source of the definition given is indicated.

Not all of the entries in the glossary are used within the document.

Concept	Explanation	Reference
1996 GLs	IPCC 1996 Revised Guidelines for Greenhouse Gas Inventories http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm	[23]
2006 GLs	2006 IPCC Guidelines for National Greenhouse Gas Inventories, http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html	[1]
Accuracy	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 or under true emissions or removals, as far as can be judged, and that uncertainties are reduced as far as practicable.	[10]
	Agreement between the true value and the average of repeated measured observations or estimates of a variable. An accurate measurement or prediction lacks bias or, equivalently, systematic error.	[1]
Activity rate	The intensity of a certain activity	
AE-DEM	Air Emissions Data Exchange Module (CollectER & ReportER); Emission Inventorying software of ETC-ACC and EEA http://air-climate.etc-acc.eu.int click on "Country support tools"	
AP	Air Pollution	
Apparent emission factor	see: "Emission rate"	
BAT	Best Available Technology; used under the IPPC Directive; see BREF	
BREF	IPPC documents, describing BAT for many industrial activities http://eippcb.jrc.es/pages/FActivities.htm	
CAFE	Clean Air for Europe: air pollution policy programme within the European Union http://europa.eu.int/comm/environment/air/cafe/index.htm	
CARDS	Programme of the EU to support the five West Balkan Countries http://europa.eu.int/comm/europeaid/projects/cards/index_en.htm	
CDR	EEA's Central Data Repository http://cdr.eionet.europa.eu/	
CLRTAP	Convention on Long Range Transboundary Air Pollution	
Comparability	Comparability: estimates of emissions and removals reported by parties in inventories should be comparable. The allocation of different source/sink categories should follow the split of the IPCC Guidelines.	[10]
Completeness	Completeness means that an inventory covers all sources and sinks, as well as all gases, included in the Revised 1996 Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories.	[10]

9 The links were checked to be correct and active when this document was drafted.

Concept	Explanation	Reference
Confidence Interval	The true value of the quantity for which the interval is to be estimated is a fixed but unknown constant, such as the annual total emissions in a given year for a given country. The confidence interval is a range that encloses the true value of this unknown fixed quantity with a specified confidence (probability). Typically, a 95 per cent confidence interval is used in greenhouse gas inventories. From a traditional statistical perspective, the 95 per cent confidence interval has a 95 per cent probability of enclosing the true but unknown value of the quantity. An alternative interpretation is that the confidence interval is a range that may safely be declared to be consistent with observed data or information. The 95 per cent confidence interval is enclosed by the 2.5^{th} and 97.5^{th} percentiles of the PDF.	[1]
Consistency	An inventory should be internally consistent in all its elements with inventories of other years. An inventory is consistent if the same methodologies are used for all subsequent years and if consistent data sets are used to estimate emissions or removals from sources or sinks.	[10]
CRF	Common Reporting Format of UNFCCC can be found at the UNFCCC website (I'll try to find the link {TP})	[10]
DPSIR	The causal framework for describing the interactions between society and the environment adopted by the European Environment Agency: driving forces, pressures, states, impacts, responses (extension of the PSR model developed by OECD). http://glossary.eea.europa.eu/EEAGlossary/D/DPSIR	
Drivers	In the EEA indicator system, indicators for driving forces describe the social, demographic and economic developments in societies and the corresponding changes in life styles, overall levels of consumption and production patterns. Primary driving forces are population growth and developments in the needs and activities of individuals. These primary driving forces provoke changes in the overall levels of production and consumption. Through these changes in production and consumption, the driving forces exert pressure on the environment. http://glossary.eea.europa.eu/EEAGlossary/D/driving_force	
EEA	European Environment Agency http://www.eea.eu.int	
EECCA	Eastern Europe, Caucasus and Central Asia	
EFDB	IPCC's Emission Factor Database http://www.ipcc-nggip.iges.or.jp/EFDB/main.php	
EMEP	http://www.emep.int	
Emission factor	The proportionality constant between the activity rate and the emission	
Emission rate	Also called "implied emission factor" or "apparent emission factor": the observed proportionality constant between the activity rate and the emissions in a source ort group of sources	
EPER	European Pollutant Emissions Register: a PRTR for industrial emissions to air and water, now replaced by E-PRTR (http://prtr.ec.europa.eu/)	
E-PRTR	European Pollutant Release and Transfer Register (E-PRTR), http://prtr.ec.europa.eu/	
ETC-ACC	European Topic Centre on Air and Climate Change http://air-climate.etc-acc.eu.int	
GAINS	Integrated assessment model developed by IIASA	
gas	The substance as used in greenhouse gas inventories	
GPG	Good Practice Guidance; a set of procedures, methods and other advice on how to compile a national emission inventory o UNFCCC: available at IPCC NGGIP's web site o LRTAP: chapter in the Guidebook	
Guidebook	EMEP/CORINAIR Guidebook on Emission Inventories http://reports.eea.eu.int/EMEPCORINAIR4/en	

Concept	Explanation	Reference
Guidelines	The reporting guidelines for reporting to the CLRTAP	
GWP	Global Warming Potential, used in UNFCCC to aggregate the emissions of different gases	
HELCOM	Helsinki Commission	
HM	Heavy Metals	
IIASA	International Institute of Applied Systems Analysis	
IIR	Informative Inventory Report: explanatory report under the LRTAP convention	
Impact	Impact on human beings, ecosystems and man-made objects resulting from changes in environmental quality. http://glossary.eea.europa.eu/EEAGlossary/E/environmental_impact	
Implied emission factor	see: "Emission rate"	
IMS	EEA's Indicator Management System	
IPCC	Intergovernmental Panel on Climate Change http://www.ipcc.ch	
IPCC NGGIP	IPPC's National Greenhouse Gas Inventory Programme http://www.ipcc-nggip.iges.or.jp/	
IPPC	Integrated Pollution and Control; a directive of the European Union EU has a set of web pages on IPPC http://ec.europa.eu/environment/air/pollutants/stationary/ippc/index.htm	
LCP Directive	Large Combustion Plant Directive http://ec.europa.eu/environment/air/pollutants/stationary/lcp.htm	
Location	The geographical dimension of a source of emissions	
LRTAP	UN-ECEs Convention on Long Range Transboundary Air Pollutants http://www.unece.org/env/lrtap/	
MSC-E	EMEP's Meteorological Centre East	
MSC-W	EMEP's Meteorological Centre West	
NEC Directive	European Unions Emission Ceilings Directive http://europa.eu.int/comm/environment/air/ceilings.htm	
NFP	National Focal Point (EEA representative from each country)	
NFR	Nomenclature for Reporting; Reporting format required under the LRTAP convention; also used by NEC Directive f the EU http://www.emep.int/emis2003/reportinginstructions.html	
NIR	National Inventory Report explanatory report under the UNFCCC convention; this report is "encouraged"	
NIS	National Inventory System (As defined by the EU) Is the same thing as the NS	
NMVOC	Non-Methane Volatile Organic Compounds	
NRC	National Reference Centre (EEA representative from each country for a specific subject)	
NS	National System (The system established to compile the National Inventory under the Kyoto Protocol)	
OECD	Organisation for Economic Co-operation and Development; is one of the initiators / coordinators of the PRTR programme	
PAH	Policyclic Aromatic Hydrocarbons	
PAMs	Policies and Measures	
PARCOM	Paris Commission	

Concept	Explanation	Reference
PDF	See: Probability Distribution Function	[1]
PM	Particulate matter	
PM_{10}	Particles smaller than 10 µm	
$PM_{2.5}$	Particles smaller than 2.5 µm	
point estimate	The "best" estimate for a specific variable or parameter	
pollutant	The substance as used in air pollution inventories and air quality characterisation	
POP	Persistent Organic Pollutants http ://www.pops.int/	
Pressures	In the EEA indicator system, pressure indicators describe developments in release of substances (emissions), physical and biological agents, the use of resources and the use of land. The pressures exerted by society are transported and transformed in a variety of natural processes to manifest themselves in changes in environmental conditions. http://glossary.eea.europa.eu/EEAGlossary/P/pressure	
Probability Distribution Function (PDF)	The PDF describes the range and relative likelihood of possible values. The PDF can be used to describe uncertainty in the estimate of a quantity that is a fixed constant whose value is not exactly known, or it can be used to describe inherent variability. The purpose of the uncertainty analysis for the emission inventory is to quantify uncertainty in the unknown fixed value of total emissions as well as emissions and activity pertaining to specific categories. Thus, throughout this chapter it is presumed that the PDF is used to estimate uncertainty and not variability, unless otherwise stated.	[1]
PRTR	Pollutant Release and Transfer Register: a system, following the provisions of the UN-ECE Aarhus Convention and its PRTR protocol, aiming at "community right to know"; a PRTR contains data on emissions the air, water, land and waste for all sources in a country	
QA/QC	Quality Assurance, quality control: systems and approaches to work along lines that ensure that you are doing the right things and are able to do it again next time; for QA/QC in emission inventories, see GPG	
RAINS	European Scale Air pollution model used in the negotiations within the LRTAP convention and the EU CAFÉ project	
Response	In the EEA indicator system, response indicators refer to responses by groups (and individuals) in society as well as government attempts to prevent, compensate, ameliorate or adapt to changes in the state of the environment. Some societal responses may be regarded as negative driving forces since they aim at redirecting prevailing trends in consumption and production patterns. Other responses aim at raising the efficiency of products and processes, through stimulating the development and penetration of clean technologies. http://glossary.eea.europa.eu/EEAGlossary/R/response	
Source	The source of emissions into the atmosphere, characterised by a location, a source category and fuel	
Source category	A classification of sources into source categories	
State	EEA definition: Condition of different environmental compartments and systems. http://glossary.eea.europa.eu/EEAGlossary/S/state_of_the_environment	
TCCCA	Transparency, Consistency, Comparability, Completeness and Accuracy: the quality criteria of the UNFCCC reporting guidelines; see CRF	
TFEIP	UN ECE's Task Force on Emission Inventories and Projections http://www.tfeip-secretariat.org/	

Concept	Explanation	Reference
Transparency	The assumptions and methodologies used for an inventory should be clearly explained. Transparency of inventories is fundamental to the success of the process for the communication and consideration of information	[10]
TSP	Total Suspended Matter: all particles in the air	
Uncertainty	Lack of knowledge of the true value of a variable that can be described as a probability density function (PDF) characterising the range and likelihood of possible values. Uncertainty depends on the analyst's state of knowledge, which in turn depends on the quality and quantity of applicable data as well as knowledge of underlying processes and inference methods.	[1]
Uncertainty range	In emission inventories the uncertainty range is expressed as the 95% confidence range between the 2.5 and 97.5 percentiles of the probability distribution	
UN-ECE	United Nations Economic Committee for Europe	
UNFCCC	United Nations Framework Convention on Climate Change http://www.unfccc.int	
US AP42	United States Environmental Protection Agency's emission estimation methods	
Validation	The establishment of sound approach and foundation. In the context of emission inventories, validation involves checking to ensure that the inventory has been compiled correctly in line with reporting instructions and guidelines. It checks the internal consistency of the inventory. The legal use of validation is to give an official confirmation or approval of an act or product [10]	[24]
Variability	Heterogeneity of a variable over time, space or members of a population (Morgan and Henrion, 1990[11]; Cullen and Frey, 1999[12]). Variability may arise, for example, due to differences in design from one emitter to another (inter-plant or spatial variability) and in operating conditions from one time to another at a given emitter (intra-plant variability). Variability is an inherent property of the system or of nature and not of the analyst.	[1]
Verification	Verification refers to the collection of activities and procedures that can be followed during the planning and development, or after completion of an inventory that can help to establish its reliability for the intended applications of that inventory. Typically, methods external to the inventory are used to check the truth of the inventory, including comparisons with estimates made by other bodies or with emission and uptake measurements determined from atmospheric concentrations or concentration gradients of these gases [10]	[24]

10 Intergovernmental Panel on Climate Change (IPCC), (1998), Meeting Report: Managing Uncertainty in National Greenhouse Gas Inventories, Report of the meeting held in Paris 13-15, October 1998, IPCC/OECD/IEA Programme on National Greenhouse Gas Inventories.

11 Morgan, M.G., and Henrion, M. (1990). Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis, Cambridge University Press, New York

12 Cullen, A.C. and Frey, H.C. (1999), Probabilistic Techniques in Exposure Assessment: A Handbook for Dealing with Variability and Uncertainty in Models and Inputs, Plenum: New York.

Many policy processes and scientists use emission inventories as the basic information needed for any study on the problems of air pollution and climate change. However, emission inventorying is not a simple task: it takes a lot of expertise, time and effort before a complete inventory is compiled. Over time TNO has contributed significantly to the development of methods and tool for this task. This booklet summarizes our experience and expertise in this field translating it in pragmatic tips and solutions for anyone working on or with emission data, both in policy and in science.

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